

## *Foreword...*

Most of the observable matter in the universe is in the plasma state. Plasma science is the study of the ionized states of matter. Plasma science includes plasma physics but aims to describe a much wider class of phenomena in which, for example, atomic and molecular excitation and ionization processes and chemical reactions can play significant roles. The intellectual challenge in plasma science is to develop principles for understanding the complex macroscopic behavior of plasmas, given the known principles that govern their microscopic behavior and use of this science for technologically developments.

Plasmas of interest range over many orders of magnitude in density and temperature from the tenuous plasmas of interstellar space to the ultradense plasmas created in inertial confinement fusion, and from the cool, chemical plasmas used in the plasma processing of semiconductors to the thermonuclear plasmas created in magnetic confinement fusion devices. A healthy plasma science enterprise can be expected to make many important contributions to our society for the foreseeable future.

Plasma science can have a significant impact on many disciplines and technologies, including those directly linked to industrial growth. To properly pursue the potential offered by plasma science, we must create and maintain a coherent and coordinated program of research and technological development in plasma science. Recognition as a distinct discipline in educational and research institutions will be crucial to the healthy development of plasma science. There is no effective structure in place to develop the basic science that underlies the many applications of plasmas, and if the present trend continues, plasma science education and plasma science research are likely to decrease both in quality and quantity.

The future health of plasma science, and hence its ability to contribute to the nation's technological development, hinges on the revitalization of basic plasma science and, in particular, on the revitalization of small-scale basic plasma experiments. Coordination of research efforts is vital, to make the most effective use of resources by maintaining complementary programs and to ensure that all critical problems are addressed. Because of the commonality underlying all areas of plasma science, renewed emphasis on plasma science will benefit all areas.

The Govt. of India has started many novel programs in the area of Plasma Science and Technology in particular for TOKAMAK research and fusion experiments with international collaborations. Sufficient trained manpower is required in the coming years for many of the proposed programs in this area. It is, therefore, very much essential to start new academic and research programs in the field of Plasma Science and Technology. New courses in this field need to be formulated and trained manpower need to be created. The overall growth of Plasma Science and Technology has attained its present status through exchange of ideas and transfer of cutting-edge

technology through various platforms where academicians, researchers and industrialists have been brought together. Yet there is much more to conceive and take forward to achieve in this exotic field.

We are happy to host the **29<sup>th</sup> National Symposium on Plasma Science & Technology integrated with an “International Conference on Plasma & Nanotechnology”- (Plasma-2014)** in **Mahatma Gandhi University** at Kottayam, in Kerala-the *God’s Own Country* during 8-11 December 2014. A pre-conference workshop on **“Plasma Based Techniques for Nanotechnology”** will be conducted on 7<sup>th</sup> December 2014 aimed at students working/ planning to work in the area of Plasma Science and Nanotechnology. The papers presented in the meeting will be peer reviewed by experts and will be published as an edited book by Apple Academy Press (AAP), Canada.

The **Plasma 2014** is jointly organized by **International and Inter University Centre for Nanoscience and Nanotechnology (IIUCNN)**, **School of Pure and Applied Physics (SPAP)** at Mahatma Gandhi University and **Plasma Science Society of India (PSSI)**. Young professionals will have the challenge to be rated competitively through various awards. The meeting will be an ideal platform for researchers to present their work, benchmark their works, to develop new interfaces and widen the scope and range of their research activities through dynamic networking. A brain storming discussion on India-Europe/ Rest of the world joint project proposals to European Union under **HORIZON 2020** program is also planned during the 4 days of the meeting. Other joint proposals with India and rest of the world through DST/DBT-Govt. of India shall also be discussed.

We wish all the delegates of **Plasma 2014** a very pleasant and fruitful stay in Kottayam. We also wish all success to all delegates of **Plasma 2014** in their research works and future endeavors.

**A very Happy New Year 2015 filled with happiness, peace, prosperity and success to you all well in advance!**

**Chairmen:**

**Prof. Sabu Thomas, Ph.D FRSC, India**

**Prof. Miran Mozetic, Slovenia**

**Prof. Uros Cvelbar, Slovenia**

**Convener:**

**Dr. Nandakumar Kalarikkal, India**

# TECHNICAL PROGRAMME OF PLASMA 2014

Day 1 : Monday 8th December, 2014				
Talk No.	Time	Type of Talk	Speaker	Abs #
Inauguration & Keynote Address (09:00-10:15)				
	9:00-09:30	Inaugural function		
K-01	09:30-10:15	Keynote Address	Prof. P. I John (IPR Gandhinagar)	From Electrojet to ITER: India's Journey in Experimental Plasma Physics <a href="mailto:john.pucadvil@gmail.com">john.pucadvil@gmail.com</a>
	10:20-11:00	High Tea		
Session 1 : Basic Plasma (10:15-13:30) (Hall 1)				
I-01	11:00-11:25	BP-I-02 - Invited	Heremba Bailing (IASST, Guwahati)	Nonlinear Waves And Structures In Strongly Coupled Complex (Dusty) Plasma
I-02	11:25-11:55	BP-I-03 - Invited	M S Janaki (SINP)	Plasma Density Pile Up On A Conical Surface During Expansion Along A Divergent Magnetic Field
I-03	11:55-12:20	BP-I-04 - Invited	Tarsem Singh Gill (GNDU)	Nonlinear wave structures in non-Maxwellian plasmas
I-04	12:20-12:45	BP-I-05 - Invited	A A Goncharov (NAS Ukraine)	Advanced Plasma Dynamical Devices (Review Of Fundamental Results And Applications)
I-05	12:45-13:10	PD-I-04 - Invited	L M Awasthi (IPR)	Investigations On Plasma Turbulence: An Opportunity To Exploit In LVPD
O-01	13:10-13:22	BP-O-01 - Oral	Gouri Shankar Sahoo (Ravenshaw Univ)	196 On the Effect of Base Pressure on Plasma Containment
O-02	13:22-13:34	BP-O-02 - Oral	Vramori Mitra (VIT, Chennai)	288 Study of Fractality of Nonlinear Oscillations in DC Glow Discharge Magnetised Plasma by using Detrended Fluctuation Analysis
	13:30-14:15	Lunch		
Session - 2 (14:00-16:30)(Hall 1)				
Buti Young Scientist Presentations (15 + 5 mins) (14:30-16:30)				
BA-01	14:30-14:50	Buti Presentation 1	Divya Singh, University of Delhi	Generation of Terahertz Frequencies by Flat Top Lasers in Modulated Density Plasmas
BA-02	14:50-15:10	Buti Presentation 2	Leena Chelikani, CUH, Hyderabad	Spatio- Temporal Imaging Of Laser Induced Shock Waves And Plasma Plume From Ambient Air, Metals, Periodic Structured Surfaces And Sub-Micron Sized Compacted Powders

BA-03	15:10-15:30	Buti Presentation 3	Uday Chakravarty, RRCAT, Indore	Enhanced laser energy absorption and x-ray emission from nano-structured targets irradiated by ultra-high intensity laser pulses
BA-04	15:30-15:50	Buti Presentation 4	Manjit Kaur, IPR, Gandhinagar	Observation of poloidal dust rotation in stationary toroidal structures
BA-05	15:50-16:10	Buti Presentation 5	Pooja Gulati, CEERI Pilani	Dielectric barrier discharge based plasma excimer sources for water sterilization application
BA-06	16:10-16:30	Buti Presentation 6	Biswajit Jana, BARC, Mumbai	Studies on Laser Produced Transient Photoplasma in Electromagnetic Field

### Session - 3

#### Poster Session - 01 (Basic Plasma + Computer Modeling)

Day 2 : Tuesday 9th December, 2014

### Session - 4 (Parallel- Hall 1) (09:00-11:30)

#### Plasma Processing, Industrial Plasma & Pulsed Power (PP + IP+PU)

I-06	09:00-09:25	PP-I-01 - Invited		
I-07	09:25-09:50	PP-I-02 - Invited	Miran Mozetic (Jozef Stefan Institute , Slovenia)	Oxygen Plasma Technology for Superior Quality of Electro- industry Products
I-08	09:50-10:15	PP-I-03 - Invited	Mukesh Ranjan (FCIPT)	Plasma for Plasmonics
I-09	10:15-10:40	PP-I-04 - Invited	Abhijit Majumdar (BESU)	Non-thermal atmospheric pressure plasma application on cell biology
I-10	10:40-11:05	PP-I-05 - Invited	Burkhard Fechner (Coherent, Germany)	From Lab to Fab - Scalable Nanoprocessing with Excimer Lasers
O-03	11:05-11:17	PU-O-01 - Oral	Suramoni Borthakur (CPP)	211 Pulsed Electrical Exploding Wire for production of Nano Powders
O-04	11:17-11:30	PP-O-02 - Oral	Vandana Chaturvedi (BARC, Mumbai)	314 Phase and Particle size analysis of DC plasma synthesized nano alumina

### Session - 5 (Parallel- Hall 2) (09:00-11:30)

#### Exotic Plasma + Computer Modeling (EP+CM)

I-11	09:00-09:25	EP-I-01 - Invited		
I-12	09:25-09:50	EP-I-02 - Invited	Vishnu M. Bannur (Calicut Univ)	Exotic Plasma - QGP



I-13	09:50-10:15	EP-I-03 - Invited	Pintu Bandhopadhyay (IPR)	pintu@ipr.res.in	Experimental Investigation of Spatio-temporal Patterns And Shear Driven Instability In A Magnetized RF Plasma
I-14	10:15-10:40	CM-I-01 - Invited	Shaktivel N. (BARC Vizag)	shakthiveln@gmail.com	High Performance Computing Technologies for Computer Simulations
I-15	10:40-11:05	CM-I-02 - Invited	B J Saikia (CPP-IPR, Guwahati)	<a href="mailto:bsaikia@cppipr.res.in">bsaikia@cppipr.res.in</a>	Radiation Transport Modeling: Stochastic Vs. Deterministic Approach
O-05	11:05-11:17	EP-O-01 - Oral	Aditya Nandan Savita (BARC Vizag)	<a href="mailto:adityanandansavita@gmail.com">adityanandansavita@gmail.com</a>	90 Preliminary studies of a warm dense plasma produced by electrically-exploded conductors
O-06	11:17-11:30	CM-O-01-Oral	Meghraj Sengupta (IPR)	<a href="mailto:meghraj@ipr.res.in">meghraj@ipr.res.in</a>	101 Fate of an electron plasma subjected to ion resonance instability: A numerical study at arbitrary aspect ratio

#### Session - 6

#### Poster session - 02 (Nuclear Fusion + Exotic Plasma)

#### Day 3 : Wednesday 10th December, 2014

#### Session - 7 (Parallel-Hall 1) (09:00-11:30)

#### Laser Plasma

I-16	09:00-09:25	LP-I-01 - Invited	Anand Moorti , RRCAT	<a href="mailto:moorti@rrcat.gov.in">moorti@rrcat.gov.in</a>	Laser Driven Plasma Based Advanced Electron Acceleration Technique
I-17	09:25-09:50	LP-I-02 - Invited	Prem Kiran (Uni. of Hyderabad)	<a href="mailto:premsp@uohyd.ernet.in">premsp@uohyd.ernet.in</a>	Emissions From Nanosecond And Picosecond Laser Ablative Plasmas In Ambient Atmosphere
I-18	09:50-10:15	LP-I-03 - Invited	Reji Philip (RRI, Bangalore)	<a href="mailto:reji@rri.res.in">reji@rri.res.in</a>	Expansion Dynamics of a Laser Produced Zn Plasma: Short-pulse and Ultrafast Excitations
I-19	10:15-10:40	LP-I-04 - Invited	Alika Khare (IIT Guwahati)	<a href="mailto:alika@iitg.ernet.in">alika@iitg.ernet.in</a>	Pulsed Laser Deposition: A Versatile Technique For Fabrication Of Thin Films For Differnet Applications
I-20	10:40-11:05	LP-I-05 - Invited	Ajai Kumar (IPR, Gandhinagar)	<a href="mailto:ajai@ipr.res.in">ajai@ipr.res.in</a>	Spectroscopy Of Laser Induced Plasma
O-07	11:05-11:17	LP-O-01 - Oral	Ashish Vyas (IIT Delhi)	<a href="mailto:ashishvyas.optics@gmail.com">ashishvyas.optics@gmail.com</a>	205 Effect of Ponderomotive and Relativistic Filamentation on Coexisting Stimulated Raman and Brillouin Scattering
O-08	11:17-11:30	LP-O-02 - Oral	Jemy James (MGU, Kottayam)	<a href="mailto:jemy.jamesmsc@gmail.com">jemy.jamesmsc@gmail.com</a>	349 Laser Assisted Synthesis of Silver Nanoparticles: A Green Approach

Session - 8 (Parallel- Hall 2) (09:00-11:30)					
Space & Atmospheric Plasma					
I-21	09:00-09:25	SA-I-01 - Invited	R P Sharma (IIT Delhi)	rpsharma@ces.iitd.ac.in	Nonlinear Dispersive Alfvén Waves and associated Effects
I-22	09:25-09:50	SA-I-02 - Invited	Zoran Lj. Petrovic IOP, Belgrade)	<a href="mailto:zoran@ipb.ac.rs">zoran@ipb.ac.rs</a>	Avalanches of Electrons and Positrons in Atmospheres of Planets and Satellites of the Solar System: Basic Phenomenology and Application to Gas Breakdown in DC and RF Fields
I-23	09:50-10:15	SA-I-03 - Invited	Vijayan Nandalan (LPSC, Trivandrum)	<a href="mailto:vijayan_nandalan@yahoo.co.in">vijayan_nandalan@yahoo.co.in</a>	Electric Propulsion (EP) - High Efficiency System For Space Mission
I-24	10:15-10:40	SA-I-04 - Invited	Satyavir Singh (IIGM, Mumbai)	<a href="mailto:satyavir@iigs.iigm.res.in">satyavir@iigs.iigm.res.in</a>	Electromagnetic Ion Cyclotron (EMIC) Waves In The Inner Magnetosphere
I-25	10:40-11:05	SA-I-05 - Invited	Bert Ellingboe ( Dublin City Univ.)	<a href="mailto:bert.ellingboe@dcu.ie">bert.ellingboe@dcu.ie</a>	A Scalable, High-VHF CCP Plasma Source for High-Rate nc-Si PECVD
O-09	11:05-11:17	SA-O-01 - Oral	Ajeet Kumar Maurya (IIGM, Mumbai)	<a href="mailto:ajeet.iig@gmail.com">ajeet.iig@gmail.com</a>	11 On The Characteristics Of Transient Luminous Events (Sprite) Producing Thundercloud/storm Over Indian Region: A Case Study
O-10	11:17-11:30	SA-O-02 - Oral	M B Dhanya (SPL, VSSC, Tvm)	<a href="mailto:mb_dhanya@vssc.gov.in">mb_dhanya@vssc.gov.in</a>	116 Solar Wind Interaction with Moon: Observation of Protons in Lunar Wake during magnetic aligned flow by SARA aboard Chandrayaan-1 Mission

Session - 9					
Poster Session - 03 (Laser Plasma, Industrial Plasma, Plasma Processing, Pulsed Power)					

Session -10 (Parallel- Hall 1)(14:00-16:30)					
Nuclear Fusion					
I-26	14:00-14:25	NF-I-01 - Invited	Vipul Tanna (IPR)	<a href="mailto:vtanna@ipr.res.in">vtanna@ipr.res.in</a>	Economics of Large Scale Cryogenic System For Fusion Devices
I-27	14:25-14:50	NF-I-02 - Invited	Santanu Banerjee (IPR)	<a href="mailto:sbanerjee@ipr.res.in">sbanerjee@ipr.res.in</a>	Edge Turbulence Studies By Fast Visible Imaging In The QUEST And ADITYA Tokamaks
I-28	14:50-15:15	NF-I-03 - Invited	Chandan Danani (IPR)	<a href="mailto:chandan@ipr.res.in">chandan@ipr.res.in</a>	Fusion Neutronics: An Overview
I-29	15:15-15:40	NF-I-04 - Invited	Vijay Bedakihale, ITER France	<a href="mailto:Vijay.Bedakihale@iter.org">Vijay.Bedakihale@iter.org</a>	ITER Assembly Approach, Planning and Current Status
I-30	15:40-16:05	NF-I-05 - Invited	Pramod Kumar Sharma (IPR)	<a href="mailto:pramod@ipr.res.in">pramod@ipr.res.in</a>	Recent Advances In SST-1 LHCD System
O-11	16:05-16:17	NF-O-01 - Oral	P V Subhash (ITER India)	<a href="mailto:subhashpv@iter-india.org">subhashpv@iter-india.org</a>	195 Neutronics Analysis and Shielding Optimization for X-Ray Crystal Spectrometer of ITER Using Both MCNP and ATTILA
O-12	16:17-16:30	NF-O-02 - Oral	Rajesh Trivedi (ITER-India)	<a href="mailto:rgtrivedi@iter-india.org">rgtrivedi@iter-india.org</a>	476 R&D Activity for ITER ICRF Power Source System

Session - 11 (Parallel- Hall 2) (14:00-16:30)					
Other Areas-1					
I-31	14:00-14:25	OA-I-01 - Invited	Petr Spatenka (CTUP, Czech Republic)	petr.spatenka@surface-treat.cz	Plasma treatment of Powder and Granulates
I-32	14:25-14:50	OA-I-02 - Invited	Vladimer Cech(BUT, Czech Republic)	i@vladimir.filonov.name	Plasma Processing of Glass-Fiber Reinforcements for Polymer Composites
I-33	14:50-15:15	OA-I-03 - Invited	Sasa Lazovic (Uni. of Belgrade, Serbia)	lazovic@ipb.ac.rs	Plasma Induced DNA Damage: Comparison with the Effects of Ionizing Radiation and Establishing Effective Treatment Doses
I-34	15:15-15:40	OA-I-04 - Invited	Uros Cvelbar (JSI, Slovenia)	uros.cvelbar@guest.arnes.si	Plasma synthesis and conversion of nanowires
I-35	15:40-16:05	OA-I-05 - Invited	Gerard van Rooij( DIFFER, Netherlands)	G.J.vanRooij@differ.nl	Plasmolysis As A Novel Approach To CO2-To-Fuel Conversion
O-13	16:05-16:17	OA-O-01 - Oral	J. Lavanya (IISST, Trivandrum)	<a href="mailto:lavanyajith@gmail.com">lavanyajith@gmail.com</a>	76 Electrochemical Characterization of Ammonia Radio Frequency Plasma Treated Reduced Graphene Oxide in Melamine Sensing
O-14	16:30-16:55	OA-O-02 - Oral	Sateesh R (NSS college, Kottayam)	<a href="mailto:satheeshr83@gmail.com">satheeshr83@gmail.com</a>	242 Effect Of Radio Frequency Power On Magnetron Sputtered TiO2 Thin Films

Session - 12					
Poster Session - 04 (Plasma Diagnostics, Space & Atmospheric Plasma)					

Day 4 : Thursday 11th December, 2014

Session - 13 (Parallel- Hall 1) (09:00-11:30)					
Plasma Diagnostics					
I-36	09:00-09:25	PD-I-01 - Invited	Surya Pathak (IPR)	surya@ipr.res.in	Microwave Sensors In Fusion Plasma
I-37	09:25-09:50	PD-I-02 - Invited	Suman Bagchi, RRCAT	<a href="mailto:sbagchi@rrcat.gov.in">sbagchi@rrcat.gov.in</a>	Interaction Of Ultrashort Laser Pulse With Transparent Solids: A Source Of Energetic Negative Ions And Neutrals
I-38	09:50-10:15	PD-I-03 - Invited	Jinto Thomas (IPR)	jinto@ipr.res.in	Laser Based Diagnostics for High Temperature Tokamak Plasma: Thomson Scattering Diagnostics in ADITYA and SST-1.
I-39	10:40-11:05	PD-I-05 - Invited	G Ravi (FCIPT)	gravi@ipr.res.in	Enthalpy Probe Diagnostics For Thermal Plasma Measurements



Session - 11 (Parallel- Hall 2) (14:00-16:30)					
Other Areas-1					
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I-32	14:25-14:50	OA-I-02 - Invited	Vladimer Cech(BUT, Czech Republic)	i@vladimir.filonov.name	Plasma Processing of Glass-Fiber Reinforcements for Polymer Composites
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I-35	15:40-16:05	OA-I-05 - Invited	Gerard van Rooij( DIFFER, Netherlands)	G.J.vanRooij@diff.nl	Plasmolysis As A Novel Approach To CO2-To-Fuel Conversion
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I-38	09:50-10:15	PD-I-03 - Invited	Jinto Thomas (IPR)	jinto@ipr.res.in	Laser Based Diagnostics for High Temperature Tokamak Plasma: Thomson Scattering Diagnostics in ADITYA and SST-1.
I-39	10:40-11:05	PD-I-05 - Invited	G Ravi (FCIPT)	gravi@ipr.res.in	Enthalpy Probe Diagnostics For Thermal Plasma Measurements

*Dedicated to*  
***Team PLASMA – 2014***





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**KEYNOTE ADDRESS  
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**KN-001**

## **From Electrojet to ITER: India's Journey in Experimental Plasma Physics**

P. I. John

*Consultant, Institute for Plasma Research*

*Gandhinagar, 382424 India*

Email: john.pucadyil@gmail.com

### **Abstract**

India has an international presence in Plasma Physics and its diverse applications such as thermonuclear fusion, material processing, strategic and environmental applications and plasma devices. From a modest start in the early 1970s, we have made great strides in the field of experimental plasma physics. Capacity building in techniques relevant to plasma production, manipulation and control of parameters, pulsed power, creation of magnetic field of complex geometries, clean vacuum and pumping systems, development and deployment of diagnostics to enable understanding of fundamental processes in plasmas and computer simulation to model plasma phenomena have been truly remarkable. Parallel to this, a community of physicists, engineers and computer experts has grown and matured. Funding mechanisms and financial support essential to broad base the research and development activity by drawing in Universities and education institutes have been nucleated. It is through these activities that the human resource and technology development essential to sustain India's ambitious forays into magnetic confinement fusion and industrial and strategic plasma applications has taken place. In this talk, I shall attempt to give a historical perspective to this journey, which started at the Physical Research Laboratory, Ahmedabad and involved the Institute for Plasma Research at Gandhinagar, many DAE Institutions, IITs and Universities.

## BP-I-01

### Plasma Heating Via Adiabatic Magnetic Compression-Expansion Cycle

K. Avinash<sup>1</sup>, M. Sengupta<sup>2</sup> and R. Ganesh<sup>2</sup>

<sup>1</sup>Department of Physics and Astrophysics, University of Delhi, Delhi 110007

<sup>2</sup>Institute for Plasma Research, Bhat, Gandhinagar Gujrat 382424

E-mail: ak0005@uah.edu

#### Abstract

Heating of collisionless plasmas in closed adiabatic magnetic cycle comprising of a quasi static compression followed by a non quasi static constrained expansion against a constant external pressure is proposed. Thermodynamic constraints are derived to show that the plasma always gains heat in cycles having at least one non quasi static process. The turbulent relaxation of the plasma to the equilibrium state and the anomalous heating during the non quasi static expansion is discussed and verified via 1D PIC simulation. Applications of this scheme to heating plasmas in mirror machines and tokamaks are discussed.

## BP-I-02

### Nonlinear Waves And Structures In Strongly Coupled Complex (Dusty) Plasma

H. Bailung

*Physical Sciences Division, Institute of Advanced Study in Science and Technology  
Paschim Boragaon, Garchuk, Guwahati-35, Assam India*

E-mail: hbailung@yahoo.com

#### Abstract

Recent basic experiments on nonlinear dust acoustic soliton (DAS) and shock structures in complex (dusty) plasmas are presented. We describe production of extended volume of dusty plasma where formation and evolution of dust acoustic soliton and shocks using different excitation techniques have been investigated [1,2]. The coupling parameter  $\Gamma$  (the ratio of inter-grain Coulomb potential energy to the dust thermal energy) is calculated from the measured plasma parameters and kept in the strongly coupled fluid regime. Observed DAS are described by the Korteweg de Vries formulation using generalized hydrodynamic model [3]. The DAS are found to survive collisions of different types such as head on collision and oblique collisions [2]. We have demonstrated the dust acoustic multi-soliton generation in dusty plasma for the first time. Charged dust are found to modify the normal ion acoustic shock structures and trigger the formation of monotonic dust ion acoustic shock [4]. Dust acoustic shocks have been excited by a novel technique (injecting a flowing dusty plasma into a stationary dusty plasma volume). The strong dissipation of the complex (dusty) plasma assists

to counter the nonlinearity for the excitation of the DA shock [4]. On the other hand, due to presence of dispersion in the system the shock front breaks into solitary wave structures when time passes by. Dynamical structurization of complex dusty plasma due to gravitational type instability is also discussed.

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### BP-I-03

## Plasma Density Pile Up On A Conical Surface During Expansion Along A Divergent Magnetic Field

Sujit Saha, Shantanu Chowdhury, M. S. Janaki and A. Ghosh

*Saha Institute of Nuclear Physics, I/AF, Bidhannagar, Kolkata 700 064*

E-mail: ms.janaki@saha.ac.in

#### Abstract

The diffusion of a plasma along a diverging magnetic field occurs in many Astrophysical as well as in laboratory situations. The free expansion of a magnetized plasma[1] in helicon plasma devices is known to generate an electric double layer (DL) which is a spatially localized steep gradient of plasma potential. Recent measurements[2] of density and potential, have shown that the DL produced in the diverging magnetic field of a helicon plasma device has a 2-D structure. In such devices, the density piles up on the maximum diverging magnetic field lines (MDMFL) forming a hollow conical structure and the plasma potential contours are U-shaped.

In this work, we present the 2-D measurements[3] in density of a plasma expanding through a physical aperture in a diverging magnetic field and correlate with 2-D potential measurement. The potential structure also exhibits a secondary lobe on either side in addition to the U-shaped major lobe on the axis with a minima lying on the most diverging magnetic field line. Such potential structures are caused by acceleration of ions by transverse electric fields[4] and their radial confinement by magnetic field guided electrons leading to an oscillation of ions about the most divergent field line. A new feature that we observe is a slow increase of the peak density along a hollow conical surface upto a certain distance followed finally by a decrease. Such characteristics are found to be generic in nature[5], and are formed with or without the presence of the double layer. A more complete understanding of these structures is required for the efficient application of such concepts in the context of space propulsion.

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**BP-I-04**

**Nonlinear Wave Structures In Non-Maxwellian Plasmas**

T. S. Gill

*Department of Physics, Guru Nanak Dev University Amritsar 143005 India*

E-mail : gillsema@yahoo.co.in

**Abstract**

In the last many years, solitary potential structures have been observed in various dynamic regions of the space plasma. These are coherent wave structures arising from the balance of nonlinearity and dispersive effects of the medium. They have been recognized to be an ideal agent for transporting energy, charge or information because they retain their shape and velocity during propagation. The plasma environment consists of multiple species and provides a rich source of nonlinear processes. However, the presence of nonthermal particles in plasma significantly modified these structures. Based upon the high energy particles in the medium, a distribution obeying power law are considered more appropriate as a manifestation of fractal or multi fractal structures observed in many different discipline of science. One such model based on kappa function [1] suitably characterized by spectral index is found to represent particles velocity distribution function observed in a number of collisionless space and astrophysical environment. The  $k$  function incorporate the superthermal particles in the population otherwise Maxwellian. In recent years, a new statistical approach, non-extensive statistics or Tsallis statistics [2] has attracted much attention. This statistics is believed to be a useful generalization of the conventional Boltzmann- Gibbs statistics, and suitable for the statistical description of long range interaction systems, such as plasma systems. It has been shown that distributions very close to the so-called (kappa)-distributions are a consequence of the generalized entropy favored by non-extensive statistics[3]. Effect of these non-Maxwellian distribution on the solitary wave structures are aim for the present talk.

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**BP-I-05**

**Advanced Plasma Dynamical Devices (Review of Fundamental Results and Applications)**

Alexey Goncharov

*Institute of Physics NAS of Ukraine, Kiev, 03650, Ukraine*

E-mail : gonchar@iop.kiev.ua

**Abstract**

The talk will review the current status an ongoing research and development of the novel generation plasma dynamical devices based on the axis-symmetric cylindrical electrostatic plasma lens configuration and the fundamental plasma optical principles of magnetic electron isolation and equipotentialization along magnetic field lines. The experimental, theoretical and simulation researches have been carried out over recent years collaboratively between IP NASU (Kiev), LBNL (Berkeley, USA) and HCEI RAS (Tomsk). These researches enable detailed and accurate description and modeling of plasma-optical systems, as well as prediction of their novel high-technology applications. The electrostatic plasma lens is a well-explored tool for focusing and manipulating high-current, large area, energetic heavy ion beams [1]. The crossed electric and magnetic fields inherent the plasma lens configuration provides the fit and attractive method for establishing a stable plasma discharge at low pressure. Using plasma lens configuration in this way a number of low maintenance, high reliability plasma devices using permanent magnets and possessing considerable flexibility towards spatial configuration were developed. These devices can be applied both for fine ion cleaning and activation of substrates before deposition and for sputtering, including synthesis new nanomaterials and exotic coatings [2].

One particularly interesting result of this background work was observation of the essential positive potential at the floating substrate. This suggested to us the possibility of a plasma lens for focusing intense, moderate energy, large area negatively charged particle beams, electrons and negative ions, based on the use of the dynamical cloud of positive space charge under magnetic isolation electrons [3]. It is described also the original approach for effective additional elimination of micro droplets in a density flow of cathodic arc plasma [4]. This approach is based on application the cylindrical plasma lens configuration for introducing at volume of propagating along axis's dense low temperature plasma flow convergent radially energetic electron beam produced by ion –electron secondary emission from electrodes of plasma optical tool. The theoretical appraisals and experimental demonstrations that have been carried out at the IP NASU provide confidence the proposed idea for removal of the micro droplet component from dense, low-temperature metal plasma formed by erosion plasma sources, particularly vacuum arc and laser-produced plasma sources, has the high practical potential for devise novel state-of-the-art plasma processing for the filtering of microdroplets (or their reduction to the nanoscale), without losses of process efficiency.

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## PP-I-02

### Oxygen Plasma Technology for Superior Quality of Electro-Industry Products

Miran Mozetic

*Jozef Stefan Institute, Jamova cesta 39, 1000 Ljubljana, Slovenia*

E-mail: miran.mozetic@ijs.si

#### Abstract

Industry of electrical components features constant growth worldwide. In India the market is currently estimated to USD 15 billion and has been increasing at annual rate of about 10% over the last decade [1]. Products are often made from metallic electrodes separated with appropriate insulating material. Electrodes are usually made from metals unless they are exposed to corrosive medium. In latter cases the metals are usually substituted with graphite. Pure graphite is rarely used due to brittleness. Instead, a composite of graphite grains embedded into the polymer matrix is applied. This material, however, is difficult to join to metal parts since the adhesion of metallic layers on the composite surface is poor. The classical technology for improving the adhesion involves wet chemical processing such as etching with sodium hydroxide, palladium seeding, electro-less nickel deposition and electrochemical metallization. Not only such wet chemical treatments are expensive but they also represent an environment hazard. The processes are replaced efficiently using oxygen plasma treatment of the composite materials. Oxygen plasma causes selective etching of the polymer component. Polymer is etched at much larger rates than graphite so it is removed from the surface upon plasma treatment [2]. The material assumes rich morphology since graphite grains stretch from the surface of the composite. Furthermore, reactive plasma particles cause also surface functionalization with polar functional groups [3]. Functionalized and nano-rough surfaces exhibit super-hydrophilic character so neither palladium seeding nor electro-less nickel is necessary to obtain good adhesion. Suitable plasma reactors preferably employ electrode-less inductively coupled discharges in order to assure for high concentration of neutral oxygen atoms in plasma as well as treatment uniformity [4]. The technology is also suitable for treatment of injection molded glass reinforced polymer materials for insulation between electrodes [5].

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## PP-I-03

### Plasma For Plasmonics

Mukesh Ranjan

*FCIPT, Institute for Plasma Research, Sector-25, Gandhinagar Gujarat, 382044*

E-mail: ranjanm@ipr.res.in

### Abstract

Plasma and plasmonics are two similar branches of physics in which free electrons play strong role. In plasma, electrons are mobile in space but are bounded by the plasma potential, in plasmonics free electrons move on metal surface and bounded by core atoms [1, 2]. In both the cases there is a characteristic electron plasma frequency. These free electrons available on metal surface so called surface plasmon have a unique property that is to feel the electric field generated by light photon. If the size of metal reduce to nanodimension ( $\sim 50$  nm), the free electron oscillation nearly match with the light field oscillations and produce resonance. This phenomenon is known as localized surface plasma resonance (LSPR)[3,4]. In this work, I will present how plasma is useful to tailor the LSPR and results in various applications by giving examples of nanoripples and nanodots structures created by plasma ions [5,6]. Plasma ion energy and fluence systematical varies the nanoscale wavelength of such nanostructures which are later uses as templates for growing metal nanoparticles. Such arrays produce anisotropic LSPR response and enhanced the light field in an evanescence manner. I will report how the coupled field in between two nanostructures enhance the Raman signal drastically and sense a single molecule or absorb more light on a solar cell surface and improve its efficiency [7, 8, 9]. Plasmonic field coupling in aligned equidistant chains of metal nanoparticles is higher compared to randomly distributed particles. I will report a bottom up approach to grow highly ordered self-assembled silver nanoparticles/nanowires arrays produced on periodically patterned Si (100) substrate [10]. The advantage of this bottom up approach over other self-assembling and lithographic methods is the flexibility to tune array periodicity down to 20 nm with interparticle gaps as low as 5 nm along the ripples.

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## PP-I-04

### Non-Thermal Atmospheric Pressure Plasma For Bio-Medical Applications

Abhijit Majumdar,<sup>1</sup> Chirayu Patil,<sup>2</sup> Adam Sanghariyat,<sup>2</sup> Akshay Vaid,<sup>2</sup> Subroto Mukherjee<sup>2</sup>

<sup>1</sup>Indian Institute of Engineering Science and Technology, Shibpur, Howrah-711103, West Bengal, India

<sup>2</sup>Facilitation Center for Industrial Plasma technologies, Institute for Plasma Research, B-15-17/P,  
GIDC, Sector 25, Gandhinagar, Gujarat 382044, India

E-mail : majuabhijit@gmail.com

### Abstract

Atmospheric pressure plasma jets (APPJ) offer a unique environment in plasma bio-medical application which allows the treatment of living tissues, blood coagulation, and biomaterials operating at room temperature. This study involves the development of plasma jet, understanding of blood coagulation and killing of infected cells/tissue by plasma. The aim of plasma interaction with tissue is not to denature the tissue, but rather to operate below the threshold of thermal damage and to induce chemically specific response or modification [1, 2]. A plasma jet (~45 kHz) is developed which is made of Delrin material at a length of 10 to 12 cm that can be driven by Ar or Ar/O<sub>2</sub> or Air combination. We observed that, Ar plasma on static blood takes 14 to 15 sec to coagulate 10 ml blood where as normal clotting take 300 sec. The blood coagulation rate increases further at a small mixture of oxygen gas with Ar.

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**PP-I-05**

**From Lab to Fab - Scalable Nanoprocessing with Excimer Lasers**

Dr. Burkhard Fechner

<sup>1</sup> *Coherent LaserSystems GmbH & Co. KG  
Hans-Boeckler-Str. 12, 37079 Goettingen*

E-Mail: Burkhard.fechner@coherent.com

**Abstract**

Excimer lasers emitting in the UV to far UV region are the key to fast and effective large area processing of smallest structures with nanoprecision. As a consequence, excimer lasers are the UV technology of choice when it comes to high-performance laser ablation, structuring or surface modification with unsurpassed quality and process repeatability in applications such as drilling the most advanced microvias or patterning biomedical sensor structures by the meter. Most important for process reproducibility, next to shortest possible ablation wavelength, is a stable behavior of consecutive laser pulses as well as the homogeneity of the on-sample laser fluency. These requirements constitute the superiority of excimer lasers as pulsed UV laser sources when it comes to precision and reproducibility in surface treatment, thin film deposition and UV micromachining. Recent progress in excimer laser design and UV optical performance will be introduced as well as enabling high-precision UV manufacturing in cost-sensitive applications.

**EP-I-02**

**Exotic Plasma – QGP**

V. M. Bannur

*Department of Physics, University of Calicut, Malappuram, 673635*

E-mail :vmbannur@yahoo.co.in

**Abstract**

Quark gluon plasma (QGP) is an exotic plasma consists of quarks and gluons, elementary particles of strong interaction. This plasma is predicted by quantum chromodynamics (QCD), theory of strong interaction. It is a plasma with 3 different kinds of charges and anti-charges. There are also 8 types of interacting fields and hence corresponding Maxwell's equations are non-linear. This highly complex, non-linear plasma may exhibit a rich variety of linear and non-linear collective modes.

Study of this plasma is important to analyse the experimental results of ultra-relativistic heavy ion collisions at LHC, RHIC, etc. There are already many theoretical and experimental, studies of QGP, but a clear signature of QGP still missing.

In this talk, I will look into the equilibrium state of QGP. That is, the statistical mechanics and thermodynamics of QGP. Initially it was thought that the QGP might be ideal plasma. Later, lattice simulation of QCD predicted that QGP is actually non-ideal and only at high temperature limit it may be ideal plasma.

## EP-I-03

### Experimental Investigation Of Spatio-Temporal Patterns And Shear Driven Instability In A Magnetized RF Plasma

P. Bandyopadhyay<sup>1</sup>, D. Sharma<sup>1</sup>, U. Konopka<sup>2</sup>, A. Sen<sup>1</sup>, P. K. Kaw<sup>1</sup> and G Morfill<sup>3</sup>

<sup>1</sup>*Institute for Plasma Research, Bhat, Gandhinagar, Gujarat, 382428*

<sup>2</sup>*Department of Physics, 206 Allison Laboratory, Auburn University, AL 36849-5311, USA*

<sup>3</sup>*Max-Planck Institute for Extraterrestrial Physics, Garching-85748, Germany*

E-mail : pintu@ipr.res.in

#### Abstract

An experiment is carried out to investigate the formation of spatio-temporal patterns and shear driven instability in a rf produced magnetized argon plasma. The capacitively coupled plasma is produced in between two parallel plates using a two-channel push-pull rf generator. The experimental chamber is kept inside the bore of a superconducting magnetic coil, which has an ability to produce 4T of magnetic field intensity. Over a range of discharge parameters, patterns of different shapes (circular annular rings, single and multiple spirals, filaments) are found to develop in between the electrodes. However, for a particular discharge condition, a shear driven instability is observed to grow along the inner edge of the inner-most self-organized spatiotemporal annular ring [1]. The growing perturbation is observed to rotate in the azimuthal direction due to crossed electric and magnetic fields. The unstable patterns are seen to shrink by keeping the angular velocity constant with the increase of magnetic field strength. A couple of indirect measurements [2] near the patterns are made to estimate the ion rotational velocity and the local electric field by introducing some micron sized dust particles in the plasma. A theoretical model calculation based on the observed growth rate and the shear layer scale length will be presented to explain the nature of the instability observed in the experiment.

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## CM-I-01

### High Performance Computing Technologies For Computer Simulations

N. Sakthivel, H. Hemani and S. Chaturvedi

*Bhabha Atomic Research Centre, Visakhapatnam*

E-mail : shakthiveln@gmail.com

#### Abstract

Computational Analysis Division (CAD), BARC is carrying out computer simulations in a variety of areas including CFD, electromagnetics, molecular dynamics and so on [1]. For carrying out computer simulations at the required space and time resolution for supporting our experimental activities, we have set up a series of High Performance Computing (HPC) facilities over the last 15 years. At present, CAD is equipped with two major HPC facilities. The first is a 20 TeraFLOPS facility using Xeon CPUs and the second is a 20 TeraFLOPS HPC facility using a combination of Xeon CPUs and Xeon-Phi co-processors. Both of these HPC facilities use QDR infiniband interconnect for achieving high bandwidth and low latency, which are important for our simulations. A high density rack cooling solution has been set up with N+1 redundancy in chillers, pumps and cooling units, each cooling rack being able to remove up to 20KWatt of heat load per 42U server rack.

During the last few years, co-processors like NVIDIA and Xeon Phi were available for scientific computing and made great contributions in HPC computing. The use of co-processors has greatly reduced the space and power requirements for a given performance. For example, a 100 TFLOPS HPC facility with CPU and co-processor consumes the same amount of electrical power as that of 20 TFLOPS HPC facility with CPUs only. As on June 2014, the performance share of supercomputing sites using co-processors is around 35% [2].

A 100 TeraFLOPS HPC is expected to be commissioned at CAD, BARC during 2015 using CPUs and Xeon Phi co-processors with Fourteen Data Rate (FDR) infiniband interconnect. FDR infiniband interconnect uses 64bit/66bit encoding instead of 8b/10b encoding, for better performance.

In this paper, we will be presenting detailed design considerations of hardware, including the merits and de-merits of available co-processors, interconnects, middleware, power distribution and cooling. The parallel programming strategies used and achieved performance of a few codes will also be presented.

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- [1] Computer Simulations for High Energy Density Applications, Annals of the Indian National Academy of Engineering., **Vol XI**, p 173-183, (2014)
- [2] <http://www.top500.org> Website of top 500 supercomputing sites.



## CM-I-02

### **Radiation Transport Modeling: Stochastic Vs. Deterministic Approach**

B. J. Saikia

*Centre of Plasma Physics – Institute for Plasma Research, Tepesia, Sonapur – 782 402, Assam*

E-mail: bjsaikia@cppipr.res.in

#### **Abstract**

Radiation transport modeling is an essential part of design and performance analysis of a fusion reactor. This not only encompasses the estimation of the key reactor parameters like tritium self-sufficiency, nuclear heating (energy deposition) for thermal analysis and cooling requirement, radiation damage to structural materials and other sensitive components for lifetime assessment, but also include the aspect of radiation shielding for components (for example, magnets) and personnel access, and activation analysis for safety assessment and radwaste management. Significant effort is devoted to computational simulations of these processes and to applications of these simulations in overlapping areas such as optimum performance of a reactor and radiation damage and protection of both materials and personnel.

There are two basic approaches to radiation transport modeling, one is stochastic and the other is deterministic. In the stochastic, namely Monte-Carlo, method large numbers of individual particle trajectories are simulated and then the results are averaged out for determining the desired quantities; on the other hand, the deterministic method uses discrete ordinates approach to solve the linearized Boltzmann transport equation for the transport of particles. Both these approaches have advantages and disadvantages. In this presentation, some of these issues will be discussed with a few examples.

## LP-I-01

### **Laser Driven Plasma Based Advanced Electron Acceleration Technique**

A. Moorti, B. S. Rao, J. A. Chakera, P. A. Naik, and P. D. Gupta

*Laser Plasma Division, Raja Ramanna Centre for Advanced Technology, Indore 452013, India*

E-mail : moorti@rrcat.gov.in

#### **Abstract**

Recent advancements in the laser technology have brought down the laser pulse duration to ultra-short (few femtosecond duration) regime, and laser power to the petawatt ( $10^{15}$  watt) level. Compact multi-terawatt and petawatt pulsed laser systems are now available in many laboratories around the world. When focused on a target to a focal spot of few microns diameter, laser intensities exceeding  $10^{20}$  W-cm<sup>-2</sup> can be achieved. Among many other things, laser plasma interaction at such high

intensities also leads to generation of relativistic electron beams. One such technique of electron acceleration, known as laser wake-field acceleration (LWFA), provides three orders of magnitude larger acceleration gradient compared to the conventional RF based acceleration technique, and hence it can lead to the development of compact electron accelerators. Using few mm length gas-jet targets and also preformed plasma channels, recently relativistic electron beams of energy in the range of few tens of MeV to few GeV have been generated. Such high-energy electron beams have been used to develop compact x-ray and  $\gamma$ -ray sources.

At Laser Plasma Division, RRCAT, Indore, we are involved with experimental investigations related to the various aspects of LWFA. In this talk, a brief overview of the laser driven plasma based electron acceleration technique, and results of the experimental investigations performed at RRCAT in this field, will be presented.

## LP-I-02

### Emissions From Nanosecond And Picosecond Laser Ablative Plasmas In Ambient Atmosphere

P. Prem Kiran, Ch. Leela, P. Venkateshwarlu, L. Vinoth Kumar, E. Manikanta

*ACRHEM, University of Hyderabad, Gachibowli, Hyderabad – 500 046*

E-mail: prem@uohyd.ac.in

#### Abstract

The high energy laser-material interaction and the subsequent plasma produced has been one of the highly studied research areas due to the fundamental aspects of plasma generation and the applications to material processing and analysis. The laser produced plasmas from materials can broadly be categorized in to laser ablative and laser blow off plasmas. Different emissions during laser ablative plasmas like (i) Spatio-temporal evolution SWs from different materials into the ambient atmosphere characterized using a shadowgraphy and interferometric imaging techniques [1,2], the em emissions in the rather unexplored RF domain and acoustic emissions will be presented. The application of the laser ablative shock waves from materials launching SWs into materials due to momentum conservation leading to an application of laser shock peening will be presented.

Authors wish to thank Defense Research and Development Organization (DRDO), Government of India for Grants-in-Aid Support. PPK thanks BRFSST, through NFP-MAT-A12-04 for travel support.

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## LP-I-03

### Expansion Dynamics Of A Laser Produced Zn Plasma: Short-Pulse And Ultrafast Excitations

N. Smijesh, Anitta R. Thomas, Kavya H. Rao, Reji Philip

*Ultrafast and Nonlinear Optics Lab, Light and Matter Physics Group, Raman Research Institute,  
Bangalore 560 080, India*

E-mail: reji@rri.res.in

#### Abstract

The hydrodynamical characteristics of ultrafast (100 fs) and short-pulse (7 ns) laser produced plasmas (LPP) generated by ablating a Zinc target, for a background pressure of 100 Torr Nitrogen, are reported. Velocities of the plume front indicate a deceleration in both the femtosecond and nanosecond excitation domains, where the plume velocity decreases exponentially with time. Plume aspect ratios indicate that initially the nanosecond plasma plume expands more radially, then it expands more axially, and thereafter the radial and axial expansion rates become similar. On the other hand the femtosecond plasma plume expands preferably in the axial direction throughout its expansion. Results are analyzed and discussed in detail.

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## LP-I-04

### Pulsed Laser Deposition: A Versatile Technique For Fabrication Of Thin Films For Different Applications

Alika Khare

*Department of Physics, Indian Institute of Technology Guwahati, Guwahati 781039*

E-mail : alika@iitg.ernet.in

#### Abstract

Pulsed laser deposition (PLD) technique is being viewed as most versatile technique among its competitors [1]. It can be easily applied to deposit multilayers of pure metals having very high melting point for highly reflecting mirror like thin films [2]. PLD technique has been applied successfully for synthesis of thin films of novel materials of complex composition [3]. In this technique, a high power laser (e.g. Q switched Nd:YAG laser) is focused on a suitable target, resulting into ablation and laser induced plasma formation of the target material. This plasma expands

in vacuum or in the presence of suitable gaseous ambient, depending on the requirement, and can be deposited on the substrate placed few cm apart from the target. Thus the technique is conceptually very simple and single system can cater all kinds of films. There is no restriction on the choice of target as well as substrate. The properties of the thin films can be easily tuned by controlling the deposition parameters. The limitation of uniform growth of the thin film over large area via PLD can be overcome by either scanning the laser beam or translating the substrate suitably.

The multi composite thin films of oxide, nitride, carbide etc. can be easily fabricated via PLD technique either using the pellet of respective material as target or using the individual multi targets in presence of a suitable gas [4]. PLD thin films have been tested for wide variety of applications viz; UV emitter and detector, mirror, nonlinear optics, waveguides, optical delay, photonics sensors etc..

In the present talk, some of the oxide thin films for photonics applications and the mirror like thin films of heavy metals grown via PLD shall be discussed.

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## LP-I-05

### Spectroscopy of Laser Induced Plasma

Ajai Kumar

*Institute for Plasma Research, Gandhinagar 382 428, India*

Email : ajai@ipr.res.in

#### Abstract

Laser induced plasma formation and its characterization continues to be receiving a great interest because it's application in industries, element analysis, Tokamak plasma diagnostics, material science and thin film deposition. Emission spectroscopy is a most powerful technique because it not only gives a general picture of dynamics and geometry of the expanding plasma plume but also explains the different mechanisms involved during the plume expansion like excitation, ionization and recombination processes.

In this talk, I shall present different physical processes in plume-gas, plume-magnetic field and plume-plume interactions. The observed phenomenon with regard to enhancement in optical emission, structure formation, plume focussing, shock waves and stagnation layer will discuss. Physical mechanism responsible for the above phenomenon will also be discussed briefly. In this talk emphasis is given to the quantitative spectral analysis for identify the various atomic processes e.g. electron impact excitation, recombination, etc., which determine the characteristics of ablated plum in different environment.

## SA-I-01

### Nonlinear Dispersive Alfvén Waves and associated Effects

R. P. Sharma

*Centre for Energy Studies, Indian Institute of Technology Delhi, Delhi-110016, India*

Email: rpsharma@ces.iitd.ac.in

#### Abstract

Alfvén waves are the normal modes of the plasma and have been observed in various space plasma regions and laboratory plasmas. Coupling between the Alfvén waves and the density perturbation has got the far reaching research interest from decades. Nonlinear interaction of Dispersive Alfvén waves (DAWs) with low frequency waves is found to play a crucial role in both astrophysical plasmas and laboratory plasmas. Nonlinear dynamics of DAW is studied taking into account the ponderomotive force. Plane DAW gets perturbed due to presence of background waves and undergoes filamentation instability. Impact of the proposed interaction on the magnetic field coherent structures and spectrum is investigated. Field intensity localization is studied using numerical and semi-analytical methods in different space plasma regions. Range Kutta method has been used for semi-analytical approach and pseudo spectral technique has been invoked for simulation. The relevance of obtained results with spacecraft observations is also discussed.

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## SA-I-02

### Avalanches of Electrons and Positrons in Atmospheres of Planets and Satellites of the Solar System: Basic Phenomenology and Application to Gas Breakdown in DC and RF Fields

Zoran Lj. Petrovi<sup>1,2</sup>, Ilija Adžić<sup>3</sup>, Saša Dujko<sup>1</sup>, Marija Savić<sup>1</sup>, Srđan Marjanović<sup>1</sup>, Dragana Marić<sup>1</sup>, Marija Radmilović-Radenović<sup>1</sup>, Gordana Malović<sup>1</sup> and Antonije Đorđević<sup>2,3</sup>

*1. Institute of Physics, University of Belgrade, POB 68 11080 Zemun, Serbia*

*2. also at Serbian Academy of Sciences and Arts, Belgrade 11001 Serbia*

*3. School of Electrical engineering, University of Belgrade, Belgrade, Serbia*

E-mail : zoran@ipb.ac.rs

#### Abstract

Any formation of plasma is preceded by gas breakdown, whereby a non-conducting gas releases free electrons and ions are produced in the process as well, thus rendering the gas to be conductive.

Release of electrons from the neutral atoms makes it possible for them to be accelerated in the external field and ionize the gas further, thus creating avalanches. The growth of ionization is a necessary step in achieving self sustained discharges. Several mechanisms exist. The original Townsend breakdown mechanisms involves avalanche of electrons with a feedback of ions drifting towards the cathode. The phenomenology of the mechanism has been the backbone of the physics of ionized gases for more than 100 years and yet it has suffered major changes in the phenomenology and in the general approach, while maintaining the basic ideas. In the talk, we shall summarize some of recent advances in this respect. If avalanche is so abrupt that it forms a sufficient field at its front to continue self maintained propagation, it may proceed without a feedback and significant effect of electrodes; in other words, the streamer mechanism is attained. Streamers are favoured at higher pressures and are precursors to more powerful discharges at atmospheric pressure, including lightning, sparks and arcs. Finally, it is possible that electrons may achieve energy that is beyond the maximum of cross sections for inelastic energy losses, and thus any further acceleration will result in reduced likelihood of collisions. Thus, electrons may be in runaway, where in their weak interaction with the background gas new electrons may be produced and support breakdown.

In this talk, we illustrate the breakdown in unperturbed gas mixtures in Earth's atmosphere, as well as in atmospheres of all planets or satellites supporting atmospheres in the solar system. Furthermore we discuss the new phenomenology of breakdown supported by swarm related transport theory, kinetic phenomena in gases and basic collisions in gas phase and on surfaces. How breakdown in RF fields differs from that in DC will also be addressed briefly. We shall provide some guidance into modeling of runaway phenomena in atmospheric gases.

Finally, we shall present avalanches created by high energy positron thermalization in the atmosphere or water (vapour or liquid). There is no multiplication of positrons, of course, but avalanche consists of numerous secondary electrons that may induce gas phase and liquid phase chemistry, as well as have strong effects on living organisms.

### SA-I-03

#### **ELECTRIC PROPULSION (EP)-High Efficiency System for Space Mission)**

Vijayan Nandalan

*Liquid Propulsion Systems Centre, ISRO, Trivandrum, 695 547*

Email: vijayannandalan@lpssc.gov.in

#### **Abstract**

A space mission craft need to undergo large velocity change to fulfil the mission. The conventional chemical propulsion system, can definitely achieve this. With the current specific impulse (figure of merit of any spacecraft engine which is the thrust generated for unit propellant mass flow rate) levels, this call for large quantity of propellant on board imposing constraint on the mass of the useful payload. The electric propulsion system, with much higher specific impulse, allows the propellant mass to be reduced considerably. This enable long interplanetary mission viable, make the communication satellite more profitable etc.

At Liquid Propulsion Systems Centre (LPSC), lead centre of ISRO for propulsion technologies, had taken up the research and development activities related to Electric Propulsion. ISRO plan to induct these systems in forthcoming satellites.

This paper highlight the basics of electric propulsion, development status of hall effect thrusters at LPSC and the plasma diagnostic tools used to characterise the hall effect thrusters

## SA-I-04

### Electromagnetic Ion Cyclotron (EMIC) Waves In The Inner Magnetosphere

Satyavir Singh

*Indian Institute of Geomagnetism, New Panvel (West), Navi Mumbai-410218, Maharashtra*

E-mail : satyavir@iigs.iigm.res.in

#### Abstract

Electromagnetic ion cyclotron (EMIC) waves are low frequency (below the proton gyro-frequency) waves that play an important role in the Earth's magnetosphere. When they propagate parallel to the ambient magnetic field they constitute the low frequency part of the left-hand circularly polarized mode (L mode) but otherwise they are coupled to the right-hand circularly polarized mode (R mode). These waves can resonantly interact with ions and relativistic electrons and can alter their energies and pitch angles and thus, can contribute to precipitation loss of particles from the magnetosphere. The EMIC waves in the terrestrial magnetosphere can primarily be excited by the hot anisotropic protons. The recent observations from Cluster spacecraft in the plasmopause region have shown the rising tone emissions which are believed to be triggered by the EMIC waves. The plasma constituents in this region where these emissions have been observed are electron, cold and hot anisotropic protons ( $H^+$ ), helium ( $He^+$ ) and oxygen ( $O^+$ ) ions. We examine the generation of obliquely propagating EMIC waves in multi-component plasma excited by the hot proton anisotropy in the plasmopause region.

## SA-I-05

### A Scalable, High-VHF CCP Plasma Source for High-Rate nc-Si PECVD

A.R. Ellingboe, Nishant Sirse, and Eamonn Monaghan

*Plasma Research Laboratory  
School of Physics and NCPST,  
Dublin City University  
Ireland*

E-mail : Albert.Ellingboe@DCU.ie

#### Abstract

We will describe a capacitive-coupled plasma source design that is scalable in size and operates at arbitrary frequency without transmission-line-based wavelength effects. Application to nc-Silicon deposition at 162MHz on large substrates (600mm x 720mm) in a  $H_2/SiH_4$  gas mixture is described. Deposition rate increases with silane flow and crystallinity increases with hydrogen-dilution and rf-power, similar to standard HF (13.56 MHz) and low-VHF (up to 75MHz) published results [1].

However, using high-VHF excitation enables access to superior regions of process space. When applied to nc-Si deposition the rate is high (18 Å/s at 0.75 W/cm<sup>2</sup>), silane utilisation is close to the theoretical maximum of 50%, crystallinity is suitably high 55-70% and appears to be controllable via process conditions, and hydrogen-dilution is comparably low at typically 4:1 for the H<sub>2</sub>:SiH<sub>4</sub> mass-flow.

The suitability of the source for nc-Si deposition is attributed to a combination of low-voltage sheaths, and high-VHF plasma chemistry and gas-phase chemistry. The high-VHF excitation results in high efficiency plasma generation (in terms of eV per electron-ion pair). The high-VHF sheath results in stochastic power coupling to the electrons which results in a two-temperature electron-energy-distribution-function comprising a cold-bulk population and a hot-tail. This, in turn, results in high partial dissociation of the silane increasing surface reactivity, but low total-dissociation which is linked to low-crystallinity; and high activated hydrogen-flux which is linked to high-stability, high-performance nc-Si layers.

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## NF-I-01

### Economics of Large Scale Cryogenic System For Fusion Devices

V.L. Tanna

*Institute for Plasma Research, Bhat, Gandhinagar-3824 28, Gujarat*

E-mail: vipul@ipr.res.in

#### Abstract

Large projects based on applied superconductivity, such as nuclear fusion and particle accelerators require powerful and complex helium cryogenic systems. In such systems, the required cryo capacity goes from kW to 100 kW at 4.5 K depending on the size and magnetic fields requirements of the machines. The cost of which represents a significant, if not dominant fraction of the total capital and operational expenditure. It is therefore important to establish guidelines and scaling laws for costing such systems, based on synthetic estimators of their size and performance. Some data on such economics is available and can be exploited to update this information and broaden the range of application of the scaling laws. We report on the economics of 4.5 K refrigeration, cryogen distribution and storage systems, and indicate paths towards their cost-to-performance optimisation based on year 2013. As a mandate of fundamental cryo engineering, efforts shall be made towards the minimization of the heat loads (static as well as pulsed) acting on the system because it has direct impact on the sizing of helium cryogenic system as well as its capital and operational costs over



years. Depending upon trade-off and requirements on to secondary cryogen i.e. Liquid Nitrogen (LN<sub>2</sub>), it is also essential to be focused for LN<sub>2</sub> consumption as equivalent consumption of 50 kW to 700 kW at 80 K is expected for which an optimized mechanisms to be worked out to meet these requirements for large scale cryogenic system.

## NF-I-02

### Edge Turbulence Studies By Fast Visible Imaging In The QUEST And ADITYA Tokamaks

Santanu Banerjee<sup>1</sup>, H. Zushi<sup>2</sup>, K. Hanada<sup>2</sup>, R.L. Tanna<sup>1</sup>, J. Ghosh<sup>1</sup>, R. Jha<sup>1</sup>,  
QUEST and ADITYA teams

<sup>1</sup> *Institute for Plasma Research, Bhat, Gandhinagar 382428, Gujarat, India*

<sup>2</sup> *RIAM, Kyushu University, 6-1 Kasuga Koen, Kasuga-shi, Fukuoka 816-8580, Japan*

E-mail : sbanerje@ipr.res.in

#### Abstract

Edge plasma in toroidal fusion devices is vital as it interfaces the plasma with the first wall components and divertors. The radial cross field transport is particularly important as it decides the strength and strike points of the heat and particle flux to the wall as well as the processes of recycling, impurity influx, and helium ash removal. Transport in tokamaks is generally “anomalous,” thus not following the magnitude and parameter scaling of “collisional transport”. Also, plasma edge is at the immediate vicinity of the confined plasma and thus affects the confinement quality as observed in the achievement of improved confinement modes. Visualization of turbulence has helped immensely in gaining deeper insights in this field. Recently the role of blobs on the convective transport and its effects on the wall loading has been extensively investigated both in experiment and theoretical fields. Nonlinear evolution of drift or interchange instabilities driven by pressure gradient or curvature of the magnetic field lines, the role of E×B flow in shearing off a radially extended structure, and ejection of blobs are active areas of this subject. In the spherical tokamak QUEST, blob dynamics is studied earlier in slab annular plasma created by electron cyclotron waves in a simple magnetic configuration characterized by open field lines [1]. In this work, electron cyclotron resonance heated (ECRH) Ohmic plasmas have been investigated by two dimensional tangential fast imaging technique [2]. Plasma current is driven inductively in the initial ECR pre-ionized slab annular plasma. At the beginning, a closed magnetic surface (LCFS) appears from the inboard side and it grows quickly. Helical perturbations, developed in the slab plasma phase, are forced to bend due to the growing LCFS and moved outwards. Since ECRH is superposed later, there exist two plasma source inputs to the SOL plasma. One is the core Ohmic plasma and the other one is the ECR region vertically extended beyond the LCFS. They serve as possible drives for the SOL fluctuations. Intermittent strong fluctuations dominated by blobs at the edge and SOL are investigated. Similar systems are now installed on the conventional tokamak ADITYA at IPR. Excellent images at high spatial and temporal resolution are obtained. Results from edge fluctuation studies and plasma evolution at long pulse operations of ADITYA at higher plasma parameters will be reported.

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## NF-I-03

### Fusion Neutronics: An Overview

Chandan Danani

*Institute for Plasma Research, Bhat, Gandhinagar, Gujarat-382428*

E-mail : chandan@ipr.res.in

#### Abstract

An overview of the research and development work conducted around the world for the fusion neutronics is presented. The main focus is on the introduction to the main elements of fusion neutronics. D-T plasma based fusion devices will generate 14 MeV neutrons. These neutrons will interact with the surrounding materials in the machine and will give rise to various nuclear effects such as different kinds of nuclear transmutation reaction, nuclear heating, radiation dose-rates, damage to the materials in terms of gas production & displacement per atom (dpa), activation of the materials etc. The neutron interaction is useful in reactors to produce tritium, which is required as fuel in plasma, through  $\text{Li}(n,t)$  nuclear reaction in blankets. Also nuclear heat deposition is a very important aspect from the power generation point of view. On the other side the activation of materials (which then becomes a radiation hazard) and material damage (hydrogen & helium gas production and dpa) are the negative impacts on the nuclear systems. The major elements of fusion neutronics are the following:

- Nuclear design and analyses of fusion reactors system and Test Blanket Modules systems in ITER
- Development of CAD to Monte Carlo radiation transport interface programs
- Activation analyses of materials under irradiation.
- Development of shutdown dose rate code systems
- Rad-waste assessment of nuclear systems
- Development of nuclear data to be used for nuclear analyses of fusion system
- Development of experimental facilities for the validation of nuclear design and measurements of nuclear cross-section data.

Nuclear design of the reactor involves the calculations of the distribution of nuclear radiation fields (neutron and gamma fluxes) over the nuclear reactor system. Monte Carlo and deterministic approaches are employed for the solution of the radiation transport equation and the radiation fields are obtained. These radiation fields are used to get various important nuclear reactor parameters such as Tritium Breeding Ratio (TBR), nuclear heating, energy multiplication factor, gas production, dpa. The reactor radial build-up has to ensure that it is fulfilling the major requirement such as sufficient TBR and at shielding of the Toroidal Field coil. The dpa will help in determining the useful life time of reactor components in the radiation environment. As an example the nuclear designs for EU PPFS design will be highlighted in this paper [1]. The Monte Carlo radiation transport code MCNP is widely used for nuclear analyses of the fusion system. This requires the generation of nuclear model of the system and for complex systems it becomes tedious and error prone. Worldwide CAD to MCNP interface programs [2,3] such as MCAM, McCAD, GEOMIT are being developed for the conversion of CAD geometries to nuclear models of the systems. High quality nuclear data are required in the nuclear design of the reactor. Measurement & evaluation of nuclear data and

generation of nuclear data libraries are important aspect of the fusion neutronics. The D-T neutron source experimental facilities are being developed for the validation experiments on breeding blanket concepts, shielding efficiency measurements and nuclear cross-section data measurements [3,4].

Activation assessments are required for the nuclear safety and licensing of the nuclear reactor systems. Neutron fluxes calculated in the radiation transport analyses along with the activation data libraries are utilized for the solution of Bateman's equation and various activation responses such as radio activity, decay-heat, contact dose rates etc. are calculated. These activation responses are used for the nuclear safety calculation and also required for Rad-Waste assessment and management of the nuclear reactor components. Activated materials inside the reactor will give rise to Occupation Radiation Exposure (ORE) for the person inside the reactor. Two main popular methods of ORE analyses are the Direct one Step (D1S)[5] and Regress Two Step method (R2S). Code systems based on these methods are also being developed.

A brief introduction to the major fusion neutronics R &D being carried out worldwide will be presented in this paper.

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## NF-I-04

### ITER Assembly - Approach, Planning and Current Status

Bedakihale Vijay, Macklin Brian, Petit Patrick, Shaw Robert, Wilson David, Blackler Ken

*ITER Organization, Route de Vinon-sur-Verdon, CS 90 046, 13067 St. Paul Lez Durance Cedex,*

*France*

E-mail : vijay.Bedakihale@iter.org

### Abstract

The ITER machine is being constructed in Cadarache, south of France and the ITER Organization (IO) has overall responsibility for integration.

The Core of the ITER Tokamak consists of a double walled Vacuum Vessel of 1400 m<sup>3</sup> volume surrounded by 18 D shaped Superconducting TF magnets. To minimise the heat transfer to the cold

magnets, silver coated actively cooled thermal shields are placed between the Vessel and Magnets. The machine core is constructed from 9 X 40<sup>0</sup> machine sectors, each consisting of a Vacuum Vessel Sector, two TF coils and Thermal Shields along with other associated components. The sector assembly scope includes on-site transport of the components, their preparation (preassembly), sub-assembly and final installation in the Tokamak pit. The assembly procedures will be specified in construction documents, which form the basis of construction for the Tokamak, in accordance with ITER baseline documents and local regulations.

To accomplish the assembly operation, specially designed, purpose-built tools, as well as standard commercially available tooling and equipment are used. To support the assembly process, a number of services and facilities - metrology, machining facility, NDT, beryllium controlled area and occupational safety - will be established at the site. The combined technical requirements for the assembled sub-systems need to be carefully planned in order to ensure that the machine operates to design specification and can be constructed within the scheduled duration. The key challenges in planning the assembly tasks are the tight installation tolerances for the large, heavy major components of the Tokamak machine.

Variation in manufactured components needs to be managed to ensure an optimized machine configuration can be achieved. In addition, variation introduced by the assembly process, i.e. vacuum vessel welding, needs to be quantified and compensated at each key assembly stage. Meticulous planning is necessary for the logistics of tracking components through the assembly building with minimum impact on other activities going on in parallel. To meet the vacuum requirements, the assembly of all of the Tokamak components shall be carried out under clean conditions. Metrology will be performed using state-of-the-art laser measurement systems to maintain consistency in all dimensional control activities. The assembly of the components containing beryllium will require additional precautions.

This presentation will summarise the key features like overall assembly approach, the planning behind it and the current status of the work along with, the principle tooling to be used, description of the major components, the work breakdown and highlight of the key functional tolerances to be achieved during assembly. Emphasis is placed on Subassembly Activities carried out in the Assembly Building adjacent to Tokamak Building to describe how these key points are considered during assembly.

## NF-I-05

### Recent Advances In SST-1 LHCD System

P. K. Sharma

*Institute for Plasma Research, Bhat, Gandhinagar-382428, Gujarat, India*

Email : pramod@ipr.res.in

#### Abstract

The 2.0 MW, CW, 3.7 GHz., lower hybrid current drive (LHCD) system on steady-state superconducting tokamak (SST1) machine is the main system to sustain and drive plasma current non-inductively for 1000 seconds. It aims to drive plasma current of 220 kA at plasma density ( $n_e$ ) of  $\sim 2 \times 10^{19} \text{ m}^{-3}$  and electron temperature ( $T_e$ )  $\sim 1 \text{ keV}$  at a toroidal magnetic field ( $B_t$ ) of  $\sim 3.0 \text{ T}$ .

Recently, the system has been upgraded by augmenting two additional klystrons, each rated for an output rf power of 500 kW CW operation to enhance its ability to generate enough rf power required to meet its above mentioned goals. These klystrons have been tested on dummy loads for an output rf power of 500 kW for pulse lengths in excess of 1000 seconds, thereby demonstrating capabilities of operating klystrons at rated power for CW operation for LHCD system for SST1 machine. Two klystrons were operated in parallel mode with single high voltage power supply (HVPS) and an anode modulator power supply (AMPS) connected to each klystron. The parallel operation of two klystrons was further carried out with single AMPS.

After connecting the klystrons to the complex network of transmission line, it was subjected to high power operation. This operation posed serious challenges in terms of high insertion losses and arcing at various places. The assembly of entire complex network of transmission line was re-visited and renovating ideas were employed to re-solve these issues. Metallic contacts of the transmission line components were improved by taking a light face-cut on flanges. Special rf seals were designed, tested and introduced between the flange joints.

During launching of power in to SST1 plasma, it was realized that special attention is needed for lower hybrid waves (LHW) to transport the power inside the plasma. To improve edge densities, for better coupling of LHCD power, gas puffing was carried out, which improved edge conditions. The signatures of LHCD power coupled in to the plasma was clearly observed in CdTe detectors which detects supra thermal electrons lying in the energy range 20-300 keV. Energy spectrum of these electrons clearly showed good interaction of LHCD power with SST1 plasma.

A simulation study on the performance of LHW with SST1 plasma is also carried out under different plasma scenarios. The results obtained from the analysis indicate that the LHCD system is equipped with enough power to realise its goal. The results obtained from these analyses are very encouraging and promising in context with SST1 plasma.

In this talk, an overview on the advances made in LHCD system for SST1 plasma, as well as, results obtained from simulations studies, would be presented, described and discussed in more details.

**PD-I-01**

**Microwave Sensors In Fusion Plasma**

Surya K Pathak

*Institute for Plasma Research, Bhat, Gandhinagar, Gujarat 382428*

E-mail: surya@ipr.res.in

**Abstract**

Significant advances in microwave and millimeter wave technology have enabled the development of a new generation plasma diagnostics. At Institute for Plasma Research (IPR) a Millimeter Wave Plasma Diagnostic Laboratory (MPDL) has been designed and established. The thrust of this laboratory is to develop advanced millimeter-/ sub-millimeter- wave plasma diagnostic instruments/sensors and techniques on relevant magnetic fusion devices and obtaining important physics results with these diagnostics. A further important mission is to train the next generation of plasma physicists and engineers.

The microwave diagnostics are broadly classified in two categories: (1) Active diagnostics where microwave is shine over the plasma and both phase as well as amplitude of reflected, transmitted, and scattered wave are measured. These measurements provide density profile and its time evolution as well as its fluctuation. (2) Passive diagnostics where plasma itself emit electromagnetic radiation in form of electron cyclotron emission (ECE) as a function of plasma radius and electron energy. By measuring and resolving this emission in both space- and energy- domain we determine plasma temperature & its fluctuation and energy distribution, respectively.

In both type of diagnostic systems, microwave receiver design is very crucial. In this talk I will discuss mainly about development of 140 GHz phase locked heterodyne Interferometer system, Frequency modulated fast scan reflectometry system and E-Band & D-band Radiometry systems as well as development of high temperature black body source for radiometric calibration. These developments have been done in last five to six year. I will also bring out measured results by installing these systems on Tokamak at IPR.

**PD-I-02**

**Interaction Of Ultrashort Laser Pulse With Transparent Solids: A Source Of Energetic Negative Ions And Neutrals**

S. Bagchi, M. Tayyab, A. Upadhyay, B. Ramakrishna, T. Mandal, J. A. Chakera,  
P. A. Naik, and P. D. Gupta

*Laser Plasma Division, Raja Ramanna Centre for Advanced Technology, Indore, India – 452 013*

E-mail: sbagchi@rrcat.gov.in

**Abstract**

The interaction of ultra-short intense laser (UIL) pulse interaction with matter has been a very active area of research in recent times because of the rich underlying physics as well as for its potential technological ramifications [1]. In this regard, a plethora of work has been reported towards realizing table top sources of high energy electrons, positively charged particles and photons. But realization of efficient, high repetition rate negatively charged particle and neutral atom accelerator based on solid targets is still illusive. In this talk, the realization of a negative ion and neutral atom accelerator based on the interaction of UIL with transparent solid targets will be discussed.

In this direction, we report our recent experimental results conducted with focusing 45 fs, 10 TW laser pulses on a 5 mm thick slab of transparent solid materials e.g. poly-methyl methacrylate (PMMA,  $(C_5H_8O_2)_n$ ). The negative ions were detected by using an in-house developed Thomson Parabola Ion Spectrograph (TPIS) equipped with a micro-channel plate (MCP) as a position sensitive device. A 16-bit EMCCD camera was employed to capture the images of the ions emitted from the plasma. In order to detect neutral atoms, large electric and magnetic fields were used to deflect all the charged particles out of the detection area of the MCP to ensure that only the photons and the neutral particles can be detected. The ion arrival time measurement technique was employed thereafter to discriminate photons and the neutral atoms in terms of their energy distributions.

Notably, in the best focussing condition, when the laser pulse is focussed right on the front surface of the target, no negative ions and neutrals were observed. But as the target position was shifted away from the best focus, the negative ions and neutrals start to appear. This observation points toward sub-surface origin of negative ions and neutrals. This was further validated by employing intentional laser pre-pulse which strongly reduces the negative ions and neutral production.

We have carried out 2D particle-in-cell simulations revealing strong self-focusing of the laser pulse immediately below the target front surface and two distinct bunches of protons emanating from the target. The first bunch comes out from the target front surface while the second bunch of protons appears from below the target front surface passing through the background plasma. It is this second bunch of protons which can capture extra electrons to form neutral and negatively charged particles before coming out of the dense plasma region. Preliminary estimates based on charge transfer cross-section match well with the experimental observation.

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**PD-I-03**

**Laser Based Diagnostics For High Temperature Tokamak Plasma: Thomson Scattering Diagnostics In ADITYA And SST-1**

Jinto Thomas, Kiran Patel, Vishnu Choudhary, Vishal Pillai, Neha Singh and Ajai Kumar

*Institute For plasma Research, Bhat, Gandhinagar, 382428.*

Email : jinto@ipr.res.in

**Abstract**

Laser based diagnostics are indispensable for high temperature tokamak plasma research as it is a non-perturbative measurement with very high spatial resolution. Various plasma diagnostics based on lasers in the range of Visible to FIR are in use: like Thomson scattering, Interferometry and Laser induced Fluorescence, etc. Incoherent Thomson scattering can provide spatio-temporal profile of electron temperature and density of plasma at the core, edge and diverter region with systematic use of high power lasers and high gain detectors along with efficient light collection and its transport. Various Thomson scattering geometries are adopted on different tokomaks depending on the accessibility and the plasma parameters.

The ADITYA tokomak is equipped with a ruby laser based single point Thomson scattering system having spectrometer based spectral dispersion and PMT based detection. The SST-1 tokomak is equipped with Vertical Thomson scattering system with multi-pulse Nd:YAG laser system having Filter polychromator based spectral dispersion and Avalanche photo diode based detector. The SST-1 Thomson scattering system has a spatial resolution of 10 mm and can operate for different temporal resolutions (33 ms, 5.5 ms and burst). The detector electronics and data acquisition developed for the Thomson scattering is capable to detect and acquire fast (50-100 MHz) low fluence signal (few hundreds of photons) effectively. We will present some recent observation in ADITYA Thomson scattering system and the initial testing, calibration and optimization of vertical Thomson scattering system at SST-1.



## PD-I-04

### Investigations On Plasma Turbulence: An Opportunity To Exploit In LVPD

L. M. Awasthi

*Institute for Plasma Research, Gandhinagar- 382428, India*

E-mail: kushagra.lalit@gmail.com

#### Abstract

In recent times, the Large Volume Plasma Device (LVPD) has taken major steps toward understanding Electron Temperature Gradient (ETG) driven turbulence, considered as a major source of plasma loss and seen as a major impediment towards achieving thermo-nuclear fusion in magnetically confined toroidal devices. Studying ETG instability in fusion devices, either by active or passive diagnostics, is a very difficult task because of its extremely small-scale length. However, through our initiatives, we have successfully demonstrated in LVPD its first, unambiguous excitation [1].

Interestingly, while making plasma congenial for carrying out ETG studies, we installed an extremely large ( $\phi \sim 1.9$  m,  $z = 4$ cm), solenoidal shaped, Electron Energy Filter (EEF), responsible for producing ETG suitable profiles [2]. The EEF produces a transverse field of 160G and therefore divides LVPD plasma into three distinct plasma regions named as Source, EEF and Target plasmas. These regions offer different plasma conditions and subsequently help in exciting, instabilities of different nature. The source plasma, which resides between the filamentary source and the first wall of EEF is rich with energetic electrons and offers a plasma scenario where instability of electromagnetic nature, having many features resembling with whistlers, is excited only in one side of the asymmetric belt formed in the region. The EEF plasma, on the other hand has its boundaries extended from the axis of EEF to a distance of few centimetres from both sides of EEF. The plasma in this region excites Rayleigh- Taylor instability [3]. Lastly, the target region, which extends between the second wall of EEF and the end plate, offers plasma suitable for carrying out ETG studies. In this region, ETG suitable profiles are produced, which satisfy threshold condition for ETG turbulence,  $= L_n/L_T > 2/3$ , where  $L_n$  and  $L_T$  are the gradient scale lengths of plasma density and electron temperature. Detailed investigations are carried out in these regions and exciting results on plasma turbulence will be presented in the conference.

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**LVPD Team:** S. K. Singh, A. K. Sanyasi, P. K. Srivastava, S. K. Mattoo, R. Jha, R. Singh and P. K. Kaw.

**PD-I-05**

**Enthalpy Probe Diagnostics For Thermal Plasma Measurements**

G. Ravi

*Institute for Plasma Research, Bhat, Gandhinagar – 382428, India*

E-mail : gravi@ipr.res.in

**Abstract**

The plasma produced in an atmospheric pressure thermal plasma processing system is of high temperature, enthalpy and velocity. The plasma, typically in the form of a jet or plume, also interacts with the cold gas surroundings. For any processing application, a precise knowledge of the temperature, enthalpy and flow fields of the plasma plume in two or three dimensions is required. Conventional probes like thermocouples cannot measure more than their melting points, advanced techniques such as spectroscopy are very complex to use, expensive and yield only chord averaged values and other techniques like laser scattering are very delicate and elaborate.

In recent times, there has been a renewed interest in the enthalpy probe diagnostic which works on calorimetric techniques. One such probe has been developed in our laboratory entirely using in-house facilities. The probe is inexpensive, miniature, modular and user-friendly. The probe area is small enough not to perturb or change local plasma/gas properties significantly and large enough to ensure proper water cooling and gas sampling. The probe is designed in such a way that minimum area occupies the plasma plume and it allows smooth flow of gas around the probe tip.

The enthalpy probe can be used to carry out point-to-point measurements to yield enthalpy, temperature and flow profiles of the plasma plume. The principle of operation, design aspects and experimental results obtained on the plasma plume of a low power dc non-transferred plasma torch will be discussed.

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OA-I-01

**Plasma treatment of Powder and Granulates**

Petr Špatenka<sup>1,2</sup>

<sup>1</sup> *SurfaceTreat Inc., Na Lukách Na Lukách 669, CZ-51401 Turnov, Czech Republic*

<sup>2</sup> *Czech Technical University of Prague, Faculty of Mechanical Engineering, Department of Materials Engineering, Karlovo nám. 2, CZ-461 17 Liberec., Czech Republic*

E-mail: petr.spatenka@surface-treat.cz, petr.spatenka@fs.cvut.cz

**Abstract**

Plasma modification of powder has attracted much interest because of new perspectives of the interfacial properties supervision. Various methods for powder treatment have been reported for low-pressure plasma treatment of powder including fluidized bed or reactors with mechanical stirring. Industrial – scale methods will be also mentioned.

Based on laboratory experiments and theoretical analysis of various treatment methods a concept for industrial scale production of plasma-modified powder was proposed. Development of an industrial-scale process will be presented.

Several applications of the plasma-treated powder and granulates will be demonstrated. Parts sintered from the plasma modified polyethylene powder preserved high surface tension, which allowed e.g. direct painting or adhesive bonding without any additional pretreatment or using them as a filler in composite materials. Plasma modification also significantly enhanced adhesion of the polymer to the substrate. Applications of plasma treated seeds in agriculture will be also presented.

This work was partially supported by the ESF and by MEYS, projects No. CZ.1.07/2.3.00/30.0006 and MSM of the Czech republic, program NPU1, project No. LO1207 and Grant Agency of USB GAJU 102/2013/S

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## Plasma Processing Of Glass-Fiber Reinforcements for Polymer Composites

Vladimir Cech, Antonin Knob, Erik Palesch, Jan Kucharcik, Tomas Plichta

*Institute of Materials Chemistry, Brno University of Technology, Purkynova 118,  
CZ-61200 Brno, Czech Republic*

E-mail : cech@fch.vutbr.cz

### Abstract

The performance of fiber-reinforced composites is strongly influenced by the functionality of composite interphases. Sizing, i.e. functional coating (interlayer), is therefore tailored to improve the transfer of stress from the polymer matrix to the fiber reinforcement by enhancing fiber wettability, adhesion, compatibility, etc. The world market is dominated by glass reinforcement in unsaturated polyester, which comprises almost 90% of the total market.

Commercially produced sizing for glass fibers is heterogeneous with respect to the thickness and uniformity, the molecules of silane coupling agents have a tendency towards self-condensation, forming siloxane oligomers rather than complete bonding with the glass surface, and the low density of siloxane bonds with the surface decreases, if water molecules diffuse to the interface since this type of bond is hydrolytically unstable. Only 10–20% of the total sizing is bonded to the fiber surface and this amount is directly related to the composite interfacial strength. Technology centers in glass companies search for new ways of solving the above problems. One of the alternative technologies is plasma processing of fibers.

Plasma polymer films of hexamethyldisiloxane, vinyltriethoxysilane, and tetravinylsilane in a mixture with oxygen gas were engineered as compatible interlayers for the glass fiber/polyester composite. The interlayers of controlled physicochemical properties were tailored using the deposition conditions with regard to the elemental composition, chemical structure, and Young's modulus in order to improve adhesion bonding at the interlayer/glass and polyester/interlayer interfaces and tune the cross-linking of the plasma polymer. The optimized interlayer enabled a 6.5-fold increase of the short-beam strength compared to the untreated fibers. The short-beam strength of GF/polyester composite with the plasma polymer interlayer was 32% higher than that with industrial sizing developed for fiber-reinforced composites with polyester matrix. The progress in plasmachemical processing of composite reinforcements enabled us to release a novel conception of composites without interfaces.

OA-I-03

**Plasma Induced DNA Damage: Comparison with the Effects Of Ionizing Radiation And Establishing Effective Treatment Doses**

S. Lazovi<sup>1</sup>, D. Maleti<sup>1</sup>, A. Leskovac<sup>2</sup>, J. Filipovi<sup>2</sup>, N. Pua<sup>1</sup>, G. Malovi<sup>1</sup>, G. Joksi<sup>2</sup> and Z. Lj. Petrovi<sup>1</sup>

<sup>1</sup>*Institute of Physics, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbia*

<sup>2</sup>*Department of Physical Chemistry, Vin a Institute of Nuclear Sciences, University of Belgrade, 11001 Belgrade, Serbia*

E-mail: lazovic@ipb.ac.rs

**Abstract**

Atmospheric pressure plasma sources such as the plasma needle are being used for wound and chronic wound healing, cancer cell removal, stem cell manipulations, in dermatology, surgery, dentistry, etc. [1,2]. In our previous work we have optimized plasma needle parameters to efficiently sterilize E. Coli and S. Aureus in planktonic samples without causing damage to the peripheral blood mesenchymal stem cells used as a model for surrounding tissue [3]. Plasma treatments of human periodontal ligament mesenchymal stem cells have led to a promotion of osteogenic differentiation without affecting cell viability [4]. These results can be important for dentistry, especially for possible support or alternative to conventional regenerative procedures, such as guided tissue regeneration, the use of bone replacement grafts, and application of exogenous growth factors or proteins. Besides the promising short term effects of atmospheric non-thermal plasma on cells, it is necessary to study the long term effects, like for example DNA damage in order to prevent undesirable effects.

We investigate plasma induced DNA damage on human primary fibroblasts. The same cell type is used to compare with DNA strand breaks induced by ionizing radiation. We find that unlike gamma exposure, contact with plasma predominantly leads to single strand breaks and base-damage while double strand breaks are mainly consequence of the cell repair mechanisms which is confirmed by detection of different cell signaling mechanisms (ATM and ATR respectively). Most importantly, we find that the effective plasma doses can be tuned to match the typical therapeutic doses of 2 Gy. Tailoring the effective dose through plasma power and duration of the treatment enables safety precautions mainly by inducing apoptosis and consequently reduced frequency of micronuclei. The connection to the radiation biology through the effective doses sets the ground for establishing standard medical procedures for cold plasma applications based on the rich experience in gamma irradiation of cells and tissues.

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**OA-I-04**

**Plasma Synthesis And Conversion Of Nanowires**

Uroš Cvelbar

*Jožef Stefan Institute, Jamova cesta 39, SI-1000 Ljubljana, Slovenia (EU)*

E-mail : uros.cvelbar@ijs.si

**Abstract**

There has been tremendous interest and progress with plasma synthesis of inorganic nanowires (NWs) for improved applications in recent years. Nevertheless, much of the progress only resulted in NWs with diameters much greater than their respective quantum confinement scales, i.e. 10–100 nm. Even at this scale, NW-based materials offer enhanced charge transport and smaller diffusion length scales for improved performance with various electrochemical and photo-electrochemical energy conversion and storage applications. However, many times synthesized materials don't meet specific properties for optimal performance in certain devices, e.g. band gap energies, or they are even hard to obtain. These deficiencies can be eliminated by additional plasma conversion processes, where we can substitute atoms in crystal networks or controllably release them and create defects. Here the NWs or one-dimensional crystalline materials of metal oxides with diameters less than 100 nm provide a useful platform for creating new materials either as substrates for heteroepitaxy or through the phase transformation with reaction. Specific results with single crystal phase transformation of e.g. hematite ( $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>) to pyrite (FeS<sub>2</sub>) NWs will be presented to illustrate the viability of using NWs for creating new materials through plasma particle reformation. Furthermore, the metal oxide NWs can be altered and modified also by other energetic particles like electrons and UV photons, which cause irradiation damages and release atoms from crystal networks. All these processes lead to improved properties, tailored band gaps and increased performance of NWs in devices.

**OA-I-05**

**Plasmolysis as a Novel Approach to CO<sub>2</sub>-To-Fuel Conversion**

Gerard van Rooij

*Technische Universiteit Eindhoven, P.O. Box 513, 5600 MB Eindhoven*

E-mail: G.J.vanRooij@diffen.nl

**Abstract**

The emission of carbon dioxide into the atmosphere is widely regarded as a severe environmental issue due to concern for its effect on climate change. The consequent increasingly stronger limits on CO<sub>2</sub> exhausts are driving the transition to sustainable energy sources. The intermittent character of, particularly, solar photovoltaics and wind imposes the need for power storage. At the same time, these sustainable energy sources produce electricity, whereas, globally, less than 20% of the energy is consumed in that form. Converting temporary electrical energy surpluses into chemical fuels would, thus, be advantageous in view of energy density as well as to address CO<sub>2</sub> emissions in other areas of energy consumption (e.g. transportation). A promising approach for this conversion involves the strongly non-equilibrium chemistry in the plasma phase. The rationale behind the plasma chemical approach is its proven high energy efficiency (up to 90%) due to selectivity in the reaction processes that can be tailored via its inherently strong out-of-equilibrium processing conditions. At the same time, the approach is characterized by low inertia (i.e. efficient and fast power switching is possible), low investment costs, and no scarce materials required. These are all prerequisites for future large scale implementation that alleviates the intermittency of sustainable energy sources. This contribution will give an overview of the research programme at the Dutch Institute For Fundamental Energy Research, DIFFER, on unravelling the plasma physical and chemical fundamentals of CO<sub>2</sub> reduction by plasmolysis.

## Popular Talk-001

### **THE PERVASIVE PLASMA Socio-Economic Impact of Plasma Technologies**

**P. I. John**

*Consultant, Institute for Plasma Research*

*Gandhinagar, 382424 India*

Email: john.pucadyil@gmail.com

#### **Abstract**

This talk shall discuss the pervasive use of plasma as a technological tool of great versatility. This is made possible by the extended parameter space in density, temperature, particle energy and chemical reactivity of the plasma state. No other medium can provide gas temperatures or energy densities as high as a plasma. No other medium can excite atomic and molecular species to radiate as efficiently. No other medium can be arranged to provide comparable transient and nonequilibrium conditions. The products of this technology span advanced materials, efficient waste to energy conversion systems, ways to decarbonize fuels, devices to convert solar energy into electricity, efficient light sources, to name a few.





# **BASIC PLASMA**



**BP-013**

**Study Of Role Of Toroidal Field Topology On Flow And Fluctuation In Simple Toroidal Device**

Umesh Kumar\*, T. S. Goud, R. Ganesh, D. Raju, Y. C. Saxena

*Institute for Plasma Research, Bhat, Gandhinagar-382428, Gujarat*

\*E-mail:umeshks@ipr.res.in

**Abstract**

It is believed that toroidal field topology plays very crucial role in determining the nature of instabilities in a currentless toroidal devices such as BETA at IPR [1, 2]. This happens because when the toroidal field topology changes it in turn change the parallel wavenumber and nature of instability strongly depends upon the value of parallel wavenumber [1, 3]. Preliminary experiment on effect of toroidal field topology on fluctuation and mean flow has been done in BETA. Mean profiles of plasma profiles and fluctuations have been obtained experimentally. Power spectrum of fluctuations clearly shows that the nature of fluctuation changes with change in magnetic field topology. Net poloidal flow has been measured. A strong correlation between the nature of fluctuations and the topology of magnetic field is shown. These and the related progress in this area will be presented.

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**BP-014**

**Arbitrary Amplitude Kinetic Alfvén Solitons In A Dusty Plasma With A q-Non-Extensive Electron velocity Distribution**

M. K. Ahmed, O. P. Sah

*Department of Physics, Birjhora Mahavidyalaya, Bongaigaon, Assam, 783380*

E-mail:mnzur\_27@rediffmail.com

**Abstract**

In most of the theoretical studies done so far on nonlinear structures of kinetic Alfvén waves in dusty plasmas, the particle distribution has been assumed to be Maxwellian. But for systems with long-range interactions, such as plasma (Coulombian long-range interaction), the traditional Maxwellian distributions might be inadequate for the description of the systems. Such a system can be described by  $q$ -nonextensive velocity distribution<sup>1</sup> which has been applied successfully in various cases<sup>2,3</sup>.

Here, we consider nonextensive dusty plasma comprising of nonextensive electrons, cold ions and immobile negatively charged dust grains. In this model of dusty plasma, we have been investigating the existence of arbitrary amplitude solitary kinetic Alfvén waves and studying their properties theoretically and numerically by deriving Sagdeev's Pseudopotential. The results that we have obtained so far are encouraging because of the appearance of the parameter  $q$  in the Pseudopotential. The results in the case  $q \rightarrow 1$  are consistent with those in the framework of the Maxwellian distribution.

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**BP-020**

**Analytical Estimate of Phase Mixing Time of Longitudinal Akhiezer - Polovin Wave**

Arghya Mukherjee and Sudip Sengupta

*Institute for Plasma Research, Bhat, Gandhinagar, Gujarat, 382428*

E-mail : arghya@ipr.res.in

**Abstract**

Phase mixing and eventual breaking of longitudinal Akhiezer - Polovin wave subjected to a small amplitude longitudinal perturbation is studied analytically. It is well known that longitudinal Akhiezer - Polovin wave breaks via the process of phase mixing at an amplitude well below its breaking amplitude, when subjected to arbitrarily small longitudinal perturbation [Phys. Rev. Lett. 108, 125005 (2012)]. Here we analytically show that the phase mixing time (breaking time) scales linearly with phase velocity of the wave, inverse-squarely with maximum fluid velocity of the electrons and inversely with the amplitude of perturbation. This analytical dependence of phase mixing time on phase velocity, maximum fluid velocity and amplitude of perturbation is further verified using numerical simulations based on Dawson sheet model.

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**BP-030**

**Interaction Mechanism Between Dust Grains In Presence Of Asymmetric Ion Flow**

Saurav Bhattacharjee and Nilakshi Das

*Department of Physics, Tezpur University, Tezpur-784028*

E-mail :sauravtsk.bhattacharjee@gmail.com

**Abstract**

As dust is the omnipresent ingredient in the universe, the field of complex plasma or dusty plasma has gained immense attention in last few decades due to its potential applications in various fields starting from astrophysics, fusion and laboratory plasma experiments. One of the profound features of dusty plasma is the formation of plasma crystal [1-2] in strongly coupled regime. Under suitable condition, when the interaction potential energy between the highly charged dust grains exceeds their thermal energy, they show some self-organized structures known as plasma crystals. Usually the interaction between the dust grains involves symmetric repulsive Yukawa type of interaction potential. The micron sized dust grains are trapped near the sheath region balancing by the gravitational and electrostatic force, acting opposite to each other. Near, the plasma sheath, there is strong ion flow from bulk plasma towards the lower negative electrode. This causes the distortion of spherical Debye cloud surrounding the negatively charged dust grains. As a result, the symmetry is broken and an asymmetric attractive interaction potential named as Wake potential comes into play [3]. Moreover, the study of dusty plasma in presence of external magnetic field makes it relevant to naturally occurring plasma and is of recent interest for dusty plasma community.

We have reported a theoretical study on the interaction mechanism between dust particles in the presence of asymmetric ion flow and an external magnetic field in complex plasma. The recent experimental and numerical results on the particle-wake interaction ensures the dominance of the wake effect in the subsonic regime of plasma flow using the cold ion approximation. The recent developments in dusty plasma research and its growing interest towards more realistic magnetized dusty plasma scenarios also demand serious attention to study the wake effect both in the sub and supersonic regimes in the presence of a magnetic field. It is a challenging task to develop a correct, quantitative theory of wake potential for different regimes of magnetic field and ion flow velocity. Analytic expressions for the wake potential have been reported in this paper for both subsonic and supersonic regimes in the presence of an external magnetic field along with Yukawa type potentials. The results show that the wake potential plays a dominant role in the subsonic regime and its strength increases with an increase in magnetic field. The behaviour of the wake potential is found to have an interesting effect on the coulomb crystallization of dust grains and is studied with the help of molecular dynamic (MD) simulation.

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**BP-034**

**Effect of Trapped Particle Nonlinearity on Ion Acoustic Wave**

Debraj Mandal and Devendra Sharma

*Institute for Plasma Research, Bhat, Gandhinagar- 382428*

E-mail :debraj@ipr.res.in

**Abstract**

The ion acoustic waves show nonlinear properties in the finite amplitude limit. Besides the hydrodynamic nonlinearity the waves strongly trap particles (both electron and ion) and show associated nonlinear effects. In our studies we simulate the propagation of self-consistently generated ion acoustic wave in a current driven collision less Vlasov plasma, which show formation of solitary structures. The nonlinearity of the structures is analyzed in the limits where, they show deviation from the existing analytic nonlinear solitary solutions, which are generating from the hydrodynamics nonlinearity. The solution show signature of nonlinear effects from the outset where they dominate the lowest order linear effect.

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**BP-040**

**Spectroscopic Investigation Of High Density Plasma Beam With N<sub>2</sub>/H<sub>2</sub> Gas Mixtures**

Parvathi S. Mohan\* and B. Ganguli\*\*

\*Cochin University of Science and Technology, Cochin - 682022

\*\*Institute for Plasma Research, Bhat, Gandhinagar – 382428

\*E-mail: ekrumohan@gmail.com

**Abstract**

Plasma spectroscopy has been carried out in a high density plasma beam [1] produced by pulsed microwaves of 2.45 GHz in an axial magnetic field of 800 Gauss using nitrogen/hydrogen gas mixtures. Emitted spectra (300nm to 800nm) were recorded. Starting from pure nitrogen, i.e. zero percentage of hydrogen spectra were taken in steps of 5% increase in hydrogen percentage until it is pure hydrogen, i.e. 100% hydrogen. Our main objective is to find out what is the optimum ratio of nitrogen to hydrogen which produces the maximum intensity of NH and NH<sup>+</sup> which are known to be the main active species responsible for nitriding.

The spectra we found are significantly different from those reported for glow discharge plasma [2] and other types of plasma with N<sub>2</sub>/H<sub>2</sub> gas mixtures. We estimated excitation temperature of hydrogen plasma as 1.002 eV. We could also find the presence of NH and NH<sup>+</sup> species in different combination of N<sub>2</sub>:H<sub>2</sub> mixture ratios. By analyzing the peak intensities due to NH and NH<sup>+</sup> radicals, we concluded that the best N<sub>2</sub>:H<sub>2</sub> ratio should be between 80:20 and 70:30.

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### BP-042

#### **Ion-Acoustic Dressed Solitons in Electron-Positron-Ion Plasma With Nonisothermal Electrons**

Parveen Bala<sup>1</sup> and Tarsem Singh Gill<sup>2</sup>

*1. Department of Physics, Guru Nanak Dev University, Amritsar-143005.*

*2. Dept of Mathematics, Statistics & Physics, Punjab Agricultural University, Ludhiana-141004.*

E-mail :pravi2506@gmail.com

#### **Abstract**

An electron-positron (e-p) plasma, usually behaves as a fully ionized gas of electron and positrons, is considered not only as a building block of our early universe but also an omnipresent constituent of a number of astrophysical environment, such as active galactic nuclei, pulsar magnetosphere, solar atmosphere, fire balls producing  $\gamma$ -ray bursts and at the center of our galaxy. Since most of astrophysical and laboratory plasmas contain ions besides e-p, it is relevant here to discuss wave motions in e-p-i plasma. Positrons are also part of plasma produced when ultra intense laser pulses interact with the matter, such as in internal confinement fusion (ICF) schemes. In the present investigation, ion-acoustic dressed solitons have been studied in an electron-positron-ion plasma with the nonisothermal distribution of electrons. The standard technique known as reductive perturbation technique (RPT) has been used to derive the equation. To the lowest order, a modified Schamel Korteweg-de Vries (KdV) equation associated with (1+1/2) nonlinearity, also known as Schamel-KdV model, has been derived. RPT is further extended to include the contribution of higher order nonlinear and dispersion terms. Using renormalization method, a stationary solution resulting from higher order perturbation theory has been found. Results of numerical computation for such contribution are shown in the form of graphs in different parameter regimes and a comparison with earlier investigations has been made. Such study is relevant to understand physics of astrophysical and cosmic plasmas where e-p jets enter in cold interstellar environment.



**BP-044**

**Dispersion Relation On Alfven Waves In Multi-Component Magneto-Plasma**

Vishnu P. Ahirwar and G. Ahirwar

*School of Studies in Physics, Vikram University, Ujjain (M.P.)-456010*

E-Mail: ganpat.physics@gmail.com

**Abstract**

The dispersion relation of Alfven waves have been theoretical studies by kinetic approaches. Dispersion relation of Alfven waves are measured in multi-component magnetosphere plasma consisting of mixture of hydrogen ( $H^+$ ), helium ( $He^+$ ) and Oxygen ( $O^+$ ) ions in magnetized cold plasma. The wave is assumed to propagate parallel to the static magnetic field. It is observed that the effect of multi-ions for different plasma densities on Alfven waves is to enhance the wave frequencies. The results are interpreted for the magnetosphere has been applied parameters by auroral acceleration region.

**BP-047**

**Self-Consistent Kinetic Trajectory Simulation Model For Magnetized Plasma Sheath (1d3v)**

Roshan Chalise and Raju Khanal

*Central Department of Physics, Tribhuvan University, Kirtipur, Kathmandu, Nepal*

E-mail : plasma.roshan@gmail.com

**Abstract**

A Kinetic Trajectory Simulation (KTS) model of a 1d3v(1D in space and 3D in velocity), time - independent, collisionless magnetized plasma is presented, which can be used for modeling various situations of interest and yields results of high accuracy. Exact ion trajectories are followed, to calculate along them the ion distribution function, assuming an arbitrary injection ion distribution. The electrons, on the other hand, are assumed to have a half Maxwellian velocity distribution at injection so that their density can be calculated analytically. Starting from an initial guess, the potential profile is iterated towards the final time-independent self-consistent state. In the present work we develop a 1d3v(1D in space and 3D in velocity) kinetic trajectory simulation model of the magnetised plasma-wall transition layer, where the charged and neutral particle dynamics and interaction between them is included in a fully self-consistent way. The plasma-surface interactions are described via fixed emission coefficients for the secondary particles. We obtained different profiles of plasma and neutral particles and cross-checked classical boundary conditions, which are usually formulated inside the PWT.

**BP-051**

**Polarization Reversal Of Helicon Wave In Non-Uniform Plasma**

Sonu Yadav, K K Barada, P K Chattopadhyay, S K Pathak, J Ghosh

*Institute for Plasma research, Bhat, Gandhinagar, 382428,*

E-mail :syadav@ipr.res.in

**Abstract**

Experiments have been performed in a plasma produced by  $m = +1$  half helical antenna with power up to 1kW at 13.56 MHz Radio frequency [1]. The right hand polarized (RHPW)  $m = +1$  mode propagates in the direction of applied magnetic field, whereas the left hand polarized (LHPW)  $m = -1$  mode propagates in the opposite direction. It has been observed experimentally that left hand polarized waves get absorbed near ECR in Helicon plasma, which is contrary to expectation, as ECR is related to electrons. This observation confirms the polarization reversal of the helicon waves [2]. A theoretical model has been presented to show that the polarization of the helicon wave gets reversed at certain radial location. It is also shown that radial boundary as well as inhomogeneity plays an important role in polarization reversal [3, 4].

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**BP-055**

**Arbitrary Amplitude Kinetic Alfvén Solitary Waves In A Plasma With Two-Temperature Electrons**

Latika Kalita

*Department of Mathematics, B. P. Chaliha College, Assam*

Email- latika84k@rediffmail.com

**Abstract**

To investigate the existence of kinetic Alfvén wave solitons, warm ions and two electron components, namely hot and cold are considered in a magnetized plasma. In this work, by using the Sagdeev Pseudopotential [1] method, an exact analytical expression for arbitrary amplitude solitary kinetic Alfvén wave is derived. The Sagdeev Potential  $K(n_c)$  has been calculated numerically and the range of parameters for the existence of solitary waves and their effects on the

plasma medium are studied in details and presented graphically for the different set of plasma parameter values.

Keywords: Sagdeev Potential, Solitary Waves, Kinetic Alfvén Wave.

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[1] Sagdeev R. Z, *Reviews of Plasma Physics* (Consultants Bureau, New York), vol 4, pp. 23, (1966).

**BP-060**

**Solitary Kinetic Alfvén Waves In A Plasma With Negative Ions**

H. Sahoo<sup>1</sup>, K.K. Mondal<sup>2</sup> and B. Ghosh<sup>1</sup>

<sup>1</sup> *Departments of Physics, Jadavpur University Kolkata-700032, India*

<sup>2</sup> *Sovarani Memorial College Jagatballavpur, Howrah-711408, India*

E-mail :bsdvghosh@gmail.com

**Abstract**

By using the Sagdeev pseudo-potential approach, the solitary kinetic Alfvén waves have been theoretically investigated in a collisionless magnetized plasma in presence of negative ions. Sagdeev potential is plotted for different plasma parameters and it is shown that both hump and dip solitons may exist for kinetic Alfvén waves which support the data received from space satellites. The negative ions are shown to have significant effects on the conditions for existence and properties of these solitons. It is shown that both hump and dip solitons can be excited in different parametric regions of negative ion concentration. We have also shown that the amplitude of the hump solitons decreases and that of the dip solitons increases with increase in negative ion concentration. There is a critical value of negative ion concentration at which the nature of the solitons changes from hump to dip or dip to hump. We have also examined the effects of propagation angle, Mach number and mass of the negative ions on the conditions of existence and nature of the SKAWs.

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**BP-073**

**Vlasov-Poisson Systems and Collisionless Plasmas - Towards Langmuir Turbulence**

Pallavi Trivedi, R. Ganesh

*Institute For Plasma Research, Gandhinagar, India, 382428*

E-mail : ganesh@ipr.res.in

**Abstract**

Landau damping in 1D collisionless plasma with a Maxwellian and nonextensive distributions have been addressed in the past [1,2]. In Astrophysical conditions, it is well known that steady kinetic turbulence with broadband spatial and temporal spectrum is an important paradigm. It then becomes necessary to ask as to what happens to the regular Landau damping in the background of steady kinetic turbulence or a system with many modes interacting nonlinearly to form a steady state.

To address the problem of Landau damping of a small amplitude wave in a background steady kinetic turbulence, we first consider forcing of the Vlasov Plasma by a external electric field for a range of amplitudes and wave-numbers. It is then demonstrated that indeed it is possible to attain a quasi-steady state with many modes. The problem of Landau damping in such a background is then addressed. This and other details will be presented.

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**BP-098**

**Effect of Transverse Magnetic Field on Bursian Diode**

Sourav Pramanik and Nikhil Chakrabarti

*Saha Institute of Nuclear Physics, 1/AF Bidhannagar, Kolkata-700064, India*

E-mail :sourav.pramanik@saha.ac.in

**Abstract**

A Bursian diode, in its simplest and classical form, consists two electrodes[1]. Electrons are emitted from cathode surface due to thermionic emission, and they are collected by anode when a potential bias is applied across the electrodes. A negative potential minima (known as virtual cathode) forms in the vicinity of anode surface due to accumulation of space charge. This virtual cathode has been shown to limit the flow of emitted electrons and control the maximum value of saturation current [2]. Virtual cathode blocks the further passage of electrons by creating a potential barrier. Only the

electrons, which are emitted from anode end with sufficient kinetic energy, can overcome the potential barrier and reach anode. Otherwise they get reflected back by the virtual cathode.

In our work, we consider a Bursian diode placed in an ambient (external) transverse magnetic field. By assuming non-relativistic motion of electrons a steady state solution have been presented. It is shown that the magnitude of potential minima of virtual cathode gets diminished as the strength of transverse magnetic field is increased. Consequently, for higher values of magnetic field, more number of electrons are allowed to enter within inter-electrode region as barrier potential gets reduced increasing maximum value of saturation current.

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## BP-102

### Phase-mixing of Lower-Hybrid Oscillations in Cold Plasmas

Chandan Maity

*Saha Institute of Nuclear Physics, 1/AF Bidhannagar, Kolkata-700 064, India*

E-mail :chandan.maity@saha.ac.in

#### Abstract

Space-time evolution of nonlinear lower-hybrid modes in cold electron-ion plasmas has been studied within a relaxation of quasineutral plasma approximation. It is shown that initially excited lower-hybrid modes phase-mix and consequently break at arbitrary amplitudes because of a non-zero ponderomotive force that makes the plasma to acquire an inhomogeneity in space. An estimate for the phase-mixing time is provided, showing its dependence on the amplitude of perturbation and on the electron to ion mass ratio. These results will be of relevance to laboratory and space plasmas.

**BP-103**

**Amplitude Modulation Of Ion-Acoustic Solitary Waves In Fully Relativistic Two-Component Plasma**

Sreyasi Banerjee<sup>1</sup> and Basudev Ghosh<sup>2</sup>

<sup>1</sup>*Department of Electronics, Vidyasagar College, Kolkata-700006, India*

<sup>2</sup>*Department of Physics, Jadavpur University, Kolkata-700 032, India*

*E-mail: sreyasibanerjee10@gmail.com*

**Abstract**

Nonlinear amplitude modulation of ion-acoustic waves in a fully relativistic two fluid plasma model has been theoretically studied by using complete set of fully relativistic dynamic equations. To describe the nonlinear evolution of the wave envelope a nonlinear Schrödinger equation is derived by using standard multiple scale perturbation technique. Using this equation it is shown that the wave becomes modulationally unstable as the wavenumber exceeds certain critical value. This critical wavenumber is found to decrease with increase in relativistic effect. The instability growth rate has also been calculated numerically for different values of plasma drift velocity. The growth rate is shown to decrease with increase in the relativistic effect.

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**BP-111**

**Investigations of Chaotic Transitions in Argon and Neon Gas Discharges**

Anu Philip<sup>1</sup>, Prijil Mathew<sup>1</sup>, Sajith Mathews T<sup>1</sup>, P.J Kurian<sup>1</sup> and P.K Chattopadhyay<sup>2</sup>

<sup>1</sup>*ResearchCenter, Dept. of Physics, S.BCollege, Changanacherry, Kottayam, Kerala-686 101*

<sup>2</sup>*Institute for Plasma Research, Bhat, Gandhinagar, Gujarat-382 428*

*E-mail: pjklasma@yahoo.ca*

**Abstract**

Nonlinearity is an inherent property of plasma and glow discharge plasmas are of particular interest due to its simplicity and wide applications. In this study, the dynamics of Argon and Neon dc glow discharge plasmas are investigated with the gas pressure as the plasma system's control parameter. Time series data indicates the transition from periodic oscillations to irregular fluctuations as the control parameter is varied. The Fourier spectrum and phase space of the data gives a clear indication of period multiplication, quasiperiodicity, and chaos. In addition, the Largest Lyapunov Exponent

(LLE), correlation dimension and other dimensions are calculated to quantify the complex nature of the glow discharge plasma.

## BP-126

### Temporal Evolution Of Linear Kinetic Alfvén Waves In Inhomogeneous Magnetized Plasma And Generation Of Turbulence

R. Goyal and R. P. Sharma

*Centre for Energy Studies, Indian Institute of Technology Delhi, Delhi 110016, India*

E-mail: ravig.iitd@gmail.com

#### Abstract

The propagation of linear Kinetic Alfvén waves (KAWs) in inhomogeneous magnetized plasma has been studied while including inhomogeneities in transverse and parallel directions relative to the background magnetic field. The propagation of KAWs in inhomogeneous magnetized plasma is expected to play a key role in energy transfer and turbulence generation in space and laboratory plasmas. The inhomogeneity scale lengths in both directions may control the nature of fluctuations and localization of the waves. We present a theoretical study of the localization of KAWs, variations in magnetic field amplitude in time, and variation in the frequency spectra arising from inhomogeneities. The relevance of the model to space and laboratory observations is discussed. A frequency spectrum with a scaling of the order of  $\omega^{-2}$  has been observed for different inhomogeneity scale lengths describing the energy transfer from lower frequencies to higher ones.

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**BP-133**

**Intermittency Route to Chaos and Back In Simple Diode Plasma Device**

Prince Alex, Saravanan A and K.S.Suraj

*Department of Physics Pondicherry University, Kalapet , Puducherry 605014 ,India*

E-mail: princealexander@gmail.com

**Abstract**

Intermittency in floating potential oscillations of plasma has been spotted in simple diode plasma experimental setup. The experiment was conducted in a glow discharge plasma setup with constant pressure and constant electrode separation as applied voltage being the only control parameter. The floating potential oscillations from the experimental system is recorded using a Lecroy DSO and initially it shows a period-8 oscillations for a range of applied voltage. With further increase of applied voltage the periodic oscillations was interrupted by irregular bursts from 602V in the form of intermittency. As the control parameter is varied the burst become more frequent and oscillations become completely chaotic as seen from the FFT spectrum. It has also been observed the system moves to a less chaotic state as the control parameter varied from 662V to 668V and finally settle down to complete periodic state at 670V.

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**BP-134**

**A Model For The Calculation  $N_2^+$  And  $H_2^+$  Ion Influx At The Cathode Surface In  $N_2$ - $H_2$  Discharge**

K.S.Suraj , Prince Alex and Saravanan A

*Department of Physics Pondicherry University, Kalapet, Puducherry 605014, India*

E-mail: suraj.kumar.sinha.pu@gmail.com

**Abstract**

A model based on electron impact ionization cross section at the plasma sheath boundary has been developed to calculate the  $N_2^+$  and  $H_2^+$  influx at the cathode surface in  $N_2$ - $H_2$  discharge. Analysis of plasma nitriding experimental results shows that treatment of the substrate with 30% $N_2$ -70% $H_2$  gas composition gives a much enhanced result with no compound layer formation on the microstructure of the nitride substrate. The analytical formula derived explains the correlation between nitride formation and the gas composition. It explains that nitride formation is efficient for 30% $N_2$ -70% $H_2$  gas composition, since the nitrogen and hydrogen molecular ions reaching the substrate surface are equal ( $I_{N_2^+}=I_{H_2^+}$ ) at this partial pressure of  $N_2$  and  $H_2$ .

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**BP-137**

**Arbitrary Amplitude Dust Kinetic Alfvén Solitary Waves In A Plasma With  $\kappa$ -Distributed Electrons**

Rumi Chaharia and Nirupama Devi

*Department of Mathematics, Cotton College, Guwahati, Assam*

Email- rumi.chaharia@gmail.com

**Abstract**

We study three-component plasma to investigate the existence of Dust Kinetic Alfvén waves with  $\kappa$ -distributed electrons, ion-inertia under the effect of polarization and the presence of dust-particles for warm and adiabatic ions. Using Pseudo-potential method<sup>1</sup> for a low- $\beta$  approximation leading to double potential theory<sup>2</sup>, an energy integral for arbitrary amplitude solitary Dust Kinetic

Alfvén waves (DKAWs) is derived. For different sets of plasma parameters, it is observed that both compressive and rarefactive solitary waves may exist. Interesting structures are found for different values of plasma parameters. Amplitudes and width of the solitons have been calculated for different parametric values of  $\alpha(T_i/T_e)$ , ratio of the ion to electron temperature),  $k_z$  (the direction cosines with respect to the direction of ambient magnetic field) and  $Z\delta_d$  (the dust grain charge) from the nonlinear dispersion relation.

#### References:

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**BP-150**

## Ion-Acoustic Solitons In Warm Magnetized Electron-Positron-Ion Plasma

<sup>1</sup>S. K. Jain and <sup>2</sup>M. K. Mishra

<sup>1</sup>*Government P.G. College, Dholpur, Rajasthan, India*

<sup>2</sup>*Department of Physics, University of Rajasthan, Jaipur-302004*

E-mail: surendrajain0110@gmail.com

### Abstract

Ion-acoustic solitons in magnetized electron-positron-ion (EPI) plasma with warm adiabatic ions and isothermal electrons has been studied. Reductive perturbation method has been applied to derive Korteweg-de Vries (KdV) equation for the system, which admits an obliquely propagating soliton solution in magnetized plasma. The system supports only compressive solitons for the selected set of parameter values. Investigations also reveal that external magnetic field does not affect the amplitude of ion-acoustic solitons, but the angle ( $\theta$ ) between wave vector and magnetic field affects the amplitude. The amplitude of the solitons increases with increase in angle  $\theta$ . Magnetization and the angle of obliqueness  $\theta$  affect the width of the soliton drastically. An increase in ionic temperature decreases the amplitude and width. It is found that the positron concentration and temperature ratio of electron to positron ( $\gamma$ ) also has impact on amplitude as well as width of the solitary wave. For the selected set of parameters, profiles have been drawn to study the combined effect with variation of two parameters on the characteristics of the ion-acoustic solitons (i.e., amplitude and width). The result may be applicable to plasma in the laboratory as well as in the magnetospheric region of the earth.

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**BP-151**

**Modulational Instability Of Ion Acoustic Waves In Dusty Plasma With Two-Electron Temperature Distribution**

<sup>1</sup>S. K. Jainand <sup>2</sup>M. K. Mishra

<sup>1</sup>*Government P.G. College, Dholpur, Rajasthan, India*

<sup>2</sup>*Department of Physics, University of Rajasthan, Jaipur-302004*

E-mail: surendrajain0110gmail.com

**Abstract**

The stability of modulation of dust ion-acoustic waves in a collisionless plasma with warm adiabatic ions, stationary dust and two temperature distribution of electrons is studied using the Krylov-Bogoliubov-Mitropolsky (KBM) perturbation technique. Nonlinear Schrödinger equation (NLSE) governing the slow modulation of the wave amplitude has been derived for the system. The region of instability for the dust ion acoustic waves is affected by the relative concentration of cold electrons ( $\mu$ ), the relative temperature of two species of electrons ( $\beta$ ) and on the polarity of the charge of the dust grain. It is found that there is shift in the instability region from higher wave number to lower wave number on changing the polarity of dust grain from positive to negative. The region of instability with relative temperature ratio of two species ( $\beta$ ) and the relative concentration of cold electrons ( $\mu$ ) on the region of instability for both the polarities of charged dust species in dusty plasma has been analyzed. The roles of the other plasma parameters (e. g., ion temperature, Mass ratio, Charge multiplicity) are also discussed in detail.

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**BP-153**

**Kolmogorov Flows In 2D Strongly Coupled Complex Plasmas**

Akanksha Gupta, Rajaraman Ganesh and Ashwin Joy

*Institute for Plasma Research Bhat, Gandhinagar Gujarat -382428*

E-mail : ganesh@ipr.res.in

**Abstract**

Stability and nonlinear properties of a special class of shear flows, namely 2D Kolmogorov flow, is addressed in the context of strongly coupled complex plasmas. In the first part, undriven,

incompressible Kolmogorov flow in two dimensional doubly periodic strongly coupled complex plasma is modelled using Generalised Hydrodynamics [1, 2], both in linear and nonlinear regime. A complete stability diagram is obtained for low Reynolds numbers  $R$  and for a range of viscoelastic relaxation time  $\tau_m$  [ $0 < \tau_m < 10$ ]. For the system size considered, using a linear stability analysis, similar to Navier Stokes fluid ( $\tau_m = 0$ ), it is found that for Reynolds number beyond a critical  $R$ , say  $R_c$ , the Kolmogorov flow becomes unstable. Importantly, it is found that  $R_c$  is strongly reduced for increasing values of  $\tau_m$ . A critical  $\tau_m^c$  is found above which Kolmogorov flow is unconditionally unstable and becomes independent of Reynolds number. For  $R < R_c$ , the neutral stability regime found in Navier Stokes fluid ( $\tau_m = 0$ ) is now found to be a damped regime in viscoelastic fluids, thus changing the fundamental nature of transition of Kolmogorov flow as function of Reynolds number  $R$ . A new parallelized nonlinear pseudo spectral code has been developed and is benchmarked against eigen values for Kolmogorov flow obtained from linear analysis. Nonlinear states obtained from the pseudo spectral code exhibit cyclicity and pattern formation in vorticity and viscoelastic oscillations in energy [3]. Properties of externally forced Kolmogorov system in the incompressible regime is also addressed. In the second part, we endeavor to address the transition from laminar to turbulent flow and other linear & nonlinear properties for a compressible Kolmogorov flow using compressible Generalized Hydrodynamic model [4].

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## BP-154

### Inverse Mirror Plasma Experimental Device (IMPED) – A Magnetized Linear Plasma Device With A Wide Operating Range For Wave Studies

Sayak Bose, P.K. Chattopadhyay, J. Ghosh and Y.C. Saxena

*Institute for Plasma Research, Bhat, Gandhinagar - 382428*

E-mail: sayak@ipr.res.in

#### Abstract

The design and plasma aspects of a magnetized linear plasma device, the IMPED [1] (Inverse Mirror Plasma Experimental Device), for experimental studies of waves and instabilities with special emphasis on phase mixing and wave breaking of nonlinear plasma oscillations are reported here. The device consist of a multi-filamentary plasma source located in the weak magnetic field region followed by a much longer uniform high magnetic field region (main chamber). Quiescent collisionless magnetized plasma is produced in the device; typically quiescence,  $\delta n/n \lesssim 1\%$  at  $\sim 10^{-4}$  mbar,  $B = 1090\text{G}$  and fill-in gas argon. Operating pressure in this machine ranges from  $1.7 \times 10^{-5}$  mbar to  $1 \times 10^{-3}$  mbar, covering both the collisionless and collisional regimes. Employing a unique and flexible transition magnetic field region (between the plasma source chamber and the main plasma chamber) in addition to the usual control features of a filament discharge, the density and temperature vary over a wide range from  $10^9$  to  $10^{12} \text{ cm}^{-3}$  and 2 to 5 eV, respectively. The plasma

produced is axially uniform  $L_{\text{uniform}} \sim 120$  cm and the radius of the uniform plasma can be varied as per experimental requirements.

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### BP-165

## Measurement Of Ion Flow Velocities At The Sheath Boundary Using Ion Doppler Shift Spectroscopy In Low Temperature Plasmas

Vara Prasad.K, Joydeep Ghosh, Nilam Ramaiya, Niraj Virani, M. B. Chowdhuri, R. Manchanda and S. Banerjee

*Institute for Plasma Research, Bhat, Gandhinagar, 382428.*

E-mail: varam.ipr@gmail.com

#### Abstract

The study of ion flows into the sheath boundaries has great importance in understanding heat flux to the boundary wall, confinement of plasma, plasma etching process etc. A plasma sheath is formed at the location of interaction of the plasma with physical boundaries or with probes inserted into it. Measurement of ion flows at the sheath boundaries in plasmas is not very straightforward and is a difficult task. Many authors used Laser Induced Fluorescence (LIF) technique for ion velocities measurements in pre-sheath and sheath regions [1, 2]. In this paper, a simple novel method is attempted to measure the ion flow velocities at the sheath boundary using Ion Doppler Shift Spectroscopy [3]. DC-Sheath is produced in front of a negatively biased stainless steel plate by inserting it into an unmagnetized Argon filament discharge plasma. Doppler shifted emission lines from the accelerated plasma ions moving towards the sheath formed near a biased metal plate are measured using a 0.5-m spectrometer with a CCD detector. Two lines of sight, one viewing the plasma without the sheath and another viewing the plasma with the sheath are arranged to obtain the reference and Doppler shifted ion spectral line respectively. Doppler shift of  $\sim 0.02$  nm for  $\text{Ar}^+$  spectral line at 472.6 nm corresponding to argon ion velocity of  $\sim 14$  km/sec is measured in the spectra collected by the line of sight passing through the sheath. The observed spectra of Ar neutral lines remained almost un-shifted which shows neutrals are not influenced by electric field inside the sheath. The ion velocities at sheath edge is then determined by subtracting the velocity gained by the ions in the sheath electric field measured by conventional and laser heated emissive probes. The estimated ion velocity at the sheath edge using the above method matches quite well with the estimated ion velocities deduced from ion acoustic wave propagation in the bulk plasma within the experimental errors. The measurements of ion flows at the sheath edge in multi ion species (Ar-Ne) plasmas are also attempted under various conditions.

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**BP-166**

**Wave Launching Experiment in Ion Cyclotron Frequency Range**

Satyajit Chowdhury, Subir Biswas, Rabindranath Pal and Nikhil Chakrabarti

*Saha Institute of Nuclear Physics, 1/AF Bidhannagar, Kolkata 700064.*

E-mail: satyajit.chowdhury@saha.ac.in

**Abstract**

Wave launching in the ion cyclotron frequency range has been attempted in the ECR produced plasma of the SINP MaPLE device [1] using a double mesh exciter. When observed along the magnetic field, above a threshold voltage in the exciter the received signal shows second and third harmonic components also. The generation of harmonics [2] depends on the exciter frequency and signal amplitude, and occurs only in the microwave propagation direction. The observed phase velocity in the axial propagation direction is much above the estimated ion acoustic velocity. Further study is in progress to reveal the exact nature of the mode being excited and the nonlinear process for harmonic generation. Preliminary results will be presented.

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**BP-171**

**Synchronization of Self Oscillatory Oscillations Between Two DC Glow Discharge Plasmas**

Neeraj Chaubey,<sup>1</sup> S. Mukherjee,<sup>1</sup> A.N.Sekar Iyengar,<sup>2</sup> A.Sen,<sup>1</sup>

<sup>1</sup>*Institute for Plasma Research,<sup>1</sup>Gandhinagar-382428,*

<sup>2</sup>*Saha Institute of Nuclear Physics,<sup>2</sup> Kolkata-700064*

Email: cneeraj@ipr.res.in

**Abstract**

Synchronization is a well studied phenomenon whose effects has been observed in simple as well as very complex systems like pendulums, flashing of fireflies, neurons motion, chemical oscillators etc.. A plasma is a highly complex system which gives different types of oscillations due to various instabilities. Synchronization studies in this system have great challenges as well as opportunities to find new interesting results. In this paper we are reporting experimental results of synchronization of self oscillatory oscillations in two DC glow discharge plasmas by varying strength of coupling current.

Two DC glow discharge plasma sources whose cathode and anode diameters were 70 mm and 5mm respectively and operating at a neutral pressure of 0.2 mbar have been deployed for synchronization

experiments. In each of the chambers a Langmuir probe was placed for measuring floating potential fluctuations. Plasma was produced in both the chambers and oscillation frequencies were monitored. When oscillation frequencies of both the chambers were close we have fixed the discharge voltage and connected anodes of both the chambers through a variable resistor. By varying the value of resistance i.e coupling strength we have seen lots of interesting results. Depending on coupling strength plasma oscillations of both the chambers goes from unsynchronized state to synchronized state through various states of synchronization. At maximum coupling strength plasma oscillations of both the chambers remain in synchronized state for a very long period.

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## BP-175

### Investigation Of Dynamics In A DC Plasma Torch

Vidhi Goyal and G. Ravi

*Institute for Plasma Research, Gandhinagar-382428, Gujarat*

E-mail :vidhigoyal@ipr.res.in

#### Abstract

The plasma torch works in the arc plasma regime and has large number of industrial applications like cutting, welding, spraying, high-heat flux material testing etc. However, the interplay between electromagnetic, flow and thermal fields leads to complex processes inside the torch. While the origin of plasma arc column fluctuations is still a mystery, an attempt has been made in some earlier work to interpret this in terms of the forces acting on the column. Many assumptions were made and the net force could be a result of some or all the forces acting on different parts of the column. In spite of the above, a clear picture of the processes has not yet emerged. In the present work, the external magnetic field and return current closure paths were used as tools to investigate the phenomenon of force balance. The one-dimensional force balance is critically evaluated. It is shown how two or three dimensional components evolve self-consistently in the presence of external magnetic field and how they influence the overall mechanism. Rigorous theoretical analysis have been carried out. Experiments have also been carried out to validate the hypothesis. Experiments also reveal interesting mode transition of the voltage fluctuations from takeover to restrike.

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## BP-196

### On the Effect of Base Pressure on Plasma Containment

<sup>1</sup>G. Sahoo, <sup>1</sup>R. Paikaray, <sup>2</sup>S. Samantaray, <sup>1</sup>P. S. Das, <sup>1</sup>N. Sasini, <sup>3</sup>J. Ghosh, <sup>3</sup>M. B. Chowduri and <sup>3</sup>A. Sanyasi

<sup>1</sup>*RavenshawUniversity, Cuttack, 753003, India*

<sup>2</sup>*ChristCollege, Cuttack, 753001, India*

<sup>2</sup>*Institute for Plasma Research, Bhat, Gandhinagar, 382428, India*

E-mail : gourishankar.sahoo@gmail.com

#### Abstract

There is always competition between different transport mechanisms in plasma. To simulate TOKAMAK Scrape-Off-Layer (SOL) like situation experimentally, a table top experiment (CPS) is set up in the plasma research laboratory of RavenshawUniversity, Cuttack [1]. It is worth noting that matter and energy can be effectively transport across magnetic field lines in a TOKAMAK SOL region and cause damage to the walls. This convective transport is a major issue which needs to be addressed. In our system convective transport of plasma in form of blob from bulk plasma produced from a gas injected washer plasma gun, is simulated by adjusting the base pressure of the system (CPS). It is well known that mean free path of charged particles decrease with increase in base pressure. After coming out from plasma gun the plasma is shaped into a structure having finite diameter. It is observed from probe as well as fast imaging data that when the classical ion-neutral and neutral-neutral mean free path is smaller than that of diameter of plasma plume convective transport of plasma in form of blob, is observed. It is well known that classical ion-neutral and neutral-neutral mean free path are basically neutral density (base pressure) dependent, when temperature of plasma does not change appreciably [2]. It is because at low base pressure where mean free path of charged species/neutrals are higher than plasma dimension, there is no source of energy formation/transfer, where as at higher base pressure where mean free path of charged species/neutrals are smaller than that of plasma dimension collisionality in plasma increases and charge particles and fast neutrals in plasma produces fresh ions/excited species in the plasma plume that sustains plasma even after the energy source (plasma gun) is switched off. This increased life time of plasma (more than pulse width of pulse forming network (PFN)) provided space for convective transport in form of blobs, similar to that of SOL region detachment phenomenon in TOKAMAKS.

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**BP-197**

**Electric Potential In A Plasma Consisting Of Finite Temperature Negative Ions  
Produced From Cs- Coated Dust Particles**

Ananya Phukan, P J Bhuyan and K S Goswami

*Centre of Plasma Physics-Institute for Plasma Research, Sonapur, Assam 782402*

Email: ananya.phukan26@gmail.com

**Abstract**

Electric potential near a wall for plasma with negative ions produced from Cs- coated dust particles is investigated analytically. The potential profile is derived analytically by using the plasma-sheath equation in a collision less plasma with finite-temperature negative and positive ions and electrons. It has been observed that potential profile depends on the production rate and the temperature of negative ions. The effect of dust particles on the potential profile is also investigated. The negative ions produced are incorporated with the negative ion extraction system used in Neutral Beam injection System.

**BP-202**

**Drift Waves In Arbitrary Mass Ratio Plasma**

Mithun Karmakar<sup>1</sup>, Samiran Ghosh<sup>2</sup>, Nikhil chakrabarti<sup>1</sup>

<sup>1</sup>*Saha Institute of Nuclear Physics, 1/AF Bidhannagar, Kolkata - 700 064, India.*

<sup>2</sup>*Department of Applied Mathematics, University of Calcutta, Kolkata-700009, India*

E-mail : mithun.karmakar@saha.ac.in

**Abstract**

In a two fluid description, drift waves have been investigated in arbitrary mass ratio collisional two component plasmas. It is shown that well-known results corresponding to electron ion plasma can be recovered using our model equations. Also the density gradient drift wave for equal mass plasma can be obtained if the temperature of the two species are taken to be different[1]. The linear mode analysis shows that in the limit of equal mass[2], there is a possibility of a novel mode which can arise due to finite inertia of both species. We have also presented a stationary vortex like solution in such plasmas.

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**BP-213**

**On The Magnets For The Multi Cusp Magnetic Field For Confining Quiescent Alkali Plasma**

A. D. Patel, Meenakshi Sharma, A. Amardas, N. Ramasubramanian, and P. K. Chattopadhyay  
*Institute for Plasma Research, Bhat, Gandhinagar-382428*

E-mail: amitpatel@ipr.res.in

**Abstract**

It is widely reported in the literature that the drift-wave oscillations in classical ‘Q-machines or Quiescent machines’ are present due to the axial magnetic field used in the Q-machines studied. In a new upcoming experiment at the institute, contact-ionized cesium plasma will be confined in a multi-cusp magnetic field, hence with  $B \sim 0$  on the axis. It is expected that this configuration will be free of drift-wave based turbulence in the finite region where the ions are not magnetized. In this presentation the results from the mapping of the magnetic field will be discussed along with its design and other physics considerations.

**BP-223**

**Inhomogeneous Downstream Plasma In An Expanding Radio Frequency Plasma System**

Soumen Ghosh and Prabal K. Chattopadhyay

*Institute for Plasma Research, Bhat, Gandhinagar-382428, India*

E-mail: soumen@ipr.res.in

**Abstract**

Efficient RF power transfer at low pressure collisionless plasma, suggests a collisionless dissipative process which is responsible for electron heating [1,2]. The effective collision frequency ( $\nu$ ) between RF oscillations ( $\omega$ ) to the thermal particle qualitatively depends on electron thermal velocity ( $v_{th}$ ) and the classical skin depth ( $\delta$ ) [3]. This effective collision frequency ( $\nu$ ) is very high compared to electron-neutral collision frequency ( $\nu_{en}$ ) for collisionless plasma and high compared to RF oscillations ( $\omega$ ). Which means electrons are experienced a dc electric field to energize themselves. When electron thermal motion are significantly high enough to make constructive interaction with the RF field in coherent manner then the plasma conductivity shows a dispersive characteristics [4] and anomalous skin effect ( $\delta_a$ ) [5] comes into play. An in-homogeneous RF field distribution along the axis of the cylindrical system may form standing wave like structure in presence of external magnetic field for helical antenna produce plasma [6]. As a consequence non-local electron heating may take part in this kind of discharge. In this presentation we are presenting experimental results to describe plasma in-homogeneity in our geometrically expanded RF plasma. Non-local electron heating far away from the antenna location gives rise of electron temperature and corresponding deep in density

near the geometrical expansion has been observed. The axial density profile starts rising to some extent, inside the diffusion chamber, however; corresponding electron temperature maintains the monotonically decreasing slope throughout from its peak position. A comprehensive analysis of these experimental observation resembles the in-homogeneous plasma in the downstream regime will be discussed in this presentation.

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### BP-236

## Observation Of Electron Temperature Gradient In Magnetized Plasma Column

S. K. Karkari, H. Kabariya, S. Gandhi, D. Patel, C. Soneji and P. Bawankar

*Institute for Plasma Research, Bhat, Gandhinagar, Gujarat, 382428*

E-mail :skarkari@ipr.res.in

#### Abstract

The equilibrium properties of magnetized plasma column associated with a conducting end plate are presented. The plasma column is sustained by direct-current (dc) operated cylindrical magnetron device. The device comprises a hollow cylindrical cathode in conjunction with a grounded end plate at one end that acts as the anode. When axial magnetic field is applied along the cylindrical axis, it results in intense ionization inside the cathode at low operating pressure (0.5-1 Pa) due to confinement of primary electrons inside the cathode tube. Hence a column of intense plasma is suspended axially along the magnetic field. Measurement of radial plasma parameters approximately 22 cm downstream from the source have been performed using planar Langmuir and emissive probes. The results indicate the presence of electron temperature gradient (ETG) inside the plasma column. The off-centered peaking in electron temperature is observed to be nearer towards the inner wall of the cathode tube, while the plasma density tends to peak towards the center. Detail plots of radial electron density show a saddle shaped behavior in  $n_e$  in comparison to uniform ion density  $n_+$  present in the central column. The demarcation in  $n_e$  and  $n_+$  profiles suggest the possibility of anodic space charge column created in the central region and consistent with the observation of a hump in plasma potential  $V_p$ . Outboard from the center, the  $V_p$  value initially exhibit a dip coinciding with the electron temperature peak and then rises sharply towards the outer periphery of the column to confine the outflow of positive ions from the plasma. A qualitative discussion is presented that gives the overall physical mechanism behind the role of external end plate behind observation of ETG and central density peaking in magnetized plasma column. The experimental results consolidate the theory of central density peaking proposed by Currelli et al.

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**BP-238**

**Global Transition From Drift Wave Dominated Regimes To Multi-instability Plasma Dynamics And Simultaneous Formation Of A Radial Transport Barrier**

Saikat Chakraborty Thakur, Christian Brandt, Lang Cui, Jordan J. Gosselin, George R. Tynan

*Center for Energy Research, University of California at San Diego, California, CA 92093, USA*

Email: saikat@ucsd.edu

**Abstract**

Recent studies in the Controlled Shear Decorrelation eXperiment reported a sharp non-monotonic global transition (at a critical magnetic field of  $B = 140$  mT, with all other source parameters kept constant) in the plasma dynamics during the route to fully developed broadband turbulence [1]. For  $B < 140$  mT, the plasma is dominated by density gradient driven resistive drift wave [RDW] instabilities, propagating in the electron diamagnetic drift direction. The resulting particle flux is radially outwards. For  $B > 140$  mT, a new global equilibrium is achieved where we observe the simultaneous existence of three radially separated plasma instabilities. The density gradient region, still dominated by RDWs, separates the plasma radially into the edge region and the core region. The edge region is dominated by strong, turbulent, shear driven Kelvin-Helmholtz [KH] instabilities, while the core region shows coherent Rayleigh Taylor [RT] modes driven by azimuthal rotation. The RT modes at the core have very high azimuthal mode number, propagate in the ion diamagnetic drift direction and are associated with intense argon ion (Ar-II) emission. In this regime, the radial particle flux is directed outward for small radii and inward for large radii, thus forming a radial particle transport barrier leading to stiff profiles, decreased turbulence levels and increased core plasma density. Simultaneously the Ar-II light emission from the core region increases by an order of magnitude leading to the formation of a very bright blue core. Blue cores have been previously observed in helicon plasma, though its origin is hotly debated in the helicon source community. The radial extent of the inner RT mode and radial location of the particle transport barrier coincides with the radial extent of the inner blue core. Simultaneously we find enhanced axial and azimuthal plasma flows in the core plasma, further helping in keeping the core and the edge distinctly separated. This new global equilibrium with simultaneous RT-DW-KH instabilities shows very interesting and rich plasma dynamics including intermittency, formation and propagation of blobs, formation of a radial particle transport barrier, inward particle flux going up against density gradients etc. This transition also suggests that changes in the cross field radial particle transport due to low frequency instabilities are crucial to helicon core formation.

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**BP-239**

**Studies Of The Role Of Diamagnetic Drift On Plasma Diffusion Across A Transverse Magnetic Field**

<sup>1</sup>P. Hazarika, B. K. Das, M. Chakraborty, <sup>2</sup>M. Bandyopadhyay

<sup>1</sup>*Centre of Plasma Physics-Institute for Plasma Research, Tepesia-782402, Assam, India,*

<sup>2</sup>*ITER-India, Institute for Plasma Research, Gandhinagar-382016, Gujarat, India.*

E-mail : hazarika.parismita@rediffmail.com

**Abstract**

An experiment has been carried out in a Double Plasma Device (DPD) to study the effect of diamagnetic drift on plasma transport process across a transverse magnetic field (TMF). The entire plasma chamber is divided into two regions viz 'source' and 'target' region by the TMF. Plasma is produced in the source region by filament discharge method and diffuses to the target region through the TMF. In order to study the effect of diamagnetic drift in the TMF region on net plasma transport across the field, two metallic plates facing each other are inserted radially in the same TMF plane but perpendicular to the TMF direction. The metallic plates are biased with respect to one another from 0 to 80 V. By changing the polarity, diamagnetic current is measured. It is observed that the diamagnetic drift of plasma in the TMF region plays a significant role in cross-field diffusion process of the charged particles.

**BP-245**

**Nonlinear Analysis Of Floating Potential Fluctuation Using Laser Heated Emissive Probe Developed Under National Fusion Program**

Vramori Mitra<sup>1</sup>, Payal Mehta<sup>2</sup>, Bornali Sarma<sup>1</sup>, ANS Iyengar<sup>3</sup>, S. Janaki<sup>3</sup>, Joydeep Ghosh<sup>4</sup> and Arun Sarma<sup>1</sup>

<sup>1</sup>*School of Advanced Sciences (SAS), VIT University Chennai, Chennai-600 127, India*

<sup>2</sup>*Venus International College of Technology, Gandhinagar, Gujarat, India*

<sup>3</sup>*Plasma Physics Division, Saha Institute of Nuclear Physics, Bidhan Nagar, Kolkata-64, India*

<sup>4</sup>*Institute for Plasma Research, Bhat, Gandhinagar-382428, Gujarat, India*

E-mail : payalmehta919@gmail.com

**Abstract**

Laser heated Emissive Probe (LHEP) made of Graphite and LaB<sub>6</sub> materials have been designed and developed under National Fusion Program through BRFST project[1-2]. LHEP's have been used to measure direct plasma potential in a test device at Institute for Plasma Research. For the first time this probe has been used to measure the floating potential fluctuations in a filament discharge plasma system. Floating potential fluctuations have been measured under different experimental conditions.

Few nonlinear techniques are used to understand the nonlinear analysis of these floating potential fluctuations viz., Empirical mode decomposition (EMD) technique, Recurrence plot analysis (RPA), Detrended Fluctuation Analysis (DFA) etc. Results of these analyses indicate that plasma floating potential oscillations are not becoming complex or chaotic in these experimental conditions.

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**BP-251**

**Extremely Long High Enthalpy Air Plasma Jet: A New Paradigm Of Air Torch Operation**

S. Ghorui

*Laser & Plasma Technology Division, Bhabha Atomic Research Centre, Trombay, Mumbai-400085*

Email: sghorui@barc.gov.in

**Abstract**

Among various types of atmospheric pressure dc arcs, air plasma torches deserve a special attention for its wide applications in variety of important processes like conversion of waste into energy, thermal barrier coatings, municipal and medical waste treatment, steel and iron making industries, hazardous waste destruction, metallurgical and alloy making industries, nuclear waste immobilization through melting and volume reduction, high temperature testing of heat shield materials, chemical processing industries and various R& D Applications. Unfortunately, due to oxidation problem, air plasma torches cannot be developed using usual tungsten based cathodes. On the other hand, hollow copper electrode industrial air torches have the disadvantages that they cannot operate at lower power, require enormous airflow rate, offer relatively lower temperature in the plasma core and produce limited length of the plasma jet. Extremely high cost and inability to operate at lower power are the two major obstacles that highly restricted their use in potential application areas.

The study reports invention of a new operating regime for hafnium electrode based atmospheric pressure air plasma torches where they can be operated at low as well as moderate power level with high efficiency, low gas flow rate and minimal noise but delivering a plasma jet of extremely high temperature and jet length as long as 60 cm. Low device and peripheral cost, use of air from atmosphere as plasma gas, light weight portable compact structure and extremely low cathode erosion are some of the attractive features of interest. The physics behind formation of such huge extremely hot air plasma jet is investigated in the paper through theoretical developments and experimental studies.

**BP-252**

**Unique Erosion Features In Hafnium Electrode Plasma Torches: A Chemical And Microstructural Investigation**

S. Ghorui<sup>1</sup>, N. Tiwari<sup>1</sup>, K.C. Meher<sup>1</sup>, R. Kar<sup>1</sup>, A. Jan<sup>2</sup>, A. Bhat<sup>2</sup> and S.N. Sahasrabudhe<sup>1</sup>

<sup>1</sup>*Laser & Plasma Technology Division, Bhabha Atomic Research Centre, Trombay, Mumbai-400085*

<sup>2</sup>*Department of Physics and Astrophysics, University of Delhi-110007*

Email: sghorui@barc.gov.in

**Abstract**

The most crucial component in any electrical discharge is the cathode. For arc discharges, the cathode is usually a hot thermionic emitter and made of 2% thoriated tungsten. Low work function and extremely low vapor pressure at operating current compared to plasma pressure are the primary criteria to be a good thermionic cathode in plasma torches. For non-oxidizing gases, thoriated tungsten meets these criteria very well. However, for oxidizing gases like air and oxygen, tungsten forms tungsten oxide, which is a volatile compound and evaporates immediately as the arc strikes. Thermo-chemical cathodes of material like Hafnium and Zirconium are the suitable candidates for handling such oxidizing gasses. Hafnium fares better compared to zirconium as it has higher melting point and better thermal and electrical conductivities. Higher melting point of Hafnium oxide (formed after reaction with the oxidizing gases) compared to Hafnium metal by several hundreds of degree centigrade is an additional advantage. In spite of these features, Hafnium cathodes emit in liquid state under most of the operating conditions. The top liquid surface of the cathode is unavoidably exposed to arc mediated instability prone flow driven environment of the plasma gas surrounding the cathode and highly susceptible to detachment resulting in high degree of cathode erosion. For development of long life, air and oxygen plasma torches it is therefore extremely necessary to develop thermo-chemical cathodes having extremely low erosion rate.

The present study reports experimental investigation of different aspects of cathode erosion in hafnium electrode plasma torches under different plasma environments. Air, Nitrogen and Oxygen are the plasma gases considered. Physical erosion rates are determined using microbalance. The change in microstructure is investigated through Scanning Electron Microscopy (SEM). Chemical changes are determined using Energy Dispersive X-ray Spectroscopy (EDX). Extremely low erosion rates, micro-cracks while re-solidification and evidence of field driven ion retracing are some of the major findings of the study. Once oxidized, the study proves their ability to operate with any gas (oxidizing/non-oxidizing) and establish them as universal cathode for plasma torches.

**BP-253**

**Arc Root Movement And Plasma Jet Instability: Direct Probing Through Simultaneous Voltage Traces And Double Exposure Fast Photography**

S. Ghorui<sup>1</sup>, N. Tiwari<sup>1</sup>, K.C. Meher<sup>1</sup>, A. Jan<sup>2</sup>, A. Bhat<sup>2</sup> and S.N. Sahasrabudhe<sup>1</sup>

<sup>1</sup>*Laser & Plasma Technology Division, Bhabha Atomic Research Centre, Trombay, Mumbai-400085,*

<sup>2</sup>*Department of Physics and Astrophysics, University of Delhi-110007*

Email: sghorui@yahoo.com

**Abstract**

Arc plasma jets are widely used in variety of processing works like cutting, welding, melting, heating, coating, spheroidization, waste processing, mineral extraction, alloy preparation, novel material synthesis, nano-particle generation, biomedical applications, fundamental studies and many more. The most challenging problem is linked with the thermal, fluid dynamic and electromagnetic instability inherent to these devices. Depending on operating conditions, sometimes the instabilities are bearable and sometimes they are drastic enough to destroy the device itself. Under most operating conditions, they bear sizable impact on the quality of the processing work done.

Owing to its immense importance, large numbers of investigations have been carried out in the past to understand the origin of such instabilities and its impact on specific processes. Although, it has long been suspected that the irregular movement of the arc root might be responsible for existence of such instabilities, it simply remained a speculation without concrete evidences. Extreme brightness of the plasma jet together with extremely high temperature in the jet core posed as the major obstacles in direct imaging of the arc root. The possibility of imaging the arc root from side remained beyond the scope, as torch wall itself becomes an obstruction in that. Modeling efforts to simulate the instabilities heavily relied on ad hoc assumptions to assist formation of arc roots and subsequent instabilities. Experimental efforts to simulate the phenomenon with arc attachment on flat anode (exposed to transverse airflow) were unable to mimic the actual electro-fluid dynamic environment realized in a plasma torch with cylindrical hollow anode.

The study presents for the first time direct imaging of the arc root, its formation, extinction, and firmly correlate observed jet instabilities with arc root dynamics. Fast photography camera PCO1200hs with a frame rate of 2500 frames per second under double exposure mode together with a four channel digital oscilloscope (HM03524) and a special reflector has enabled us to extract the information presented in the study. Well know steady, takeover, and re-strike mode behavior of arc are fully captured in terms of associated voltage instabilities and corresponding arc root motion. Interesting behavior under transition from one mode to another, coexistence of multiple arc roots and correlation of jet structure with arc root location are some of the major findings of the study. Observed direct evidences of arc root behavior are expected to give a new direction to the future developments in the area.



**BP-254**

**Studies On Bio Polymer Coated Viscose Fabric Using Low Temperature Oxygen Plasma**

<sup>1</sup>N.Karthikeyan, <sup>2</sup>K.A.Vijayalakshmi, <sup>1</sup>K.Vignesh

<sup>1</sup>*Plasma Laboratory, Sri Vasavi College, Erode-638316, India.*

<sup>2</sup>*Department of Physics, Sri Vasavi College, Erode-638316, India.*

Email: karthck1947@gmail.com

**Abstract**

Plasma processing technology that aims to modifying the chemical and physical properties of a surface. In the field of surface modification/engineering, many methods have been employed to alter the substrate to improve the surface properties such as adhesive ability, wettability, Bio-compatibility, and permeability. In the recent years the biopolymers are used to change the functional properties of textile material. Chitosan is an amazing natural and biodegradable biopolymer derived from chitin. It has a wide range of applications in many fields. Moreover, chitosan has several advantages over other chemical disinfectants since it possesses a stronger antimicrobial activity. The pure textile material viscose is taken and coated by bio polymer (chitosan) and exposed to oxygen plasma. The material is cleaned with water and ethanol, and fabric are dried in air woven 40<sup>0</sup> C at 2 Hrs. The chitosan solution was prepared by sol-gel process, and the coated on a pure viscose materials by tip coating process for 1 hrs. The coated fabric was dried at room temperature. The Air and Oxygen Plasma parameters are pressure 0.03mbar, voltage 400V and exposure time 10 mins. The coated viscose fabric is analyzed by different characterization studies such as XRD, FTIR, SEM and Anti-microbial. Intensity variation is calculated in XRD(X-Ray diffraction) analysis, and the different function groups are calculated in FTIR(Furiers Transform Inferred spectrometry) in the wavelength 400-4000cm<sup>-1</sup>, SEM (Scanning electron microscopy) analysis shows that the surface of the textile fabric. Water absorption levels are calculated by a Lab experimental process with different time of exposure for Air and Oxygen Plasma treatment. These results are showed that the fabric surface treated with plasma was changed when compared with untreated fabric.

**BP-259**

**Precision Control & Monitoring Of Heat Pipe Oven Temperature Using MODbus Protocol on LabVIEW<sup>®</sup> for the Plasma Wakefield Accelerator Source**

<sup>1</sup>Pooja Bhatt, <sup>1</sup>Chirag S. Dalal, <sup>2</sup>Chhaya K. Chavda, <sup>2</sup>K. K. Mohandas, <sup>2</sup>V. Sivakumaran, <sup>2</sup>Sneha Singh and <sup>2</sup>Ravi A. V. Kumar

<sup>1</sup>*Dharmsinh Desai University, Nadiad 387 001*

<sup>2</sup>*Accelerator Division Institute for Plasma Research, Gandhinagar 382 428*

E-mail : mohandas@ipr.res.in

**Abstract**

A heat pipe oven is used as the source to generate a uniform column of lithium vapour which will be used to produce laser photo-ionized plasma for the Plasma Wake Field Acceleration (PWFA) experiment proposed to be carried out at IPR. In the current heat-pipe oven system, the oven temperature is monitored and controlled manually. The new system will use the MODbus protocol and LabVIEW<sup>®</sup> application software (using fuzzy logic toolkit) to automate this process, thereby providing a more precise control over the oven temperature ( $\pm 1^\circ\text{C}$ ) which is essential to generate a uniform column of lithium vapour. The fuzzy logic controller will control the PID parameters thereby completely automating the temperature control system. This will also acquire data from the 15 channel temperature monitoring system which gives an instantaneous temperature profile of the heat-pipe oven.

This paper will discuss the methodology and the results of the temperature control / monitoring using this system.

**BP-260**

**Vapour Density Diagnostics For The IPR-PWFA Lithium Heat Pipe Oven**

K. K. Mohandas, V. Sivakumaran, Sneha Singh, Sonam Brambhatt and Ravi A. V. Kumar

*Accelerator Division, Institute for Plasma Research, Gandhinagar 382 428*

E-mail :mohandas@ipr.res.in

**Abstract**

A prototype (40 cm long) Lithium heat pipe oven for Plasma Wakefield Acceleration (PWFA) Experiment has been developed as part of the ongoing Accelerator Programme at Institute for Plasma Research, Gujarat.

The Lithium vapour in the oven is produced by heating solid lithium in helium buffer gas. The characterization and optimization studies of the Lithium vapour column formed in the oven are being carried out using different optical diagnostics (White light absorption, UV absorption and Hooks method) as a function of oven temperature and the He buffer gas pressure.

The Lithium vapour in the oven is photo-ionized using a UV excimer laser to form the Lithium plasma column for Plasma Wakefield Acceleration Experiments. The diagnostic setup for plasma electron density measurement using UV absorption studies and interferometry techniques are also being carried out.

Measurement of the Li neutral density is important for the PWFA experiment as it has a direct bearing on the plasma electron density measurements.

Here we present the comparative studies of different diagnostics used for measuring the line integrated Lithium neutral density. Also, the preliminary results on Lithium plasma density measurements using UV absorption and He-Ne/CO<sub>2</sub> interferometry would be presented.

## BP-263

### **Solitary Wave Solutions Of Modified Kadomtsev-Petviashvili Equation For Hot Adiabatic Dusty Plasma Having Non-Thermal Ions With Trapped Electrons**

<sup>1, 2</sup>, Apul Narayan Dev, <sup>1</sup>Rajesh Subedi and <sup>2</sup>Jnanjyoti Sarma

<sup>1</sup>Department of Science and Humanities, College of Science and Technology, Phuentsholing, Bhutan

<sup>2</sup>Department of Mathematics, R. G. Baruah College, Guwahati-781025, Assam, India

E-mail: apulnarayan@gmail.com

#### **Abstract**

In this article the investigation of the properties of dust acoustic (DA) solitary wave propagation in an adiabatic dusty plasma including the effect of the non-thermal positive and negative ions and trapped electrons is presented. The reductive perturbation method [1] has been employed to derive the lower order modified Kadomtsev-Petviashvili (mK-P), higher order new modified Kadomtsev-Petviashvili (mK-P) for dust acoustic solitary waves in a homogeneous, unmagnetized and collisionless plasma whose constituents are trapped electrons, singly charged positive non-thermal ions, singly charged negative non-thermal ions and massive charged dust particles. The stationary analytical solution of the lower order mK-P and higher order new mK-P equation solved by well-known *tanh*-method. These solutions are numerically analyzed and where the effect of various dusty plasma constituents DA solitary wave propagation is taken into account. It is observed that both the ions in dusty plasma play as a key role for the formation of DA solitary waves and also the ion concentration and trapped electrons concentration controls the transformation of compressive potentials of the waves.

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**BP-266**

**Study Of Polarization Bremsstrahlung From keV-Electrons Incident On a Dilute Gaseous Target**

<sup>1</sup>R. Shanker, <sup>1</sup>Namita Yadav, <sup>1</sup>Pragya Bhatt, <sup>1</sup>Raj Singh, and <sup>2</sup>C.A. Quarles

<sup>1</sup>*Department of Physics, Banaras Hindu University, Varanasi-221005, India*

<sup>2</sup>*Department of Physics and Astronomy, Texas Christian University, Fortworth, TX 76129, USA*

E-mail: shankerorama@gmail.com

**Abstract**

An apparatus has been developed to measure the polarization bremsstrahlung spectra generated from collisions of energetic electrons with isolated atoms and molecules [1]. A considerable reduction of thick target bremsstrahlung (TTB) background produced by scattered electrons from the chamber wall is achieved. In this talk, the details of the experimental setup with regard to design of its components, experimental technique, data acquisition and analysis etc. will be discussed. The reliability and performance of the setup are demonstrated by obtaining new results on angular-and energy distributions of bremsstrahlung produced from collisions of 4.0 keV-electrons with free-argon atoms. These results are compared with the theoretical predictions of the *ordinary*-and the *polarization* bremsstrahlung emissions. In this comparison, the experimental data for energy distributions of BS photons are found to indicate a mild signature of polarization bremsstrahlung over the ordinary bremsstrahlung while they are found to exhibit a noticeable difference in shape of angular distributions.

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**BP-278**

**Electrical Technique To Improve Anomalous Diffusion Across A Transverse Magnetic Field**

<sup>1</sup>B. K. Das, <sup>1</sup>P. Hazarika, <sup>1</sup>M. Chakraborty, <sup>2</sup>M. Bandyopadhyay

<sup>1</sup>*Centre of Plasma Physics-Institute for Plasma Research, Tepesia-782402, Assam.*

<sup>2</sup>*ITER-India, Institute for Plasma Research, Gandhinagar-382016, Gujarat.*

E-mail : bdyt.ds@rediffmail.com

**Abstract**

The cross-field diffusion process of charged particles has been carried out in a plasma source which is divided into two parts viz. source and target regions by a transverse magnetic field (TMF)

constructed by inserting strontium ferrite magnets inside two rectangular stainless steel tubes [1]. This magnetic field is strong enough to magnetize the electrons whereas ions remain unmagnetized. Plasma produced in the source region by filament discharge method flows towards the target region through this negatively biased TMF. The magnet tubes are biased negatively with respect to ground potential to impede the electron flow along the field lines. It is observed that the cross-field diffusion process is highly dependent on the sheath that is formed in the vicinity of the TMF tubes. A significant oscillation of plasma particles in the TMF zone has also been detected. This observation is beneficial for negative ion source development. In the present experimental conditions it is observed that the diffusion is a non classical diffusion process and scales with  $1/B$  (anomalous diffusion) rather than  $1/B^2$  (classical diffusion) at lower voltage applied to the TMF tubes. At higher negative bias, deviation from the anomalous behaviour has been observed and can be consider as a tuning knobe to improve anomalous diffusion.

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### BP-279

## EffectsOf Magnetic Field On Self-Diffusion In Two-Dimensional Yukawa Systems

Mahmuda Begum and Nilakshi Das

*Department of Physics, Tezpur University, Tezpur, Napaam, Assam-784028, India*

Email: mbegumtu@gmail.com

#### Abstract

Self-diffusion of dust particles in two-dimensional Yukawa system is investigated by using molecular dynamics simulations in presence of external magnetic field. It is assumed that dust particles interact with each other by modified Yukawa (i.e. screened Coulomb) potential. Dependence of self-diffusion co-efficient on plasma parameters and magnetic field has been investigated for different regimes using Green- Kubo expression which is based on integrated velocity autocorrelation function (VACF). The study gives interesting results of dust particle diffusion in two-dimensional Yukawa system.

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**BP-280**

**Electron Acoustic Solitary Structures In A Plasma With Hot Electrons Featuring Tsallis Distributon**

Ramandeep Kaur, Honey Arora and Parveen Bala

*Dept of Mathematics, Statistics & Physics, Punjab Agricultural University, Ludhiana – 141004*

Email: rkdhanjal-cobsmsp@pau.edu

**Abstract**

Electron acoustic mode is a high frequency mode and occurs in plasmas having two electron components, hot and cold. It may also exist in electron-ion plasmas with two ions hotter than electrons.

A theoretical investigation is carried out for understanding the electron acoustic solitary structures in a plasma consisting of cold electrons, hot electrons and stationary ions. The hot electrons are assumed to have nonextensive distribution. The Sagdeevpseudo-potential technique is used to carry out the analysis for electron acoustic solitons and further extended to the small amplitude approximation. Sagdeev pseudo-potential depends on various plasma physical parameters such as nonextensive parameter  $q$ , electron density ratio, electron temperature ratio and Mach number. The presence of nonextensive electrons modifies the parametric region where electron acoustic solitons can exist. The existence of nonlinear structures in the three different ranges of nonextensive parameter  $q$  i.e.,  $-1 < q < 0$ ,  $0 < q < 1$  and  $q > 1$  have been studied in detail and results are plotted graphically.

**BP-288**

**Study of Fractality of Nonlinear Oscillations in DC Glow Discharge Magnetised Plasma by using Detrended Fluctuation Analysis**

Vramori Mitra<sup>1</sup>, Bornali Sarma<sup>1</sup>, Arun Kumar Sarma<sup>1</sup>, M. S. Janaki<sup>2</sup>, A. N. Sekar Iyengar<sup>2</sup>

<sup>1</sup>*VIT University, Vandalur – Kelambakkam Road, Chennai- 600 127, Tamil Nadu, India.*

<sup>2</sup>*Saha Institute of Nuclear Physics, 1/AF Bidhannagar Calcutta - 700 064, India.*

E-mail: vramori.mitra@vit.ac.in

**Abstract**

Fractality in real system is a ubiquitous feature to grasp the different structures in nature. The natural world is field with fractal examples such as mountain, clouds, and trees [1]. Detrended Fluctuation Analysis (DFA) is an important tool to study the fractal properties of a dynamical system. It provides a valid indicator of statistical persistence or anti persistence of a time series. It has been observed that plasma fluctuations have multifractal character in presence of different magnetic field. The paper presents the investigation of the multifractal properties of floating potential fluctuations obtained by Langmuir probe by using DFA technique [2-3]. The multifractal behavior of fluctuations with the

increase of discharge voltage have been investigated at different magnetic field. It has been noticed that the fractal dimension is increasing with the increase of magnetic field however the values of the total fluctuation function and scaling exponent are decreasing. The results indicates that with the raising magnetic field plasma oscillations are becoming more irregular and complex and the long range correlation of plasma oscillation is being dwindled .

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### BP-291

## Experimental Observation Of Chaotic Bursting To Chaotic Spiking In A Glow Discharge Plasma

Pankaj Kumar Shaw, D. Saha, S. Ghosh, M. S. Janaki and A. N. S. Iyengar

*Saha Institute of Nuclear Physics, 1/AF, Bidhannagar, Kolkata - 700064, India.*

E-mail :pankaj.shaw@saha.ac.in

#### Abstract

Spiking and bursting are commonly observed in various plasma systems : low temperature laboratory plasmas, fusion plasmas and space plasmas involving the magnetosphere and ionosphere. In the present work, we report the experimental observation in a glow discharge plasma of a transition from chaotic bursting to chaotic spiking with the increase in the discharge voltage. This chaotic bursting is characterized by alternations between multiple continuous spikes and a long duration of inactive period, whereas chaotic spiking is made up of fast, continuous spikes without an inactive period. The chaotic nature of the bursting and spiking fluctuations are identified by Lyapunov exponent[1] and corroborated by 0-1 test for chaos[2]. A detailed statistical analysis of the interspike interval along with the bifurcation diagram and their return maps have been carried out to characterize the chaotic behavior of these fluctuations. Non deterministic nature of the fluctuations has been identified by nonlinear prediction error analysis[3]. These types of behavior are generally related to anode double layers instabilities[4]. The results of the different methods like return map, normal variance and nonlinear prediction error analysis suggest that the intrinsic noise may be playing a vital role in the dynamics of the system.

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**BP-294**

**Observation of High Amplitude Ion Acoustic Peregrine Soliton in Multicomponent Plasma with Negative Ions**

Pallabi Pathak, Sumita K. Sharma and Heramba Bailung

*Institute of Advanced Study in Science and Technology, Paschim Boragaon, Garchuk, Guwahati, Assam, India, Pin-781035*

E-mail: pallabipathak276@gmail.com

**Abstract**

The growth of nonlinear ion-acoustic wave in a multicomponent plasma with negative ions has been studied experimentally in a double plasma device. In normal electron-ion plasma, the ion acoustic solitons are described by the Kortweg-de Vries (KdV) equation [1,2]. In a multicomponent plasma with critical density of negative ions, excitation and propagation of ion-acoustic modified KdV solitons are observed [3]. At the critical concentration of negative ions, multicomponent plasma also supports the propagation of a special type of soliton known as “Peregrine soliton” which is the localized solution of nonlinear Schrodinger equation (NLSE) [4-6]. In the present work, development of high amplitude ion acoustic Peregrine soliton in a multicomponent plasma with negative ions is studied. The experiment is performed in a double plasma device, which is separated into source and target section by a fine mesh grid. Argon plasma is produced in both the sections at working pressure  $\sim 10^{-4}$  Torr using filamentary discharge [6]. SF<sub>6</sub> gas is introduced into the Ar plasma which effectively produces F<sup>-</sup> negative ions. The flow of SF<sub>6</sub> gas is controlled such that the negative ion to positive ion density ratio reaches a critical value ( $\sim 0.10$ ), which is confirmed from the Langmuir probe data. Typical values of plasma parameters are electron density  $\sim 10^8$  cm<sup>-3</sup>, electron temperature  $\sim 1 - 2$  eV. Ion acoustic Peregrine solitons are excited by applying a modulated sinusoidal wave form to the source anode. The observed perturbations are detected in the target section by using an axially movable planar Langmuir probe. Under suitable condition the modulated wave perturbation is found to undergo self modulation due to modulational instability and a high amplitude single period solitary peak is formed. The solitary peak has been identified as the Peregrine solitons. The maximum amplitude of the observed Peregrine soliton is found to be  $\sim 5$  times the carrier wave amplitude.

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**BP-302**

**Design Of A Line Type Pulsed Modulator For S-Band Magnetron For SYMPLE**

<sup>1</sup>Priyavandna J. Rathod, <sup>1</sup>Anitha V. P, <sup>1</sup>G. Veda Prakash, <sup>2</sup>Z. H. Sholapurwala

<sup>1</sup>*Institute for Plasma Research, Bhat, Gandhinagar – 382428*

<sup>2</sup>*Zeonics Systech Defence & Aerospace Engineers Pvt. Ltd., Bangalore 560 075*

E-mail :priyajrathod@gmail.com

**Abstract**

Experiments proposed in SYMPLE (System for Microwave and Plasma Experiments) [1], include interaction of high power microwave (HPM)(3.1 MW, 3GHz, 5μs) from an S magnetron with an over-dense ( $n_e \sim 1 \times 10^{18}/m^3$ ) plasma, to address nonlinear wave – plasma interaction. The time sequence of the experiment necessitates the HPM output in single pulse mode or with a repetition, one pulse in a few seconds. The HPM output characteristic is critically determined by the pulsed modulator driver. The requirements of the pulsed modulator for our application are 52 kV, 120 A, 5μs width and pulse reproducibility  $\pm 0.2$  %.

The solid state pulse modulators available off the shelf, non indigenous, are costly and designed to suit conventional applications in medical / material processing fields, where the repetition required is  $\sim 100$ -200 Hz. Here the technology involves a feedback mechanism where in the system measures the current amplitude of the previous pulse and determines the amount of level adjustment, to achieve the pre-set value, on the next pulse. This process undergoes iteration with first few pulses before stabilization to give repetitive pulses. Hence, the first few pulses are highly non repetitive, a permissible deviation for these applications. However, in basic plasma research cited above, it is critical that the first pulse itself is of the same characteristic as the rest, resulting in a need to carry out indigenous development of such modulators.

A line type modulator, simple, cost effective, rugged and easy to fabricate, is designed by us. Designed to deliver pulses of 52 kV, 120 A, 5μs width and  $\sim 450$  ns rise, it consists of a charging power supply, pulse forming network (PFN), a thyrotron switch, triggering unit and a pulse transformer. Design of the Guillemin type E type PFN [1] with mutual coupling (15-20 %) between the adjacent sections is verified with PSPICE simulation. An account of the indigenous design, development and dummy load testing of the modulator is presented here.

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**BP-325**

**Conceptual Design Of A Permanent Ring Magnet Based Helicon Plasma Source**

Mainak Bandyopadhyay, Dass Sudhir, Arun Pandey and Arun Chakraborty

*ITER-INDIA, Institute for Plasma Research, Gandhinagar 382016, Gujarat*

E-mail: mainak@iter-india.org

**Abstract**

Helicon plasma sources are very efficient plasma sources due to its high ionization efficiency. The physics behind such high efficiency is still a subject of investigation. However, due to having high plasma density ( $\sim 10^{13}\text{cm}^{-3}$ ) using low RF power ( $\sim$  few kW) Helicon based plasma sources are used in the fields of plasma processing and space exploration. Large area, high plasma density sources are also needed in neutral beam ion sources and therefore Helicon source with multi-driver configuration would be a promising candidate. The present work is linked to that application. Institute for Plasma Research has initiated a multi-driver based large size Helicon negative ion source R&D program. The program is initiated through a single driver Helicon plasma source having permanent ring magnet for its necessary axial magnetic field. The conceptual design activity is being carried out using two computer codes [1] “HELIC” and “BfieldM”. “HELIC” is developed to design Helicon plasma sources. It computes power deposition spectra to plasma for given antenna configuration, magnetic field and geometrical inputs. In Helicon plasma, magnetic field topology inside the source is very important in wave excitation and source operation. Magnetic field distribution due to permanent ring magnets is calculated by BfieldM code. The configuration to initiate the experimental campaign quickly is depicted in the schematic figure. The paper will also describe the simulated plasma performance of this configuration using the above mentioned codes.

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**BP-327**

**Determination Of RF And Extractor Power Supply Parameters For The Helicon Plasma Source System**

N. Sharma, M. Chakraborty, N.K. Neog, M. Bandyopadhyay<sup>1</sup>

*Centre of Plasma Physics – Institute for Plasma Research, Tepeia 782402 Assam*

<sup>1</sup>*ITER-India, Institute for Plasma Research, Gandhinagar, Gujarat*

E-mail: narayansharma656@gmail.com

**Abstract**

A helicon plasma setup is being developed to study ion-ion plasma of highly electronegative gases. The set-up consists of an insulating cylinder of borosilicate glass over which a helical antenna will be

would for supplying RF power at 13.56MHz frequency to excite helicon wave [1]. To launch helicon wave with efficient antenna coupling and plasma generation in electronegative gases, the parameter of RF power supply plays an important role and is crucial. Therefore, special attention is given to generate specification of the RF power supply. Detailed calculation of the power requirements and other related parameters are determined and will be presented [2].

Besides, the concentration of +Ve and -Ve ions in various electronegative gases will be measured by extracting the ions. Ion extraction will be done by the extraction system. The extraction system consists of the grids across which the sufficient voltage will be applied for a fixed gap distance and hole radius [3]. An appropriate high voltage (HV) DC power supply will be required to power the grid system to extract the ions. The specification of HV DC power supply for the extractor has been found out and the detailed parameters will be presented.

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**BP-352**

### **Observation of Pressure Gradient Driven EMHD Turbulence in Asymmetric Electron Belt Plasma of LVPD**

A. K. Sanyasi, L. M. Awasthi, S. K. Mattoo, P. K. Srivastava, S. K. Singh, R. Singh and P. K. Kaw

*Institute for Plasma Research, Bhat, Gandhinagar - 382428*

E-mail : amulya@ipr.res.in

#### **Abstract**

Installation of Electron Energy Filter (EEF) in LVPD divides plasma column into three distinct experimental regions, namely source, filter, and target regions. The source region lies between the cathode and the first wall of EEF, the EEF region within the two walls of EEF and target region is the region between the second wall of EEF and the end plate. Activation of EEF produces a transverse field of 160G whereas ambient field along the axis of device is produced by a set of 10 coils garlanded around the length of the device. The activation of EEF substantially modifies the magnetic field configuration and plasma profiles in the source plasma. We have reported before that an asymmetric belt like structure forms in LVPD, containing mostly the energetic electrons emanating out from the location of filaments in the source region and closes its path in the EEF region after traversing the path in the source region. The energetic belt is asymmetric as it enters differently from both sides of the axis of the device. It enters straight, along the magnetic field lines from the right hand side of the system whereas they becomes inclined while entering from left and enter towards the radial centre of EEF.

Investigations are carried out for plasma turbulence in the source region. The radial profiles of plasma density ( $n_e$ ) and electron temperature ( $T_e$ ) shows an enhancement in RHS energetic belt, where field lines are straight but in the contrary profiles remain dormant in the left hand side where

again the energetic belt exists. A similar trend is shown by the fluctuations of density and magnetic field. The belt fluctuation enhances 20 times to core fluctuations. Results have shown that the observed turbulence is electromagnetic in nature and has broad power spectra,  $f = 5 - 30 \text{ kHz}$  with frequency ordering in the lower hybrid regime. The coupled density and magnetic field fluctuations propagate in radial and vertical direction with typical phase velocities of,  $v_{ph} \sim 10^5 \text{ cm/s}$ . The observed mode exhibits right hand polarization. Our recent investigations have nullified previous assumption that this is energetic electron driven whistler mode as it was later confirmed that even by switching off the source function of RHS side belt region, the fluctuation of the region persists. This shows that there must be some other source other than energetic electrons for the observed turbulence. The pressure profiles in the belt region offer typical density and temperature gradient scale lengths as 21 cm and 40 cm when EEf is activated. Investigations are presently continuing for identifying pressure gradient as a source for the observed turbulence and the detailed results will form the part of presentation in the conference.

## BP-353

### Resistive Wall Destabilization Of Electron Plasmas In SMARTEX-C

Lavkesh T. Lachhvani, Manu Bajpai, Prabal K. Chattopadhyay, Sambaran Pahari<sup>1</sup>

*Institute for Plasma Research, Gandhinagar – 382428*

<sup>1</sup>*Bhabha Atomic Research Center, Vishakhapatnam – 530012*

E-mail: lavkesh@ipr.res.in

#### Abstract

Non neutral plasmas exhibit excellent confinement and stability properties in the cylindrical trap[1]. Diocotron modes propagating in non-neutral plasma[2], being negative energy modes grow when electrostatic potential energy of the system is dissipated by the image currents induced in the boundaries through resistance. Resistively destabilized  $l=1$ [3], [4] and  $l=2$ [5] diocotron modes were experimentally observed in the cylindrical traps and the measured growth rate was well described by the linear perturbation theory. This paper reports the experimental investigations of resistive wall destabilization of linear toroidal diocotron modes in a small aspect ratio toroidal trap (SMARTEX-C). This has been possible due to long time confinement ensured in SMARTEX-C and the arrest of other competing instabilities. The observed growth rates have also been compared with those predicted by linear perturbation theory for our geometry. The observed growth rates have confirmed that capacitive wall probes (in spite of resistive termination) do not destabilize the mode while an entire resistive wall is seen to do so and accentuates charge loss even in presence of other instabilities.

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## BP-354

### A Physical Model Explaining ETG Suitable Plasma InLVPD By EEF Field Modulation

A. K. Sanyasi, L. M. Awasthi, P. K. Srivastava, Prabhakar Srivastava and S. K. Mattoo

*Institute for Plasma Research, Bhat, Gandhinagar – 382428*

E-mail : amulya@ipr.res.in

#### Abstract

Electron Temperature Gradient (ETG) driven turbulence has been reported in LVPD by suitably dressing the plasma in the far target region using 1m radial extent of electron energy filter (EEF)[1-2]. EEF produces a strong transverse magnetic field of 160G with respect to the axial ambient field of 6.2G. The EEF is designed for meeting mainly two purposes i.e., 1) cooling of target plasma by scavenging energetic electrons and 2) producing ETG suitable plasma profiles. The former has been understood to some extent with plasma diffusion and collisional theory [3] but the later one is still not understood completely. We have attempted to unfold this by looking into the role of EEF field in the modification of plasma profiles. The EEF installed in LVPD divides plasma into three regions of source, EEF and target plasmas. We have tried to establish a correlation between the source plasma and target plasma profiles with respect to the EEF field profiles in the two regions. The source function used for plasma production is a multi-filamentary cathode having 36 number of filaments, arranged in the periphery of a rectangle of cross-section ( 65 cm x 45 cm). The source plasma offers a hollow density and flat electron temperature in the core region but both exhibits peak at the radial location(  $x=65\text{cm}$  ), in line of filaments. We observed that these profiles in core plasma of source region transformed into plasma suitable for ETG turbulence (  $\gamma = L_n / L_T > 2/3$  , where  $L_n$  and  $L_T$  are gradient scale length of density and electron temperature respectively).

In this paper, we will present a physical model developed based on coupled field profiles of EEF and ambient field, explaining evolution of ETG suitable profiles. We have closely looked into these modified field profiles and found that the plasma produced in the narrow band ( primarily in line with source function) in the source region is diffuses to a plasma column of broad radial cross-section in the target region, whereas the core plasma of source region diffuses to plasma of approximately same radial cross section. We are therefore proposing a physical model that explains the formation of flat density profile in the target region. We found that the parallel plasma transport along the field lines plays a dominant role and perpendicular diffusion becomes insignificant in the modification of plasma profiles. Model is based on the hypothesis involving, plasma particle balance equation and by balancing the volume production of net flux from source function with the diffusing plasma. This

hypothesis validates the experimentally obtained reduction in plasma density in the target region as by showing a deficit of flux in the target region by nearly a factor of 8. This paper will present a comparison of experimentally observed profiles with the results of proposed model.

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### BP-355

## Fluctuation Induced Particle Flux In The Background Of ETG Plasma: Possible Case Of Intermittency

Prabhakar Srivastava, L. M. Awasthi, A. K. Sanyasi, P. K. Srivastava, R. Jha, and S. K. Mattoo

*Institute for Plasma Research, Bhat, Gandhinagar, 382428*

E-mail :prabhakarbh01@gmail.com

#### Abstract

The ETG turbulence is considered as a major source for turbulent electron thermal transport and plasma loss in fusion devices. Unambiguous excitation of Electron Temperature Gradient (ETG) turbulence is demonstrated in the steady state, collision less Argon plasma of LVPD [1]. Direct measurement of instability in fusion devices is difficult because of its extremely small-scale length ( $k_{\perp} \rho_e \sim 1$ ), hence investigations are primarily restricted to theoretical and simulation studies. Although, significant study on fluctuation-induced transport is carried out in Scrape of Layer (SOL) region but studying ETG turbulence and induced transport still remains an unexplored area in fusion devices.

In LVPD, we initiated investigations on fluctuation induced plasma transport for two different plasmas namely, 1) when ETG turbulence is excited and, 2) when ETG conditions are not satisfied. These two scenarios are identified by plasma satisfying ETG threshold,  $\gamma = L_n / L_T > 2/3$  where  $L_n$  and  $L_T$  are the gradient scale lengths of plasma density and electron temperature. The typical extreme scale lengths obtained for electron temperature, a responsible source for ETG turbulence are,  $L_T \sim 50$  and 600 cm respectively. We have estimated the particle flux by measuring the correlated fluctuations of plasma density and electric field using a 3- pin Langmuir probe array with probe pins fixed at vertices of an equilateral triangle. The time-averaged flux,  $\bar{\Gamma} = \langle \bar{n}_e \bar{v} \rangle$  is calculated and the preliminary result indicates that the direction of flux is radially outward in ETG background. The calculated Probability Distribution Function(PDF) for the particle flux, density and potential fluctuations is found to be non-Gaussian. It seems leptokurtic with peak at the centre and fatter wings. The fourth order moment of PDF of flux, the kurtosis( $K$ ) is  $>3$  ( $K=3$  is for Gaussian level). These results are indicative of intermittent nature of particle transport. The detailed results on it will be presented in the conference.

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**BP-359**

## **Interface Software Development, Integration And Performance Results Of The High Current Power Supply In Large Volume Plasma Device**

R. Sugandhi<sup>1</sup> P. K. Srivastava<sup>1</sup> A. K. Sanyasi<sup>1</sup>, Prabhakar Srivastava<sup>1</sup>, L. M. Awasthi<sup>1</sup>, S. K. Mattoo<sup>1</sup>,  
Kaushik Patel<sup>2</sup>, Radhe Panchal<sup>2</sup> and Varunesh Kumar<sup>2</sup>

<sup>1</sup>*Institute for Plasma Research, Gandhinagar 382428*

<sup>2</sup>*Veeral Controls, Gandhinagar 382023*

E-mail: ritesh@ipr.res.in

### **Abstract**

Large Volume Plasma Device (LVPD) [1] at Institute for Plasma Research, is dedicated for carrying out investigations on Electron temperature gradient (ETG) turbulence, plasma transport and unfolding relevant filter physics. In LVPD, as a major activity of XII<sup>th</sup> plan, we are undertaking upgradation in different subsystems namely, 1) up gradation of plasma source for density scale up from  $10^{11} - 10^{12} \text{ cm}^{-3}$ , 2) acquiring high current, low voltage DC power supply of rating ( 10 kA / 20 V ) for feeding power to the new plasma source, 3) switching to 40 channel, higher bandwidth data acquisition system from present 12 channel DAS, 4) development of a large area, uniform emissivity plasma source (W filaments, 98 in number and each of diameter 1.6 mm and length 18 cm), 5) developing LabVIEW controlled, motorized linear probe drives for probe shaft movement( travel length ~ 100 cm) and 6) development of new diagnostics like  $\mu$  - wave interferometer, electron energy analyzers etc. Latest among all is the integration of regulated DC power supply.

The interface development for the power supply is a requisite for (1) remote configuration, calibration and performance monitoring under Constant Current (CV) and Constant Voltage (CV) mode of operation (2) Factory Acceptance Test (FAT) with dummy load (3) System Acceptance Tests (SAT) with the machine and (4) integration and operational control for routine experimental campaigns. The developed interface consists of (1) hardware interface using RS-485 multi drop communication on fiber optics (2) software interface using Modbus RTU [3] based request and reply protocol (3) test applications for performance testing at communication/subsystem/system level. The software interface is validated using standard Modbus testers (Modbus poll, Modbus slave etc.). We have developed a customized application using LabVIEW 2013 toolset [4] and NI Modbus library [5]. This user interface facilitates a dashboard for configuration settings, online monitoring of readings, alarms management and CC/CV mode of operation in interactive and profiled fashion. Using this dashboard, the delivery of the PS performance is confirmed and performance logs (e.g. ripple, stability, operation limits and condition test etc.) are recorded. The reported work will highlight requirements, interface description, architectural details and performance results obtained during FAT and SAT of the power supply.

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**BP-360**

**Architecture of Control and Data Acquisition System of Applied Plasma Physics Experiments in Linear Device**

Ritesh Sugandhi and S. Karkari

*Institute for Plasma Research, Gandhinagar, Gujarat 328428*

E-mail: [ritesh@ipr.res.in](mailto:ritesh@ipr.res.in)

**Abstract**

A Linear Plasma device named as Applied Plasma Physics Experiments in Linear Device (APPEL) is under development at Institute for Plasma Research (IPR) for fundamental studies of magnetized plasma interaction with material objects immersed in plasma. The basic phenomena associated when physical objects comes in contacts with magnetized plasma are (1) Equilibrium properties (drifts, cross-field transport) (2) Magnetized sheaths (wall current, hot spots, arc) (3) Power coupling by RF antennas (parasitic waves) (4) Saturation current measurement with oblique B-field etc. The device will offers simplicity and well controlled plasma state, flexibility in the choice of target materials, setup of mock-up experiments for verification of simulation and modelling codes which are otherwise difficult in the conventional tokamak device. The experiments will be conducted using the automated control system. During the pre-design, development and procurement of different subsystems, a parallel initiative and efforts are underway to conceptualize the control system as a plug and play integration platform. The control system will provide the integration of various subsystems viz. (1) High density plasma source, (2) Material placing, (3) Magnet coils and Power supplies, (4) Vacuum chamber and pumping system and (5) Plasma diagnostics. Control system software architecture is modelled as a 3 tier architecture (1) Integration Tier to cater integration of interfaces of different subsystem in fail safe manner incorporating interlocks and safety (2) Control tier for to cater configuration, controls logics and data archival and (3) Application tier driven by web services to facilitate the collaboration and data sharing. The proposed control hardware architecture will be realized with state of art PLC's and fast controllers and software will be realized using open source control frameworks e.g. EPICS, Tango, MDS+.

This paper reports the requirements and rationales, a state of art survey of control system for similar devices in the world[1,2,3], Survey of realizing technologies, high level architecture describing work flows, operation sequences, state diagram and integration strategy.

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## BP-361

### Dust Acoustic (DA) Waves In A Magnetised Plasma With Boltzmann Distributed Electrons And Ions

B. C. Kalita<sup>1</sup>, Mamani Choudhury<sup>1, 2</sup>, S. Chetia<sup>1</sup>.

<sup>1</sup>Department of Mathematics, Gauhati University, Guwahati-781014

<sup>2</sup>Department of Mathematics, Handique Girls' College, Guwahati-781001

E-mail :choudhurymamani@gmail.com

#### Abstract

The nonlinear of dust-acoustic waves in a dusty plasma whose constituents are negatively charged dust, ions and electrons following Boltzmann distribution, is investigated by Sagdeev potential method. Existence of both subsonic and supersonic compressive solitons of interesting characters is established in this magnetized plasma model based on dust charge  $Z_d$  (involved in  $f$ ) and temperature ratio  $\alpha$ . The condition of the existence of solitons is  $\frac{k_z^2}{M^2} < \frac{1 + (1-f)\alpha}{f} < \frac{1}{M^2}$ .

The amplitudes and depths of the potentials of subsonic and supersonic compressive solitons increase with the increase of dust charge  $Z_d$ , but decrease with the increase of temperature ratio  $\alpha$ .

## BP-362

### Analysis Of Kinetic Energy Of Ion And Electron In Magnetized Plasma Sheath

B.R Adhikari, Roshan Chalise and Raju Khanal

Central Department of Physics, Tribhuvan University, Kirtipur, Kathmandu, Nepal

E-mail: b.r.adhikari@hotmail.com

#### Abstract

The wall is charged up negatively with respect to the surrounding plasma, due to the higher velocity of the electrons compared with that of the ions. As a result a positive space charge region is formed in front of the wall. This positive- space- charge region, known as the sheath. In all plasma applications sheath is responsible for the flow of particles and energy towards the wall. The plane which separates the sheath and presheath region is called sheath edge, where the in-streaming ions have to satisfy the "Bohm Criterion" to ensure the stability of the overall plasma. The kinetic energy of ion and sheath thickness in magnetized plasma sheath region has been numerically investigated by using a kinetic trajectory simulation model keeping other parameter fixed, varying magnetic field and its

obliqueness. It has been reveal that the kinetic energy of ions reaching the material wall can be controlled by the strength of applied magnetic field and orientation. Kinetic energy of ion increases as we move towards the wall whereas the kinetic energy of electrons decreases as expected, which becomes prominent as the strength as well as obliqueness of the field increases. It is found that by increasing the magnetic field strength there is an increase in the ion energy and a decrease in the sheath thickness. Furthermore, the magnetic field has a direct effect on the ion flux toward the wall and sheath thickness. Our Results are expected to be precise and is useful in material processing, plasma etching and for confinement of plasma in fusion devices.

## BP-374

### Surface Modifications Of Natural *Kanchipuram* Silk (*Pattu*) Fibers Using Glow Discharge Plasma

K.Vinisha Rani, Bornali Sarma, and Arun sarma

*VIT University, Chennai, Vandalur-kelambakkam Road, Chennai-600127, Tamil Nadu, India.*

E-mail: kvinisha.rani2014@vit.ac.in

#### Abstract

An experiment has been carried out to modify the surface of natural Kanchipuram silk (pattu) fibers using a DC glow discharge Plasma to understand its surface properties in terms of absorption. Silk is an externally spun fibrous protein secretion formed into fibers [1-2]. Plasma treatment is an eco-friendly, dry and clean process over wet chemical method and does not suffer from any environmental and health concerns [3-4]. Experiments have been performed considering three variable parameters such as discharge current, treatment time and working pressure. An optimized experimental condition has been achieved to make it hydrophobic or hydrophilic. The Chemical structure, physical properties, morphological studies of raw and plasma treated silk fibers have been carried out by using FTIR spectroscopy, UV VIS Photo spectrometer, X-Ray Diffraction, Thermo Graphical Analyzer, Scanning Electron Microscope (SEM) etc. A comparison studies have been done with untreated and different treated fibers also.

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**BP-377**

**Dispersion Relation On Alfven Waves In Multi-Component Magneto-Plasma**

Vishnu P. Ahirwar and G. Ahirwar

*School of Studies in Physics, Vikram University, Ujjain (M.P.)-456010*

E-Mail: ganpat.physics@gmail.com

**Abstract**

The dispersion relation of Alfven waves have been theoretical studies by kinetic approaches. Dispersion relation of Alfven waves are measured in multi-component magnetosphere plasma consisting of mixture of hydrogen ( $H^+$ ), helium ( $He^+$ ) and Oxygen ( $O^+$ ) ions in magnetized cold plasma. The wave is assumed to propagate parallel to the static magnetic field. It is observed that the effect of multi-ions for different plasma densities on Alfven waves is to enhance the wave frequencies. The results are interpreted for the magnetosphere has been applied parameters by auroral acceleration region.

**BP-400**

**A Novel Approach To The Study Of Hysteresis, And Negative Resistance In Glow Discharge Plasma**

Prijil Mathew<sup>1</sup>, Anu Philip<sup>1</sup>, Sajith Mathew<sup>1</sup>, P.J. Kurian<sup>1</sup>, P.K Chattopadhyay<sup>2</sup>

<sup>1</sup>*Physics Research Centre, S.B College, Changanacherry, Kerala-686101*

<sup>2</sup>*Institute for Plasma Research, Bhat, Gandhinagar 382428, Gujarat*

Email: pjklasma@yahoo.ca

**Abstract**

We have produced hysteresis loops in discharge current verses voltage plots in a low-pressure, magnetic field free, Glow discharge plasma by varying discharge voltage. The variations in area of the hysteresis loop with pressure and electrode distance are studied. This behaviour can be attributed to a region of negative differential resistance in the voltage versus current characteristic of the discharge. A model is presented in order to understand the physical processes leading to this negative resistance.

**BP-406**

**Investigation Of Nonlinearity In A Plasma And A Non-Plasma Device**

<sup>1</sup>Sudeshna Lahiri, <sup>1</sup>Dola Roy Chowdhury, <sup>2</sup>M. S. Janaki and <sup>2</sup>A. N. Sekar Iyengar

<sup>1</sup>*TechnoIndia, Kolkata*

<sup>2</sup>*Saha Institute of Nuclear Physics, Kolkata - 700064, India*

Email:sudeshna\_lh@yahoo.co.in

**Abstract**

The dissipative physical systems like plasmas are well-known nonlinear media capable of sustaining a wide variety of waves and instabilities. The vast majority of efforts are based on estimating the Largest Lyapunov Exponent, Hurst exponent and correlation dimension calculation. In this paper we like to compare the dynamics lying behind a plasma [1] and a non-plasma system [2]. As a plasma system we have chosen a glow discharge plasma and as a non-plasma system we have chosen ‘BZ’ (Belousov-Zhabotinskii) reaction. Fluctuations of the plasma floating potentials from cylindrical dc glow discharge argon plasma at an intermediate gas pressure of 0.22 mbar and at the range of discharge voltage (300-700 volt) investigated to probe the nature of the complex system dynamics. The system observable, i.e the electrostatic floating potential was measured using a Langmuir probe. The experiment was performed keeping the neutral pressure and electrode configuration constant, and discharge voltage (DV) was the control parameter. Over several regions of the discharge voltage, the floating potential fluctuation time series data exhibits periodic oscillations, and irregular fluctuations.

Study of chemical oscillations have focused primarily on the (BZ) reaction in which bromate ions are reduced in an acidic medium by an organic compound (usually malonic acid) with or without a catalyst (usually ferrous and/or ferrous ions). We have varied the concentration of the solution and also the reaction temperature and data was collected using an absorption spectrophotometer. In the case of plasma, the discharge voltage has a discernible effect on the behaviour of this complicated system. As the discharge voltage increases, the system follows a quasiperiodic route to chaos. On the other hand in the non-plasma system the nature of oscillation depends on the reaction temperature and also on the concentration of the solution. From the power spectrum plots and from the log frequency vs log power plots we have also seen a marked difference in the system dynamics lying behind the nonlinear oscillations. The value of Hurst exponent varies from 0.5 to 1.0 in plasma where it is around 1.0 in chemical oscillations.

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**BP-410**

**Characterization of Ionizer hot plate for Multi-Cusp Plasma Device (MPD)**

Zubin Shaikh<sup>1</sup>, Meenakshi Sharma<sup>2</sup>, A.D.Patel<sup>2</sup>, J.D.Khatri<sup>2</sup>, S. Sahoo<sup>2</sup>, H.H.Joshi<sup>1</sup> and  
N.Ramasubramanian<sup>2</sup>

<sup>1</sup>*Department of Physics, Saurashtra University, Rajkot-360005*

<sup>2</sup>*Institute for Plasma Research, Bhat, Gandhinagar-382428*

E-mail: zubin.ipr@gmail.com

**Abstract**

In an upcoming basic experiment at IPR, contact-ionized cesium ions will be confined by a multicusp magnetic field configuration. The cesium ions will be produced by impinging collimated neutral atoms on an ionizer consisting of a hot tungsten plate. The temperature of the tungsten plate will also be made high enough ( $\sim 2700$  K) such that it will contribute electrons also to the plasma. It is expected that at this configuration the cesium plasma would be really quiescent and would be free from even the normal drift waves observed in the classical Q-machines in the central region. Hence for quiescent plasma, the design of the hot plate ionizer is very critical. Thermionic Electron emission from tungsten plate is exponentially proportional to the temperature of the plate. A small amount of temperature gradient on the plate might cause a large potential difference in plasma which will result in a drift thus affecting the experiment. Hence it is necessary to have hot plate temperature to be uniform about 1%. To measure the thermal contours of the ionizer hot plate a non-contact method (IR-Camera) will be used and will be characterized. The results of this characterization will be presented in this paper.

**BP-424**

**Hysteresis Effects And Characterization Of Floating Potential Oscillation  
Amplitudes In A Co-axial Electrode Geometry**

Rahul Kumar<sup>1</sup>, Ramesh Narayanan<sup>2</sup> and Awadhesh Prasad<sup>3</sup>

<sup>1</sup>*Department of Physics, Indian Institute of Technology Delhi, Hauz Khas, New Delhi-110016, India*

<sup>2</sup>*Centre for Energy Studies, Indian Institute of Technology Delhi, Hauz Khas, New Delhi-110016, India*

<sup>3</sup>*Department of Physics and Astrophysics, University of Delhi, New Delhi – 110007, India*

E-mail : rams@ces.iitd.ac.in

**Abstract**

Plasma discharges, initiated in a coaxial electrode system ( $\approx 6$  cm long), with the central axial rod (diameter  $\approx 0.15$  cm) being the powered anode and the outer cylindrical tube acting as the grounded cathode, has been studied using Langmuir probe measurements. The discharge current ( $I_d$ ) – discharge voltage ( $V_d$ ) characteristics [1] is seen to have two consecutive negative differential regions (NDR) at high pressures (750 mTorr - 950 mTorr). These NDR regions are not observed when the

anode and cathode are interchanged. The first NDR (at about 3-7 mA) is seen to be associated with a voltage threshold. This voltage threshold is observed to shift to higher values with plasma exposure time with the voltage drop across the first NDR being almost constant.

Under certain operating conditions, a hysteresis is observed in the amplitudes of self-excited oscillations of the floating potential ( $V_f$ ) and discharge current in an unmagnetized co-axial electrode-geometry DC glow discharge plasma system. This hysteresis effect is observed between the two NDR regions. In some conditions it is observed to occur closer to the second NDR ( $\sim 40$  mA) and in other conditions it is observed at lower discharge currents ( $\sim 16$ -20 mA).

The characterization of these oscillations revealed the transition of low-amplitude high-frequency period-n oscillations to a large-amplitude, low-frequency period-1 oscillations through a chaotic intermediate route. The transition of the low amplitude, high frequency period-n oscillations to chaotic type is observed to be linked to the dynamical change in the plasma system i.e. after a negative differential resistance region whereas the transition from chaotic to period-1 is observed to be linked to a discharge current threshold. This paper will present the characterization of the  $V_f$  oscillations near the chaotic transition region using spectral and nonlinear dynamical tools.

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### BP-429

## Studies Of Wave Phenomena In Plasma In A Diverging Magnetic Field

A. Ghosh, M.S. Janaki, S.K. Saha, S. Chowdhury

*Saha Institute of Nuclear Physics, 1/AF Bidhannagar, Kolkata-700064, India.*

E-mail : abhijit.ghosh@saha.ac.in

#### Abstract

In our experimental device, RF plasma is made to expand from a narrower source tube to a bigger expansion chamber; all experiments have been performed in this expansion chamber. The plasma density and potential profiles have been reported ([1],[2]). From the density profiles, it is understood that diamagnetic drifts exist in the azimuthal direction. From the plasma potential profiles, we can see that  $\mathbf{ExB}$  drift is also there in the azimuthal direction. Also, at suitable experimental conditions, a strong double layer exists in the axial direction [1].

We have observed fluctuations in the range of 18 kHz in the floating potential. These fluctuations have maximum amplitudes in the region where strong density gradients exist. Also, they are coherent, propagate in the azimuthal direction, have a large parallel (to  $\mathbf{B}$ ) wavelength comparable to the device dimension. Variation of the phase angles with the azimuthal positions show that the wave corresponds to the  $m=1$  mode. These observations indicate the presence of a drift mode. However, few other measurements are still required to confirm this as a drift wave.

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**BP-444**

**Mixed Mode Oscillations In Glow Discharge Plasma**

Sabuj Ghosh, Pankaj Kumar Shaw, Debajyoti Saha, A.N. Sekar Iyengar, M.S. Janaki

*Saha Institute of Nuclear Physics, 1/AF, Bidhannagar, Kolkata – 700064*

E-mail : sabuj.ghosh@saha.ac.in

**Abstract**

Different kind of Mixed Mode Oscillations have been observed as floating Potential Fluctuation of a glow discharge plasma system as Discharge Voltage is changed. The different kinds of MMOs are categorized based on the pattern followed by MMOs[1]. Floating potential fluctuations were analyzed by power spectra, phase space reconstruction, entropy measurements, Hurst Exponent estimation etc. A nonlinear dynamical view about the fluctuation has been obtained through these analyses[2].

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**BP-461**

**Electrostatic Excitations In Beam-Plasma Interaction And Complex Plasmas: A Review Of Research Work**

N. S. Saini and Plasma Physics Group

*Department of Physics, Guru Nanak Dev University, Amritsar-143005*

E-mail: nssaini@yahoo.com

**Abstract**

The existence of nonlinear ion-acoustic (IA) solitary structures in different plasma environments has been confirmed theoretically as well as experimentally by a number of researchers. For the last many years there has been great interest in studying the different kind of solitary structures in various plasma systems. It is established that stationary nonlinear localized electrostatic waves may also be excited when an electron/ion beams are injected into a plasma. The presence of electron beams is also clearly indicated by space observations in the upper layer of the magnetosphere, where a coexistence of two different electron populations (say, warm energetic ones and cold, i.e., inertial electrons) is reported by various satellite missions. Focusing on nonlinear electrostatic (ES) excitations, it is well known that the injection of an electron/ion beam into a plasma strongly affects the conditions for the occurrence of solitary waves and may modify their properties. This is shown either by small amplitude solitary wave theory (based on a reductive perturbation method) or by more rigorous studies of large amplitude excitations (described by a pseudo-potential approach). We have also

studied the envelope solitary structures which are governed by the solutions of NLSE. Some problems are carried out in multicomponent as well as complex plasmas to analyze the effects of physical parameters on the characteristics of ion-acoustic, electron-acoustic, dust acoustic and dust ion acoustic waves. These solitary structures are influenced by the various plasma parameters in electron-beam plasma systems. The findings of the various studies may be useful in understanding the nonlinear structures in different plasma environments. A brief review focusing on this work will be presented.

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### BP-467

#### Investigation Of Nonlinearity In Presence Of External Forcing And Magnetic Field In DC Glow Discharge Plasma

Debajyoti Saha, Pankaj Kumar Shaw , Sabuj Ghosh, M. S. Janaki and A. N. Sekar Iyengar

*Plasma Physics Division, Saha Institute of Nuclear Physics, Kolkata-700064*

E-mail :debajyoti.saha@saha.ac.in

#### Abstract

Detection of nonlinearity has been carried out in periodic and aperiodic fluctuations of DC glow discharge plasma (GDP) with the help of the production of surrogate data technique to provide some rigor and certainty. We introduce 'Delay vector variance' analysis (DVV) first time in our glow discharge plasma system which allows reliable detection of nonlinearity and provides some easy to interpret diagram conveying information about the nature of our experimental Floating potential fluctuations (FPF). The method of False nearest neighbourhood is deployed on our FPF's to find a good embedding so as to be acquainted with the precise knowledge of  $m$  which is desirable for carrying out DVV analysis. An attempt to model the experimental observations by a second order nonlinear ordinary differential equation derived from the fluid equations of plasma has revealed convincing results.

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**BP-493**

**A Polynomial Regression Model For Predicting Storm Time Dst Index Using Vbz As Input**

Remya Remanan<sup>1</sup> and K. Unnikrishnan<sup>1,2</sup>

<sup>1</sup>*School of Pure and Applied Physics, Mahatma Gandhi University, Kottayam-686560, Kerala*

<sup>2</sup>*Department of Physics, N.S.S Hindu College, Changanacherry-686102, Kerala*

E-mail :sreeremmu@yahoo.com

**Abstract**

The prediction of space weather is necessary for scientific and economic purposes because the solar wind and high energy particle emissions due to the variations of solar activity can affect space weather, which in turn damage the communication satellites, global positioning satellites etc. Geomagnetic storm prediction is one of the applications of space weather and geomagnetic storm time index (Dst) is the proxy of magnetospheric ring current [1] and thus the occurrence of geomagnetic storm. The solar wind speed and southward component of the IMF are the main parameters behind the intensity of geomagnetic storms[2].

In order to carry out the regression analysis, the hourly values of Dst index is used as the dependent variable and vBz is used as the independent variable. Storm events with  $Dst \leq -100$  nT are used for prediction and the time series of the data sets used here starting for the first 48 hours after the SSC and 2 hours' time lag is given to the Dst index data with respect to vBz before making prediction. The period of study is 2001-2005 which includes low, moderate and high solar activity phases. The regression coefficients are estimated from a training data set, which was extracted from a dataset of 34 storm events, observed during 2001–2005. The trained model is validated by predicting the occurrence of geomagnetic storms from a validation dataset recorded during 2001–2005. The dataset used for training the model is not used for predicting the geomagnetic storms or validating the model.

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**BP-494**

**Particle In Cell Simulation Of Buneman Instability**

Roopendra Singh Rajawat, Sudip Sengupta and Predhiman K. Kaw

*Institute for Plasma Research, Bhat, Gandhinagar - 382428*

E-mail: rupendra@ipr.res.in

**Abstract**

Nonlinear Evolution of Buneman instability has been investigated using a 1-D particle-in-cell simulation code. In the linear regime, and in the limit  $kV_0/(\omega_p) \sim 1$ , the code reproduces the well known scaling of growth rate with mass ratio as  $\sim (m/M)^{(1/3)}$ . In addition the code correctly reproduces the saturation limit of Buneman instability [1]. In the nonlinear regime of the instability, before the occurrence of saturation, it has been analytically shown [2] that in the low frequency, long wavelength quasi-neutral limit, the scaling of growth rate with mass ratio reduces to  $\sim (m/M)^{(1/2)}$ . We have successfully verified this scaling in our simulations.

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**BP-495**

**Study On Discharge Dynamics In An Atmospheric Pressure Dielectric Barrier Discharge**

S.S. Kausik<sup>1</sup>, W.H. Tay<sup>2</sup>, S.L. Yap<sup>2</sup> and C.S. Wong<sup>2</sup>

<sup>1</sup>*Centre of Plasma Physics, Institute for Plasma Research, Sonapur-782402, Assam, India*

<sup>2</sup>*Plasma Technology Research Centre, Department of Physics, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia*

E-mail: kausikss@rediffmail.com

**Abstract**

Dielectric barrier discharge (DBD), which is also known as silent discharge, atmospheric pressure discharge, and barrier discharge has been extensively investigated for the last few decades because of its wide applications in industry for ozone synthesis [1-2], surface treatment of materials [3-4], removal of gaseous pollutant [5-6], bio-medical applications[7-8], and so on. In this work, the discharge dynamics in an atmospheric pressure dielectric barrier discharge (DBD) is studied in a DBD reactor consisting of a pair of stainless steel parallel plate electrodes. The DBD discharge has

been generated by a 50 Hz ac high voltage power source. The high-speed intensified charge coupled device (iCCD) camera is used to capture the images of filaments occurring in the discharge gap. It is observed that frequent synchronous breakdown of micro discharges occurs across the discharge gap in case of negative current pulse. The discharge gap dependence on synchronous breakdown is also studied by changing the discharge gap. The role of memory charges in the formation of plasma filaments has been investigated.

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## BP-497

### Evolution Of Relativistic Electron Current Beam In A Cold Plasma

Roopendra Singh Rajawat and Sudip Sengupta

*Institute for Plasma Research, Bhat, Gandhinagar - 382428*

E-mail: rupendra@ipr.res.in

### Abstract

Evolution of relativistic electron current beam in a cold homogeneous plasma with immobile ions has been studied analytically using Langrange variable method [1,2]. It is found that the beam current, when longitudinally perturbed, diminishes with time due to phase mixing effects arising because of spatial variation of relativistic electron mass. The time in which current diminishes scales with the amplitude of perturbation( $\Delta$ ) as  $\sim 1/\Delta^3$ . This scaling has been verified using a 1-D particle-in-cell simulation code.

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**BP-507**

**Ion-Acoustic Double-Layer in an Inhomogeneous Plasma**

<sup>1</sup>Harvinder Kaur Ghai, <sup>2</sup>Tarsem Singh Gill

<sup>1</sup>*Khalsa College, Amritsar*

<sup>2</sup>*Guru Nanak Dev University, Amritsar*

Email :hkaur\_21@yahoo.com

**Abstract**

In the present investigation Ion-Acoustic Double Layers in a inhomogeneous plasma consisting of Maxwellian and nonthermal distribution of electrons are studied. We have derived a modified Korteweg-de Vries (mKdV) equation for Ion-Acoustic Double Layers Propagating in a collisionless inhomogeneous plasma. In this paper we are studied the effect of the nonthermal parameters on amplitude, width and velocity of the double layer. The temperatures and number densities of cold and hot electrons also influence the formation of double-layer.

**BP-512**

**Dissipative Solitons In Pair-Ion Plasmas**

Ashish Adak

*Dept. of Instrumentation Science, Jadavpur University, Kolkata700032*

E-mail :ashish\_adak@yahoo.com

**Abstract**

The effects of ion-neutral collisions on the dynamics of the nonlinear ion acoustic wave in pair-ion plasma are investigated. The standard perturbative approach leads to a Korteweg-de Vries equation with a linear damping term for the dynamics of the finite amplitude wave. The ion-neutral collision induced dissipation is responsible for the linear damping. The analytical solution and numerical simulation reveal that the nonlinear wave propagates in the form of a weakly dissipative compressive solitons. Furthermore, the width of the soliton is proportional to the amplitude of the wave for fixed soliton velocity. Results are discussed in the context of the fullerene pair-ion plasma experiment.

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**BP-514**

**Modified Burgers Equation And Higher Order Modified Burgers Equation In Hot Adiabatic Dusty Plasma With A Negative Ion Rich Non-Thermal Ion And Trapped Electron**

N. C. Adhikary<sup>1</sup>, A. N. Dev<sup>2</sup>, M. K. Deka<sup>3</sup> and J. Sarmah<sup>4</sup>

<sup>1</sup> *Physical Sciences Division, Institute of Advanced Study in Science and Technology, Vigyan Path, Paschim Boragaon, Garchuk, Guwahati – 781035, Assam*

<sup>2</sup> *Department of Science and Humanities, College of Science and Technology, RUB, Bhutan*

<sup>3</sup> *Institute of Science and Technology, Gauhati University*

<sup>4</sup> *Department of Mathematics, R.G. Baruah College, Guwahati-781025, Assam*

E-mail : nirab\_iasst@yahoo.co.in

**Abstract**

In this report the investigation of the properties of dust acoustic (DA) shock wave propagation in adiabatic dusty plasma including the effect of the negative rich non-thermal ions and trapped electrons is presented. The reductive perturbation method has been employed to derive the modified Burgers equation and new form of higher order nonlinear modified Burgers equation for dust acoustic shock waves in a homogeneous, unmagnetized and collisionless plasma whose constituents are electrons, singly charged positive ions, singly charged negative ions and massive charged dust particles. The stationary analytical solution of the modified Burgers equation and new analytical solution of higher order nonlinear modified Burgers equation are numerically analyzed and where the effects of various dusty plasma constituents DA shock waves propagation are taken into account. It is observed that both positive and negative ions in dusty plasma play as a key role for the formation of both positive as well as the negative DA shock waves and also the ion concentration controls the transformation of negative to positive potentials of the waves.

**BP-516 (I)**

**Field Limitations Of The Applicability Of Local Approximation For EDF In High Pressure Plasmas**

A.A. Kudryavtsev, K.D. Kapustin, and M.B. Krasilnikov

*St. Petersburg State University, 7-9, Universitetskaya nab., St. Petersburg, 199034, Russia;*

E-mail : akud53@gmail.com

**Abstract**

The local approximation is widely used for calculation of the electron distribution function (EDF) in plasmas. As was shown before [1], the condition of its applicability is determined by ratio between the energy relaxation length and a characteristic plasma length which results in fact that the EDF at high and at intermediate pressure can be determined using LFA. To prove that, the detailed

mechanisms of EDF formation in DC positive column plasmas are analyzed to reveal the nonlocal effects at intermediate and high pressures.

Computational simulation for argon gas have been performed. The model involves direct ionization, electronic excitation from ground-state atoms, step-wise ionization from metastables, Penning ionization, and de-excitation. To provide simulations COMSOL MULTIPHYSICS TM modules which are iterated to a converged solution have been used. The calculations have been performed in the wide range of pressures from 6 to 200 Torr.

In present work the strong dependence of electron fluxes distribution on elastic cross-section is found and explained. We show that the applicability of local approximation for EDF depends not only on the ratio between the energy relaxation length and a characteristic plasma length but also on the ratio between the heating  $E_{\text{heat}}$  and ambipolar  $E_{\text{amb}}$  electric fields. Thus, for the condition  $E_{\text{heat}} < E_{\text{amb}}$  at the glow discharge periphery, local approximation for EDF is not valid even in high pressure plasmas. As a result, non-locality of EDF at the plasma periphery results in non-monotonic excitation profile [2].

Work is partially supported by RNF grant 14-19-00311 and SPbGU grant 11.38.658.2013.

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## BP-517 (I)

### The Role of Current Filaments in A Long Spark In Air

A.V. Oginov, A.A. Rodionov, K.V. Shpakov

*Lebedev Physical Institute of RAS, 119991, Russia, Moscow, Leninskii ave. 53*  
E-mail: oginov@lebedev.ru

#### Abstract

Recent studies of natural lightnings show that the high-energy radiations are generated during thunderstorms. Besides hard x-ray and gamma radiation [1], a neutron generation is also observed [2]. In a laboratory long spark discharge with the parameters similar to lightning the neutron generation is observed also [3]. The model or mechanism to explain the generation of hard x-rays and neutron bursts during atmospheric discharge in air is under discussion.

The formation of 500–700 mm long sparks in air on ERG installation (LPI, 1 MV, 60 kJ, 150 ns risetime) at different initial electric field distributions was investigated. A volumetric streamer corona of 0.2–1.0 kA on both of electrodes at atmospheric pressure was followed by a formation of bright channel of 12 kA leader. A fine microstructure of a leader stage of a 200–1200 ns discharge was observed. The distribution of  $\mu\text{m}$ -scale microchannels over the mm-size leader cross section near the electrodes and in the gap was investigated. Optical and autograph diagnostics were used to estimate a current density in a single microchannel. It was shown earlier [4] that the formation of leader current structure can be attributed to the instability of initial ionization wave front producing streamers. Another possibility is to consider current filaments as the quasi-equilibrium structures with strong radial electric field due to Hall effect [5]. The possibility of current carrying by the relativistic

electrons drifting in the crossed electric and magnetic fields and the acceleration of ions to keV energy range in a strong radial electric field at experimental conditions was examined. The observed experimental results are compared with the filament model estimations of x-ray emission intensity and neutron flux.

The role of vortex field structures as a possible mechanism for generation of high energy radiations in atmospheric discharge was considered.

This work was supported by the RFBR grant 13-08-01379.

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## BP-518 (I)

### Orthogonal Symmetric Discharge System

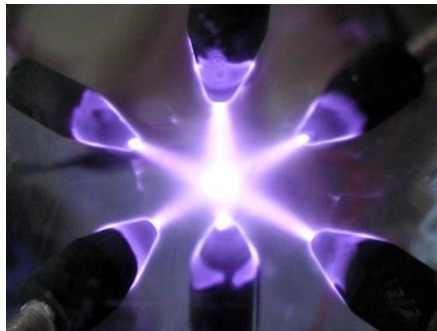
Pavel Studenovský

*Laboratory of Electrical Discharges, Sartoriova 31, 169 00 Prague, Czech Republic*

E-mail:pavel@studenovsky.cz

#### Abstract

Variable periodic sequences of current pulses are applied by symmetric orthogonal electrode system, on diluted air in glass evacuated chamber. The main objective of the project was to experimentally investigate morphology and form of resulted complex 3D discharges at different sets of applied parameters and tries to check a possibility to generate some more stable and distinct plasma configurations. A sample is shown below.



Complex discharge (at P:cca 40 Torr) Applied power ~ 250W

# **COMPUTER MODELING FOR PLASMA**





## CM-02

### **Numerical Study on Second Harmonic Ion Cyclotron Resonance Heating Of Low Ion Temperature Plasma**

Asim Kumar Chattopadhyay

*Institute for Plasma Research, Bhat, Gandhinagar 382 428, India*

Email: asim@ipr.res.in

#### **Abstract**

Studies on absorption of second harmonic wave in the ion cyclotron frequency range (ICRF) are conventionally carried out for high ion temperature plasmas in view of their relevance for fusion experiments. At high ion temperatures these studies predict lower power deposition directly on the electrons. In the present work, I examine the absorption of ICRF in a relatively lower density and lower ion temperature plasma that is commonly found in smaller tokamaks and basic plasma devices. For my study I have chosen the typical temperature and density values found in the Aditya tokamak. The numerical study has been carried out using the full-wave ion cyclotron heating code, TORIC combined with a Fokker-Planck quasilinear solver, SSFPQL. In such low temperature, low density plasmas, ion absorption for second harmonic resonance heating is less but significant amount of direct electron heating is observed. The physics of this absorption process and the implications of these results will be discussed.

## CM-09

### **Development Of A 0-D Code For The Simulation Of Runaway Electron Production And Energy Dynamics In Tokamaks**

Santosh P. Pandya

*Institute for Plasma Research, Bhat, Gandhinagar-382428, Gujarat, India.*

E-mail: psantosh@ipr.res.in

#### **Abstract**

Runaway Electrons (REs) generation, energy dynamics and loss are the major concern for the present day tokamaks having long discharge duration as well as future fusion tokamak reactors like ITER. Because of their highly directional relativistic velocity and formation of beam can produce severe damage to the first wall and other in-vessel components if local high power deposition takes place. REs are generated during different phases of a plasma discharge. They mainly produced during current ramp-up phase, disruption phase and failed breakdown conditions. Production of REs depends on toroidal electrical field and plasma density. In large tokamaks, REs can be confined for longer durations hence, they gain energy up to few tens of MeVs and with significant fraction of discharge plasma current. It is essential to estimate RE parameters, namely: density, energy, energy distribution function and pitch angle etc. RE parameters are useful for plasma control, machine safety

and physics studies. In order to estimate RE parameters before the plasma discharge and to investigate RE parameters after the plasma discharge for post analysis, a numerical tool has been developed.

Attempts have been made to develop a simple code and fast model which can estimate REs parameters based on the input plasma parameters. In addition to that other modules of this integrated code can generate essential signal for different RE related diagnostics. The objective of the code is to estimate first order RE parameters but not going into the detailed physics of the REs. In this paper, development of a 0-D code is described based on the RE generation and energy dynamics models. The code takes steady-state or fully time dependent plasma parameters as inputs and solves these models numerically. Moreover the code utilizes coupled circuit algorithm with coupled circuit parameters (considering plasma and runaway current). Present version of the code can estimate time dependent evolution of RE density, number, current, energy (considering all losses like synchrotron radiation loss, collision loss with plasma density, bremsstrahlung radiation loss), pitch angle, parallel and perpendicular energy-components, upper bound of the RE-energy, energy distribution function, pitch angle distribution function, motion of RE in momentum space etc. The diagnostic modules of the code generate synchrotron and bremsstrahlung radiation spectrum emitted by REs. The code has been validated for few plasma discharges of the Frascati Tokamak Upgrade (FTU) and the output results compared with the experimental results from the RE diagnostics. Reasonably good agreement has been found between simulated and experimental results. The code has also been applied on the TEXTOR-94 tokamak plasma parameters and re-produced all the results given in the Reference. After the benchmarking, the code will be utilized to predict and/or to estimate above mentioned runaway parameters of the ADITYA and SST-1 Tokamaks.

## CM-29

### Investigation Of Phase Equilibria And Critical Properties Of Strongly Coupled Pair Ion Plasmas

Swati Baruah, R. Ganesh<sup>1</sup> and K. Avinash<sup>2</sup>

<sup>1</sup>*Institute for Plasma Research, Bhat, Gandhinagar-784 028, Gujarat*

<sup>2</sup>*Department of Physics and Astrophysics, University of Delhi, New Delhi*

E-mail: baruah.s1@gmail.com

#### Abstract

Existence of phase transition in strongly coupled pair-ion plasmas with soft core is investigated. Extensive Molecular Dynamics (MD) simulations are performed in the canonical (NVT) ensemble, on such plasmas at different temperatures to analyze the phase stability. Our studies show interesting phase co-existence between liquid-like and vapor-like phase. The different phases are identified by calculating the ensemble averaged density. This and the corresponding critical properties are calculated directly from MD simulation. The critical temperature is obtained as 0.105 and corresponding critical value of density is estimated at 0.34.

We have used a novel method to allow the location of phase coexistence through a constant density simulation in which the temperature is changed in a single time-step (quenching) in order to place the system in a thermodynamically and mechanically unstable state; it spontaneously separates into two coexisting phases. The results obtained from this temperature quench molecular dynamics

(TQMD) method also represent coexistence of vaporliquid phase in pair-ion plasmas. The behavior of this 2D pair-ion plasma model is in good agreement with the mean-field theory.

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## CM-54

### Simulation Of Exploding Foil Produced Dense Plasma And Comparison With Preliminary Experimental Results

Aaditya V. Majalee, V.R. Ikkurthi, PoonamPahari, Vinayak Mishra, Aditya N. Savita,  
SambaranPahari and S. Chaturvedi

*Computational Analysis Division, Bhabha Atomic Research Centre (BARC), Autonagar,  
Visakhapatnam, 530 012*

E-mail : aadityam@barc.gov.in

#### Abstract

The passage of a large current in a short time through a metallic foil produces plasma in the warm-dense regime which then expands explosively at high velocity. Rapidly vapourizing conductors have long been known to generate plasmas of high pressure. Keller *et. al.* [1] used rapidly vapourizing metals foils to accelerate thin dielectric plates to velocities of 4-5 km/s. The densities of interest range from  $0.01-1 \rho_0$ , where  $\rho_0$  is the normal density of the solid, and the temperature varies from room temperature upto 5 eV. The solid phase at temperatures upto melting point, and low-density phase of the material at high temperatures, can be modelled with known models. But the warm-dense plasma is a regime where proper models with experimental validation are not present.

In the present work, we have simulated the early-time behaviour of an electrically-exploded foil. This is done using a combination of a 3-D Lagrangian Hydrodynamic code with a 2-D Finite Element Code to determine the self-consistent current density distribution in the medium. The 3-D code calculates the hydrodynamic expansion & heating of the foil. The 2-D code calculates the current density distribution through the foil due to joule heating. We have also employed a multi-phase electrical resistivity model [2]. We have used two different Equations of State (EOS) for simulation of the foil. The first EOS is used in the pre-burst regime and second EOS is used during the post-burst period. Detailed information about the code can be found from Majalee *et. al.* [3] and about the EOS from Majalee *et. al.* [4] respectively. The experimental details are mentioned in a companion paper by Savita *et. al.* [5].

Early time simulation shows a good match with the experimental current and voltage waveforms. The simulations also show a re-strike, as in the experiment, but the time of occurrence of peak current and the peak current value are different. However, the general trend of the experiments is simulated to some extent during the post-burst period. Exploding foil results for higher capacitor charging voltages ( $> 1.6$  kV) show a better match in the post-burst regime as compared to the low-capacitor voltage results. The physical reasons for the mismatch will be identified and solutions suggested for improving the model.

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## CM-101

### Fate Of An Electron Plasma Subjected To Ion Resonance Instability: A Numerical Study At Arbitrary Aspect Ratio

M. Sengupta and R. Ganesh,

*Institute for Plasma Research, Bhat, Gandhinagar 382428, India*

E-mail : ganesh@ipr.res.in

#### Abstract

The ion resonance instability in a cylindrically confined electron plasma has been analyzed by R. C. Davidson and others as a rotational two stream instability between two magnetized fluids - electron and ion, causing one or more unstable diocotron mode/s to evolve in the combination [1]. Specifically they considered a uniformly filled circular cross section of electron fluid with a fractional population of an ion species distributed evenly over it. Using linear perturbative model for the two fluids rigidly rotating in equilibrium at their respective angular frequencies [1], they showed how different azimuthal mode/s could get excited and evolve at different growth rates as a function of the fractional ion density [1].

We carried out a set of simulations on the ion resonance instability that verify Davidson et. al. 's analysis and take it further, numerically, in the less explored parametric space of different toroidal aspect ratios and different ion to electron mass ratios. We did this with the help of a newly developed 2D Electrostatic PIC code that uses unapproximated, mass-included equations of motion for simulation [2].

A nonlinear picture of how the ion resonance instability evolves as we move from cylindrical to tighter and tighter toroidal cross sections, and also as we vary the ion to electron mass, will be presented.

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## CM-122

### Modelling Of Disruption For ITER Using TSC Code

Amit K. Singh, I. Bandyopadhyay

*ITER-India, Institute for Plasma Research, Gandhinagar-382016, Gujarat.*

E-mail: amit.singh@iter-india.org

#### Abstract

Disruptions are considered a major obstacle to the use of tokamaks for fusion power. The electromagnetic and thermal loads are produced during vertical disruption events (VDEs) and major disruptions (MDs) impose stringent requirements on the strength of Tokamaks in-vessel components. Open field line halo currents flowing through vessel during a VDE create potentially damaging  $J \times B$  forces. A predictive understanding of halo current evolution is essential for ensuring the robust design of those components. Elaborate modeling of disruptions and VDEs have been carried out using the Tokamak Simulation Code (TSC). The plasma evolution during the disruptive phase and the growth of the halo currents are primarily governed by the halo region width and resistivity. However, due to limited diagnostics in most existing tokamaks, it is difficult to set a definitive value for these parameters in the simulations. To resolve this, detailed experimental validation with experimental data in DIII-D tokamak is presently being carried out. In the present work, the simulation results for major disruptions (MDs) and VDEs in ITER and DIII-D using the TSC code will be discussed.

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## CM-143

### Molecular Dynamics Simulation Of Plasma Sheath

Sandeep Kumar, Amita Das and Sanat Kumar Tiwari

*Institute for Plasma Research, Bhat, Gandhinagar - 382428*

E-mail :sandeep.kumar@ipr.res.in

#### Abstract

The behavior of plasma sheath is well known for the case when plasma is weakly coupled. However, in variety of situations the plasma can be in strong coupling regime, such as high energy density regime etc. Molecular Dynamics simulations can help understand the behavior of plasma sheath

potential for the case when the plasma is a strong coupled regime. We employ the open source molecular dynamics codes LAMMPS for our studies. We first reproduce the electrostatic sheath profile in the weak coupling regime with our MD simulations. Some initial results in the strong coupling regime will also be presented.

## CM-189

### Effect Of Ion-Neutral Collision On The Spatial Potential Of A Dust Grain

R. Moulick and K. S. Goswami

*Centre of Plasma Physics- Institute for Plasma Research  
Sonapur, Guwahati, Assam-782402*

E-mail: rakesh.moulick@gmail.com

#### Abstract

The presence of Ion-Neutral collision can lead to interesting phenomena of dust charging, totally different from the expectations based on the traditional OML theory [1, 2]. The potential around a dust grain is investigated for collisional plasma considering the radial motion of the ions. Fluid equations are solved for the one dimensional radial coordinate in spherical geometry [3]. It is observed that with the gradual increase of ion neutral collision, the potential structure around the dust grain changes its shape and is different from the usual Debye- Hückel potential. The shift however, starts from a certain magnitude of ion neutral collision and the electron-ion density varies accordingly. The potential variation is interesting and reconfirms the fact that there exists a region of attraction for negative charges in the vicinity of the dust. The collision modeling is done for the full range of plasma i.e. considering the bulk and sheath jointly [4, 5]. Initial values for the solution is generated by Taylor series expansion about the actual starting point [5-7]. The potential variation with collision is also shown explicitly and the variation is found to cope up with the earlier observations [8].

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## CM-204

### Catalyst Assisted Growth of Carbon Nanotube through Plasma Route

Aarti Tewari and Suresh C. Sharma

*Delhi Technological University, Shahabad Daulatpur, Bawana Road, Delhi-110042*

E-mail: aartitewari1386@rediffmail.com

#### Abstract

A detailed study of the complex processes involved in the growth of carbon nanotube (CNT) in plasma assisted by catalyst is carried out. The kinetics of all the plasma species, growth rate of the carbon nanotube because of surface and bulk diffusion of ions to the catalyst surface is accounted in the theoretical model. The role of plasma sheath in the growth of catalytic assisted growth of CNT is traced out in the study. It is seen that the growth rate of carbon nanotube is affected by the ion density and temperature. The results thus obtained can be extended in practical applications of CNT as in field emission devices.

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## CM-208

### Avoiding Disruptions and Runaways in ITER

Indranil Bandyopadhyay

*ITER-India, Institute for Plasma Research, Gandhinagar-382016*

Email: indranil@iter-india.org

#### Abstract

Plasma disruptions and runaway currents are a major cause of concern for ITER construction and operation. Vertical Displacement Events (VDEs) and Major Disruptions (MDs) of the plasma current will induce large electromagnetic forces on the ITER machine and the machine components have to be designed robust enough to withstand these forces. The magnitude of these forces for ITER was estimated originally through modelling using the DINA code, which has recently been validated using the Tokamak Simulation Code (TSC). However, uncertainties in these predictions still remain due to uncertainties in Halo current modelling. To resolve this presently a globally concerted effort being spent on validation of TSC model with experiments in DIII-D and CMOD tokamaks. Some of these modelling results both for DIII-D as also ITER will be presented in this presentation.

On the other hand, disruptions in ITER will generate large runaway currents and must be mitigated for safe operations. This has been an area of active research over the past several years. In ITER, during the thermal quench preceding the current disruption, there can be rapid resistive growth of the



toroidal electric field to very high values of about 50 times the critical electric field for runaway current generation. This may result in unprecedented runaway currents up to 10 MA, unless mitigated. This probably poses an even greater problem in ITER and robust mitigation systems must be developed. Different mitigation schemes involving massive gas injection (MGI) or shattered pellet injection (SPI) are being considered for disruption and runaway mitigation, however none of these methods so far have been absolutely proven to be successful in ITER. Various groups around the world are presently involved in modeling and experiments to develop the disruption and runaway mitigation systems in ITER. The present status of these ongoing activities, both experimental as well as modeling in development of disruption and runaway mitigation systems in ITER will be presented.

## CM-320

### **Excitation Of Terahertz Surface Plasmons In A Semiconducting Guiding System By A Density Modulated Electron Beam**

Pratibha Malik and Suresh C. Sharma

*Affiliation: Delhi Technological University, Shahbad Daultpur, Bawana Road, Delhi-110042*

E-mail : pratibhamalik27@gmail.com

#### **Abstract**

This paper investigates the effect of density modulated relativistic electron beam on the excitation of surface plasmons of submillimeter wavelength (0.1 THz to 10 THz) in a semiconducting guiding system, separated by a small gap. The coupling of the electromagnetic surface wave with density modulated electron beam in the guiding system is presented, which shows a considerable enhancement in the energy of the radiation wave. The growth rate of the instability increases with modulation index ( $\Delta$ ) and maximized for  $\Delta=1$ . It is found that the growth rate ( $\gamma$ ) for  $\Delta=0$ , approaches to  $1.46 \times 10^9$  rad./sec. In addition to this, maximum enhancement in the efficiency of the system is observed, as modulation index approaches unity.

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## Guiding Center Trajectory Of Electron Plasma Cloud Using Capacitive Probe Diagnostics In SMARTEX-C

Lavkesh T. Lachhvani, SudipSengupta, Manu Bajpai, Prabal K. Chattopadhyay, Sambaran Pahari<sup>1</sup>

*Institute for Plasma Research, Gandhinagar – 382428*

<sup>1</sup>*Bhabha Atomic Research Center, Vishakhapatnam – 530012*

E-mail: lavkesh@ipr.res.in

### Abstract

Non-neutral plasmas in cylindrical traps are routinely confined for very long times[1] and are extensively studied under thermal equilibrium[2]. In contrast, small aspect ratio toroidal traps offer several challenges. Various instabilities manifest in the presence of a strong spatially inhomogeneous magnetic field and cause rapid charge loss which is detrimental to confinement. Small Aspect Ratio Toroidal Electron Plasma EXperiments (SMARTEX-C) [4] attempts to confine pure electron plasmas in a C-shaped trap with aspect ratio  $\sim 1.59$  and successfully does so for  $\sim 100$  ms. E X B drift (due to self-field) of the charge cloud in a spatially non-uniform toroidal magnetic field and in a rectangular cross-section of SMARTEX-C gets destabilized possibly due to ion/neutral driven instabilities[6]. Capacitive probe diagnostics being non-perturbative to the plasma gives valuable information about the plasma dynamics in the trap[5]. The work reported here involves analysis of the capacitive probe data and attempts to develop physics based model which explains the observed signal due to image currents. Guiding center trajectory of the electron plasma, while undergoing diocotron instability, is obtained using two probe data assuming it to be a point like charge particle. This is then used to explain the observed linear to non-linear transition of the E X B dynamics.

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**CM-484**

**PIC Simulations Of Pseudospark Discharge Based Plasma Cathode Electron  
(PCE) Gun**

A.S.Jadon, N. Kumar, U.N. Pal, H. Rahaman and Ram Prakash

CSIR-Central Electronics Engineering Research Institute (CSIR-CEERI), Pilani, Rajasthan-333031

E-mail: er.arvindsinghjadon@gmail.com

**Abstract**

Pseudospark (PS) discharge based hollow cathode devices are promising source of high brightness, high intensity electron beam pulses [1-4]. In recent years, pseudospark discharge attracted significant attention from diverse fields, such as, pulsed-power switching, electron and ion beam generation, free electron masers and EUV radiation sources due to their unusual and interesting discharge properties [1-6]. The pseudospark discharge is an axially symmetric, self sustained, transient, low pressure gas discharge in a hollow cathode (HC) with a planar anode configuration. The PS discharges are characterized by very rapid breakdown phase during which high density particle beams are generated and high energetic electron beam is formed during the hollow cathode phase of the pseudospark discharge [3-4].

In the present work, an effort has been made to analyze the temporal behavior of discharge current, applied voltage, plasma density, electric field profile in pseudospark discharge based plasma cathode electron gun (PCE-Gun) at different operating conditions using particle-in-cell (PIC) simulation code "VSim 6.2". The plasma generation process by self-ionization and triggered discharge has been examined by varying the input discharge control parameters. The analysis has been performed for the discharge current, which is controlled mainly by the applied voltage, operating gas and gas pressure. A high density and energetic electron beam with beam current ~100 A has been generated by optimizing the internal plasma parameters of the pseudospark discharge in the gun. The results of these efforts will be presented.

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# **EXOTIC PLASMA**



EP-05

## Experimental Study of Linear Dust Acoustic Waves In Inhomogeneous Dusty Plasmas

J. Pramanik<sup>1</sup>, P Patra<sup>1</sup>, P.Sen<sup>1</sup>, D.Banerjee<sup>2</sup>

<sup>1</sup>*Department of Physics, Kharagpur College, Kharagpur – 721305*

<sup>2</sup>*Institute of Plasma Research, Bhat, Gandhinagar - 382428*

E-mail : jotir\_moy@yahoo.com

### Abstract

The propagation of linear dust acoustic waves in inhomogeneous dusty plasmas consisting of electrons, ions and charged dust particles is studied experimentally by exciting them in a controlled manner with a variable frequency external source. It is shown that the amplitude of the dust acoustic waves is affected by the presence of the dust density inhomogeneity. Experimental results shows spatial growth of the density perturbation produced by the wave when the wave propagates in the directions of increasing density and a damping when the wave propagates in the direction of decreasing density. The work reported here is mainly concerned with the range where the wavelength is smaller than the characteristics length of variation of the plasma density.

Ducet et al., (1974) obtained similar results for the propagation of linear ion acoustic waves in an inhomogeneous electron-ion plasma. However, Singh and Rao reported (1997) that linear dustacoustic waves amplitude decreases (increases) with the increase (decrease) in the density of the dust particles. Therefore an appropriate theory is required which will explain our experimental observations.

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**EP-07**

**Radiative-Condensation Instability In Gravitating Strongly Coupled Dusty Plasma With Polarization Force**

R. P. Prajapati, S. Bhakta and R. K. Chhajlani<sup>1</sup>

*Department of Pure & Applied Physics, Guru Ghasidas Central University, Bilaspur-495009*

<sup>1</sup>*S. S. in Physics, Vikram University, Ujjain-456010*

E-mail : prajapati\_iter@yahoo.co.in

**Abstract**

The radiative-condensation instability (RCI) of self-gravitating strongly coupled dusty plasma (SCDP) is investigated including the effects of dust thermal velocity and polarization force on the dust grains. In particular the outer core of the dense neutron star which is supposed to be strongly coupled system. The modified generalized hydrodynamic equations and electron temperature perturbation equation with radiative effects are solved using the linear perturbation method. In classical hydrodynamic limit we obtain the modified condition of Jeans instability due to radiative cooling, polarization force and dust thermal velocity. In kinetic limit viscoelastic effects also modify the condition of Jeans instability along with these parameters. The dust thermal velocity and viscoelastic effects have stabilizing while polarization force and radiative cooling have destabilizing influence on the growth rate of the Jeans instability. The growth rate stabilizes faster in kinetic limit as compared to the hydrodynamic limit. The radiative effects stabilize the growth rate of unstable radiative modes. In isobaric mode (short wavelength), the basic condition of radiative instability is obtained which is unaffected due to the presence of polarization force and viscoelastic effects.

**EP-36**

**Dust Kinetic Alfven Solitary Waves In A Superthermal Dusty Plasma**

Manpreet Singh and N. S. Saini

*Department of Physics, Guru Nanak Dev University, Amritsar 143005*

E-mail : singhmanpreet185@gmail.com

**Abstract**

Most of the space and astrophysical environments confirm the presence of various kinds of non-linear waves, viz. ion acoustic solitary waves, magnetosonic waves, kinetic Alfven waves etc. Kinetic Alfven waves (KAW) play an important role in transporting and dissipating energy in the space and heliospheric plasma environments. KAWs are dispersive in nature with electrostatic field parallel to external magnetic field. Solitary kinetic Alfven waves are formed with nonlinearity and dispersive effects. Dust is an ubiquitous component of space and astrophysical environments. The presence of dust in a plasma leads to modification of solitary waves and introduces new modes

(dust- ion acoustic mode, dust acoustic mode, dust lower hybrid modes, etc.). We have investigated the small but finite amplitude dust kinetic Alfvén solitary waves in a dusty plasma consisting of charged dust fluid, electrons and ions featuring kappa distribution. The reductive perturbation method is used to derive the well known KdV equation. From the solitonic solution, it is observed that positive potential dust kinetic Alfvén solitary waves are formed. It has been shown that propagation properties of these waves are significantly modified by the obliqueness, the concentration of dust and superthermality of electrons as well as ions. The findings of the present investigation may be helpful in understanding the formation of coherent solitonic structures in the space and astrophysical dust plasma systems (the planetary rings and cometary tails).

## EP-37

### **Dromions In Magnetized Dusty Plasma With Superthermal Electrons And Ions**

Yashika Ghai, Ripin Kohli, N. S. Saini

*Department of Physics, Guru Nanak Dev University, Amritsar 143005*

E-mail: yashu.gh92@gmail.com

#### **Abstract**

Dromions are exact nonlinear solutions of a large class of 2-D partial differential equations known as Davey–Stewartson (DS) Equations. Dromions may be considered as an extension of the soliton solutions to the 2-D space having stable localized structures with exponential decay in both dimensions and are characterized by time-dependent boundary conditions. Dusty Plasmas are low temperature fully or partially ionized electrically conducting gases whose constituents are electrons, ions, charged dust grains and neutral atoms and are ubiquitous in our cosmic environment. The presence of dust increases the complexity of plasma. Most of the space and astrophysical plasma environments show the existence of dust and superthermal particles (electrons/ions), i.e., the particles obeying kappa distribution. The reductive perturbation technique is employed to derive Davey–Stewartson equations in dusty plasma consisting of inertialess kappa distributed electrons/ ions and extremely massive negatively charged dust fluid in the presence of magnetic field. Dromion solutions to these equations are derived using Hirota bilinear method. Further, we have studied the existence domain for dromions, as well as the influence of strength magnetic field, temperature of electrons and superthermality of electrons as well as ions on the characteristics of dust acoustic solitary waves (DASWs). The results of this investigation would be useful in understanding the solitary structures in polar cap boundary layer (PCBL) region.



## EP-43

### Coupling Of Drift Wave With Dust Acoustic Wave

Atul Kumar and Amita Das

*Institute for Plasma Research, Bhat, Gandhinagar, Gujarat -382428*

E-mail: atul.kumar@ipr.res.in

#### Abstract

Drift wave occurs universally in magnetized plasmas producing the dominant mechanism for the transport of particles, energy and momentum across the magnetic field lines. It is a local wave, which propagates in the direction of diamagnetic drift velocity [1] in an inhomogeneous region of plasma. Dusty plasma contains micron- or submicron- sized charged dust particles in addition to electron ion plasma. In a magnetized plasma, there can be many collective modes but the lowest frequency modes i.e.  $\omega \ll \omega_{ci}$  (strong magnetic field approximation) dominate the transport. Now these low frequency modes may couple with the low frequency dust acoustic waves linearly or nonlinearly under some assumptions. We investigate low frequency mode characteristics due to the coupling of dust acoustic waves and drift waves in strongly coupled dusty plasma using the *Generalized Hydrodynamic (GH) model* [2]. The GH model is a fluid model, which reflects the strong coupling effects in dusty plasma.

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## EP-62

### Experimental Characterization Of Complex Plasma In DPEx

Surabhi Jaiswal, P. Bandyopadhyay and A. Sen

*Institute for Plasma Research, Bhat, Gandhinagar, Gujarat,*

E-mail: surabhi@ipr.res.in

#### Abstract

We present a detailed characterization of the behaviour of a complex (dusty) plasma [1,2] created in our Dusty Plasma Experimental (DPEx) chamber. The experiments are performed in a U-shaped glass tube and the plasma is formed by applying a DC voltage between a disk type anode and a grounded cathode in the background of argon gas. The plasma parameters are measured along the axis of the chamber by using three different kinds of electrostatic probes over a wide range of discharge parameters. The variations of plasma density, floating potential, plasma potential and electron

temperature measured with a single Langmuir probe do not show observable changes along the axis of the chamber for a particular discharge parameter. The results from Langmuir probe are also compared with the emissive and double probe data.

Complex plasma is created by introducing micron sized dust particles inside the plasma which are found to form a long dust cloud near the sheath region due to a balance between the electric and gravitational forces. The complex plasma is characterized by tracking individual particles through video imaging and analysing the data using the IDL based SPIT code [3]. The basic complex plasma parameters such as pair-correlation function ( $g(r)$ ), inter-particle distance ( $d$ ), dust density ( $n_d$ ) and the dust temperature ( $T_d$ ) are estimated experimentally over a wide range of plasma and discharge parameters.

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## EP-88

### Stabilization Of Rayleigh-Taylor Instability In A Non-Newtonian Incompressible Complex Plasma

S. Garai, D. Banerjee, M. S. Janaki and N. Chakrabarti

*Saha Institute of Nuclear Physics, 1/AF Bidhannagar, Kolkata - 700 064*

E-mail : [sudip.garai@saha.ac.in](mailto:sudip.garai@saha.ac.in)

#### Abstract

In a dusty plasma, gravity plays an important role in the dust dynamics due to the heavy mass of the dust particles compared to the electron and ion mass. The Rayleigh Taylor instability (RTI) [1] in a multi species neutral fluid with opposing direction of density gradient (i.e. heavy fluid is supported by the lighter one) and gravity is a classic example of gravity induced instability. Similarly inverse stratification of dust particles/ mass density influenced by the gravity leads to RT like instability in a dusty plasma which has been a research interest for understanding various astrophysical phenomena [2, 3]. Although velocity shear drives the instability in most of the cases [4, 5] but the stabilization of RT instability both in magnetized and un-magnetized plasma in presence of velocity shear and curvature is a interesting issue and many linear and nonlinear theories have suggested that indeed there is a stabilizing effect [6]. In this work, we investigated the effect of velocity shear for a non Newtonian un-magnetized dusty plasma with an experimentally verified model of shear rate dependent viscosity [7]. We have found that the non-Newtonian property has also a significant role in stabilization of RTI along with velocity shear stabilization in the short wavelength regime. The conventional generalized dust fluid equations have been used in this work followed up with the standard numerical eigenvalue techniques for solving the differential eigenvalue equation in MATLAB software.

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## EP-90

### Preliminary Studies Of A Warm Dense Plasma Produced By Electrically-Exploded Conductors

Aditya Nandan Savita<sup>1</sup>, Sambaran Pahari<sup>1</sup>, Aaditya V. Majalee<sup>1</sup>, Neeraj Shiv<sup>1</sup>, Kshitish Barada<sup>2</sup>,  
Joydeep Ghosh<sup>2</sup>, Shashank Chaturvedi<sup>1</sup>

<sup>1</sup>Computational Analysis Division, Bhabha Atomic Research Centre, Visakhapatnam.

<sup>2</sup>Institute for Plasma Research, Bhat, Gandhinagar 382428.

E-mail : adityanandansavita@gmail.com

### Abstract

Warm dense plasmas are an exotic regime for study. Intermediate to metallic and plasma state, they present a disordered liquid state that cannot be described in terms of usual simplifying assumptions of perfect order (lattice like) or perfect disorder (gas like) [1]. They also do not exhibit the kind of collective behavior seen in lower-density plasmas and therefore represent “non-ideal” plasmas. Warm dense matter typically has strongly coupled ions and partially degenerate electrons [2] and therefore belongs to the strongly coupled regime. Few theories exist that can produce thermodynamic data, transport coefficients and optical properties of warm dense plasmas in a self consistent way. Further, because of the difficulty in producing these plasmas in the laboratory, theories if any, remain untested in most cases.

Experimental investigation of warm dense Al-plasma has been initiated in our laboratory. The objective is to carry out simultaneous measurements of Equation of State (EOS) data (internal energy, pressure, density) & electrical resistivity. Al-foil is taken from a solid metallic state (at normal density & temperature) to a dense plasma regime, through liquid and vapour phases using a high energy pulsed power source. The characteristic time in which we heat the material is long enough to allow the formation of homogenous plasma. The other requirement -- that the plasma volume is controlled mechanically by closed-vessel walls -- has been partially achieved; if the plasma is indeed homogenous, the density will then depend on the initial mass of the material placed in the vessel [1].

In this paper, we present the results of initial investigations towards forming warm dense plasmas, namely the study of Al-foil (13  $\mu\text{m}$ , 42 mg) exploded in air using a 2 kJ capacitive power supply in less than half a millisec. Time resolved foil current (upto  $\sim 25$  kA) and foil voltages (upto  $\sim 5$  kV) were obtained for different input energies. The particle density ( $\sim 1.17 \times 10^{24} / \text{m}^3$ ) and temperature ( $\sim 0.5$  eV) were measured using spectroscopy [3]. The investigations also included different boundary conditions. The entire process of plasma formation was visualized with a resolution of 10  $\mu\text{s}$  using a

fast video camera and correlated with other diagnostics. All of these results will be presented and preliminary comparisons with a theoretical MHD model will be made [4]. Details of the theoretical model are presented in a companion paper by Majalee *et. al.* [4].

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### EP-97

#### Instability Of A Vortex In A Strongly Coupled Dusty Plasma

Sayanee Jana<sup>1</sup>, Debabrata Banerjee<sup>2</sup> and Nikhil Chakrabarti<sup>1</sup>

<sup>1</sup>Saha Institute of Nuclear Physics, 1/AF Bidhannagar, Kolkata - 700 064

<sup>2</sup>Institute for Plasma Research, Bhat, Gandhinagar - 382 424

E-mail: sayanee.jana@saha.ac.in

#### Abstract

Dusty plasma can be often found in a strongly coupled state when the average potential energy between the dust particles exceeds the average kinetic energy per particle. The strong correlation between the dust particles induces elastic property in the fluid phase of the dusty plasma which enables the system to support transverse shear wave [1, 2]. This transverse shear wave gets nonlinearly saturated into vortex like structures which has been reported both analytically [3] and in molecular dynamics simulations [4]. In the present work, we have considered an elliptical vortex core as the long scale equilibrium state and studied its stability to short scale secondary perturbation. The free energy related to the velocity shear of the elliptical vortex flow can drive the secondary instabilities of transverse shear wave when the resonance condition between vortex rotation frequency and collision modified secondary wave frequency are satisfied. Such process can transfer energy from long scale vortex to the short scale secondary wave where the usual dissipation ultimately takes away the vortex energy.

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**EP-115**

**Phase Transition In The Dusty Medium With The Help Of Biasing A Conducting Grid With Positive Voltage**

P Sen, P Patra, J. Pramanik

*Department of Physics, Kharagpur College, Kharagpur – 721305*

E-mail : jotir\_moy@yahoo.com

**Abstract**

DC Glow discharge Argon plasma is produced in a SS make cylindrical discharge chamber. Dust particles are levitated in the plasma sheath region by balancing their gravitational forces with the electrostatic forces and they are confined above an oval shaped conducting wire. A vertical layer of self excited dust acoustic waves (DAW) propagating downwards which was seen by illuminating the layers with a sheet of laser light. A Cu make mesh of dimension 3.5 cm X 3 cm is used as grid having 15 lines per cm. The Propagation characteristics of DAW have been analyzed from the recorded video in absence and presence of grid. DC voltages are applied through the grid and their effect on DAW has been studied. It has been shown that due to increase of external dc voltage, coulomb coupling parameter also increases, resulting the bending of the layer of DAW. It clearly shows that the DAW gradually transforms into shear wave which is an indication that dusty medium transfer into solid like state from fluid state.

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**EP-130**

**Cerenkov And Cyclotron Resonant Electron Beam Interaction With Lower Hybrid Wave In Dusty Plasma**

Ved Prakash<sup>1</sup>, Ruby Gupta<sup>2</sup>, Suresh C. Sharma<sup>3</sup> and Vijayshri<sup>1</sup>

<sup>1</sup>*School of Sciences, Indira Gandhi National Open University, Maidan Garhi, New Delhi- 110 068*

<sup>2</sup>*Department of Physics, SwamiShraddhanandCollege, University of Delhi, Alipur, Delhi-110 036*

<sup>3</sup>*Department of Applied Physics, Delhi Technological University, Shahbad Daulatpur, Bawana Road, Delhi-110 042*

E-mail : vedprakashimd@gmail.com

**Abstract**

Anaxial electron beam is injected into dusty plasma at an angle to the confining magnetic field to investigate the energy transfer from the electron beam to the lower hybrid wave (LHW). A dispersion relation is derived detailing the effect of a population of charged dust grains on the growth of lower hybrid waves. Charge and mass of dust grains, external magnetic field and angle of propagation of beam significantly modify the dispersion properties of these waves and play a crucial role in their growth. It is found that the electron beam drives the waves to instability via Cerenkov and cyclotron interactions. Numerical calculations of the growth rate and unstable mode frequencies have been carried out for the laboratory LHW and dusty plasma parameters. The dependence of the amplitude of the excited wave on the beam velocity is also discussed.

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**EP-147**

**Large Amplitude Solitary Structures In Electronegative Dusty Plasma**

Ripin Kohli and N. S. Saini

*Department of Physics, Guru Nanak Dev University, Amritsar-143005*

E-mail : ripin.kohli@gmail.com

**Abstract**

Dust is an ubiquitous component of space and astrophysical environments. It has a wide range of applications in the different fields as well as in the study of astrophysical and space environments. For the last few years, the electronegative plasma has attracted a great deal of attention for the study of nonlinear solitary structures in dusty plasmas. In the present investigation, electronegative plasma consisting of ion fluid, negative dust, negative ions and electrons featuring non-Maxwellian distribution is considered. The Sagdeev method is employed to derive the energy balance equation in terms of Sagdeev potential. From the expression of Sagdeev potential, the critical value of the Mach number is determined to see the existence of solitary structures. From numerical analysis, we have analyzed the combined effects of nonthermality of electrons, dust concentration and concentration of negative ions on the amplitude and width of the large amplitude solitary structures. It is observed that both positive and negative potential ion acoustic solitary structures are formed. The result of this investigation would be useful for understanding nonlinear electrostatic structures in different kind of space and astrophysical environments which show the existence of dust grains, electrons and two types of ions.

**EP-155**

**Self-Organized Poloidal Dust Rotation In DC Glow Discharge And Its Evolution With Gas Pressure**

Manjit Kaur, Sayak Bose, P. K. Chattopadhyay, D. Sharma, J. Ghosh and Y. C. Saxena

*Institute For Plasma Research, Gandhinagar, 382428*

E-mail: manjit@ipr.res.in

**Abstract**

Stationary self-organized poloidal dust rotation in toroidal structures have been obtained experimentally [1] in parallel plate DC Glow discharge using mono-dispersed MF micro-particles in the absence of any external magnetic field. The cause for the formation of these structures has been investigated experimentally using electric probes and optical diagnostics. The presence of stationary rotation of dust particles in these structures indicates that the difference between the drag force and repelling electric force is continuously being compensated by the dust friction on neutral gas. Particle image velocimetry (PIV) analysis of the structures reveal that the angular velocity profiles of the

charged micro-particle rotation in the toroidal structures is of solid body like nature i.e., dust rotation velocity is minimum at the centre of the cloud whereas it is maximum at the edge. The dust particle velocity at the cloud edge has a vertical variation too; it increases as dust particles move towards the cathode sheath. The effect of external discharge parameters on the dust-torus has been studied. One of the very important results of these experiments is that the overall dust particle velocity in the Dust-Torus is found to increase with an increase in neutral gas pressure (which should, in fact decrease due to increased neutral friction force).

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### EP-156

## Periodic Progressive Wave And Spiky Solution For Schamel – KdV And Higher Order KdV Equations In Dusty Plasma With Non Thermal Ion And Trapped Electron

Ranjit Kumar Kalita<sup>1</sup>, Apul Narayan Dev<sup>2</sup>, Hare Krishna Deka<sup>3</sup>, Jnanjyoti Sarma<sup>4</sup>

<sup>1</sup>*Department of Mathematics, Morigaon Assam, Pin – 782105, India*

<sup>2</sup>*Department of Science and Humanities, College of Science and Technology, RUB, Bhutan.*

<sup>3</sup>*Department of Mathematics, KKHSOU, Guwahati-781006 Assam, India*

<sup>4</sup>*Department of Mathematics, R.G.Baruah College, Guwahati-781025 Assam, India.*

E-mail :kalitaranjit@yahoo.com

#### Abstract

A modified Korteweg-de Vries (mKdV) equation, Schamel –KdV and other higher order KdV equation with mixed nonlinearity has been derived by using the reductive perturbation technique to study the effect of non thermal ion and trapped electron in dusty plasma. Different nonlinear wave equations are derived for dust acoustic (DA) solitary wave in homogeneous unmagnetized collisionless plasma whose constituents are electron, positive ion, negative ion and massive charge dust particles. Using different analytical method derived compressive and rarefactive solitary wave in dusty plasma. In this observation, specially spiky and explosive modes as well as periodic progressive waves are derived by using elliptic integrals. This analytical solution of various nonlinear wave equations are numerically analyzed, where the effect of non thermal ion and trapped electron are taken into account in dusty plasma. The treatment for analytical solution is basically related to higher order nonlinear wave equations with mixed nonlinearity in dusty plasma.

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**EP-167**

**Dust Flow Field Analysis In Non-Uniform Boundary Plasma Setups**

Modhuchandra Laishram, Devendra Sharma, Predhiman K. Kaw

*Institute for Plasma Research, Bhat, Gandhinagar, India, 382428*

E-mail : modhu@ipr.res.in

**Abstract**

Negatively charged dust particles are often confined by spatial non-uniformities of the region of plasma material boundaries where an electrostatic sheath structure is present with electric field strong enough to confine the dust medium. Flow structure of a dust medium confined by such a potential cavity is analyzed in the a cylindrical plasma geometry routinely encountered in many of the linear plasma experiments.

Considering the supersonic ion flow which is essentially sheared in such a configuration, the equilibrium solutions of a hydrodynamic model for the dust flow field are obtained in the present work. Possibilities of single and multiple vortex like solutions are discussed and analyzed in the linear limit.

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**EP-198**

**Interaction Of Dust Acoustic Waves With Dust Voids**

Rinku Mishra and M.Dey

*Centre of Plasma Physics – Institute for Plasma Research, Nazirakhat, Kamrup (M), Assam*

E-mail: arra4723@gmail.com

**Abstract**

Dust void (a dust free region) in complex plasma was first experimentally detected in a rf discharge plasma by Praburam & Goree [1] and subsequently, other experiments also had detected dust voids and physical properties of such void structures were investigated using various diagnostic tools. In this work we attempt to investigate the phenomenon of interaction of Dust Acoustic Waves (DAW) with dust voids which to our knowledge has not been explored so far. In doing this we have developed the DA radiation pressure term and incorporate it in the force balance equation of a dust particle while developing the 1D analytical model using fluid theory. Solution for the analytical model is being achieved numerically by solving force balance equation and dust charging equation under specific boundary conditions.

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**EP-276**

**Influence Of Surface Tension On Two Fluids Shearing Instability**

Rahul Banerjee, S. Kanjilal

*St. Paul's Cathedral Mission College, 33/1 Raja Rammohan Roy Sarani, Kolkata, Pin-700009*

E-mail : rbanerjee.math@gmail.com

**Abstract**

When two different density fluids are divided by an interface, the interface becomes unstable with exponential growth under the action of a constant acceleration acting in the direction perpendicular to the interface from the heavier to lighter fluid or under the action of relative velocity shear of two fluids. These two types of instabilities are known as Rayleigh-Taylor and Kelvin- Helmholtz instabilities, respectively. Temporal development of the nonlinear structure of the interface consequent to Rayleigh-Taylor or Kelvin-Helmholtz instability is of much current interest both from theoretical and experimental points of view. The nonlinear structure is called a bubble if the lighter fluid penetrates across the unperturbed interface into the heavier fluid and it is called a spike if the opposite takes place. The instabilities arise in connection with a wide range of problems ranging from direct or indirect laser driven experiments in the ablation region at compression front during the process of inertial confinement fusion to mixing of plasmas in space plasma systems, such as boundary of planetary magnetosphere, solar wind and cluster of galaxies. In high energy density physics (HEDP), formation of supernova remnant or formations of astrophysical jets are also seen in these types of instabilities.

Using extended Layzer's potential flow model, we investigate the effects of surface tension on the growth of the bubble and spike in combined Rayleigh-Taylor and Kelvin-Helmholtz instability. The nonlinear asymptotic solutions are obtained analytically for the velocity and curvature of the bubble and spike tip. We find that the surface tension decreases the velocity but does not affect the curvature, provided surface tension is greater than a critical value. For a certain condition we observe that surface tension stabilized the motion. Any perturbation, whatever be its magnitude, results is stable with nonlinear oscillations. The nonlinear oscillations depend on surface tension and relative velocity shear of two fluids.

**EP-282**

**Properties of Gravitationally Equilibrated Yukawa Systems-A Molecular Dynamics Study**

Harish Charan, Rajaraman Ganesh and Ashwin Joy

*Institute for Plasma Research, Gandhinagar 382 428 Gujrat, India*

Email : charan.harish@gmail.com

**Abstract**

The dynamic and static properties of a gravitationally equilibrated Yukawa liquids have been studied. Several new findings are reported. For example it has been observed that due to introduction of gravitational field, the system gets compressed and is seen to acquire a sharp free surface depending on the values of coupling parameter, screening parameter and magnitude of gravitational force. Unlike barotropic fluids, which follow an exponential density profile under gravity, our system exhibits a spatially scale free linear dependence. Gravity is seen to lead to different diffusion coefficients in different directions. Gravity breaks the symmetry of the Yukawa system which is demonstrated in the 2D angular-radial distribution function. The Voronoi diagrams of the system shows the the system is structured like a crystal whereas diffusion calculation and Fourier transform of velocity auto-correlation function show that the system is of liquid nature. While in the absence of gravitational force system is predominantly longitudinal in nature, for non-zero values of gravity, we see that the system is predominantly solid like with the transverse peaks dominating the longitudinal one. The above said observations lead to the conclusion that for a chosen value of coupling parameter, screening parameter and magnitude of gravitational force, the system can acquire novel structure of "Anisotropic Solid-like Yukawa Liquid" [1].

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**EP-309**

**Numerical Investigation Of The Forced Kadomstev-Petviashvili (fKP) Equation In A Complex Plasma**

Madhurima Choudhury<sup>1</sup>, P. Bandyopadhyay<sup>2</sup> and Abhijit Sen<sup>2</sup>

<sup>1</sup>*St. Xavier's College, University of Calcutta, 30, Mother Teresa Sarani, Kolkata, 700016*

<sup>2</sup>*Institute for Plasma Research, Bhat, Gandhinagar, 382428*

E-mail : madhurimachoudhury811@gmail.com

**Abstract**

The study of nonlinear collective excitations in a complex plasma, such as a dusty plasma system, has attracted a great deal of attention in recent times. In particular the excitation and evolution of a soliton, a self-reinforcing solitary wave which arises from an exact balance of the nonlinear and

dispersive effects of the medium, has been of particular interest. Such nonlinear structures for dust acoustic waves have been observed in the laboratory for pulsed perturbations launched using a modulated voltage source [1]. Theoretical interpretations of these observations have been provided using solutions of one dimensional model equations such as the Korteweg-de Vries (KdV) equation. In a practical situation the effects arising from the transverse direction are often important particularly when the scale lengths in the parallel and perpendicular directions are of comparable sizes. In such a case it is more appropriate to model the excitations by the two dimensional generalization of the KdV equation, namely the Kadomstev-Petviashvili (KP) equation. In a situation where wave excitation occurs continuously due to a charged object moving through the plasma medium or alternatively the plasma flows over a stationary charged object, one needs to include a time dependent source term in the nonlinear evolution equation. A one dimensional model of such a situation has been described by a forced KdV equation and shown to yield interesting pre-cursor solitons in fluid flow experiments [2]. To study the stability of such solitons due to transverse perturbations as well as explore the existence criteria for such structures in a two dimensional geometry we are carrying out a detailed numerical investigation of the forced Kadomstev-Petviashvili (fKP) equation. An experimental investigation of solitary structures in a flowing dusty plasma is currently being planned at IPR and our theoretical findings could provide useful insights for interpreting the experimental results.

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**EP-316**

**Oblique Collision of Dust Acoustic Solitons in a Strongly Coupled Dusty Plasma**

Abhijit Boruah, Sumita K. Sharma, Heremba Bailung

*Institute of Advanced Study in Science and Technology, Paschim Boragaon, Garchuk,  
Guwahati, Assam, India, Pin-781035*

E-mail: abhijitboruah@rocketmail.com

**Abstract**

Dusty Plasma contains nanometer to micrometer sized dust particles along with electrons and ions. Dusty plasma exhibits a very low frequency wave mode called dust acoustic wave (DAW) which is analogous to ion acoustic wave in normal plasma where the dust mass provides the inertia and the tension is provided by the background electron and ion pressure[1]. Dust acoustic wave give rise to soliton as a non-linear phenomenon when the amplitude of the wave becomes larger. The dust acoustic solitons are also described by the Korteweg-de Vries (KdV) equation. The solitons have a defining characteristic that it survives a collision with other soliton. In one dimension there are two types of collision one is head-on collision and the other is overtaking collision. In two dimensions, when two incident solitons of same amplitude collide at a critical angle  $\theta$  then it yields a new soliton whose amplitude is equal to 4 times that of individual incident soliton [2, 3]. The oblique collision between two ion-acoustic solitons has been observed experimentally [4, 5]. In this paper, we present the observation of interaction between two dust acoustic solitons colliding obliquely with different angles. The experiment is performed in a glass chamber which is 100 cm in length and 15 cm in diameter [6]. Radio frequency discharged Ar plasma is produced at a working pressure of 0.1-1

Pa. Floating dust particles (gold coated silica particles of diameter  $\sim 5\mu\text{m}$ ) are confined above a graphite plate. Dust particles are illuminated by using a green laser sheet. Two dust acoustic solitons of equal amplitude are excited simultaneously by applying a short negative pulse to the exciters. The angle between the exciters are varied to observe oblique collision between the dust acoustic solitons at different incident angles. The observation shows that at a colliding angle of  $\sim 44^\circ$  the resulting amplitude of new soliton formed at the time of collision becomes  $\sim 2.8$  times of the initial amplitude.

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### EP-356

## Delayed Charging Effects On The Kelvin-Helmholtz Instability In Complex Plasma

Debabrata Banerjee

*Institute for Plasma Research, Bhat, Gandhinagar-382 428*

E-mail : debabrata.banerjee@ipr.res.in

#### Abstract

The effect of finite time delay in dust charging process on the stability of parallel dust flow with hyperbolic tangent profile is studied through eigenvalue analysis in inhomogeneous dust cloud. Dust number density, dust mass and dust charge are considered to be of exponential variation instead of steady state along with the sheath potential. Inhomogeneities in number density and mass of dust grain have the role of inertial stabilization on the growth of the Kelvin-Helmholtz instability like a stratified neutral fluid. A positive feedback is reported due to the coupling of charge gradient and ambient sheath electric field at finite charging time to enhance the instability [1,2]. Dust neutral collision is also considered keeping in mind its important role in dusty plasma experiments. The role of finite dust temperature is also reported.

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**EP-369**

**Viscosity Of The QGP Using Screened Cornell Potential**

Prasanth. J. P. and V. M. Bannur

*Department of Physics, University of Calicut, Malappuram, 673635*

E-mail : prasanthjp36@gmail.com

**Abstract**

Quantum chromodynamics (QCD) predicts that at high temperature and baryon density the hadronic state changes into a deconfined state of quarks and gluons. This deconfined state of matter, in analogy with the electromagnetic plasma where ions and electrons are dissociated, has been called Quark Gluon Plasma (QGP).

The experimental results (The Relativistic Heavy-Ion Collider (RHIC) at the Brookhaven National Laboratory and the Large Hadron Collider (LHC) at CERN) have shown that the strongly coupled QGP has been created and behaves like an almost perfect liquid. The transport properties like shear viscosity of the QGP have attracted a lot of attention and are a currently hot topic.

The present work investigates the applicability of using Mayer's Cluster expansion method to find the shear viscosity  $\eta$  of the Quark Gluon Plasma. Within the Cluster expansion method we calculate the ratio of  $\eta$  to the entropy density  $s$ , i.e.  $\eta/s$ . We derived an equation of state using Mayer's cluster expansion method which allows us to include the Screened Cornell potential between the partons in the deconfined phase. We achieve this EoS by solving second and third cluster integral and entropy density calculated using thermodynamic relations.

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**EP-375**

**Obliquely Propagating Dust Ion-acoustic Solitary Waves In Electron-Positron-Ion Plasmas**

Barjinder Kaur, and N. S. Saini,

*Department of Physics, Guru Nanak Dev University, Amritsar, 143005*

E-mail: barjinder.kaur@yahoo.in

**Abstract**

Over the last many years, there has been a great deal of interest in the study of nonlinear excitations in electron-positron-ion plasmas under different conditions. It is believed that electrons and positrons are present in various astrophysical environments and laboratory experiments. A number of observations by various satellites missions confirmed the presence of superthermal particles in most of the space and astrophysical environments. The presence of dust in plasma modifies the properties and generates new kind of low frequency modes (DIA, DA etc.) in the plasma. In the present study, the properties of propagation of nonlinear dust ion-acoustic solitary waves in magnetized electron-positron-ion plasma consisting of ion fluid, charged negative dust and superthermal electrons as well as positrons are investigated. A reductive perturbation technique is applied to derive Korteweg-de Vries (KdV) equation and its analytical solution is presented. From the solitonic solutions of KdV equation, the influence of superthermality of electrons/positrons, dust concentration ( $\delta_d$ ), angle of rotation ( $\theta$ ), direction cosines ( $l_x$  and  $l_z$ ) etc. on the amplitude and width of dust ion-acoustic solitary waves has been studied. These physical parameters significantly affect the properties of the solitary structures. It is observed that both polarity (compressive and rarefactive) dust ion-acoustic solitons are formed.

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**EP-389**

## **A Numerical Study Of Rayleigh-Taylor Instability In Strongly Coupled Dusty Plasma Medium**

Vikram Singh Dharodi, Amita Das and Sanat Kumar Tiwari

*Institute for Plasma Research , Bhat Gandhinagar, 382428*

E-mail : vikramsingh@ipr.res.in

### **Abstract**

We use Generalized Hydrodynamic fluid model for a visco -elastic medium, like a strongly coupled incompressible dusty medium in our numerical studies. A two dimensional simulation study is carried out to investigate the role of transverse shear modes ( characteristics normal mode of the visco – elastic medium) on Rayleigh-Taylor instability. In this case it is shown that the instability growth rate gets suppressed due to the transverse shear mode arising from the strong coupling effects. Interesting interplay of vorticity evolution and transverse shear waves are shown during the evolution.

**EP-462**

## **Quasi Periodic-Periodic-Chaotic Switching Behaviour In DC Magnetron Sputtering Plasma**

S. Gopikishan<sup>1</sup>, Pankaj Kumar Shaw<sup>2</sup>, I. Banerjee<sup>1</sup>, A. N. Sekar Iyengar<sup>2</sup>,  
A. K. Das, S. K. Mahapatra<sup>1</sup>

<sup>1</sup>*Department of Applied Physics, Birla Institute of Technology, Mesra, Ranchi 835215, India.*

<sup>2</sup>*Plasma Physics Division, Saha Institute of Nuclear Physics, 1/AF, Bidhannagar, Kolkata, 700064*

E-mail : gopikishans@bitmesra.ac.in

### **Abstract**

Transition of the plasma in a cylindrical DC magnetron sputtering system observed as a function of discharge voltage at constant pressure. It was found that quasi periodic to periodic then chaotic in plasma. The natures of quasi periodic, periodic and chaotic signal have been analyzed by lyapunov, phase space, wavelet, etc. This transition may be due to ion acoustic instability by field distribution associated with electron-ion interactions.



**EP-473**

**Dust Charging In Presence Of Magnetic Field In Low Pressure Hydrogen Discharge**

D. Kalita<sup>1</sup>, B. Kakati<sup>1</sup>, B.K. Saikia<sup>1</sup> and M. Bandyopadhyay<sup>2</sup>

<sup>1</sup>*Centre of Plasma Physics-IPR, Nazirakhat, Sonapur, Kamrup -782 402, Assam, India*

<sup>2</sup>*ITER-India, Institute for Plasma Research, Bhat, Gandhinagar- 382 428, India*

E-mail: deijikalita2009@gmail.com

**Abstract**

Dust formation and its charging play a crucial role in plasma processing devices and in fusion devices where magnetic fields are often used. So, a systematic study on dust charging in presence of magnetic field is very necessary to overcome the difficulties occurs due to presence of dust grains in such devices. In the present work, the effect of magnetic field on plasma parameters and dust charging are addressed in low pressure hydrogen plasma. Different researchers have confirmed that the presence of magnetic field makes the plasma anisotropic. The experiment is performed in the dusty plasma device where plasma is created by the hot cathode filament discharge technique. The plasma is confined by a full lined cusp magnetic field cage. To observe the effect of magnetic field on plasma parameters and dust charge, a permanent magnet having magnetic field strength 1.2 kG is placed inside the plasma chamber. The plasma parameters are measured axially at different distance from the magnet with the help of a cylindrical Langmuir probe. To study the effect on dust charging in presence of magnetic field, tungsten dust particles having 4 - 6 micron are used. The tungsten (W) dust particles are kept on a SS plate inside the plasma volume which is biased negatively to levitate the dust particles. The charge accumulated on the dust grain is calculated from the modified quasi-neutrality conditions for dusty plasma and also from the capacitance model. From the present experiment, a strong influence on dust charging is observed in presence of magnetic field. In low pressure unmagnetized plasma, the dust charging is highly depends on electron temperature rather than plasma density. But, recent experimental results shows that in magnetized plasma, dust charging is highly depends on ion and electron flux only.

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**EP-488**

**Effects of Strong Coupling on Dust Acoustic Waves Driven By Ion-Dust Streaming Instability**

Manish K. Shukla, K. Avinash

*Department of Physics & Astrophysics, University of Delhi, Delhi-110007, India*

E-mail : shuklamanish786@gmail.com

**Abstract**

The effect of strong coupling on the marginal stability of DAWs excited by ion –dust drift dust is studied. The ion drifts are driven by the electric field  $E_0$  which is generally present in the discharge. Strong coupling effects on marginal stability are studied using a theory based on augmented Debye Huckel approximation [1]. Marginal stability boundary is calculated in  $E_0 - P$  ( $P$  is the pressure of the neutral gas) space with strongly coupled dust grains. We show that in the presence of strong coupling, the stability boundary is substantially modified. Results from our calculations will be presented and discussed in the experimental context.

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**EP-498**

**Design Of A System To Study Charged Dust Grains In RF Plasma**

S.S. Kausik<sup>1</sup>, B.K. Saikia<sup>1</sup> and C.S. Wong<sup>2</sup>

<sup>1</sup>*Centre of Plasma Physics, Institute for Plasma Research, Nazirakhat, Sonapur-782402, Kamrup(M), Assam*

<sup>2</sup>*Plasma Technology Research Centre, Department of Physics, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia*

E-mail: kausikss@rediffmail.com

**Abstract**

The research in dusty plasma continues to draw the interest of researchers throughout the world, considering the abundance of naturally occurring as well as artificially and industrially produced dusty plasma systems. In this report, a conceptual design of an experimental system to study charged dust grains in radio frequency (RF) plasma is described. The studies are aimed not only to investigate a unique phenomenon associated with dusty plasma called plasma crystal but also to study waves in dusty plasma for providing a deeper understanding of the behavior of particulate matter in plasma.

The experiment will be carried out in a high vacuum dusty plasma experimental set up. Plasma will be produced by capacitively coupled RF discharge method. Monodisperse micron sized dust grains will be used as dust particles. RF compensated Langmuir probe and optical diagnostics will be incorporated into the experimental system. Laser will be used to illuminate the dust grains and high speed camera will be used to capture the image of dust grains, which will be analyzed for further studies.

## EP-503

### Nonlinear KdV Equation In Strongly Coupled Dusty Plasma

Sweta Gaurav, K. Avinash

*Department of Physics & Astrophysics, University of Delhi, Delhi-110007, India*

E-mail : gaurav2453@gmail.com

#### Abstract

The nonlinear propagation of low frequency longitudinal Dust Acoustic Wave in un-magnetized strongly coupled Dusty plasma medium is studied by using a theory based on augmented Debye Huckel approximation [1]. Expressions for various thermodynamic functions e.g., Internal energy, entropy, Helmholtz energy, pressure including strong coupling effects are obtained. Further using standard reductive perturbation method a nonlinear KdV equation including strong coupling effects derived and solved numerically. In the paper the numerical solutions of the modified KdV equation will be presented and discussed.

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# **INDUSTRIAL APPLICATIONS OF PLASMA**



## IP-023

### Plasma Assisted Deposition Of GaAs/Au Nanostructures

S. Roy<sup>1</sup>, O. Mangla<sup>2</sup>, and S. Annapoorni<sup>2</sup>

<sup>1</sup>*Physics Department, Kalindi College, East Patel Nagar, University of Delhi, Delhi-110008*

<sup>2</sup>*Department of Physics and Astrophysics, University of Delhi, Delhi-110007*

E-mail : savitaroy64@gmail.com

#### Abstract

Gallium Arsenide (GaAs) is a III-V semiconductor having a direct band gap of 1.425 eV in bulk. The physical properties of GaAs changes drastically in nanoscale domain. It has been observed that gold (Au) acts as catalyst in the nucleation of novel nanostructures [1]. These nanostructures have potential applications in areas such as in creating optically active nanodevices and nanoscale semiconductor based devices [2,3]. In the present work, we have used plasma generated in dense plasma focus (DPF) device, consisting of GaAs ions, for formation of GaAs nanostructures. The substrate is first plasma coated with few nanometers of Au and then GaAs is deposited onto it. The deposited nanostructures are characterized for their surface morphology, optical and electrical properties.

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## IP-105

### Surface Modification Of High Density Polyethylene And Polycarbonate By Atmospheric Pressure Cold Argon/Oxygen Plasma Jet

R. Shrestha<sup>1,2</sup>, J.P Gurung, A. K. Shrestha, D P Subedi<sup>1</sup>

<sup>1</sup>*Department of Natural Science, Kathmandu University, Dhulikhel, Nepal*

<sup>2</sup>*Department of physics, Basu College, Kalighat, Byasi, Bhaktapur, Nepal*

E-mail: rajendra\_t2002@yahoo.com

#### Abstract

In this paper, atmospheric pressure plasma jet and its application for polymer surface modification is reported. Atmospheric pressure plasma jet sustained in Argon/oxygen mixture has been used to

modify the surface properties of high density polyethylene (HDPE) and polycarbonate (PC). The surface properties of the untreated and plasma treated HDPE and PC samples were characterized by contact angle measurement with water and glycerol. The contact angles were used to determine the surface energy and its polar and dispersion component. The effect of treatment time, frequency of the applied voltage and distance of the sample from the nozzle from the wettability of the sample were studied. It was found that the water contact angle of untreated PC sample is  $89^\circ$  while it decreases to  $35^\circ$  after 5min. Moreover, it was found that, the best plasma treatment can be obtained with frequency 27 kHz and a distance of 3.5 cm between surface of samples (HDPE and PC) and plasma jet's nozzle. Our result showed that atmospheric pressure non thermal plasma can be effectively used to enhance the surface wettability and surface energy of the HDPE and PC. Argon/Oxygen plasma jet is more efficient on treatment of polymers than Argon jet.

## IP-114

### Effect of Electrode Material, Frequency and Applied Voltage on Discharge Delay Time of Dielectric Barrier Discharge

Saravanan A, Prince Alex and K.S. Suraj

*Department of Physics, Pondicherry University, Puducherry-605014, India.*

E-mail: sarvaanphysics@gmail.com

#### Abstract

In the present work the effect of electrode material, pressure, frequency and applied voltage on discharge delay time of dielectric barrier discharge (DBD) has been studied. An experimental system including IGBT based unipolar and bipolar pulsed power supply has been developed and is capable of produce controllable square wave of desired frequency in the range of 1 KHz-10 KHz. The duty cycle and voltage can be adjusted. The gate of the IGBT is controlled by the programmable PIC microcontroller which gives great level of accuracy. We presenting the response time of DBD in the full range of frequency (1.0– 10.0 KHz) and for different cathode material. The upper frequency limitation of 10 KHz is limited by the power rating of the power supply. We found that with the increase of frequency and amplitude of applied pulse the response time is reduced.

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**IP-243**

**Diagnostics Of Plasma Mode Switching In Inverted Polarity Planar Magnetron**

Samir Chauhan, Mukesh Ranjan, Subroto Mukherjee

*Institute For Plasma Research, Gandhinagar, 382428*

E-mail : samir@ipr.res.in

**Abstract**

The magnetron sputtering system is widely used in industry as well as research for thin film deposition and nanoparticle fabrication. This is very efficient device which utilize magnetic field near cathode to trap electrons. The electric and magnetic field is so aligned that they form closed EXB drift loop, which enhances local plasma density near cathode by two orders of magnitude compared to similar device without magnetic field. This makes it possible to work at lower working pressure and higher deposition (sputtering) rate. When the polarity of the electrode with magnetic field is reversed i.e. cathode is made anode its properties changes all together. Reverse (Inverted) polarity DC planar magnetron is currently being studied as plasma source for various application e.g. etching, cathode plasma polymerization, in-house ion source etc. M. Ranjan et. al.[1] reported such experiment which was later used by A.T.Hindmarch et. al.[2] for application in micro fabrication. J.G.Zhao and H.K.Yasuda [3,4] reported similar device for cathode polymerization. Nevertheless it is no more simple and stable device that it used to be, it has different discharge characteristic in different pressure regime in contrast to normal magnetron. We observed two different mode of operation depending on background pressure and report here the measurement of density and electron temperature in such different modes. We also report observation of fire rod structure and typical anode double layer oscillation in discharge current and floating potential. This instability may have role in mode switching which occur with hysteresis in current voltage characteristics of this type of discharge.

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## IP-295

### Structuring Of NCD (Nano Crystalline Diamond) Using DC Plasma Source

Infant Solomon Vinoth. S, Bornali Sarma and Arun Sarma

VIT University, Chennai, Vandalur-Kelambakkam Road, Chennai-600 127, Tamil Nadu, India.

E-mail : infantsolomon.vinoth2013@vit.ac.in

#### Abstract

Diamond Like Carbon (DLC) has a significant fraction of  $sp^3$  bonds, because of which DLC has high mechanical hardness, chemical inertness, optical transparency etc [1-4]. Diamond Like Carbon (DLC) are produced on a glass substrate using DC plasma enhanced system in presence of Ar-CH<sub>4</sub> gas in an optimized experimental condition. The role of Argon gas is to reduce the Hydrogen doping on the DLC, which will lead to the reduction in the hardness of the film. The Ar-CH<sub>4</sub> ratio have been varied using mass flow controller to optimize the deposition condition and to support the supplement of  $sp^3$  bonding in carbon. The compositional (EDAX), morphological (SEM), mechanical (Hardness) and optical characterizations (Raman and FTIR) have been done to understand the film properties.

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## IP-300

### Surface Plasmon Resonance Of Copper Nanostructures Fabricated Using Hot, Dense And Extremely Non-Equilibrium Plasma

B.D. Naorem<sup>1</sup>, S. Roy<sup>2</sup> and M.P. Srivastava<sup>3</sup>

<sup>1</sup>Physics Department, Miranda House, University of Delhi, Delhi 110007

<sup>2</sup>Physics Department, Kalindi College, University of Delhi, Delhi 110008

<sup>3</sup>Department of Physics and Astrophysics, University of Delhi, Delhi 110007

E-mail: bilasini@gmail.com

#### Abstract

Nanostructures of metals such as gold, silver and copper are of great interest due to the tunability in electronic and optical properties with size of the nanostructures and are known to exhibit surface

plasmon resonance (SPR) in visible region [1]. We present fabrication of copper nanostructures on glass and silicon substrates using copper ions generated with one and three shots of hot and dense argon plasma. Atomic force microscopy (AFM) images show nanodots and nanorods which are in conformity with those observed in scanning electron microscopy (SEM). On increasing the number of shots the mean size of nanodots on glass increases. However, no such trend is observed for nanodots on silicon substrate. The surface plasmonic properties of nanostructures were studied using UV visible spectroscopy. Copper nanostructures exhibit SPR peak which red shifts with decrease in the number of shots.

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### IP-301

#### **Preparation And Characterization Of HMDSO Coatings On The Surface Of PP Films Using DC Excited Glow Discharge Plasma Enhanced Chemical Vapor Deposition**

A.Arun Kumar and K.Navaneetha Pandiayaraj

*Surface Engineering Laboratory, Department of Physics, Sri Shakthi Institute of Engineering and Technology, L&T by pass, Chinniyam Palayam PO, Coimbatore-641062. India*

Email:dr.knpr@gmail.com

#### **Abstract**

The plasma based HMDSO coating is an fascinating area of research in the biomedical or dental field which is based with respect to their biological properties. In the present investigation, HMDSO like films are prepared on the surface of polypropylene substrate by low pressure dc excited glow discharge plasma enhanced chemical vapor deposition techniques at room temperature using hexamethyl disiloxane (HMDSO) as precursor compound. The chosen of operating parameter is one the important factor to determining the HMDSO film quality with high deposition rate and consequence of high concentration of activated species. Thus, the HMDSO films are deposited on the surface of PP films as a function of discharge power and deposition time. The surface morphology, chemical composition and hydrophilicity of the obtained films were further analyzed by scanning electron microscopy (SEM), atomic force spectroscopy (AFM), X-ray photo electron spectroscopy (XPS), fourier transform infrared spectroscopy (FTIR) and contact angle analysis.

**IP-305**

**Characterization Of Dc Plasma Spray Torch And Synthesis Of Lanthanum Zirconate For Thermal Barrier Coatings By Ball Milling Method**

S. Sivakumar, K. Praveen, and G. Shanmugavelayutham

*Plasma Processing Laboratory, Department of Physics, Bharathiar University,  
Coimbatore – 641 046*

E-mail: velu1976@yahoo.co.in

**Abstract**

The Electrothermal efficiency of the DC plasma torch was measured by using energy balance equations. The torch was operated at power levels from 4 to 40 kW in non-transferred arc mode. The plasma torch input power, flow rates of primary gas were optimized for better electrothermal efficiency. Plasma torch has various interesting features such as protective coating to prevent degradation, extremely high temperatures, low environmental impact, short processing time which makes suitable technique for synthesizing composite materials. Thermal barrier coatings (TBCs) are one of the most advanced high temperature protective coatings and being widely used in aeronautic, motor industry and heat power station for their good performance like thermal barrier and oxidation resistance. Recently yttria partially stabilized zirconia (8YSZ) is used as the commercial materials for TBCs applications. However, the major disadvantage of YSZ is the limited operation temperature about 1200 °C for the long-term applications. It is terminate us to identify new and novel materials that can work at higher temperature. Among the interesting candidates for TBCs, Lanthanum Zirconate (LZ) has been proposed as a promising TBCs material for its high melting point, more stable structure and lower thermal conductivity than YSZ. In the present work, LZ was synthesized by method of planetary ball milling. For LZ synthesis, the mixture of  $\text{La}_2\text{O}_3$  and  $\text{ZrO}_2$  powders with 1:2 mole ratios were ball milled for 24 hours. Subsequently, the structural, phase formation and morphological studies were analyzed by XRD, FESEM with EDAX.

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**IP-318**

**Study of Transient Electric Fields in Capacitively Coupled Discharges**

Sarveshwar Sharma, Sanjay K. Mishra, Predhiman K Kaw

*Institute for Plasma Research, Bhat, Gandhinagar, Gujarat-382428*

E-mail : sarvesh@ipr.res.in

**Abstract**

In radio-frequency capacitively coupled plasma (RF-CCP) discharges the analytical prediction of the existence of transient electric field regions between sheath edge and bulk plasma has been reported by Kaganovich [Phys. Rev. Lett. 89, 265006 (2002)]. In present research, semi-infinite particle-in-cell (PIC) simulation technique is used to validate the theoretical prediction for the existence of transient electric field in the linear regime. It is shown that the PIC simulation results are in good agreement with the results predicted by theoretical model in this regime. We have also confirmed that the linear theory overestimates the transient electric field as one moves from linear to weakly nonlinear regime. The consequence of applied RF current density and electron temperature on evolution of transition field and phase mixing regime has been investigated.

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**IP-394**

**Phasor Voltage Network Method For Determining Electrical Model Of 13.56MHz RF Plasma And Its Matching Network For Low Power Industrial Application**

Anand Visani, Vishal Jain, Purvi Kikani

*Institute for Plasma Research, Bhat, Gandhinagar, India*

E-mail : avisani@ipr.res.in

**Abstract**

In this report, L type matching network is devised for a low power industrial RF plasma application. A voltage network technique is adopted for defining the source impedance using a standard 50 Ohm RF load and then the electrical model of RF plasma load is determined using the same source impedance parameter in the network under unmatched condition. The two impedance parameters are then matched by identifying suitable series inductor and parallel capacitor in such a way that the source impedance with matching network becomes exactly complex conjugate of load impedance.

It was observed that after fine tuning of capacitor value on actual load condition, maximum power from the power source was transferred to the load with minimum reflection. This matching is done in open loop control manner and hence, if the operating condition like gas flow or pressure is varied, a fine tuning in matching would be required. The plasma is a dynamic load and calculation of electrical model a particular operating condition just gives a close approximation to the actual value and hence, a fine tuning is required during the actual operation. With this approach, significantly increased in active power coupling up to 500W to the load was observed. The experimental results with conducting Cu and nonconductive PTFE target with successful matching of 600Watt 13.56 MHz RF power with plasma load discussed here. Experiments at the different power level for 30 minutes duration was conducted to verify the coating film quality and its thickness. It was observed that at 0.08 mbar pressure with 3 inch magnetron at 80W, 120W, 220W RF power treatment generates coating thickness of 0.11 micron, 0.3 micron and 0.44 micron respectively. The coating thickness was measured by surface profile meter (Nano Map 500ES, aep Technologies) and film characterization was performed using FTIR-ATR measurements.

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## IP-408

### Surface Modification Of Polystyrene Petri Dish To Enhance Cell Adhesion By Atmospheric Pressure Argon Plasma Jet [APAPJ] Treatment

J.P. Gurung<sup>1</sup>, R. Shrestha<sup>2</sup>, S. Adhikari<sup>1</sup>, D.P. Subedi<sup>2</sup>, B.G. Shrestha<sup>1\*</sup>

<sup>1</sup>Animal Cell Culture Laboratory, Department of Biotechnology, Kathmandu University, P.O. Box-6250, Dhulikhel, Nepal

<sup>2</sup>Plasma Physics Laboratory, Department of Natural Science, Kathmandu University, P.O. Box-6250, Dhulikhel, Nepal

Email: gurungjyotiprakash@gmail.com

#### Abstract

Polystyrene is widely used as a substrate for monolayer growth in animal cell culture. As manufactured, polystyrene are hydrophobic in nature and is treated with corona discharge,  $\gamma$  - radiation or chemicals to produce charged and wettable surface. High wettability and charged surface enhances the adhesion and spreading of cells in substrate [1]. Atmospheric pressure plasma discharge is also used to treat polystyrene substrate that reduces contact angle and enhances cell adhesion by surface modification [2].

In this paper, we employed APAPJ to functionalize hydrophobic, bactericidal grade polystyrene Petri dishes. We observed that APAPJ treatment for 60-240 s at a distance of ~ 3.5 cm, operated at a voltage of 7 kV, frequency of 27 kHz and gas flow rate of 2 l/min exhibited enhancement in adhesion of normal mouse fibroblast cell-line (3T3) and breast cancer cell-line (MDA-MB-231). We investigated on cell attachment qualitatively by Crystal Violet (CV) staining and quantitatively by taking absorbance at 540 nm. We also demonstrated the reduction in contact angle and increase in surface energy of polystyrene samples, aiding in cell adhesion. In conclusion, APAPJ could be a promising tool for surface modification of polystyrene plates, important for animal cell culture.

**Keyword:** APAPJ, Polystyrene, CV, Contact angle, 3T3, MDA-MB-231

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## IP-417

### Investigation Of The Current –Voltage Characteristics Of A DC Non-Transferred Arc Plasma Torch Using Heat Balance Measurements

Yugesh.V<sup>1</sup>, Gavvisidayyah Hiremath<sup>1</sup>, G. Ravi<sup>2</sup>, K. Ramachandran<sup>3</sup>

<sup>1</sup>Karunya University, Coimbatore, Tamil Nadu 641114

<sup>2</sup>Institute for Plasma Research, Gandhinagar, Gujarat 382025

<sup>3</sup>Bharathiar University, Coimbatore, Tamil Nadu 641046

E-mail: yugeshv@gmail.com

## Abstract

Non- transferred arc plasma torches have received considerable attention due to their many applications. However, irrespective of the class/configuration of torch, there exists a unique relation between current and voltage and, as a consequence, between the voltage/electro-thermal efficiency and experimentally controllable parameters. A low power (~ 25 kW) dc non-transferred plasma torch with wall, gas and magnetic stabilization mechanisms incorporated into it, has been used in our experiments. Plasma power and electro-thermal efficiency were measured using calorimetric techniques. The torch, with nitrogen as working gas at atmospheric pressure, was operated over a wide regime of gas flows (10 - 50 lpm) and current (70 – 180 A). It is shown that while current and voltage characteristics follow a Nottingham type relation, the relationship between controllable and uncontrollable parameters is much more complex.

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IP-447

## Ballistic Deposition Model For Structure And Morphology Of Vapor Deposited Thin Films

N. Vijay<sup>1</sup>, P.N. Maya<sup>2</sup>, and S.P. Deshpande<sup>2</sup>

<sup>1</sup>*IIUCNN, Mahatma Gandhi University, Priyadarsini Hills, Kottayam, 686560*

<sup>2</sup>*ITER-India, Institute for Plasma Research, Gandhinagar, 382016*

E-mail : nimithash88@gmail.com

### Abstract

Surface modifications and coatings have various industrial applications. They are generally used as protective coatings, corrosion resistance coating, barrier coating, functional coating etc. Plasma assisted physical vapor deposition is widely used for the fabrication of uniform surface coatings of hard composite materials especially on structures having complex shapes [1]. The deposited films often show large porosity with complex columnar morphology and rough surfaces under different deposition conditions. The micro-structure of such films is an interesting yet challenging problem and various models have been proposed to understand their growth and structure [2]. One of the simplest yet powerful model to capture the essence of the morphology of the films is ballistic deposition model where, the particles from the vapor phase fall on random bins and stick upon the first contact [3,4].

In this work we report on the structure and porosity developed in ballistic deposition of particles using a 3-D ballistic deposition model. We study the structure and porosity of the deposits for (a) different angle of incidence of the particles and (b) different densities of initial nucleation sites. We found that the saturated roughness and the net porosity of the film critically depends on the angle of incidence of the particle. With the angle the saturated roughness increases and this can be explained in terms of the inefficiency in the build up of lateral correlations between the neighboring sites which is arising due to the shadowing. Once the growth reaches a steady-state, the initial density of the nucleation sites have little role in deciding the further structure build up of the film. In order to examine the effect of various sticking rules in the film structure, we have simulated structures with (a) sticking only on the phases of the bin, (b) sticking only on the diagonal bins and (c) sticking on both phases and diagonal bins. This shows that, the net porosity is maximum when the sticking is allowed both on the phases and the diagonal bins.

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**IP-459**

**Study On Plasma Spraying And Oxidation Behaviour Of Ball Milled Zirconia/Alumina And Zirconia/Titania Composite Powders**

K. Praveen, S. Sivakumar, G. Shanmugavelayutham

Plasma Processing Laboratory, Department of Physics,  
Bharathiar University, Coimbatore- 641046.

**Abstract**

Plasma sprayed coatings were used in gas turbines to protect from high temperature oxidation, wear and corrosion. Several materials were proposed, among them zirconate based coatings shows better resistance. Hence, the present study focuses the synthesis of Zirconia-Alumina and Zirconia-Titania composite, plasma spray deposition and oxidation of coatings. Bi-layered coating were prepared with Alumina as an intermediate. The oxidation behavior of coatings were performed at 600<sup>o</sup>C for 30 hours. The oxidation behaviour of the two composite coatings were compared and characterization study on before and after oxidation of the coatings were analysed by XRD and FESEM equipped with EDX.

**Keywords:** Plasma spray, Oxidation, Zirconates, Composites.

**IP-477**

**Plasma Spray Deposition And Characterization Of YSZ-SrZrO<sub>3</sub>**

M.C.Ramkumar<sup>1</sup>, P.V.Ananthapadmanabhan<sup>2\*</sup>, Y.Chakravarthy<sup>2</sup>, VandanaChathurvedi<sup>2</sup>,  
A.Pragatheeswaran<sup>3</sup> and K.Navaneetha Pandiyaraj<sup>1</sup>.

<sup>1</sup>*Surface Engineering Laboratory, Department of Physics, Sri Shakthi Institute of Engineering and Technology, L & T by pass, Chinniyampalyam (post), Coimbatore, Tamil Nadu-641062.*

<sup>2</sup>*Laser and Plasma Technology Division, Bhaba Atomic Research Centre, Mumbai-400085.*

<sup>3</sup>*Department of Physics, Karunya University, Coimbatore, Tamil Nadu-641114.*

E-mail: pvananth@barc.gov.in

**Abstract**

Atmospheric plasma spray (APS) deposition is extensively used for preparing metallic and nonmetallic coatings. Plasma spray technology utilizes the high temperature and high enthalpy of the thermal plasma medium to melt the injected powder and propel the molten particles towards the substrate [1]. Thick coating with controlled porous microstructure can be achieved by APS method and porous microstructure will help to reduce the thermal conductivity and protect the components from high temperature. Ytria stabilized zirconia (YSZ) powder is the most widely used material for the thermal barrier coatings to improve performance and to extend life of components exposed to high temperatures. Due to low its thermal conductivity, high melting point and phase stability, YSZ is



used for TBC applications. However, at temperatures above 1200 °C, volume changes due to sintering and phase changes in YSZ leads to formation of cracks in coating layers leading to coating failure. Recently Perovskite type SrZrO<sub>3</sub> has been shown to be a potential TBC material to overcome these disadvantages of YSZ [2]. SrZrO<sub>3</sub> has low thermal conductivity value similar to that of YSZ. Further, it has low sinterability and high thermal expansion compared to YSZ, SrZrO<sub>3</sub> is considered as a potential material for thermal barrier coating applications. This paper presents investigations on plasma spray deposition of YSZ - SrZrO<sub>3</sub> composite powder and characterization of the coatings. SrZrO<sub>3</sub> and YSZ powder in the ratio of 50:50 by weight were prepared and the composite powder was plasma spray deposited on stainless steel substrates. Thermal cycling tests were performed on the samples and compared with plasma sprayed coatings of YSZ and SrZrO<sub>3</sub>. The phase analysis of plasma spray deposited samples has been analyzed by XRD. The XRD result show the coatings deposited at different power levels are found to consist of YSZ and SrZrO<sub>3</sub>.

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## IP-486

### Plasma Selective Etching of Composite Surfaces for Improved Tracking Resistance Properties

Harinarayanan Puliyalil<sup>1</sup>, Gregor Filipič<sup>1</sup>, Uroš Cvelbar<sup>1, 2</sup>

<sup>1</sup>*Jozef Stefan International Postgraduate School, Jamova cesta 39, Ljubljana 1000, Slovenia, EU*

<sup>2</sup>*Jožef Stefan Institute, Jamova cesta 39, Ljubljana 1000, Slovenia, EU*

E-mail : Hari.Puliyalil@ijs.si

#### Abstract

Carbonization of the surface at high voltage arcing (surface tracking) is a major problem for insulating materials. The extend of this surface damage is measured in terms of comparative tracking index (CTI), which is the standard test used to determine the performance level of insulating materials [1]. Typical methods to improve CTI includes compositing and blending with various flame retardant fillers [2]. Since surface tracking is a phenomenon occurring only on the surface, CTI performance could be improved by changing the surface characteristics of the material. Surface modification of composite materials is achieved in both laboratory and industrial scale by means of plasma selective etching for various applications including adhesion, studying the particle distribution in composite coating, etc. [3]. In this work, we studied the effect of cold plasma selective etching on the CTI performances for glass filled polyphenol composites. With a cumulative treatment time of 60 seconds, the surface polymer was completely removed keeping the glass fibers and glass beads intact. After the surface modification the tracking voltage was increased up to 60%. To have a detailed understanding on the etching rate with various gases, the experiments were repeated with O<sub>2</sub>+Ar, N<sub>2</sub> and NH<sub>3</sub>. During the treatment, plasma was monitored by means of optical emission spectroscopy (OES) where the intensity of species including CN, CO, etc. gave an indication of the etching rate and etching mechanisms. The surface energy which increased with the increase in

treatment time, was calculated by Young–Dupré equation. The chemical and morphological changes were studied by Scanning electron microscopy (SEM), X-ray photoelectron microscopy (XPS) and Energy dispersive X-ray spectroscopy (EDXS).

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**IP-501**

**Electric Field Simulations Of Biased Dielectric-Covered Electrodes**

Anand Kumar Srivastava and Ravindra Kumar

*Birla Institute of Technology, Mesra, Jaipur Campus, 27-MIA, Jaipur (Raj.)-302017*

E-mail : anand\_ipr@yahoo.co.in

**Abstract**

Dielectric Barrier Discharges (DBD) are the most trusted sources to produce uniform non-thermal plasma at atmospheric pressure. Such sources are proposed for various industrial applications such as material treatment, display devices, water/air purification, pollution control, bio-medicine, aerodynamic drag reduction etc. The efficiency of the DBD plasma source is largely dependent on the selection of suitable electrode shape, dielectric material, power supply etc. The first check before designing the plasma system is to quantify the vacuum electric field between plasma forming electrodes.

Using E-STAT simulator, we have simulated various shapes of dielectric-covered electrodes that are suitable for plasma-based industrial applications. Under biased conditions, we have obtained the values of local electric field/potential and their spatial variations before the plasma formation process. A Comparison of field analysis for various DBD electrodes has been presented. Such information might be very useful for designing a DBD plasma system.

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**IP-506**

**Electrical And Optical Characterization Of Commercial Hg-Based UV-Lamp And Its Comparison With Environment Friendly DBD-Based UV-Lamp**

Aditya Sinha, U N Pal, Mahesh Kumar and Ram Prakash

<sup>1</sup>*CSIR-Central Electronics Engineering Research Institute (CSIR-CEERI), Pilani,  
Rajasthan-333031*

E-mail: adi.sin.89@gmail.com

**Abstract**

The sterilization effects of UV radiation are well known, and low-pressure mercury vapor lamps are commonly used for water purification at the industrial level. The UV radiation causes germicide as a result of photochemical damage of DNA and RNA that prevent reproduction of the organism. At present the mercury lamp based systems uses UV light radiation at peak germicidal wavelength (254nm) for water purification. However, the mercury lamps sometime lead to catastrophic explosion and the toxic mercury mixing with the water causes serious health problems. Moreover, mercury based light sources including fluorescent lamps dominate the market of lamps and about 1.2 billion lamps are fabricated each year world-wide. These light sources, as do several other commercially important types, contain some amount of mercury. As a consequence, at the end of the lamp life-time a considerable amount of “undesirable” waste is generated. It is well-known that mercury is a highly toxic material and it must be prohibited as a light dosant material on environmental grounds. In this paper an effort has been made to study the electrical and optical properties of a commercially available low-pressure Hg-based UV-lamp [1] and a novel environment friendly dielectric barrier discharge (DBD) based UV-lamp [2-4]. The results are compiled for comparison of the electrical and optical properties of both the lamps. The DBD based UV-lamp shows excimer radiations with wide wavelength range as compared to the Hg-based UV-lamp, which has sharp atomic transition, and is more effective for germicidal application of water. The results of these efforts will be presented.

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**IP-510**

**Effect of Bias Voltage on Microstructural and Mechanical Properties of  $Ti_xN$  Thin Films**

Omveer Singh<sup>1</sup>, Raj P. Dahiya<sup>1,2</sup> and Hitendra K. Malik<sup>3</sup>

<sup>1</sup>Centre for Energy Studies, Indian Institute of Technology Delhi, New Delhi – 110016

<sup>2</sup>Deenbandhu Chhotu Ram University of Science and Technology, Murthal, Haryana – 131039

<sup>3</sup>Department of Physics, Indian Institute of Technology Delhi, New Delhi – 110016

E-mail: poonia.omveer@gmail.com

**Abstract**

Titanium (Ti) and its alloys have been widely used for the quality improvement of commercial products such as aircraft, automobile components, etc. These materials exhibit poor tribological properties, enabling their application in mechanical engineering. In the present work, we have deposited Ti thin films using DC sputtering technique on Si substrate. Nitriding over these samples is carried out with the help of indigenous hot cathode arc discharge plasma system, where we can control the plasma parameters and work piece separately. A mixture of  $H_2$  and  $N_2$  gases in the ratio of 80:20, respectively, was fed into the plasma chamber. The effect of bias voltage on the crystal structure, morphology, micro-hardness and nitrogen concentration of the nitrided layer have been investigated by employing various physical techniques such as X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM) and nanoindentation testing. It has been found that bias voltage affects largely the crystal structure and hardness of the  $Ti_xN$  thin films.

**IP-515 (I)**

**Antibacterial Effects of Amine-Containing Plasma Thin Films Containing Metallic Nanoparticles**

Chih-Hao Lin and Meng-Jiy Wang

*Department of Chemical Engineering, National Taiwan University of Science and Technology  
Taipei 106, Taiwan*

E-mail : mjwang@mail.ntust.edu.tw

**Abstract**

In this study, we present an antibacterial coating which effectively inhibited the colonization of *E. coli* and *S. aureus*. In particular, the antibacterial coating was based on the plasma polymerized technology and to combine with two different of nanoparticles, silver and copper nanoparticles[1], by directly reducing metal ions within plasma polymerized thin films correspondingly.

The plasma polymerization was facilitated by heptylamine precursor to generate amine-containing

thin films which served as the matrix[2], followed by immersing the films in metal salt solutions that the reduction of metal ions was subsequently achieved by the amine functionalized complexes, which was considered as a reducing agent for the ionic properties. The ultraviolet and visible spectrum (UV) analyses results revealed that the amount of metal nanoparticles within the films associated closely to the thickness of the plasma polymerized films, the concentration of applied solutions, and the time of immobilization. Moreover, the thickness of plasma polymerized heptylamine films was modulated by adjusting the plasma parameters and could be confirmed by the measurements using ellipsometry.

Finally, the bactericidal effects of metal nanoparticles were presumably attributed to the size in nano scale and the high surface to volume ratio, which allows the close interactions with microbial membranes, beside the release of metal ions in solution. In summary, the metal nanoparticles were successfully embedded in plasma polymerized heptylamine films which provided chelating ligands between the immobilized metal ions and amine groups. The advantages of the application of plasma polymerization technology include that the method can be carried for any type of solid materials and devices, which possess great potential for applications in biomaterials and related fields.

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## IP-519 (I)

### Development of the Plasma Electron Spectroscopy Method for Gas Analysis

A. Kudryavtsev, V. Belyaev, N. Khromov, A. Saufutdinov, S. Sysoev

*St. Petersburg State University, 7-9, Universitetskaya nab., St. Petersburg, 199034, Russia*

E-mail: akud@ak2138.spb.edu

#### Abstract

A plasma electron spectroscopy method [1] of gas analysis on the registration of non-local electrons from the reaction of Penning ionization  $A + \text{He}^* \rightarrow A^+ + \text{He} + e$  of atomic or molecular impurities A by metastable helium atoms  $\text{He}^*$  is reported. The electrons released in this process gain kinetic energy  $E_e = E_m - E_i$ , where  $E_i$  is the ionization energy of an impurity atom or molecule under analysis and  $E_m = 19.8$  eV is excitation energy of metastable He atoms. Their energy is sufficient to ionize any other atom or molecule with generation of characteristic electrons having kinetic energy of several eV according to [1]. In non-local plasma [2], the different electron groups behave independently of each other (do not have time “to mix their energy” due to collisions in the discharge volume). Therefore, energetic electrons, arising in reactions [1], do not lose their energies in the plasma volume giving rise to characteristic maxima in the EDF. Experiments in short (without positive column) micro-discharge are performed to demonstrate the practical realization of proposed method.

The discharge occurs between a plane, disk-shaped cathode and anode placed at 1-4 mm distance. A ring-shaped additional electrode (anode) located between electrodes, is used as sensor to record its voltage-current characteristics and their first and second derivatives with respect to the applied voltage.

Experiments are performed in helium and in mixtures of helium with mixtures of air, nitrogen, argon and so on. The total gas pressure ranged from 5 to 100 Torr and the discharge current varied from 0.5 to 5 mA. It is demonstrated that the obtained maxima appear at the characteristic energies corresponding exactly to the expected maxima for penning electrons of the known gas impurities used. Records of characteristic maxima of penning electrons could be utilized in principle for detection of gas impurities like poison gases, gas pollutions in the atmosphere or in the industry, etc.

Work is partially supported by RNF grant 14-19-00311 and SPbGU grant 11.38.658.2013.

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### IP-526 (I)

## Theory Of Plasma Effect On Gyrotron Amplifier

Shahrooz Saviz, Elaheh Allahyari

*Department of Physics, Science and Research branch, Islamic Azad University, Tehran, Iran.*

E-mail : elahe.allahyari@gmail.com

#### Abstract

The theory of cold plasma effects on gyrotron amplifier is investigated. In this study, the electron beam is very thin and hollow. All electrons have the same energy and momentum. Dispersion relation for a plasma gyrotron is obtained. The effect of various parameters, including the parameters of the electron beam in gyrotron, the radius of the cylinder, the electron beam radius, the plasma column radius, the plasma dielectric coefficient and momentum spread of electron beam were studied. Numerical analysis show that the growth rate and bandwidth are independent of the dielectric coefficient of plasma and plasma column radius. In Addition, for the mixed mode ( $\Delta$  less than 0.005), super-wide bandwidth amplifier obtains [1]. In comparison with the dielectric loaded gyrotron, plasma loaded is more stable rather than dielectric loaded waveguide case.

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**IP-528 (I)**

**Effect Of Various Plasma Treatments On The Dielectric Properties Of SnO<sub>2</sub> Nano Semiconductor**

Akhil Chandran M.K<sup>1</sup>, Vladimir Srdic<sup>2</sup>, Gregor Filipič<sup>3,4</sup> and Goran Stojanović<sup>1</sup>

<sup>1</sup>*Department for Microelectronic, Faculty of Technical Sciences, University of Novi Sad, Serbia*

<sup>2</sup>*Department of Materials Engineering, Faculty of Technology, University of Novi Sad, Serbia*

<sup>4</sup>*Jozef Stefan International Postgraduate School, Jamova cesta 39, SI-1000 Ljubljana, Slovenia*

<sup>5</sup>*Jozef Stefan Institute, Jamova cesta 39, SI-1000 Ljubljana, Slovenia*

E-mail : akhil@uns.ac.rs

**Abstract**

For any dielectric semi conducting nano materials, di electric properties are really important which determines various activities such as sensing, catalytic activity, adsorption, etc. These properties depend on the chemical composition and surface characteristics. Various physical and chemical properties of nano materials are able to tune by choosing various chemical treatments or novel synthetic routes. Among various metal oxide semiconductors, SnO<sub>2</sub> is extensively used for gas sensing applications. One of the advanced techniques used for improving the sensing properties of SnO<sub>2</sub> is surface plasma treatment. High energy reactive species in plasma can modify the surface by collision and chemical reaction. Impregnation of foreign atoms alters the band gap width which is very important for any semi conducting material. We used various plasma gases and plasma parameters to treat the SnO<sub>2</sub> nano powder which was synthesized chemically. The chemical and physical changes were measured by using techniques including XPS, SEM, TEM, UV-VIS spectroscopy, etc.

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## LP-022

### Particle-In-Cell Simulations of Stimulated Raman Scattering In Fusion Plasmas

Pinki Yadav, D. N. Gupta, and K. Avinash

*Department of Physics and Astrophysics, University of Delhi, Delhi 110 007, India*

E-mail: pinkiyadav864u@gmail.com

#### Abstract

Stimulated Raman process of a laser in fusion plasmas with energetic electrons has been investigated via particle-in-cell simulations. The Langmuir wave and scattered electromagnetic sideband wave grow initially, and dump after attaining a maximum level that shows a periodic exchange of energy between the pump wave and the daughter waves. The presence of drifting energetic electrons in laser produced plasma influences the stimulated Raman scattering process. The plasma wave generated by Raman scattering may be influenced due to the presence of the energetic electrons, which enhances the growth rate of the instability. Our results show that the presence of energetic (hot) electrons in the plasma is shown to have an important effect on the evolution of the interacting waves. This phenomenon is modeled via two-dimensional particle-in-cell simulations of the propagation and interaction of the laser under Raman instability.

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## LP-024

### Relativistic Electron Beam Driven Wake-Field Excitation in A Cold Plasma

Ratan Kumar Bera, Amita Das and Sudip Sengupta

*Institute for Plasma Research, Bhat, Gandhinagar-382428, Gujarat*

E-mail : rkbera@ipr.res.in

#### Abstract

Studies of charged-particle acceleration process remain one of the most important areas of research in laboratory, space and astrophysical plasmas. Excitation of nonlinear plasma oscillation by an intense, short and ultra relativistic electron beam is considered here. From analytical solution of one dimensional fluid equations it can be shown that a large amplitude accelerating gradient can be generated in the beam's wake under a certain condition of constant beam density with respect to plasma density. Fluid simulation has been performed to excite the Wakefield structure and the results are shown to compare well with the analytical calculations. A nice matching has been obtained

between wake excitation profile to the Akheizer-Polovin mode. In simulation we have found that relativistic beam driven wake excitation leads to wave breaking phenomena and follows the Akheizer-Polovin wave breaking time formulas. In simulation we have also excited the wakefield when the beam profile is self consistently evolved.

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**LP-027**

**Harmonic Radiation Generation By Propagation Of Intense Laser Pulses In Plasma Embedded In An Electric field**

Nirmal Kumar Verma and Pallavi Jha

*Department of Physics, University of Lucknow, Lucknow-226007*

E-mail : nirmal87lu@gmail.com

**Abstract**

Harmonic generation by interaction of intense laser pulses with plasma is of great current interest due to its potential for producing x-ray lasers and coherent radiation sources, ranging from ultraviolet to soft x-ray region [1]. Interaction of intense laser pulses with homogeneous plasma leads to the generation of odd harmonics of the laser frequency [2]. Even harmonics of the laser frequency can be generated by interaction of linearly polarized laser pulses with inhomogeneous plasma [3] and also in the presence of external magnetic field [4].

When an intense laser beam propagates through plasma in presence of an electric field, plasma density oscillations at the fundamental frequency arise. These density oscillations couple with the transverse quiver velocity of the plasma electrons, leading to the generation of a current density oscillating at the second harmonic of the laser frequency. The current density provides the source that drives the laser field leading to the generation of second harmonic radiation.

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**LP-028**

**Harmonic Generation By Propagation Of Obliquely Incident Laser Beam In Underdense Plasma**

Ekta Agrawal and Pallavi Jha

*Department of Physics, University of Lucknow, Lucknow-226007*

E-mail : ektaagrawal555@gmail.com

**Abstract**

Generation of harmonic radiation is an important subject of laser plasma interaction and attracts great attention due to wide range of applications. The interaction of linearly polarized, laser pulses with homogeneous plasma leads to generation of odd harmonics of laser frequency [1]. However, second harmonics have been reported when linearly polarized laser pulses propagate in plasma in presence of density gradients [2] and externally applied magnetic field [3]. Second harmonic emission by spatially asymmetric quivering electrons caused by the ponderomotive force has been experimentally observed [4].

In the present paper, an analytical study of second harmonic generation by an obliquely propagating P-polarized laser beam in homogeneous underdense plasma, in the mildly relativistic regime has been proposed. The Lorentz force and Continuity equations are perturbatively expanded to derive the current driving the wave equation governing the evolution of amplitude of the second harmonic. Efficiency of second harmonic radiation as well as its detuning length has been obtained and their variation with the angle of incidence is analyzed.

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**LP-031**

**Enhancement Of Wakefield Generated By Two-Color, Short Laser Pulses  
Propagating In Plasma**

Rohit Kumar Mishra, Akanksha Saroch and Pallavi Jha

*Department of Physics, University of Lucknow, Lucknow-226007*

E-mail : mrohitk@gmail.com

**Abstract**

The concept of laser wakefield acceleration of charged particles was first proposed by Tajima and Dawson [1]. Since then a number of innovative techniques for enhancement in the amplitude of the generated wakefields have been presented [2-4].

This study deals with the possibility of enhancement in amplitude of the generated wakefields by propagation of two color, short laser pulses through homogeneous plasma. The two color laser pulses polarized along different directions have the frequency difference equal to the plasma frequency. The net ponderomotive force driving the longitudinal wakefields arises due to two contributions. The first is the sum of the ponderomotive force due to the envelopes of the two individual laser pulses, while the second contribution arises due to the beating of the two pulses. It is seen that the former ponderomotive force is out of (in) phase with respect to the latter, when the two laser pulses are polarized in the same (opposite) directions, thereby reducing (enhancing) the net ponderomotive force. The electrostatic wakefields driven by this ponderomotive force also show the same trend of results. Also the wakefield amplitude generated by two color, oppositely polarized laser pulses is the same as that generated by a single laser pulse having intensity greater than the sum of the intensities of the constituent pulses, in a two color pulse system. Further, two-dimensional simulation studies, using VORPAL code, are conducted to verify the analytical results.

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## LP-035

### Amplitude Saturation Effects Of A Laser-Driven Plasma Beat-Wave On Electron Acceleration

Mamta Singh and D. N. Gupta

*Department of Physics and Astrophysics, University of Delhi, Delhi 110 007, India,*

E-mail: mamtaphysics21@gmail.com

#### Abstract

Alarge amplitude plasma beat-wave can be driven by two lasers differing in frequencies equal to the plasma frequency that may accelerates the plasma electrons to a higher energy level. As the plasma beat wave grows, it becomes susceptible to the oscillating two-stream instability. The decayed sideband plasma wave couples with the pump wave to diminish its energy by the instability, and saturate it. The saturation amplitude of the plasma beat-wave traps the electrons to accelerate them for higher energy gains. Our study shows that the saturation of plasma beat-wave amplitude significantly affects the electron energy gain during acceleration.

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## LP-048

### Self-Focussing And Compression Of Laser Pulses In Inhomogeneous Plasma

Hemlata and Pallavi Jha

*Department of Physics, University of Lucknow, Lucknow-226007, India*

E-mail : hemlata.7.kashyap@gmail.com

#### Abstract

Optical guiding of intense laser pulses in a plasma channel is beneficial for a variety of applications including plasma based accelerators, harmonic generation, X-ray sources and advanced laser fusion schemes. A longitudinally varying plasma density channel may be useful in overcoming electron dephasing in wakefield accelerators [1,2]. Tapering the plasma density along the axis of propagation enhances the self-focusing property of a laser beam [3].

The present study deals with the propagation of short, intense, linearly polarized laser pulses in a tapered plasma channel . The plasma is assumed to be cold and underdense. The wave equation describing the evolution of the laser field amplitude driven by relativistic nonlinearity has been set up. A variational technique is used to obtain the equations describing the simultaneous evolution of

the laser spot-size and pulse length in a tapered plasma channel. Numerical methods are used to study the simultaneous focussing and compression of the laser spot-size and pulse length respectively.

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## LP-057

### Thermal Effects In Plasma Beat Wave Acceleration : Simulation Study

Maninder Kaur and Devki Nandan Gupta

*Department of Physics & Astrophysics, University of Delhi, New Delhi-110007*

E-mail : maninder.panesar@gmail.com

#### Abstract

Thermal effects in plasma beat wave acceleration (PBWA) via particle-in-cell (PIC) simulation have been investigated. In PBWA, two lasers, having frequency difference equal to the plasma frequency, excite a large-amplitude, high phase-velocity plasma beat wave resonantly by the ponderomotive force, obeying the energy and momentum conservation. The large amplitude plasma wave can trap the electrons and accelerate them to high energy. The finite plasma electron temperature can modify the structure of the wakefield. The electrons may have sufficiently high momentum for a thermal plasma electron distribution. This results in large fraction of trapped electrons as the plasma wave amplitude increases. Thermal velocity of electrons moving in the direction of wave can lead to enhanced particle trapping and lower the threshold for wave breaking, which ultimately affects the particle acceleration as well as the electron beam properties. In our simulations, we have studied the effect of temperature on energy gain of accelerated electrons. It has been observed that increase in plasma electron temperature leads to large momentum spread and enhance the amount of self-trapped electrons, which will affect the quality of electron bunch.

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**LP-085**

**3D-FDTD Model For The analysis of Laser Induced Plasmonics In Nanoparticles**

Sijoy C.D., G. Singh and S. Chaturvedi

*Computational Analysis Division, Bhabha Atomic Research Centre (BARC), Visakhapatnam*

E-mail : sijoy@barc.gov.in

**Abstract**

A unique optical property of metallic nanoparticles (NPs) is the strong plasmonic resonances excited via collective oscillations of the conductive electrons driven by external electromagnetic fields in the visible and near-infrared electromagnetic (EM) spectrum [1]. This has widespread applications in targeted thermal therapy, nonlinear microscopy, laser induced structural modifications of NPs, enhanced laser absorptions, optical nano-antenna and waveguides etc. The interaction of a short laser pulse with nanoparticles depends on the size, separation and orientation of the particles. In order to predict the absorption properties of NPs, it is necessary to solve Maxwell's equations considering the effect of free charges in metallic NPs. Analytical models [2] exist for simple NP structures (spherical, elliptical and rod-shaped NPs). However, for complicated NP distributions and for the mixture of different types of NPs embedded in dielectric media, a more advanced computational scheme such as the Finite-Difference Time-Domain (FDTD) method for electro-magnetics is required [3]. In this scheme, the complex permittivity of the NP is modeled by using a Lorentz-Drude or Drude model with single or multiple poles. In this paper, we describe the details of a general FDTD scheme using polarization current density for modeling short laser pulses with NPs. The polarization current density is updated using an auxiliary differential equation (ADE) scheme [3,4] which is self-consistently coupled with a 3D parallel FDTD Maxwell's solver. We also report the results of the validation tests conducted, parallel performance of the code and the preliminary results of laser interaction with NPs.

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**LP-099**

**Effect Of Laser Energy On Nanoparticles Produced By Laser Ablation Of Copper In Distilled Water**

Prahlad K. Baruah, Kh. Shantakumar Singh, Ashwini K. Sharma and Alike Khare  
*Laser and Photonics Lab, Department of Physics, Indian Institute of Technology Guwahati,  
Guwahati-781039*

E-mail: alika@iitg.ernet.in

**Abstract**

Laser ablation of a solid target immersed in liquid is a simple and effective method for the preparation of nanoparticles in colloidal form. Focusing of a high power laser onto the target results in ablation of the material and then plasma formation takes place. The surrounding liquid confines the plasma and as a result the plasma achieves a state of high temperature, high pressure and high density regime. These extreme conditions favor the formation of nanoparticles. In the present work, the 2<sup>nd</sup> harmonic of a high power Q-switched Nd:YAG laser was focused onto a copper target of high purity immersed in distilled water. The laser energy was varied while the ablation time was fixed at 15 minutes. The formation of nanoparticles was noted with change in colour of the prepared colloids. The UV-visible absorption spectra show absorption in the ultraviolet region due to interband transition and in the visible region due to surface plasmon resonance (SPR) oscillations in copper nanoparticles. Both the peaks were observed to be blue shifted with the increase in laser energy. The variation of size of the nanoparticles characterized using Transmission electron microscope will also be discussed in the conference.

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**LP-104**

**Propagation Of Cosh Gaussian Laser Beam In Relativistic-Ponderomotive Plasma Using Density Ramp**

Munish Aggarwal<sup>1</sup>, Harish Kumar, Richa Aggarwal

<sup>1</sup>*Department of Applied Science, Lyallpur Khalsa College of Engineering, Jalandhar – 144001*  
E-mail: sonuphy333@gmail.com

**Abstract**

Self-focusing of Cosh-Gaussian laser beam in plasma with upward increasing density ramp has been investigated. The slowly increasing plasma density ramp profile  $n(\xi) = n_o + n_o \tan(\xi/d)$  is taken

similar to Sadighi-Bonabi *et al.* [1]. Such density profile is quite useful in decreasing the beam width parameter which leads to strong self-focusing. The beam width parameter decreases in the presence of ramp and thereby strong focusing of laser beam is observed at optimized intensity. Self-focusing is reported on account of combined role of plasma density ramp and relativistic ponderomotive self-focusing (**RPSF**). The comparison has been reported both in the presence of ramp and density ripple

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### LP-123

#### Beat Wave Excitation of Electron Plasma Wave by Cross Focusing of Intense Cosh-Gaussian Laser Beams In Plasma

Naveen Gupta and Arvinder Singh

*National Institute of Technology, Jalandhar*

Email: naveens222@rediffmail.com

#### Abstract

This paper presents theoretical investigation of the effect of cross focusing of two coaxial Cosh-Gaussian (ChG) laser beams on plasma wave excitation process in an under dense plasma. The plasma wave is generated on account of beating of two coaxial laser beams of frequencies  $\omega_1$  and  $\omega_2$ . The mechanism for laser produced nonlinearity is assumed to be a ponderomotive force, and following W.K.B approximation and moment theory the differential equations governing the evolution of spot size of laser beams with distance of propagation have been derived. The ponderomotive nonlinearity depend not only on the intensity of first laser beam but also on that of second laser beam. Therefore, the behavior of first laser beam affect that of second laser beam and hence cross focusing of the two laser beams takes place. By changing the decentered parameter, the peak intensity of laser beams can be shifted in the transverse direction and a noticeable change is observed on the cross focusing of the two laser beams as well as on the power of generated plasma wave. The results are presented in the form of graphs for typical set of laser and plasma parameters.

LP-128

**Effect Of Focusing Conditions On RF Emissions From Laser Induced Breakdown Of Air**

L. Vinoth Kumar, E. Manikanta, Ch. Leela and P. Prem Kiran

*Advanced Centre of Research in High Energy Materials (ACRHEM), University of Hyderabad,  
Gachibowli, Hyderabad - 500046*

E-mail: prem@uohyd.ac.in

**Abstract**

Laser induced breakdown (LIB) of materials (solids, gases etc) is a source of electromagnetic (em) radiation over a wide range of frequencies. The low frequency emissions (RF) from LIB have many potential applications [1]. The results on RF emissions over 30 MHz - 1 GHz, from nanosecond LIB of atmospheric air, under different focusing conditions ( $f/D$  of 10, 18.75, 25 and 37.5) are presented. The breakdown was achieved by focusing the second harmonic of Nd:YAG laser pulses (7 ns, 532 nm and 1 Hz) with energy in the range of 5-100 mJ per pulse. The leading edge of the laser pulse with intensity ( $I$ ) greater than the breakdown threshold ( $I_{br}$ ) of air ( $\sim 10^8$ - $10^9$  W/cm<sup>2</sup>) creates the breakdown, whereas, the trailing edge of the pulse interacts with the seed electrons of the plasma. The focusing conditions are reflected by the RF emissions that originate from the interaction of seed electrons with the cluster of neutral atoms and molecules in the plasma. Under similar experimental conditions, the amplitude of RF emissions were observed to be relatively lesser in the loose focusing conditions as the number of electrons and their corresponding energies are too low to propel cascade of ionization that results in RF emissions. With the focusing geometries ( $f/D$ ) 10, 18.75 and 25, the RF emissions from LIB were observed to be significant at lower input laser energies. At higher laser energies, the intense breakdown reduces the probability of electron-neutral interaction. Besides, it will contribute to the plasma frequency ( $\omega_p$ ) approaching the laser frequency ( $\omega_L$ ) leading to higher reflectance of incoming laser pulse from the plasma, thereby reducing the laser-plasma interaction [2]. With the focusing condition ( $f/D$ ) 37.5, even at very high input laser energies, the breakdown is not sufficient to attain high value of  $\omega_p$ . Thus the RF emissions were not observed to fall at higher input laser energies used in our study unlike the other focusing regimes. Thus, focusing conditions play a vital role in generating RF emissions from laser produced plasmas with relatively higher strength.

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## LP-132

### Self-Trapping Of Electromagnetic Beams In Underdense And Overdense Plasma

Sonu Sen<sup>1</sup>, Megha Sen Sharma<sup>2</sup>, Akhilesh Dubey<sup>3</sup>, Meenu Asthana Varshney<sup>4</sup> and Dinesh Varshney<sup>5</sup>

<sup>1</sup>*Department of Engineering Physics, Lakshmi Narain College of Technology, Bhavrasala, Sanwer Road, Indore- 453 331*

<sup>2</sup>*Devi Ahilya Shishu Vihar, Chatribagh, Indore-452001*

<sup>3</sup>*Department of Engineering Physics, Indore Institute of Science and Technology, Indore-453331*

<sup>4</sup>*Department of Physics, M. B. Khalsa College, Indore-452002*

<sup>5</sup>*School of Physics, Vigyan Bhawan, Devi Ahilya University, Khandwa road Campus, Indore-452001*

E-mail : ssen.plasma@gmail.com

#### Abstract

Self-trapping of electromagnetic beams in underdense and overdense plasma is presented in this paper. The nonlinearity in the dielectric function arises on account of relativistic variation of mass. An appropriate expression for the nonlinear dielectric constant has been used to study electromagnetic beam propagation in underdense and overdense plasma. The variation of beamwidth parameter with distance of propagation, self-trapping condition and critical power has been evaluated. Numerical estimates are made for underdense and overdense plasma for typical values of relativistic beam-plasma interaction process. Since the relativistic mechanism is instantaneous, this theory is applicable to understanding of self-focusing and propagation of electromagnetic beam in underdense and overdense plasma.

## LP-138

### Generation Of Terahertz Frequencies By Flat Top Lasers In Modulated Density Plasmas

Divya Singh<sup>1,2</sup>, Hitendra K. Malik<sup>1</sup>

<sup>1</sup>*Dept. of Physics, PWAPA Laboratory, IIT Delhi, New Delhi - 110016.*

<sup>2</sup>*Deptt. of Physics & Electronics, Rajdhani College, University of Delhi, New Delhi -110015.*

E-mail- hkmalik@physics.iitd.ac.in

#### Abstract

We present here the scheme of generation of Terahertz frequencies of radiation by excitation of nonlinear currents due to two laser pulses of flat top profiles of different frequencies and wave numbers but same field amplitudes in a plasma of corrugated density having sufficient electron neutral collisions. In the process of generation of terahertz radiation, due to the gradient present in the field amplitude of lasers, the ponderomotive force is developed with frequency of beat wave that

**LP-129**

**Effect Of Focal Geometry On The Acoustic Shock Wave Emissions From LIB Of Atmospheric Air**

E. Manikanta, L. Vinoth Kumar, Ch. Leela, P. Prem Kiran

*Advanced Centre of Research in High Energy Materials (ACRHEM), University of Hyderabad,  
Hyderabad - 500046.*

E-mail : prem@uohyd.ac.in

**Abstract**

The plasma produced during laser induced breakdown (LIB) of materials is well known to be a source of radiation over X-ray, UV-Visible, RF and Acoustic shock waves. The characteristics of the emissions indicate the evolution of plasma in real time [1]. Out of all these emissions acoustic shock waves (ASW) are mechanical emissions [2-4] in contrast to other electromagnetic emissions. Typical parameters of the ASWs are time of arrival ( $T_a$ , time taken by the wave to reach the detector), peak to peak pressure ( $P_{pk-pk}$ ), acoustic signal pulse duration ( $\delta t$ ), the kinetic energy ( $E_s$ ) carried by ASW and frequency ( $f$ ). These parameters give quantitative information about ionized medium. In this paper, we present the role of focusing geometry on the evolution of ASWs during ns-LIB of air. The parameters of laser are 532nm, rep rate of 1Hz and the energies from 10 to 100mJ. For detection of ASWs, microphone (frequency response over 20 Hz to 140 kHz and dynamic range of 174dB re 20  $\mu$ Pa) are used. Results shows that, at a given laser energy as we moved from high (loose focusing) to low focal number (tighter focusing), the ASW parameters ( $P_{pk-pk}$ ,  $E_s$ ,  $\delta t$ ) have increased and arrival time decreased. This clearly indicates the good conversion of optical energy into acoustic energy. It is observed that, frequencies of these ASWs are the function of focal geometry at a given laser energy. These frequencies are in audible-ultrasonic range, with peak values in ultrasonic range. By varying focal geometry ultrasonic frequencies of required frequencies and peak pressures can be generated during ns LIB of air in a simple manner.

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leads to a nonlinear oscillatory current densities that excites the THz radiation with the frequency of the order of beat wave.

The effect of flatness of the lasers, their beam width and electron neutral collisions frequency is discussed for these currents generation and therefore for terahertz radiation generation. The effect of variable density plasma is also to be discussed. It is found that for flat beam lasers, the modulated density of plasma helps in achieving resonance condition hence maximum transfer of energy for better amplitude of emitted terahertz radiation. We will also calculate the efficiency of the mechanism of terahertz generation.

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## LP-142

### The Effect Of Plasma Channel On The Self-Distortion Of Laser Pulse Propagating Through The Collisionless Plasma Channel

Navpreet Singh<sup>1</sup> and Arvinder Singh<sup>2</sup>

<sup>1</sup>*Guru Nanak Dev University College, Mithra, Kapurthala, Punjab*

<sup>2</sup>*National Institute of Technology, Jalandhar, Punjab*

E-mail: navpreet.nit@gmail.com

#### Abstract

This paper presents an investigation of the laser pulse distortion/breakup and the effect of the plasma channel on the laser propagation through the collisionless plasma. Moment theory has been used to derive differential equations of the beam width parameter of the laser propagating through uniform homogenous plasma and preformed plasma channel having parabolic density profile. Differential equations have been set up and solved numerically by using Runge Kutta method. From analysis, it is observed that the low intensity front and rear parts of the laser pulse get defocused/diffracted while the high intensity central portion of the laser pulse gets self guided during the propagation through uniform homogenous plasma. As a result of this, laser pulse gets distorted. This distortion of the laser pulse has not been observed when the laser beam is propagated through the plasma channel having parabolic density profile. The laser pulse is guided as a whole, even the low intensity front and rear parts of the laser pulse are also guided. Therefore, it is predicted that plasma channel plays a significant role to prevent the distortion / beam breakup of the laser.

LP-144

## Production Of Energetic Neutrals From Interaction Of Ultra-Short Laser Pulses With Transparent Solid Targets

S. Bagchi, M. Tayyab, A. Upadhyay, B. Ramakrishna, T. Mandal, J. A. Chakera, P. A. Naik, and P. D. Gupta

*Laser Plasma Division, Raja Ramanna Centre for Advanced Technology, Indore – 452 013*

E-mail: sbagchi@rrcat.gov.in

### Abstract

The interaction of an intense, ultra-short laser pulse with matter produces a high density, high temperature plasma which offers high brightness, low emittance energetic photons and charge particles with ultra-short pulse duration, on a table top [1]. Although a number of explorations have been reported on particle acceleration from these plasmas, generation of neutral atoms has been hardly reported [2]. In this paper, we report realization of an energetic, micrometre sized neutral atom generator based on interaction of moderately intense, ultra-short laser pulse interaction with transparent solid target. We also show that the neutral atom emission characteristics can be controlled by simple changes in the laser parameters.

The experiments were performed by focusing 45 fs, 10 TW laser pulses on poly-methyl methacrylate (PMMA,  $(C_5H_8O_2)_n$ ) which is a transparent dielectric material, to a focal spot size of 10  $\mu m$ , at a base pressure of  $10^{-5}$  mbar, to a maximum intensity of  $3 \times 10^{18}$  W-cm<sup>-2</sup>. The energy and spectrum of the reflected laser beam were monitored using an energy meter and a visible region spectrograph. A fast photo-diode was used to monitor the pre-pulse condition of the laser. A 16-bit EMCCD camera (ANDOR iXon) in tandem with an in-house developed Thomson Parabola Ion Spectrograph (TPIS) with a micro-channel plate (MCP) as a position sensitive device, was employed to record the ion emission characteristics on every single laser shot. The TPIS employing electric and magnetic fields in parallel offers unambiguous detection of charged particles. A typical TPIS spectrum consists of central bright region consisting primarily of photons and neutral particles, if any. Therefore, application of sufficiently strong fields can throw out all the charged particles from the active region of the MCP, thus detecting only the neutral atoms and photons. The time resolved MCP signal gives the information on neutral atoms which comes later in time compared to photons which appear instantaneously.

Experimental results show that when the laser beam is focussed right onto the front surface of the target, no neutral emission was observed. However, as soon as the laser beam was focussed slightly away from the target front surface, the neutral particles start to appear. A slight increase in laser pre-pulse strongly diminishes the neutral production. Observation of these behaviour points towards sub-surface production of the neutral beam. To understand the underlying phenomenon, we have also carried out 2D particle-in-cell simulations which reveal the presence of protons emanating from beneath the target surface, apart from those produced on the target surface. These protons with sub-surface origin can therefore capture electrons on the go to produce neutral particles. Estimations based on simple charge transfer cross-sections match well with the observed neutral atom flux.

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**LP-145**

**Studies On Proton Acceleration From Layered Targets**

M. Tayyab, S. Bagchi\*, B. Ramakrishna, T. Mandal, A. Upadhyay, J. A. Chakera, P. A. Naik and P. D. Gupta

*Laser Plasma Division, Raja Ramanna Centre for Advanced Technology, Indore 452 013*

E-mail: sbagchi@rrcat.gov.in

**Abstract**

The acceleration of high-energy ion beams up to several tens of MeV, following the interaction of intense ultra-short laser pulses with solids, has been one of the most active areas of research in the last decade. High energy ion beams, mainly protons, with extremely low emittance ( $<0.01 \pi$  mm mrad), short pulse duration, high brightness, and high peak current have been demonstrated [1, 2]. Mechanisms leading to forward-accelerated, high brightness, short pulsed proton and heavy ion beams, operating at currently accessible intensities in laser matter interactions, are mainly associated with large electric fields set up by laser-accelerated electrons, at the target rear interface. Protons which are present as hydrocarbon contaminants at the target surface are preferentially accelerated by this field. The process is normally referred to as Target Normal Sheath Acceleration (TNSA) mechanism [3]. Since the ion acceleration process is intrinsically linked to hot electron energy spectrum, efficient laser energy coupling to the plasma is very much essential to increase ion acceleration efficiency for its potential applications.

In this paper, we present, our initial experimental results on MeV ions generation by relativistic ( $>10^{18}$  W-cm<sup>-2</sup>) short-pulse (45 fs) laser interaction with thin Al and Mylar foils of different thicknesses, including multi-layer target with front surface coated with High-Z layers. The accelerated ion beam has been primarily characterized using a Thomson Parabola Ion Spectrograph (equipped with a micro-channel plate and a 16 bit EMCCD camera) placed along the target normal. The ion beam profile and the divergence were measured using radiochromic films and CR-39 sheets. We have observed that Al target produces more energetic protons as compared to Mylar foil. However when a thin layer (100 nm) of Au and Al is deposited on the Mylar foil (on laser side), the proton energy and flux increases many fold. On the contrary, when the coating layer is on the back side (not facing the laser) there is no such enhancement in proton energy and flux. The result can be explained in terms of efficient laser energy absorption in high-Z layers. The detailed analysis of the results will be presented and our current understanding of same will be discussed.

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**LP-152**

**Resonant Second Harmonic Generation in Clusters in the Presence of Wiggler Magnetic Field**

Shivani Vij<sup>1</sup>, Munish Aggarwal<sup>2</sup>, Niti Kant<sup>3</sup>

<sup>1</sup>*Department of Applied Sciences, DAV Institute of Engineering & Technology,  
Jalandhar - 144008*

<sup>2</sup>*Department of Physics, Lyallpur Khalsa College of Engineering, Jalandhar - 144001*

<sup>3</sup>*Department of Physics, Lovely Professional University, Phagwara, Punjab - 144411*

Email: svij25@yahoo.co.in

**Abstract**

Resonant second harmonic generation of shortpulse laser in cluster plasma in the presence of transverse wiggler magnetic field has been analysed. An intense short-pulse laser propagating through a gas embedded with atomic clusters, converts it into hot plasma balls. The laser beam produces a second harmonic due to nonlinear response of electrons. The magnetic wiggler provides the uncompensated momentum to second harmonic photon, causing the process of harmonic generation to be resonant. We explore the impact of laser intensity and cluster size on the efficiency of second harmonic generation. Pulse slippage of second harmonic pulse out of the domain of fundamental laser pulse has been observed on account of group velocity mismatch between fundamental and second harmonic pulse. Enhancement in the efficiency of the second harmonic is seen for optimum values of wiggler magnetic field.

**LP-164**

**Strong Terahertz Pulse Generation From Laser Wakefield In Plasmas**

D.N. Gupta, M. Kaur, and K. Gopal

*Department of Physics & Astrophysics, University of Delhi, New Delhi-110007*

E-mail dngupta@physics.du.ac.in

**Abstract**

We propose a scheme to generate strong terahertz (THz) pulses from two co-propagating laser-pulses interaction with a plasma. The plasma-based THz source is emitted from amplified transverse-wakefield driven by a trailing pulse launched after the seed laser pulse. One-dimensional (1D) theoretical models are developed for studying wakefield amplification in transverse direction and the corresponding THz waves are observed in two-dimensional (2D) particle-in-cell (PIC) simulations. Our results show that THz amplitude of strength of 1 GV/cm can be obtained from interactions of a laser of intensity of  $1 \times 10^{18}$  W/cm<sup>2</sup>, which depends linearly with the number of laser pulse. Such plasma-based THz source has a tunability in amplitude and spectra.

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## LP-172

### Study Of Thz Radiation Generation By Photo-Mixing Of Two Laser Beams In A Plasma Having Dc Electric Field

Prateek Varshney, Kanika Verma, Vivek Sajal and Ravindra Kumar

*Department of Physics and Materials Science and Engineering, Jaypee Institute of Information Technology Noida-20307, Uttar Pradesh*

E-mail: varshneyprateek28@gmail.com

#### Abstract

Resonant excitation of terahertz radiation by photo-mixing of two laser beams of different frequencies ( $\omega_1$  &  $\omega_2$ ) and wave numbers ( $\vec{k}_1$  &  $\vec{k}_2$ ) is studied in a plasma having transverse static electric field. The nonlinear ponderomotive force at frequency difference of beating lasers couples with density ripples and give rise to strong transverse nonlinear current, which results into the excitation of THz radiation at resonance. The produced THz wave amplitude can be controlled by changing the field strength of applied electric field, THz frequency and laser beam radius. Present study can be useful for developing THz source for medical applications.

## LP-191

### Pulse Chirp Controlled Proton Acceleration From Thin Foil Targets

A. Upadhyay, M. Tayyab, S. Bagchi, B. Ramakrishna, T. Mandal, J. A. Chakera, P. A. Naik and P. D. Gupta

*Laser Plasma Division, Raja Ramanna Centre for Advanced Technology, Indore 452 013*

E-mail : ajitup@rrcat.gov.in

#### Abstract

The last decade has seen a strong focus on the laser accelerated charge particles, leading to the possibility of table top accelerator of electrons, proton, and ions. In the case of proton acceleration, the maximum proton energy, its energy spread, and bunch charge play a strong role in applications like radio-oncology, inertial confinement fusion, and many more. Hence, there is a strong emphasis to evolve new means to control and enhance these beam parameters.

In our recent experiments on proton acceleration, we have observed that the maximum proton energy not only depends on the laser pulse duration and the focussed intensity, but also on the optimal target thickness and the choice of the target materials [1]. It can also be controlled by the laser pulse chirp. Our experiments using a 7 TW, 45 fs, 800 nm wavelength Ti:sapphire laser beam obliquely focussed using an off-axis parabola to a spot size of 10  $\mu\text{m}$  on the front surface of 6.5  $\mu\text{m}$  and 12.5  $\mu\text{m}$  thin aluminium foils, yielded accelerated protons from the front as well rear surface of the foils through the ‘target normal sheath acceleration (TNSA)’ mechanism. The accelerated protons were characterized using a Thomson parabola ion spectrograph, radiochromic films, and CR-39 sheets. The pulse chirp was scanned from positive to negative to observe an enhancement in the maximum proton energy for the negative chirp case.

2D particle-in-cell (PIC) simulations have been performed using the code EPOCH [2] to understand the above experimental results. In a 2D simulation box, a Gaussian laser pulse of the same fluence as used in our experiments was focused on the front surface of a 6.5  $\mu\text{m}$  thin pre-ionized over-dense plasma slab, kept at 45 degree to the laser pulse. While keeping the pulse fluence same, the chirp was changed from positive to negative. Linear pulse chirp of  $\pm 10$  nm was used and in some simulations the chirp was also accompanied by pulse skew. The electron and proton energy spectrum, TNSA field and absorbed laser energy in the plasma was deduced from the simulation results to corroborate and understand the experimental results. The simulation results will be presented and the understanding developed towards the interaction mechanism will be discussed.

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## LP-193

### Relativistic Self Focusing Of Cosh-Gaussian Laser Beam In Preformed Plasma Channel

Nehpreet Kaur Walia and Tarsem Singh Gill

*Department of Physics, Guru Nanak Dev University, Amritsar*

E-mail : nehpreetwalia@gmail.com

#### Abstract

This paper presents theoretical investigation of relativistic self focusing of Cosh-Gaussian (ChG) laser beam in preformed plasma channel. Starting from nonlinear Schrodinger type wave equation second order differential equation governing the evolution of spot size of laser beam with distance of propagation has been obtained by using method of moments. The differential equation so obtained has been solved numerically by using fourth order Runge Kutta method. The effect of laser parameters as well as channel, such as intensity, decentered parameter, density and depth of channel on relativistic self focusing of the laser beam has been investigated in detail. The numerical simulation results predict that ChG laser beams show smaller divergence as they propagate and thus lead to enhanced energy transport.

**LP-194**

**Effect Of Relativistic Transparency On Proton Acceleration In Thin Foils**

A. Upadhyay, S. Bagchi, J. A. Chakera, P. A. Naik and P. D. Gupta

*Laser Plasma Division, Raja Ramanna Centre for Advanced Technology, Indore 452 013*

E-mail : ajitup@rrcat.gov.in

**Abstract**

The technological advancement in compact ultra-intense, ultra-short pulse lasers using chirped pulse amplification has led to a surge in the research on compact particle accelerators. There is a distinct possibility that these relatively cheaper, table-top accelerators may pave way for a table-top synchrotron radiation source, as well as a table-top cancer treatment (proton therapy) machine using a mono-energetic, collimated proton beam. However, the currently understood mechanisms of proton acceleration using laser viz. target normal sheath acceleration (TNSA) and radiation pressure acceleration (RPA), have their own limitations in terms of the proton beam quality and stringent requirements on laser parameters. Although, the RPA mechanism provides mono-energetic acceleration using ultra-thin foil targets, it demands extremely high laser intensity and pulse contrast. On the contrary, a relativistic intense laser pulse, due to its induced transparency, may pass through the overdense plasma of the thin foil target and create a snowplow structure of electrons leading to longitudinal electrostatic field suitable for proton acceleration. Such a mechanism, referred to as "relativistically induced transparency acceleration (RITA)", may yield a quasi-mono-energetic proton bunch [1]. In this paper, we explore the proton acceleration by relativistic induced transparency acceleration mechanism using 2D particle-in-cell (PIC) simulations with an aim to produce quasi-mono-energetic protons, with not so demanding laser and target parameters.

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**LP-199**

**Higher Harmonic Generation Of Relativistically Guided Q-Gaussian Laser Beam In Plasma Channel Produced By Two Pre-Pulse Technique**

Arvinder Singh and Naveen Gupta

*Department of Physics, NIT Jalandhar*

E-mail : arvinder6@lycos.com

**Abstract**

This paper presents theoretical investigation of relativistic guiding of q-Gaussian laser beam and its effect on higher harmonic generation in a plasma channel produced by two prepulse technique.

Tunnel ionization of air is carried out with the help of first prepulse and second prepulse creates a plasma channel. Third pulse is passed through this induced plasma channel and its dynamics is studied under the combined effect of density non uniformity of plasma channel and relativistic non linearity. Comprehensive study has been carried out to investigate the combined effect of first two prepulses over the guided pulse. Moment theory has been used to derive differential equations for spot size of laser pulses. The differential equations so obtained have been solved numerically by Runge Kutta fourth order method. The effect of intensities of prepulses on the guiding of third pulse as well as on higher harmonic generation has been investigated. Also the effect of plasma density, frequency of laser beams, and deviation of intensity distribution of guided pulse from Gaussian distribution on its guiding and higher harmonic generation has been investigated. The results are interesting and will be helpful to understand the physics of laser plasma interaction.

## LP-205

### **Effect Of Ponderomotive And Relativistic Filamentation On Coexisting Stimulated Raman And Brillouin Scattering**

Ashish Vyas, Ram Kishore Singh and R. P. Sharma

*Centre for Energy Studies, Indian Institute of Technology, Delhi-110016*

E-mail: esz128091@ces.iitd.ac.in

#### **Abstract**

This paper presents a theoretical model to study the interplay between the two important scattering processes in laser plasma interaction namely, stimulated Raman scattering (SRS) and Brillouin scattering (SBS) along with the combined effect of relativistic and ponderomotive nonlinearities, at relativistic laser power. As the intense non-uniform laser beam propagates through the plasma both the non-linearities are operative. On account of both the nonlinearities pump laser beam gets filamented in such a manner that one enhances the self-focusing caused by the other non-linearity [1]. A five wave interaction model (5WI) is developed and modified coupled equations for dimensionless beam width parameters of the pump and scattered beams are derived, when relativistic and ponderomotive nonlinearities are operative. These coupled equations are solved analytically and numerically to study the dynamical evolution of the pump beam and the scattered beams. We have demonstrated that the coexistence of SRS and SBS affects the pump filamentation process due to pump depletion and at the same time these scattering processes (SRS and SBS) also get modified due to the filamentation process. We have derived the expression of the back-reflectivity of the scattered waves (SRS and SBS) for the five wave interaction case and simulated it. It is observed from the results that the filamentation process and pump depletion (5WI) affects the back-reflectivity of scattered beams (SRS and SBS) significantly. Results are also compared with the three wave interaction case (isolated SRS or SBS case).

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## **Relativistic Electromagnetic Cusp Soliton In Plasma**

Deepa Verma, Amita Das, Predhiman Kaw and Sanat Kumar Tiwari

*Institute for Plasma Research, Gandhinagar-382428*

E-mail : deepaverma@ipr.res.in

### **Abstract**

A variety of solitary structures have been found to exist in plasmas interacting with highly intense laser beams. The studies related to existence, evolution and stability of these localized structures keep gaining attention in scientific community because of their applications in fields like Inertial confinement fusion and particle accelerators. Both electron and ion also play important role in formation of different category of such electromagnetic solitons. Single peak, paired and multi-peak solitons have been found to exist at electron dynamics time and length scales. Flat-top, cusp and high amplitude single peak solitons have also been found to exist after inclusion of ion dynamics. In this abstract, we have presented analytical and numerical results related with the formation and time evolution of cusp soliton. We found that the Analytic solution has been matched well with exact solutions. The cusp solitons have been found to be unstable during evolution and they disintegrate because of the Forward Raman scattering.

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LP-210

## Energy Coupling During Nano And Pico Second Pulsed Laser Shock Peening Of Stainless Steel And Aluminum Surfaces

P.Venkateshwarlu<sup>1</sup>, Pardhu Yella<sup>2</sup>, Ramesh Kumar Buddu<sup>3</sup>, Raole P.M.<sup>3</sup>, K. Bhanu SankaraRao<sup>2†</sup>, Koteswararao V. Rajulapati<sup>2</sup>, P. Prem Kiran<sup>1\*</sup>

<sup>1</sup>*Advanced Centre for Research in High Energy Materials (ACRHEM),  
University of Hyderabad, Hyderabad 500 046*

<sup>2</sup>*School of Engineering Sciences and Technology, University of Hyderabad,  
Hyderabad 500 046*

<sup>3</sup>*FRMDC Division, Institute for Plasma Research, Bhat, Gandhinagar 382 428, Gujarat*

<sup>†</sup>*Present address: Ministry of Steel (Govt. of India) Chair Professor, Mahatma Gandhi Institute of  
Technology, Hyderabad 500075*

E-mail: premkiranuoh@gmail.com

### Abstract

The laser produced plasma and generated shock waves have important applications in understanding dynamic response of materials and high pressure physics, as they reveal the properties of the material under dynamic compressions and material processing techniques like laser shock peening (LSP), Pulsed Laser Deposition, Cutting and Drilling [1-3].

We present the interaction of second harmonic of Nd-YAG pulsed lasers (7 nanosecond and 30 picosecond, 532nm, 10Hz repetition rate) with austenite 304 stainless steel (SS) and aluminum (Al) surfaces to estimate coupling of laser energy to the surface. The surface modifications like crater dimensions and the ablation depth were measured using SEM and Surface profiler. Effect of incident pulse duration (ns and ps) and the plasma shielding effect on the energy coupling to material surface is studied. Though Al has less density compared to SS, the energy absorbed by Al surface is found to be comparable to that of SS. The role of material properties like density, thermal conductivity, absorption coefficient, melting point, latent heat of vaporization etc. on the energy absorbed by the surface is presented. In addition to the material properties, the plasma shielding effect is observed to play a dominant role in ns laser ablation of the metal surfaces.

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**LP-215**

**Influence Of Self-Generated Magnetic Fields On Electron Acceleration In Plasma  
By Circularly Polarized Laser**

Jyoti Rajput<sup>1,2</sup>, Niti Kant<sup>2</sup> and Arvinder Singh<sup>1</sup>

<sup>1</sup> *Department of Physics, National Institute of Jalandhar, Punjab 144011.*

<sup>2</sup> *Department of Physics, Lovely Professional University, G. T. Road, Phagwara 144411.*

E-mail: jyoti\_physics@yahoo.com

**Abstract**

The collimating and pinching properties of self-generated magnetic fields helps in accelerating electrons to obtain high quality relativistic electron beam. Resonant enhancement in the electron acceleration by a circularly polarized laser pulse in plasma is studied under combined effect of these self-generated magnetic fields. The resonance occurs between the electron and electric field of the laser pulse for the optimum value of magnetic fields and the electron acquires much higher energies at this point. Variation of electron energy with the laser initial intensity, initial spot size is discussed along with electron trajectory in the presence of intense laser fields and such self-consistent magnetic fields.

**LP-218**

**Intensity Enhancement Of Harmonic Generation From Plasma Plume Using  
Apertured Laser Beam**

M. Kumar, U. Chakravarty, R. Rathore, J. A. Chakera, P. A. Naik, and P. D. Gupta

*Laser Plasma Division, Raja Ramanna Centre for Advanced Technology, Indore 452013*

E-mail: mukund@rrcat.gov.in

**Abstract**

High order harmonic generation from plasma plume is a versatile technique for generation of ultrashort extreme ultraviolet (XUV) radiation [1] with good spatial coherence [2]. It is generated by the interaction of intense, ultrashort laser pulses with plasma plumes. The plasma plume was created by focusing a low intensity ( $10^9$ - $10^{10}$  W/cm<sup>2</sup>), 200 ps laser beam on a target placed in a vacuum chamber evacuated to  $10^{-5}$  mbar. After an optimum delay, the femtosecond pulse ( $\sim 45$  fs) was focused in the plasma plume at an intensity of  $\sim 10^{14}$ - $10^{15}$  W/cm<sup>2</sup>. The generated XUV radiation was analysed using an in-house developed XUV spectrograph, and recorded on a CCD camera.

Although there are several techniques for harmonic generation, HHG from plasma plume has the advantage of using various solid target plumes, which increases the possibility of occurrence of resonant ionic transition lying close to some harmonic order and results in large increase in intensity of these harmonics. However, the resonance enhancement occurs in some specific material plume for



some specific harmonic orders only (e.g. 13<sup>th</sup> harmonic in indium plume). In order to increase the conversion efficiency of a group of harmonics generated, it is necessary to use some other alternative technique. There are several alternative ways to enhance the harmonic intensity viz. increasing the interaction length by increasing the medium length [3], tuning the medium density [4], improving the phase matching condition in the plasma etc.

In this paper, we present a detailed experimental study on the effect of laser beam shaping on the intensity, conversion efficiency, and spatial coherence of the high order harmonics generated from pre-formed plasma plumes. The study was carried out on carbon (graphite) plasma plume, which is well known for its high conversion efficiency for relatively low harmonic orders (cutoff ~ 29H). It is observed that placing an aperture in the beam path of harmonic generating laser beam enhances the harmonic intensity and laser to harmonic conversion efficiency. At constant laser energy, more than an order of magnitude enhancement in harmonic intensity is observed at about half the beam diameter. Further, the spatial coherence of the generated harmonics was also found to increase. An increase in fringe visibility from 0.5 (for no aperture) to ~ 0.7 at apertured beam (1/3<sup>rd</sup> of the beam diameter) is observed for 13<sup>th</sup> harmonic. We have identified an optimum condition for efficient harmonic generation with better spatial coherence using apertured laser beam. The results are explained on basis of an improvement in the phase matching conditions (between laser and harmonic beam) due to aperturing (spatial shaping) of the laser beam.

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## LP-221

### Temporal Variation of Shock Wave Velocity in Soda-Lime Glass

Y.B.S.R.Prasad, S. Barnwal, A. Upadhyay, M.P. Kamath, S.Bagchi, A. Kumar,  
A.S. Joshi, P.A. Naik, and P.D. Gupta

*Laser Plasma Division, Raja Ramanna Centre for Advanced Technology, Indore 452013.*

E-mail : yprasad@rrcat.gov.in

#### Abstract

Study of high energy density physics using high energy, high power lasers is an important application of these lasers. Study of megabar level shocks in matter which can be produced with these lasers these lasers is a strategically important area. In this paper, we report on the temporal variation of the velocity of the shock wave produced in soda lime glass using an Nd:glass laser focussed to intensities of  $4 \times 10^{13}$  and  $10^{14}$  W/cm<sup>2</sup>. The experiments were conducted using a high power laser system at RRCAT, using laser energy up to 10 J, with a pulse duration of ~500 ps. This study was carried out using the optical shadowgraphy technique. The shocked region was probed with a second harmonic of the laser beam (360 ps). As the shock wave passes through a transparent material, the sudden increase in the density leads to a change in the real and imaginary parts of refractive index of the material, thus forming shadows [1] with the probe beam. The optical shadowgraphs were recorded with an

optical magnification of 50-60X using a CCD camera. The shadowgraphs recorded at different probe delays under nearly identical conditions provided the temporal profile of the shock velocity. It is seen that the shock velocity reaches a peak value of  $8 \times 10^6$  cm/s at around 1 ns from the peak of the heating beam and falls thereafter. The shock data could be obtained even at shorter delays by minimizing the shadow of the target region of the target front surface and by using a probe pulse shorter in duration compared to the pump laser pulse. The shock velocities recorded correspond to a peak transient pressures of 80 Mbar in the medium. The experimental results are compared with the simulation studies. The experimental details and the results will be discussed and explained in terms of shock coalescing / rarefaction and two dimensional effects.

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### LP-222

#### Chirped Pulse Shadowgraphy For Studying The Evolution Of Shock Wave Velocity

Y.B.S.R. Prasad, S. Barnwal, R. Patidar, A.K.Sharma, A.S.Joshi, P.A.Naik and P.D.Gupta

*Laser Plasma Division, Raja Ramanna Centre for Advanced Technology, Indore 452013.*

E-mail : yprasad@rrcat.gov.in

#### Abstract

Pressures of several tens of mega bars can be generated in solid targets using high power lasers focussed to an intensity of  $10^{13-14}$  W/cm<sup>2</sup>. These shocks travel in the medium with a high velocity  $\sim 10^6-7$  cm/s. Usually, the shock velocity measurements are done by recording the shock luminosity breakout on the target rear surface using an optical streak camera. However, this gives a time averaged value of the shock velocity. Temporal variation of the shock velocities can be obtained in transparent targets like glass, perspex etc. In this paper, we report on the temporal profile of shock velocity in soda lime glass, with tens of picoseconds temporal resolution, using the chirped pulse shadowgraphy technique described in ref. 1. The shocked region was imaged onto the entrance slit of a spectrograph with 50X magnification. The spectrum was recorded with a grating of 1200 g/mm with 0.3 nm resolution. The spectrum of the transmitted chirped laser probe beam passing through the shocked region provided information about the temporal variation of the shock velocity over the probe beam duration, which was 450 ps in the present case. This technique appears to be a simpler alternative to the Velocity Interferometer System for Any Reflector (VISAR) [2] and optical shadowgraphy using a long probe with a streak camera [3] in terms of better temporal resolution and much lesser complexity. The details of the experiment will be presented and the results will be discussed.

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**LP-227**

**Particle Acceleration By Whistler Pulse In High Density Quantum Plasma**

Punit Kumar, Abhisek Kumar Singh and Shiv Singh

*Department of physics, University of Lucknow, Lucknow-226007*

E-mail: punitkumar@hotmail.com

**Abstract**

Lately, significant progress has been made in the field of plasma based accelerators for attaining high electron energies [1-3]. Work on acceleration by ponderomotive force of the laser pulse has been pursued vigorously and electron acceleration is being achieved. Whistler is known to accelerate electrons to high energies. Chen et al. [4] demonstrated the possibility of particle acceleration by plasma magnetowaves, abundant in astrophysical settings. PIC simulations have shown positive results for celestial acceleration [5]. Lower hybrid waves have been successfully employed to sustain runaway electrons in a tokamak to maintain the toroidal current. The field of quantum plasma Physics has a long and diverse tradition and is becoming a area of increasing interest motivated by its potential applications in modern technology. The high-density, low-temperature quantum Fermi plasma is significantly different from the low-density, high-temperature “classical plasma” obeying Maxwell-Boltzmann distribution. During the last decade, there has been a growing interest in investigating new aspects of dense quantum plasmas by developing the quantum hydrodynamic (QHD) model [6]. In the present work, we analytically examine electron acceleration by the ponderomotive force associated with a right circularly polarized gaussian whistler pulse in a magnetized high density quantum plasma obeying Fermi-Dirac distribution using the recently developed quantum hydrodynamic (QHD) model. The QHD model consists of a set of equations of where quantum Bohm potential and Fermi pressure have been taken into account. Effective acceleration takes place when the peak whistler amplitude exceeds a threshold value and whistler frequency is greater than the cyclotron frequency. Threshold amplitude decreases with ratio of plasma frequency to electron cyclotron frequency. The electron gain at velocities about twice the group velocity of the whistler.

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**LP-228**

**Raman Backscattering Of Laser In Magnetized Quantum Plasma**

Punit Kumar and Nisha Singh Rathore

*Department of Physics, University of Lucknow, Lucknow-226007*

E-mail : punitkumar@hotmail.com

**Abstract**

Plasma interaction dynamics is a highly motivating area of research. The physical phenomenon of interaction of a high-intensity laser radiation with plasma leads to a number of relativistic [1,2] and nonlinear effects such as self modulation [3,4], self-focusing [5], Raman scattering, and various parametric instabilities [6]. In the presence of transverse external static magnetic field [7] electrons attain transverse velocity components, and produce transverse current density components, which may parametrically excite an electrostatic upper hybrid Langmuir wave and a backscattered Raman electromagnetic wave.

Plasma where the density is quite high and the de-Broglie thermal wavelength associated with the charged particle approaches the electron Fermi wavelength and exceeds the electron Debye radius, the study of quantum plasma becomes important [8,9]. During the last decade, there has been a growing interest in investigating new aspects of dense quantum plasmas motivated by its potential applications in modern technology [10]. In the present paper, we present a mechanism of exciting Raman shifted electromagnetic waves in plasma in the presence of static external magnetic field. The presence of backward Raman shifted second harmonic would be manifestation of self-generated magnetic fields in laser-plasma interaction. The analysis is based on the recently developed quantum hydrodynamic (QHD) model [11,12].

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**LP-229**

**Optical Guiding Of Dark Hollow Laser Beam In Axially Nonuniform Collisional Plasma Channel**

Gaganpreet Kaur, Naveen Gupta, Arvinder Singh

*Dept. Physics, NIT Jalandhar*

E-mail : samragagan93@gmail.com

**Abstract**

This paper presents theoretical investigation of optical guiding of dark hollow Gaussian (DHG) laser beam in an axially nonuniform collisional plasma channel created by Gaussian laser pulse. Due to nonuniform intensity distribution along the wavefront of DHG laser beam, nonuniform heating of plasma takes place. Due to nonuniform heating the dielectric properties of plasma channel get modified in such a way that nonlinear refraction opposes diffractive divergence. Following W.K.B approximation and method of moments second order differential equations governing the evolution of spot size of prepulse and DHG laser beam have been derived. Numerical simulations have been carried out to investigate the effect of guided beam intensities, position of intensity maxima of DHG beam from axis, axial nonuniformity of plasma channel on the guiding of DHG laser beam.

**LP-231**

**Classical Radiation Reaction Effects On Laser Driven Auto-Resonant Particle Acceleration**

Vikram Sagar, Sudip Sengupta and P.K.Kaw

*Institute For Plasma Research, Gandhinagar, 382428*

E-mail : vicky@ipr.res.in

**Abstract**

The relativistic dynamics of a charged particle is studied in the combined field of an ultra intense laser and a static axial magnetic field by taking radiation reaction effects into account. The Landau-Lifshitz form describes the radiation reaction term in the particle equation of motion. It is shown that the radiation reaction effects dominate the particle motion at higher laser intensities. For a particle placed in a linearly polarized continuous electromagnetic wave and a static axial magnetic field, two significant effects in the radiation reaction dominated regime are seen viz., (1) net energy gain by a initially non-resonant particle which is caused due to resonance broadening and (2) saturation in energy gain by the initially resonant particle. This study has been extended to different laser polarizations and to particle dynamics in finite duration laser pulses.

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## LP-233

### Study On Nitrogen Z-pinch Plasma For X-Ray Lasing

S. Barnwal<sup>\*</sup>, S. Nigam, K. Aneesh, Y. B. S. R. Prasad, P. K. Tripathi, P. A. Naik, C. P. Navathe, and P. D. Gupta

*Laser Plasma Division, Raja Ramanna Centre for Advanced Technology, Indore 452013*

E-mail : sbarnwal@rrcat.gov.in

### Abstract

Fast capillary discharge scheme has already been a great success in achieving soft x-ray lasing at 46.9 nm wavelength from argon z-pinch plasma [1]. There has been a significant interest in extending this scheme for x-ray lasing at shorter wavelengths [2, 3]. Various groups across the globe are working in practically realizing the proposed x-ray lasing scheme at 13.4 nm in H-like N ions ( $N^{6+}$ ) [2,3]. Unlike the argon laser, x-ray lasing in nitrogen is based on recombination pumping scheme which requires rapid ionization to  $N^{7+}$  during Z-pinch formation, followed by dominant collisional recombination to  $N^{6+}$  through fast cooling during pinch expansion phase. Experimental efforts are presently going on at RRCAT in this direction using a newly developed fast capillary discharge system. This system is able to reach closer to the required parameters theoretically predicted by Vrba et al [4] to achieve lasing at 13.4 nm from nitrogen z-pinch plasma.

Experiments have been performed to record the temporal profile of the emission from nitrogen Z-pinch plasma produced by fast capillary discharge scheme. Nitrogen gas was fed into a ceramic capillary of 2.8 mm inner diameter and 15 cm length, upto an initial gas pressure of 0.35 mbar. Before passing the main current, a prepulse of 25 A was passed to pre-ionize the gas, which facilitates uniform compression of the plasma along the entire length, during the main discharge. Then a fast discharge current (quarter period – 60 ns) of 45 kA was allowed to pass through the preionized gas to form nitrogen Z-pinch plasma. The temporal profile of the x-ray emission from this pinch plasma was recorded using a quadrant diode and a fast oscilloscope. A pulse having a rise - time of 7-8 ns was observed, which was completely absent at lower gas pressure (0.35 mbar). It starts building up at higher pressures (>3 mbar) superimposed over the background plasma emission. The time of this pulse matches well with the fast dip observed in the current pulse which is a clear indication that it occurs at the instant of pinch formation. The discharge current was further increased in steps upto a higher value i.e. ~60 kA and the gas pressure was also raised till 6.0 mbar. In this process, it was observed that the amplitude of the x-ray pulse, generated during the pinch formation, rises and becomes quite dominant even higher than the background signal. This result is a very encouraging sign towards demonstrating x-ray lasing in nitrogen. The results obtained and their analysis will be discussed in detail.

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## LP-235

### Measurement of Gain-Coefficient of 46.9 nm Capillary Discharge Soft X-ray Laser

S. Barnwal, Y. B. S. R. Prasad, S. Nigam, K. Aneesh, P. A. Naik, C. P. Navathe,  
and P. D. Gupta

*Raja Ramanna Centre for Advanced Technology, Indore 452013*

E-mail: sbarnwal@rrcat.gov.in

#### Abstract

Soft x-ray lasing has been recently demonstrated at 46.9 nm from argon z-pinch plasma pumped by fast capillary discharge at RRCAT [1]. Experiments have been performed to measure the gain coefficient of this laser. This was done by measuring the variation of the pulse energy of the argon soft x-ray laser beam with plasma column length. In these experiments, it is required that all other experimental parameters e.g. current amplitude, its rise-time, prepulse etc. which have effect on the laser pulse energy, must remain fixed for different plasma column lengths. Any change in the capillary length alters the inductance of the discharge circuit which affects the current pulse duration and this is not desired. Hence, metallic rods (made of either tungsten or SS) of different lengths were introduced into the capillary from high voltage electrode side, in order to change the length of the plasma column. This metallic rod was kept in direct contact with the high voltage electrode. This arrangement does not change the inductance of the discharge circuit. A ceramic capillary of 2.8 mm diameter and longer length (~30 cm) was used in the experiment. First, the lasing conditions were optimized at the discharge current of ~ 40 kA with quarter period ~ 75 ns leading to  $dI/dt \sim 7 \times 10^{11}$  A/s. The laser beam energy was obtained to be ~ 2.5  $\mu$ J at the optimized conditions. By changing the length of the metallic rods inside the capillary, plasma column length was successively reduced to 24 cm, 19 cm, 12 cm, 9 cm and 6 cm. The laser energy was measured at each length of the argon plasma column after optimizing the pressure and keeping other conditions fixed. The results show an exponential increase in the laser gain for plasma length below ~15 cm beyond which the gain increases linearly with length. From the gain variation for smaller lengths of the plasma column, the gain coefficient of this laser was estimated to be  $0.7 \text{ cm}^{-1}$  using Linford's formula [2]. Also, this corresponds to a gain length product of 10.5 for a plasma column length of 15 cm. Details of the experiments will be presented and the results obtained will be discussed.

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**LP-237**

**Stimulated Raman And Brillouin Backscattering Of A Ring Rippled Laser Beam  
In Intense Laser Plasma Interactions**

Gunjan Purohit<sup>1</sup>, Priyanka Rawat<sup>1</sup> and Rakhi Gauniyal<sup>2</sup>

<sup>1</sup>*Department of Physics, DAV (PG) College, Dehradun, Uttarakhand 248001*

<sup>2</sup>*Uttarakhand Technical University, Dehradun, Uttarakhand 248007*

E-mail: gunjan75@gmail.com

**Abstract**

The effect of the propagation of ring rippled laser beam on the excitation of electron plasma wave (EPW) & ion acoustic wave (IAW) and resulting stimulated Raman & Brillouin backscattering (SRBS & SBBS) in a collisionless plasma is investigated in the presence of relativistic-ponderomotive nonlinearity. The growth of ring ripple, riding on an intense Gaussian laser beam in plasma has also been studied. To understand the nature of propagation of the ring ripple like instability, a paraxial-ray approach has been invoked in which all the relevant parameters correspond to a narrow range around the irradiance maximum of the ring ripple. From numerical analysis, it has been observed that the focusing is released by the coupling of relativistic-ponderomotive nonlinearity, which significantly affected the dynamics of the excitation of EPW & IAW and back reflectivity of stimulated Raman and Brillouin scattering (SRS). The well established typical laser plasma parameters have been used in numerical analysis. The back reflectivity of SRS & SBS is enhanced due to the strong coupling between ring rippled laser beam and the excited EPW & IAW. The results also shows that back reflectivity of SRS & SBS reduce for higher intensity of laser beam. It is expected that the present work may be more useful in order to understand the real picture of back reflectivity of stimulated Raman & Brillouin scattering in intense laser plasma interaction.

**Keywords:** Ring ripple, self-focusing, relativistic-ponderomotive nonlinearity, electron plasma wave, ion acoustic wave, stimulated Raman & Brillouin scattering



**LP-250**

**Particle in Cell Simulation of Non-linear Evolution Filamentation  
Instability in Counter-streaming Relativistic Beams**

Chandrasekhar Shukla, Bhavesh G. Patel, Kartik Patel<sup>1</sup> and Amita Das

*Institute for Plasma Research, Bhat, Gandhinagar - 382428*  
<sup>1</sup>*Bhabha Atomic Research Centre, Trombay, Mumbai - 400 085*

E-mail : cshukla@ipr.res.in

**Abstract**

The filamentation instability driven by counter streaming relativistic electron beams are important because of its relevance in magnetic field generation [1], in particle acceleration [2] and in inertial confinement fusion [3]. The evolution of this instability has been carried out using 1D3V relativistic electromagnetic Particle in Cell (PIC) simulation. In simulation, the spatial direction is chosen orthogonal to beam vector. The vortices have been observed in phase space distribution for momentum component along spatial direction during non-linear evolution of filamentation instability. These vortices merge with time and stabilize the filamentation instability.

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**LP-271**

**External Magnetic Field Induced Instabilities In Laser-Produced Plasma**

Narayan Behera, R. K. Singh and Ajai Kumar

*Institute for Plasma Research, Bhat, Gandhinagar-382 428*

E-mail:nbehera@ipr.res.in

**Abstract**

The interactions of expanding laser produced plasma plume with the uniform external magnetic field can initiate several interesting physical phenomena like plume confinement, ion acceleration/deceleration, emission enhancement/decrease and plasma instabilities. Due to the transient nature of plasma parameters of laser produced plasma, plasma plume expands in high beta

region to diffuse magnetic field into the plume. Expansion of plume in difference region causes the velocity gradient in the plasma plume which can initiate the various plasma instabilities. These instabilities responsible for edge and field aligned structured in the expanding plasma plume. In this presentation we will discuss the striation like structure observed in laser produced aluminum plasma plume propagates across the 0.45 T magnetic field. Details of experimental conditions for appearance of this structure are briefly discussed. The validity of different instabilities, e.g. R-T and K-H instabilities in the present observation are also discussed.

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**LP-286**

**Dynamics Of Shock Wave And Cavitation Bubble Produced By Laser Ablation Of Cu In Water**

Alamgir Mondal, R.K. Singh and Ajai Kumar

*Institute for Plasma Research, Bhat, Gandhinagar-382 428*

E-mail : alamgir.mondal@ipr.res.com

**Abstract**

Dynamics of laser produced plasma in water ambient has been investigated using fast shadowgraphy and optical beam deflection technique. Details of experimental technique, diagnostic systems, optimization and data acquisition are presented. The high power laser-matter interactions in water ambient initiate the highly directed plasma plume followed by generation of shock wave and cavitation bubble. In this presentation, a systematic experimental investigation of expansion dynamics and geometrical aspect of plasma plume, shock wave and cavitation bubble in water medium are presented. Also the observed phenomenon like, oscillations, collapse and re-bounce of the expanding cavitation bubble are briefly discussed.

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**LP-296**

**Three-Temperature Non-Equilibrium Radiation Hydrodynamics Study Of Laser-Driven Thin Al Foils**

Sijoy C.D., V. Mishra and S. Chaturvedi

*Computational Analysis Division, Bhabha Atomic Research Centre (BARC), Visakhapatnam*

E-mail : sijoy@barc.gov.in

**Abstract**

Lasers have been widely used for the ablative acceleration of thin metallic foils to extremely high velocities [1,2]. These studies are important for the concept of inertial fusion energy, impact fast ignition and laser driven equation of state (EOS) studies. We have developed a new two-dimensional (2D), axis-symmetric, three-temperature (3T), non-equilibrium, radiation-hydrodynamics (RHD) code for the study of laser-driven thin Al foils. The proposed RHD model allows the evolution of different temperatures for the ions, electrons and thermal radiation. For the EOS of Al, we have used the Quotidian EOS model [3] modified by incorporating first principles results [4]. The validated RHD code is then applied to study laser-driven shocks in Al foils for laser intensities in the range  $10^{13}$ - $10^{15}$  W/cm<sup>2</sup>. This paper reports the details of the 3T-RHD model, details of the EOS model, validation tests and the simulated results of shock-velocity and shock-pressure for the range of laser intensities mentioned above. The results are compared with known theoretical and experimental scaling laws. We also report the impact of the initial transient time (time required to reach the steady shock) on shock velocity measurement for different laser intensities-this is important when simulation results are compared with experimental measurements.

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**LP-328**

**Development Of Numerical Models For Laser Driven Shocks In Air And Its Comparison With Experiment**

S Sai Shiva<sup>1</sup>, Ch. Leela<sup>1</sup>, C. D. Sijoy<sup>2\*</sup>, V. R. Ikkurthi<sup>2</sup>, S. Chaturvedi<sup>2</sup>, P. Prem Kiran<sup>1</sup>

<sup>1</sup>*Advanced Centre of Research in High Energy Materials (ACRHEM), University of Hyderabad, Prof. C. R. Rao Road, Gachibowli, Hyderabad-500046*

<sup>2</sup>*Computational Analysis Division, Bhabha Atomic Research Centre (BARC), Visakhapatnam*

E-mail : premkiranuoh@gmail.com

**Abstract**

A one-dimensional, three-temperature (electron, ion and thermal radiation temperatures), non-equilibrium, radiation hydrodynamic (RHD) model has been developed to numerically study the evolution of shockwaves due to laser induced breakdown of quiescent air. The governing RHD equations (in Lagrangian form) are solved by using an implicit scheme. Similarly, the energy relaxation between the electrons and ions and the electrons and thermal radiation are determined implicitly. Apart from these, the energy equation takes into account the flux-limited electron thermal heat flux. The RHD equations are closed by using a two temperature equation of state (EOS) model for the air. The laser absorption model takes into account the photoionization (PI) and the inverse bremsstrahlung (IB) processes [1]. The experimental characterization of spatio-temporal evolution of the laser induced shock front generated by focusing a second harmonic (532 nm, 7ns) of Nd:YAG laser in air is performed using a shadowgraphy technique. These measurements are made from 200 ns to 10  $\mu$ s after the laser pulse [2]. This paper reports the details of the RHD model and the comparison of the simulated and experimental results for input laser energies of 50, 75 and 150 mJ per pulse.

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LP-349

## Laser Assisted Synthesis Of Silver Nanoparticles: A Green Approach

Jemy James<sup>1,3</sup>, Pranitha Sankar<sup>2</sup>, Anju K.Nair<sup>1</sup>, Reji Philip<sup>2</sup>, Nandakumar Kalarikkal<sup>1,3</sup>

<sup>1</sup>*International and Inter University Centre for Nanoscience and Nanotechnology*

<sup>3</sup>*School of Pure and Applied Physics*

*Mahatma Gandhi University, Kottayam-686560, Kerala*

<sup>2</sup>*Optics Group, Raman Research Institute, Bangalore-56008, Karnataka*

E-mail: jemy.jamesmsc@gmail.com

### Abstract

Silver nanoparticles (Ag NPs) are emerging as one of the most versatile products in terms of its application ranging from air disinfection to bio-medical applications. This has led the scientific community search for newer approaches for synthesis of Ag NPs using various methods like chemical, physical and biological processes [1]. These processes had some drawbacks including the need for plethora of chemicals or requirements of multiple washing and heating. The significance of liquid phase Laser Ablation arises in this context.

Here we report the laser assisted synthesis of Ag NPs through the ablation of a Silver target in distilled water at room temperature. The Silver target was irradiated using a Q-switched Nd-YAG laser of wavelength of 1064nm, 9ns pulse width and 10Hz repetition rate. The ablation has been carried for 180mJ of laser energy. The formation of nanoparticles has been observed with the yellow colour change of the transparent aqueous medium.

The yellow aqueous solution of nanoparticles has been characterized using UV-Vis spectroscopy (Shimadzu UV-2450). The absorption spectrum of the solution clearly shows a peak at 402nm indicating the presence of nanoparticles with radius of 10-20nm. This was later confirmed by the High Resolution Transmission Electron Microscopy (JEOL, JEM-2100). The further characterization of the nanoparticles and its correlation with plasma parameters will be carried out. The biomedical application of the as prepared nanoparticles is being planned, in particular for bio-sensing [2]. The present study opens up an efficient green approach for the synthesis of metal nanoparticles of desired size and morphology by tuning the laser parameters through the ablation of the targets in liquid media without polluting the environment by the use of harmful precursors.

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**LP-358**

**Stimulated Brillouin Scattering Of The Beat Wave Of Two Counter-Propagating Lasers In A Plasma**

Kanika Verma, Prateek Varshney, Vivek Sajal, Ravindra Kumar

*Department of Physics and Materials Science and Engineering, Jaypee Institute of Information Technology, Noida, UP-201307*

E-mail: kanikaverma307@gmail.com

**Abstract**

Stimulated Brillouin scattering (SBS) of a non resonant beating mode of two counter-propagating lasers is studied. Two counter-propagating lasers of frequencies  $\omega_1$  &  $\omega_2$  and wave vector  $k_1$  &  $k_2$ , drive a non resonant space charge beat mode at phase matching condition of frequency  $\omega_0 \approx \omega_1 \sim \omega_2$  and wave number  $\vec{k}_0 \approx \vec{k}_1 + \vec{k}_2$ , which decays parametrically into a pair ion acoustic wave  $(\omega, \vec{k})$  and a side band electromagnetic wave  $(\omega_3, \vec{k}_3)$  such that the momentum should remain conserved. Growth rate of SBS comes out to be  $1.25 \times 10^{-4}$  for  $1.7 \times 10^{-12}$  Gauss which is smaller as compared to stimulated Raman for the same parameter.

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**LP-396**

**Terahertz Radiation Generation By The Beating Of Two Cosh-Gaussian Laser Beams In Magnetized Plasmas**

Ram Kishor Singh and R. P. Sharma

*Centre for Energy Studies, Indian Institute of Technology Delhi, New Delhi-110016*

E-mail: ram007kishor@gmail.com

**Abstract**

This paper presents a theoretical model for terahertz (THz) radiation generation by the beating of two cosh-Gaussian laser beams in a collisionless magnetoplasma. Here, the lasers exert a nonlinear ponderomotive force along the transverse direction which imparts an oscillatory velocity to electrons that couples with the density ripple to produce a transient transverse current due to the spatial variation of their fields, driving THz radiation. The importance of laser-beam-width parameters,

decentred parameter, externally applied transverse magnetic field, amplitude and periodicity of the density structure have been discussed for THz emission. The generated THz radiation amplitude increases significantly with increasing magnetic field. By changing the decentred parameter, the peak intensities of lasers can be shifted in the radial direction and a notable modification is found in the THz field amplitude and its conversion efficiency.

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**LP-399**

**Terahertz Radiation Generation By Relativistic Self Focusing Of Hollow Gaussian Beam In Magnetoplasma**

Saba Hussain and R. P. Sharma

*Centre for Energy Studies, Indian Institute of Technology Delhi, New Delhi-110016*

E-mail: [sabahussain44@yahoo.com](mailto:sabahussain44@yahoo.com)

**Abstract**

The present paper proposes a model for the generation of terahertz (THz) radiation by the self focusing of the Hollow Gaussian Beam (HGB) in collisionless magnetized rippled density plasma. At high intensities, when the incident power of the laser beam exceeds the critical power required for self focusing, then the change in the electron mass occurs due to relativistic effect, introducing a non linearity in the plasma leading to the self focusing of the HGB. The non linear interaction of this highly intense self focused HGB with the Electron Plasma Wave (EPW) in the rippled density plasma, satisfying proper phase matching conditions results in the resonant excitation of THz radiations at the difference frequency. In this model the dependence of generated THz radiations on the order of the HGB has been studied. The effect of enhancement in the static background magnetic field has been studied. The results show that the intensity of the generated radiations is highly sensitive to the order of the beam and applied magnetic field.

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**LP-407**

**Second Harmonic Generation Of Upper Hybrid Electromagnetic Radiation From A Plasma Slab**

Manpreet Kaur<sup>1</sup>, Sukhdeep Kaur<sup>1</sup> and Parveen Bala<sup>2</sup>

<sup>1</sup>*Department of Physics, Guru Nanak Dev University, Amritsar-143005*

<sup>2</sup>*Dept of Mathematics, Statistics & Physics, Punjab Agriculture Univ, Ludhiana- 141004*

E-mail : sukhdeep.iitd@gmail.com

**Abstract**

A linearly polarized electromagnetic beam is incident on a plasma slab and reflected and transmitted inside the slab. The beam imparts oscillatory velocity to electrons give rise to density perturbation. Non linear current density is responsible for second harmonic generation of upper hybrid electromagnetic radiation. Increased efficiency of second harmonics is observed for a particular set of parameter

**LP-409**

**A Comparative Study Of Spatial Distribution Of Plasma Parameters Along And Perpendicular To Plasma Flow Direction Via Planar Langmuir Probe**

Satchi Kumari and Alika Khare,

*Laser and Photonics Lab, Department of Physics,  
Indian Institute of technology Guwahati, Guwahati-781039*

E-mail : alika@iitg.ernet.in

**Abstract**

The laser produced ruby plasma has been investigated using planar copper Langmuir probe. The effect of spatial location on plasma parameters for probe placed along (probe 1) and perpendicular (probe 2) to plasma expansion direction is studied. The electron temperature was estimated using characteristic I-V curve of Langmuir probe. It was found to decay exponentially from 14.2 eV to 4.5 eV with increase in distance from 10 mm to 80 mm w.r.t. target in case of probe 1 and from 17 eV to 4.9 eV in case of probe 2 as shown in figure 1(a).



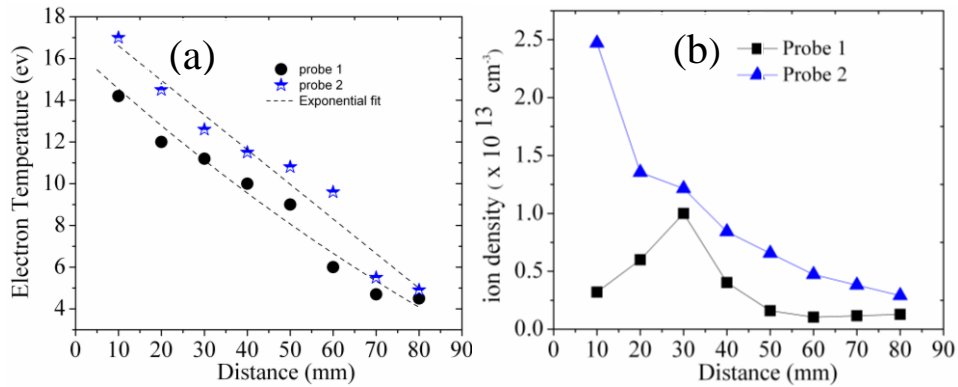


Figure 1. (a) Ion density and (b) Electron temperature as a function of distance.

The ion density was found to first increase from  $1.2 \times 10^{12} \text{ cm}^{-3}$  to  $1.0 \times 10^{13} \text{ cm}^{-3}$  upto 40 mm, and then dropped down to  $1.6 \times 10^{12} \text{ cm}^{-3}$  at 50 mm and finally shows steady behavior for probe 1. In case of probe 2 the ion density was found to decrease from  $2.4 \times 10^{13} \text{ cm}^{-3}$  to  $2.9 \times 10^{12} \text{ cm}^{-3}$  on increasing the probe distance from 10 mm to 80 mm as shown in figure 1(b). The detailed analysis shall be presented in the conference.

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## LP-413

### Performance of Crystalline Lens in the Presence of Laser Induced Multiphoton Ionization

Pradeep Kumar Gupta and R. P. Sharma

*Centre for Energy Studies, Indian Institute of Technology Delhi, New Delhi-110016*

E-mail: pkiitd@gmail.com

#### Abstract

This paper presents a study of the propagation characteristic of a spatial Gaussian laser pulse in crystalline lens, when graded index (GRIN) structure of crystalline lens and the plasma, generated by multiphoton ionization during laser-tissue interaction, are simultaneously taken into account. Multiphoton ionization requires an irradiance threshold to be surpassed, for plasma generation. Plasma introduces the nonlinearity in the crystalline lens due to which propagation of beam gets affected. Decrease in refractive index occurs because of increasing plasma density which causes the defocusing of laser pulse. Extended paraxial approximation has been taken into account for a significant radial profile change of Gaussian pulse. Electrons inside plasma gain energy from electromagnetic field and dissipate out this energy in inelastic collisions with heavy particles, therefore temperature of plasma reaches up to thousands of Kelvin and hence leading to generation of a high pressure. This high pressure and temperature leads to explosive expansion of plasma which in turn causes the bubble formation in crystalline lens.

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**LP-466**

**Nanosecond And Femtosecond Laser Produced Aluminum Plasmas: A Comparative Study**

Pranitha Sankar, Jijil JJ Nivas, N. Smijesh, Reji Philip

*Ultrafast and Nonlinear Optics Lab, Light and Matter Physics Group, Raman Research Institute, Bangalore 560080*

Email: reji@rri.res.in

**Abstract**

Optical emission spectroscopy<sup>1</sup> (OES) and optical time of flight<sup>2</sup> (OTOF) studies of laser produced plasmas (LPP) generated by irradiating an Aluminum target by ultrafast (100fs, 800nm) and short (7ns, 1064nm) laser pulses at 5 Torr nitrogen background pressure have been carried out for various laser fluences. Electron temperatures have been calculated from the line intensities measured from the emission spectra, and electron number densities have been estimated from the measured spectral linewidths. It is found that the electron temperature increases with fluence for ns excitation, while it remains nearly a constant for fs irradiation. This temperature increase is attributed to photoionization and inverse bremsstrahlung processes. Optical time of flight studies reveal the occurrence of two successive peaks (fast and slow, respectively) in the emission dynamics of neutrals for ns excitation. On the other hand, only one peak (the slow peak) is observed in the case of fs excitation. The arrival time of the fast peak remains almost the same with laser fluence, but the slow peak gets delayed in time with fluence. It is shown that the fast peak corresponds to recombined neutrals while the slow peak arises from un-ionized neutrals, similar to OTOF findings reported in certain recent papers<sup>3,4</sup>. Results are analyzed on the basis of fundamental differences pertaining to the generation of ultrafast and short-pulse laser plasmas.

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**LP-483**

**On Pair Production With Focused Ultrafast Intense Laser Pulses: Role of Polarization**

Chitradip Banerjee and Manoranjan P. Singh

*Laser Plasma Division, Raja Ramanna Centre for Advanced Technology, Indore 452013*

E-mail : mpsingh@rrcat.gov.in

**Abstract**

Pair production by focused ultrafast intense laser pulses through the Schwinger mechanism has attracted a lot of attention of late, see for example Ref. [1] and the references therein. These studies are motivated by the quest of a suitable configuration of electromagnetic field which can create electron-positron pair for intensities much less than the critical intensity of  $4.65 \times 10^{29}$  W/cm<sup>2</sup> so that it can be realized by the present day laser and other light source facilities. It has been suggested [2] that multiple colliding ultrashort intense linearly polarized laser pulses offer such a possibility. It is quite natural to ask as to what happens if other possible polarizations for the colliding laser beams are used. This work is an attempt to answer this question. Here the effect of the polarization is considered in a systematic way. For simplicity we consider only two colliding focused laser pulses. The analytical calculation employs a 3-dimensional model of the electromagnetic field which is the exact solution of Maxwell's equations [3]. It is observed that the threshold value of laser peak intensity or laser pulse energy for creating a single pair strongly depends on the laser polarization. It is further found that circularly polarized laser pulses having the identical polarization result in the significant reduction in the threshold value of peak electric field for the process. For a fixed intensity there is an order of magnitude increase in the number of created pairs for the circular polarization. Besides this study, the situation where the frequencies of the colliding laser beams are not same is also analyzed.

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**LP-502**

**Interaction Of High-Contrast, Ultrashort-Pulse, High Intensity Laser With Matter: Study Of Plasma Emission And Cherenkov Radiation**

Indranuj Dey, Amitava Adak, Amit D. Lad, Moniruzzaman Shaikh, and G. Ravindra Kumar

*Tata Institute of Fundamental Research, Dr. Homi Bhabha Road, Colaba, Mumbai – 400005*

E-mail : indranuj.dey@tifr.res.in

**Abstract**

The rapid advancement in the field of table-top high-contrast, ultra-short pulse, high intensity lasers, has enabled the generation of high density plasmas, using all types of targets. The high density plasma furnishes hot electrons and energetic ions, the transport dynamics of which are interesting from both physics and application points of view [1,2]. Since the electrons are much more mobile and intense, their interaction with the plasma and bulk matter yields various types of radiation viz., X-ray, Cherenkov, optical, THz and microwaves. These radiations carry the signature of the hot electron jets (0.1 – 2 MeV), and have often been used as a diagnostic to study their interaction dynamics [3,4].

In this work, an 800 nm laser with pulse width  $\sim 30$  fs is focused onto a thick dielectric (BK7) slab with resultant peak intensity in the range of  $\sim 10^{18} - 10^{19}$  W/cm<sup>2</sup>. The plasma dynamics and hot electron transport in the bulk transparent medium is investigated by rear-side imaging of the plasma emission and Cherenkov radiation respectively, by an ICCD camera. The novelty of the experiment lies in the achievement of a high laser pulse contrast ratio (LPCR = pedestal/peak)  $\sim 10^{-9}$ , which is 3 orders of magnitude better than previous experiment [3]. This discounts the possibility of a dense pre-plasma formation and subsequent reflection of the main pulse, thereby allowing better coupling of the laser to the target. It is of great interest to observe how the high-contrast affects the generation of fast electrons by studying the Cherenkov radiation. While the plasma emission studies help in understanding the temporal plasma evolution.

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# **NUCLEAR FUSION & TECHNOLOGY**



**NF-016**

**Development Of Beam Diagnostic For 400 MeV Proton Beam Intensity Using Chromox-6 Scintillation Screen At Fermilab MuCool Test Area**

M. R. Jana<sup>1</sup>, M. Chung<sup>2</sup>, B. Freemire<sup>3</sup>, M. Leonova<sup>4</sup>, A. Moretti<sup>4</sup>, M. Palmer<sup>4</sup>, A. Tollestrup<sup>4</sup>,  
Y. Torun<sup>4</sup> and K. Yonehara<sup>4</sup>

<sup>1</sup>*Institute for Plasma Research, Bhat, Gandhinagar – 382428*

<sup>2</sup>*Ulsan National Institute of Science and Technology, Ulsan 689-798, Korea*

<sup>3</sup>*Illinois Institute of Technology, Chicago, Illinois – 60616, USA*

<sup>4</sup>*Fermi National Accelerator Laboratory, Batavia, Illinois – 60510, USA*

E-mail: muktijana@gmail.com

**Abstract**

Muon Colliders and Neutrino Factories need a low emittance muon beam which can be produced by a process called Ionization cooling. In this process, a muon beam is sent to a low-Z absorber (e.g. Hydrogen) to reduce all components of the momentum and only the longitudinal component is replaced by using RF cavities. These absorber and RF cavities are placed in a strong magnetic field to focus the muon beam in the absorber. MuCool Test Area (MTA) at Fermilab is actively involved to develop this technology. In this program, demonstrating various types of RF cavities in a high magnetic field environment with intense proton beam has been progressed. As a unique approach, we have tested a High Pressure RF (HPRF) cavity filled with hydrogen gas by using a 400 MeV proton beam in an external magnetic field (3 Tesla). The gas acts as a cooling material. When the energetic proton beam passes through the HPRF cavity, it ionizes the gas and produces the electron-ion pairs in the cavity. Such a beam-induced plasma consumes RF power and loads the cavity. The plasma dynamics was studied and was successfully controlled by doping an electronegative gas in the cavity. The measurement of beam position and profile are essential requirement in this analysis. When a dense hydrogen gas was contained in the cavity no energized beam monitor device could be used due to safety reason. Besides, the beam monitor should work in a strong magnetic field. We have developed a passive beam diagnostic system using the Chromox-6 scintillation screen. A CCD camera with a telescope lens was located outside the hazard zone to monitor the image. This paper shall present the system and the analysis of the beam position and beam profile. A neutral density filter was assembled to the CCD camera to reduce the intensity of scintillating light. The background pedestal was filtered out from the raw data and the image was fitted with Gaussian function to compute the beam size. The beam profile obtained from scintillation screen was compared with multi-wire beam profile. The beam transmission efficiency through a collimator with a 4 mm diameter hole was measured by the toroidal current monitor. The transmission efficiency estimated from the image was consistent with the toroid measurement. Consequently, the linearity of the system was quite good even the screen was exposed  $\sim 10^{12}$  protons per pulse.



**NF-025**

**Development And Operation Of A Flexible Transmission Line Based Novel 17 KJ Capacitor Bank With Matching Plasma Focus Device**

R. K. Rout, Ram Niranjana, Rohit Srivastava and Satish C. Gupta

*Applied Physics Division, Bhabha Atomic Research Center, Mumbai-400 085*

E-mail: niranjan@barc.gov.in

**Abstract**

Pulsed power technology is an advanced field of research. A pulsed neutron source is very much important for its numerous applications. In this context a novel capacitor bank (CB) with an appropriate plasma focus (PF) device were developed and were operated here. The CB consists of six numbers of custom made and indigenous capacitors (10 $\mu$ F, 25 nH, 25 kV, 34 cm x 24 cm x 60 cm size, 80 kg weight each). The capacitors are connected in parallel to a common collector plate having an open air spark gap. The output points of the spark gap are joined to the plasma focus device through 48 numbers (optimized for available space) of five meter long RG 213 cables (50 $\Omega$ , 245nH/m, 10 mm diameter). The plasma chamber of the PF unit is connected to a diffstac vacuum pump and gas filling system with a 5 meter long SS below. The design provides the flexibility of positioning the PF unit, the pulsed neutron source at desired place for any dedicated application away from the capacitor bank, the vacuum system and the power supply unit. The current derivative of the discharge circuit is monitored through a Rogowsky coil. The time period observed was 16.5  $\mu$ S. The energy driver has delivered 17 kJ (60  $\mu$ F, 24 kV) of energy and peak current of 491 kA to the PF load. The estimated neutron yield from the existing scaling law ( $Y_n \sim 1.7 \times 10^{-10} I_b^{3.3}$ ;  $I_b$  is CB current in Amp.) is  $1.3 \times 10^9$  per shot. The time integrated and time resolved neutron emission studies are carried out with a calibrated silver activation detector and with a plastic scintillator detector coupled to a photomultiplier tube respectively. The average neutron yield obtained for the ten best shots was  $(8.1 \pm 0.4) \times 10^8$  neutrons/shot and the average neutron pulse width was  $44 \pm 6$  ns at 17 kJ of operation energy with 5mb deuterium gas filling pressure. The unit is expected to generate 100 times more neutrons with use of tritium gas along with deuterium gas. The system is planned to be used in thermal neutron activation analysis. The details of the development and results shall be presented.

**NF-065**

**Study Of Impurities In Vacuum Vessel In Different Campaigns Of SST-1**

Kalpesh R. Dhanani, Ziauddin Khan, D. C. Raval, Siju George, Y. Paravastu, P. Semwal, G. Ramesh,  
F. S. Pathan, M. S. Khan, S. Pradhan

*Institute For Plasma Research, Bhat Village, Gandhinagar, 382428*

E-mail : kdhanani@ipr.res.in

**Abstract**

SST-1 is designed as a medium size steady state long pulse operational tokamak with superconducting TF & PF magnets. Vacuum vessel is assisted with various in-vessel components like ECRH, ICRH, Limiters and other diagnostic system. Vessel conditioning plays a crucial role in tokamak to achieve good confinement and high performance plasmas by means of controlling impurities. Impurities cannot be removed alone by pumping the vacuum vessel as the gas molecules tend to hide and adsorb on the surfaces of vacuum vessel and other in-vessel components. The impurities levels in vacuum vessel are mainly removed by wall conditioning procedure which consists of vessel baking and Glow discharge cleaning (GDC). Vacuum vessel is baked at 120 °C, limiters at 250 °C and pumping line at 100 °C for the initial vacuum conditioning in order to remove various kinds of impurities like H<sub>2</sub>O, C, H and O<sub>2</sub>. GDC is also performed regularly as a standard wall cleaning procedure every day for 2 hours using hydrogen gas after normal plasma operation to further reduce these impurities. The paper will describe the evolution of impurities and their comparisons for different SST-1 campaigns.

**NF-072**

**DAC Controlled Voltage Variable RF Attenuator For Generating RF Pulses of Different Shapes and Amplitudes For ICRH System.**

Manoj Singh, HM Jadav, Ramesh Joshi, Sunil Kumar, Srinivas YSS, SV Kulkarni  
and RF-ICRH group

*Institute for Plasma Research, Bhat, Gandhinagar – 382428*

E-mail: parihar@ipr.res.in

**Abstract**

ICRH system has to be used for interface and antenna conditioning, heating, pre-ionization and current drive experiments in the Aditya and SST-1 tokamak [1] machines. ICRH-DAC (Data Acquisition and Control) controls and monitors the RF power (1.5MW, 20-40 MHz) to dummy load / Aditya / SST-1 tokamak [1]. It is necessary that DAC system should provide flexibility to generate variable duty cycles and variable amplitude pulses upto maximum duration. Generation of this RF-shot pulse by DAC is very critical task as this pulse has been used to

- Define the duration of the RF power generated by the 1.5MW cascaded amplifier.

- Pulse acts as a trigger pulse to the DAC situated at the SST-1 hall.
- Pulse acts as a trigger pulse to the ICRH-Diagnostics placed at different locations.
- Pulse is used as a reference point for the data acquisition and post shot analysis.
- Pulse used to provide the time delay between two different system operations.

Controlling parameters of RF-pulse from the DAC are delay time, on time, off time, fall time, no of pulses, amplitude etc. for the desired pulse durations. System operational performance monitoring and post acquisition shot analysis is referenced from this pulse only.

During the High power testing of 1.5MW tube, it was observed that HVPS overshoots as current drawn from power supply increased beyond 22A, towards the end of pulse as this is unregulated supply and this limitations preventing further higher power commissioning work. To overcome this overshoot problem DAC hardware pulse generation facility is modified and new circuit is integrated with the DAC hardware and software.

This Poster discusses functionality of in-house developed hardware and application software associated with pulse generation, integration with the system and test results.

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Paper code: NFE

**NF-074**

## Helium Ion Irradiation On The Materials Relevant To Fusion Research

N.J. Dutta, N. Buzarbaruah, S.R. Mohanty

*Center of Plasma Physics-Institute for Plasma Research, Sonapur, Kamrup-782402*

E-mail: nilamjadu889@gmail.com

### Abstract

In fusion research, materials study plays an important role to understand their properties in harsh fusion conditions for the better performance of fusion reactors. Hence, in recent years, there has been an increasing interest in testing radiation induced damage on fusion reactor materials through deployment of small scale laboratory experiments [1–5]. It is well known that in fusion reactors, there is a wide presence of alpha particle interaction with the reactor materials. Therefore, detailed study on alpha particle interaction on reactor materials will give better insight to physical damages as well chemical changes occurred due to the said interaction. Apprehending importance of the subject we have studied the helium ion irradiation on the fusion materials (tungsten and graphite) by using an ion source.

After irradiation of helium ions, both the reference and irradiated tungsten samples were characterized by different characterization tools to know the details changes that occurred due to ion irradiation. The optical micrographs of ion irradiated samples show uniform mesh of cracks. However, micrographs of Field Emission Scanning Electron Microscope (FESEM) show various types of crystalline defects such as voids, pinholes, bubbles, blisters which arise due to multiple heat loads on tungsten surface by helium ion pulses. Formations of some nanostructures are also observed at certain places in FESEM micrograph. It is noticed that the prominent peaks of X-ray diffraction spectrum (XRD) of irradiated samples are shifted towards higher Bragg angles.

On the other hand, in the case of irradiated graphite samples, FESEM micrographs show mostly rounded microstructure at higher resolution. While viewed under Transmission Electron Microscope at very high resolution, the reference and irradiated samples illustrate layered type two dimensional sheaths and rounded structure, respectively. XRD spectrum of irradiated sample indicates appearance of some new peaks. Further we are analyzing the graphite samples by Raman spectroscopy and X-ray Photoelectron Spectroscopy to establish some of our encouraging observations. The detailed results will be presented in the paper.

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### NF-075

#### Development Of IECF Based Linear Neutron Source At CPP-IPR And Its Current Status

N. Buzarbaruah, N.J.Dutta, J.K.Bhardwaz, D. Borgahain, S.R.Mohanty

*Centre of Plasma Physics-Institute for Plasma Research, Nazirakhat, Sonapur, Assam-782402*

E-mail: neelanmiks@gmail.com

#### Abstract

Inertial Electrostatic Confinement Fusion (IECF) device is a relatively compact neutron source having the advantage of confining ions in converging electrostatic fields for fusion purposes. It has been reported that this simple device can deliver  $10^8$  DD n/s in continuous mode of operation [1, 2]. Efforts are being made for the development of a cylindrical IECF device at CPP-IPR. We had earlier reported about the theoretical and computational techniques executed for the conceptual design of the linear neutron source [3]. It was seen that neutron production rate (NPR) and ion density has a linear dependence on the applied potential.

In this present work, we simulated the electric potential distributions and ion trajectories for different grid geometries of electrodes using SIMION 8.0 code [4]. The results predicted ion recirculations for different grid transparencies of inner electrode and a better fusion is expected with optimum transparency in the range of 84%-92%. Recently, IECF chamber was installed and integrated with all necessary components namely the Turbo Molecular Pump (TMP), gate valve, pressure gauges, Residual Gas Analyzer (RGA) and high voltage DC feedthrough (150 kV). After coupling all the supporting units in the chamber, vacuum compatibility was checked and the base pressure of  $10^{-7}$  mbar was achieved. Filamentary discharge plasma in  $H_2$ , He and Ar medium was produced and was characterized using an Optical Emission Spectroscope (OES) and Langmuir probe. Details of the results will be presented in the paper.

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**NF-077**

## **RF Pulse Control For ICRH Heating Experiment In ADITYA**

H M Jadav, Manoj Parihar, Ramesh Joshi, Sunil Kumar & S.V. Kulkarni

*Institute for Plasma Research, Bhat village, Gandhinagar – 382428*

Email: jadav@ipr.res.in

### **Abstract**

Ion Cyclotron Resonance Heating (ICRH) performed several physics experiments like heating, wall conditioning, density mitigation and disruptions. VME based ICRH Data Acquisition Control system (DAC) has been commissioned since long time. Feedback control for RF power is must when system is working with high power in kW. RF power delivers in pulse mode. VME based DAC system generates digital pulse for desired time required for experiment. In pulse duration due to plasma impedance power may reflect back to source. It requires arrangement for suspend the RF pulse during high reflection of RF power. This paper presents the control circuit design and validation for ICRH heating experiments in Aditya. This circuit sense reflected power signal from directional coupler and compare with reference signal. If reflected power signal is more than reference signal then it switches off RF pulse for latch time which is expectedly 5ms. It resumes RF pulse after suspending RF pulse for settable time. As plasma response time is around 5 ms so one can get continuous heating for full RF pulse duration.

**NF-078**

**ICRH DAC Software Modifications for ICRH Experiments in ADITYA**

Ramesh Joshi<sup>1</sup>, H M Jadav, Manoj Parihar, B R Kadia, K M Parmar, A Varia, Gayatri Ashok, Y S S Srinivas, Sunil Kumar & S.V. Kulkarni

*Institute for Plasma Research, Bhat village, Gandhinagar – 382428*

<sup>1</sup>Email: rjsoshi@ipr.res.in

**Abstract**

Ion Cyclotron Resonance Heating (ICRH) performed several physics experiments like heating, wall conditioning, density mitigation and disruptions. VME based ICRH Data Acquisition Control system (DAC) has been developed since so many years. There are several changes and modifications have been performed for different experiments. This paper presents recent changes and modification with ICRH DAC software. RF heating experiment demands variable duty cycle pulses rise and decay time. RF attenuator has been introduced for control RF with different shape and amplitude pulses for experimental requirements. Decay with RF shot used to control rise of voltage at the end of pulse for high voltage power supplies. VME data acquisition cards have been replaced with new analog input modules as old cards have giving random problems and those are not repairable. Analog input modules have been procured and driver program have been developed to integrate with existing system. VME systems has been triggered using external trigger from main control system has been putted in polling mode by which it continuous monitoring and control while waiting for trigger. We ensure with testing for failsafe operation of each and every components. Several encouraging results have been achieved and published with above mentioned modifications.

**References:**

[1] *Generation of multiple analog pulses with different duty cycles within VME control system for ICRH Aditya system*, PSSI 2008, BARC

**NF-080**

**High Temperature Vacuum Baking Of PFC Graphite Tiles Of SST-1**

Gattu Ramesh Babu, Y. Paravastu, Arun Prakash, Ziauddin Khan, S. Pradhan

*Institute for Plasma Research, Bhat Village, Gandhinagar, 382428*

E-mail: gattu@ipr.res.in

**Abstract**

Plasma facing components (PFC) of SST-1 Tokamak is fabricated using graphite tiles which are mechanically attached to copper back plates. These graphite tiles have adsorbed many impurities and water vapour during machining. Prior to assembly of these graphite tiles, these tiles have to be baked in good vacuum condition at higher temperature. For this purpose, a specially designed High

temperature vacuum chamber is used to bake all the 3800 graphite tiles of all PFCs. About 200 tiles per batch are baked in programmed manner upto 1000°C for 10 hours flat-up at  $1.0 \times 10^{-5}$  mbar. Residual gas analyzer (RGA) is used for analyzing the contribution / release of different adsorbed gases. After baking, commercial grade vacuum sealing machine is used to pack baked graphite tiles at  $1.0 \times 10^{-2}$  mbar till further usage. About 10 batches of tiles were baked and remaining are in progress. This paper describes high temperature vacuum baking chamber usage, procedure established and partial pressure estimation of different gases at different temperatures based on RGA data.

## NF-081

### **Commissioning Of 10kV, 7A HVDC Integrated Power Supply For Triode Based 20KW Stage CWRP Amplifiers**

Kirit M Parmar, Bhavesh R Kadia, YSS Srinivas, H M Jadav, Ramesh joshi,  
SV Kulkarni and ICRH group

*Institute for Plasma Research, BHAT, Gandhinagar-382428*

E-mail: kmparmar@ipr.res.in

#### **Abstract**

1.5MW amplifier chains at different frequencies are under development for various fusion related ICRH experiments on Aditya and SST1 tokamaks. A low power RF signal at required frequency is amplified in several stages namely Low Power Amplifier, 2kW, 20kW, 200kW and 1.5MW to obtain the required RF output power. Triode tube is generally used in the 20kW stage RF amplifier which requires 10kV, 7A power supply as Plate power supply. In addition, a soft start filament power supply is also integrated in the same power supply panel. Integrating the plate and filament supplies enables easy controls and interlocks necessary for following proper sequential switching. Integrated power supply (IPS) consists all necessary protections e.g. over voltage, over current, under voltage. The 10kV, 7A Integrated Power supply (IPS) is of Modular topology and is tested to meet all tube requirements generally used in 20kW stage amplifiers. It has very low ripple and good regulation. IPS has two power supplies which are installed in the same panel. A PLC ensures smooth control and provides adequate protection. The two supplies interconnected in a specific configuration for the specific operation of the amplifiers. Output of plate power supply return (negative) is designed to withstand 10 kV DC with respect to ground as per system requirement. The power supply is installed and commissioned at IPR after successful electrical tests including open circuit test, load test, load regulation test, calibration test, wire burn test, protection circuit test, heat run test. This paper presents results of factory acceptance tests and the commissioning tests performed at site. Typical specifications, topology, protections, controls, operation sequence of constituent supplies of IPS are mentioned.

#### **References:**

[1] Design and Development of DC Power Supply System for 1.5MW, 40MHz, RF Amplifier. Pankaj Lochan Khilar, Azadsinh Makwana, Jignesh Soni, K.G. Parmar, K. Sathyanarayana, YSS Srinivas, Mahesh Kushwah, D. Bora and RF group. **Power Modulator Conference 2006, USA**

**NF-082**

**Commissioning Of Integrated Power Supply (15kV, 28A And Three Auxiliary Supplies) For Testing Of 200kW Stage CWRF Amplifiers**

Bhavesh R Kadia, YSS Srinivas, Kirit M Parmar, H M Jadav, Ramesh joshi, Sunil Kumar,  
S V Kulkarni and ICRH group

*Institute for Plasma Research, Bhat, Gandhinagar-382428, Gujarat*

E-mail : brkadia@ipr.res.in

**Abstract**

Institute For Plasma Research (IPR) is involved in the development of High Power RF sources for various fusion related ICRH experiments. All the high power RF tetrode tubes need a DC high voltage and high current power supplies for Aditya & SST-1 Tokamaks i.e. Plate power supply, Screen grid power supply, Control grid power supply and soft start Filament power supply with necessary indications, interlocks, controls and protections. Integrated power supply (IPS) consists all the above four power supplies along with required control and protections e.g. over voltage, over current, under voltage and reverse current etc.

The ratings of constituent power supplies' of IPS are chosen to meet requirements of Tetrode based 200 kW stage CWRF amplifier used in High Power ICRH systems. IPS has four power supplies which are integrated with each other, PLC controlled and interconnected in a specific configuration for the specific operation of the RF amplifiers. Outputs of all power supplies are floating at 10 kV DC as per system requirement. The power supply is installed and commissioned at IPR with all electrical tests including open circuit test, load test, load regulation test, calibration test, wire burn test, protection circuit test, heat run test, controls and interlocks signals tests etc.

This poster presents results of the commissioning tests, typical specifications, topology, protections, controls, operation sequence and interfacing with DAC of constituent supplies of IPS.

**NF-083**

**Design and Development of Protection Circuits for High voltage Power Supplies used in various stages of 1.5 MW CWRF Amplifier**

Bhavesh R Kadia, YSS Srinivas, Kirit M Parmar, S.V. Kulkarni & ICRH Group.

*Institute for Plasma Research Bhat, Gandhinagar-382428, Gujarat*

E-mail : brkadia@ipr.res.in

**Abstract**

High voltage and high current power supplies used for high power RF amplifiers require protection circuits for individual supplies as well as integrated overall system. Protection circuit is necessary to protect the system in the event of fault or undesirable operating condition. Protection circuit and isolation cards are designed, developed in house and are in use.



A protection circuit, forms a critical part of control and interlock system and it protects the power supply as well as load. The protection circuits of individual supplies are fed with voltage and current signals from sensing devices like potential divider and DCCT or pulse CT etc. Appropriate action would be taken by the circuit to protect the supply in the event of over voltage or over current, In addition, necessary signals are also generated by the protection circuit to act on other supplies of the amplifiers system. The isolation cards consists Transmitter and Receiver which separate out the ground reference of low voltage electronics from high voltage power circuits is required for proper operation of protection card. Protection card has been subjected to modifications with growing requirements and complexity of the systems. The protection card, in its present form, enables to generate TTL signal with different logics, relay based PFC signal, crowbar-firing signal, in addition to removal of mains input to the supply in case of faults.

This paper describes the critical requirement, actual circuit used, applications and test results

## NF-084

### **Development, Testing And Integration With DAC Of 450 A DC Filament Power Supply For 200 KWCWRF Amplifier**

Bhaves R Kadia, Kirit parmar, YSS Srinivas, H. M. Jadav, Azad Makwana,  
S.V. Kulkarni & ICRH Group.

*Institute For Plasma Research, BhatGandhinagar-382428, Gujarat*

E-mail : brkadia@ipr.res.in

#### **Abstract**

The filament of 200kW tetrode based amplifier requires a low voltage and high current power supply. Stable operation of the amplifier demands low value of ripple, good regulation, reliable controls and protections for all power supplies. The Filament Power Supply (FPS) is used to feed the filament of tetrode in 200kW CWRF source. A 200kW CWRF amplifier needs Tetrode tube as an amplification device to generate high power at RF frequencies for plasma heating application.

The selected FPS topology is a conventional 12 pulse DC power supply with primary voltage controlled by power controller which is followed by step-down transformer that has two secondaries. The output of each secondary (star and delta) is rectified with diode-bridges. DC output the bridges are connected in series configuration and filtered. The protections like over voltage, over current and hard wired interlocks with cooling system and DAC are incorporated in the supply. The power supply has provision for local operation (front panel controls) or remote operation by the data acquisition control (DAC) as required. This poster presents the required specifications, design criteria, fabrication details, interfacing with DAC and results.

## NF-086

### **2D Thermal Design Validation Of Use Of Beryllium As Plasma Facing Material And CuCrZr As Heat Sink Material For ITER Shield Blanket Module First Wall**

Ritesh Kumar Srivastava, Paritosh Chaudhari

*Institute for Plasma Research, Gandhinagar-382424*

E-mail: riteshs@ipr.res.in

#### **Abstract**

ITER Shield Blanket Module (SBM) is the one of the most challenging component of ITER machine. It consists of First Wall (FW) and Shield Block (SB) as its two major parts. First wall is detachable from SB and design for operational life of 10 years on the other hand SB is designed for 20 Yrs. FW is the critical part which faces plasma directly. Function of FW is to protect the Vacuum Vessel (VV) and other in vessel components from direct plasma heat load. It also provides passage to different diagnostics and also performs as a heat exchanger using water as a coolant. There are number of plasma facing materials (PFM) like Be, W etc and heat sink material like CuAl25 and CuCrZr.

This report presents the use of Beryllium as plasma facing material and CuCrZr as heat sink material for ITER SBM FW with the use of FEM code i.e. ANSYS. 2D thermal analysis was done to estimate the temperature gradient on the materials and was compared with other PFM and heat sink materials. Water was used as coolant in the analysis.

This report provides confidence to explore the engineering design of ITER SBM in depth which establish the methodology for the design tool development and allow to go further designs validation.

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## NF-096

### **Study The Effect OF Thermal Cyclic On SS316L To CuCrZr Brazed Joint Sample**

K.P Singh, Alpesh Patel , Kedar Bhoje, S S Khirwadkar, S Belsare, Nikunj Patel, Prakash Mokaria

*Divertor & First Wall Technology Development Division, Institute for Plasma Research, Bhat,*

*Gandhinagar 382 428*

E-mail: kpsingh@ipr.res.in

#### **Abstract**

SS316L is known structural support material in ITER like tokamak machine. In divertor PFC (Plasma facing component) & first wall module, the dissimilar material joining such as SS316L material with heat sink material CuCrZr (CRZ) is an important considerable area both in thermal as well as

structural [1-4].

In the present study, the effect of thermal cycles on the SS/CuCrZr brazed joint sample will be investigated. The SS/CRZ sample is prepared by vacuum brazing route using nickel based filler material. Vacuum brazing of SS/CRZ is performed @ 970C for 15mins under high vacuum of  $10^{-6}$  mbar using commercially available nickel based filler material, NiCuMn-37. Custom made graphite fixtures were used in the vacuum brazing. Uniform load (SS Pin) of 5kPa was applied during the brazing.

The SS/CRZ brazed joint sample has undergone initially 100 (hundred) no. of thermal cycles @ 450C, 5Sec ON/OFF using Gleeble 3800 machine (Thermo mechanical Simulator).

The brazed sample was undergone for Non-destructive testing (NDT), microstructural examination and micro-hardness measurement before and after the thermal cyclic study. The results of the experimental works will be presented in the paper.

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## NF-109

### Glow Discharge Wall Conditioning System Of SST-1

D.C.Raval, Ziauddin Khan, Kalpesh R. Dhanani, Siju George, P. Semwal, Y. Paravastu, G. Ramesh,  
F. S. Pathan, M. S. Khan, S. Pradhan

*Institute for Plasma Research, Bhat, Gandhinagar 382 428*

E-mail: raval@ipr.res.in

#### Abstract

Glow discharge conditioning (GDC) is one of the most common and efficient wall conditioning used in Tokamak devices. GDC with hydrogen gas is found to be an efficient and standard technique to reduce carbon and oxygen impurities residing on the wall of vacuum vessel. Its efficiency depends on the glow parameters, base pressure and the spatial distribution of glow inside vacuum vessel. For this purpose, two numbers of DC power supplies of 0-15 A, 0-1 kV were installed at two radial locations in SST-1. GDC-H with 0.15 A/m<sup>2</sup> current density was found to be optimized for SST-1 wall conditioning. The baking in SST-1 reduces the water (H<sub>2</sub>O) vapor by 95% and oxygen (O<sub>2</sub>) by 60% whereas the GDC reduces the water vapor by an additional 57% and oxygen by another 50% as measured with residual gas analyzer. The minimum breakdown voltage for H-GDC in SST-1 Tokamak was experimentally observed to 300 V at 8 mbar cm. As a result of these adherences, SST-1 VV achieves an ultimate of  $4.5 \times 10^{-8}$  mbar with two turbo-molecular pumps with effective pumping speed of 3250 l/s. The detailed of SST-1 GDC with evolution of impurities is discussed and presented.

## NF-110

### The Role Of $E \times B$ Flows On Global Linear Microinstabilities

Deepak Verma, Aditya K. Swamy, R. Ganesh

*Institute for Plasma Research, Gandhinagar Gujarat, 382428*

E-mail: deepak.verma@ipr.res.in

#### Abstract

In many major Tokamaks around the world, these low frequency microinstabilities are routinely suppressed by the presence of an “electric field”. This electric field could be applied from “outside” or could be self-consistently generated by the plasma processes themselves, for example, shearing fields such as zonal flows and the shear of the radial electric field produces a decorrelation of the mode, thus leading to stabilization. They are also believed to play role in L-H transition, which is a phase transition-like phenomena from low (L) confinement mode to high (H) confinement mode [1][2]. Hence it is important to understand the effect of flow shear on the nature of global microinstabilities.

We present here a formulation which attempts to incorporate an equilibrium flow shear in the instability analysis of global microinstabilities which includes key physics elements such as Landau damping, passing and trapped particle physics, radial and poloidal coupling due to magnetic drifts, finite Larmor radius effect (FLR) effects to all orders and is fully electromagnetic in nature and Transit frequency resonance [3][4]. Details of the formulation will be presented.

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## NF-119

### Dynamic Heater System For Controlling The Temperature Of Turbines Bearing In SST-1 Helium Cryogenic System

Dikens Christian, R. Panchal, P. Panchal, R. Patel, V.L. Tanna and S. Pradhan

*Institute For Plasma Research, Bhat, Near Indira Bridge, Gandhinagar-382428, Gujarat*

E-mail: dikens@ipr.res.in

#### Abstract

During the recent SST-1 cool-down campaigns, we have observed that bearings temperature of turbine A and B gets decreasing below the ideal operating limits of 5°C. It creates an alarming situation at 0°C and at very cold condition below -5°C turbines A and B get trip. The technical reason behind this observation is, cold helium gas comes out from the purifier gets back to the return line is

quite cold in the range of 80 - 82 K mix with the room temperature gas. Due to this fact, temperature of the helium gas at the turbines bearing found relatively colder than the room temperature. In order to overcome this issue, we have adopted temperature monitoring and controlling philosophy to maintain the operating temperature of helium gas at the desire location. Installation of dynamic heater system serves the purpose of helium gas temperature control at turbines bearings. This paper describes the heater sizing, dynamic control of heater scheme and other technical benefits. This is one of the essential technical aspect to facilitate overall smooth and reliable operation of the HRL system.

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## NF-120

### Upgradation Of Control System For The SST-1 LN2 Shield Distribution After Valve Box Installation

G.Mahesuria, R.Patel, R.Panchal, D.Sonara, H. Nimavat, GLN Srikanth, V.L.Tanna and S.Pradhan

*Institute for Plasma Research, Bhat, Gandhinagar-382428, Gujarat*

E-mail: gaurang@ipr.res.in

#### Abstract

The Steady state superconducting tokamak (SST-1) machine consists of cable-in-conduit-conductor (CICC) wound superconducting toroidal as well as poloidal coils, cooled using 1.3 kW at 4.5 K helium refrigerator -cum- liquefier (HRL) system [1]. Liquid nitrogen (LN2) cooled bubble shields are provided to reduce the direct thermal heat load on the coils inside the cryostat. The flow of cryogens in different paths is regulated using the dedicated supply and return distribution valve box in replacement of contingency plan [2]. Monitoring and controlling system is essential for the hydraulically balanced cool-down of the SST-1 80 K thermal shields. In order to envisage this operation a program is develop with the use of ladder language in the existing Schneider PLC and the Graphical user interface developed in the Wonderware Intouch SCADA. It is a state of art with independent applications developed in Intouch SCADA software for real time data monitoring, control, logging and historical logged data retrieving. The performance of the SCADA based data acquisition and data retrieval system found to be satisfactory during the recent SST-1 cool down campaign. This paper describes the commissioning and the validation results of the SST-1 LN2 distribution system.

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Cryogenic Systems Performances In SST-1
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April 2014, Integrated Liquid Nitrogen Distribution Network for the cooling of SST-1 80K  
thermal shields system.

## NF-121

### Drift Kinetic Equations (DKE) And Neoclassical Transport

Madhurjya P Bora

*Physics Department, Gauhati University, Guwahati 781014*

E-mail : mpbora@gauhati.ac.in

#### Abstract

In this talk, we are presenting a comprehensive theory of the neoclassical transport in toroidal devices such as tokamaks with the help of the Drift Kinetic Equations (DKE). We systematically derive the neoclassical theory by defining the collision operator for passing and trapped particles. We then outline the derivation of the equilibrium solution to the DKE with a model collision operator. Finally, we outline an efficient numerical scheme to solve the complicated set of equations with a parallel solver in the toroidal canonical momentum space.

## NF-124

### Effect On Electrostatic And Magnetic Fluctuations Due To Biased Electrode In ADITYA Tokamak

Pravesh Dhyani, J. Ghosh, Y.C. Saxena, P.K. Chattopadhyay, R.L. Tanna, D. Raju, S. Joisa, S.B. Bhatt, P.K. Atrey, C.N. Gupta, C.V.S. Rao, R. Jha and ADITYA team

*Institute for Plasma Research, Gandhinagar, 382 428*

E-mail: pravesh@ipr.res.in

#### Abstract

Suppression of electrostatic fluctuations has been observed in many fusion devices during L-H transition, considered to be due to sheared  $E_r \times B_\phi$  drift flow. Stabilization of  $E_r \times B_\phi$  flow shear due to large sheared radial electric field has been repeatedly emphasized to explain L-H transition in magnetically confined fusion devices [1]. Role of current density profile modification is also considered as a candidate for the observation of precursor magnetic oscillations in the H- mode transition [2, 3]. Biased electrode experiments [4] have been performed in ADITYA tokamak to study confinement improvement and effect of biased electrode on the stability of magnetohydrodynamic modes through  $E_r \times B_\phi$  flow shear stabilization [5].

With the application of bias voltage on electrode placed inside the Last Closed Flux Surface (LCFS) above some threshold voltage in typical discharges of ADITYA tokamak, significant reduction in both magnetic and electrostatic fluctuations leading to two distinct regimes of improved confinement with different characteristics are observed. The important observation is that the magnetic fluctuations are reduced prior to that of electrostatic fluctuations. In this paper experimental observations on ADITYA tokamak discharges, in which reduction of coupling between electrostatic turbulence and

magnetic fluctuations via current profile modification, giving rise to improved confinement regimes during onset of biasing have been discussed.

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## NF-125

### High-Current Long-Pulse Plasma Discharges In Aditya Tokamak

R.L. Tanna, Pintu, Kumar, J. Ghosh, K. A. Jadeja, K. M. Patel, Nilesh Patel, K.S. Acharya, S. B. Bhatt, K.S. Shah, M.N. Makawana, C.N. Gupta, M. B. Kalal, D. S. Varia, V. K. Panchal, N. C. Patel, C. Chavda, A. Amardas, D. Sangwan, Harshita Raj, P. K. Chattopadhyay, K. Sathyanarayana, S. K. Jha, D. Raju, M.V. Gopalkrishna, K. Tahiliani, R. Jha, S. Purohit, J. V. Raval, Asim Kumar Chattopadhyay, Y. S. Joisa, C.V.S. Rao, Umesh Nagora, P. K. Atrey, S.K. Pathak, N. Virani, N. Ramaiya, S. Banerjee, M. B. Chowdhuri, R. Manchanda, Kiran Patel, J. Thomas, Ajai Kumar, S. Gupta, Kumar Ajay, S. Pandya, K. Mahavar, M. Gupta, Praveenlal E.V, Minsha Shah, Praveena Kumari, R. Rajpal, S. V. Kulkarni & ICRH Group, B. K. Shukla & ECRH Group, P.K. Sharma & LHCD Group, R. Goswami, R. Srinivasan, I Bandyopadhyay, R.P. Bhattacharyay, Amit Sircar, N. Ramasubramanian, H. D. Pujara, H.A. Pathak, A. Vardharajalu, A. Das, S.P. Deshpande, K.K. Jain, Prabhat Ranjan, D. C. Reddy, D. Bora, Y. C. Saxena, S. K. Mattoo, A. Sen, P. I. John and P. K. Kaw.

*Institute for Plasma Research, Bhat, Gandhinagar 382 428*

E-mail: rtan.ipr@gmail.com

#### Abstract

Repeatable plasma discharges of maximum plasma current of  $\sim 110$  kA and discharge duration beyond  $\sim 200$  ms with plasma current flattop duration of  $\sim 120$  ms with negative converter operation has been obtained for the first time in the first Indian tokamak ADITYA. ADITYA ( $R = 75$  cm,  $a = 25$  cm), an ohmically heated circular limiter tokamak regularly being operated to carry out several experiments related to controlled thermonuclear fusion research. In recent operational campaign, special efforts are made to enhance the discharge performance as well as plasma parameters. The discharge reproducibility has been improved with Lithium wall conditioning and much-improved plasma discharges are obtained by precisely controlling the plasma position. In these improved discharges, chord-averaged electron density  $\sim 2.5 - 3.5 \times 10^{19} \text{ m}^{-3}$  using multiple hydrogen gas puffs, plasma temperature  $\sim 500 - 600$  eV has been achieved and maintained till the end of the discharges. The measured confinement time matches quite well with ALCATOR scaling. Improved discharges are attempted over a wider parameter range to carry out various confinement scaling experiments. Encouraging preliminary results of ICR heating has also been obtained. In this paper we will present all the results related to the achievement of high-current long-pulse plasma discharges in ADITYA tokamak, a big leap forward in Indian fusion research.

**NF-127**

**Role Of Sacrificial Layer On Picosecond Laser Shock Peening Of Stainless Steel Surfaces**

Pardhu Yella<sup>1</sup>, P. Venkateswarlu<sup>2</sup>, Koteswararao V. Rajulapati<sup>1</sup>,  
Ramesh Kumar Buddu<sup>3</sup>, Raole P.M.<sup>3</sup>, K. Bhanu SankaraRao<sup>1†</sup>, P. Prem Kiran<sup>2</sup>,

<sup>1</sup>*School of Engineering Sciences and Technology, University of Hyderabad, Hyderabad 500 046*

<sup>2</sup>*Advanced Centre for Research in High Energy Materials (ACRHEM), University of Hyderabad, Hyderabad 500 046*

<sup>3</sup>*FRMDC Division, Institute for Plasma Research, Bhat, Gandhinagar 382 428*

*†Present address: Ministry of Steel (Govt. of India) Chair Professor, Mahatma Gandhi Institute of Technology, Hyderabad 500075*

E-mail: prem@uohyd.ac.in

**Abstract**

Laser Shock Peening (LSP) has become one of the most sought after advanced surface treatment techniques to improve the strength of the structural materials used in aeronautical and fusion reactor industries for preventive maintenance and to improve the mechanical properties. This is achieved by inducing compressive residual stresses thereby improving the resistance to fatigue and stress corrosion of critical engineering structural components [1]. In the current investigation this technique is adopted on to stainless steel (SS) 304 and 316L(N) which are promising candidates for fusion reactor structural materials. 30 ps laser pulses are used in confinement mode of LSP to generate plasma that launches a shock wave into the material of interest. In contrast to the water layer used in the underwater peening [2], various sacrificial layers like black and Zn paint, polymer (absorbing and transparent) tapes are used as confinement media. X-ray diffraction studies have been performed on the laser peened samples in order to understand the variations in precise lattice parameter and also to understand the strain induced in these materials. In this paper, correlations has been made between laser energies applied, different sacrificial layers used, resultant surface modification, microstructural features and induced residual stresses for the above mentioned structural materials. Compared to the direct ablation mode of LSP, confinement mode has shown improvised compressive residual stresses. By varying the sacrificial layers and their thickness, it is shown that the required compressive residual stresses can be engineered in the materials studied.

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**NF-135**

**Effects Of Quasi-Periodic Variation In 3D EMC3-EIRENE SOL Plasma Transport Simulation Of Tokamak Aditya**

Bibhu Prasad Sahoo<sup>1</sup>, Devendra Sharma<sup>1</sup>, Ratneshwar Jha<sup>1</sup> and Yuhe Feng<sup>2</sup>

<sup>1</sup>*Institute for Plasma Research, Bhat, Gandhinagar, 382428*

<sup>2</sup>*Max-Planck-Institut für Plasmaphysik, Wendelsteinstr. 1, Greifswald, D-17491, Germany*

E-mail: bibhuprasad@ipr.res.in

**Abstract**

Recently through probe measurements of flow velocity and drifts were made in the open field line SOL region of the tokamak Aditya. The plasma flow in Aditya SOL presents a combination of transport and drift driven flows [1,2]. The transport driven component was derived from the net flow in experiments involving helicity inversion where a slab model was used for interpretation of data. In our 3 dimensional EMC3-EIRENE [3,4] computer simulations of the Aditya SOL plasma the transport driven flows are simulated in a realistic geometry following Aditya MHD equilibrium. while the transport simulated along magnetic flux surfaces suggest important modifications for the existing slab model. The simulation results indicate important 3D effects that can be incorporate for obtaining required correction in the data from the probes that have finite effects of their relative toroidal and poloidal locations.

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**NF-139**

**Design and Test Results of a 200kV, 15mA High Voltage Power Supply**

Amal S, Urmil M Thaker, Kumar Saurabh and Ujjwal K Baruah

*Institute for Plasma Research (IPR), Bhat, Gandhinagar, Gujarat 382 428*

Email:amal@ipr.res.in

**Abstract**

A compact, low power, portable 200kV High Voltage DC power supply has been designed and developed at IPR, Gandhinagar. The design is based on symmetrical Cockcroft-Walton voltage generator with a high frequency front end converter. The high voltage is generated by a series fed seven stage voltage multiplier circuit driven by a 15 kHz quasi sine wave inverter. A 17 kV-0-17 kV, 15 kHz ferrite core transformer interfaces the voltage multiplier circuit with IGBT based half-bridge

inverter. The use of high frequency gives us advantages of less ripple, faster response and low stored energy in the system. Additionally the scheme allows the use of smaller capacitor and magnetic parts thus minimizing the weight of components and improving portability of the system. This poster discusses the design, developmental aspects of various subsystems of 200kV Test system viz., high frequency inverter, high voltage high frequency transformer, voltage multiplier circuit, and test results of 200kV power supply in detail. This power supply will be used as a DC source for HV testing of electrical installations.

#### References:

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## NF-149

### Design of the ITER IN-DA ECE Diagnostic Transmission Line Layout and Support Structures

Sajal Thomas<sup>1</sup>, Shrishail B Padasalagi<sup>2</sup>, H. K. B. Pandya<sup>2\*</sup> and Ravinder Kumar<sup>1</sup>

<sup>1</sup>ITER-India, IPR, 382016, Gandhinagar, <sup>2</sup>I Institute for Plasma Research, Bhat 382428

E-mail: sajal.thomas@iter-india.org

#### Abstract

The Electron Cyclotron Emission diagnostic (PBS 55F1) [1] provides essential information for plasma operation and for establishing performance characteristics. It will be used for measuring full profile (core to edge) of electron temperature, electron temperature fluctuations and radiated power in the electron cyclotron frequency range (70-1000 GHz). The ITER ECE Diagnostic system consists of port plug optics including hot calibration sources, polarization box, broadband transmission system and ECE radiation measurement Instruments (Michelson Interferometer and radiometers). The Indian domestic agency is responsible for delivering Broadband transmission system for transporting low power ECE signals from the port plug optics to the diagnostics hall, the hot calibration source in the diagnostics hall, two Fourier Transform Spectrometers (FTSs) based on Michelson Interferometers (70 to 1000 GHz) and a 122-230 GHz radiometer system. The remainder of the ITER ECE diagnostic system is the responsibility of the US domestic agency and the ITER organization. The transmission system comprises straight waveguide pieces, Miter Bends, vacuum window and some quasi-optical components. Waveguide thickness was finalized in accordance with ASME criteria for waveguides with outer pressure. Support Structures have been designed for optical components like Splitter Box Assembly and Parabolic Mirrors. Support Structure of waveguides need to meet a very high level of precision. Various existing support structure designs had been checked but all those fail to meet the requirements. During the design process, the gravitational sagging of the waveguides has been studied to optimize the support span length. Structural Integrity of the entire Transmission Line and the Support Structures has been checked, including seismic analysis.

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**NF-159**

**Implementation Of DEGAS2 Code To Study The Neutral Particle Transport In Aditya Tokamak And Its Initial Results**

Ritu Dey, Joydeep Ghosh, Malay Bikas Chowdhuri and ADITYA Team

*Institute for Plasma Research, Bhat, Gandhinagar, Gujarat*

E-mail : ritu.dey@ipr.res.in

**Abstract**

Study of neutral particle dynamics in the tokamak is very important due to the significant role it plays in achieving H-modes, its effect on the active plasma density control and heat loss to plasma facing components. In Aditya tokamak, spatial profile of neutral particles are experimentally observed [1] and the observation suggests important roles of charge exchange processes into the penetration of neutral particle in plasma core. In this context, DEGAS2 [2], which is a neutral particle transport code based on Monte Carlo algorithms, is implemented to understand the underlines physics of neutral particle behavior. This code is extensively used for investigating the dynamics of neutrals in various tokamaks having divertors as the plasma facing component. However, to employ the code on Aditya tokamak plasma limited by a poloidal ring limiter, its machine geometries and plasma parameters has to be incorporated in the code through the required modification. In this work, details on the implementation of the code in Aditya tokamak are presented along with initial simulation results to understand the experimentally observed neutral particle behavior.

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**NF-162**

**Plasma-Wall Interactions In Presence of Fusion Neutrons- A Modelling Perspective**

P.N. Maya<sup>1</sup>, M. Warriar<sup>2</sup>, C. Dube<sup>1</sup>, P.M. Raole<sup>3</sup>, and S.P. Deshpande<sup>1</sup>

<sup>1</sup>ITER-India, Institute for Plasma Research, Gandhinagar, 382016

<sup>2</sup>Computational Analysis Division, BARC, Visakhapatnam, Andhra Pradesh – 530012

<sup>3</sup>Institute for Plasma Research, Gandhinagar- 382044

E-mail: pnmaya@iter-india.org

**Abstract**

Plasma-material interactions play a crucial role in deciding the operational life time of a steady-state nuclear fusion reactor such as a tokamak. The interaction of the hydrogen isotope plasma along with the energetic neutrons (14 MeV) and alpha particles (3.5 MeV) can cause material erosion, structural damage, fuel retention and changes of thermo-mechanical properties of the material that lead to the

eventual mechanical failure of the material depending on the choice of the wall material. In this work we report on neutron induced material damage and the subsequent plasma wall interactions in tungsten, which is the proposed divertor material for ITER, from a modelling perspective. The modelling of neutron damage is currently a priority need due to the non-availability of a fusion relevant high fluence neutron source. ITER-like neutron fluxes can cause very high dpa (displacement per atom) which is a measure of the damage in the system. The interaction of the fusion plasma with the neutron-damaged material can trigger hitherto unobserved phenomena which might lead to the failure of the materials much before the anticipated life-time. Hence it becomes extremely important to understand the damage created by the neutrons and the subsequent plasma-wall interactions due to the hydrogen isotopes and alpha particles.

One of the standard approaches is to simulate the neutron damage by creating the equivalent damage by the use of energetic heavy ions. The surrogate ion irradiation is modelled as a series of elastic collisions with the lattice atoms and inelastic scattering by the electron cloud. The elastic collisions result in the formation of primary knock-on atoms (PKA) which often carry a large fraction of the incident energy and undergo successive collisions with the lattice atoms. This results in the formation of ion-vacancy pairs (Frenkel pairs) and their dynamics leading to the formation of vacancy and interstitial clusters. The evolution of these clusters has two consequences: (1) trapping of D/T ions from the plasma at the defect sites leading to fuel retention and (2) micro-structural changes leading to the thermo-mechanical failure of the material. The consistent modelling of such a system involves different time and space scales which makes it an inherent multi-scale problem [1]. Here we outline our approach to this problem starting from ab-initio/density functional calculations of activation energies of specific defects to rate equation models of predicting the fuel retention and the material damage. The crucial part is understanding the dynamics on the individual scales and how to link the different scales. Specifically, we discuss the Frenkel pair generation due to energetic tungsten and gold ion irradiation using molecular dynamics simulations and binary collision models [2,3]. The details of the collision dynamics and the short-time (~few ns) evolution of the Frenkel pairs will be presented which will be eventually used in a higher level Monte Carlo code for calculating the long-term evolution of point defects and their clustering.

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**NF-170**

### **Automation And Control For Offline Impedance Matching Using PLC And LABVIEW For ICRH Transmission Line In SST-1**

Aniruddh Mali<sup>1</sup>, Ramesh Joshi, Krupa Mehta, H.M.Jadav & S.V. Kulkarni

*Institute for Plasma Research, Bhat village, Gandhinagar – 382428*

<sup>1</sup>Email: aniruddhkmali@gmail.com

#### **Abstract**

Ion Cyclotron Resonance Heating (ICRH) transmission line has two impedance matching networks, one for offline matching which has been employed before experimental shot. Another is online

impedance matching which has been employed during experimental shot. Offline matching network consists of two static stubs, coarse tuner and coarse phase shifter identical in both transmission lines. Both stubs are being used to vary transmission line length. Phase shifter is used for matching of impedance and phase shifting. PLC (Programmable Logic Controller) based automation and control technique has been used for the system as it works below 1 kHz frequency operation of stepper motors. There are motorized arrangement installed in each stubs and phase shifters. PLC based system has been developed for automation and control. LabVIEW software has been used (as SCADA/ HMI) i.e. front end GUI. User interface has been designed using LabVIEW which communicates with OPC (OLE for Process Control) server. Further, OPC communicates with PLC for control of motorized arrangement. This paper will describe technical approach, system feasibility and optimized solutions for the same.

## NF-178

### Structural Assessment Of Manufacturing Model Of Iter-Cryostat Lower Cylinder, Upper Cylinder And Top-Lid

Avik Bhattacharya, Girish Gupta, Vipul More, Gaurav Jogi, Anil Bhardwaj

*ITER-India, Institute for Plasma Research, Gandhinagar, Gujarat*

E-mail: avik.bhattacharya@iter-india.org

#### Abstract

ITER-Cryostat is a stainless steel structure surrounding the Tokamak Machine. It surrounds the Vacuum Vessel & the Superconducting magnets and provides a vacuum environment. Cryostat is a cylindrical vessel having a diameter of ~29 m and height of ~30m. The Cryostat is a very large component and will be manufactured in four sections- The Base section, Lower cylinder, Upper cylinder & the Top lid. The Cryostat will be manufactured in three stages-Factory Fabrication, Temporary Workshop assembly and Tokamak Pit assembly. The first stage will be performed in India and the final two stages will be completed in Cadarache, France. Cryostat will be subjected to various loads such as vacuum load, thermal loads from the superconducting magnets, inertial loads of the ITER Tokamak machine and seismic loads. A previous analysis on the design model of Cryostat has already been performed by ITER Organization. However the manufacturing model includes the design changes that occurred in subsequent stages. To assess the impact of this changes on the overall structure of Cryostat, the manufacturing model is analyzed for the above loads as per ASME Code 2010 Section VIII Div. 2 Part 5 Design by Analysis and Load Specification document of Cryostat. The Structural assessment of the Manufacturing model of the ITER Cryostat is performed on the manufacturing model considering all the above mentioned loading conditions. CATIA V5 and ANSYS Workbench Design Modeler module has been used to create a surface model of the Cryostat lower cylinder, upper cylinder and top-lid. ANSYS Workbench Mechanical is used for the Stress Analysis. Cryostat is assessed against failure due to elastic and plastic collapse. The paper shall present the results of the analysis carried out on the manufacturing model.

#### References:

- [1] Design and Description document and System requirement document for Cryostat
- [2] Cryostat Load specification Document
- [3] Structural Integrity Report of the Design model of the ITER-Cryostat.

## NF-179

### Prototype High Voltage Bushing: Design and Development

Sejal Shah, D. Sharma, M. Bandyopadhyay, C. Rotti, K. Pandya, H. Tyagi, J. Soni, D. Parmar, A. Gahlaut, H. Patel, A. K. Chakraborty

*ITER-India, Institute for Plasma Research, Gandhinagar, 382025*

E-mail: sshah@iter-india.org

#### Abstract

High Voltage Bushing (HVB) is one of important component of DNB. It is basically a vacuum feedthrough and provides 100 kV isolation between grounded DNB Vessel and high voltage feedlines which are operational requirements of beam source. DNB HVB is designed based on ITER vacuum, electrical and safety requirements. Its diameter is ~2 m and length is ~ 1 m. The width of the ceramic insulator ring of HVB is 50 mm. This ceramic ring is also having brazed metallic Kovar plate for welding purpose. This component is of a safety important class and it is important to establish the manufacturing feasibility and validate its performance in an appropriate scale. Hence, half-sized bushing has been fabricated as per ITER requirement.

Before fabrication of the prototype HVB, electrostatic analysis has been carried out to study electric field distributions near the triple point, electrostatic shield surfaces and on the insulators. The obtained stresses are 0.3 kV/mm and 2.09 kV/mm on triple point shield and metal parts respectively, which are under acceptable limits [1]. Structural analysis showed maximum von misses stress 56.2 MPa and maximum deflection 0.34 mm which is also within acceptable limit. The experimental validation of these results of the half scale bushing is important to ensure its functional performance.

In this paper, the manufacturing details of large size ceramic ring which is brazed with kovar plate using active metal brazing shall be presented and assessment of the brazed joint shall be discussed. In addition, the experimental results shall be presented.

#### **Reference:**

[1]Shah S. et al., Fusion Eng. & Des.**86**,p.892–895, (2011).

## NF-184

### Engineering Design Of PLC Based Control And Monitoring For 100kw, 45.6 MHz ICRH DAC

Krupa Mehta, Ramesh Joshi, Aniruddh Mali, H M Jadav & S.V. Kulkarni

*Institute for Plasma Research, Bhat village, Gandhinagar – 382428*

Email: krupa.amr@gmail.com

#### Abstract

Ion Cyclotron Resonance Heating (ICRH) Data Acquisition Control system (DAC) system for 100kW, 45.6 MHz has been conceptualized for RF ICRH experimental activities in tokamak. This

system will be used for control and monitoring for 2 kW, 20 kW and 100 kW RF amplifier stages respectively. Each lower stage amplifier output is fed to next higher stage amplifier. ICRH system consists of different power supplies for each stage. First two stages need single high voltage power supplies and 100 kW stage needs four power supplies named screen grid, filament, plate and control grid. For failsafe operation of the system it needs DAC for control and monitor and synchronization of each RF stages respectively.

This paper will describe conceptual design of PLC based DAC system. PLC will be used for voltage and current monitoring as well as control of each power supply with interlock. PLC system will provide MODBUS protocol which communicates with Experimental Physical and Industrial Control System (EPICS). EPICS will provide channel access as well as data acquisition and monitoring synchronization with alarm handling capability. EPICS process variables will be displayed in LabVIEW Graphical User Interface. CA lab tool will be used for LabVIEW and EPICS process variable communication. Control System Studio will be used for user interface design which will further interface with EPICS using python or C API. MODBUS async EPICS driver is freely downloadable from EPICS website. This driver has two way communications with EPICS process variable (PV) and PLC registers (channels). For Fast data acquisition ( $\geq 1$  kHz), NI data acquisition module is interfaced with ICRH DAC will be driven by PLC for the given experimental shot time. EPICS will be used as synchronization tool for PLC, National Instruments (NI) data acquisition module as well as user interface communication.

#### References:

- [1] Benchmarking and Analysis of the User-Perceived Performance of EPICS based ICRH DAC
- [ IESA International Conference on Industrial Engineering Science and Applications -2014, 2-4 April 2014]

### NF-188

#### Estimation Of Hard X-Ray Flux Using MCNP For The Runaway Electrons Produced In ITER Hydrogen-Phase

Rajnikant Makwana<sup>1</sup>, Santosh P. Pandya<sup>2</sup>, Jagannathan Govindrajan<sup>3</sup>, Robin Barnsley<sup>3</sup> and Michael Walsh<sup>3</sup>

<sup>1</sup>*Department of Physics, M. S. University of Baroda, Vadodara - 390002*

<sup>2</sup>*Institute for Plasma Research, Gandhinagar, India, 382 428*

<sup>3</sup>*International Thermonuclear Experimental Reactor Organization, Cadarache, France*

E-mail: rajniipr@gmail.com

#### Abstract

Production of Runaway Electrons (RE) is major threat for large tokamaks since they can substantially damage the in-vessel and First Wall (FW) components. From machine protection point of view and to control plasma parameters, it is very essential to detect runaways directly or indirectly and to take necessary actions to mitigate them. One of the establish indirect method is the detection of Hard X-Rays (HXR) generated due to the interaction of REs with plasma impurity ions and with FW components. This leads to the thin target and thick target Bremsstrahlung.

In International Thermonuclear Experimental Reactor (ITER) the Hard X-ray diagnostic is foreseen during the non-nuclear phase of operation. Being a nuclear machine, the radiation shielding of the ITER is designed to be extremely thick. Hence, the HXR generated inside the vessel will be highly

attenuated. Unlike other tokamaks, in ITER the HXR-monitor need to be deployed inside the diagnostics port plug. In order to define detector's toroidal & poloidal position, number of detectors, distance from plasma and other necessary design parameters demands estimation of HXR during different phases of a plasma discharge. A methodology has been developed to generate HXR from the RE-plasma and RE-FW interactions and propagation through the ITER vacuum vessel. These calculations have been performed using Monte Carlo based MCNP code. HXR signal estimated for confined and de-confined REs, assuming two different RE energy distribution functions. HXR production is simulated and the resultant spectra are compared. For the de-confined REs, three different striking cases are considered and HXR spectra have been compared. Further studies have been made to investigate effect of RE beam striking at 180° toroidally away from the detector and out of detector field of view. The effect of RE beam size and location of HXR flux at single toroidal and poloidal location were also studied. These simulations result provides essential inputs for design of ITER HXR monitor for Hydrogen-Phase in ITER.

**NF-192**

### **Study Of Castelled Divertor Gaps**

S. Adhikari and K.S. Goswami

*Centre of Plasma Physics-Institute for Plasma Research Sonapur, Assam 782402*

E-mail: sayanadhikari207@gmail.com

#### **Abstract**

To insure the thermomechanical durability of ITER it is planned to manufacture the castellated armour of the divertor i.e. to split the armour into cells. This will cause an increase of the surface area and may lead to plasma deposition and tritium accumulation in the gaps in between cells. The geometry of castellation used was the same as proposed for the vertical divertor target in ITER. Recent experimental studies show that a non-negligible amount of deuterium is deposited in the gaps between tiles. With this idea in mind, a numerical analysis of plasma deposition in this critical region is presented.

**NF-195**

### **Neutronics Analysis And Shielding Optimization For X-Ray Crystal Spectrometer Of ITER Using Both MCNP And ATILA**

P.V. Subhash<sup>1</sup>, S.Jakhar<sup>2</sup>, Gunjan Indauliya<sup>1</sup>, T Sai Chaitanya<sup>1</sup>, Sajal Thomas<sup>1</sup>, Sapna Mishra<sup>1</sup>, Russell Feder<sup>3</sup>, Deepak Aggarwal<sup>2</sup>, Sanjeev Varshney<sup>1</sup>, Shrishail Padasalagi<sup>1</sup> and Vinay Kumar<sup>1</sup>

<sup>1</sup> ITER-India, Institute for Plasma Research, Gandhinagar Gujarat   <sup>2</sup> Institute for Plasma Research, Gandhinagar Gujarat   <sup>3</sup> Princeton Plasma Physics Laboratory, Princeton, NJ, USA

E-mail : subhashpv@iter-india.org

#### **Abstract**

Neutronics analysis has been carried out for an X-ray Crystal Spectrometer (XRCS) [1], which will be installed in an equatorial port assigned for the ITER[2] diagnostics. The Shut\_Down Dose Rates (SDDR)



along with other important neutronics parameters, due to the XRCS opening in the port-plug components, must lie within the ITER specified SDDR criteria. In this paper details of XRCS neutronics model and the analysis results will be presented. In order to achieve the ITER specified SDDR limits a proper radiation shielding for the XRCS is being designed. Monte-Carlo N-Particle Transport (MCNP) neutronics code along with deterministic Attila codes are in use to perform the calculations. Both the 'local' and 'global' ITER neutronic models are considered for the calculations. The shielding needs to be optimized by considering both engineering and scientific constraints. The initial shielding optimization has been done with the local model which is then refined using a full ITER global model to take into accounts the effects of streaming neutrons from other ports. In the 'local' model the effect of streaming neutrons from other adjacent ports are neglected. The neutronic parameters like neutron flux, nuclear heating and biological shutdown dose rates are calculated. The calculations are repeated with a deterministic neutron transport code called 'Attila'. For this a tailor made Attila model is used [3]. The analysis results obtained from Attila are compared with those obtained from MCNP. Furthermore, the effectiveness of various configurations of shielding around the XRCS system and application of different shielding materials will be discussed in this paper.

### References:

- [1] S.K. Varshney, R. Barsnsley. M. G. O'Mullane and S. Jakhar, *Bragg spectrometer for ITER*, Rev.Sci. Instrum., 83, p 10E126-1-3, (2012)
- [2] [www.iter.org](http://www.iter.org)
- [3] P.V. Subhash, Russel Feder, S. Jhakhhar, Sajal Thomas and Deepak Aggarwal, *ITER Related neutronics calculations with Attila computer code*, American Nuclear Society Transactions, Vol 108, 2013.

## NF-212

### Pre-Assembly Tests of 80 K Booster Systems Cryostats and VJ lines

R. Patel, GLN Srikanth, G. Mahesuriya, K. Patel, P. Shah, H. Nimavat, V.L. Tanna and S. Pradhan

*Institute for Plasma Research, Bhat, Gandhinagar-382428, Gujarat*

E-mail: [rpatel@ipr.res.in](mailto:rpatel@ipr.res.in)

### Abstract

The Steady State Superconducting Tokamak (SST-1) machine is equipped with liquid nitrogen (LN2) cooled bubble panel type thermal shield to minimize the steady state heat loads on the superconducting magnet system at 4.5 K from ambient. The 80 K Booster system is essential for single phase LN2 flow inside bubble panels for uniform temperature distribution within (80 K-85 K). Design, analysis and manufacturing of the 80 K booster system were done by the M/s Cryozone. Booster system is in form of three storey building as pump cryostat at bottom, sub-cooler vessel cryostat at middle and pressurized vessel cryostat at upper. Flexible bellows type process interface provided between the cryostats. After factory acceptance test (FAT) at vendor site, the 80 K booster system has been delivered to IPR site in disassemble form with each cryostats in different box package. Before carrying out installation, commissioning and testing of booster system at IPR site, it is envisaged to have possible pre-assembly tests of each cryostats and VJ lines as there may be any chance of non-conformity issues viz. damage during transportation. In order to validate the same before actual assembly at IPR site, several tests have been carried out viz. helium leak tightness of the cryostats, NER test, high pressure holding test at ambient as well as at liquid nitrogen conditions. This paper describes the procedures and test results at individual component level of the 80 K booster

system in prior to their final integrated installation.

### References:

[1] V.L.Tanna et al, "Recent Progress and Development of Cryogenics system towards the refurbishment of SST-1", Cryogenic Engineering Conference and International Cryogenic Materials Conference at Fukuoka, Japan, May 2012, pp. 6129-623.

## NF-217

### Overview Of Instrumentation & Control System For ITER Vacuum Vessel Pressure Suppression System

Dileep Shukla, Vipul More, Girish Gupta, Anil Kumar Bhardwaj

*ITER-India, Institute for Plasma Research, A/29 GIDC Electronic Estate, Gandhinagar*

E-mail: dileep.shukla@iter-india.org

### Abstract

Vacuum Vessel pressure suppression system (VVPSS) serves the critical function of protecting vacuum vessel from overpressure situation caused by in vessel coolant leakage. Vacuum vessel is connected to VVPSS tank through relief line with two rupture disk in series and bypass line with bleed valves. VVPSS tank will be connected to detritiation system & drain tanks. It consists of suppression tank partially filled with water at room temperature (30<sup>0</sup> C) connected to Vacuum Vessel through a relief line. In an event of overpressure inside Vacuum Vessel, the rupture disks shall break open or bleed valves will open to vent the steam inside vacuum vessel to the VVPSS tanks where it shall come in contact with water and condense.

VVPSS mainly has four physical units suppression tank, connection line, relief line, bleed line. VVPSS is required to monitor variables such as temperature, pressure, water level, valve status, etc. Several system functions shall use closed loop control to perform or maintain their proper state. These closed loop control systems shall be directed to operate depending on the operational state of the Tokamak machine. The instrumentation system design includes the design of transducers and their supports, selection of cables, selection and design of feedthroughs, as well as the development of adequate signal monitoring techniques. The instrumentation of the ITER VVPSS is provided for monitoring the state of readiness of the system. It is important to continuously verify that the system is available to perform its required function for the ITER Tokamak. Poster shall present preliminary details about plant system components of I&C for VVPSS system.

**NF-232**

**Studies On Keyhole Plasma Characteristics During Laser Welding  
With Optical Emission Spectroscopy**

Ramesh Kumar Buddu<sup>1</sup>, M. B. Chowdhuri<sup>2</sup> and P.M. Raole<sup>1</sup>

<sup>1</sup>FRMDC Division, <sup>2</sup>Spectroscopic Diagnostics Division  
*Institute for Plasma research, Bhat, Gandhinagar 382428*

*Email: buddu@ipr.res.in*

**Abstract**

Laser welding is one of the potential joining processes for the fabrication development of various structural materials (steels) for fusion reactor fabrication applications. The laser welding process is governed by the plasma keyhole dynamics, which deliver the power coupling to the material during the laser interaction. Plasma formation during the laser power and shield gas interaction play the critical role in the welding process efficiency and defect free welds formation. Plasma emission spectroscopy technique is a potential candidate to understand plasma dynamics through the spectral lines monitoring and its correlation with the laser parameters. Experiments have been carried out to study the plasma keyhole dynamics during the CO<sub>2</sub> laser welding by varying Argon shielding flow rates and Laser powers for SS316L plates joining. Visible emission spectral lines in the range of 400 -700 nm are recorded for the data analysis during the welding process. Spectra lines from neutral Cr and Fe were used to estimate the plasma electron temperature and density by standard line ratio technique. Plasma electron temperature in the wide range was observed with different input parameters like laser power (1.5 - 3.5 kW), gas flow rates and weld speed. Electron temperatures in range of 0.1 – 1.2 eV were measured with different process parameters. The intensity of the emission spectra was noticed lowered during the running stage of the laser welding in comparison with the initial stage. The weld beads with different shapes were identified indicating the keyhole profile variations during the laser beam welding which are responsible for the welding quality.

**References:**

- [1] A. Ancona, V. Spagnolo, P. M. Lugarà, and M. Ferrara, Optical sensor for real-time monitoring of CO<sub>2</sub> laser welding process, *Appl. Optics*, **40**, 6019-6025, (2001).
- [2] J. Mirapeix, P. B. García-Allende, A. Cobo, O. M. Conde, and J. M. López-Higuer, Feasibility study of imaging spectroscopy to monitor the quality of online welding, *Appl. Optics*, **48**, 4735-4742. (2009).

**NF-246**

**Implementation Of Soft Start Logic In ECRH DAC For Smooth Rise Of HV In RHVPS For Reliable Operation Of High Power Gyrotrons**

Jatinkumar Patel, B.K. Shukla, Harshita patel, N. Rajanbabu, Pragnesh Dhorajiya and  
Paresh Patel, Sumod C.B., Dipal Thakker, L.N. Gupta

*Institute for Plasma Research, Bhat, Gandhinagar. Pin- 382428*

E-mail : [jatin@ipr.res.in](mailto:jatin@ipr.res.in)

**Abstract**

In Electron Cyclotron Resonance Heating (ECRH) system, gyrotrons need to be operated with all necessary protections for its reliable and safe operation. In SST-1, 82.6 GHz and 42 GHz ECRH systems are used for various plasma experiments. The 42 GHz gyrotron system delivers 500kW of microwave power for ~500ms and 82.6 GHz gyrotron delivers ~200kW power for 1000 S operation. The RHVPS (Regulated High Voltage Power Supply) has been commissioned for high power operation of gyrotrons. The handshake interface between RHVPS and ECRH DAC (Data Acquisition and Control) has been established with failsafe mode by using 100 meters long fiber optic cables (FOC). The ECRH DAC, with a VMEbus hardware has a control software developed on Vxworks RTOS and GUI on linux platform using Tcl-tk tool kit. This system has been used to operate -80kv, 75A RHVPS successfully with a constraint of smooth rise of high voltage (HV).

A dedicated -80kV, 15A RHVPS unit has been commissioned for ECRH system and it is tested for parameters of -45kV, 15A with gyrotron operation of 250 ms. It observed that during the rise of high voltage,  $dI_{\text{beam}} / dt$  interlock operates frequently which immediately triggers the crowbar and turns off the RHVPS. This leads to refining a soft start HV reference signal from ECRH DAC which enables HV output with smooth rise. The soft start control logic and rise time algorithm for RHVPS reference signal has been developed maintaining all other functionalities intact. The analog output module IP-220A (12-bit) having fast settling time (5 $\mu$ s) is used for soft start logic development. The Graphical User Interface (GUI) console has been modified and updated with additional parameters i.e. rise time and HV set value. The ECRH DAC system has been updated with this modification and gyrotron is operated successfully at various electrical parameters. The soft rise of HV output has minimized the unwanted tripping of RHVPS.

This paper presents the soft start logic for RHVPS operation and its integration within ECRH DAC and its implementation as well as effect on ECRH operation with results.

**NF-247**

## **Mode Analysis To Study Waves & Instabilities As An Agent For Plasma Non-Uniformity In Negative Ion Sources**

Dass Sudhir, Mainak Bandyopadhyay, Arun Chakraborty

*ITER-INDIA, Institute for Plasma Research, Gandhinagar 382016-Gujrat*

E-mail: dass.sudhir@iter-india.org

### **Abstract**

High density, large area, uniform plasma sources are required for high power neutral beam injector (NBI) systems. In case of negative ion source based NBI system, non-uniformity of the plasma in the ion source is a major issue due to the presence of transverse magnetic filter of few tens of Gauss in it [1]. Charged particle transport due to  $E \times B$  drift was proposed as possible cause for the plasma non-uniformity. However, few recent studies express alternate views [2, 3]. It is clear that considerable amount of free energy is available in the plasma due to the presence of gradients (an order of values over  $\sim 20$ cm distance along the ion source axis) in plasma density, electron temperature & magnetic field in a negative ion source, which may be responsible for different instabilities and chaos. It is understood from literature study that gradient driven free energies in magnetized plasma having negative ions are responsible for different instabilities and chaos [4,5]. Some of these unstable modes can affect the plasma transport inside the ion source and may responsible for inducing plasma non-uniformity. Preliminary calculations indicate the presence of drift mode in ion sources with filter field, which is very well known for anomalous particle and energy transport in plasma devices having transverse magnetic field [6]. In the present work a normal mode analysis is carried out for magnetized plasma using fluid theory. The corresponding dispersion relations are derived, various propagating and unstable modes were found. These modes are studied in operating conditions of a fusion grade neutral beam negative ion source and results will be presented.

### **References:**

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## NF-273

### Structural Assessment Of Manufacturing Model Of Cryostat Base Section

Gaurav Jogi, Girish Gupta, Avik Bhattacharya, Vipul More, Anil Bhardwaj

*ITER-India, Institute for Plasma Research, Bhat, Gandhinagar, 382428*

E-mail: gaurav.jogi@iter-india.org

#### Abstract

Cryostat is a cylindrical vessel that provides a vacuum environment to avoid excessive thermal loads from being applied to the components being operated at cryogenic temperatures (i.e. superconducting magnet systems, thermal shield, etc.). Cryostat is made up of four sections 'Base Section, Lower Cylinder, Upper Cylinder & Top lid'. The Cryostat base section comprises of the base cylinder, sandwich structure, pedestal ring, horizontal and skirt support. The pedestal ring is supported vertically by 18 bearings installed on the concrete crown which supports the Tokomak machine and transfer entire structural load to the building. The pedestal ring has interfaces to the 18 TF coil gravity supports (TFGS) and the ring also supports the. Gravity and seismic loads are the major loads from the Tokomak machine which are transferred through the pedestal ring.

To assess the impact of manufacturing changes in the Cryostat Base Section, structural assessment has been done based on available load specification. Manufacturing model of Cryostat Base Section was used for generating a shell model for structural assessment in Ansys Workbench. Structural assessment was performed as per ASME Section VIII Div. 2 Part 5 for the worst failure mode of base section. Base Section was assessed for Failure against Plastic Collapse (Elastic Analysis), Failure against Buckling (Elastic & Elastic-Plastic Analysis). Stresses obtained in the Plastic Collapse was lower than the allowable stresses for Category I & the buckling factor for the base section is greater than or equal to 2 as the solution was carried out for a load factor of 2.

## NF-277

### Fabrication Methodology Of ITER Cryostat

Girish Gupta<sup>1</sup>, Rajnikant Prajapati<sup>1</sup>, Mitul Patel<sup>1</sup>, Vaibhav Joshi<sup>1</sup>, Jagrut Bhavsar<sup>1</sup>, Mukesh Jindal<sup>1</sup>, Vipul More<sup>1</sup>, Amit Palaliya<sup>1</sup>, Avik Bhattacharya<sup>1</sup>, Gaurav Jogi<sup>1</sup>, Manish pandey<sup>1</sup>, Saroj Jha<sup>1</sup>, Anil K Bhardwaj<sup>1</sup> and Pandurang S Jadhav<sup>2</sup>

<sup>1</sup>*ITER-India, Institute for Plasma Research, Bhat, Gandhinagar, 382428*

<sup>2</sup>*Larsen and Toubro, Surat, 394510*

E-mail: girish.gupta@iter-india.org

#### Abstract

The Cryostat is a large vacuum vessel, which is a part of ITER device. Its main function is to provide vacuum environment ( $10^{-4}$ Pa) for magnet system and thermal shield which works at 4K and 80K respectively to reduce the thermal heat load from the surroundings. Cryostat transfers all the loads

that derived from the Tokamak machine and from the Cryostat itself, to the floor of the Tokamak pit. Cryostat having ~29m Diameter, ~29m Height and major shell thickness is of 50mm.

Vacuum requirement for ITER Cryostat is challenging due to large number of penetrations (~300), many weld joints and its large surface area. Manufacturing has been divided into three stages (Indian factory, ITER Site workshop and Tokamak Pit) due to the large size and limitation during transportation. It is essential to identify the proper sequence and size of components during fabrication and assembly of each stage in advance. Due to transportation limit the Cryostat is being fabricated in 54 segments at Indian factory and based on Pit assembly requirements, segments will be assembled in four main sections (Base section, Lower Cylinder, Upper Cylinder and Top lid) at ITER site workshop. These four main sections will be assembled in Tokamak pit for final assembly.

This paper will discuss the manufacturing methodology, which will be used to achieve the required tolerance and to fulfil the project requirements.

## NF-283

### High Speed Fiber Optics Data Link For Analog Signal, Using Aurora Protocol

Jatin Upadhyay<sup>1</sup>, Jignesh Soni<sup>2</sup>

<sup>1</sup>Gujarat Technological University, Chandkheda, Ahmedabad-382424-Gujarat

<sup>2</sup>Institute for Plasma Research, Bhat village, Gandhinagar – 382428

E-mail: upadhyayjatin7@gmail.com

#### Abstract

This paper will describe for front end signal conditioning electronics of the Data Acquisition and control system (DACS) of the Negative ion source. The link will be used for interconnection of High Speed analog signals (Frequency > 100 kHz) of the sub-systems that are floated at high voltage (approx. 50 KV), to the DACS. Specialty of the link is that high frequency analog signal transmitted through digital technology and FPGA. The link will be divided into two parts: (1) TX module & (2) RX module

(1) TX Module: TX module will take the analog signal which having a voltage level (0 -10 V and/or +/- 5 V, frequency > 100 KHz) then it will be converted to digital data through ADC. After that digital data will be encoded and converted into serial data bus using aurora protocol. Serial data will be transmitted into the high speed fiber optics channel.

(2) RX Module: RX module will receive the light signal and convert them to the electrical signal. After that the high speed data will be decoded and converted to parallel data using aurora protocol. The parallel data are converted to analog signal using the DAC.

#### References:

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- [2] Hovhannes A. Gomtsyan - Encoding methods for the Fiber Optics Communication Lab. IEEE.
- [3] Aurora 8B/10B Protocol Specification SP002 (v2.2) April 19, 2010.

## Design And Integration Of Second Calorimeter For Neutral Beam Indian Test Facility (INTF)

Suraj Pillai<sup>1</sup>, Chirag Mistry<sup>1</sup>, Venkat Nagaraju<sup>1</sup>, Jaydeep Joshi<sup>1</sup>, Ashish Yadav<sup>1</sup>, Dhananjay Kumar Singh<sup>1</sup>, Rambilas Prasad<sup>1</sup>, Jogendra Nandyala<sup>2</sup>, Jayakar Amarlapudi<sup>2</sup>, Chandramouli Rotti<sup>1</sup>, Mainak Bandyopadhyay<sup>1</sup>, Arun K. Chakraborty<sup>1</sup>

<sup>1</sup> ITER-India, Institute for Plasma Research, Gandhinagar Gujarat

<sup>2</sup> Designtech Systems Ltd., Pune, Maharashtra

E-mail: suraj.pillai@iter-india.org

### Abstract

Vacuum vessel of INTF (Indian Test Facility) [1] is designed to install a full-scale test set-up of Diagnostic Neutral Beam (DNB) for the qualification of beam parameters and the behavior of beam-line components prior to installation and operation in ITER. A beam dump named as ‘Second Calorimeter’ has been designed to absorb the power of beam at a distance of 20.665 meters and will also provide calorimetric data at the termination of beam. Heat Transfer Elements (HTEs) are used as basic building blocks and are stacked vertically to form a V-shaped Calorimeter. Taking into consideration the thermo-mechanical design (presented separately in the conference), cooling circuit design is optimized using FATHOM software. The support has been designed to be accommodated into the required available space and to satisfy the interface requirements. The integrated structure is analyzed using Finite Element Analysis and results have been compared with ASME limits. Various conditions such as “Operational”, “Test”, “Emergency” and Faulted” conditions are considered during the design.

In this contribution, the design and integration work of Second Calorimeter is reported.

### References:

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**NF-289**

**The Operation Of Cryo-Condensation Pumps With NBI Helium Cryoplant**

Bhargav Pandya, A.K.Sahu, L.K.Bansal, S.K.Sharma, B.Choksi N.Contractors, S.Parmar, B.Sridhar, V.Vadher, K.Qureshi, P.Bharathi, L.N.Gupta, D.Thakkar, C.B.Sumod, V.Prahlad, S.Rambabu, P.J.Patel, and U.Baruah

*Institute for Plasma Research, Nr. Indira Bridge, Gandhinagar, Gujarat 382428*

E-mail: bpandya@ipr.res.in

**Abstract**

NBI system is designed to deliver ~1.7MW of neutral beam ( $H^0$ , 30-55 keV) for the SST-1 tokamak system for performing heating and current drive. To generate the ion beam and for the neutralization of the ion beam requires a hydrogen gas feed around 80TorrL/s, as well in the passage of the neutral beam transport from source to the tokamak needs a high vacuum  $\sim 10^{-5}$  mbar range. This pressure range with the above gas load can't be handled by means of any mechanical pumping system hence a special kind of cryo-condensation pumps were indigenously designed and developed by NBI group. For the cooling of the cryo-condensation pumps (~4K), helium plant with its auxiliary components & Liquid nitrogen distribution system had been established. Recently two such pumps have incorporated within large NBI vacuum chamber ( $20m^3$ ). The low temperature panels are cooled to a ~4K temperature by liquid helium and filled gradually and filled up to top of the panel. The ultimate vacuum has been achieved of  $8 \times 10^{-7}$  Torr inside the NBI chamber. The different gas feed scan has been taken from 4-100TorrL/s and measured corresponding vacuum inside the vessel gives a pumping speed of the cryo-condensation pumps. The pressure inside the chamber is behaving nearly linearly with respect to the different hydrogen gas feed rate to the system in the plasma box as well in the neutralizer section. Here in this paper we describe cryogenic component layout within NBI chamber, experimental work results; cooldown scenarios of the cryopumps, demonstration of hydrogen pumping, and regeneration of the condensed hydrogen gas on the helium panel to the atmosphere.

**NF-292**

**Thermo-Mechanical Analysis Of Heat Transfer Elements (Htes) Of Second Calorimeter For Neutral Beam Indian Test Facility (INTF)**

Chirag Mistry<sup>1</sup>, M. Venkatanagaraju<sup>2</sup>, Jaydeep Joshi<sup>2</sup>, Jayakar Amarlapudi<sup>3</sup>,  
Chandramouli Rotti<sup>2</sup>, Mainak Bandyopadhyay<sup>2</sup>, Arun K. Chakraborty<sup>2</sup>

<sup>1</sup>*L. D. College of Engineering, Ahmedabad, Gujarat*

<sup>2</sup>*ITER-India, Institute for Plasma Research, Gandhinagar Gujarat*

<sup>3</sup>*Designtech Systems Ltd., Pune, Maharashtra*

E-mail: mistrychirag\_me@yahoo.com

**Abstract**

Heat Transfer Elements (HTEs) are made up of CuCrZr materials and are designed to absorb as high as  $\sim 10 \text{ MW/m}^2$  of heat flux. They are already been used as basic building blocks in all beam line components of SST-1 Neutral Beam Injector (NBI). In INTF beamline, two calorimeters are integrated. First calorimeter is placed between residual ion dump and the duct entrance, at a distance 5.95m from the beam source. The second calorimeter is placed at a distance  $\sim 20.6\text{m}$  from the beam source where all the 1280 beamlets are focused. HTEs are proposed to be used in both the calorimeters of Indian Test Facility (IN TF) as beam dump. Due to focused beam falling on the second calorimeter, it supposed to handle total heat load ( $\sim 2.84\text{MW}$ ) with maximum heat flux ( $\sim 93\text{MW/m}^2$ ).

As a first step, various topologies of stacking of Heat Transfer Elements (HTEs) in a V-shaped configuration, have been assessed to accommodate the above mentioned total heat load and corresponding heat flux. HTEs are stacked vertically utilizing HTEs full length ( $\leq 800\text{mm}$ ) to accommodate full beam size ( $500\text{mm} \times 500\text{mm}$ ). To ensure safe operation under such high heat flux, minimum angle 10 degree at the angular part of the V is optimized. For cooling of the HTEs, flow rate  $\sim 1\text{kg/s}$  in each of the HTEs is considered. Dittus Boeilter Equation is used for calculating the heat transfer coefficient for forced convection. The Boiling heat transfer term is also added by interpolating the data of forced convection and fully developed boiling curve. ANSYS program was used as Finite Element Analysis (FEA) tool to carry out first thermal analysis and followed by structural analysis. The thermal results are compared with the thermal withstanding limits of CuCrZr ( $\sim 350^\circ\text{C}$ ). The structural results are compared with the ASME limits of monotonic as well as cycling loading limits. FEA of HTEs used in the second calorimeter, is presented in this paper.

**References:**

[1] Chirag Mistry (M Tech Thesis), "Design and Analysis of Beam Dump in Indian Test Facility at IPR", ITER-India, IPR, 2014.

**NF-303**

**Automation Of Antenna-Plasma Impedance Determination And Matching In  
Aditya And SST-1 For ICRH**

Kanijfatema Masi, Raj Singh

*Institute for Plasma Research, Gandhinagar – 382428*

E-mail : kanijfatema.m@gmail.com

**Abstract**

Ion Cyclotron Resonance Heating (ICRH) of plasma using radio frequency has been established as a good technique. RF power is fed to the plasma and heating is done using resonance phenomena. The RF source has 50 Ohm output impedance. Plasma impedance is very low. Hence matching of RF source impedance to plasma impedance becomes essential for proper heating of plasma. For proper antenna-plasma matching plasma impedance should be known first. Once the plasma impedance is known then matching parameters are decided which include phase shifters lengths and stub tuner lengths.

This paper will describe the method used to determine the plasma impedance and design of matching network. The prototyping will be done on 3 1/8" line. Plasma impedance will be determined using VSWR curve method. VSWR curve will be found using fixed probe method. In this method voltage probes will be fixed over a section of coaxial transmission line which is more than  $\lambda/4$  length. These fixed probes will pick up the voltage from the coaxial transmission line which in turn will give an idea about VSWR in the line and it will give the phase and magnitude of the reflection coefficient. Hence plasma impedance can be determined. But the voltage signals which are used to construct the VSWR curve may have errors. In order to minimize the error least square technique will be used which gives the best fit of the VSWR curve into the probe voltage data. The impedance determination will be done using the LabVIEW software. Once the load impedance is known, the values of phase shifter and stub tuner lengths can be determined. These values will match the plasma impedance. There will be two parts on the programming side. One is to determine the plasma impedance and the other is to match this impedance. Once the plasma impedance is determined, the computer program will find out the lengths of stub tuners and phase shifters. These lengths will be communicated to the controller of the motors to move the stub and phase shifters. Double stub matching technique will be used in this prototype experiment. The whole process will be fully automatic and there will be no human intervention. This concept will be used in Aditya and SST-1 and hence results obtained will be directly applicable to Aditya and SST-1. Here in this paper we present the implementation of finding of phase of reflection coefficient using LabVIEW.

**NF-308**

**Qualification Of Liquid Penetrant Examination (LPE) Consumables For ITER Cryostat**

Anil Kumar Bhardwaj<sup>1</sup>, Amit Palaliya<sup>1</sup>, Rajnikant Prajapati<sup>1</sup>, Jagrut Bhavsar<sup>1</sup>, Mukesh Jindal<sup>1</sup>,  
Vaibhav Joshi<sup>1</sup>, Mitul Patel<sup>1</sup>, Gaurav Jogi<sup>1</sup>, Girish Gupta<sup>1</sup>, Vipul More<sup>1</sup>, Avik Bhattacharya<sup>1</sup>, Saroj  
Jha<sup>1</sup>, Manish Pandey<sup>1</sup>, Siva Kumar<sup>2</sup> and Nayan Desai<sup>2</sup>

<sup>1</sup>ITER-IndiaA29, Institute for Plasma Research, Gandhinagar, 382016.

<sup>2</sup>Larsen & Toubro Ltd, Surat 394510

E-mail: amit.palaliya@iter-india.org

**Abstract**

ITER Cryostat is manufactured as per ASME Section VIII Div.2, which requires the use of liquid dye penetrant examination for the surface inspection of ITER cryostat welds. ITER Vacuum Handbook only allows ITER qualified LPE consumables on any ITER Components/Parts.

A test set up has been developed to assess the risk of leak blockage due to application of liquid dye penetrant of Magnaflux brand liquid dye penetrant product family. Test was performed on manufactured leak samples provided by IO. There is 18% blockage of the leak after performing LPE and backing. The maximum accepted blockage is 35% as per approved LPE qualification procedure. Hence the LPE product family (Magnaflux) is qualified for use on ITER projects and shall be included in the ITER approved consumable list. This Poster represents experimental work carried out for qualification of LPE consumables for ITER cryostat.

**References:**

- [1] ITER Vacuum Handbook (ITER\_D\_2EZ9UM v2.3)
- [2] Procedure for Qualification of LPE Consumables for ITER Cryostat – ITER-CR-LTTS-210 (ITER\_D\_PATNFK v1.0)
- [3] Intermediate report-Qualification of Liquid Dye Penetrant for the ITER Cryostat (AK4GUX v1.1)
- [4] Procedure for Liquid Penetrant Examination\_L&T – ITER-CR-LTTS-201 (ITER\_D\_CW4R9P v1.1)

**NF-310**

**Development Of 35 KWHV Power Supply For 8KWICRF Amplifier Of Ring Resonator**

Kartik Mohan, Gajendra Suthar, Rohit Agarwal, Raghuraj Singh, P. Ajesh, Harsha Machchhar, JVS Hari Krishna, Manoj Patel, , Kumar Rajnish, Dipal Soni, Rohit Anand, Akhil Jha, Sriprakash Verma, Pareshkumar N. Vasava, Hriday N. Patel, Hrushikesh N. Dalicha, R.G. Trivedi, Aparajita Mukherjee

*ITER-India, Institute for Plasma Research, Gandhinagar – 382016, Gujarat*

kartik@iter-india.org

**Abstract**

The Ion Cyclotron Heating and Current Drive (IC H&CD) system for ITER application has to couple 20 MW Radio Frequency power into ITER plasma for heating and driving plasma current in the frequency range of 35-65MHz . There will be 8 RF sources to generate total 20 MW of RF power. Each RF source is capable to deliver 2.5MW power output at VSWR of 2.0 and Bandwidth of 2MHz as per ITER requirement and each RF source consist two amplifier chains of 1.5MW and a combiner to generate 2.5MW power.

ITER-India has developed 3.5kV, 10A DC Power Supply for 8kW ICRF amplifier of ring resonator. This power supply is comprised of three modules of individual rating 1.2 kV, 10A. Expansion of this power source can be done by adding the modules in series and by changing the input transformer & inductor with required rating. This power supply can also be used for biasing screen grid of HPA-2 & HPA-3 amplifier. This poster presents the test results of the power supply along with the chances of advancement.

**NF-321**

**Automatic Gas-Feed Control System For Vacuum Vessel**

Kiran Patel, K.A. Jadeja and Ajai Kumar

*Institute for Plasma research, Bhat Gandhinagar- 382428*

E-mail: kkp Patel@ipr.res.in

**Abstract**

In Vacuum system, regulation of gas feed for particular gas is most important to manage operational pressure of particular experiment. Piezoelectric gas leak (Piezo) valve is commonly used for remotely fine tuning of gas feed for various gas species in high & ultra high vacuum systems. The conditioning of Piezo valve is also play a major role to set pressure in vacuum system, where variation is occurred in gas-feed pressure for fixed applied voltage with different conditioning of valve. A automatic gas feed control system is developed to operate piezo valve and manage pre-defined (operational) pressure with various boundary conditions for safety of vacuum system i.e. over voltage & over pressure limitation. A LabVIEW based program developed for the measurement of the difference

between base pressure of vacuum system and operational pressure generate error signal, which is used as feedback signal to control voltage of Piezo valve. The various control methodology like PID and fuzzy logic implementation for the optimization of stabilization time and performance of the overall system.

**References:**

[1] I. J. Nagrath and M.Gopal, *Control System Engineering*, Second Edition.

**NF-322**

**MgB<sub>2</sub>-Brass Joint Resistance Optimization For SST-1 Superconducting Magnet Current Leads**

Upendra Prasad<sup>1</sup>, A.Bano<sup>1</sup>, A.Panchal<sup>1</sup>, P.Raj<sup>1</sup>, P.Varmora<sup>1</sup> and S.Pradhan<sup>1</sup>,

<sup>1</sup>*Institute For Plasma Research, Bhat, Gandhinagar, India*

E-mail: upendra@ipr.res.in

**Abstract**

MgB<sub>2</sub> superconducting strands characterization has been initiated for the suitability of SST-1 superconducting magnets current leads. The DC I-V characteristics [1] of commercial strands are being studied in JC facility around 20 K at IPR. The conventional NbTi and copper based current leads will be replaced by MgB<sub>2</sub> and brass based current leads. The considerable amount of cryogenic cost saving is expected after adopting MgB<sub>2</sub> and brass based current leads because they will be operated ~ 20 K instead of 4.2 K. MgB<sub>2</sub> superconductor is used as a link between magnet leads and bottom of the brass wires. In order to optimize MgB<sub>2</sub>-copper and MgB<sub>2</sub>- brass joint resistance for the suitability for this type of current leads, various joint configurations has been fabricated and tested up to 4.2 K and encouraging results have been achieved. The joint configurations design, fabrication and validation will be highlighted in this paper.

**References:**

[1] I-V Characteristics and cryogenic stability study of MgB<sub>2</sub>strand, Upendra Prasad,Z. Khan, P. Raj, A. Kundu, A. Panchal and S. Pradhan, IPR Internal report

**NF-323**

**Fluid Simulation Of The Drift Tearing Instability**

<sup>1</sup>Jervis Ritesh Mendonca, <sup>1</sup>Debasis Chandra, <sup>1</sup>Abhijit Sen, <sup>2</sup>Anantanarayanan Thyagaraja

<sup>1</sup>*Institute for Plasma Research, Bhat, Gandhinagar-382428,*

<sup>2</sup>*Astrophysics Group, Bristol University, Bristol, BS8 1TL, UK*

E-mail : jervis.mendonca@ipr.res.in

**Abstract**

The tearing instability in a plasma is driven by the radial gradient of the equilibrium toroidal current density. We have studied this instability by using the CUTIE code developed at Culham, UK by A. Thyagaraja [1]. We have benchmarked the code and study the drift tearing mode using the 2-fluid CUTIE model. We have carried out linear and nonlinear numerical simulations of the tearing modes including effect of plasma rotations. In the linear study, we have used both the time evolution method and the resolvent method. The time evolution method evolves the system until the only dominant linear eigenmode is visible. The resolvent method is used to determine the linear growth rate and frequency from the CUTIE equations. [2]. In the resolvent method we find the entire eigenspectrum by scanning the complex plane for poles and determine both the linear growth rate as well as the real frequency. We have verified linear time evolution results with that of resolvent one. In the non-linear study we have examined the following situations. First we held the mean density and temperature profiles fixed in time and radius. After this, we proceeded to vary both the density and temperature profiles one at a time, and studied the changes in the nonlinear dynamics and saturation of the unstable modes. We find that when the density and temperature are co-evolved nonlinearly, the evolutionary dynamics and the saturation of the unstable modes are significantly altered due to the variation of the profiles.

**References:**

- [1]A. Thyagaraja. Plasma Phys. Cont. Fusion, 42:B255, 2000.
- [2] J. G. I. Douglas, A. Thyagaraja, and E. Kim. Linear eigenspectra in tokamak fusion plasmas. In 37th EPS Conference on Plasma Physics, page D4.514, 2010. See also the Sheffield Univ. PhD Thesis by J.G.I. Douglas, 2012 for a full discussion and many examples.
- [3]Global two-fluid turbulence simulations of L-H transitions and edge localized mode dynamics in the COMPASS-D tokamak,A. Thyagaraja, M. Valovič, and P. J. Knight,PHYSICS OF PLASMAS 17, 042507 #2010

**NF-324**

**Design And Development Of Water Cooling System For High Heat Flux Test Facility At IPR**

Rajamannar Swamy, S.S.Khirwadkar, Sunil Belsare, Nikunj Patel, Tushar patel, Prakash Mokaria

*Institute for Plasma Research, Bhat, Gandhinagar-382428, Gujarat*

E-mail : rajamannar@ipr.res.in

**Abstract**

High Heat Flux Test Facility (HHFTF) is commissioned at Institute for Plasma Research (IPR) targeted towards Divertor technology development [1]. Each high heat flux test of Divertor components requires computation of heat loads and the cooling parameters determination under available experimental constraints.

HHFTF consists of various subsystems like Electron Beam system, Vacuum system [2], target handling system, test mock-up, diagnostics. These subsystems require cooling at various process parameters to meet their heat load requirements. A water cooling system is designed and developed for various subsystems using chiller, water distribution system, portable high pressure water circulation system and high pressure high temperature water circulation system.

Present paper describes detailed Engineering design and relevant technical details of the various water cooling systems established for HHFTF.

**References:**

1. "New High heat flux test facility at IPR for testing plasma facing components", S.S.Khirwadkar, M.S.Khan, Rajamannar Swamy,et.al. 27<sup>th</sup>Symposium on Fusion technology (SOFT-2012), Belgium.
2. "Conceptual design of vacuum chamber for testing of high heat flux components using electron beam as a source", M.S.Khan, Rajamannar Swamy, S.Khirwadkar, Journal of Physics Conference Series 390 (2012).



**NF-326**

**Conceptual Design, Development And Procurement Of LT Power Distribution System For Twin Source**

KG Parmar<sup>1</sup>, Deepak Parmar<sup>2</sup>, Agrajit<sup>1</sup>Gahlaut, V Mahesh<sup>1</sup>, M NVishnuDev<sup>2</sup>, B. Prajapati<sup>1</sup>, H. Shishangiya<sup>2</sup>, Mainak Bandyopadhyay<sup>2</sup>, G. Bansal<sup>1</sup>, Jignesh Soni<sup>1</sup>, R.K. Yadav<sup>2</sup>, K. Pandya<sup>1</sup>, H. Mistri<sup>1</sup> and ArunKumar Chakraborty<sup>1</sup>

<sup>1</sup> *Institute for Plasma Research, Gandhinagar.*

<sup>2</sup> *ITER-India, Gandhingar*

E-mail : kgparmar@ipr.res.in

**Abstract**

Twin RF driver based negative ion Source (TS)<sup>1</sup>experiment is envisaged with the objective of understanding the physics and technology of multi-driver coupling. To provide the ac power to this experimental set-up of TS and its respective sub-system, an electrical power distribution system is conceptualized, designed and presently under procurement. The electrical ac power distribution system involves load estimation and selection of switchgear, protection, metering, cable sizing, cable tray and support structure, installation, testing and commissioning of the LT AC distribution system. The system is comprised of 1600A and 800A with 50kA breaking current capacity ACB based Main Distribution Panel (MDP) and MCCB based Sub Distribution panels (SDP) of rating 100A (one no.) and 200A (two nos.) to meet the required electrical load for the TS experimental system. The electrical loads for the TS experimental setup comprise of 180kW RFG, Source Power Supplies, Vacuum Pumps, Data acquisition and controls system (DACS) and other auxiliaries. New approach is adopted in the TS electrical distribution system compared to ROBIN power supply system<sup>2</sup> by introducing LT offload isolators of rating 1600A and 800A on the incoming side of ACBs in MDP. LT offload isolator facilitates in complete isolation of the LT system in the event of any major fault or maintenance of the system. The papers also discuss the means of interconnecting MDP and SDPs, laying cables and cable trays and routine test to be carried out on the LT distribution system.

**References:**

1. Two RF driver based negative ion source for fusion R&D at *Fusion Engineering (SOFE) 2011 IEEE/NPSS 24<sup>th</sup> Symposium*
2. Design and implementation of AC Power distribution system for negative ion source at IPR, at *24<sup>th</sup> National Symposium on Plasma Science and Technology, 2009*

**NF-330**

**Analysis Of The Contaminated Optical Viewports Mounted On The Aditya Tokamak**

Nilam Ramaiya, M.B. Chowdhuri, R. Manchanda, S. Banerjee, Niraj Virani and J.Ghosh

*Institute for Plasma Research, Bhat, Gandhinagar 382 428*

E-mail: nilam@ipr.res.in

**Abstract**

Optical windows and mirrors are very essential components for diagnosing the tokamak plasma using spectroscopic techniques and imaging systems. The issue of their morphology and optical property degradation, protection and maintenance is perceived to be very serious for the reactor grade of plasma devices, like ITER. In such devices the intensive contamination happens due to the radiation damage and plasma -wall interaction through the deposition of the eroded materials and the sputtering by plasma ions and neutrals. The deposition of layers results in a sharp decrease of the lifetime and influence on the accuracy and effectiveness of the measurements. The experimental data collected using such optical components can affect not only physics interpretation but even the safe operation of the machine. Therefore, it is necessary to study the exposed optical components to maintain the transmissivity and to prolong the life time.

In this context, the viewports mounted on the various locations of the Aditya tokamak have been analysed to understand the properties of the coating on viewports. Transmission of the coated viewports has been studied and compared the same with transmission of a new (uncoated) viewport. It is observed that because of coating transmission of the viewport has been decreased drastically and reduction of transmission has a unique wavelength dependency. To study the surface topography of the coating and its material characterization, SEM with EDX analysis of an optical viewport have been carried out. The detailed results emphasizing the wavelength modification of transmission in the coated windows will be presented during the symposium.

**NF-331**

**Control and Data Acquisition System for Characterization of Microwave Components for ECE Diagnostics in ITER-INDIA Lab**

Vismaysinh Raulji<sup>1</sup>, Jignesh Patel<sup>1</sup>, Praveena Kumari<sup>1</sup>, Suman Danani<sup>2</sup>, Rachana Rajpal<sup>1</sup>,

<sup>1</sup>*Institute for Plasma Research, Nr.Indira Bridge, Bhat, Gandhinagar-382428*

<sup>2</sup>*ITER-India, A-25 GIDC Electronic Estate, Sector-25, Gandhinagar-382016*

E-mail: vismay@ipr.res.in

**Abstract**

A very novel, compact, economical control and data acquisition system with enriched graphical user interface has been designed and developed indigenously for the characterization and insertion loss

measurement of ECE transmission line components. The characterization of microwave components requires a controlled ramp of precise voltage with 2 mV resolution which has to be fed to the (75-110) GHz RF source based on VCO having tunable voltage range of 3.87V to 14V and simultaneous acquisition of detector's data placed in transmission path. The hardware and software design facilitates all the requirements, easy maintenance and flexibility in customization according to user need. The front panel graphical user interface (GUI) application in LabVIEW provides control commands to the hardware consisting of onboard components viz: ADC, DAC, CPLD RAM and Single Board Computer.

The embedded data acquisition system is designed with Single Board Computer (SBC) based on PC/104 platform, which is featured with Intel® Atom™ N450 1.66 GHz Processor, on board 4GB Flash, display chipset, Ethernet controller and embedded windows XP. Selection of minimum voltage value, maximum voltage value and ramp step value are done through GUI panel and the step value is transmitted to XILINX CPLD board via PC/104 bus. The board receives command and generates controls signal for the 16 bit DAC. The DAC output is applied to the tunable Giga Hz Microwave source and the response of the detector placed at the microwave experimental set up is acquired by the 16 bit ADC. The point to point acquisition takes place to capture the minor response of detector. Once data is successfully archived, the data is transferred to remote server and hardware & software get ready for the next shot. The system is successfully tested standalone and also with the microwave set-up and gave good result within the acceptable noise level for one frequency of the source. High voltage resolution of 2 mV is achieved with a noise band of 1 mV. This application is also tested with Linux operating system. The detailed hardware & software design, development and testing results will be discussed in the paper.

## NF-332

### Overview of Indian LLCB TBM program and R&D activities

R. Bhattacharyay and Indian TBM Team

Institute for Plasma Research, Bhat, Gandhinagar – 382428, Gujarat

#### Abstract

India is working towards the development of Lead-Lithium cooled Ceramic Breeder (LLCB) blanket system, which is the primary option of Indian Test Blanket Module (TBM) program towards the realization of DEMO reactor. The LLCB TBM will be tested from the first phase of ITER operation (H-H phase) in one-half of the ITER port no-2. The LLCB blanket concept consists of lithium titanate as ceramic breeder (CB) material in the form of packed pebble beds. The FW structural material is ferritic steel cooled by high-pressure helium gas and Lead-Lithium eutectic (Pb-Li) flowing separately around the ceramic breeder pebble bed to extract the volumetric heat from the CB zones. The engineering design of LLCB TBM is currently in progress along with the process design of LLCB TBM auxiliary systems such as helium cooling systems (HCS), Lead-Lithium cooling system (LLCS) and helium purge system (HPS).

The Indian TBM R&D activities are primarily focused on (i) Development and characterization of blanket materials such as structural (IN-RAFMS), Tritium breeding materials (Pb-Li, and  $\text{Li}_2\text{TiO}_3$ ) (ii) Development of technologies for critical components of various auxiliary systems such as circulators, pumps, heat exchangers, diagnostic equipments etc., (iii) Development and testing of manufacturing technologies for TBM system. Lead-Lithium technologies development activities are focused on liquid metal loop developments for MHD experiments, corrosion experiments, diagnostics

calibration and operational experience with critical loop components. Work is also in progress to develop numerical codes and their benchmarking with the available experimental results.

This paper will describe an overview of LLCB TBM design and various R&D activities with primary focus on liquid metal technology related R&D activities.

## NF-333

### Ethernet Based, Frequency-Programmable Sweep Generator For Langmuir Probe Biasing

Pramila,<sup>1</sup> Kaushal Patel<sup>2</sup>, Hitesh Mandaliya, C.J.Hansalia, Rachana Rajpal, R,Jha

<sup>1</sup> *Institute For Plasma Research, Near Indira Bridge, Bhatt, Gandhinagar, 382428*

<sup>2</sup> *Vishwakarma Govt. Engg. College, Chandkheda, Ahmadabad*

E-mail : pramila@ipr.res.in

#### Abstract

A prototype design for the sweep generator with variable frequency range of 100Hz to 1KHz is implemented for the Langmuir Probe Diagnostics using Xilinx FPGA XC3S500E and high resolution Texas Instrument Digital to Analog (DAC) Converter IC, DAC 8871. For remote operation, it also features an on-board Wiznet make Ethernet controller- module WIZ830MJ having a 10/100 Ethernet controller (W5300), MAC and TCP/IP, all integrated on a single chip. The concept of the waveform generation using digital-technique with a Field Programmable Gate Array (FPGA) IC has its distinct advantages of better stability, high precision and flexibility of operation with better noise-free performance over the traditional analog based techniques. The Ethernet based embedded solution implemented in this design enables the user to operate it remotely with the flexibility of parameter settings like frequency and amplitude and dc offset.

The waveform generation (required frequency range of 100Hz to 1KHz) and the data-communication protocol for the Ethernet interface is implemented in FPGA using the VHDL coding. Any desired frequency value can be obtained using a clock-divider IP-core sitting inside the FPGA. The digitized output is converted to its corresponding analog waveform by a 16-bit serial interface digital-to-analog converter. After proper buffering this output analog signal is given to the summing amplifier which is implemented using the low-offset (100 $\mu$ V) FET-based amplifier OPA27, for adding required dc shift to the sweep waveform. The parameter settings for the sweep waveform are done through the front-panel GUI in LabVIEW on a remote PC connected through the Ethernet..

The sweep waveform generated in this design is of low amplitude with max. of +/-10V range. This low amplitude waveform is voltage-amplified (+/-200V) using the Apex make power amplifier IC PA85 for the generation of the final waveform in-line with the required floating potential range of the Langmuir probe.

#### References:

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- [2] Wiznet, "WIZ830MJ Datasheet (Ver. 1.1)" 2008

**NF-334**

**Design and Development of Multi-Channel Signal Conditioning System for Soft X-Ray Imaging Camera in Aditya Tokamak**

Praveena Kumari, Jignesh Patel, Vismaysinh Raulji, Jayesh V Raval, Hitesh Mandaliya, Minsha Shah, Salman Ansari, Praveen Lal E.V, C J Hansalia, Y S Joisa, Rachana Rajpal, R Jha

*Institute for Plasma Research, Gandhinagar, Gujrat, 382428*

E-mail: praveena@ipr.res.in

**Abstract**

An Electronics signal conditioning system is designed for soft X-ray Tomography for the measurement of electron temperature of core plasma and its activity in Aditya Tokamak. The 20 channel front end signal conditioning system provides a low noise modularized compact design for easy handling, maintenance and placement near the vessel port. The soft X-ray Tomography uses AXUV (absolute extreme ultraviolet) detector array, biased with variable voltage from 0 to  $\pm 15V$  provided by the electronics to get higher response. Because of very low sensitive area ( $10\text{mm}^2$ ) the signal to noise ratio is very poor. In a very harsh tokamak environment an accurate current measurement is quite challenging when the current is at or below noise level.

High sensitive transimpedance amplifiers are implemented using the world's lowest input bias current operational amplifier OPA129 to convert the sensed current into voltage. The voltage signals are amplified with variable gain in two stages by very low noise instrumentation amplifiers and differentially driven to the embedded data acquisition (DAQ). The front end electronics and DAQ both are installed in tokamak hall without using Opto-isolation, follow single point grounding scheme to improve linearity and reduce noise band of the system. The DAQ system is an in-house developed Embedded Data Acquisition System (DAS) based on Single Board Computer (SBC), accessible from remote PC through LAN. After plasma shot the acquired data is automatically uploaded to aditya server in form of matlab file. The system is tested successfully in Aditya. The hardware, software and results will be described in detail in the poster.

**References:**

- [1] Embedded Data Acquisition System with MDSPlus, Rachana Rajpal, FED
- [2] Optimizing Low-Current Measurements and Instruments Jonathan L. Tucker, Keithley Instruments, Inc.

## NF-335

### Automation Of Aditya Test Stand Vacuum Facility Using Siemens S7- 300 PLC

Bharat Arambhadiya, Vismaysinh Raulji, Kumarpalsinh Jadeja, Kaushal Patel, Shailesh Bhatt,  
Rachana Rajpal, Dr. Joydeep Ghosh

*Institute for Plasma Research, Gandhinagar-382428*

E-mail: bharat@ipr.res.in

#### Abstract

The existing Aditya tokamak is going to be upgraded to have a divertor instead of a Limiter. Aditya vacuum vessel is having four vacuum pumping lines. It is proposed to automate Aditya vacuum control system with Siemens S7 300 PLC during Aditya UPGRADE. To demonstrate implementation, a study case is taken by automating one pumping system of Aditya vacuum test stand. This prototype is equivalent of Pumping Line-1 of Aditya vacuum system.

Currently, system is operated manually by the operator. The operator has to memorize full control sequence and operate different components/instruments as per control sequence, and interlocks. Each instrument has to be operated separately. This leads to cumbersome & tedious task on the operator part as well as making it essential for the operator to be present at the setup for monitoring.

Turbo molecular pump (TMP) unit has inputs outputs for remote controlling and monitoring. PLC controls TMP using these control points using digital input/output modules. Ion gauge and pirani gauges provide vacuum measurements as analog outputs in log-linear format. PLC acquires measurements using analog input module. The SCADA is developed using LabVIEW with NI OPC server for variable exchange and programming is done in Ladder logic. The detailed hardware & software design, development and testing results will be discussed in the paper.

## NF-336

### Design, Implementation And Optimization Of High Speed Ethernet Network For I&C Interfacing At High Heat Flux Test Facility

R. Sugandhi<sup>1</sup>, T. Patel<sup>1</sup>, R. Roshan<sup>2</sup> and S. Khirwadkar<sup>1</sup>

<sup>1</sup>*Institute for Plasma Research, Gandhinagar, Gujarat 382428*

<sup>2</sup>*National Institute of Technology, Yupia, Arunachal Pradesh, 791112*

E-mail: ritesh@ipr.res.in

#### Abstract

The high performance and redundant network is a must for an experimental facility, operating under harsh environmental conditions. The networking parameters measurement and optimization is required at different TCP/IP layers to improve the bandwidth utilization and jitter time scales. It is essential when multiple instrumentation system needs to work in a controlled and collaborative manner.

The high heat flux test facility [1] is one such system, used for the testing of plasma facing components under high heat flux exposure. The operation of the system controlled by various I&C devices, which needs high performance network for inter-connectivity under the harsh operating conditions. An interconnection gigabit networking system is designed based on the requirements, data flows and I&C devices. Gigabit Ethernet network is implemented in the redundant ring configuration to provides the aliveness and necessary redundant path against single node failure. The networking is laid using the Power on Ethernet (PoE) managed CISCO network switches (3No's, 24 ports) and standard networking guidelines are followed for physical laying of the network. The network performance is measured using tools like flooded ping, iperf [2] and jperf [3] tools. The performance is measured in homogenous and heterogeneous operating systems between two nodes. The network parameters viz. Maximum segmented size (MSS), TCP Window etc. at TCP/IP layer are optimized. The performance under optimum and default parameter range is measured. It has been observed that optimum parameters provides 30-40% improvement in bandwidth. This paper discusses requirements, rationales for selection, physical and logical architecture, implementation details, performance measurements and the comparative study.

#### References:

- [1] High heat flux test facility:  
<http://www.ipr.res.in/~dftd/High%20Heat%20Flux%20Test%20Facilities.html>  
[2] Iperf : <http://sourceforge.net/iperf>  
[3] Jperf: <http://sourceforge.net/jperf>

**NF-339**

### **Preliminary Design Of 4kV, 1A Series Connected IGBT Switch For Triode Based ICRH Amplifier Protection**

Mandeepsingh Chhabada<sup>1</sup>, Bhavesh Kadia<sup>2</sup>, Y.S.S. Srinivas<sup>2</sup>, S.V. Kulkarni<sup>2</sup>

<sup>1</sup>*LJIET, Sanand- Sarkhej Circle, S.G. Highway, Ahmedabad-382210*

<sup>2</sup>*Institute for Plasma Research, Bhat village, Gandhinagar – 382428*

E-mail: mandeepchhabada8@gmail.com

#### **Abstract**

High power RF and microwave tubes used in RF oscillator and amplifier circuits, need few hundred kilo-watts to few mega-watt high voltage (~30kV) DC power supplies. They have features like low ripple, good regulation, fast protection along with facility for remote operation and control.

Fast crowbar protections were developed to protect the tubes (Tetrode etc.) and are in use. The crowbar protections acts within 10µsec and also limit the fault energy within 10 Joules. This is achieved by short circuiting the 400kW to 3MW rated DC power supply with a crowbar switch, which causes enormous stresses on the power supply as well as power lines.

With the development of solid state devices such short circuits of conventional supplies can be avoided by using a suitable solid-state series switch that can open the fault. Such series switches operating at ~100kV, ~100A continuous current are commercially available for import but not within our country.

It is envisaged that a series IGBT switch rated at 4kV, 1A would be suitable for 2kW stage ICRH

amplifier, and would be scaled in future for higher voltage switch (e.g. 15 and 30kV) development.

This paper presents selection of suitable IGBT device, preliminary design of static and dynamic voltage equalizing circuits, driver circuits with optical input signal. Further, isolation level requirements of various circuits and components would be mentioned.

## NF-344

### Engineering Design Of Beam Transmission Duct And Shine-Through Armor For SST-1

S.Rambabu, S.K.Sharma, B.Sridhar, P. Bharathi, V Prahlad and U.K Baruah

*Institute for Plasma Research, Bhat, Gandhinagar-382428*

E-mail:rambabu@ipr.res.in

#### Abstract

Neutral Beam Injector (NBI) is capable of delivering a hydrogen beam of power 1.7MW to the SST-1 tokamak for the purpose of heating its plasma. The Beam transmission duct (BTD) and shine-through (ST) armor are the two important components essential for integrating NBI with SST-1. The functional requirements of BTD are to dissipate the heat generated due to transmission of beam, to maintain the required level of high vacuum  $\sim 1 \times 10^{-6}$  Torr, to provide the specified angle for injection of the neutral beam into SST-1, to accommodate for the thermo-mechanical expansion and contractions of SST-1. The ST armor acts as a dump for the unused portion of neutral beam. It dissipates the thermal energy carried by the unused portion of the beam. These components are to be tested and integrated with the radial ports of SST-1

In this paper, we present the engineering design of BTD and ST armor.

## NF-345

### Digital Signal Processing On FPGA For Plasma Diagnostics

Hitesh Mandaliya, Rachana Rajpal, Abhijeetkumar, R. Jha

*Institute for Plasma Research, Gandhinagar, Gujarat- 382428*

E-mail : mhitesh@ipr.res.in

#### Abstract

The overall goal of this experiment is to establish a technology for real time processing of the signals coming from various sensors via signal conditioning electronics. One such requirement is interferometer diagnostics of Aditya and SST-1 Tokamak. The two signals (Reference and Probe) are phase shifted to each other and for feedback application the phase shift between these two needs to be measured in real time. The existing system of the interferometer system provides two analog signals in form of sin and cosine trigonometry functions (IQ modulated). To find phase difference we need to



evaluate inverse tan of these two signals. No Van Neumann Architecture processor provides trigonometry functions in hardware. Even some high-end 32 bit processors with real time Operating System with supporting ANSI-C library can not perform trigonometric calculations within 100ns time period, which the requirement of the experiment with sampling frequency of the order of 10MSPS. FPGA can solve this problem by using CORDIC algorithm. Calculation of the algorithm using IP on FPGA logic cells reduces the latency and jittering of the output results and also maintains high throughput transfer rate with deterministic response. We used IP (Intellectual Property VHDL Code) to find arc tan of these two signals.

For the initial development, our intention was to prove the DSP application on FPGA. So we decide to feed the data from available records in form of file from computer to FPGA. Ethernet communication is used to transfer the data to be processed from computer to FPGA and processed data from FPGA to computer. To facilitate this interface we used Microblaze soft processor along with dedicated Ethernet controller chip to establish the communication between FPGA fabric and computer.

The poster will high light the details of microblaze processor interface, Ethernet chip the CORDIC algorithm usage and the comparison of three results, one from LabVIEW (processed by x86 processor on Host), results of MATLAB processed offline and third result which is processed by FPGA using fixed point number system.

## NF-348

### **Structural Fabrication: Study Of Infrastructure Facilities Required To Convert Concept To Reality**

Gautam R Vadolia

*Institute for Plasma Research, Bhat, Gandhinagar 382428*

E-mail: gautamv@ipr.res.in

#### **Abstract**

Blanket, Divertor, Magnet, TBM, and Remote Handling technologies for fusion programme will require some basic structural fabrication facilities for experimentation and fabrication of prototypes prior to full scale job fabrication by Industry.

A mixture of conventional technologies and novel joining processes such as electron beam welding, hybrid metal inert gas and laser welding, large area brazing and Hipping etc. may be primary requirement for fabrication of fusion reactor grade components.

IPR has already started establishing some of the advanced manufacturing technology like waterjet cutting. In this study an attempt is made to survey availability of novel joining facilities with in India and outside India. Few proposals for in-house installation of such facilities are also discussed.

#### **References:**

- [1] Nuclear India May –June 2006/ Vol.39/No.11-12
- [2] Presentations from DRDL, DMRL, BARC, and IPR at WS&FT 08 (workshop on steel and fabrication technologies for fusion programme) organized at IPR on 21-22 July 2008.

**NF-365**

**Recent Result Of Better Plasma Performance Using Lithium Coating In Aditya Tokamak**

K.A. Jadeja, K. M. Patel, S. B. Bhatt, J. Ghosh, R. L. Tanna, N. D. Patel, K. S. Acharya, Niral Patel, Nilam Ramaiya, M. B. Chowdhuri, Manoj Kumar, Pintu Kumar, S. Joisa, P. K. Atrey, C. N. Gupta, J. V. Raval, U. C. Nagora, Ajai Kumar, R. Jha and Aditya Team

*Institute for Plasma Research, Near Indira Bridge, Bhat, Gandhinagar-382428*

E-mail: kumarpal@ipr.res.in

**Abstract**

In fusion devices, different types of wall coating is performed using low-z materials like lithium, boron, carbon, silicon to get better plasma parameters such as density, temperature and confinement time. Lithium coating is widely used due to its low atomic mass compare to others low-z substances. The lithium coating on first wall material and vessel wall is proven technique of wall conditioning in various tokamak devices. In recent campaign of Aditya tokamak, lithium coating was performed in ultra high vacuum condition using fresh lithium rods. Partial pressures of various gas species during lithium coating in glow discharge cleaning was measured using residual gas analyzer. For quantitative measurement of lithium coating on wall, lithium line radiation was measured using spectroscopy diagnostics. The effect of lithiumization reflected very strongly in plasma discharges as improvement in all plasma parameters such as impurity reduction, high temperature ( $\sim 500$  eV), high density ( $3 \times 10^{19} \text{ m}^{-3}$ ), longer plasma duration (more than 200 ms) etc. was obtained after lithiumization. The recent results of improved plasma parameters with lithium coating in Aditya tokamak will be presented in this paper.

**References:**

- [1] S.B. Bhatt, Ajai Kumar, B. K. Das et al., IEEE Transaction in Plasma Science, Vol.40, No.6, June 2012
- [2] M. B. Chowdhuri, R. Manchanda, J. Ghosh, S. B. Bhatt, et al. Plasma Science and Technology, Vol.15, No.2, Feb. 2013.
- [3] B. K. Das, S. B. Bhatt, Ajai Kumar et al., IPR/RR-554/ 2012

**NF-367**

**Design, Fabrication, Assembly, Installation And Testing Of The Beam Intercept  
For Negative Ion Beam Profile Measurement In ROBIN**

K.Pandya<sup>1</sup>, G.Bansal<sup>1</sup>, J.Soni<sup>1</sup>, H.Tyagi<sup>2</sup>, H.Mistry<sup>1</sup>, A.Gahlaut<sup>1</sup>, K.G.Parmar<sup>1</sup>, V.Mahesh<sup>1</sup>,  
B.Prajapati<sup>1</sup>, R.K.Yadav<sup>2</sup>, M.Bandyopadhyay<sup>2</sup> and A.Chakraborty<sup>1</sup>

<sup>1</sup>*Institute for Plasma Research, Near Indira Bridge, Bhat, Gandhinagar – 382428 India*

<sup>2</sup>*ITER-India, Institute for Plasma Research, Gandhinagar – 380025 India*

E-mail : kpandya@ipr.res.in

**Abstract**

The RF based negative hydrogen ion beam experiment is designed to deliver a current of 10 A, over an extraction area of  $\sim 300 \text{ cm}^2$ , when operated in the surface conversion mode. The total current in the accelerated beam is directly measured using current transformers in the power supply. A secondary measurement of the current is possible with the direct interception of the ion current on a measurement device, normally in the form of a plate. While this secondary measurement mode is used for an integrated measurement of the current, a more improved measurement is possible in a differential mode, in a multichannel current interceptor mode and the same has been considered for measurements in ROBIN experiment [1] [2].

This beam interceptor plate is made of aluminum and has the dimensions of 600mm (w) 600mm (h). The central part of the interceptor plate consists of a vertical and horizontal array of electrically isolated aluminum blocks of size 30mm  $\times$  30mm (total: 38 Nos.) for beam profile measurement. The beam interceptor is installed inside the vacuum vessel  $\sim 1.5\text{m}$  away from the third grid, ground grid. Electrical connections are made on individual aluminum blocks of vertical and horizontal arrays for current measurements. The vacuum compatible electrical feedthroughs are used to take out the wirings out of the vacuum vessel. At a time, the current of an individual block and integrated current of all the remaining blocks are measured using in house developed FPGA based high speed current multiplexer and interface electronics system. The typical current measurement time for each block is about 8 ms in which 80 data points are collected for individual block with a sampling rate of 10 kHz. The blocks are scanned in the later part of the extracted beam where the beam current is more stable. Typical ion beam extraction time is kept about 500ms in which all the aluminum blocks in vertical and horizontal arrays are scanned at least once for current measurements. Preliminary results for lower beam currents of  $\sim 20 \text{ mA}$  have been obtained using this device.

In this paper design, fabrication, assembly and testing of the new beam intercept will be described in details.

**References:**

- [1] AIP Conference Proceedings, **1390**, p 604 (2011)
- [2] Fusion Engineering and Design, **88**, p 778-782 (2013)

**NF-368**

**Vacuum Vessel Baking Of Aditya Tokamak For Improved Plasma Operation**

K. M. Patel <sup>\*</sup>, Kiran Patel, K. A. Jadeja, K. S. Acharya, S. B. Bhatt, M. B. Kalal, Nilesh Patel, Mitul Raval, R. L. Tanna, Pintu Kumar, D. S. Varia, N. C. Patel, Santosh Panya, K. Mahavar, J. Ghosh, P. K. Chattopadhyay, Y. C. Saxena and Aditya Team

*Institute for Plasma Research, Nr. Indira Bridge, Bhat Village, Gandhinagar - 382428*

E-mail : kaushal@ipr.res.in

**Abstract**

In tokamaks, the presence of the impurities, i.e. gas species other than the fuel gas, deteriorates the plasma confinement. The gas molecules tend to get adsorbed on the surfaces of the solid state materials of the vessel wall. A very basic and efficient method to release the gas molecules from their hiding places is material baking. Vessel baking is a key tool in the “first wall conditioning”, which is necessary in order to achieve high plasma purity. Baking of the vessel increases the wall out gassing rate and enables it to achieve ultimate vacuum in shorter duration. The Aditya vacuum vessel was baked up to 110 °C in order to obtain high-current, long-duration plasma discharges in Aditya tokamak.

The Aditya tokamak vacuum vessel is made with joining four quadrants electrically isolated from each other through Viton gaskets, which makes it difficult to achieve uniform baking of vacuum vessel. Other bottleneck is the performance of metallic (Aluminum, Copper) wire seals during baking which are used to attach diagnostics and other utilities to the vessel. By overcoming all these bottlenecks baking of Aditya vacuum vessel is carried out by placing heating tapes around the vessel which are heated by passing current through them. The current in these heating tapes was controlled through relay circuits.

In this paper observations of improved partial pressures of impurity gases after baking of vacuum vessel and its effect over the plasma performance will be presented.

**NF-370**

**A Tritium Transport Model For Lead Lithium Cooled Ceramic Breeder (LLCB)  
Test Blanket Module (TBM) System**

Priyanka Brahmabhatt, Amit Sircar and E. Rajendra Kumar

*Institute for Plasma Research, Bhat, Gandhinagar 382428*

E-mail : priyanka@ipr.res.in

**Abstract**

Tritium is bred in LLCB TBM by neutrons interacting with lithium isotopes present inside solid Ceramic Breeder (CB) and inside liquid PbLi alloy. Tritium generated in TBM can penetrate the metal structures and can be lost by permeation to the environment. Tritium being radioactive and

scarce material, it is important to recover tritium as much as possible and minimize the tritium losses towards the coolant and later into the environment [1]. Tritium dissolves in and permeates through structural materials, thus it is important to understand permeation, diffusion and dissolution phenomenon of tritium [2].

Objective of this study is to estimate the total tritium losses into the environment and tritium inventories inside the breeder, inside the purge gas, inside coolant loop and inside the structural materials. In this work, the tritium transport from PbLi and CB through different heat transfer surfaces to environment has been studied and analyzed by a simplified diffusion limited permeation model. This model is based on mass balance equation considering tritium generation rate, tritium extracted by Tritium Extraction System (TES), tritium extracted by Coolant Purification System (CPS) and tritium permeation through various routes. This model gives a simple picture of tritium transport in LLCB TBM and estimates tritium losses through permeation.

#### References:

- [1] D. Demange, L.V. Boccaccini, F. Franza et al., Fusion Engineering and Design, 89, p 1219-1222, (2014).
- [2] F. Franza, A. Ciampichetti, I. Ricapito, M. Zucchetti., Fusion Engineering and Design, 87, p 299-302, (2012).

**NF-371**

## **Design And Analysis Of Sparger For Hydrogen Isotopes Saturation In Liquid Lead Lithium**

Sudhir Rai and Amit Sircar

*Institute for Plasma Research, Bhat, Gandhinagar-382428*

E-mail : sudhirrai@ipr.res.in

### **Abstract**

Liquid PbLi is used as breeder material in addition to its use as neutron multiplier and coolant in Indian Lead Lithium cooled Ceramic Breeder (LLCB) Test Blanket Module (TBM). Tritium bred in PbLi is extracted by Tritium Extraction System for LLCB TBM.

A laboratory scale Hydrogen Isotope Extraction System (HIES) is being developed. It is necessary to saturate liquid PbLi with hydrogen isotopes to determine the efficiency of hydrogen isotopes extractor column of HIES. Saturation of liquid PbLi with hydrogen isotopes is needed for other experiments too, viz. testing of permeation based hydrogen isotope sensors in liquid PbLi and experimental study of permeation of hydrogen isotopes (dissolved in liquid PbLi) through structural materials.

A sparger is used to distribute the gas in liquid PbLi. The solubility of hydrogen isotopes in liquid PbLi is very small. Therefore, one has to design a sparger, which reduces saturation time by uniform concentration distribution of the gas within liquid PbLi. We have, in this work, discussed different configurations of sparger. Designs for all the sparger configurations are done for hydrogen and deuterium gas, keeping constant gas pressure at sparger inlet with liquid PbLi at 723 K.

This paper describes the design and analysis of gas sparger for hydrogen and deuterium using reported values of solubility and diffusivity of hydrogen isotopes in liquid PbLi. The model is implemented into the multiphysics code COMSOL to simulate hydrogen and deuterium transport in

liquid PbLi. The model considers transport equations for convection and diffusion of gases in Liquid PbLi. Initially a simple configuration of sparger is analyzed. On the basis of results obtained for hydrogen isotopes concentration distribution in PbLi, sparger design is improved and optimized considering different configurations to reduce saturation time for PbLi.

**NF-372**

## **Design Of Cryogenic Molecular Sieve Bed Adsorber System For Hydrogen Isotopes Removal System**

V. Gayathri Devi, Amit Sircar, B. Sarkar, Himanshu Kapoor and Deepak Yadav

*Institute for Plasma Research, Bhat, Gandhinagar 382428, India*

E-mail : gayathri@ipr.res.in

### **Abstract**

Efficient design of Tritium Extraction System (TES) for the fuel cycle of any fusion reactor is very important to maintain the tritium breeding ratio and hence sustain the fusion reaction. The Tritium Extraction System (TES) for Lead Lithium Cooled Ceramic Breeder (LLCB) Test Blanket Module (TBM) consists of two main subsystems, Atmospheric Molecular Sieve Bed (AMSB) adsorber and liquid nitrogen cooled Cryogenic Molecular Sieve Bed (CMSB) adsorber. AMSB is used for extracting moisture from the helium purge gas, whereas CMSB for hydrogen isotopes, oxygen and nitrogen [1].

A prototype experimental setup for Hydrogen Isotopes Removal System (HIRS) has been planned. The HIRS experiment would be done for process gas pressure of  $0.12\text{ MPa}$  and flow rate of  $4\text{ Nm}^3/\text{hr}$  for the Helium purge gas with the concentration ranges of  $100\text{-}1000\text{ ppm}$  for water vapour,  $1000\text{-}5000\text{ ppm}$  for hydrogen isotopes and  $10\text{ ppm}$  for  $\text{O}_2$  &  $\text{N}_2$  in the temperature range  $77\text{ - }600\text{ K}$ . The purge gas mixture of Helium gas with ppm levels of hydrogen isotopes is prepared in a mixing chamber and it is then humidified in a controlled evaporation mixing chamber. This composition of the purge gas is chosen keeping in mind the purge gas of LLCB TBM. The purge gas mixture is then stored in a supply tank at  $0.2\text{ Pa}$  and then supplied to the HIRS for the extraction of moisture in AMSB at  $303\text{ K}$  using zeolites MS 4A and hydrogen isotopes at  $77\text{ K}$  using zeolites MS 5A. The pure Helium gas at the outlet is analysed using a Gas Chromatography system with sensitivity of  $1\text{ ppm}$ . Once the breakthrough is attained, the experiment is stopped and the regeneration at  $600\text{ K}$  is carried out by temperature swing using heaters installed in the system and the system is made ready for next set of experiments.

This paper describes the design and analysis of the CMSB adsorber system in detail, which comprises of liquid nitrogen cryostat, CMSB along with instrumentation and control system, for a design pressure of  $0.5\text{ MPa}$ . The design and analysis was carried out as per ASME Section VIII, Division 2.

## References:

[1] Paritosh Chaudhuri et al, Fus. Engg. Des. **87**, p1009– 1013, (2012).

## NF-373

### **Design And Development Of A Cold Trap For Regeneration Of AtmosphericMolecular Sieve Bed In Hydrogen Isotope Removal System**

Deepak Yadav, V Gayathri Devi and Amit Sircar

*Institute for Plasma Research, Bhat, Gandhinagar -382428*

E-mail: deepakyadav@ipr.res.in

#### **Abstract**

Tritium Extraction System (TES) for Lead Lithium cooled Ceramic Breeder (LLCB) Test Blanket Module (TBM) is one of the most important concepts to be tested and verified in ITER. TES has two main components, viz. Atmospheric Molecular Sieve Bed (AMSB) system and Cryogenic Molecular Sieve Bed (CMSB) system. AMSB adsorbs the moisture in helium purge gas and CMSB adsorbs hydrogen isotopes, oxygen and nitrogen. Once the AMSB is saturated with moisture, it has to be regenerated. During regeneration process, Liquid nitrogen cooled Cold Trap is used for retention and removal of the water vapour. A cold trap is designed and developed for this purpose.

The Helium Purge gas at the outlet of LLCBTBM consists of Helium gas mixed with Hydrogen isotopes (~1000 ppm), moisture (~100 PPM) alongwith oxygen and nitrogen (~10 ppm). The moisture in the purge gas mixture is adsorbed when it passes through AMSB column filled with Zeolite 4A adsorbent. The moisture desorbed during regeneration of AMSB is passed through the cold trap, where it gets frozen in the freezing zone of the cold trap at 77 K. After operation, the frozen water vapour is heated with the help of tubular heater installed at the centre of the cold trap at 323 K. The water molecules obtained in liquid form are collected from the bottom of the cold trap.

The test section of designed cold Trap is composed of triple concentric annular tubes made of SS-316. The gas mixture flows in from the top of the inner tube and flows out from the bottom. The coolant liquid nitrogen flows in and flows out of the middle section. The outer section is evacuated by a rotary pump for a vacuum adiabatic condition. This paper describes in detail the design, construction and working of the cold trap. This includes the sizing, thermal and fluid dynamics study in the cold trap.

## NF-380

### **Fabrication, Testing & Commissioning Of Electrical Interfaces As A Test Facility At ITER-India Lab For ITER Like R&D ICRF Source**

Gajendra Suthar, Kartik Mohan, Rohit Agarwal, Hrushikesh N. Dalicha, Raghuraj Singh, P. Ajesh,

Kumar Rajnish, R.G. Trivedi, Aparajita Mukherjee

*ITER-India, Institute for Plasma Research, Gandhinagar – 382016, Gujarat*

E-mail : gajendra.suthar@iter-india.org

#### **Abstract**

The Ion Cyclotron Heating and Current Drive (ICH & CD) system has to couple 20 MW Radio Frequency power to ITER plasma for heating and driving plasma. ITER-India is developing Driver and final stage high power RF amplifiers as a part of R&D program using vacuum tubes in the frequency range of 35 MHz to 65 MHz. Each RF source will provide 2.5 MW of RF power.

ITER-India is developing a test facility for this system having six auxiliary dc power supplies for biasing the electrodes of amplifier vacuum tubes which includes screen grid rated 0-2kV/2A & 8A, control grid rated 0- (-) 1000V/1.5A & 6A & filament rated 12V/400A & 24V/1200A for pre driver and final stage respectively, dc load banks of low voltage/ high current, medium voltage/ medium current & high voltage/low current sweeping entire range of the power supplies, grounding for human and system protection and LT distribution system of 250kW capacity to feed various loads during R&D phase.

This paper presents the details of Fabrication, testing & commissioning of Electrical interfaces (Grounding, LT distribution, DC load bank and Auxiliary DC power supplies) as a test facility at ITER-India lab.

#### **References:**

[1] Power system by C.L. Wadhwa

## NF-383

### **Safety Key Lock management system at ITER-India Lab for overall safety during testing of ITER like R&D ICRF source**

Rohit Anand , Kartik Mohan, Gajendra Suthar, P. Ajesh, Rohit Agarwal, Raghuraj Singh, Harsha Machchhar, JVS Hari Krishna, Manoj Patel, Kumar Rajnish, Dipal Soni, Akhil Jha, Sriprakash Verma, Pareshkumar N. Vasava, Hriday N. Patel, Hrushikesh N. Dalicha, R.G. Trivedi, Aparajita Mukherjee

*ITER-India, Institute for Plasma Research, Gandhinagar – 382016, Gujarat*

E-mail : rohit.anand@iter-india.org

#### **Abstract**

The Ion Cyclotron Heating and Current Drive (IC H&CD) system for ITER application has to couple 20 MW Radio Frequency power into ITER plasma for heating and driving plasma current in the



frequency range of 35-65MHz. There will be 8 RF sources to generate total 20 MW of RF power. Each RF source is capable to deliver 2.5MW power output at VSWR of 2.0 and Bandwidth of 2MHz as per ITER requirement and each RF source consist two amplifier chains of 1.5MW and a combiner to generate 2.5MW power.

The safety key lock management system has been designed for incorporation in the ITER like R&D ICRF source. The flow of different type of keys in a sequential manner has been adopted for the safe operation of the RF chain. The key management system will be incorporated from the initial step, i.e. the operation of High Voltage Power Supply (HVPS). It will combine two independent systems, which are HVPS and RF R&D chain, through the use of safety interlocks. The keys with proper sequence number engraved on them allow systems like HPA-2, HPA-3 etc. to be used easily and safely.

This poster presents the detailed design of safety interlocks and its wise integration with the RF R&D chain.

## NF-384

### **An Overview Of Coaxial Transmission Line Components For ITER ICH&CD System**

Harsha Machchhar, R.G. Trivedi, Raghuraj Singh, Kumar Rajnish, P. Ajesh, Manoj Patel, JVS Hari Krishna, Akhil Jha, Rohit Agarwal, Gajendra Suthar, Dipal Soni, Rohit Anand, Sriprakash Verma, Pareshkumar N. Vasava, Hriday N. Patel, Hrushikesh N. Dalicha, Aparajita Mukherjee

*ITER-India, Institute for Plasma Research, Gandhinagar – 382016, Gujarat*

E-mail : harsha@iter-india.org

#### **Abstract**

The Ion Cyclotron Heating and Current Drive (ICH &CD) system for ITER application is being developed to couple 20 MW Radio Frequency (RF) power into ITER plasma for heating and driving plasma current in the frequency range of 35-65MHz [1]. There will be 8 RF sources to generate total 20 MW of RF power and one prototype source for test facility. Each RF source will be capable to deliver 2.5MW output power at VSWR of 2.0 having bandwidth of 2MHz as per ITER requirement and each RF source consist two parallel amplifier chains of 1.5MW and a combiner to generate 2.5MW power

Coaxial transmission line components of different line size such as 3 1/8", 6 1/8" and 12", having 50 ohm impedance and capable of handling high power are used to interconnect multistage high power amplifier. These components are coaxial line sections, coaxial bends, coaxial tees, coaxial directional couplers, etc. 12" coaxial transmission line components are water and air cooled. RF characterizations of these transmission line components are essential to evaluate the losses and power measurements with minimal errors before using them.

Prior to final integration of single chain of amplifier, capable to deliver 1.5MW RF power, coaxial transmission line components are characterized. In this paper characterization methods and test results of coaxial transmission line components will be discussed.

## NF-385

### Conceptual Design And Development Status Of Mismatch Transmission Line (MMTL) To Test RF Power Sources For ITER ICH&CD System

Raghuraj Singh, R.G. Trivedi, Kumar Rajnish, P. Ajesh, Harsha Machchhar, Manoj Patel, JVS Hari Krishna, Akhil Jha, Rohit Agarwal, Gajendra Suthar, Dipal Soni, Rohit Anand, Sriprakash Verma, Pareshkumar N. Vasava, Hriday N. Patel, Hrushikesh N. Dalicha, Aparajita Mukherjee

*ITER-India, Institute for Plasma Research, Gandhinagar – 382016, Gujarat*

E-mail : raghurajsingh@iter-india.org

#### Abstract

The Ion Cyclotron Heating and Current Drive (ICH &CD) system for ITER application is being developed to couple 20 MW Radio Frequency (RF) power into ITER plasma for heating and driving plasma current in the frequency range of 35-65MHz. There will be 8 RF sources to generate total 20 MW of RF power and one prototype source for test facility. Each RF source will be capable to deliver 2.5MW output power at VSWR of 2.0 having bandwidth of 2MHz as per ITER requirement and each RF source consist two parallel amplifier chains of 1.5MW and a combiner to generate 2.5MW power. Typically such high power RF sources are characterized with matched load but due to expected variance in load conditions corresponding to voltage standing wave ration (VSWR) 2:1 during experiment. Therefore it is necessary to test the performance of such RF source with mis-match load having VSWR-2:1 at different phase angles of reflection coefficient for the specified constant output power for 3600s.

A single chain of amplifier capable to deliver 1.5MW RF power is under fabrication therefore a MMTL system is designed to test the performance with mis-match load conditions.

This paper describes the conceptual design and development status of the MMTL in detail.

## NF-386

### Development, Testing And Integration Of Signal Conditioning Board With Local Control Unit Of R&D ICRF Source

Kumar Rajnish, Dipal Soni, Manoj Patel, Sriprakash Verma, Hriday Patel, Gajendra Suthar, Harsha Machchhar, Raghuraj Singh, P. Ajesh, Rohit Anand, R.G. Trivedi, Aparajita Mukherjee

*ITER-India, Institute for Plasma Research, Gandhinagar – 382016, Gujarat*

E-mail : krajnish@iter-india.org

#### Abstract

The Ion Cyclotron Heating and Current Drive (ICH &CD) system for ITER application is being designed, fabricated and commissioned to couple 20 MW Radio Frequency (RF) power into ITER plasma for heating and driving plasma current in the frequency range of 35-65MHz [1]. There will be 8 RF sources to generate total 20 MW of RF power and one prototype source for test facility. Each

RF source will be capable to deliver 2.5MW output power at VSWR of 2.0 having bandwidth of 2MHz as per ITER requirement and each RF source consist two parallel amplifier chains of 1.5MW and a combiner to generate 2.5MW power [2].

R&D activities for development of one chain of RF source with tetrode based technology as well as Diacode based technology has initiated. These Tetrode and Diacode requires Anode voltage biasing power supply having rating of ~27KV, 190A, Filament Power supply having rating of 20V, 1000A high voltage-high current and other power supply of CG/SG having rating of 600-1500V, 1A-20A. To operate these power supplies remotely and monitor the health status of these power supplies along with RF parameter, different type of control signal will be interfaced with Local Control Unit (LCU). To minimize the noise interference and ground loop coupling, optical transmission media will be used. Optical transmitter and receiver for Analog and digital signal is developed, tested and integrated with system.

This paper presents the configuration and test result of these modules that is used with R&D source at ITER-India test facilities.

#### References:

- [1] IC RF sources Conceptual Design Review Presentations: (ITER\_D\_2MK77U)
- [2] SRD 51(ITER\_D\_28B33K)

## NF-388

### Data Acquisition And Control System For The Setup Of New High Heat Flux Test Facility At IPR

S Belsare, S S Khirwadkar, R Swamy, Y Patil, R Sugandhi, Kedar Bhope,  
Kalpesh G, P Mokaria, T Patel

*Divertor & First Wall Technology Development Division, Institute For Plasma Research, Bhat,  
Gandhinagar 382 428*

E-mail: belsare@ipr.res.in

#### Abstract

Institute for Plasma Research is setting-up a High Heat Flux Test Facility using 200kW/45kV High Power Electron Beam System as a heat source. This High Heat Flux Test Facility using 200 KW High Power Electron beam (EB) System will be extensively useful to test the materials, small-scale divertors or first wall components and other HHF components. Also this will be useful to simulate the heat removal capabilities of high heat flux components and to estimate the thermal shocks absorption capability of plasma facing materials (PFMs).

This HHF test facility includes subsystems like High Pressure High Temperature Water Circulation System / Helium loop, HHF Test Chamber with High Vacuum pumping system, 200KW High Power Electron Beam as a controlled heat source, various Diagnostics systems (IR Camera, Fast response pyrometers, 2- Colour Pyrometers, RGA, Thermocouples and CCD as well as very high speed cameras etc) and remote positioning system for pyrometers.

For the automation and successful operation of the system, it requires reliable and flexible control system which should be advanced, rugged and time proven. Further, the data generated in the experimental phase needs to be acquired, monitored and stored for post-test data reduction and analysis. In the present test bed, this will be done using a combination of PLC based control system

for slow controls, PXI based control for fast controls and a PXI based data acquisition system. The control system consists of PLC to directly control all the subsystems except Electron Beam System and fast control loop. The Electron Beam System has its own dedicated Siemens PLC (S-7 400). Communication between main PLC and central control room computer will be done through Industrial Ethernet (IE). Control program and GUI will be developed using standard PLC programming software and SCADA software, respectively. There are approximately 128 Analog and 200 digital control and monitoring signals required to perform complete closed loop control of the system. PXI based Data Acquisition and control system is a combination of PXI RT (Real time) system, front end signal conditioning electronics, host system and DAQ program. All the acquisition signals coming from various sub-systems are connected and acquired by the PXI RT system through suitable link for signal conditioning, electrical isolation and better noise immunity. Real time and Host application programs will be developed in LabVIEW and the data shall be stored in Data Server with a facility of real-time visualization/online display of selected parameters. Present paper describes design details of the Data Acquisition and Control System, its integration with various sub-systems of HHFTF.

## NF-390

### **Exploring The Capability Of ATILA Code Along With Its FORNAX Activation And Transmutation Data Base For Dose Rate Calculations In ITER Like Geometry**

Deepak Aggarwal<sup>1</sup>, Chandan Danani<sup>1</sup>

<sup>1</sup>*Institute for Plasma Research, Gandhinagar 382428*

E-mail : deepakagg@ipr.res.in

#### **Abstract**

To assess the dose rates in ITER diagnostics ports, ITER IO has issued specifications of a calculation benchmark exercise in which several ITER organizations have participated. A validated computational tool is needed for reliable dose rate calculations in a complex geometry like ITER. We have selected to use ATILA code to perform such calculations. It has been selected as a secondary computational tool to the Monte Carlo MCNP code in assessing the nuclear field in the various components of ITER. Other ITER partners perform their dose rate assessment using codes based on the Monte Carlo approach (like MCNP code) for transport calculation and the radioactivity inventory code FISPACT or other equivalent decay data libraries for dose rate assessment. ATILA is a newly developed CAD based finite element code which uses Discrete Ordinates approach to solve the linearized Boltzmann transport equation for the transport of neutron, gamma and charged particle in a 3-D geometry. ATILA has a built-in activation capability that tracks the population of isotopes created through nuclear activation and decay processes. Activation and depletion calculations in ATILA use FENDL-2.1 as well as a module called FORNAX [1]. The FORNAX module of ATILA uses the neutron transport flux solution to calculate the build-up and decay of radioisotopes in the model structures.

The calculation model used resembles the configuration and geometrical arrangement of an upper diagnostics port plug (UPP) in ITER. The source specifications and the irradiation history were selected such that the ITER operation mode to accumulate a fluence of  $0.3 \text{ MWa/m}^2$ . We present in this paper the inter-comparisons of the results for neutrons flux, decay gammas flux, and dose rates

obtained by the various analysts from the other organizations involved with our results obtained using ATTILA at  $10^6$  seconds (~12days) following irradiation, as specified by ITER IO. In this paper some validation calculations performed using ATTILA for neutron leakage in spherical shells of Beryllium, Vanadium and Iron has also been shown [2].

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- [1] Mahmoud Z. Youssef, Russell Federet al., Benchmarking of the 3-D CAD-based Discrete Ordinates code ATTILA for dose rate calculations against experiments and Monte Carlo calculations, Fusion Engineering and Design, Volume 88, Issue 11, November 2013, Pages 3033–3040
- [2] <http://www.iaea.org/inis/collection/NCLCollectionStore/Public/32/004/32004955.pdf> Integral Data Test of FENDL-2 Fusion Nuclear Data Library with Neutronic Integral Experiments.

## NF-391

### Parametric Study Of Residual Stresses In Multi-Pass Welding For A Fusion Grade Reactor

ManoahStephen M, Ravi Prakash, Ranjana Gangradey

*Institute for Plasma Research, Bhat Village, Gandhinagar, Gujarat-382428*

Email: manoah@ipr.res.in

#### Abstract

Vacuum vessel and Cryostat for a Fusion Grade machine are massive structures involving fabrication of chambers with high thickness, about thickness up to 60 mm or more, made of special grade steels. Such machines require accurate planning of welding as the distortions and tolerance levels are stringent. High Thickness Welding of Vacuum Vessel is considered to be one of the most important elements in building a reactor of Fusion Grade due to large ineluctable distortions of welded parts after welding process as it is not easy to correct the large deformations after the welding process and finally the corrections are very expensive.

There are number of parameters that are considered to predict the thermal residual stress, distortion & other mechanical effect on the weld structure. Conservative assumption of residual stresses in highly restrained steel structures can lead to unnecessary repairs of defects in welded joints. Hence a multi-pass welding of high thickness stainless steel plate is simulated numerically in a non-linear thermo-mechanical FE-analysis. In particular, the through thickness variation of the weld and heat affected zone of the residual stresses and their sensitivity to variation in weld parameters are studied. Simulation results are of review studies of identified welding process like MIG, MAG and NG-TIG for welding large structural D shaped Vacuum Vessel profile as a case study.

**NF-392**

**Engineering Methodology For Bolt Design Of In-Vessel Structure For A Fusion Grade Reactor**

ManoahStephen M, Ravi Prakash

*Institute for Plasma Research, Bhat Village, Gandhinagar, Gujarat-382428*

E-mail: manoah@ipr.res.in

**Abstract**

The control coils are designed to flow with large currents and are located inside the vacuum vessel of Tokamak, the magnetic confinement Plasma device. The coils are subjected to large toroidal and poloidal magnetic fields inside the machine. In order to suspend the control coils inside the vacuum vessel suitable support structures have to be designed to encapsulate the coil and should withstand the normal operating load condition. The electromagnetic loads are arising due to the interaction of magnetic field generated by the coil with ambient magnetic field inside the machine. This paper summarizes the engineering design by analysis methodology using finite element analysis method in ANSYS to design the bolts which withstand all electromagnetic loads.

The shear and tensile forces were calculated for the individual load cases using coupled constraint method. The results were derived for all possible combination cases by taking the linear combinations of the individual cases. The estimation of bolt sizes, shear pin sizes, bolt spacing and fatigue assessment for the same was carried out for an in-vessel support structure for a fusion grade reactor.

**NF-395**

**Engineering Design Methodology Of End And Central Support For In-Vessel Structure For A Fusion Grade Reactor**

Ravi Prakash, ManoahStephen M,

*Institute for Plasma Research, Bhat Village, Gandhinagar, Gujarat-382428*

E-mail : prakash@ipr.res.in

**Abstract**

The control coils are designed to flow with large currents and are located inside the vacuum vessel of Tokamak, the magnetic confinement Plasma device. The coils are subjected to large toroidal and poloidal magnetic fields inside the machine. In order to suspend the control coils inside the vacuum vessel suitable support structures have to be designed to encapsulate the coil and should withstand the normal operating and disruption load condition. The electromagnetic loads are arising due to the interaction of magnetic field generated by the coil with ambient magnetic field inside the machine. This paper summarizes the design by analysis methodology using finite element analysis method in ANSYS to design the spherical end supports to withstand all electromagnetic loads. The spherical end support has to be designed which provides the support for the control coil to the vacuum vessel,

so that the reaction forces from the coils and support should not affect the vessel to which it is supported.

The worse operational, combined operational & disruption and full disruption cases were calculated for the individual load cases. The results were derived for all possible combination cases by taking the linear combinations of the individual cases. Maximum load for each of the support locations were estimated by conservative approach. The lug, pin and spherical bearing dimensions were calculated. The bearing, tensile and shear stresses calculations for each of the individual components were carried out for an in-vessel end and central support for a fusion grade reactor.

## NF-398

### Activation Analyses Of Indian-LLCB TBM-Set For ITER Irradiation Scenarios

A K Shaw, H L Swami, D Aggarwal and C Danani

*Institute for Plasma Research, Gandhinagar 382 428*

Email: akshayak@ipr.res.in

#### Abstract

International Thermonuclear Experimental Reactor (ITER) will provide the opportunity for testing of different tritium breeding blanket modules of several ITER parties. The Indian Test Blanket Module (TBM) based on the concept of lead-lithium cooled ceramic breeder (LLCB) will be tested in ITER equatorial port no#2. Indian LLCB-TBM consists of different materials namely Lead-Lithium for neutron multiplication, tritium breeder & cooling, Lithium-ceramic Lithium Titanate ( $\text{Li}_2\text{TiO}_3$ ) as tritium breeder, IN-RAFMS (Reduced Activation Ferritic/Martensitic Steel) as TBM structural material and SS316L(N)-ITER Grade as the shielding material.

14 MeV neutrons will be generated during the thermonuclear fusion inside the ITER chamber. These neutrons will spread and interact with the plasma facing components inside ITER. The radionuclide generated in course of (n,  $\gamma$ ) neutron interaction with different materials of LLCB-TBM will release the gamma photons according to their half-lives. For rad-waste management of LLCB test blanket system, it is very much essential to estimate the activity, decay heat and shutdown contact dose rate for each LLCB-TBM material. Here the activation analysis of different materials of LLCB-TBM has been performed using ITER irradiation phases DD, DT1 and DT2. In this paper, we have calculated neutron-induced activation, decay heat and shutdown contact dose rate for IN-LLCB TBM in ITER irradiation scenarios. These results will be utilized for LLCB TBS safety and rad-waste management. The Activation analysis has been carried out using FISPACT-2007 [1] code with activation cross-section data file EAF-2007.

#### Reference:

[1] R.A. Forrest, The European Activation System: EASY-2007 Overview, UKAEA Report, UKAEA FUS 533, 2007.

**NF-411**

**Piping Flexibility Analysis Of High Pressure High Temperature Experimental Helium Cooling Loop**

Aditya Kumar Verma, Brijesh Kumar Yadav, Ankit Gandhi, E. Rajendra Kumar

*Institute for Plasma Research, Bhat, Gandhinagar-382428*

E-mail: adityakumar@ipr.res.in

**Abstract**

Experimental Helium Cooling Loop (EHCL) is a high pressure-high temperature helium gas system. EHCL is similar to the First Wall Helium Cooling System (FWHCS) of LLCB TBM and in this loop up to one fourth ( $\frac{1}{4}$ ) size of TBM First wall mock ups can be tested.

The EHCL is designed to operate with helium gas at 8.0 MPa pressure and at 300-400 C temperature. The flow rate varies from 0.2 kg/s to 0.4 kg/s. The selected size for the connection pipes is DN 50. The high temperature pipes in this loop are at 400 C and at 8 MPa pressure, and these pipes are connected to pressure equipment in a limited space. Thus to ensure safety of the Piping System and to maintain the structural integrity under loading conditions (both external and internal), which may occur during the lifetime of the system, the details flexibility analysis was carried out.

This poster presents the results of detail flexibility analysis of EHCL pipes. To carry out the analysis the entire piping system of the loop was modeled and the static and dynamic analysis was carried out in CEASER II software. For the floor response spectra, the floor level in two horizontal and one vertical direction was computed. As IPR lies in zone -III, and the process loop is planned to be located at ground level at IPR campus, accordingly the FRS was used to find out the induced stress in the process loop. The dynamic effect and weight effects are considered in the design so that the stresses created by the combined loads do not exceed the allowable stresses prescribed by the design codes. Finally the piping layout satisfying the code requirements along with the results are presented in the poster.

Contents: This poster presents the piping flexibility analysis results of the EHCL loop.

**References:**

- [1] Conceptual Design of Experimental Helium Cooling Loop for Indian TBM R&D Experiments; B. K. Yadav, A. Gandhi, A. K. Verma, T. S. Rao, A. Saraswat, E. R. Kumar, M. Sarkar, K. N. Vyas <http://waset.org/publications/9997588/conceptual-design-of-experimental-helium-cooling-loop-for-indian-tbm-r-d-experiments>
- [2] Helium Loop Karlsruhe (HELOKA): A valuable tool for testing and qualifying ITER components and their He cooling circuits, FED, Volume 81, Issues 8–14, February 2006, p1471-1476.
- [3] Conceptual and preliminary engineering design of experimental helium loop for China HCCB TBM components test, FED, Volume 85, Issues 10–12, December 2010, p. 2146-2149.



**NF-412**

**Isolated Analogue Signal Measurement Units With High Speed Voltage To Frequency Converters**

Tejas Patel<sup>1</sup>, Vinod Patel<sup>1</sup>, Sandip Raiyani<sup>1</sup>, Amit Patel<sup>2</sup>, Aruna Thakar<sup>2</sup>

<sup>1</sup>*Amtech Electronics India Limited, Gandhinagar, Gujarat*

<sup>2</sup>*IPR, ITER-India, Gandhinagar, Gujarat*

E-mail : tejas@amtechelectronics.com

**Abstract**

Analogue signal measurement for operational parameters of a high power system is a concern due to its noisy reference and associated EM radiations. Conversion of electrical signals in to optical is one of the possible solutions for high voltage ground isolation; transforming analogue signal in to equivalent optical signal is still a challenge. Voltage to frequency conversion is found to be the optimum solution; where modulated optical frequency can be transmitted from the system under operation and a receiver unit can be coupled with an isolated sensitive digitization system.

A low frequency transmitter unit with 1% measurement accuracy and EMI compliance to IEC standards is successfully developed and tested; the modules are being used.

As a further development, a high frequency link with 300 kHz bandwidth is designed with fast VFCs, along with a receiver using same chips for frequency to voltage converter.

Design analysis, functional test results and immunity tests as per applicable IEC standards are discussed in the paper.

**NF-418**

**Improved Electronics For Langmuir Probe Diagnostics For APPEL Device**

C.Hansalia, G.Priyadarshini, Pramila, H.Kabariya, R.Rajpal, S.Karkari and R.Jha

*Institute for Plasma Research, Bhat, Gandhinagar-382428.*

E-mail : hansalia@ipr.res.in

**Abstract**

Langmuir Probe Diagnostic is used in Tokamaks and Basic Plasma Experiment Devices for measuring the edge plasma parameters like density, temperature, floating potential and plasma potential. The construction of a traditional Langmuir probe is based on coaxial design where the inner conductor is exposed to the plasma and the outer conductor encircling it, works as circuit common or return path. In a general measurement scheme, the Langmuir Probe is mounted on a plasma device with a vacuum feed-through/gate-valve arrangement and its inner conductor is biased with a sweep voltage of +40V/-140V at some variable frequency of dc to few KHz and the resultant current is measured. Here, the precise and noise-free measurement is a very crucial requirement. Traditionally,

this current is measured using a sensing resistor in series with the bias voltage and measuring the voltage drop across it. Putting a resistor in series path to measure a current is not a good idea compared to finding some better ways to measure it with zero impedance as the sensing resistor induces some error in current measurement. Another issue is related to the cable and probe capacitance with ac bias voltage. This capacitive effect causes the differentiation of the sweep bias voltage into pulse shaped noise voltages at the output increasing the noise floor of the measurement system even without any probe current or absence of plasma.

To mitigate the drawbacks of the sensing resistor scheme and the capacitive effects of coaxial cables and the probes, an improved measurement scheme is conceptualized for the first time in the Institute for our upcoming APPEL (Applied Plasma Physics Experiments in Linear Device) System. In this scheme, a direct current measurement method is proposed by eliminating the sensing resistor and using current to voltage (I/V) convertor with high voltage/high power IC PA85 followed by a dedicated difference amplifier AD629. Instead of coaxial cables and connectors, triaxial connectors and cables are proposed with shield driving scheme to neutralize their capacitive effects. The Triaxial cables and probes have three conductors; the central conductor, inner shield and the outer shield. The central conductor as usual will be biased with the sweep voltage and the inner shield will also be driven by the same but buffered sweep voltage for neutralizing the capacitive effect. The detailed design will be presented in this poster presentation.

#### References:

- [1] “Langmuir probe differential measurement technique in inductively coupled RF plasmas” Second International Workshop & Summer School on Plasma Physics 2006
- [2] “General Operating Conditions Application Note 1” from Apex Micro Technology.

**NF-421**

### **Preliminary Design Of Instrumentation & Control For Experimental Helium Cooling System**

T. Srinivas Rao, Ahishek Saraswat, D. Mohanta, E. Rajendra Kumar

*Institute for Plasma Research, Bhat, Gandhianagr-382428*

E-mail: tsrao@ipr.res.in

#### **Abstract**

This poster talks about Instrumentation and Control design for Experimental Helium Cooling Loop (EHCL). The experimental helium cooling facility is designed for the testing of **Lead Lithium Ceramic Breeder Test Blanket Module (LLCB TBM) First wall mock-ups**[1]. This facility consists of high pressure and high temperature helium gas loop with its pressure and inventory control system. The main controlling parameters of the loop are flow, pressure and temperature. The Instrumentation and Control system of the EHCL is designed to carry out these controls. Interlocks are provided to protect the facility under abnormal condition, trip signals are generated using triplicate signals and using 2 of 3 logic. This paper also discusses about detailed Process & Instrumentation Diagram (P&ID) emphasizing the Conventional, Investment protection & Safety Interlocks and Measurement & Control system configuration of EHCL. Sensors selection for high temperature and high pressure helium applications will be presented. For pressure measurement, electronic type

pressure transmitter with welded end process connection is provided. For measurement of temperature of Helium gas at Inlet and outlet lines of TSM and Recuperator discharge line towards heater, K type thermocouples are selected. For accurate flow measurement of Helium gas throughout the circuit, Coriolis Type Mass Flow meter is being considered [2].

#### References:

- [1] Status and progress of Indian LLCB test blanket systems for ITER, Fusion Engineering and Design. Paritosh Chaudhuri, E. Rajendra Kumar, A. Sircar, S. Ranjithkumar, V. Chaudhari, C. Danani, B. Yadav, R. Bhattacharyay, V. Mehta, R. Patel, K.N. Vyas, R.K. Singh, M. Sarkar, R. Srivastava, S. Mohan, K. Bhanja, A.K. Suri. [http://ac.els-cdn.com/S0920379612001226/1-s2.0-S0920379612001226-main.pdf?\\_tid=2c0523b0-33fa-11e4-9aa700000aab0f27&acdnat=1409811210\\_c9879e0374e180255019118d5cc082b0](http://ac.els-cdn.com/S0920379612001226/1-s2.0-S0920379612001226-main.pdf?_tid=2c0523b0-33fa-11e4-9aa700000aab0f27&acdnat=1409811210_c9879e0374e180255019118d5cc082b0).
- [2] Conceptual Design of Experimental Helium Cooling Loop for Indian TBM R&D Experiments. B. K. Yadav, A. Gandhi, A. K. Verma, T. S. Rao, A. Saraswat, E. R. Kumar, M. Sarkar, K. N. Vyas. <http://waset.org/publications/9997588/conceptual-design-of-experimental-helium-cooling-loop-for-indian-tbm-r-d-experiments>.

**NF-422**

### **Effect Of Bending Strain On Critical Current Of YBCO, BSCCO And Di-BSCCO High Temperature Superconducting Tapes**

Piyush Raj, Anees Bano, Arun Panchal, Mahesh Ghate, Subrata Pradhan

*Institute for Plasma Research, Bhat, Gandhinagar -382428, Gujarat*

E-mail : praj@ipr.res.in

#### **Abstract**

Bending tolerance is one of the most critical mechanical properties of High temperature superconducting (HTS) conductors for fabrication of superconducting coil. It is essential to estimate critical bending strain to optimize the bending radius during magnet fabrication for various HTS tapes. An indigenous set up to provide required in-situ bending strain to HTS tapes has been developed and validated at room temperature as well as at 77 K. In this paper, the critical current (I-V) characteristic of YBCO, BSCCO and Di-BSCCO superconducting tape under the influence of bending strain at various current ramp rate in self field has been discussed. The bending radius is varied from 48.14 mm to 15.73 mm by indigenous set as mentioned earlier. It is observed that in uniform bending condition, the degradation in current carrying capacity of HTS tapes are 3-4% at 77K. The effect of pure mechanical strain has been experimentally observed.

## NF-423

### Testing Of Process Sensors For High Temperature Liquid Metal Applications

Abhishek Saraswat, T. Srinivas Rao, Srikanta Sahu, Ashok Prajapati, Sandeep Gupta,  
Rajendra P Bhattacharyay, E. Rajendra Kumar

*Institute for Plasma Research, Bhat, Gandhinagar-382428*

E-mail: asaraswat@ipr.res.in

#### Abstract

Indian Lead Lithium cooled Ceramic Breeder (IN - LLCB) Test Blanket Module (TBM) is being developed for testing its performance in ITER. IN – LLCB TBS includes several ancillary systems. One of the important ancillary systems is Lead-Lithium Cooling System (LLCS). The LLCS play a major role in extracting the heat of TBM and the tritium, which is generated during the operation. The sensors/diagnostics requirements for measurement of critical process parameters (like Pressure, Level and Flow) for LLCS have been identified. Testing of these sensors in Pb-Li environment is very essential to validate the functional operation, reliability and long term performance. Pressure and Level Transmitters were selected and deployed in the testing facilities specially developed to test these sensors. Performance validation was established by performing continuous long-duration testing of selected sensors in Pb/Pb-Li environment. Results obtained from these tests are being analysed and will be presented.

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- [1] Status and progress of Indian LLCB test blanket systems for ITER, Fusion Engineering and Design. Paritosh Chaudhuri, E. Rajendra Kumar, A. Sircar, S. Ranjithkumar, V. Chaudhari, C. Danani, B. Yadav, R. Bhattacharyay, V. Mehta, R. Patel, K.N. Vyas, R.K. Singh, M. Sarkar, R. Srivastava, S. Mohan, K. Bhanja, A.K. Suri.  
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## NF-425

### 1-D Neutronic Shielding Analyses For ITER Like Fusion Devices

H L Swami, C Danani

*Institute for Plasma Research, Gandhinagar, Gujarat-382428*

E-mail: hswami@ipr.res.in

#### Abstract

A preliminary calculation of radiation shielding for ITER like nuclear fusion devices is carried through 1-D nuclear analyses. Here, the scope of 1-D neutronic shield design study is to establish a methodology of nuclear shield design for future nuclear fusion devices & reevaluate the ITER 1-D

neutronic analyses with recent nuclear data libraries. Optimization study to assess the shielding capability of ITER like device is also carried out. The 1 –D neutronic model has been prepared with concentric cylinders using radial thickness & materials of major components of machine. The neutron wall load at inboard side is kept 0.59 MW/m<sup>2</sup> & outboard side is 0.78 MW/m<sup>2</sup> [1] and all nuclear responses are normalized according to these neutron wall loads. This radiation shielding study is carried out using Monet Carlo Neutron Transport codes MCNP & nuclear cross section data libraries FENDL-2.1, 3.0 [2]. The main nuclear responses neutron flux, gamma flux, nuclear heating, dpa & gas production profiles are estimated and presented in this paper. The impact of recent nuclear data library FENDL-3.0 on ITER nuclear responses is also highlighted.

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## NF-426

### A Comparative Study On Fusion Reactor/Iter Structural Materials Activation Analyses

H L Swami, A K Shaw, D Aggarwal

*Institute for Plasma Research, Gandhinagar, Gujarat-382428*

E-mail: hswami@ipr.res.in

#### Abstract

Activation Analyses play an important role in nuclear reactor design; activation analyses along with nuclear analyses provide the necessary information for nuclear safety & maintenance strategy. The activation analyses also help in selection of materials in nuclear reactor by providing the radio-activity & dose rate level after irradiation. Here, a comparative activation analyses study of some Fusion reactor structural materials is carried out. In this study the fusion parameters are taken from ITER [1]& ITER TBM First Wall neutron flux spectrum is used for irradiation of structural materials. The ITER irradiation (20 years) scenario [2] is used in this activation analysis. The Materials which is selected for this study is relevant to ITER Plasma Facing Components are IN-RAFMS [3], Steel grade-P91, SS-316 LN-IG, SS-316L, SS304 & tungsten [4]. The analyses are done using EASY – FISPACT [5] activation code & Monte Carlo radiation transport code. The compared responses are contact dose rate, decay heat & radio activity. The details of newly formed radio-nuclides during and after irradiation are also analyzed in this paper.

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Development of India-specific RAFM steel through optimization of tungsten and tantalum contents for better combination of impact, tensile, low cycle fatigue and creep properties

K. Laha<sup>a</sup>, S. Saroja<sup>a</sup>, A. Moitra<sup>a</sup>, R. Sandhya<sup>a</sup>, M.D. Mathew<sup>a</sup>, T. Jayakumar<sup>a</sup>, E. Rajendra Kumar<sup>b</sup>

<sup>a</sup>Metallurgy and Materials Group, Indira Gandhi Centre for Atomic Research, Kalpakkam 603 102, TN, India

<sup>b</sup>Institute for Plasma Research, Bhat, Gandhinagar 382 428, Gujarat, India

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## NF-427

### Spectroscopic Observations In SST-1 Tokamak

R. Manchanda, M. B. Chowdhuri, Nilam Ramaiya, Niral Virani, J.Ghosh and SST-1 team

*Institute for Plasma Research, Bhat, Gandhinagar 382424*

E-mail: mranjana@ipr.res.in

#### Abstract

Impurity plays an important role in understanding tokamak plasma behavior since it affects the plasma performance through radiation loss and diluting fuel ion concentration. Impurity comes into the plasma as a result of plasma wall interaction and contaminates it. Then the study of impurity production and transport into the plasma becomes crucial. Along with that, plasma parameter, like ion and electron temperature can be inferred from the measurement of line width due to Doppler broadening and intensity ratios of spectral lines.

On SST-1 tokamak, eight optical fibers, interference filter and photomultiplier tube based spectroscopic systems have been installed to monitor the temporal evolution of the hydrogen and impurity emissions. Emissions are at two wavelengths of H I, and one of C II, C III, O I, O II, O III and O V. A low resolution and broadband survey spectrometer having three channels is used to record spectra in 350-900 nm wavelength range for the monitoring of overall plasma qualities. It also enables us to monitor radiations from 3 different lines of light simultaneously.

A 0.5 m visible spectrometer has been used to monitor the spectral emissions and normally used to estimate the plasma electron temperature of the emitting plasma region and to monitor the special spectral lines arising due to various experiments carried out to improve plasma performance. All systems are absolutely calibrated for its intensity to quantify the impurity influx and to estimate the plasma parameters. The detailed information regarding spectroscopic systems, absolute calibration and the results obtained and their variation with plasma parameters will be presented during the symposium.

**NF-428**

**Signal Conditioning And Integrator Electronics For Hard X-Ray Flux/Intensity Measurement Diagnostic In Aditya Tokamak**

Minsha Shah, Rachana Rajpal, Praveenlal Edappala, C J. Hansalia, Jayesh Raval, Shankar Joisa

*Institute for Plasma Research, Bhat, Gandhinagar-382428*

Email: minsha@ipr.res.in

**Abstract**

X-ray radiation emits from Tokamak plasma in the different energy ranges e.g soft x-ray emission (100ev-10kev), hard x-ray emission (100kev and above). Hard X-Ray diagnostics is used to monitor hard x-ray energy emitted from Tokamak plasma limiter. To monitor the intensity of runaway electrons a new diagnostics named Hard X-Ray Flux/Intensity Measurement (HXRFM) has been developed for ADITYA and SST-1 Tokamak which gives the time evolving signal of Hard X-ray flux. This diagnostics consists of scintillator crystal, Photo multiplier tube (PMT), high voltage power supply and associated electronics.

The electronics scheme for this diagnostic includes signal conditioning & an OP-Amp based analog integrator. The load resistor of 100K at the output of PMT converts the PMT current into voltage which is then amplified or attenuated by signal conditioning electronics. The integrator integrates this conditioned voltage with time constant (RC) of 10microseconds, which finally gives the time evolving signal of Hard X-ray Flux. The integrator acts like a storage element that “produces a voltage output which is proportional to the integral of its input voltage with respect to time”. In other words the magnitude of output signal is determined by the length of time a voltage is present at its input as the current through the feedback loop charges or discharges the capacitor as the required negative feedback occurs through the capacitor.

This paper describes the electronics scheme & results that are obtained during plasma shots in Aditya Tokamak.

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**NF-431**

**Neutronics Analysis of the 40 Degree CAD Model Of ITER With The 3-D  
Deterministic Neutron Transport Code, ATTILA**

Deepak Aggarwal<sup>1</sup>, C Danani<sup>1</sup>, B J Saikia<sup>2</sup>, M Z Youssef<sup>3</sup>

<sup>1</sup>*Institute for Plasma Research, Gandhinagar 382428*

<sup>2</sup>*Centre of Plasma Physics – Institute for Plasma Research, Guwahati 782402*

<sup>3</sup>*University of California-Los Angeles, Los Angeles, CA 90025, USA*

E-mail : deepakagg@ipr.res.in

**Abstract**

The 3-D Discrete Ordinates code, ATTILA, is being used by TBM neutronics team of IPR to undertake the nuclear analysis tasks which will be performed in collaboration between IPR and University of California, Los Angeles (UCLA). This design-oriented code can provide a full flux mapping everywhere and thus components subjected to excessive radiation can be easily identified. ATTILA can thus be used as a potentially quicker alternative to the MCNP code for the neutronics studies of various fusion components of ITER including ITER components to be supplied by ITER-India. ATTILA seems to lend itself as a powerful design tool with minimal turnaround time between CAD-based design changes and studying their impact on performance. It has been decided to perform the ATTILA calculations at IPR for the five responses set forth for calculation benchmarking purposes by the ITER nuclear designers in the standard 40 degree CAD model of ITER and compare the results to those obtained by ATTILA calculations performed at UCLA [1] and CAD based MCNP calculations by other ITER parties. This benchmarking study is needed to enable an increased fidelity and accuracy in modeling complex geometries in fusion systems. Further it will enhance our confidence in using the ATTILA code for performing neutronics calculations for large-scale and complex models such as ITER shielding blanket, ports, vacuum vessel and magnets.

It has been observed that the neutron and gamma flux at the equatorial locations are underestimated whereas the flux and nuclear heating are overestimated in the Divertor (Inboard, Outboard and Dome) and inner TF coil regions in the ATTILA calculations performed at IPR. Efforts are being made to quantify the differences and discrepancies for the results obtained from ATTILA with the published results for this benchmarking exercise.

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## NF-448

### Study Of Disruptive Termination Of The Aditya Plasma Discharges

S. Purohit, Y.S. Joisa, M. B. Chowdhuri, J.V. Raval, J. Ghosh, R. L. Tanna, D. Raju, C. N. Gupta, S. B. Bhatt, R. Jha and Aditya team

*Institute for Plasma Research, Bhat, Gandhinagar, 382 428*

E-mail: pshishir@ipr.res.in

#### Abstract

Disruptive termination of tokamak plasma holds major concern about the health of the tokamak as the amount of energy thrown away at the termination is huge. It is observed that in disruption, plasma thermal quench is followed by a sharp current decay. One of the ways to understand the plasma disruption is the study of the amount of current decay time for the respective discharges. For Aditya tokamak, a statistical analysis has been carried out for the identification of the disruptive discharges and decay time were estimated for the same. A Matlab code was developed for the determination of current decay times, which were found to be in the range of 0.8 to 2.5 ms. It was seen that the decay time is inversely proportional to edge safety factor. It is believed to be that there is a correlation between the pre-disruptive instabilities and the decay time. In this regard, the pre-disruption phase of these discharges was studied to understand the instabilities and their nature. For this purpose dominant frequencies of the MHD oscillations and magnetic island widths, 8 to 16 cm, were estimated from the Mirnov diagnostic installed on ADITYA. In this work, the details discussion on the relevant physics involving the current decay time and pre-disruptive instabilities is presented.

## NF-450

### Design Of A Timing Circuit For HPM - Plasma Interaction Experiments

Praveenlal Edappala, Rachana Rajpal, Hitesh Mandaliya, Salman Ansari, R Jha, Priyavandna J Rathod, Anoop Susheel, Nasir Shah, Saurabh Kumar, Rajesh Kumar and Anitha V P

*Institute for Plasma Research, Bhat, Gandhinagar-382428*

Email: praveen@ipr.res.in

#### Abstract

The design of a low cost micro controller based stand-alone timing system for High Power Microwave (HPM) - Plasma interaction experiments is conceptualized and designed. The interaction experiments involves generation of a pulsed ( $\sim 100 \mu\text{s}$ ) high density plasma and a pulsed ( $\sim 50 \text{ ns}$ ) HPM after a pre-set, controllable delay from the initiation of the plasma discharge. The time synchronization requirements include four sequential trigger pulses per shot, the shot repetition being one shot in every 20 seconds. The first TTL trigger pulse is used for isolating a high voltage power supply used to charge a pulse forming network (PFN), prior to the discharge of the later through a washer gun plasma source (WGPS). The second TTL pulse, after a pre-set delay, is to drive Ignitron

switch of the PFN circuit, to generate plasma. The technical requirements for the other two trigger pulses, used in HPM generation, are highly challenging, and include i) two fast 10ns, 10 V trigger pulses to drive a 40 KV equipment, ii) a controllable delay in the range of a few  $\mu$ s between the fast triggers and iii) high voltage (HV) isolation of  $> 40$  KV between the fast triggers.

A low cost microcontroller based timing circuit is designed and prototyped. Fiber optic transceiver modules are designed to trigger the 40 KV equipment with very high isolation voltages. The circuit is also integrated with a LCD module and control switches to set the all required delay and used as a standalone timing system. The microcontroller is programmed in assembly language to have precise control of delays in the micro seconds range. Power-On false trigger removal circuit is also implemented as a safety interlock. At the fiber optic receiver side, high speed MOSFET driver chip is used to achieve the fast rise time of 10nS. The receiver circuitry is made very compact, and is powered by a 12 V battery, in consideration of the HV isolation requirement. The prototype design is tested with 40KV trigger generator successfully. The whole system will be tested and installed for the experimental setup. A detailed account of the design features and the innovative techniques are discussed in the paper.

## NF-453

### Fundamental And Second Harmonic ECRH Assisted Plasma Start-Up In Tokamak SST-1

B. K. Shukla, S. Pradhan, Paresh Patel, Rajan Babu, Jatin Patel, Harshida Patel, Pragnesh Dhorajia, Prashant Singh, R. Jha, D. Bora, RHVPS Division, WCS Division, APPS Division, Diagnostics Division and SST-1 Team

*Institute for Plasma Research, Bhat, Gandhinagar-382428*

E-mail: shukla@ipr.res.in

#### Abstract

In SST-1, Electron Cyclotron resonance Heating (ECRH) system is used to carry out pre-ionization and start-up of tokamak at 0.75T and 1.5T operating toroidal magnetic field. The 42GHz ECRH system on SST-1 consists of a high power microwave source (Gyrotron),  $\sim 20$  meter long transmission line and a mirror based launcher. The Gyrotron delivers 500kW power for 500ms duration at 50kV beam voltage and 20A beam current. The circular corrugated waveguide based transmission line consists of a matching optic unit, two DC breaks, 63.5mm inner diameter corrugated waveguides, bend with bi-directional couplers, one polarizer and few bellows etc. The total transmission loss in the line is less than 1.1dB. The ECRH launcher consists of two mirrors one focusing and one plane to launch focused ECRH beam in plasma.

The SST-1 tokamak operates at 0.75T and 1.5T operating toroidal magnetic fields. The 42GHz ECRH system corresponds to second harmonic at 0.75T operation and fundamental harmonic at 1.5T operation. Since the loop voltage of SST-1 is low  $\sim 3.0$ V, in this case assisted breakdown is mandatory for reliable start-up of tokamak.

The ECRH is main heating system responsible for tokamak start-up and various experiments have been carried at second harmonic and fundamental harmonic.

At 0.75T operating toroidal magnetic field in SST-1,  $\sim 220 - 300$ kW, ECH power is launched in second harmonic X-mode and successful ECRH assisted breakdown is achieved at low loop voltage  $\sim 3$ V. The ECRH power is launched around 50ms prior to loop voltage. The hydrogen pressure in

tokamak is maintained  $\sim 1 \times 10^{-5}$  mbar and the pre-ionized density is  $\sim 4 \times 10^{12}$ /cc.

At 1.5T operating toroidal magnetic field, the ECH power is launched in fundamental O-mode. The ECH power at fundamental harmonic is varied from 100kW to 250kW and successful breakdown and plasma start-up is achieved in all the ECRH shots. In case of fundamental harmonic ECRH is launched at the start of loop voltage. The breakdown and start-up of SST-1 is very consistent with ECRH assisted discharges. In fundamental harmonic there is no delay in breakdown while at second harmonic  $\sim 30$ ms delay is observed, which is normal at second harmonic breakdown.

The paper discusses about 42GHz ECRH system and the results of ECRH assisted breakdown in SST-1 tokamak at fundamental and second harmonic.

## NF-460

### Design Of Mode Selective Coupler For 42GHZ, 200kW 3 Sec DST-Gyrotron

Shaik Ejazuddin, B.K. Shukla, S.V. Kulkarni and D. Bora

*Institute for Plasma Research, Gandhinagar, 382428*

E-mail : shaik.ejazuddin@ipr.res.in

#### Abstract

The gyrotron has become an integral part of the fusion reactors for pre-ionization, current start-up, heating, current drive and for stabilizing neo-classical tearing modes etc. The required frequency of gyrotron lies in the range of 42 GHz to 170 GHz and depends upon the toroidal magnetic field of the tokamak. The power requirement also varies according to tokamak and final requirement is from 5 MW to 20 MW.

Five organizations of India are developing a gyrotron and IPR is involved with test set-up, magnets, microwave power detection and characterization etc. The output or dominating mode of the indigenously being developed gyrotron is TE03. However, along with TE03 mode there may be possibility of other modes also being present. So we need a mode selector for selecting the particular mode and knowing the output power from gyrotron in that particular mode. In this paper we will discuss about the design of TE03 mode selective coupler, its simulation results and also the measurements of the fabricated coupler designed based upon the simulation results.

#### References:

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NF-463

## Multi-Field Characterization of Geodesic Acoustic Modes (GAMs) In SINP Tokamak

Lavkesh T. Lachhvani, Joydeep Ghosh, P. K. Chattopadhyay, Nikhil Chakrabarty<sup>1</sup> and Rabindranath Pal<sup>1</sup>

*Institute for Plasma Research, Gandhinagar – 382428*

<sup>1</sup>*Saha Institute of Nuclear Physics, 1/AF Bidhannagar, Kolkata – 700 064*

E-mail: lavkesh@ipr.res.in

### Abstract

Potential fluctuations in the edgeregion (from scape off layer to 1.0 cm inside the last close flux surface) of Saha Institute for Nuclear Physics (SINP)-tokamak are investigated using three Langmuir probe arrays. Each array contains three single probes [1] spaced radially. The probe arrays are placed at different poloidal and toroidal locations of the machine to obtain poloidal, toroidal and radial modes of the fluctuations. Coherent fluctuations, showing modes of frequency 15–22 kHz, in floating potential, magnetic field and poloidal velocity are observed in the typical discharges of SINP-tokamak of different  $q_{\text{edge}}$  values. Coherency of  $\gamma > 0.9$  along with zero slope at observed frequency in the cross-phase spectrum reveals oscillations are highly coherent. The observed poloidally and toroidally coherent modes exhibit the properties similar to that of Geodesic Acoustics Modes (GAM) [2], [3]. Local wave number spectra of fluctuations, however show small poloidal  $k_{\theta}$  and toroidal  $k_{\phi}$  at the observed frequency in very low  $q_{\text{edge}}$  (VLQ) discharges, which decreases further into high  $q_{\text{edge}}$  (HQ) discharges. The characteristics of observed GAM modifies itself from continuous GAM in HQ discharges to GAM eigenmodes in VLQ discharges. This may be due to the finite Larmor radius effect becoming prominent in VLQ discharges. Observed GAM frequency matches well with the calculated ones using measured temperature and edge safety factor.

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## NF-465

### Throughput Calibration Of Gas Dosing Valve For Pumping Speed Study Of Indigenously Developed Fusion Grade Cryopump

Pratikkumar Nayak<sup>1</sup>, Paresh Panchal<sup>1</sup>, Samiran Mukharjee<sup>1</sup>, Ranjana Gangradey<sup>1</sup>, S. Kasthurirangen<sup>1</sup>

*Institute for Plasma Research, Bhat, Gandhinagar, Gujarat-382428, India*

E-mail: pratik@ipr.res.in

#### Abstract

A large pumping speed in the 10<sup>-5</sup> mbar pressure range is primary and must requirement for fusion grade cryopump. For that a special type of cryopump is being developed at Institute for Plasma Research (IPR). The test experiments are done to see the pumping speed performance of prototypes. And for that the flow meter method is adopted, which is one of the recommended by the American vacuum society (AVS). In this method accurate throughput value of gas dosing is required for different test gases. This paper describes the experimental setup and experimental study carried out on gas dosing valve. The gas dosing throughput is calibrated in free molecular range for different opening of dosing valve, and the throughput range is varying from ~1E-4 to 10 mbar-litre/s. The calibration results are studied for hydrogen, helium, nitrogen and argon gases and compared.

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## NF-469

### Design And Analysis Of A Rotating Tritium Target Holder For 14-MeV Neutron Generator

Anuraj.R, Dhaval Rajyaguru, Sudhirsinh Vala, C.V.S. Rao, T.K. Basu and B. Sarkar

*Fusion Neutronics Laboratory, Institute for Plasma Research, Bhat, Gandhinagar – 382 428*

E-mail : d.rajyaguru@ipr.res.in

#### Abstract

A water-cooled rotating tritium target holder is under development for the accelerator based 14-MeV neutron generator to be built at Fusion Neutronics Laboratory (FNL), IPR. Deuterium beam of 300 keV energy and 30 mA current intensity bombards a solid Tritium target. The target is made by

adsorbing Tritium gas in a thin Titanium layer on a 5mm thick Copper back-plate. Total heat generated in the target is 9kW which has been estimated for a beam size of 10mm diameter. This heat has to be efficiently removed to avoid any release of tritium adsorbed in the titanium layer. The rotating target holder consists of mainly a cooling circuit which effectively cools the target plate. Rotating actuator is used to make it compatible with high vacuum environment while rotating. The analysis of the effective cooling of target plate is performed using the code Ansys.

Calculations have been carried out for heat removal generated during the process and for effective utilization of Tritium gas. Preliminary results indicate that 0.645 Kg/s mass flow rate of water is required, the Hoop's stress generated in the pipe is 0.1 MPa and Force exerted by water jet on Cu plate is 5N. Based on these preliminary results, more detailed calculations are underway and an engineering design is in advanced stage for review and finalization.

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## NF-471

### Effect of TF Ripple On The Performance Of Tokamak Plasmas

A. Amardas, R.L. Tanna, J. Ghosh, P.K. Chattopadhyay, M.B. Kalal, D.Raju, J.V. Raval, S. Purohit, Y.S. Joisa, C.V.S. Rao, Umesh Nagora and P.K. Atrey

*Institute for Plasma Research, Bhat, Gandhinagar-382428*

E-mail: amar@ipr.res.in

#### Abstract

In tokamak plasmas, toroidal field (TF) ripples induced losses of energetic particles found to have a significant effect on plasma rotation and thereby on stability of plasma, energy balance and heat load limits on first wall components. Hence it is very important to study the relevant physics by modifying the toroidal ripple externally. The TF ripple is modified locally with a ferrite insert in Aditya tokamak and its effect on the performance of plasma operation is studied. Finite element simulation of modified ripple and the experimental results of effect of modified ripple on the run-away electrons, energetic particle loss and confinement etc. will be presented in this poster.

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**NF-474**

**Test Results of 3MW RF Dummy Load&10kW Solid State RF Power Amplifier  
for ITER ICRH Frequency Range**

Akhil Jha, Manoj Patel, Rohit Agarwal, Raghuraj Singh, P. Ajesh, Harsha Machchhar, JVS Hari Krishna, Gajendra Suthar, Kumar Rajnish, Dipal Soni, Rohit Anand, Sriprakash Verma, Pareshkumar N. Vasava, Hriday N. Patel, Hrushikesh N. Dalicha, R.G. Trivedi, Aparajita Mukherjee

*ITER-India, Institute for Plasma Research, Gandhinagar – 382016, Gujarat*

E-mail : akhil.jha@iter-india.org

**Abstract**

The Ion Cyclotron Heating and Current Drive (ICH & CD) system has to couple 20 MW Radio Frequency power to ITER plasma for heating and driving plasma current, in the frequency range of 35-65 MHz. ITER –India is responsible for delivery of 8+1(spare) RF sources to ITER Organization. Each RF source will provide 2.5MW of RF power @ 2VSWR for frequency range of 35 to 65MHz. ITER-India has commissioned 3 MW RF dummy loads (DL)& 10 kW Solid State Power Amplifier (SSPA) with the help of industrial partners which will be used as a test bed for ITER RF power source in India. 3MW DL is designed first time for 3600s duration RF power with ITER ICRH frequency range. The SSPA is wideband amplifier and will be used as a pre-driver amplifier in the ITER RF source.

This paper presents the major technical specifications, schematic diagrams, test setup and test results.

**NF-475**

**Development Of UHV Compatible Wilson Feed-Through For Probe Drive**

K. M. Patel, K. A. Jadeja, K. S. Acharya, S. B. Bhatt, J. Ghosh, P. K. Chattopadhyay

*Institute for Plasma Research, Bhat, Gandhinagar - 382428*

E-mail : E-mail : kaushal@ipr.res.in

**Abstract**

Welded bellows are generally used to drive different systems inside the high vacuum chamber ( $\sim 10^{-8}$  torr) for their linear and rotational motions inside the chamber. However, welded bellows are too expensive and have to be imported. The other cheaper option available is Wilson feed-through, for linear as well as rotational motion of any assembly inside the vacuum. But Wilson feed-through has a drawback, which restricts its usage in many systems owing to the fact that during its linear/rotational motion, the vacuum of the system is disturbed due to leak through the O' rings. This limitation of the Wilson feed-through has been removed by providing a differential pumping between two O' rings. The interspace volume between two O-rings has been increased and by pumping of this volume through an extra rotary pump up to a vacuum level of ....., the Wilson feed-through based systems

have been successfully installed and operated in ultra-high vacuum chambers. This UHV compatible Wilson feed-through, can provide linear as well as rotational motion with negligible disturbance to the vacuum of the system. An UHV compatible Wilson type feed-through is designed and fabricated and has been used to install a Langmuir probes to characterize hydrogen plasma during glow discharge cleaning of Aditya Tokamak. The complete UHV compatible Wilson type feed-through system with all its details is discussed in this paper.

## NF-476

### R&D Activity For ITER ICRF Power Source System

Rajesh Trivedi , Aparajita Mukherjee, Raghuraj Singh, Kumar Rajnish, Harsha Machchhar, P. Ajesh, Gajendra Suthar, Dipal Soni, Manoj Patel, Kartik Mohan, Jvs Hari, Rohit Anand, Sriprakash Verma, Rohit Agarwal, Akhil Jha, Pareshkumar N. Vasava, Hriday N. Patel, Hrushikesh N. Dalicha

*ITER-India, Institute for Plasma Research, A-29 GIDC Electronic Estate, Sector-25, Gandhinagar – 382016, Gujarat*

E-mail : rgtrivedi@iter-india.org

#### Abstract

ITER-India is in-charge for the procurement of ITER Ion Cyclotron Resonance Frequency (ICRF) sources (1 Prototype + 8 series units) along with auxiliary power supplies & Local Control Unit. An R&D phase has been initiated for establishing the technology considering single amplifier chain experimentation (1.5MW/35-65 MHz/3600s/VSWR 2.0) prior to Prototype and series production.

R&D RF source will be tested with ITER like specifications at ITER-India Lab and for the same high power test facility and infrastructure are under development. All RF transmission line components have been procured. 3MW/CW Dummy Load is commissioned. 15kW Solid State Power pre-driver amplifier is tested and kept ready to feed the driver amplifier, which is cascaded with the final amplifier of RF amplifier chain. Pre-FAT activities for driver & final stage amplifiers are under progress at supplier's site. All auxiliaries and AC/DC power supplies required for high power test facility are at advance stage of commissioning.

This paper will describe the status of R&D activities and progress of the test facility at ITER-India Lab to demonstrate ITER-like test for RF source system.



**NF-479**

**Improved Plasma Parameters Using Upgraded Ohmic Capacitor Bank Power Supply in ADITYA Tokamak**

M.B. Kalal, R.L. Tanna, Pintu Kumar, D.S. Varia, Kunal Shah, K. Sathyanarayana, P.K. Chattopadhyay and Joydeep Ghosh

*Institute for Plasma Research, Bhat, Gandhinagar 382 428*

E-mail: mbkalal@ipr.res.in

**Abstract**

Aditya tokamak is operated using two independent power supply systems, Aditya Pulsed Power Supply (APPS) system as well as with a multistage capacitor bank power supply (CBPS). When APPS power supply is not available for Aditya tokamak operations, it is regularly operated with capacitor bank power supply. CBPS contains different capacitor banks made up of combination of capacitors connected in parallel. The capacitor banks are charged to different voltages and are switched in at appropriate times to provide power to Ohmic and vertical field coils. To realize an experimental demand for initial higher loop voltage for plasma production followed by a lower loop voltage for burn-through and sustaining the plasma current separate Ohmic capacitor banks (named fast and slow bank-I and slow bank-II) are used. To increase the plasma current and duration, the Ohmic slow bank-II (SBII) power supply is upgraded by adding 10 numbers of new energy storage capacitors of 1000 Micro F / 5 kV. This has increased the capacitance of SBII from 30 mF to 40 mF and 3 numbers of 450 Micro F / 8 kV in Ohmic slow bank-I (SB-I) power supply which has increased the capacitance of SBI from 2 mF to 3.35 mF. All the new energy storage capacitors are tested on dummy load as well as on actual load up to full operating parameters by holding the voltages up to 600 seconds before installation. The performance of the upgraded power supply is tested successfully in Aditya tokamak. It has provided an additional loop voltage in the start-up phase as well as in the plasma current flat-top phase, which helped in producing successful plasma discharges at higher operating pressure and lower E/P value. In addition to that toroidal magnetic field provided by DC Electrotherm power supply is also upgraded for higher  $B_T$  operation (increased from 0.21 T to 0.36 T). The significant improvement in plasma parameters has been observed after using upgraded power supplies with plasma current increased from 30 kA to 50 kA and plasma duration increased from 25 ms to 40 ms. The chord average electron density ( $n_e$ ) increased from  $5-6 \times 10^{12}$  / c.c to  $1 \times 10^{13}$  / c.c. The installation and testing of upgraded Ohmic capacitor bank power supply as well as plasma discharge performance improvement's results will be discussed in this paper.

NF-482

## The Outgassing Study Of Cryogenic Sealing & Support Material For Indigenous Cryopump

Paresh Panchal, Jyoti Agrawal, Samiran Mukherjee, Ranjana Gangradey

*Institute for Plasma Research, Bhat, Gandhinagar 382428*

E-mail: pmpanchal@ipr.res.in

### Abstract

Cryosorption Cryopump a project at Institute for Plasma Research uses several materials for different purposes. The main materials of Cryopumps are sorbents, adhesives, supports and cryogenic sealing materials. The supports and sealing being used inside the pump should have cryogenic compatibility as well as Vacuum compatibility. The cryogenic compatibility can be tested based on the thermal cycling of the materials. For supports G10 is identified as cryogenic compatible low thermal conducting material. Similarly indium is the widely acceptable Cryo-seal material. Both the materials are commercially available in market, but before using them into a UHV component they should be tested for their outgassing rates to avoid any malfunctioning in the UHV component. For that purpose Outgassing Measurement facility is established at IPR which has a known conductance of 2.46 l/s and base Outgassing rate of  $3 \times 10^{-12}$  mbar-ltr/s-cm<sup>2</sup>.

In this article measurement of Outgassing rate of Indium and G-10 reinforced fiberglass is presented. Necessary experiments to find out total gas load coming from the materials are performed at elevated temperatures as well as regeneration temperatures of the cryopump. The net outgassing rate has been calculated by subtracting the outgassing rate of blank system which was measured just before putting the sample in.

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**NF-487**

**Pumping Performance Study For Cryopump With The Use Of Test Particle Monte Carlo Simulation For Cryopump Development**

Rana Chirag, Ranjana Gangrady, Ravi Prakash, Samiran Mukherjee, Jyoti Aggrawal.

*Institute for Plasma Research, Bhat, Gandhinagar, Gujarat 382428*

Email: chirag7640@gmail.com

**Abstract**

Towards the development of prototype technologies IPR has developed Cryoadsorption Cryopump. The pump and its spin off technologies are completely indigenous. Development of the pump was aimed at deliverable a pump offering large pumping speed. An important part of the project was arriving at transmission probability (Capture Co efficient) analysis for the concept of arrangement of various sub components at 4K and 80K. To establish the methodology a number of bench mark problems were solved. Simulation for the geometry configuration of commercial cryopump was carried out using Monte Carlo Code. In the molecular regime numerical simulation of Monte Carlo result show good agreement with the pumping speed for commercial cryopump. Case study was done by means capture coefficient approach and throughput method as per AVS approach. This paper discusses results of simulation with respect to pumping speed by finding capture coefficient.

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**NF-489**

## **Studies Of Microstructure, Delta Ferrite And Ferrite Number In Multi-Pass TIG Welded 25mm Thick SS304**

Shamsuddin Shaikh, Sandip Bhagvat, N.L. Chauhan, Krushnansinh Garasia, Ramesh Kumar Buddu and  
P.M. Raole.

*FRMDC Division, Institute for Plasma Research, Bhat, Gandhinagar 382 428.*

E-mail: shams.ipr5508@gmail.com

### **Abstract**

Austenitic stainless steels are widely used in the fusion reactor components fabrication due to the superior mechanical, corrosion resistant and good weldability properties. Multipass TIG welding is applied for the development of structural materials for large scale fabrication. During the multipass welding process, the developed microstructure has impact on the welded joint structural properties. Austenitic steel welds generally have combined ferrite, austenite and small fractions of delta ferrite phase in microstructure. The complete understanding of the magnetic delta phase and its role on mechanical properties is still not very well understood in multipass TIG welds. It has major implication in fusion reactor applications. The present study is focused on investigation of the 25 mm thick AISI SS304 TIG multipass welds (20 passes) microstructure and delta ferrite studies with low and high magnification and the examination optical microscope and Scanning Electron Microscope. EDX analysis has been carried out and elemental distribution in weld zone was analyzed. Schaeffler diagram and WRC-1992 prediction methods are used for solidification modes analysis in the TIG multi-pass welds with the  $Cr_{eq} / Ni_{eq}$  suggested equations by using chemical composition data. Solidification mode of Ferrite to Austenite (FA) mode is observed. Ferrite number measurements further confirmed the presence of delta ferrite significantly as evident from experimental observation of Ferrite number (FN) with Ferritescope. The results will be presented in this paper.

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**NF-513**

## **Generation And Transport Of Saw-Teeth Induced Runaway Electrons In Aditya Tokamak**

Harshita Raj, Joydeep Ghosh, R. L. Tanna, P. K. Chattopadhyay, D. Raju, S. K. Jha, J. Rawal, S. Joisa, S. Purohit, CVS Rao, P. K. Atrey and Rabindranath Pal<sup>1</sup>

*Institute for Plasma Research, Gandhinagar – 382428*

*<sup>1</sup>Saha Institute of Nuclear Physics, 1/AF Bidhannagar, Kolkata – 700 064*

E-mail: harshita.raj@ipr.res.in

### **Abstract**

Sawtooth oscillations are commonly observed in temporal profiles of temperatures in almost all tokamaks including Aditya tokamak. These oscillations are known to be due to periodic reorganization of magnetic surfaces in core plasma. In typical discharges of Aditya tokamak highly correlated Hard X-Ray (HXR) burst (generated due to the interaction of runaway electrons (RE) with limiter) with sawtooth crash are regularly observed during initial period of plasma current flat-top. This suggests that sawtooth crash generates these runaway electrons, which in turn produces the HXR bursts. The electric field produced in the toroidal direction due to change in poloidal magnetic field during the sawtooth crash is the most probable reason for generation and acceleration of these REs. The induced toroidal electric field is calculated and the energy gained by REs due to this electric field has been estimated and compared with the experimental measurements. The estimated values match fairly well with experimental measurements. Further, it is observed that in the later part of plasma current flat-top, no HXR bursts accompany the sawtooth crash. This may be due to different transport patterns of runaway electrons in the initial and later parts of plasma current flat-top where the Mirnov oscillations are measured to be of different magnitudes. The generation and transportation of the sawtooth crash induced REs and presence and absence of correlated HXR bursts with each sawtooth crash is presented in this paper.

# **PLASMA DIAGNOSTICS**



**PD-000**

**Thermal Imaging of SST-1 Limiters and Calculation of Heat Flux Deposition and Estimation Of Total Power Drawn Limiters**

Kanchan Mahavar, Santosh P. Pandya, Hitesh Patel, Shwetang N. Pandya,  
Kumar Ajay and SST-1 Team

*Institute for Plasma Research, Bhat, Gandhinagar-382428, Gujarat*

E-mail: psantosh@ipr.res.in

**Abstract**

In tokamak plasma discharge experiments the main power loss channels are radiation, charge exchange neutrals and plasma transport losses. The powerlosses due to radiation and charge-exchange neutrals are estimated from the bolometric and Neutral Particle Analyzer measurements respectively. For comprehensive information about the plasma power balance, requires measurement of power losses through convection and conduction. These measurements can be carried out by the thermal imaging of the Plasma Facing Components (PFCs) heated due to the direct contact by the plasma and plasma surface interaction. Thermal imaging diagnostic of these PFCs provides real time monitoring of the surface temperatures remotely with wide field of view (FOV). First plasma experiments of the Steady State superconducting Tokamak-1 (SST-1) were commenced with limiter configuration. The limiters are located at two toroidal locations 180° apart, having graphite tiles as plasma facing material. The power deposited by the plasma on the limiter tiles can be determined by numerically solving the heat conduction equation of the limiter tile for the incident heat flux at the surface. It has been observed that the power deposited is mainly onto the high filed side limiters (inboard side).

Thermal imaging system is deployed on the SST-1 tokamak at radial port#12 having an IR-Camera (spectral response  $\sim 2\mu\text{m}$  to  $5\mu\text{m}$  range,  $320 \times 256$  pixel array, temperature sensitivity  $\sim 25\text{mk}$ ). The IR-camera works in the snapshot mode with frame rates 200 frames per second provides sampling time of 5 ms. The IR-camera is located out side the vacuum vessel and a CaF<sub>2</sub> vacuum view port has been used for the IR signal transmission ( $>95\%$  in  $2\mu\text{m}$  to  $5\mu\text{m}$  range). The IR-camera can measure temperature in the range of  $-10^\circ\text{C}$  to  $1200^\circ\text{C}$  with temperature resolution of  $0.025^\circ\text{C}$ . The system has wide FOV  $\sim 22^\circ$  (horizontally)  $\times 17^\circ$  (vertically) which covers inboard limiter in direct view and outboard limiter in reflected view using stainless steel mirror (reflectivity  $>90\%$ ) mounted on the high field side. The system provides spatial resolution of  $\sim 1 \times 1 \text{ mm}^2$  on the inboard limiter tiles and  $\sim 2 \times 2 \text{ mm}^2$  on outboard limiter tiles. This paper reports infrared thermographic observations carried out during recent SST-1 experimental campaigns and includes estimation of heat flux deposition to limiter and total power drawn by the set of limiters. The measurements presented in this paper were performed during the toroidal magnetic field is 1.5 Tesla. The total deposited power to the set of limiters was found to be below 20% to 40% of the total input ohmic power during current flattop. Electron Cyclotron Resonance Heating (ECRH) power is also dumped during plasma discharges and percentage power loss through limiters considering ECRH as well as ohmic is estimated. Inputs from this analysis will be useful to carry out global power balance study after taking inputs from other diagnostics.



**An Estimation Of Neutral Hydrogen Density As Well As The Ion Temperature In  
The Core Regime Of Aditya Plasma Using The Energetic Charge Exchange  
Neutral Spectrum As Obtained On The Channels Of Neutral Particle  
Analyzer[NPA] For Several APPS Discharges**

Kumar Ajay, Snehlata Gupta, Santosh P. Pandya, J. Govindarajan and Aditya team

*Institute for Plasma Research, Bhat, Gandhinagar-382428, Gujarat, India.*

E-mail : [ajaykuma@ipr.res.in](mailto:ajaykuma@ipr.res.in)

**Abstract**

Core-ion temperature measurements are routinely carried out by the energy analysis of passive Charge Exchange (CX) neutrals escaping out of the ADITYA-tokamak (Minor radius  $a=25$  cm, major radius  $R=75$  cm) plasma using a 45-degree parallel plate electrostatic energy analyzer [1]. The temporal evolutions of peak ion temperature in the core regime [typically 80 eV to 120 eV for Aditya circular ohmic plasma] as estimated by analyzing the energetic neutral spectrum obtained on four Channeltrons of multichannel data acquisition system [MEASARminus-A measurement system for CEM array, Dr. Sjuts optotechnik GmbH, Germany] for several plasma discharges in Aditya, provides an estimate for the core neutral hydrogen [ $H^0$ ] density and its evolution with time. Expected neutral density in the core regime has been estimated for several APPS discharges. The Charge Exchange Diagnostic system on Aditya [2] and data analysis techniques (using numerical algorithms developed) for NPA measurements are also described.

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**PD-008**

**First Results From The Infrared Imaging Video Bolometer In SST-1 Tokamak**

Santosh P. Pandya, Kanchan Mahavar, Zubin Shaikh<sup>1</sup>, Shamsuddin Shaikh, Hitesh Patel,  
Shwetang N. Pandya, Kumar Ajay, J. Govindarajan and SST-1 Team  
*Institute for Plasma Research, Bhat, Gandhinagar-382428, Gujarat*  
<sup>1</sup>*Saffrony Institute of Technology, Mehsana-384435, Gujarat*

E-mail : psantosh@ipr.res.in

**Abstract**

In recent years, the advance imaging plasma diagnosis techniques provides very useful spatiotemporal profile of various plasma parameters and better understanding of complex phenomenon. Infrared Imaging Video Bolometer (IRVB) is one of them which provides temporally resolved two-dimensional (2D) images of plasma radiation brightness. Infrared Imaging Video Bolometer has been successfully installed at the mid-plane of radial port# 2 in Steady State Tokamak-1 (SST-1) with tangential viewing geometry. The IRVB is designed and developed for the SST-1 tokamak utilizes a 2.5  $\mu\text{m}$  thick and 9 x 7  $\text{cm}^2$  size free standing Platinum foil as a radiation absorber element which provides broad radiation absorptions band  $\sim 1\text{eV}$  to 8 keV. The foil is clamped on a metal frame. Pinhole camera geometry with square aperture of 0.7 x 0.7  $\text{cm}^2$  provides 13 x 10 2-D array of bolometer pixels (Total 130 bolometer channels) and  $\sim 8$  cm of spatial resolution at the plasma mid plane with a  $61^\circ \times 48^\circ$  wide field of view (FOV). This wide FOV covers a tangential and a poloidal cross-sectional view of SST-1 first phase plasma. The FOV provides unique plasma viewing geometry which is confirmed by results of a basic radiation power loss model using synthetic IRVB diagnostics and presented here for SST-1 IRVB. An Infrared Camera having 320 x 240 focal plane arrays, 100 Hz full frame rate and temperature sensitivity  $\sim 0.02^\circ\text{C}$  is used to record 2-D temperature distribution of the foil through infrared transmitting vacuum view port and located outside the vacuum vessel. 2-D heat diffusion equation is applied on foil temperature data and numerically solved to estimate total radiated power incident on the foil and considering the etendue of the system, total radiated power from the plasma can be estimated during plasma discharge. The Noise Equivalent Power Density of the IRVB foil has been found to be  $\sim 200 \mu\text{W}/\text{cm}^2$ . The operation of IRVB was carried out during recent experimental campaigns where electron cyclotron resonance heating (ECH) has been used in tokamak for ECH assisted start-up because of the limited breakdown voltage. The foil of the IRVB get heated up due to ECH microwaves and contaminated bolometric signal. The microwave heating of the foil is suppressed after providing proper shielding to the IRVB module. The present paper describes experimental system, calibration, results of synthetic diagnostic and first results obtained during the recent plasma discharges are reported here.

**PD-010**

**Numerical Calculation Of Runaway Electron Energy Distribution Function And  
Estimation Of Associated Synchrotron Emission Spectra For The SST-1  
Tokamak**

Santosh P. Pandya, Shwetang N. Pandya, Kumar Ajay and J. Govindarajan

*Institute for Plasma Research, Bhat, Gandhinagar-382428, Gujarat*

E-mail : psantosh@ipr.res.in

**Abstract**

In tokamaks confined electrons for longer time scale are continuously accelerated under the application of toroidal electric field and surpass some threshold energy, called “critical” energy. These electrons are eventually gain energy as high as tens of mega-electron volts and called runaway electrons (REs). Understanding of the RE production, energy dynamics and loss is of grate interest, because these relativistic REs can cause a major damage to the in-vessel components and the first wall. The behavior of runaway electrons was theoretically and experimentally studied in several tokamaks. Various diagnosis techniques are available to detect confined and de-confined REs. One of the established method is detection of synchrotron radiation emitted by REs in presence of tokamak magnetic filed. The technique has widely been used in many tokamaks and various REs parameters have been estimated [1-6]. For the Steady State superconducting Tokamak-1 (SST-1) during long steady-state plasma discharge operation with 1.5 Tesla of toroidal magnetic filed, it is expected that the REs can gain sufficiently high energy and starts synchrotron emission in the infrared range (if  $E > 20$  MeVs). An InfraRed (IR) Camera located outside the vacuum vessel and having tangential viewing line of sight in electron approach direction can detect this synchrotron spot. In recent experimental campaigns, IR-camera having spectral response in 8  $\mu\text{m}$  to 12  $\mu\text{m}$  range (long-wave infrared band) with 18 ms time resolution (60 Hz frame rate) is deployed on RadialPort#7 at equatorial plane.

In the present paper, numerical simulation of RE production and energy dynamics is presented for the expected SST-1 plasma parameters, time evolution of synchrotron radiation spectrum and peak wavelength is calculated, experimental setup and initial attempts for the runaway detection are described. Though the synchrotron radiation is not observed during the set of discharges and possible reasons are numerically investigated by considering experimental plasma parameters and reported here. It has been found that the energy of the REs is well below than the required threshold for detection of synchrotron emission using long wave infrared camera.

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## Characterization of Hollow Cathode Discharge Plasma through Spectroscopic Measurement Of Atomic Excitation Temperature

M. L. Shah, B. M. Suri and G. P. Gupta

*Laser and Plasma Technology Division, Bhabha Atomic Research Centre, Mumbai – 400085*

*E-mail: gupta\_gomati@yahoo.com*

### Abstract

Understanding of the plasma behaviour in a hollow cathode discharge (HCD) lamp is important for the optimization of its applications. The HCD plasma is weakly-ionized plasma containing electrons, ions and atoms. The atomic excitation temperature describes the distribution of atoms in various energy levels as per the Boltzmann law. We have recorded the optical emission spectra from the plasma produced in a see-through type, homemade uranium HCD lamp with neon as a buffer gas. We have measured the atomic excitation temperature using the Boltzmann plot method [1] utilizing several uranium atomic spectral lines. From the linearity of the generated Boltzmann plot, it is inferred that the HCD plasma is in partial local thermodynamic equilibrium (PLTE). Applying the McWhirter criterion [2] to all the upper levels of the utilized atomic uranium transitions to be in PLTE, we have deduced the electron number density in the HCD plasma.

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## Influence Of Discharge Voltage And Pressure On The Electron Temperature And Electron Density In A Low Pressure Discharge

A. K. Shrestha<sup>1,2</sup>, R. Shrestha<sup>1</sup>, H. B. Baniya<sup>1</sup>, D. P. Subedi<sup>1</sup>, C.S Wong<sup>3</sup>

<sup>1</sup>*Kathmandu University, Department of Natural Science, Dhulikhel, Nepal.*

<sup>2</sup>*Damak Multiple Campus, Jhapa, Nepal*

<sup>3</sup>*Plasma Technology Research Centre, Physics Department, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia*

*E-mail: arundmk1010@yahoo.com*

### Abstract

This paper reports the measurement of electron temperature ( $T_e$ ) and electron density ( $n_e$ ) in a low pressure DC glow discharge in air using Langmuir double probe. Three different methods namely: Slope method, Dote method and Interception method were used to calculate the electron temperature ( $T_e$ ) and mean value of  $T_e$  obtained from the above three methods were used to calculate the electron density ( $n_e$ ). The objective of the study is to investigate the effect of discharge voltage and pressure

on electron temperature ( $T_e$ ) and electron density ( $n_e$ ). Experiment showed that electron temperature gradually increased as the voltage increased from 800V to 980V but decreased on decreasing the pressure from 0.07 mbar to 0.70 mbar at constant 980V voltage. In contrast, electron density increased on increasing both discharge voltage and pressure showing a maximum value at around 0.5mbar and gradually decreased beyond this pressure. Similar pattern was also observed on ion saturation current on changing the discharge voltage and discharge pressure. The electron temperature in the discharge was found to be in the range (2.0-6.0) eV and the density in the order of ( $10^{15}$  -  $10^{16}$ )  $m^{-3}$ .

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### PD-079

## Development of Online Plasma Edge Density and Temperature Measurement Module Using MATLAB<sup>®</sup>

Ramesh Joshi<sup>1</sup>, Gayatri Ashok and S.V. Kulkarni

*Institute for Plasma Research, Bhat, Gandhinagar – 382428*

Email: rjsohi@ipr.res.in

### Abstract

Ion Cyclotron Resonance Heating (ICRH) is very prominent auxiliary heating system for SST-1 machine. ICRH heating experiment needs many diagnostics like Langmuir probe, magnetic loop, electric dipole etc. One of the important diagnostic extensively used for plasma edge density and edge temperature measurement is Langmuir probe. Langmuir probes have been installed near the SOL region of ICRH antenna in SST-1 tokamak. Signals are taken thorough electrical feed through and coaxial cable which is connected to the biasing circuit of Langmuir probe. Actual probe signals are referenced by settable ramp during experiment. Data has been acquired by DAQ systems. Matlab module which calculates the plasma edge density and temperature has been developed and installed in DAQ system.

In SST-1 tokamak the initial plasma discharge is obtained using ECRH and ohmic. The program that has been integrated in the DAQ system give the values of density and temperature after each shot of SST-1. The values which are obtained are very useful for launching of the auxiliary waves (LHCD and ICRH) into the plasma. This module has been developed by considering the error bar in the measurement of the signals for Langmuir probes installed in magnetically confined devices. Our

program gives us an average edge density of  $5 \times 10^{11}$  per  $\text{cm}^3$  and an average temperature of 12 to 14 eV for a plasma current of around 65 kA. This paper describes the Matlab module and the experimental results.

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**PD-131**

**Effect Of Uniform Transverse Magnetic Field On The Lifetime Of Laser-Produced Copper Plasma**

Kh.Shantakumar Singh and Ashwini K. Sharma

*Department of Physics, Indian Institute of Technology, Guwahati, Assam -781039*

E-mail: s.khwairakpam@iitg.ernet.in

**Abstract**

We report on the effect of uniform magnetic field on the lifetime of laser-produced copper plasma. The high power pulsed laser (Q-switched Nd: YAG laser HYL 101) of wavelength 532 nm, pulse duration of 10 ns and repetition rate of 10 Hz was focused on the copper target to produce plasma. The laser energy supplied on the copper target was 40 mJ. In the presence of magnetic field the intensity of the copper atomic lines increased due to the confinement of the plasma. The lifetime of the atomic transition (512.8 nm) decreased initially and then increased slightly when the magnetic field was increased from  $B = 0$  to 0.5 T. It may be due to an increase in the electron impact collision with radiating atoms which shortens its lifetime when strength of the magnetic field increases. However, at higher magnetic field due to increase in radial expansion and deformation of plasma the electron impact collision decreased resulting in an increase in the lifetime of the radiating atom.

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PD-161

## X-Ray Crystal Spectroscopy: Survey and Edge Spectrometers for ITER

Sanjeev Varshney

*ITER-India, Institute for Plasma Research, Gandhinagar – 380016*

E-mail: sanjeev@iter-india.org

### Abstract

X-ray Crystal Spectroscopy (XRCS) of Hydrogen or Helium like ions of low or medium Z impurities in the plasmas is of significant importance in the nearly 45 planned diagnostics for ITER [1]. India is responsible to deliver two X-ray crystal spectrometers to ITER. The XRCS-Survey [2], a broad-band Bragg spectrometer, is one of the important diagnostic systems which will be put in the first set of diagnostics on ITER helping the start-up of the plasma operations. The primary function of this spectrometer will be to accurately measure plasma impurity concentration and their in-flux at fast enough rates in order to protect and/or control the machine during all phases of the ITER operations. The XRCS-Edge, a modified Johann spectrometer, is dedicated to measure profiles of ion temperature and poloidal rotation velocity in the plasma edge regions. Edge spectrometer is mainly required for advanced plasma control and will provide valuable data for edge pedestal physics. These systems will have to reliably function in the high neutron environment of the ITER.

Both the x-ray spectrometers are being designed to meet the ITER requirements. Preliminary performance has been simulated with the impurity emission data modelled with ADAS atomic database and SANCO impurity transport code. The talk will focus on the current state-of-the-art of the x-ray crystal spectroscopy for high temperature plasmas, recent advances in the applicable technology, and the design challenges for ITER. The latest design developments of the ITER X-ray Survey and Edge spectrometers will also be discussed.

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**PD-169**

## **Investigative Study of Cylindrical Magnetron Plasma Device Through Probes During Film Deposition**

Sankar Moni Borah

*Gauhati University, Jalukbari, Guwahati 781014, Assam, India*

E-mail : sankarmoni@gauhati.ac.in

### **Abstract**

One of the important diagnostics tool during the study of various plasma thin film deposition processes is the use of different probes like the Langmuir probe, the Emissive probe and the Mach probe among others. Such probes provide in-situ data of the various plasma properties during the deposition inside the device chamber which plays a very significant role in determining the optimum film deposition condition. In this study using different probes, an attempt has been made to co-relate the plasma parameters and obtain proper deposition conditions for films in a direct current cylindrical magnetron sputtering plasma device. This device has been used to deposit hard coating of titanium nitride thin film on bell-metal.

A Langmuir probe is often used as a diagnostic tool in various types of plasmas including magnetron systems [1]. It facilitates the local estimation of the plasma parameters like plasma density, electron temperature and electron energy distribution function (EEDF) in the plasma volume. Emissive probe has been used for accurate measurement of plasma potential in direct current discharges for many years [2]. Mach probes are in use to find out the ion drift velocity and plasma characteristics in the scrape-off layers of magnetized fusion plasmas [3].

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**PD-187**

**Retarding Grid Energy Analyzer For Measuring Ion Energy Distribution In Plasma Generated By Intense Ion Beam**

Mishra Love, Roychowdhury Pradip, Kewlani Hitesh, Gantayat L.M

*Accelerator and Pulse Power Division, Bhabha Atomic Research Centre, Trombay, Mumbai 400085*

E-mail : lovem@barc.gov.in

**Abstract**

High current ion sources finds various applications in diverse areas of science and technology. The ECR ion source developed for proton accelerator at BARC delivers 40 mA beam current at 50 keV beam energy. The space charge of low energy intense ion beam deteriorates the ion beam quality and results in substantial beam loss. Efficient transport of such low energy intense ion beam is limited by neutralization of the space charge of ion beam. The measurement of the energy distribution of background gas plasma ions generated by the ion beam particle collision provides a method for space charge neutralization 'f' measurement. We present a design of a retarding grid energy analyzer for measuring the energy distribution of residual gas ions which are repelled by the space charge of ion beam traversing through the beam transport line to calculate an estimate of space charge neutralization 'f'. The present work describes the design of retarding grid energy analyzer (RGEA).

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**PD-190**

**The Usefulness of Oblique View Electron Cyclotron Emission (ECE) Calculations for ITER**

P.V.Subhash<sup>1</sup>, Yashika Ghai<sup>2</sup>, Amit K.Singh<sup>1</sup>, Aparna M.P<sup>3</sup>, Divya V.S<sup>3</sup>, Basitha Thanseem T.K<sup>3</sup>,  
Hitesh Pandya<sup>1</sup> and P. Vasu<sup>1</sup>

<sup>1</sup> ITER-India, Institute for Plasma Research, Gandhinagar Gujarat

<sup>2</sup> GNDU, Amritsar, Punjab,

<sup>3</sup> University of Calicut, Kerala

E-mail : subhashpv@iter-india.org

**Abstract**

One or more ECE detector is used in tokamaks for temperature measurement, besides a perpendicular view ECE detector, many tokamaks including ITER will have one or more oblique view ECE

detection systems. This additional ECE system is expected to throw some light on the difference in electron temperature estimation between ECE and Thomson Scattering (TS) measurement. Computational calculations are employed in order to understand the usefulness of the oblique view ECE system for ITER. Two aspects are examined, one the radial resolution comparison with perpendicular view and second the possibility of obtaining information regarding the effect of non-thermal (super thermal) populations on ECE measurements. The results of our studies suggest that an improved (more resolved) spectra can be obtained by using oblique view [1]. The details of the modelling and possible physical explanations for this will be presented. Secondly, the super thermals are included in the calculations through a bi-Maxwellian distribution and its effects on ECE spectrum are studied. The contribution of the super thermals on ECE spectrum is considered through two oblique and one perpendicular views. This is established through a parametric study, which includes a considerable parametric regime relevant to ITER Scenario 2. The frequency regime, appears in the difference spectrum between  $N_{||+}$  and  $N_{||-}$  are found to be exactly corresponds to the frequency range which is affected by the super thermals. From the property of this asymmetry a method to relate the contribution from super thermal and difference spectrum between  $N_{||+}$  and  $N_{||-}$  is obtained. The detailed methodology and the further results will be discussed.

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### PD-200

#### Progress In The Design Of The ITER IN-DA ECE Diagnostic

Ravinder Kumar<sup>1</sup>, Suman Danani<sup>1</sup>, H. K. B. Pandya<sup>1</sup>, Sajal Thomas<sup>1</sup>, V. Kumar<sup>1</sup>, G. Taylor<sup>2</sup>, V.S. Udintsev<sup>3</sup>, G. Vayakis<sup>3</sup>, and M. Walsh<sup>3</sup>

<sup>1</sup>ITER-India/Institute for Plasma Research, Gandhinagar-382016, India

<sup>2</sup>Princeton Plasma Physics Laboratory, Princeton, NJ 08543, USA,

<sup>3</sup>ITER Organization, Route de Vinon sur Verdon, 13115 St Paul-Lez-Durance, France

E-mail: ravinder.kumar@iter-india.org

#### Abstract

The ECE Diagnostic system in ITER [1] will be used for measuring full profile (core to edge) of electron temperature, electron temperature fluctuations and radiated power in the electron cyclotron frequency range (70-1000 GHz). The ITER ECE Diagnostic system consists of port plug optics including hot calibration sources, polarization box, broadband transmission system and ECE radiation measurement Instruments (Michelson Interferometer and radiometers). The Indian domestic agency is responsible for delivering Broadband transmission system for transporting low power ECE signals from the port plug optics to the diagnostics hall, the hot calibration source in the diagnostics hall, two Fourier Transform Spectrometers (FTSs) based on Michelson Interferometers (70 to 1000 GHz) and a 122-230 GHz radiometer system [2]. The remainder of the ITER ECE diagnostic system is the responsibility of the US domestic agency and the ITER organization. The transmission system comprises straight waveguide pieces, Miter Bends, vacuum window and some quasi-optical components. The required transmission loss ~15 dB (up to 400GHz) and ~ 22 dB (above 400 GHz)

demands a significant design challenge for transmission line design. The high-throughput FTSs with frequency resolution  $\leq 3.75$  GHz and scanning repetition rate  $\leq 20$  ms in low vacuum is yet another design challenge. In this paper and presentation, the progress of the preliminary design of Michelson Interferometer (70-1000 GHz), local hot calibration source, broadband transmission system and O-mode radiometer (122-230 GHz) shall be described. Some analytical results showing ohmic and mode conversion losses in oversized circular waveguide components shall also be presented.

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### PD-206

#### **Design and Development of Single Langmuir Probe, Double Langmuir Probe and Emissive Probe for Online Measurement of Plasma Parameters in ECR Ion Source**

H.Kewlani, P.Roychowdhury, L.Mishra, S.H. Gharat.

*Accelerator and Pulse Power Division, Bhabha Atomic Research Centre, Trombay, Mumbai-400085*

E-mail: kewlani@barc.gov.in

#### **Abstract**

Development of 50 KeV, 50 mA Electron Cyclotron Resonance (ECR) ion source is going on at Accelerator & Pulse Power Division, BARC. In the ECR Ion source high density plasma is generated to extract 50 mA of  $H^+$  ion beam. The properties of ion beam depend on the plasma parameters. An Automated Single Langmuir Probe, Double Langmuir Probe and Emissive probe setup have been designed and developed to measure the plasma parameters. The plasma parameters of interest are electron density ( $n_e$ ), electron temperature ( $T_e$ ), plasma potential ( $V_p$ ) and floating potential ( $V_F$ ). The Automated single Langmuir Probe was used to characterize the steady state and pulse ECR plasma. A voltage sweep pulse of  $-100$  V to  $+100$  V amplitude and  $250\ \mu s$  to  $100$  ms duration is applied to single Langmuir probe. The probe I-V characteristics are recorded on DSO and stored in computer. One can vary voltage sweep amplitude range and pulse duration range as per requirement.

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**PD-214**

**Relativistic Guiding Of Dark Hollow Laser Beam In Axially Non-Uniform Plasma Channel**

Rajpreet Kaur, Naveen Gupta and Arvinder Singh

*Department of Physics, NIT Jalandhar, Jalandhar 144011*

Email: rajpreetkaur46@gmail.com

**Abstract**

Relativistic guiding of dark hollow gaussian laser (D.H.G) beam in a plasma channel formed by a Gaussian laser pulse has been investigated theoretically. Due to ionization induced defocusing of the prepulse the plasma channel formed is axially non uniform. When delayed dark hollow laser beam propagate through such a plasma channel, the competition between nonlinear refraction and diffractive divergence results into guided propagation of the laser beam. Following W.K.B approximation and moment theory approach second order nonlinear differential equations governing the evolution of spot size of laser beam have been obtained. The effect of guided beam intensities, position of intensity maxima of D.H.G beam from axis, axial non uniformity of plasma channel on the propagation of guided laser beam has been investigated. Relativistic laser guidance up to several Rayleigh lengths has been observed.

**PD-230**

**Simulation Of Laser Cooling For Li Atoms In 2-D: Using Vlasov Method**

Nagaraju Guthikonda, Ravi Udigiri, Ashok Vudayagiri

*School of Physics, University of Hyderabad, Hyderabad-500046*

E-mail: avsp@uohyd.ernet.in

**Abstract**

For the past few decades plasma physicists are devoted to devising, developing and proving techniques for diagnosing the properties of plasma called, "Plasma Diagnostics" [1]. From the diagnostics point of view, atomic beam supported emission spectroscopy is well suited as it offers high space and time resolution and causes almost no perturbation of the plasma. For measuring the most important plasma parameters "Laser Cooling Process" can be employed [2], in which the neutral particles are confined into a narrow beam and by injecting the beam of neutral particles, characteristic line radiation which is emitted from a narrow section of the plasma is to be studied.

For understanding the plasma dynamics we need a well collimated beam of spatial resolution of a few mm and time resolution of few  $\mu$ s where these parameters have to be optimized for Laser cooling. Since the thermal beam has large divergence, we need to make simulation of 2D laser cooling to reduce velocity along Y-direction and find out the minimum required parameters for a good collimated beam. This 2D cooling can be achieved by considering the system as a homogeneous and

perfectly collisionless fluid system. The phase density of the system is represented by a continuous function  $F$  and is given by  $F(x, v, t)$ . Where  $x$  is the position,  $v$  is the velocity and  $t$  is time. By applying Vlasov equations we can study the phase space dynamics of the fluid in the absence and presence of the radiation field. The obtained graphs between the transverse velocity ( $v_t$ ) and transverse position ( $X$ ) and between transverse Position ( $X$ ) and longitudinal Position ( $Z$ ) shows how laser cooling is achieved. We have obtained numerical values for captured velocity ( $v_{cap}$ ), appropriate laser frequency ( $\omega_L$ ), saturation constant ( $S$ ) for a well collimated beam, which are very useful for our experimental setup in the lab.

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## **PD-234**

### **An Overview of Resonance Probe for Diagnosing Complex Plasmas**

S. K. Karkari

*Institute for Plasma Research, Bhat Gandhinagar, Gujarat, India, 382428*

E-mail : skarkari@ipr.res.in

### **Abstract**

A concept of measuring local electron density in weakly magnetized plasma based on quarter wave resonator was introduced by Stenzel in 1976 [1]. In the recent years, the technique has attracted noticeable interest for diagnosing industrial plasmas. The resonance probes, also popularly known as hairpin probe due to its characteristic shape, have been successfully applied in many industrial plasma systems including deposition plasmas and dual radio-frequency operated confined CCP discharge. The principle is based on creating a standing wave that corresponds to the plasma permittivity in the near field region around the resonator. The above probing technique has the advantage over microwave interferometer because they are capable of providing local measurement of electron density. Besides its popularity in industrial plasma applications, its usefulness remained primarily underexplored in magnetized plasma systems until very recently the hairpin was applied to measure  $n_e$  in strongly magnetized field, existing near the extraction grid of the negative ion source [2]. Consecutively the basic resonance characteristics were investigated within laboratory plasma set-up [3]. In addition the resonance probes were also applied in conjunction with pulse-photo-detachment of negative ions for the determination of negative ion density [4] in pulse plasmas [5]. In this paper, we shall discuss the latest applications of resonance probe for interpreting complex plasmas that involve magnetic field and negative ions. In particular the concept of pulse-hairpin probe for identifying negative ion parameters in electro-negative plasma and its relevance in the basic study of sheaths formed around cylindrical objects shall be discussed. Some of the recent development of this technique shall be discussed in connection to its application in the new applied linear plasma physics experimental device being developed at IPR.

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## PD-240

### **Analysis of 2-Dimensional Total Radiation Power Loss Profiles Measured With Tangential Viewing Infrared Imaging Video Bolometer On The ADITYA Tokamak**

Shwetang N. Pandya, Santosh P. Pandya, Kanchan Mahavar, Zubin Shaikh, Shamsuddin Shaikh, Kumar Ajay and the ADITYA Team

*Institute for Plasma Research, Bhat, Gandhinagar-382428, Gujarat*

E-mail: shwetang@ipr.res.in

#### **Abstract**

In tokamaks, plasma heating and current drive is achieved by various means like ohmic, neutral beam, ECRH, ICRH and LHCD. These define input power for the plasma discharge while major power-loss channels are radiation, charge exchange neutrals and plasma transport losses to PFCs. The power losses due to the radiation are estimated from the bolometric measurements and it has significant contribution in the plasma discharge power balance studies. Thus, the measurement of total plasma radiation loss is an important diagnosis parameter for any plasma device and hence a bolometric measurement is essential. Recently, the Infrared Imaging Video Bolometer (IRVB) has emerged as a powerful 2-D imaging technique for bolometric measurement on plasma devices. A tangential viewing infrared imaging video bolometer (IRVB) was deployed on the ADITYA tokamak for these studies. The IRVB is competent for radiation absorption from ~5 eV to 8 keV using a free standing ultra thin Platinum foil having dimensions 6.3 cm x 6.3 cm x 0.0002 cm that views the plasma with a Field of View (FoV) of 46° x 46°. The IRVB images plasma radiation with 9x9 bolometer pixels (81 channels) at a temporal resolution of ~6 ms. The spatial resolution at plasma mid-plane is ~7 cm and Noise Equivalent Power Density (NEPD) is ~0.4 mW/cm<sup>2</sup>. The tangential FOV covers plasma current approach side of the plasma column. Plasma radiation (mainly from impurities) and charge exchange neutral flux enters through an aperture and is incident on radiation absorbing foil. This, thereby, alters the 2D temperature distribution profile of the foil. Numerical analysis of spatiotemporal temperature profile is done by means of heat diffusion equation and incident power profile on the foil is deduced. Considering system *etendue*, line integrated 2D power profile that is brightness (watt/cm<sup>2</sup>), images are obtained and analyzed. Present paper describes the analytical results of power-brightness images which provide useful information namely: total radiated power from entire plasma volume, fraction of power radiated from input ohmic power, location of peak brightness indicating localize radiation source, plasma emissivity (watt/cm<sup>3</sup>) profile after inversion of brightness profile etc. Analysis infers that the typical power fraction radiated from the entire volume of plasma is about 10% to 40% of the total input power for the present set of plasma discharges analyzed. Time varying hollow brightness profile of a radial/poloidal cross-section

indicates that the radiation is emitted from plasma edge region. Power loss profile peaks during the plasma initiation phase (indicating burn through phase of impurities) and during plasma termination phase, mainly due to sudden decrease of plasma temperature. Poloidally asymmetric radiation profile has also been observed in several set of discharges.

## PD-241

### **Investigation To Increase Thermal Sensitivity Of Infrared Imaging Video Bolometer Using Finite Element Analysis And Comparison With Experimental Results For Different Ultra Thin Metal Foils Used As Radiation Absorbing Element**

Hitesh Patel, Santosh P. Pandya, Kanchan Mahavar, Shwetang N. Pandya and Kumar Ajay

*Institute for Plasma Research, Bhat Village, Near Indira Bridge, Gandhinagar – 382 428*

E-mail: psantosh@ipr.res.in

#### **Abstract**

Bolometers are inevitable diagnostic tool for any tokamaks to study several plasma phenomena related to radiated power loss because of impurity ions present in the plasma. The bolometers kept near to the plasma for optimum signal and spatial resolution, are therefore, generally susceptible to electro-magnetic noise, radiation and neutron induced noise. So the bolometers are of great importance, particularly for the next generation fusion devices. The Infrared Imaging Video Bolometer (IRVB) has emerged as a powerful 2-D imaging technique for bolometric measurements on various plasma devices and has potential to overcome above mentioned noises. The bolometer utilizes a free standing ultra thin metal having large lateral dimensions that views plasma through an aperture forming pinhole-camera geometry. Radiation from plasma in wide energy band enters through an aperture and impinges on the foil clamped in a metal frame. Due to the absorption of incident radiation power, foil temperature rises and infrared camera located outside the vacuum vessel registers spatially and temporally resolved 2-D temperature distribution of the foil through an infrared transmitting vacuum view port. Using thermal diffusion numerical analysis, temperature information is converted in to total radiation power loss from the plasma. In IRVB, the foil is an important element that decides sensitivity, wavelength absorption range, field of view, temporal and spatial resolution of the system etc. Depending upon the requirements, the foil can also be coated with graphite layer in order to improve its emissivity ( $\geq 0.90$ ) towards infrared camera side and plasma side for better absorption of higher wavelength radiation. Since the thermal response of the foil material mainly decides sensitivity and the time response, thermal analysis coupled with Finite Element Analysis (FEA) of different foils namely *Pt, Al, Sn, Ta, Ti, Au, Ni and Mo* has been studied in the present work. In Finite Element Modeling (FEM), these foils have been used without graphite layer, with one side layer as well as with both side layers to check the effect on sensitivity for the IRVB. The graphite layer has two fold effects. Firstly, it increases the black body radiation emission and secondly its extra thickness increases the heat capacity of the foil. In addition, different “foil-frame” materials have been investigated to improve sensitivity. The graphite coating also contributes to a change in the thermal properties. Three dimensional transient thermal analysis and steady state analysis of different foils were carried out in order to obtain local foil properties such as thermal diffusivity and the product of the thermal conductivity and foil thickness. These quantities are necessary for solving 2D heat diffusion equations. The thermal diffusivity has been obtained by two

different methods. A comparison has been made between FEA and experimental results and a good agreement was found between these two results showing the accuracy of the proposed model.

**PD-298**

## **Monte Carlo Simulation of Fixed-Anode X-Ray Source Spectra**

Sapna Mishra, Sanjeev Varshney, T. Sai Chaitanya and Vinay Kumar

*ITER-India, Institutes for Plasma Research, Gandhinagar - 380016*

E-mail: sapna.mishra@iter-india.org

### **Abstract**

At ITER-India a Fixed-anode (FA) X-ray source is being designed for the testing of X-ray crystal spectrometer and its components. The source comprises a line filament as an electron source and Cu anode as a fixed target and allows X-ray beam output through a thin Be window. It will be operating at varying potential difference up to 30 keV. In order to ensure the output X-ray beam satisfying the design requirements, a simulation of X-ray beam characteristics is necessary. The Monte Carlo simulation is an accurate method enabling the calculations of X-ray spectra that are essentially close to the real spectra [1].

The simulation of X-ray spectrum from the source is carried out by considering electron and photon transport in a Monte Carlo code. A photon spectrum with characteristic Cu X-ray lines,  $K_{\alpha}$  and  $K_{\beta}$  at 8.05 keV and 8.93 keV along with the bremsstrahlung radiation has been obtained at different source parameters. The results will be used in determining dose parameters and assessing tube shielding requirements. The simulation results have also been compared with Spektr [2] output for tungsten target and they are found in a good agreement.

This paper will include the results of X-ray spectra simulated under different operating conditions of the X-ray source for the ITER-India lab activities.

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**PD-307**

**Conceptual Design Of Space Resolved Crystal Spectrometer For  
Aditya Upgrade Tokamak**

M. B. Chowdhuri<sup>1</sup>, N. B. Pablant<sup>2</sup> and J. Ghosh<sup>1</sup>

<sup>1</sup>*Institute for Plasma Research, Bhat, Gandhinagar 382 428*

<sup>2</sup>*Princeton Plasma Physics Laboratory, Princeton University, Princeton, New Jersey 08543, USA*

E-mail : malay@ipr.res.in

**Abstract**

In high temperature plasma devices, space resolved crystal spectrometer is a key diagnostic which can provide the spatial profile of the ion temperature, toroidal and poloidal velocities of the ionic species present in the plasma. It can also be utilized to study the core impurity behavior and electron temperature estimation. For Aditya Upgrade tokamak having  $\langle n_e \rangle$  of  $3 \times 10^{19} \text{ m}^{-3}$  and  $T_e(0)$  of 500 eV, conceptual design of a space resolved crystal spectrometer has been carried out to study the toroidal rotation velocity and the core impurity behavior. For this purpose, soft X-ray line at 1.3447 nm from He-like Ne ions has been considered and corresponding Mica 002 crystal having 2d spacing of 1.984 nm has been selected. Crystal to plasma center distance has been kept at 2.7 m and it will be placed tangentially at an angle of 35°. The width and height of the crystal are determined to be 25 and 20 mm, respectively. The radius of curvature of spectrometer is 0.74 m and spectral resolution is 0.00078 nm when coupled to a CCD detector having a dimension of 26×26 mm and pixel size of 13.5 µm. Soft X-ray emission from the plasma core will be monitored at 5 spatial locations with a spatial resolution of 3.0 cm. In this presentation, details on the conceptual design of the system and installation plan on Aditya tokamak will be discussed.

**PD-315**

**Optical Imaging Of SST-1 Plasma**

Manoj Kumar, Vishnu Chaudhary, Ajai Kumar and SST-1 team

*Institute For Plasma Research, Bhat, Gandhinagar-382428*

Email: mkg@ipr.res.in

**Abstract**

Optical diagnostics are important non invasive investigative tool to measure various plasma parameters like plasma size, shape, movement etc. We have installed optical imaging diagnostics on SST-1 which consists of two 1024 x 1024 elements CCD camera placed 180 degree opposite geometrically. Each camera has a field of view of 70°. This system covers around 90% of the vacuum vessel. The PCI based image acquisition hardware is selected for real time image transfer to computer database. The LabVIEW based automated host is developed for visual and image analysis purpose. The images are taken at a frame rate of ~40 ms which provide information about time evolution of

plasma images. From the measured plasma images plasma size, shape and movement has been extracted. The imaging system shows the formation of plasma ring during machine operation. From this plasma ring estimated plasma diameter is around 500 mm. The plasma diameter is estimated from known references within the vacuum vessel. The variation of plasma images with respect to magnetic field and ECRH power will also be presented.

## PD-329

### **Development And Testing Of Prototype Soft X-Ray Imaging Camera In ADITYA Tokamak.**

Jayesh V. Raval, Praveena Kumari, Vismaysinh Raulji, Minsha Shah, S. Purohit, Y.S. Joisa, Rachana Rajpal, Aditya team.

*Institute for Plasma Research, Bhat, Gandhinagar, Gujarat 382428.*

E-mail: ravaljv@ipr.res.in

#### **Abstract**

Soft X-Ray diagnostics is very useful tool to study various properties of tokamak plasma. As the temperature of tokamak plasma reaches very high, core plasma radiation takes place in Soft X-Ray range. It is very important to know the details about electron temperature, Saw-tooth oscillation and study of MHD activity in tokamak plasma [1]. To study mentioned phenomena, prototype Soft X-Ray imaging camera has been designed and fabricated [2]; It consist of a linear array of 16 silicon photo diode (AXUV 16ELO) which views plasma and detects the Soft X-Ray radiation through a slot hole of 0.5mm x 5mm and 10mm thick Beryllium foil respectively. Signal current generated from the each photodiode is amplified and conditioned by signal conditioning unit and digitised and acquired by 8 channel embedded acquisition system. This prototype has been installed in ADITYA tokamak to test performance of entire system. In this communication we have presented the system design and initial results during experimental campaign in ADITYA. Temporal evolution of Soft X-Ray signal at different radial position; acquired by system, matches well with signal acquired by silicon surface barrier diode (SBD) in radial camera.

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PD-347

## Design of Charge Exchange Diagnostic System for SST-1 Tokamak

Snehlata Gupta, Santosh P. Pandya, Hitesh Patel, Kumar Ajay

*Institute for Plasma Research, Bhat Village, Near Indira Bridge, Gandhinagar – 382428*

E-mail: ajaykuma@ipr.res.in

### Abstract

The charge exchange diagnostic has been designed and integrated with SST-1 Tokamak to measure the ion temperature and its evolution during the plasma discharge. The diagnostic is a passive one, limited to measure the core ion temperature. Estimation of the core ion temperature in magnetically confined plasma using passive charge exchange diagnostic (CXD) is based on the energy analysis of the charge exchange neutrals escaping out of the plasma confinement [1, 2]. The charge exchange (CX) neutrals are produced due to the charge exchange collisions between the neutrals (which have penetrated into the plasma) and the hot plasma ions inside the plasma. As the energy exchange is negligible in these collisions, the charge exchange neutrals have the same energy distribution as that of ions inside the plasma. The CXD for SST-1 uses a stripping gas-cell configuration for stripping the CX-neutrals into ions and these ions are further analyzed in a 45° parallel plate electrostatic analyzer using ion detectors (the channel electron multipliers, CEM) and the Pulse Counting Module for counting the ions.

The pulse counting module of the CXD system in SST-1 uses the MESAR System [3]. MESAR is a modular electronic instrument (manufactured by Dr. Sjus GmbH, Germany) to operate systems with multiple CEMs or photomultipliers (PMTs) and evaluate all output signals simultaneously by pulse counting. It has provisions for setting high voltage bias to CEMs, discriminator threshold, dead time and measurement time interval adjustment, pulse counting and recording the signal via a RS232 interfaced PC. This paper reports the design parameters and describes in detail the CXD system for SST-1 Tokamak.

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PD-357

## Developing High Temperature Compatible Langmuir Probes And Data Acquisition System For CIMPLE-PSI

Puspalata Sah and N. Aomoa

*Centre of Plasma Physics-Institute for Plasma Research, Sonapur 782 402, Assam, India*

E-mail: getguddy@gmail.com

### Abstract

It is challenging to use Langmuir probes in high temperature thermal plasmas because of the very high heat load depositing on all exposed parts of the probe system. CPP-IPR is developing a segmented thermal plasma torch assisted magnetized Divertor Simulator system which will be used to study plasma surface interaction (PSI) processes under intense Tokamak Divertor like plasma conditions (*CPP-IPR Magnetized Plasma Experiments for Plasma Surface Interaction-CIMPLE-PSI*). A collimated plasma jet configuration appropriate for such experiments will be produced here which will be characterized by optical emission spectroscopy (1.33m McPherson Spectrometer and CCD camera). However, it is essential to use Langmuir probes also for validation of OES results and for spatial resolution. Use of probes will be even more difficult in this particular device as the plasma beam will be optimized in steps to produce extreme heat flux density up to about  $50 \text{ MW/m}^2$ . Under this situation it would be more pragmatic to go for a dynamic design of the Langmuir probes and explore different techniques to withstand the heat load. This paper reports some simple, in-house developments in this direction, where the probe is biased momentarily (using output of a simple transformer) and withdrawn from the plasma immediately after that. As for the sheath material on the probe tip (tungsten or graphite pencil leads) either boron-nitride or alumina are used. These probes were used for actual measurements in the un-magnetized but the same segmented plasma torch assisted High Heat Flux (HHF) system, which is being utilized as the pilot system to CIMPLE-PSI, for development of diagnostics and preliminary PSI studies. For an argon plasma jet (180 A, 9 kW, 15 mbar), the plasma density at a distance of 245 mm from the torch nozzle tip was measured to be  $7.9 \times 10^{17} \text{ m}^{-3}$  and temperature about 0.3 eV. The paper will report some more recent results on the characterization of the plasma jet in the HHF system. A low cost data acquisition system was also developed for computerized acquisition and storage. It is based on low-cost AVR microcontroller (ATmega328) which can offer 10 bit resolution. PC based controlling program read the output of the microcontroller at pre-decided time intervals. It has been already used to acquire the Langmuir probe data and will be integrated to water cooling temperature in the future.

**PD-363**

**Modbus Based Integration of Stepper Motor Drives For Probes Positioning In Large Volume Plasma Device**

R. Sugandhi, P. K. Srivastava, A.K. Sanyasi, Prabhakar Srivastava and L.M. Awasthi

*Institute for Plasma Research, Gandhinagar 328428*

E-mail : ritesh@ipr.res.in

**Abstract**

One of the major problems encountered in Large Volume Plasma Device (LVPD) during investigations is the handling of 1m length probe shafts carrying probes [1]. The accurate positioning of the diagnostics during movement at various coordinate positions within the device is a necessary requirement to fulfill. In this direction, we have designed, fabricated and successfully installed 12 nos. of 1m travel length, lead screws based assemblies and corresponding driver units. Each of these driver units consists of a bi-phase motor, precise stepper drives and feedback encoder device.

An interface for integration of the driver units using standard Modbus protocol [2] is proposed. Broadly, this interface offers (1) simple serial connectivity with extension up to 247 units, (2) standardization of the command protocol for a portable implementation and (3) auto translation of the coordinate of the probe positioning into lower level stepper drive commands. The novelty of the work is the simultaneous operation of the multiple probe drive in a synchronous and profiled fashion. The interface consists of following parts namely, (1) RS-485 multi drop communication (2) software interface using Modbus RTU [3] protocol (3) test applications for performance testing at drive and system level and (4) arbitration logic for sharing of the serial line resource. This software interface is validated using standard Modbus testers (Modbus poll, Modbus slave etc.). Further to it, a customized application is developed using LabVIEW 2013 toolset [3] and NI Modbus library [4]. This user interface facilitates a dashboard for configuration settings, online status monitoring, alarms management and interactive and profiled operation. The reported work highlights requirements, interface description, architectural details and obtained performance results of the probe drive.

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**PD-364**

**A Novel Design Of Emissive Probe For Plasma Potential Measurements In LVPD**

P. K. Srivastava, A. K. Sanyasi, and L. M. Awasthi

*Institute for Plasma Research, Bhat, Gandhinagar, 382428*

E-mail : pkumar@ipr.res.in

**Abstract**

Emissive probe is considered effective in measuring the plasma potential in plasmas wide ranging from RF plasmas to tokamak plasmas. Past investigations have revealed that the three most popular methods are adopted and are namely, 1) the floating potential method, 2) the inflection point method and 3) the separation point method in the limit of zero emission but there is always a level of discrepancy attached and they do not always give same measurement of plasma potential.

In this direction, we have attempted to improve upon these measurements by adopting a new design of emissive probe and its measurement circuitry. The emissive probe is rapidly switched, against which it is compensated for cable capacitance, by using a centre-tapped design. Different measurements are performed to overcome the poisonous effects affecting potential measurements like capacitive charging, magnetic insulation and dc offset. A detailed experimental investigation is carried out in the three regions of LVPD plasma. The three regions of source, EEf and target plasmas offer distinctly different plasma environment and thus provide a suitable bed for comparing these measurements with respect to cited techniques. This paper will present a comparison of plasma potential measurement based upon different designs and operating techniques and will highlight the merit and demerits of the design.

**PD-366**

***In-Situ*Plane Switching (IPS) Heating Mechanism For High Density Plasma Source In LVPD**

P. K. Srivastava, Prabhakar Srivastava, A. K. Sanyasi, R. Sugandhi, L. M. Awasthi and S. K. Mattoo

*Institute for Plasma Research, Bhat, Gandhinagar, 382428*

E-mail : pkumar@ipr.res.in

**Abstract**

This paper will discuss a novel technique of using in-situ, semiconductor switch, right behind the multi filamentary plasma source for IPS (in plane switching) based control of current feeding to all filaments of the plasma source. The new plasma source of LVPD will consists of 98 filaments (W-make, diameter= 1.6mm and Length=18 cm), evenly distributed over the cross section (diameter ~ 1.8 m). In this source, filaments will have independent control of current through a software interface activating IGBT based switches. All features of present plasma source will be retained in the upcoming source. The major gain of this technique is that it offers a much simplified version of

heating mechanism, which otherwise would have been a very large, cumbersome transmission line system because of heavy current requirement of each filament ( $\sim 100\text{A}$ ), for optimized emission. This technique will eliminate the need of costly, high current vacuum feedthroughs ( $\sim 186$  no's) and will replace it with a simple, compact heating mechanism, which can be operated through a software interface using a simplified selection of digital control electronics. Paper will discuss the performance of a prototype switching mechanism for heating a source consisting of two such filaments when the switches are immersed in plasma.

## PD-397

### Plasma Flows Measurement By Using Gundestrup Probe In ADITYA Tokamak

Deepak Sangwan, R Jha, R. Tanna, R. Manchanda

*Institute for Plasma Research, Bhat, Gandhinagar, 382428*

E-mail : sangwanphy@gmail.com

#### Abstract

Plasma flow measurement by using Mach probes is very common in tokamak scrape-off layer (SOL) [1-3]. They are normally used to measure toroidal (parallel) flows in the SOL of tokamak. To measure flows in other direction a multiple plate Mach probe is needed, which is known as Gundestrup probe. We have used Gundestrup probe to measure multidirectional plasma flows in the SOL plasma of ADITYA tokamak including perpendicular (poloidal) flows [4-6]. The Gundestrup probe in ADITYA consists of eight Molybdenum plates of dimension  $3\times 3\text{ mm}\times\text{mm}$ , to measure plasma flows in parallel, poloidal and at  $\pm 45$  degree to the toroidal direction. Comparison of poloidal flow measurement by poloidally separated plates and by the  $\pm 45$  degree plates [7] and effect of  $Z(\text{effective})$  on the plasma flows are studied. The flow profile is measured by keeping probe at different radial location from the last closed flux surface. The observed parallel flow is in clockwise direction as seen from top of the machine and Mach number is in the range 0.2-1. On the other hand the poloidal flow Mach number is in the range 0.1-0.5.

## PD-403

### Emission Spectroscopic Study Of Excitation Temperature In Argon And Nitrogen Plasma Jet

K C Meher, N Tiwari, S N Sahasrabudhe and S. Ghorui

*Bhabha Atomic Research Centre, Mumbai*

E-mail : kailashc@barc.gov.in

#### Abstract

DC plasma jets provide an attractive means for industrial process applications like cutting, welding, melting, spraying as well as novel applications like waste treatment, gasification, nano-material synthesis etc. It has easier process control and unique ability to create a jet having high energy

density, high temperature, chemically inert as well as reactive environment for various process applications. While argon and nitrogen are the two among the mostly used gasses for processing works, they possess distinctly different features. Being a diatomic gas, nitrogen can support much higher power compared to argon for the same electrode configuration. However, higher power does not necessarily mean higher temperature as a good part of the input power goes into dissociation of the nitrogen molecules. As temperature is a decisive factor for most of the process applications, it is important to characterize a plasma jet in terms of its temperature under different process conditions.

Most of the reported studies on plasma temperature are concerned with argon plasma or plasma generated using binary gas mixtures with power level lying below 20 kW. For diatomic gasses, these studies mostly deal with low temperature nitrogen plasma jets where the rotational and vibrational temperatures of nitrogen plasma are determined from respective molecular spectra. Unfortunately, for high power applications, temperature in the core of the plasma often exceeds 10,000 K, nitrogen cannot exist in molecular form and hence temperature cannot be determined from its molecular spectra.

The current study determines the axial temperatures of atmospheric pressure argon and nitrogen plasma jets discharging into ambient atmosphere. Boltzmann plot technique is used in determining the plasma core temperature from the intensities of atomic and ionic lines. For a given torch, obtained temperatures of nitrogen plasma jet are compared with those of argon under similar operating conditions. Wherever possible, results are compared with data available in literature.

## PD-416

### Observation On C III and H $\alpha$ Emissions From The Vicinity Of Aditya Tokamak Limiter Using A Limiter Viewing Diagnostics

Roshin Raj S<sup>1</sup>, R. Manchanda<sup>2</sup>, M. B. Chowdhuri<sup>2</sup>, Nilam Ramaiya<sup>2</sup>, Niral Virani<sup>2</sup>, J. Ghosh<sup>2</sup> and  
Aditya team

<sup>1</sup>National Institute of Technology, Calicut, 673 601

<sup>2</sup>Institute for Plasma Research, Bhat Gandhinagar 382424

E-mail : mranjana@ipr.res.in

#### Abstract

Impurity production and transport in edge region of any tokamak can have significant influence on the core plasma properties of the device. Impurities mostly enter inside the plasma through the plasma-surface interaction occurring at plasma boundary. Being the first surface to come in contact to the high temperature plasma, limiter in Aditya tokamak is a primary source of impurity. To understand the production mechanism of hydrogen and impurity particle released from limiter and their transport in the edge region of the tokamak, a limiter viewing diagnostics has been developed and installed on Aditya tokamak.

This diagnostic views a mid-plane limiter tile and both sides of its vicinity toroidally. This system is having a lens and optical fibers based light collection system, an interference filter for wavelength selection and 8 channel PMT array as the detector. Eight lines of sight terminate on the inboard side of limiter and vessel wall to record the spectral emissions of H $\alpha$  at 656.28 nm and C III at 464.7 nm. In this presentation, we will be discussing in details the design and development of the diagnostics and the initial results obtained from the Aditya Tokamak by analyzing the H $\alpha$  and C III signals.



**PD-430**

**Nonlinearity Compensation In Spectrographic Systems Used For Plasma Diagnostics Application**

Debi Prasad Das, Sarita Das

*CSIR-Institute of Minerals and Materials Technology, Bhubaneswar, Odisha, Pin-751013  
and Academy of Scientific and Innovative Research (AcSIR)*

E-mail : dpdas@immt.res.in

**Abstract**

High resolution spectrographs are being used for both active and passive spectroscopic diagnostics of the plasma. Two of the high resolution spectrographic systems are Echelle Spectrograph and Czerny Turner Spectrograph. Advanced spectrographic systems are equipped with ICCD cameras. The spectra in a broadband (e.g. 200-900 nm) can be acquired by an Echelle spectrograph in one shot. However, the Czerny turner spectrograph rotates the gratings to acquire the spectra in a narrow band. The bandwidth is dependent on the type of the grating and the center wavelength. By using step and glue method the spectra of a longer wavelength range can be captured by Czerny turner spectrograph. There are some parameters which are required to be set while capturing the spectra in these spectrographic systems with the ICCD camera. The exposure time, gain and number of accumulations are set for the ICCD camera and slit width of the spectrograph can be varied to allow appropriate light to the spectrograph. A detailed study using a Mercury-Argon (Hg-Ar) lamp is made using two spectrographs (Echelle Spectrograph system: model ME5000 and DH734-18U-C3 from M/S Andor, UK and the Czerny turner spectrograph system: model No: ARC SP 2756 and PI MAX3:104i-Unigen2-P43 of M/S Princeton instruments, USA). The lamp intensity spectra is first analyzed and found to vary with time. The variation of Hg I lines were found to be in opposite to Ar I lines. Many experiments were conducted to characterize the lamp using the spectrographic data for its time evolution. Then the intensity of certain important Hg and Ar lines were plotted with different exposure times, gain factor and number of accumulations. Though, it was expected that the intensity of the recorded photons will have linear relationship with respect to these parameters, but they were experimentally found to have nonlinear relationship due to instrumental limitations. This would affect the intensity calibration when these parameters are changed during recording. Accordingly, an inverse modeling method is proposed to linearize the readings through a software method. These results would aid to the plasma diagnostics researchers using optical emission spectroscopy for intensity calibration and hence accurately measuring the intensity using a nonlinear spectrographic system.

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**PD-449**

### **Measurements of Chord Averaged Plasma Density In SST-1 Tokamak**

P. K. Atrey<sup>1,2</sup>, Umeshkumar C. Nagora<sup>2</sup>, B. K. Shukla<sup>2</sup>, Dhaval Pujara<sup>1</sup> and S. Mukherjee<sup>2</sup>

<sup>1</sup>*Institute of Technology, Nirma University, Ahmedabad*

<sup>2</sup>*Institute for Plasma Research, Gandhinagar*

*Email: atrey@ipr.res.in*

#### **Abstract**

A 100 GHz Microwave interferometer is used to measure the chord averaged plasma density in SST-1 tokamak. The discharges are initiated with ECR pre-ionisation with different ECR power and then it has been taken over by ohmic. Initially, ECR pick-ups were observed in interferometer signal. Trouble shooting to remove the pick-ups is done and source of ECR pick-ups is found out. A band pass filter is used to remove the ECR pick-ups. The measured density by interferometer is found in the range of  $0.5 - 1.0 \times 10^{13} \text{ cm}^{-3}$ . Expected density range due to ECR pre-ionisation is  $0.2 - 0.6 \times 10^{13} \text{ cm}^{-3}$  at different power of ECR. The plasma density variations with the variation of ECR power and gas pressure are studied. Operating parameter space of SST-1 discharges is studied in terms of Hugill diagram. The analysis and the results will be reported in paper.

**PD-451**

### **Development Of A Segmented Plasma Torch Assisted Simple Experimental System To Be Used For High Heat Flux Testing And Plasma Surface Interaction Studies**

Ngangom Aomoa and Mayur Kakati

*Centre of Plasma Physics-Institute for Plasma Research, Sonapur 782 402, Assam, India*

*Email: ngangomaomoa@yahoo.com*

#### **Abstract**

To simulate the extreme heat load on plasma facing components in a Tokamak device, different high heat flux sources have been utilized including electron, ion, neutral beam or plasma assisted systems. The electron beam systems demonstrate excellent control, but the plasma assisted systems have the advantage of reproducing exactly similar physical/chemical environment inside the fusion machine, in terms of ion composition, temperature and particle/heat fluxes. Using a segmented plasma torch we have developed a high heat flux system which was also optimized for the production of a long well collimated laminar plasma beam even without using any confining magnetic field, which can be made to interact with a remotely placed material target to study the Plasma-Surface Interaction (PSI) processes. In this paper we report on extensive characterization of the system, in terms of the heat flux deposition, electron temperature, electron density, plasma jet velocity and ion flux incident on the target surface. Calorimetric measurements confirm deposition of more than 10 MW/m<sup>2</sup> power

flux on a 20 mm diameter copper target placed at distance of 140 mm from the torch anode (argon 20 lpm, hydrogen 10 lpm, 300 Amps plasma current). OES measurements with a 1.33 m McPherson spectrometer gives ion density in the  $10^{20} \text{ m}^{-3}$  range (Stark broadening of  $\text{H}\beta$ ), temperature around 0.3 eV and velocity few kms/m (Doppler shift of argon lines). Some other recent studies indicate that for this specific mixture of plasma gases, the yield of  $\text{H}^+$  ion at the arc output may highly supersede the  $\text{Ar}^+$  ion density (Z. Ahmad 2009). This assertion was apparently supported by observations that the argon lines in this experiment had extinguished upon injection of hydrogen into the argon plasma, which may be a result of depletion of argon ion density (M.J. de Graaf et al. 1993). This experimental configuration therefore represents a relatively simple and low cost system for production of ITER relevant high heat/ion flux hydrogen plasma, which may be used for high heat flux testing of plasma facing components as well as for fusion relevant PSI studies. Some more recent actual PSI results using tungsten targets in this system will be also presented.

**PD-478**

## **Measurement Of Bulk Plasma Temperature Using $\text{N}_2$ Molecular Spectra In 6 MW Plasma Wind Tunnel At VSSC, Trivandrum**

<sup>1</sup>Niral Virani, <sup>1</sup>J. Ghosh, <sup>1</sup>Nilam Ramaiya, <sup>1</sup>R. Manchanda, <sup>1</sup>M. B. Chowdhuri,  
<sup>2</sup>Aravindakshan Pillai.L, <sup>2</sup>Sreenivas.N, <sup>2</sup>Krishnaraj.K

<sup>1</sup>*Institute for Plasma Research, Bhat, Gandhinagar 382428*  
<sup>2</sup>*Vikram Sarabhai Space Centre, ISRO, Trivandrum*

E-mail : niralpatel.87@gmail.com

### **Abstract**

Bulk plasma temperature is an important parameter required to be determined while characterizing 6 MW Plasma Wind Tunnel Facility at VSSC, Trivandrum. Spectroscopic measurements remain the most suitable non-invasive diagnostics for the estimation of bulk or gas temperature of the plasma species in these kinds of systems. The resolved emission spectra of the plasma produced in the target chamber of 6 MW plasma wind tunnel at high gas pressures was recorded by a three-channel Avantes AVS-DESKTOP-USB2 spectrometer with a CCD camera. The plasma emission from the air-plasma was found to be dominated by continuum radiation and emissions of molecular nitrogen,  $\text{N}_2$  first positive emission spectrum. The vibrational temperature of  $\text{N}_2$  is determined from Boltzmann plots of the two  $\text{N}_2$  first positive molecular band spectra corresponding to  $\Delta v = 3$  and 4 by fitting the experimentally observed spectra. At high pressure plasmas,  $\text{N}_2$  exchanges vibrational energy faster with the heavy particles as done by the rotational and translation energies and hence both the vibrational and the rotational temperatures can be used to estimate the temperature of the gas. The gas temperature hence determined agrees quite well with the estimated temperature from the blackbody fit to the underlying continuum radiation that appears as a slopping baseline.

For improving the speed of spectroscopic data analysis and to display the results in user friendly manner a GUI (Graphical User Interface) has been developed using LABVIEW and MATLAB. The GUI readily displays the bulk plasma temperature by analyzing the recorded molecular spectra including the required fittings, background correction etc.

In this presentation, details on the spectral measurements and the development of the GUI application for spectroscopic data analysis will be presented.

**PD-490**

**Detection Of Na D Spectral Lines And Their Usage In Monitoring The Reduction Processes Of Iron Oxide In Microwave Hydrogen Plasma**

<sup>1</sup>Sarita Das, <sup>1</sup>Debi Prasad Das, <sup>1</sup>Priyanka Rajput, <sup>2</sup>Joydeep Ghosh,  
<sup>1</sup>Bhagyadhar Bhoi, <sup>1</sup>Barada Kanta Mishra

<sup>1</sup>CSIR- Institute of Minerals and Materials Technology, Bhubaneswar, Odisha, Pin-751013

<sup>1</sup>Academy of Scientific and Innovative Research (AcSIR)

<sup>2</sup>Institute for Plasma Research, Bhat, Gandhinagar, Gujarat, Pin-382428

E-mail: sarita@immt.res.in

**Abstract**

The microwave produced hydrogen plasma used for the direct reduction of iron oxide pellet has been characterized by the well-known and the non-invasive optical emission spectroscopy (OES) technique in the visible region. Two highly intensified spectral lines are observed at 589nm and 589.6nm in the recorded spectra along with the H $\alpha$  line in both presence and absence of iron oxide pellet in the plasma. These spectral lines are identified as Sodium D lines by comparing with a low pressure sodium vapour lamp. The intensities of these Na line are found to be varying systematically with hydrogen flow rate, microwave power and the chamber pressure. More importantly, the intensities of these Na D lines are found to be varying in a typical pattern which can be highly correlated with the reduction process of iron oxide pellet kept inside the plasma for reduction purpose. In this paper, we show that the intensity variations of these Na D spectral lines can be efficiently used for knowing the exact temporal behaviour of the reduction process of iron oxide in hydrogen plasmas. The source of Sodium in our plasma seems to be hydrogen gas used for plasma production. However, in other systems trace amount of sodium can be introduced with the hydrogen gas very easily in form of NaOH etc. to obtain the plasma containing the Na D lines for monitoring the reduction kinetics and the rate of reduction.

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# **PLASMA PROCESSING**



PP-141

## Development of Tungsten Coated Graphite Tiles For Fusion Plasma Applications

Uttam Sharma<sup>1</sup>, Sachin Singh Chauhan<sup>1</sup>, A. K. Sanyasi<sup>2</sup>, Jayshree Sharma<sup>3</sup>, K K Choudhary<sup>4</sup>  
J. Ghosh<sup>2</sup>

<sup>1</sup>Department of Physics, Shri Vaishnav Institute of Technology and Science, Indore -453331

<sup>2</sup>Institute for Plasma Research, Bhat, Gandhinagar 382 428

<sup>3</sup>Department of Physics, M.B.Khalsa College, Indore 452009

<sup>4</sup>National Defense Academy, Pune

E-mail : druttamsharma1971@gmail.com

### Abstract

Plasma wall interaction (PWI) in fusion grade machines puts stringent demands on the choice of materials in terms of high heat load handling capabilities and preferably low sputtering yields. Tungsten is considered to be one of the suitable materials for constructing plasma facing components in fusion devices such as tokamaks because of its superior physical and chemical properties like low physical sputtering yield and high sputter energy threshold, high melting point, fairly high recrystallization temperature, low fuel retention (D-T) capabilities, low chemical sputtering with hydrogen and its isotopes. Even if the material is having superior qualities this also will undergo sufferings of erosion by sputtering. We are looking for a feasible solution towards compensating the erosion loss by *in-situ* coating of tungsten in the fusion machine without a break. Plasma glow discharge is one of the common techniques available with all fusion reactors and can be suitably used for coating of tungsten on first wall.

We are in the process of producing laboratory scale tungsten coatings suitable for fusion applications at SVITS, Indore. The process will be Plasma Assisted Chemical Vapor Deposition (PACVD) and is considered as one of the most preferable techniques for fabricating tungsten coated graphite tiles. A coating reactor system has been designed, fabricated, installed and the coating procedures have been initiated. The plasma required for the PACVD with H<sub>2</sub>, N<sub>2</sub>, and Argon gases is produced using a radio frequency source of 13.56 MHz capable of delivering maximum power of 600 W and have been characterized at different fill pressures and input RF powers in order to identify the uniform coating region using RF compensated single Langmuir probes, which has been fabricated in house. Maximum plasma density  $\sim 2.80 - 5.00 \times 10^{16} \text{ m}^{-3}$  has been obtained in the system. The region of uniform density over the cathode has been identified as an area of  $\sim 100 \text{ cm}^2$  of uniform density. The poster will present the initial results on the physical characteristics and chemical composition of the tungsten coatings produced for benchmarking the experiment.

### References:

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**PP-163**

**A Comparative Study Of Microstructure Of Monolayer CrN<sub>x</sub> Films Prepared By Arc Discharge And Dc Magnetron Sputtering**

M.S. Nadkarni and V.G. Goswami

*S.S & L.S Patkar-Varde College of Arts & science And V.P Varde College of Commerce & Economics, S.V Road, Goregaon (W), Mumbai-400105*

E-mail :msnadkarni1958@rediffmail.com

**Abstract**

The monolayer CrN<sub>x</sub> films synthesized using cathodic arc discharge and DC Magnetron sputtering. The main difference between these two techniques is the ionization rate of the particles sputtered or evaporated from the target material. DC Magnetron sputtering Coatings often suffer from under-dense morphologies due to the low ionization rate of sputtered target and form less dense nano-particles. Whereas, coatings prepared by cathodic arc discharge were having very dense morphologies, due to the high ionization rate and available energies, but often exhibit a high density of micro particles (droplets) ejected from the cathode.

The structures of coatings were investigated using the SEM. The XRD was carried out to specify the phase structures. Crystal structure of CrN and Cr<sub>2</sub>N is studied. The Cr<sub>2</sub>N phase exhibits a higher hardness.

The compositions, phase structure, texture, grain size and properties of CrN<sub>x</sub> coatings are strongly influenced by the reactive nitrogen gas content, the applied substrate bias and substrate temperature. The investigation includes micro hardness, roughness tests, adhesion, friction coefficient and wear rate.

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**PP-186**

**Biomedical Application of ZnO Coated On Plasma Treated Material**

S.Inbakumar<sup>1&2</sup> and P.M.Andavan<sup>3</sup>

<sup>1</sup>*Department of R&D., Bharathiar University, Coimbatore, Tamilnadu,*

<sup>2</sup>*Physics Division- Kumaraguru College of Technology, Cbe-641049*

<sup>3</sup>*Department of Physics, Govt Arts College, Coimbatore, Tamilnadu*

E-mail : s.inbakumar@gmail.com

**Abstract**

ZnO solid solutions were prepared by sol – gel method. The precursor solutions were prepared from zinc acetate dihydrate ( $\text{Zn}(\text{CH}_3\text{COO})_2 \cdot 2\text{H}_2\text{O}$ , E-Merck, India) was dissolved in 1:1 mixture of ethanol and doubly distilled water. The ‘sol’ mixture was stirred for 6h at a temperature of 50°C. The resultant product was dried and calcined at 500°C for an hour to get a pure nano ZnO. The crystallographic studies were performed using XRD (Shimadzu 6000 X-ray diffractometer) with  $\text{CuK}\alpha$  wavelength and scanning in the  $2\theta$  range from 20 to 80°. Surface morphology analyses were taken by high resolution scanning electron microscope (HRSEM, FEI Quanta FEG 200) and the elemental compositions were obtained by energy dispersive X-ray spectrophotometer (EDS). Silver nanoparticles were then applied to plasma treated polyester to impart sunscreen activity to the treated textiles. The effectiveness of the treatment was assessed through UV–VIS spectrophotometry and ZnO coated fabrics were involved with the antibacterial analysis [1].

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**PP-216**

**Plasma Assisted Decomposition Of Hazardous VOCS Using DBD Device**

S. Mohanty<sup>1</sup>, S. P. Das<sup>1</sup>, G. Sahoo<sup>1</sup>, S. Samantaray<sup>1</sup>, R. Paikaray<sup>1</sup>, P. S. Das<sup>1</sup>, D.S.Patil<sup>2</sup>

<sup>1</sup>*Ravenshaw University, Cuttack-753003, Odisha*

<sup>2</sup>*BARC, Anushakti Nagar, Mumbai-400085*

**Abstract**

One Di-electric Barrier Discharge (DBD) device is set up at Ravenshaw University, Cuttack, India to study the plasma assisted destruction of volatile organic compounds/pollutants (VOC) like aniline, toluene Nitro-benzene, Chloro-benzene, Xylene etc. Plasma density and electron temperature of the VOC in the presence of carrier gas argon plasma is measured and the results are compared with that of the plasma in the absence of VOCs. It is also found that sticky end products deposited on the glass surface after ignition of plasma for nearly 15-20 minutes. The deposit was subjected to absorption spectroscopy. From the density data and absorption spectroscopy signature it was found that the VOC

is decomposes to aromatic compounds, hydrocarbons and other non-polluting materials. Volatile Organic Compounds (VOCs) releasing from different industrial and agricultural processes is a serious problem for air pollution. Vocs like benzene, Toluene, Xylene etc. having toxic characteristic. Therefore, control and decomposition of these VOCs are required. They should either be removed or these should be made less harmful gases like CO<sub>2</sub> with usable products. Therefore, a more effective and economical abatement technique is required which is fulfilled by non-thermal plasma (NTP) technology. NTP like Dielectric Barrier Discharge (DBD), Corona discharge, Surface discharge and packed-bed plasma reactors are used. From the above, DBD with and without catalyst is more effective than the other depending upon the different conditions like surface area, concentration of voc, applied voltages, nature of the voc, GRD, catalyst, as well as carrier gas. So our present work aims at decomposition of aniline, toluene Nitro-benzene, Chloro-benzene, Xylene using NTP-DBD reactor by studying the dielectric surface deposition and characterize these. Experimental setting of the DBD reactor with power and carrier gas supply system. Spectral analysis and diagnostic are done with Emissive and absorptive UV/VIS spectrometer. Electron temperature and plasma density are calculated.

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### PP-268

#### Characteristics Of The Nano-Scale Neodymium Oxide (Nd<sub>2</sub>O<sub>3</sub>) Synthesized In RF Thermal Plasma Reactor

G. D. Dhamale<sup>1</sup>, V. L. Mathe<sup>1</sup>, S. V. Bhoraskar<sup>1</sup>, S. N. Sahasrabudhe<sup>2</sup> and S. Ghorui<sup>2</sup>

<sup>1</sup>Department of Physics, Savitribai Phule Pune University, Pune-411007

<sup>2</sup>Laser and Plasma Technology Division, Bhabha Atomic Research Center, Mumbai-400085

E-mail : gdhamale@gmail.com

#### Abstract

Synthesis and characterization of nano-scale Nd<sub>2</sub>O<sub>3</sub> particles have attracted much attention in recent days due to its wide application in optical industries. Various photonic applications like dopant in high power Nd:YAG laser [1], synthesis of novel luminescent and thermoluminescent materials, and thin film applications are some of the potential application areas. Present study reports the radio frequency thermal plasma synthesis of nanophase Neodymium Oxide and characterization of the synthesized nanoparticles in terms of its optical properties, phase formation, size distribution and morphology.

Synthesis of Neodymium oxide is carried out in a 3MHz, 27kW inductively coupled atmospheric pressure RF thermal plasma reactor. Argon is used as plasma forming gas, sheath gas as well as carrier gas. For synthesis, commercially available coarse grain Nd<sub>2</sub>O<sub>3</sub> powder is fed axially through the carrier gas near the top edge of plasma ball. The coarse grain particles enter into the plasma zone, get melt, evaporate, and become a part of the plasma. A steep temperature gradient existing in the

tailing edge of the plasma forms the nano-particles through nucleation and quenching. Synthesized particles deposited inside the reactor are characterized through different techniques like, Transmission Electron Microscopy (TEM), Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD), Ultraviolet-Visible Spectroscopy (UV-Vis) and Fourier Infra-red Spectroscopy (FTIR). Nano-particles obtained possessing hexagonal crystal structure (pdf# 83-1346) with little presence of hydroxide form of the parent material. Precursor material is mainly possessing hexagonal structured neodymium hydroxide. TEM study reveals that particles are monosized and having faceted morphology with narrower size distribution (average size~20nm peaked at 16nm). FTIR study reveals the presence of metal-oxygen peak.

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### PP-285

#### **Studies OnStructural And Morphological Properties Of Tungsten Nanoparticles Synthesized By A Plasma Expansion Technique**

Trinayan Sarmah, Puspallata Sah, N. Aomoa and M. Kakati

*Thermal Plasma Processed Materials Laboratory,  
Centre of Plasma Physics-Institute for Plasma Research, Sonapur 782402, Assam*

E-mail: mayurkak@rediffmail.com

#### **Abstract**

Because of its superior material properties like very high melting temperature, hardness, good thermal conductivity, tungsten is considered one of the most favourite materials for high heat applications including plasma fusion research [1]. Lower sputtering yield or lower retention of tritium are two other unique properties which have made tungsten to be the most promising material to be used as plasma facing material in future Tokamak plasma fusion machines [1]. Synthesis of this strategic material in superfine particle form is considered important as the nano-structuring may render further enhancement of the material properties. For example Wnano-powder promises to yield very strong and wear resistant materials via the press- sinter route with a lower temperature compared to conventional micro-crystallinepowders [2]. In the present work nanosized W powder was synthesized by a supersonic thermal plasma expansion technique using ammonium paratungstate (APT) as the precursor. The APT powder was injected in to the argon plasma with a powder feeder, which was subsequently reduced by hydrogen, which also was injected as a carrier gas for the precursor particles. XRD shows synthesis of almost phase pure tungsten whereas HRTEM confirms almost spherical nanoparticle sizes. Measurement of inter atomic planar distances indicates presence of both pure metal as well as oxides. The paper will present more recent results on further synthesis of tungsten nanoparticles under wide variation of experimental variables like pressure in the sample collection chamber (600 to few mbar), precursor feed rate (0.6-5 g/m) as well as precursor types, along with advanced material characterization of the synthesized material. Another important functional form of this material is tungsten coating, which may be formed by keeping a substrate very close to the plasma torch nozzle. The particles deposited by inertial impaction produced a nanostructured coating, adhesion of which was further enhanced by heating the substrate up to 750C.

Optimization of this deposition process is also going on, the latest results from which also will be presented in this paper.

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### PP-293

## Treatment Of Water Hyacinth Fibers Using Glow Discharge Plasma And Its Characteristics

Hari Prakash, Bornali sarma and Arun Sarma

*School of Advanced Sciences (SAS), VIT University Chenna, Chennai-600127, Tamil Nadu*

E-mail: hari.prakash2013@vit.ac.in

#### Abstract

Water hyacinth is one of the natural fibres that are available in few regions of our country. It is being used to make some fancy items. To change the surface properties of water hyacinth, it has been treated in glow discharge plasma under various experimental conditions, viz., pressure, time, discharge current etc. This work has been carried out to understand the surface properties of water hyacinth and its quantitative changes in absorption probability. Treated water hyacinth material are characterised and analysed using Fourier Transform Infrared Spectroscopy (FT-IR), Diffuse Reflectance Spectroscopy (DRS-UV), X-ray diffraction (XRD), scanning electron microscopy with electron diffraction X-ray (SEM-EDAX) and Thermo gravimetric analysis(TGA). Surface chemistry of the fibre has been altered as depicted by FT–IR studies, while the XRD analysis of the samples shows the effects of super molecular structure of the fibres by changing its degree of crystallinity of fibres. The change fibre surface morphology with plasma treating under some optimized experimental conditions have characterized by SEM-EDAX. The Changes in the moisture content of plasma treated fibers are characterized quantitatively using Thermo Graphic Analyzer (TGA). The influences of these plasma treatments on the chemical and mechanical properties of these Water hyacinth fibres as are discussed in this report.

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## Phase and Particle Size Analysis of DC Plasma Synthesized Nano-Alumina

Vandana Chaturvedi<sup>1</sup>, P.V. Ananthapadmanabhan<sup>1</sup>, Y. Chakravarthy<sup>1</sup>, A. Pragatheeswaran<sup>2</sup>, Jyothi Sharma<sup>3</sup>, T. Mahata<sup>3</sup>, S. Bhandari<sup>1</sup>, B. Raneesh<sup>4</sup>, A. Nagaraj<sup>1</sup>

<sup>1</sup>Laser and plasma technology division, Bhabha Atomic Research Center, Trombay, -400085

<sup>2</sup>Department of Physics, Karunya University, Coimbatore, Tamilnadu, -641114

<sup>3</sup>Powder Metallurgy Division, Bhabha Atomic Research Center, Vashi, Maharashtra, - 400705

<sup>4</sup>School of Pure and Applied Physics, Mahatma Gandhi University, Kottayam, Kerala 686 560

vandanachaturvedi15@gmail.com

### Abstract

Nano-crystalline aluminium oxide has been synthesized by thermal plasma route using a DC plasma reactor. A 40 kW DC arc plasma torch based reactor was set up for synthesizing nano-crystalline alumina powder. The experimental set-up consists of a double-walled stainless steel reaction chamber, over which the DC plasma torch is mounted. A water cooled powder collection segment made of stainless steel is located below the reaction chamber. A mixture of argon and nitrogen was used as the plasma gas, which was injected through a side inlet in the insulator segment. Input power to the plasma torch was varied from 16-26 kW by controlling the gas flow and arc current.

X-Ray diffraction (XRD) was used for phase analysis of the product. The results revealed the presence of metastable gamma alumina along with the stable alpha alumina. The extent of conversion was found to increase with increasing plasma input power. The powder was characterized by Scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The TEM images confirmed the nanometre size of the particles in the range of 4-21 nm. Surface area analysis (BET) and particle size analysis by laser scattering have also been used to characterize the particle size of plasma synthesized alumina nanoparticles. BET, TEM and particle size by laser scattering show the high degree of particle agglomeration. Results also showed the decrease in size of the particles and an increase in nano conversion with increasing plasma power.

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**PP-317**

**Effect of Cold Plasma Treatment on Seed Germination**

R.Rane<sup>1</sup>, A.Vaid<sup>1</sup>, A.Vikram<sup>2</sup>, A.Thakur<sup>2</sup>, S.Mukherjee<sup>1</sup>

<sup>1</sup>*FCIPT, Institute for Plasma Research, Gandhinagar, Gujarat, 382044, India*

<sup>2</sup>*Dr. Y. S. Parmar Agriculture University, Solan, Himachal Pradesh, 173230 India*

E mail: ramu@ipr.res.in

**Abstract**

This study investigated effect of cold oxygen plasma treatment on germination of capsicum seeds. Effects of different treatment time on the germination of capsicum seeds are studied. Plasma treated seeds were germinated in lab condition. We found that 03 min. treatment time could significantly improve germination percentage compared to the untreated seeds. Surface morphology of plasma treated seeds is studied by Scanning Electron Microscopy (SEM) while hydrophilicity of the surface is studied by contact angle measurement.

The observations recorded on germination and seed vigour index-mass indicate that there is progressive increase in germination (i.e. around 20 %) due to plasma treatment. The plasma treatment in combination with priming enhanced germination up to 30% compared to control seeds. The observations recorded after 4 months of storage at ambient conditions; there is decrease in germination compared to germination in fresh treated seeds. Our results show that cold plasma has important application prospects for increasing germination rate of seeds.

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**PP-337**

**Study On Thermal And Adhesive Properties Of Surface Modified Polyvinylchloride (PVC) By Dc Glow Discharge Plasma**

A.Suganya, M.Kiruthika and G. Shanmugavelayutham

*Plasma Physics Laboratory, Department of Physics, Bharathiar University, Coimbatore-46  
Tamilnadu*

E.mail: velu1976@gmail.com

**Abstract**

This paper reports the surface processing of poly (vinyl chloride) (PVC) film by using DC glow discharge (Air, Ar, O<sub>2</sub>) plasma, and its effects on surface properties. The surface properties, including surface wettability, optical, thermal and adhesive of the PVC film were characterized. It was

observed that the Air, Ar, O<sub>2</sub> plasma processing can improve the surface wettability of the PVC film significantly with different plasma discharge time(3-20mins) and also alter the functional groups which is confirmed by FTIR measurements. Above 15 min plasma processing can reduce the surface water contact angle of PVC in Air, Ar, and O<sub>2</sub> plasma. The optical property examination UV analysis revealed that the plasma processing resulted in a rougher surface that has observed in AFM analysis. Then the crystalline nature was observed through the XRD pattern. Thermal properties and adhesive properties were analyzed by DSC and T-Peel measurements. It is concluded that the surface chemistry and texture, induced by air, Ar, O<sub>2</sub> plasma processing, co-contributed to the surface wettability improvement of PVC film surface.

## PP-338

### Synthesis And Surface Characterization Of Bamboo Charcoal Carbon Using Low Temperature Plasma Treatment

K.Vignesh<sup>1</sup>, K.A.Vijayalakshmi<sup>2</sup> and N.Karthikeyan<sup>3</sup>

<sup>1</sup>*Department of Physics, Sri Vasavi College, Erode-16, Tamilnadu*

<sup>2</sup>*Sri Vasavi College, Erode-16, Tamilnadu*

E-Mail: vignesh.kutti@gmail.com

#### Abstract

Bamboo Charcoal Carbon (BCC) is an excellent material for its highest porous structure, dense molecular porous, hard quality, and strong adsorption capacity. It is used in various applications such as, removal of harmful gases, water treatment, improving blood circulation, blood purification, absorption, De-odorizing, air purification and the composite materials of these carbon materials are used for EMI shielding, Far infrared ray and AnionEmission, and Ultraviolet Radiation Resistance etc. Bamboo charcoal carbon (BCC) was synthesized by pyrolysis process. The bamboo charcoal carbon was surface modified by Air, Oxygen plasma treatment. Surface modified BCC was characterized by FTIR, XRD, SEM, UV and antimicrobial studies. Functional group modifications were analyzed using FTIR spectroscopy. The crystalline structure and particle size was calculated using XRD studies. The morphological change and elemental composition was observed by using SEM and EDAX analysis. The absorption nature of the material is measured by using UV-VIS spectroscopy. The antibacterial effect of the material was observed by standard disc diffusion plate method.



**PP-346**

**Synthesis And Characterization On D.C Conductivity Of Free Standing Thin Film Of Interfacial Polyaniline / FA / Ag Nano Composites Induced By DC Low Temperature Plasma**

K.A. Vijayalakshmi<sup>1</sup>, K. Vanitha<sup>2</sup>, M. Revanasiddappa<sup>3</sup> and S.C. Raghavendra<sup>4</sup>

<sup>1</sup>*Department of Physics, Sri Vasavi College, Erode-638316, India.*

<sup>3</sup>*Department of Engineering Chemistry,* <sup>4</sup>*Department of Electronic and Communication Engineering, PESIT- Bangalore South Campus, Bangalore-560100.* <sup>2</sup>*Research scholar, R&D Centre, Bharathiar University, Coimbatore-46*

Email : winvanitha@gmail.com

**Abstract**

The PANI/FA/Ag composites have been synthesised with various composition (5, 10, 15, 20, 25 wt %) of Fly Ash in PANI. (PANI/FA/Ag nano composite) film was treated by DC glow discharge air plasma. The modified surface was characterized by FTIR, XRD and UV analysis. The morphology of these samples were studied by Scanning Electron Microscopy. The broadening sharp peaks in the XRD pattern indicates that the synthesized PANI-Ag nano composite. The IR spectrum analysis gives the information to the chemical spectroscopy which shows the various bonding nature of different frequency variations between 4000- 400 cm<sup>-1</sup>. The UV –visible absorption spectrum analysis shows the presence of characteristics absorption bands of PANI/FA/Ag nano composite. The morphological studies revealed the homogenous distribution of fly ash particles. The (D.C) conductivity was studied in the temperature range from 40-140°C that indicates the semiconducting behaviour of the composites. The study of dc conductivity shows an evidence for the transport properties of the composite.

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**PP-381**

**Development Of Atmospheric Pressure Plasma Torch Array For Blood Coagulation**

Akshay Vaid<sup>1</sup>, Chirayu Patil<sup>1</sup>, Adam Sanghariyat<sup>1</sup>, Ramkrishna Rane<sup>1</sup>, Subroto Mukherjee<sup>1</sup>

*Institute for Plasma Research, Bhat, Gandhinagar-382428*

E-mail : akshay@ipr.res.in

**Abstract**

Non thermal plasmas found their applications in various bio-medical applications. We report the development of atmospheric pressure plasma torch array (APPTA) for blood coagulation application. We have chosen honeycomb arrangement for APPTA as we are able to generate plasma plumes whose divergence can be controlled and is useful for both large and small arteries.

In this work we have shown that by varying the different flow rates plasma plumes divergence can be controlled. We have also characterized the plasma plume using current-voltage characteristics and estimated plasma density. We have tested our APPTA on blood using argon as gas and found that coagulation time is around 15 secs as compared to natural coagulation of 205 secs. We have also observed that coagulation time by using the coagulation agents (heparin) is approx 20 secs which is still more as compared to blood coagulation through APPTA. All the results and discussions will be presented.

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**PP-420**

**Effect of Plasma Parameters on the Growth of Aluminum Nitride Thin Film**

Partha Saikia<sup>1</sup>, Bipul Kumar Saikia<sup>1</sup>, Subroto Mukherjee<sup>2</sup>, Rama Krishna Rane<sup>2</sup>, Joseph Alfonsa<sup>2</sup>

<sup>1</sup>*Centre of Plasma Physics, Institute for Plasma Research, Sonapur-782 402, Kamrup, Assam*

<sup>2</sup>*Facilitation Centre for Industrial Plasma Technologies, IPR, Gandhinagar, Gujarat 382044.*

E-mail : partha.008@gmail.com

**Abstract**

The behavior of the plasma parameters in the background of the multi-component plasma is completely different from the normal single component plasma. It is due to the complex discharge behavior of the molecular gases and complexity generated by the various plasma species under the influence of crossed magnetic and electric fields [1]. Plasma collective behavior plays an important role in the magnetron discharge. Therefore, the dependence of the sputtering efficiency as well as the physio-chemical processes leading to quality film growth in reactive sputtering on plasma parameters (density profile, temperature and energy distributions) is undoubtedly a subject for investigation. Keeping this idea in mind, an attempt is made to relate the micro-structure of AlN films on high speed steel substrates with the plasma parameters of the magnetron discharge plasma.

In this study, the AlN films are deposited onto bare AISI M2 high speed (substrate A) and pulsed plasma nitrided AISI M2 high speed (substrate B) by DC magnetron sputtering with a mixture of nitrogen (N<sub>2</sub>) and argon (Ar). N<sub>2</sub> is added at a fixed Ar partial pressure and various deposition times are employed to carry out the deposition of AlN thin films of similar thickness. The Langmuir probe and the Optical Emission Spectroscopy study show a gradual decrease of electron and heavy ion density as a function of nitrogen addition in the discharge which in turn reduces the film deposition rate. Under such circumstances, the growth of more open AlN planes such as the (100) having higher strain energy at the expenses of the planes with the lower strain energy such as the (101) is favored. Similar kind of growth habits of the AlN films on the substrate A and B eliminates the possibility of the substrate induced growth in this investigation.

**Reference :**

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PP-499

## Magnetic Properties of Thermal Plasma Synthesized Invar Alloy Nanoparticles

Suyog A. Raut<sup>1</sup>, Nilesh Kanhe<sup>1</sup>, S.V. Bhoraskar<sup>1</sup>, A.K. Das<sup>2</sup>, V.L.Mathe<sup>1\*</sup>

<sup>1</sup>*Department of Physics, SP Pune University, Pune 411007*

<sup>2</sup>*Lasers and Plasma Technology Division, BARC Mumbai 400085*

E-mail:suyogar@physics.unipune.ac.in

### Abstract

Fe-Ni alloy nanoparticles are of great interest because of diverse practical applications in the fields such as magnetic fluids, high density recording media, catalysis and medicine. We report the synthesis of Fe-Ni nanoparticles via thermal plasma route. Thermal plasma assisted synthesis is a high temperature process and gives high yields of production.

Here, we have used direct arc thermal plasma plume of 6kw as a source of energy at operating pressure 500 Torr. The mixture of Fe-Ni powder in required proportion (Invar Composition) was made to evaporate simultaneously from the graphite anode in thermal plasma reactor to form Fe-Ni bimetallic nanoparticles. The as synthesized particles were characterized by X-Ray Diffraction (XRD), Thermo-Gravimetric Analysis/Differential Scanning Calorimetry (TGA/DSC), Vibrating Sample Magnetometer (VSM).

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PP-522 (I)

## Amine Functionalized SiO<sub>x</sub> Films By Atmospheric Pressure Plasma Jet (APPJ) Deposition For The Promotion Of Biocompatibility

Yu-Chun Lin, Meng-Jiy Wang

*Department of Chemical Engineering, National Taiwan University of Science and Technology  
Taipei 106, Taiwan*

E-mail : mjwang@mail.ntust.edu.tw

### Abstract

Silicon oxides (SiO<sub>x</sub>) possess advantageous characteristics such as excellent mechanical property, gas permeability, and scratch resistance that allow the applications in versatile fields [1-2], whereas the limitation of SiO<sub>x</sub> for biomedical applications might be the lack of specific functionalities. On the

other hand, materials with amine functional groups revealed appropriate wettability which possesses great potentials for biomaterials [3]. In this study, SiO<sub>x</sub> films containing amine groups were acquired using (3-aminopropyl)triethoxysilane as precursor, by an atmospheric pressure plasma jet. The APPJ facilitated the atmospheric plasma chemical vapor deposition procedures with the mixture gasses of argon and oxygen.

The parameters for APPJ deposition such as the flow rate of carrier gas, the applied power for deposition were optimized according to the obtained chemical and physical properties of the plasma polymerized SiO<sub>x</sub> films, which were characterized by FTIR, ESCA, surface wettability, and SEM. The biofunctionalities of the amine-containing plasma polymerized SiO<sub>x</sub> films were evaluated by directly L-929 fibroblast cells on the samples. Qualitatively, the cell morphology was visualized by confocal microscope while the cell proliferation was quantified by cell density using lactate dehydrogenase assay. In summary, this study reports a method to incorporate a layer of surface coating, composed of silicon oxides containing amine functional groups, presumably on any type of substrates with good mechanical properties. The technique could be further applied on dentures, artificial joints, and related biomaterials that requires good mechanical properties and biocompatibility.

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# **PULSED POWER**



**PU-019**

**Design and Development of Compact Capacitor Charging Power Supply for Pulsed Power Drivers**

S. K. Sharma, R. Verma, R. Shukla, P. Banerjee, P. Deb, E. Mishra and A. Shyam

*Bhabha Atomic Research Center, Visakhapatnam*

E-mail: surender@barc.gov.in

**Abstract**

High energy capacitors banks are used in pulsed power drivers for providing peak power, to generate short high power pulses, for plasma target production and liner plasma interaction [1]. Capacitors used have low inductance and specific DC life (few hundred hours), so it had to be charged rapidly and discharged into the load. A series resonant converter based high voltage power supply is designed and developed for the rapid charging of capacitor bank. It is short circuit proof and zero current switching (ZCS) technique is used to commute the semiconductor switch, which reduces the switching losses at high frequency operation [2]. A high frequency inverter switching makes the overall system size small. The power supply has a DC converter, high frequency oscillator switching at 10 kHz, ferrite core transformer and voltage doublers to generate high voltages up to 45 kV. The power supply has charged a 1.6  $\mu\text{F}$  capacitor bank in 0.5 seconds to 45 kV with a charging rate of 3.3 kJ/s. The protection circuit is included in the system and the good regulation of charging voltage is achieved by the feedback system. The design details, modeling and the experimental testing results for current and voltage traces of the power supply will be presented.

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**PU-182**

**Impedance Matching Between Pulse Forming Network (PFN) And Washer Plasma Gun For Optimization Of Input Energy Delivery To The CPS Device**

<sup>1</sup>S. Samantaray, <sup>2</sup>R. Paikaray, <sup>2</sup>G. Sahoo, <sup>2</sup>P. S. Das, <sup>3</sup>J. Ghosh and <sup>3</sup>A. Sanyasi

<sup>1</sup>*Christ College, Cuttack, 753003*

<sup>2</sup>*Ravenshaw University, Cuttack, 753003*

<sup>2</sup>*Institute for Plasma Research, Bhat, Gandhinagar, 382428*

E-mail : samantaray.subrata@gmail.com

**Abstract**

A multistage pulse forming network (PFN) is designed and tested for the Compact Plasma System(CPS) [1]. The arrangement of the capacitors and inductors in the PFN is very similar to that of Guilemin E type network [2]. Taking different values of capacitors and inductors as per the impedance of the gun and plasma, a condition for optimization is investigated and presented in this communication.

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**PU-183**

**A Low Cost Optically Isolated Setup For DC High Voltage Measurements**

A. K. Saxena, A. C. Jaiswar and T. C. Kaushik

*Applied Physics Division, Bhabha Atomic Research Centre, Trombay, Mumbai- 400094.*

E-mail: a\_saxena@barc.gov.in

**Abstract**

Measurement of high DC voltage is crucial for any power supply design used in pulsed power applications. There are various commercially available probes based on resistive divider concept [1], but these probes share the same ground as of power supply. When the power supply is connected to a capacitive pulsed power system with large voltage reversal, it becomes hazardous to use output of these probes in other control circuits. Furthermore long distance measurements are also difficult with these commercial probes.

Considering these points an optically isolated DC high voltage (HV) measurement setup is designed which utilizes two units to optically transmit and receive the low voltage output of any commercially available HV probe with ratio 1000:1 or any in-house designed resistive divider. The transmitter unit accepts the low voltage output and converts it into a calibrated frequency signal using a voltage to frequency converter (LM331). Modulated output is then fed in to an IR-LED through a transistor driver. This unit is operated on a rechargeable battery with no ground reference and enclosed inside a metallic box for EMI shielding. Receiver unit converts this modulated optical signal in to an electrical signal using a phototransistor; the output of phototransistor is amplified and fed in to a frequency to voltage converter (LM 331). The voltage output of frequency to voltage converter is derived through a ten meters long coaxial cable and displayed in a digital panel meter. To achieve optical isolation between two units, both are operated with individual batteries and are mounted on an insulation base at a separation of 80 mm. The components for both circuits are so chosen that deviation in output voltage of second circuit from the input voltage of first circuit is less 3 % at low values and less than 1% at higher values. The electronic setup has been designed to measure voltages up to 20 kV and has been successfully tested up to 15 kV. The output shown in digital panel meter of this setup has been compared with the voltages measured on a standard HV probe (Fluke make, Model: 80K-40, accuracy:  $\pm 2\%$ ) and the difference between the two values up to 15 kV was found to be less than 200 volts. The minimum measurable voltage (threshold) of this setup has been found to be 500 volts. Further modifications are in progress to use optical fibers for long distance EMI free communication between two units.

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## PU-185

### Development Of A 200KJ Capacitor Bank System For Pulsed Power Applications

A. K. Saxena, S. P. Nayak, A. M. Rawool, A. C. Jaiswar and T. C. Kaushik

*Applied Physics Division, Bhabha Atomic Research Centre, Trombay, Mumbai- 400094*

E-mail: tckk@barc.gov.in

#### Abstract

High energy capacitor banks with relatively long discharge times (100's of  $\mu\text{s}$ ) are employed for various applications like electromagnetic launchers [1], high power lasers, flux compression generators and in various other pulsed power systems. Generation of large currents require parallel operation of multiple capacitors, which needs special protection schemes to avoid catastrophic failure of capacitors as well as other components under fault conditions. As large currents are involved, components like closing switch, crowbar, transmission lines and charge dump also require careful design considerations for safe bank operation.

The present capacitor bank consists of three racks, each containing twelve capacitors and contributing to one third of total bank energy (200 kJ). To optimize the bank performance a dedicated numerical scheme is developed and reported in an accompanying paper. A transformer based high voltage power supply is designed to charge these capacitors up to a voltage of 15 kV and as per the numerical calculations at this voltage bank can generate a current pulse of peak value 370 kA and rise time of 25  $\mu\text{s}$ . A rail-gap with crowbar arrangements [2] utilizing the propulsion of current carrying plasma

under self generated magnetic field has been developed for switching of current from bank to load. To achieve desired pulse rise time for applications like rail gun, a provision has also been made to include a pulse shaping inductor near the load. To protect capacitors under fault conditions, special metal strip based resistors [3] has been designed using SS-304 strips in a geometry that can withstand voltage up to 30 kV and can absorb energies up to 150 kJ. For first phase of this bank operation, these resistors were mounted on twelve capacitors placed in a single rack with connections having least possible inductances. The functionality of this bank along with control system had been verified by charging a single rack at 10 kV and diverting its energy through the triggered rail gap switch to a short-circuit load. Analysis of the obtained data indicates a bank inductance of 220 nH and peak current of 170 kA without load cables and 714 nH and 107 kA with 8 meters long coaxial load cables. Experimental results and details about design features will be discussed in the conference.

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## PU-211

### Pulsed Electrical Exploding Wire For Production Of Nano Powders

S. Borthakur, N. Talukdar, N.K. Neog, T.K. Borthakur

*Centre of Plasma Physics – Institute for Plasma Research, Sonapur, Kamrup, Assam 782402*

E-mail: tkborthakur@yahoo.co.uk

#### Abstract

Pulsed Electrical Exploding Wire (PEEW) for production of various kinds of nano powders is a well-known method. In this paper, development of a PEEW system for production of copper nano powder will be discussed. The pulsed power system that is used in this experiment consist of a HV energy storage capacitor of rating 10 $\mu$ F, 20 kV; an ignitron switch with driver circuit, controls and related HV charger. The Capacitor is charged up to 10 kV and it is discharged through the ignitron switch into the copper wire. The voltage and the current are measured by HV probe and a Rogowski coil. The copper wire is placed inside an evacuated chamber of which two ends are connected to two copper rods to pulsed power input. After discharge, the wire is exploded, melted, sublimated and condensed in collision with ambient air forming tiny particles of copper. Collection of nano particle produced thereby is collected at the bottom of the chamber. A special arrangement is done to fix multiple copper wires inside the chamber and discharge it one by one without breaking the vacuum. The collected copper particles are observed in TEM and XRD. The details results of the experiment will be presented in the full paper.

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**PU-219**

**Studies On Effect Of Gaseous Quenching Media On Performance Of Electrically Exploded Foils**

S.P. Nayak, Ankur Chowdhury, M.D. Kale, T.C. Kaushik, and Satish C. Gupta

*Applied Physics Division, Bhabha Atomic Research Centre, Trombay, Mumbai-400085*

E-mail: spnayak@barc.gov.in

**Abstract**

Electrically Exploded Foils (EEF) have been used for variety of applications such as generation of high temperature plasma for pulse fusion[1], hypervelocity projectile[2], High Power Microwave[3] etc. In most of these applications, EEF are used to sharpen current pulses generated by relatively slow discharging energy storage capacitors. Basically, they are operated as opening switches to generate fast rising voltage/current pulses in loads connected across them. Magnitude of voltage/current pulse in load and its rise-time is greatly influenced by the performance of EEF acting as opening switches. Parameters such as cross-sectional area of EEF, its constituent material and quenching medium surrounding it play a major role in deciding its performance as opening switch.

In the present studies, EEF have been placed in two gaseous quenching medium, i.e. dry air and N<sub>2</sub>. Input circuit comprises of 2.6kJ/24 kV capacitor bank connected in series with EEF. Stray inductance of input circuit is 0.5μH. Aluminum was chosen as EEF material. Readily available 0.3μH load was connected in parallel to EEF. Keeping circuit parameters fixed, cross-sectional area, length and gases used for quenching have been varied sequentially to observe their individual effect on performance of EEF. Thickness of EEF has been kept constant in all experiments and its width has been varied in steps, keeping length constant in a particular gas. Then, length is changed, width is varied keeping quenching medium same. Finally, the entire procedure is repeated after changing the quenching medium and the pressure at which gas is filled in explosion chamber. From the results, it has been observed that for same width, time of burst remains almost constant for change in length, quenching medium used and pressure to which it has been filled. With fixed cross-section and quenching medium, peak voltage generated across EEF increases up to a particular length and then decreases. However, upon increasing fill pressure, voltage decreases. Higher peak voltage across switch is obtained when dry air is used instead of N<sub>2</sub>. Peak load current and load power increases up to a particular length and then decrease at constant cross-section and quenching medium. Upon increasing gas fill pressure, both peak load current and load power increases. It is again observed that with dry air as quenching medium, higher peak load current and power is generated in the load.

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## Numerical Simulation of 200kJ/15kV Capacitor Bank Performance

S. P. Nayak, A. K. Saxena, A. M. Rawool, A. Jaiswar and T. C. Kaushik

*Applied Physics Division, Bhabha Atomic Research Centre, Trombay, Mumbai-400085*

E-mail : spnayak@barc.gov.in

### Abstract

High energy storage capacitor bank have been long used in variety of application. One of them is electromagnetic launchers where high current pulses with relatively long pulse duration (100's of  $\mu$ s) need to be generated [1]. In such capacitor banks, large number of capacitor are charged and discharged in parallel. Normally, individual currents add up leading to generation of high current in load. However, in faulty conditions, currents from individual capacitors may not flow along desired path and sometimes may lead to catastrophic failures. Hence, in order to protect individual capacitors in such events, protection schemes need to be developed. Various possible schemes include fast opening heavy duty fuses, protection resistors and crowbar current into safe low impedance path [2]. Out of these three methods, fast acting heavy duty fuses are relatively difficult to design and develop. Crowbar of current into safer path can be done but requires operation of fast closing switch at desired time. Availability of such fast acting closing switches may pose a challenge. Hence, use of protection resistors is an economical and easy way to prevent failures.

In the present work, modeling and numerical simulation of 200kJ/15kV capacitor bank has been carried out for both normal and fault conditions. Entire model has been prepared in P-Spice software. Circuit parameters have been determined using both theoretical calculation and experimentally observed values. Thirty six capacitors have been placed in parallel and protection resistors have been connected in series with each of them. Fault conditions may arise due to short circuit in bus bars connecting individual capacitors, short circuit at the mouth of capacitor or short circuit within a capacitor. Out of these three, internal short circuit condition is the most fatal one. In such cases, in addition to its own energy, other capacitors connected in parallel also dump their energy into the faulty capacitor. This may lead to violent explosion of capacitor unit if cans enclosing them are not sufficiently strong. Resistance value of protection resistors were varied in the simulation and energy dissipated across it and energy getting dumped in faulty capacitor was observed. Finally,  $0.18\Omega$  resistance value has been chosen in which about 90% of energy dissipated and remaining 10% got dumped into faulty capacitor which is tolerable. During normal discharge event, each capacitor generates 10.3kA current when charged to 15kV. Negligible energy is dissipated across these resistors in normal discharge. P-Spice simulation has also been carried out for determining inductance of pulse shaping inductor for conditioning current pulses as required.

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**PU-262**

**Design, Development and Testing of Water based Co-axial Blumlein Pulse Generator**

Sanjay Singh, S. P. Nayak, Ashutosh Jaiswar, T.C. Kaushik and Satish C. Gupta

*Applied Physics Division, Bhabha Atomic Research Centre, Trombay, Mumbai-400085*

E-mail: sanjay@barc.gov.in

**Abstract**

Pulses with high peak power find extensive applications in industrial and scientific areas. Industrial applications include electromagnetic forming, treatment of metal and polymer materials, insulation testing etc. Scientific applications include study on properties of material, plasma physics studies etc. [1]. High voltages are commonly generated by Marx generators in which a number of capacitors are charged in parallel and then discharged in series. The voltage thus generated has longer rise time and pulse duration. So, output voltage generated by the Marx generators has to be conditioned for applications requiring pulse having rise time of tens of ns. Inductive energy storage system offers a compact alternate method to generate desired voltage pulses. However, such systems require development of opening switches which is relatively difficult. Blumlein are co-axial transmission line based pulse generators and can be made compact if dimensions and dielectric medium between conductors are chosen wisely.

In the present work, water based co-axial Blumlein pulse generator has been designed and developed for generating fast rectangular voltage pulses across 25  $\Omega$  resistive load. De-mineralized water has high dielectric constant and high break-down voltage which helps in generating high voltage longer duration pulses in smaller generator length. However, energy stored in de-mineralized water gets discharged on its own within 7.16  $\mu$ s [2] with water conductivity of 1  $\mu \Omega^{-1}cm^{-1}$ . Hence, care has been taken while charging the generator. Developed system is of over-all length 1.7 m and diameter 450 mm. Generator conductors are made of SS304 and Delrin is used for insulators between conductors. 10  $\mu$ H charging inductor is selected based on system simulation results for droop in pulse amplitude for a given charging inductor. 0.15  $\mu$ F, 50 kV capacitor and Tesla transformer are used for charging of the generator. Currently generator is charged for 47 kV and pulse of FWHM 133.33 ns is generated across 25  $\Omega$  ceramic resistive load at 25°C dielectric temperature. Pulses of FWHM 121.81 ns and 115.50 ns are generated at dielectric temperature 38°C and 45°C respectively. Pulse FWHM at different temperature is in agreement with decrease in the dielectric constant of de-mineralized water with increase in temperature. Work is underway to enhance the output to 100 kV for which the systems is designed.

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## Equation Of State Of Strontium In Wide Ranges Of Density And Temperature Including Warm Dense Plasma Regime

Vinayak Mishra, Sijoy C. D., Aditya Nandan Savita, Shashank Chaturvedi

*Computational Analysis Division, Bhabha Atomic Research Centre, Visakhapatnam*

E-mail : vinayakm@barc.gov.in

### Abstract

The equation of state (EOS) of materials under extreme conditions of pressure and temperature is of great interest in condensed matter physics, geophysical and planetary sciences, etc. The EOS of materials is also an important input to the hydrodynamic simulations of the shock wave experiments in which materials may undergo “solid – liquid – vapour – warm dense plasma” phase transitions. The pressure effect on the EOS of Sr has been studied extensively. However, the temperature effect on the EOS properties of Sr are scarcely available in the literature. In this work we report our theoretical EOS results of Sr in solid, liquid and warm dense plasma regime.

The EOS of matter describes pressure and total energy as functions of density and temperature. It has three contributions, T=0 K contribution (or cold contribution) due to ion-electron and electron-electron interactions, ion-thermal contribution due to ionic vibrations at high temperatures and electron thermal contribution due to electronic excitations at high temperature. We shall present our comparative study of EOS results, in wide ranges of density and temperature, obtained from first principles calculations [1] as well as various empirical EOS models such as QEOS model [2], universal metal EOS model and exp-N formula [3]. We shall also present the thermo-dynamic properties deduced from the calculated EOS. To validate our calculations we shall compare our results with available published experimental results.

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**PU-445**

**Development Of A Plasma Based Multi-Gap Pseudospark Switch For 40 KV/10KA Ratings**

V. Pathania, H. Rahaman, B. L. Meena, D. K. Pal, N. Kumar, U. N. Pal and Ram Prakash

*CSIR-Central Electronics Engineering Research Institute (CSIR-CEERI), Pilani,  
Rajasthan-333031*

E-mail: varunpathania14@gmail.com

**Abstract**

CSIR-CEERI Pilani has been working for nearly two decades in the field of plasma closing switches, particularly, thyatron and pseudospark switches, to meet the demand of repetitive pulsed power for high power gas lasers, accelerators and drivers of high power microwaves, etc[1]. The thyatron switch is a well-established technology and is commercially available from limited vendors for various applications [2-3]. On the other hand, despite many advantages of pseudospark over the thyatron switch like low standby power, ruggedness to current reversal and fast rise time current, its capability as an alternative to thyatron needs to be proven yet [4]. However, in many applications the thyatron switch has already been replaced by the low cost pseudospark switch [5].

The kind of multi-gap (i.e., the double gap) pseudospark switch reported here is found to be comparable to the commercially available thyatron switches in the range of hold-off voltage up to 40 kV and switch current up to 10 kA. For this, a modular pseudospark with two gaps, which are separated by a cavity drift space region, has been designed and developed. It employs a single trigger unit in the cathode region to initiate the discharge for rapid breakdown of both the gaps. The achieved results of the double gap pseudospark switching along with design consideration and circuit optimization will be presented.

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PU-452

## Particle-In-Cell & Monte Carlo Simulations Of X-Ray Radiation From Pinched Electron Beam

Gursharn Singh, Sijoy C.D. and Shashank Chaturvedi

*Bhabha Atomic Research Centre, Visakhapatnam*

E-mail : gursharn@barc.gov.in

### Abstract

We have performed two & three-dimensional simulations of x-ray radiation emission from a pinched electron beam diode. In such systems two different type of physical phenomena coexist. One is electron beam dynamics, which can be solved by Particle-in-Cell simulations and the second is electron beam interaction with a solid target, leading to emission of X-rays. Therefore the simulation also involves two different types of computations.

The first stage, viz., electron beam emission and pinching, is simulated using a locally developed Particle-in-Cell (PIC) software called MWS [1]. From PIC simulations we can calculate the properties of the electron beam just before interaction with the solid target. These electron beam parameters form the input for second stage.

In the second stage, the electron beam interacts with the target material. Phenomena like electron-impact excitation and bremsstrahlung result in emission of X-rays [2]. These X-rays are themselves reabsorbed to some extent within the target. This emission and re-absorption of X-rays is computed using Monte Carlo simulations for electron & photon transport.

Since this study is our first step in this direction, validation is necessary. In this paper, we will describe the capabilities of the software as well as validation against results reported in the literature [3]. We will also summarize simulation parameters that play an important role in the accuracy.

A set of parameter taken from Ref [3], where electron current vary from 20 to 26 kA with varying pinch length from -2.0 to 10 mm with cathode inner radius 5.0 mm. For comparative study the spot size and dose at 1 m distance are calculated and compared with results from Ref [3]. A difference of maximum ~2 % observed compare to Ref[3]. Well matching results not only validate the software but also give a trusted tool for experimental support and optimization.

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**PU-456**

**Study On Generation Of Pulsed High Current With Aluminium Electrolytic Capacitor**

Pankaj Deb, Anurag Shyam

*Energetics and Electromagnetics Division,  
Bhabha Atomic Research Centre, Visakhapatnam - 530012*

E-mail : pankajdeb24@gmail.com

**Abstract**

Aluminum electrolytic capacitors have high energy density and mainly used in power supply filters. The paper describes the experimental analysis and behavior of Aluminum electrolytic capacitor when used to generate pulsed high peak current. Aluminum electrolytic capacitor is also found suitable to be used as an energy storage capacitor for compact pulsed power generator. From the experiment analysis output we found that 30mF, 27 kJ Aluminum electrolytic capacitor bank delivered 35 kA pulsed current and pulsed duration of 800us into 4uH inductive load using solid state semiconductor switch. This capacitor bank have energy/weight ratio 1000 J/kg. Electrical characteristics such as voltage dependence, equivalent series inductance and circuit equivalent resistance of the capacitor bank is examined. These capacitors can be used in many pulsed power application like Pulse forming system, Electromagnetic Launchers, Rock Fragmentation, Generation of pulsed high magnetic field inside a solenoid and also in space applications.

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**PU-470**

**High Power Microwave Generation By Reflex Triode Vircator**

B.Adhikary, R. Verma and A. Shyam

*Energetics and Electromagnetics Division,  
Bhabha Atomic Research Centre, Visakhapatnam – 530012*

E-mail : biswajitadhikary@yahoo.com

**Abstract**

A reflex triode type virtual cathode oscillator was studied experimentally. Reflex triode has higher efficiency and can run with longer pulse lengths [1]. The design of Reflex Triode with an impedance of 20ohm will be described. Reflex triode has been directly driven by a compact fast Marx generator [2]. Study of Reflex Triode has been done with different types of cathodes like velvet cloth, and graphite. The anode consists of a round wire SS mesh with ~70% transparency through which the electron beam passes, generating a dense cloud of negative charge known as a virtual cathode. High Power Microwave output was measured in single shot operation at 20 kV charging with the A-K gap set to 10 mm. The experiments were carried with typical electron beam parameters of 140kV, 7kA and 170ns rise time. The whole experimental setup and diagnostics for HPM measurement will be discussed.

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**PU-481**

**Experiments On Hypervelocity Electromagnetic Implosion Of Cylindrical Liners**

R. Verma, E. Mishra, R. Shukla, P. Banerjee, K. Sagar, M. Meena and A. Shyam

*Energetics & Electromagnetics Division,  
Bhabha Atomic Research Centre, Visakhapatnam 530012*

Email: rishiv@barc.gov.in

**Abstract**

An alternative approach to achieve ICF (Inertial Confinement Fusion) conditions has been explored by conducting experiments on electromagnetic implosion of cylindrical liners. In this scheme the magnetic field driven near isentropic compression of matter and hypervelocity implosion of metallic conductor is explored to attain density and temperature suitable to generate fusion reactions. A

cylindrical metallic shell (i.e. liner) containing a capsule of deuterated matter is radially compressed by  $J \times B$  force. In the referenced context, preliminary experiments have been conducted on a fast modular capacitor bank for investigating the intricacies in hypervelocity liner implosion dynamics. In the Z-Pinch experiments, a 30mm-long, 10mm diameter, 400 $\mu$ m thick Aluminum liner (Al-1100) was imploded at a peak current of  $\sim 450$ kA and radial/volume compression of more than  $5\times/25\times$  was achieved. A small magnetic field (of  $\sim 0.1$  Tesla) was injected for diagnostic purpose. The mass averaged implosion velocity exceeded 0.5km/s. In  $\theta$ -Pinch experiments, maximum implosion velocity of  $\sim 0.4$ km/s was obtained from flash x-ray imaging and high-speed photography. Diagnostics included flash radiography, high-speed camera, azimuthal 16-probe B-dot array and an on-axis floating B-dot probe. Discharge parameters are chosen to avoid bulk melting and vaporization of the liner. Presently the optimization experiments are underway for achieving implosion velocity  $>1$ km/s.

## PU-485

### Synchronization Of Rail-Gap Switches For 1.2MJ 'RUDRA' Capacitor Bank

Ekansh Mishra, Rishi Verma, Manraj Meena, Karuna Sagar and Anurag Shyam

*Energetics and Electromagnetics Division,  
Bhabha Atomic Research Centre, Visakhapatnam 530012*

E-mail : ekanshmishra1210@gmail.com

#### Abstract

Synchronization is an important consideration in large capacitor banks where multiple modules and discharge switches are operated in parallel. For avoiding the cross-flow of energy in between the parallel connected capacitors/modules, it becomes mandatory that all the switches must conduct within the time limit of their jitter. Asynchronization not only impact safety consideration of capacitor modules but it affects temporal characteristics of pulse at common load. In our case, the task is to ensure simultaneous breakdown with multi-channel initiation in all six railgap switches (connected with each 200kJ module), that is required for safe and synchronized operation of 1.2MJ 'RUDRA' capacitor bank (largest of its type in India) by utilizing an appropriate triggering scheme. The performance of railgap switch critically relies upon multi-channel breakdown between the extended electrodes (rails) in order to ensure distributed current transfer along electrode length and to minimize the switch inductance, conduction delay and jitter. The initiation of several simultaneous arc channels along the electrode length in railgap switch depends on the gap triggering technique and on the rate at which the electric field changes within the gap. In the existing railgap switches, the consequently imposed stringent requirement on the trigger pulse is that it must have a fast rate of rise  $>5$ kV/ns and high peak voltage, largely exceeding the main gap voltage (i.e. typically in the range of 10kV– 40kV).

To meet aforesaid criteria of trigger pulse six channels Transmission Line Transformer (TLT) based driver with input and output impedance of  $\sim 1.25\Omega$  and  $20\Omega$  respectively is designed and developed for demonstrating synchronized, multi-channel discharge of all six modules. At  $\sim 22$ kV of primary charging, the TLT produces  $>150$ kV output pulse of 120ns duration (FWHM) with rise time of better than 30ns (10% – 90%). This corresponds to voltage gain efficiency of  $>85\%$  and  $dV/dt$  of  $>5$ kV/ns. Six channels TLT based driver is capable of efficiently driving synchronized discharge in all the six

parallel connected Railgap switches within the time limit of  $<10\text{ns}$  (i.e. transit time isolation within the parallel connected six modules) to avoid cross-flow of energy in between the parallel connected capacitors/modules. Two modules (each of  $200\text{kJ}$ ) of  $1.2\text{MJ}$  'RUDRA' capacitor bank are successfully operating in synchronized parallel operation using TLT based driver and total  $\sim 800\text{kA}$  current with quarter time  $\sim 10\text{-}12\mu\text{s}$  is successfully delivering on common load/liner at charging voltage of  $\sim 13\text{kV}$ .

**OTHER AREAS**



**OA-003**

**Electrical And Optical Properties Of Molybdenum Doped Zinc Oxide Films  
Formed By Bias Magnetron Sputtering**

K. Radhamma, R. Subba Reddy and S. Uthanna

*Department of Physics, Sri Venkateswara University, Tirupati – 517 502, India*

E-mail: uthanna@rediffmail.com

**Abstract**

High electrical conductivity coupled with optical transmittance of doped zinc oxide thin films leads for the development of transparent conductors, flat panel displays and solar cells. In this investigation an attempt is made in the deposition of molybdenum doped zinc oxide (MZO) films by bias magnetron sputtering and studied their structure, electrical and optical properties.

Thin films of MZO were formed on unheated glass substrates by reactive magnetron sputtering of mosaic Mo-Zn target. The films were deposited at a fixed oxygen partial pressure of  $2 \times 10^{-2}$  Pa, sputter pressure of 5 Pa and at different substrate bias voltages in the range 0 to -120 V. Chemical composition of the films determined with energy dispersive X-ray analysis was zinc = 47.5 at.%, oxygen = 49.8 at.% and molybdenum = 2.7 at.%. indicated that molybdenum substituted the zinc in ZnO films. X-ray diffraction studies revealed that the films formed at unbiased substrates were amorphous while those deposited at -80 V showed the (002) reflection confirmed the growth of improved crystallinity. At higher bias voltage of -120 V the intensity of the diffraction peak decreased due to high energy ions induce high defect density in the films and resputter hence decrease in the crystallinity [1]. Crystallite size of the films determined from the X-ray diffraction peak using the Debye-Scherrer's relation increased from 5.2 to 9.8 nm with increase of substrate bias voltage from 0 to -80 V respectively while at high voltage of -120 V it was 7.5 nm indicated the growth of nanocrystalline films. Atomic force microscopic studies revealed that root mean square roughness of the films increased from 3.5 to 7 nm and grain size increased from 60 to 110 nm with increase of bias voltage from 0 to -80 V respectively.

Electrical resistivity of the films formed on unbiased substrates was  $0.85 \Omega \text{cm}$ . It was decreased to  $0.12 \Omega \text{cm}$  with increase of substrate bias voltage of -80 V was due to improvement in the crystallinity. The films deposited at higher bias voltage of -120 V exhibited the resistivity of  $0.32 \Omega \text{cm}$  due to reduction in the crystallite size where the grain boundary scattering of charge carriers predominates. The optical transmittance of the films in the visible region was in the range 80 – 85 %. The optical band of the deposited films determined from the transmittance data using Tauc's plots increased from 3.15 to 3.29 eV with increase of substrate bias voltage from 0 to -120 V.

In conclusion, Mo doped ZnO films were formed by RF bias magnetron sputtering technique and studied the influence of substrate bias voltage on the structural, electrical and optical properties. Mo (2.7 at.%) doped ZnO films formed at -80 V were nanocrystalline with electrical resistivity of  $0.12 \text{ ohm.cm}$ , optical band gap of 3.27 eV and figure of merit of  $1.90 \Omega^{-1} \text{ cm}^{-1}$ .

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## External Magnetic Field Effect On Absorption Of Surface Plasma Waves By Metallic Nano-Particles

Deepika<sup>1</sup>, Prashant Chauhan<sup>1</sup>, Anshu Varshney<sup>1</sup>, D.B. Singh<sup>2</sup> and Vivek Sajal<sup>1</sup>

<sup>1</sup> Department of Physics and Material Science & Engineering,  
Jaypee Institute of Information Technology, Noida-201307, UP

<sup>2</sup> Laser Science and Technology Center, Metcalfe House, Delhi-110054

Email:deepika7nov@yahoo.co.in

### Abstract

Configuration of metal surface embedded with metallic nanoparticles is used for absorption of surface plasma waves (SPW) in the presence of external magnetic field (y-direction). The SPW (propagating in z-direction) excites resonant plasma oscillations in the particles incurring attenuation of the surface plasma wave. For spherical metallic particles with plasma frequency  $\omega_{pe}$  in the presence of external magnetic field, the resonant plasma oscillations occur at  $\omega^2 = \omega_{pe}^2/3 + \omega\omega_c$ , where  $\omega$  and  $\omega_c$  are frequency of the SPW and cyclotron frequency respectively. At this frequency, energy is absorbed by the electrons inside nanoparticles and sharp increase in the absorption of SPW by the metallic particles, depending upon its size and magnetic field strength occurs. The change in absorption constant with external magnetic field is studied. The results are of direct importance in nanoparticle based thin film solar cells.

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**OA-046**

## **Development Of ZnO Film For Solar Cell Application By Thermal Evaporation System And Its Characterizations**

Aditya Gupta<sup>1</sup>, Hari Prakash<sup>2</sup> and Arun Sarma<sup>2</sup>

<sup>1</sup>*School of Electrical Engineering (SELECT),* <sup>2</sup>*School of Advanced Sciences (SAS), VIT University  
Chennai, Vandalur-Kelambakkam Road, Chennai-600127, Tamil Nadu*

E-mail : aditya.gupta2012@vit.ac.in

### **Abstract**

Bi-layered Zn rich ZnO film has been developed on uniformly etched soda-lime glass substrate using vacuum thermal evaporation system. The experiment has been performed by analyzing samples with different concentrations of etched soda-lime. At the same time, the tray containing the ZnO powder has been covered with mesh grids of different sizes each time. It has been shown this provides relatively lower resistivity and exhibits an excellent light scattering property [1] and relatively good electrical properties of the film. The produced film is characterized with SEM-EDAX, FTIR and DRS setup. This has shown improvement in its performance and quantum efficiency (QE). Thus, the developed glass/bi-layered ZnO film with a Zn-rich layer is a new promising upcoming material since its resistivity is low while its light-scattering property is still high.

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**OA-058**

## **Existence Of Extremal Solution Abstract Measure Integro-Differential Equations**

V.B. Patare

*Department of Mathematics, Nutan Mahavidyalaya, Sailu, Parbhani-431 503 (MS)*

E-mail: vijaypatare30@gmail.com

### **Abstract**

In this chapter, an existence result for perturbed abstract measure differential equation are proved by using Leray-Schauder nonlinear alternative, under the caratheodory condition. The existence of extremal solutions is also proved, under certain monotonicity conditions.

**OA-061**

**Near Field Optical Resonance Study Based On Metallodielectric Systems For Plasmonic Systems**

Richa Sharma, R.P. Sharma, Alokji

*Centre For Energy Studies, IIT Delhi, Hauz Khas New Delhi 110016*

E-mail: richas330@gmail.com

**Abstract**

Response of nanoparticle (Au, Al) placed in air with different shape and size such as sphere, ellipsoid, array of sphere to an external uniform static electric field using simulation based on the discrete dipole approximation studied in the present article. The present study deals with the investigation of the electromagnetic field induced by optical excitation of localized surface plasmon resonances in metal nanostructures at subwavelength scale. The study reveals the dependence of the induced near field on the size and geometry of the nanoparticles, thereby one gets an estimate of the largest local electric field enhancement near the particle surface

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**OA-076**

**Electrochemical Characterization of Ammonia Radio Frequency Plasma Treated Reduced Graphene Oxide in Melamine Sensing**

J.Lavanya<sup>1</sup>, S.Neogi<sup>2</sup> and N.Gomathi<sup>1</sup>

<sup>1</sup>*Department of Chemistry, Indian Institute of Space Science and Technology, Trivandrum, Kerala, 695547*

<sup>2</sup>*Department of Chemical Engineering, Indian Institute of Technology, Kharagpur, West Bengal, 721302*

Email: lavanyajth@gmail.com

**Abstract**

Introducing active sites by functionalization increases electrocatalytic activity of graphene. Apart from metal and metal oxide functionalized graphene, nitrogen functionalization plays a key role in modulating the electronic property and increases the surface area of reduced graphene oxide (RGO) [2]. In this work, we report the synthesis of N-doped reduced graphene oxide (NRGO) by using ammonia radio-frequency plasma treatment on RGO synthesized via chemical reduction method [1]. NRGO was characterized by XPS, FTIR and Raman spectroscopy. The surface area was calculated by BET surface area. The electron transfer kinetics and electrocatalytic activity was studied by CV

and EIS. Due to enhanced catalytic activity N-doped graphene was successfully applied for sensing melamine.

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**OA-136**

**Surface Modes Of Binary One Dimensional Plasma Photonic Crystals**

Shikha Shukla, Surendra Prasad, Vivek Singh

*Department of Physics, Faculty of Science, Banaras Hindu University, Varanasi-221005*

E-mail: prasad.surendra@gmail.com

**Abstract**

Properties of TE surface modes [1] supported at the boundary of homogeneous medium and semi-infinite one dimensional binary Plasma Photonic Crystals is studied. The condition of existence of these modes is obtained by using transfer matrix method and continuity conditions of field and its derivatives at the boundary [2]. The effect of termination layer thickness and plasma frequency on dispersion properties, transverse field distribution and group velocities of these modes are investigated. It is found that the thickness of termination layer affects the frequency domain of these modes. In the first and third band gap, frequency of surface modes is high for thinner termination layer where as in the second band gap; it is high for thicker termination layer. Group velocities of these modes along the boundary are also calculated and found to be controlled by termination layer thickness. Effect of plasma frequency on surface modes is also investigated and found that the modes frequency increases with increase in plasma frequency. The transverse field distributions of modes are found to be affected by termination layer thickness and plasma frequency. It is inferred from this study that by properly selecting plasma frequency and the thickness of termination layer, surface mode frequency can be improvised in requisite frequency range.

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**OA-157**

**Electron Beam Welding: Heat Flow Model Including Peclet Number**

Suresh Akella<sup>1</sup>, Harinadh Vemanaboina<sup>1</sup>, Ramesh K Buddu<sup>2</sup>

<sup>1</sup>*Sreyas Institute of Engineering & Technology, Hyderabad, 500068*

<sup>2</sup>*Institute for Plasma Research, Bhat, Gandhinagar, Gujarat 382428*

Email: S4akella@gmail.com

**Abstract**

Electron beam welding is recognized as a low heat input for obtaining thinnest bead width and longest weld penetration among the technologies to provide low distortion. The challenge is to keep the electron beam focused without distractions to surroundings which is obtained by performing the process in a Vacuum chamber. EBW modeling is similar to Laser weld in terms of the heat flux flow with a surface heat on bead area in the form a Gaussian distribution and when the beam forms a key hole the heat is conducted to the base metal by a frustum distribution. As there is no blind end at the bottom a portion of the heat would leave out to ambience through the lower end of the bead. The heat flow mechanism is calculated using Peclet number from which with empirical formulae power distribution is determined. Peclet number variation as a function of radial distance, penetration depth & distance from wall is calculated. A finite element analysis is done and Temperature graphs were obtained for welding using Ansys software. Weld material used is SS304 and temperature dependent thermal and structural properties are considered. The output obtained is the thermal isotherms around the weld to estimate the fusion, bead and heat effected zones.

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**OA-181**

**Pulsed Power Plasmas For Production Of Nanoparticles**

Anurag Shyam, Rashmita Das and Rishi Verma

*Pulsed Power Division, Institute for Plasma Research, Gandhinagar  
Energetics and Electromagnetics Division, Bhabha Atomic Research Centre, Vishakhapatnam*

E-mail: anurag.shyam@yahoo.com

**Abstract**

Pulsed power converts material into vapour and plasma rapidly. While recombining and condensing nanoparticles are formed. There are several methods by which vapour/plasma can be generated by pulsed power. We are producing copious amounts of nanoparticles by exploding wires through pulsed power. A 10kJ plasma focus is also being operated for nanoparticles. The nanoparticles are characterized by AFM, TEM and X-ray spectroscopy.

**OA-201**

**Design And Analysis Of Duct Liner For Vacuum Vessel Of Indian Test Facility**

Dhananjay Kumar Singh, J. Joshi, A. Yadav, G. Roopesh, H. Patel, Rambilas Prasad, MV Nagaraju, S. Pillai, D. Sudhir, M. Patel, C. Rotti, M. Bandyopadhyay, A. Chakarborty

*ITER-India, Institute for Plasma Research, Gandhinagar, Gujarat.*

E-mail: dhananjay.singh@iter-india.org

**Abstract**

INTF (Indian test facility) [1] vacuum vessel is designed to install a full-scale test set-up of Diagnostic Neutral Beam (DNB) for the qualification of beam parameters and the behavior of beam-line components prior to installation and operation in ITER. Vacuum vessel is a cylindrical chamber of diameter 4.5 m and length of 8 meters and having a cylindrical tapered duct of length ~12 m and of varying diameter in the range of 0.9 m to 1.2 m. The duct is attached to front end of the vessel to house a calorimeter for beam characterization at a distance 20.6m from the beam source.

It is assessed that ~ 20% neutral hydrogen beam of energy 100keV can be reionized due to rise in pressure inside the conductance limited duct region. These reionized energetic hydrogen ions can deviate from its original path in presence of earth's magnetic field ~ 0.3G. The trajectories of those ions are unpredictable due to uncertainty of their formation locations. These devious ions may get focused due to magnetic field and may generate footprint of high heat flux on the duct wall and may damage the duct of the vacuum vessel. This established the need to design a duct liner to cover the required length of duct from inside of the vessel. To design the duct-liner, ~ 200kW/m<sup>2</sup> is assumed to be the heat load falling uniformly on the duct liner wall. By using finite element analysis through ANSYS, the design is optimized in terms of material, liner wall thickness and cooling requirements. In this contribution, the design including the thermo-mechanical analysis results of the duct liner is

presented to establish that the temperature and thermal stress in vessel duct is in the required limits.

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OA-242

## Effect Of Radio Frequency Power On Magnetron Sputtered TiO<sub>2</sub> Thin Films

Satheesh R.<sup>1</sup>, Sankar S, K.G. Gopchandran<sup>2</sup>

<sup>1</sup>*Sree Vidhyadhi Raja NSS College, Vazhoor, Kottayam 686505, Kerala,*

<sup>2</sup>*Dept of Optoelectronics, University of Kerala, Kariavattom-695581, Thiruvananthapuram*

E-mail: satheeshr83@gmail.com

### Abstract

Titanium dioxide thin films exhibit excellent properties like high dielectric constant , high transmittance in the visible and near IR region , high refractive index and wide optical band gap [1]. Bulk TiO<sub>2</sub> occurs in three crystalline polymorphs: anatase (tetragonal), rutile (tetragonal) and brookite (orthorhombic) [2]. Structure, phase composition, electrical and optical properties of TiO<sub>2</sub> thinfilms are very sensitive to deposition conditions [3]. In catalysis, photocatalysis, and dye-sensitized solar cells, anatase has proven advantageous over the rutile phase [4-6]. Though rutile phase has been extensively investigated in the past, anatase is found to exhibit interesting properties recently [7], which makes it a promising material for gas sensors, solar cells and dielectrics in memory cell capacitors and semiconducting FET [8, 6, 9]. Thus accurate knowledge of the refractive indices and absorption coefficients in opaque and in band gap regions of semiconductor thin films is indispensable for the design and analysis of various optoelectronic devices.

In the present work thin films of TiO<sub>2</sub> were prepared using RF planar magnetron sputtering on amorphous quartz substrates at different deposition power. Influence of sputtering power on thin film crystallization was carried out. Structural study reveals that the deposited film was polycrystalline and films showed a trend towards crystallinity with increase in sputtering power. Phase content and crystallite size of the deposited film showed dependence on sputtering power. Optical studies showed that all the films showed an average transmittance above 60% in the visible region and their transmittance decreased towards UV region. Films showed an increase in refractive index with increase in sputtering power. The calculated band gap (from transmission spectra) showed a decrease with increase in sputtering power. The variation of refractive index with wavelength is used in the discussion of refractive index dispersion in single oscillator (Wemple and Didomenico) model. From the calculated dispersion energy parameter, the band gap for anatase film and mixed phase film, that showed highest rutile content were calculated and is in good agreement with the values calculated from transmittance spectra.

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**OA-297**

**Bi Incorporation on the CuInS<sub>2</sub> Thin Film Solar Cells for Critical Efficiency Studies**

A. D. Sivagami, Bornali Sarma and Arun Sarma

*School of Advanced Sciences (SAS), VIT University Chennai, Vandalur- Kelambakkam road,  
Chennai-600 127, Tamilnadu*

E-mail:ad.sivagami2014@vit.ac.in

**Abstract**

CuInS<sub>2</sub> is one of the promising materials for photovoltaic applications because of its suitable band gap energy of 1.53 eV [1, 2]. Nanostructuring the light harvesting layer results in very low reflection and increased photon absorption which can lead to higher solar cell efficiency [1-4]. The crystal quality is an essential factor for tuning the conversion efficiency of a solar cells. Nanoparticles of CIS were synthesized from Copper, Indium, Sulphur elements with and without Bismuth addition by solid state melt growth process. Thin films of undoped and Bi doped CIS from the composites of synthesized nano crystals have been deposited by Vacuum thermal evaporation method. An effort has been taken to study the influence of deposition parameters and the effect of Bi impurity addition over the crystal quality improvement. The crystallinity, compositional, morphological and optical properties of deposited films have been characterized and analysed by X-Ray diffraction (XRD), Energy Dispersive X-Ray (EDAX), Scanning Electron Microscope (SEM), UV-Visible spectrometer and Photoluminescence (PL) spectra analysis. Quantitative analysis of the film properties have been done based on the characterizations.

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## OA-341

### Calculation of Error Matrix using Finesse for the supervisory control of an optical cavity

S. Sunil, Amit K. Srivastava & Ziauddin Khan

*Institute for Plasma Research, Bhat, Nr. Indira Bridge, Gandhinagar, 382428.*

E-mail: sunil@ipr.res.in

#### Abstract

In a gravitational wave detector, the frequency stabilization of a Fabry-Perot cavity is carried out using Pound-Drever-Hall (PDH) locking system. When more than one cavity forms a Multiple Input Multiple Output (MIMO) layout, stabilization of individual cavity uses PDH technique. Optical cavities made up of a pair of mirrors are planned for prototyping MIMO control system. Frequency stabilization from supervisory control point of view is being carried out using Finesse simulation software. The stabilization of individual cavity is carried out by comparing it with a reference locked cavity. Any deviation in parameters like the length or tilt of the mirrors forming the cavity from the reference cavity creates an error matrix which is minimized by the supervisory control. Such an application finds its use at following places: (i) in locking an optical cavity to a frequency stabilized continuous wave laser, (ii) to frequency stabilize any resonator and (iii) optimize an optical resonator for the study of plasma parameters.

## OA-342

### Validation of Sandwich bottom plate to rib weld joint for ITER Cryostat

Mitul Patel<sup>1</sup>, Vaibhav Joshi<sup>1</sup>, Rajnikant Prajapati<sup>1</sup>, Girish Gupta<sup>1</sup>, Jagrut Bhavsar<sup>1</sup>, Mukesh Jindal<sup>1</sup>,  
Amit Palaliya<sup>1</sup>, Gaurav Jogi<sup>1</sup>, Vipul More<sup>1</sup>, Avik Bhattacharya<sup>1</sup>, Saroj Jha<sup>1</sup>, Manish Pandey<sup>1</sup>,  
Anil Kumar Bhardwaj<sup>1</sup>, Hemal Desai<sup>2</sup>, Pandurang Jadhav<sup>2</sup> and Niyant Mehta<sup>2</sup>

<sup>1</sup>ITER-India, Institute for Plasma Research,  
A-29, GIDC Electronic Estate, Gandhinagar;  
<sup>2</sup>Larsen & Toubro Ltd, Heavy Engineering, Surat

E-mail: mitul.patel@iter-india.org

#### Abstract

Cryostat is a large stainless steel vacuum vessel providing vacuum environment to ITER Machine components. The cryostat is ~29 meters in diameter and ~29 meters in height having thickness varies from 40 mm to 180 mm.

Sandwich structure of Cryostat Base section withstands vacuum loading and limits the deformation under service conditions. Sandwich structure consists of top and bottom plates internally strengthened with radial and circular ribs.

Sandwich structure bottom plate to rib weld joint has been designed with full penetration joint as per ITER Vacuum Handbook requirement considering Nondestructive examinations and welding

feasibility. Since this joint was outside the scope of ASME Section VIII Div. 2, it was decided to validate through mock-up of bottom plate to rib joint. Welding sequence was established to control the distortion. Tensile test, Macro-structural examination and Ultrasonic tests were carried out. The results from the welded joint were found to confirm all code and specification requirements. Ultrasonic examination validation of calibration block concludes that full weld volume is covered in scanning and all possible defects will be detected. Current work represents validation of manufacturing and testing feasibility of the weld joint through mockup. Ultrasonic Examination method establishment using different scanning probes and validated of the same through calibration block is also discussed.

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### OA-350

#### Excitation Energy Dependence of Dye Fluorescence Lifetime in the Presence of Metal Nanoparticles

Sarayoo Sasidharan<sup>1</sup>, Tintu Kuriakose<sup>1</sup>, Jinto Thomas<sup>2</sup>, Ravi A.V. Kumar<sup>2</sup>, Reji Philip<sup>1</sup>

<sup>1</sup>Raman Research Institute, Bangalore 560080, India

<sup>2</sup>Institute for Plasma Research, Gandhinagar 382424, India

Email: reji@rri.res.in

#### Abstract

The controlled manipulation of fluorescence properties of fluorophores has opened up new applications in biomedical fields<sup>1</sup>. Presence of metal nanoparticles will alter the fluorescence properties of dye molecules due to surface plasmons<sup>2-9</sup>. We have investigated the fluorescence spectra, emission intensities and lifetimes of Rhodamine B dye molecules attached to silver nanoparticles, excited by ultrafast (100 fs) laser pulses, employing a fast (2 ps resolution) streak camera. Resonant and non-resonant energy coupling to the surface plasmons leads to fluorescence intensity quenching and enhancement, respectively. Interestingly, we also observe a systematic variation of fluorescence lifetime with excitation laser power: the lifetime is reduced from 2.5 ns to 1.8 ns when the laser power is increased from 0.1 mJ to 0.3 mJ. Results from this novel observation are analyzed and discussed in detail.

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## OA-376

### Modbus TCP/IP Communcation For Slow Controller Of Local Control Unit For ITER-INDIA Gyrotron Test Facility (IIGTF)

Deepak Mandge<sup>1</sup>, Vipal Rathod, Ronak Shah, Anjali Sharma, Sharan Dilip, Amit Yadav, Rajvi Parmar and S. L. Rao

*ITER-India, Institute for Plasma Research  
#A-29, Electronics Estate, GIDC, Sector-25, Gandhinagar- 382 025*

E-mail: deepak.mandge@iter-india.org

#### Abstract

Electron Cyclotron (EC) system on ITER will be used to provide 20 MW of RF power at a cyclotron resonance frequency of 170 GHz, into the plasma for EC Heating and Current Drive (EC H&CD) applications[1]. As a part of in kind contributions to ITER, ITER-India has a procurement package whose main scope is to supply a set of two EC RF power sources for ITER [2]. To support the ITER deliverables ITER-India has planned to setup a Gyrotron Test Facility (IIGTF) for establishing the integrated system performance of Gyrotron. IIGTF will be having a Test Gyrotron, a Transmission Line test set, Dummy load, High voltage and Auxiliary power supplies, water cooling connections, Gyrotron diagnostics, crowbar Protection systems, and a Local control unit (LCU) to test the Gyrotron [1].

The Local Control Unit consists of a slow controller (Siemens PLC), a fast Controller (PXIe System), Signal Conditioning Modules and Fast Interlock modules. All auxiliary systems and power supplies are controlled by PLCs. Sequence control and soft interlock functions are implemented in PLCs. High voltage and Magnet power supplies, Fast Local Protection and Data Archiving are performed by Fast Controller [3]. As a result, there would be many process variables that need to be exchanged between slow and fast controllers for proper operation of Gyrotron. Hence, it is utmost important to establish standard communication protocol between slow and fast controllers. Modbus TCP/IP is one such standard protocol, which is simple, reliable and efficient across different controllers. It is basically a serial server/client protocol which uses TCP/IP as a transmission medium.

In this paper, details of Implementation of Modbus TCP/IP protocol in Siemens PLC is discussed where Siemens S7 PLC is Modbus Server and PXIe system is Modbus Client.

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**OA-393**

## **Coupled LC Nano-Circuit Model For Interacting Nanostructures**

U. Chakravarty, J.A. Chakera, P.A. Naik, and P.D. Gupta

*Laser Plasma Division, Raja Ramanna Centre for Advanced Technology, Indore 452 013*

E-mail : uday@rrcat.gov.in

### **Abstract**

In the recent times there has been an upsurge in the study of light interaction with nanostructures because of their promising applications in focusing light beyond the diffraction limit, surface enhanced Raman scattering, photo cancer therapy, plasmonic electrical circuits, and the list continues. The key to such applications is the electric field enhancement and plasmon resonance (frequency  $\omega_0$ ) supported by nanostructures which in turn depends on their geometry. The easily understood light and individual particle interaction are nano-sphere, nano-cylinders and nano-ellipsoids. Though individual particle light interaction can be studied easily in the quasistatic limit (particle size  $\ll$  incident light wavelength) but to analytically solve electromagnetically interacting nanoparticles is difficult and it requires computational assistance using finite element simulations. Recently nanostructure pairs like bow tie [1], two gold nano-rod, two gold nano-spheres etc. have been studied and it is shown to exhibit multiple resonance which can be tuned by varying the separation between them. In this paper we find the resonance condition in such electromagnetically interacting nanostructure pair by applying the fundamentals of nano-circuit theory (approximation of the Maxwell's equations) proposed by Engheta et.al. [2]. An individual nanostructure has an inherent capacitance (C) and inductance (L) and the ohmic loss is represented by a resistance (R). Coupling to a neighboring nanostructure can occur both inductively and capacitively which is solved by using coupled LCR circuit equations. It is found that if the coupling is capacitive there are two resonances one is the un-shifted individual particle resonance ( $\omega_0$ ) and another blue shifted resonance ( $\omega_+$ ). If the coupling is predominantly inductive (M) there are again two resonance frequencies one is red shifted ( $\omega_-$ ) and the other is blue shifted ( $\omega_+$ ). These new resonant frequency depend on the strength of coupling and in case of weak coupling just contribute to the broadening of a single particle resonance. Equivalent circuits of some complex nanostructures interacting with light will also be discussed which helps in understanding the frequency response, quality factor (Q) of the resonator, field enhancement and light absorption. This simplistic approach helps in clear understanding of electromagnetically interacting nanostructures and provides pointers for designing novel optical materials structured for a desired optical response.

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**OA-414**

**INFLUENCE OF GRAIN SIZE ON THE CO<sub>2</sub> SENSING BEHAVIOUR OF Zn DOPED SnO<sub>2</sub> THIN FILMS**

S. Deepa, K. Prasanna kumari and Boben Thomas\*

*Research centre in Physics, Mar Athanasius College, Kothamangalam College P.O,  
Kothamangalam, Kerala 686 666*

Email: dr.boben1@gmail.com

**Abstract**

Semiconductor gas sensors serves as an important tool for detecting harmful toxic and inflammable gases like CO<sub>2</sub>, LPG, CO, H<sub>2</sub>, etc,. Semiconductor metal oxide materials such as SnO<sub>2</sub> are used as gas sensor because they display chemiresistance behaviour [1]. Recent research has focussed on improving the sensitivity, selectivity and time response of these gas sensors[2],[3]. Improvement in sensor response has been realized by reducing the size of SnO<sub>2</sub> thin films used to fabricate the gas sensors [4], [5].

Zn doped SnO<sub>2</sub> thin films are deposited by spray pyrolysis technique from aqueous solution of SnCl<sub>4</sub> 5H<sub>2</sub>O at 310 °C. The structural analysis shows that the lightly doped films are tetragonal rutile with crystallite size ranging from 14-39nm. The diffraction peak positions corresponding to 101, 220 planes of the doped samples record a change compared with undoped sample [6]. With increase in doping concentration, the lattice strain also demonstrates a corresponding variation. Morphological analysis shows that the particles are spherical in shape and are uniformly distributed. It is observed that the particle size decreases for small doping concentrations of Zn. The UV-Vis absorbance spectra of the samples are recorded and the band gap energies estimated for different doping concentrations. The CO<sub>2</sub> and LPG sensing properties are investigated in detail. It is found that 2wt % Zn doped SnO<sub>2</sub> sample shows maximum response towards CO<sub>2</sub> at an operating temperature of 350°C, while the LPG response is poor. Ac conductivity measurements (using Agilent 16451B impedance analyser) are discussed in relation to the sensing characteristics of the sample [7].

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**OA-415**

**Particle Size Dependent Electrical And Dielectric Properties Of Polycrystalline Yttrium Iron Garnet**

K B Modi<sup>1</sup> and P U Sharma<sup>2</sup>

<sup>1</sup>*Department of Physics, Saurashtra University, Rajkot 360 005*

<sup>2</sup>*M. N. College, Visnagar 384 315*

E-mail: poojausharma@gmail.com

**Abstract**

The influence of high energy mechanical ball milling induced particle size reduction (1.8  $\mu\text{m}$  to 10.4 nm) on transport and dielectric properties of un-milled and milled polycrystalline yttrium iron garnet,  $\text{Y}_3\text{Fe}_5\text{O}_{12}$  (YIG), for 3, 6 and 12 hours duration, has been studied over the wide frequency ( $f = 100 \text{ Hz} - 1 \text{ MHz}$ ) and temperature ( $T = 300 - 673 \leftrightarrow \text{K}$ ) ranges. On milling, YIG decomposes into two phases, ferrimagnetic garnet phase and weak ferromagnetic yttrium ortho ferrite,  $\text{YFeO}_3$  - phase. The variation of two probe dc conductivity, ac resistivity and dielectric constants, real ( $\epsilon'$ ), imaginary ( $\epsilon''$ ) parts of dielectric permittivity and loss tangent ( $\tan \delta$ ) has been explained in the light of structural and micro-structural parameters. The two transitions have been observed in thermal variation of dc conductivity curves, corresponding to bi-phasic nature of the milled samples. The rise in  $\rho_{ac}$  values at higher frequency has been observed for milled samples due to the presence of large polaron. The abnormal behaviour of ( $f, T$ ) for un-milled sample is due to the collective contribution of the two types of charge carriers to the polarization. The  $M'$  versus  $M''$  plots shows two semicircular arcs; confirming mixed phase character of milled samples.

**OA-492**

**Online Measurement of Coating Thickness for Plasma Spray Coating System**

Santosh Kumar Behera and Debi Prasad Das

*CSIR-Institute of Minerals and Materials Technology, Bhubaneswar, Odisha, Pin-751013*

E-mail: skbehera@immt.res.in

**Abstract**

Plasma spray coating is used to coat molten or semi-molten particles on a substrate. The plasma provides both heat as well as the velocity to the spray powders. The quality of the coating depends on the stability of the plasma and powder injection process. It is expected to have a uniform coating. Conventionally, the coating thickness is measured offline or by stopping the spraying process. However, an online coating thickness measurement is highly desired to protect exceeding thickness and increase cost due to repetition of the job. This paper presents a novel technique to measure online coating thickness as well as surface profile generation of the coated surface during plasma spray coating. The present paper proposes a system which uses a point laser system which moves along with the robotic arm of the plasma spray coating system and monitors the thickness of the coated

surface at a predefined distance to avoid damage. The bias due to the vibration of the robotic arm movement is compensated using suitable filtering algorithms. Some real-time test results with a stepper motor based movement of laser sensor using National Instrument's hardware and LabVIEW software will be discussed. The developed measurement system is very much accurate (10 micron) and reliable. This has potential application in plasma spraying industries.

**Key Words:** Plasma Coating, Plasma spray torch, laser sensor, LabVIEW, online coating thickness measurement.

## OA-524 (I)

### In Vitro Biocompatibility Of Amorphous Carbon Based Coatings By Varying Of Surface Chemistry And Nitrogen Concentrations.

*V. Luk'yanchenko, N. Donkov\*, A. Zykova \*\*\*, V. Safonov \*\*\*,  
Miroshnichenko K. \*\*\*, A. Samoylenko\*\*\*\**  
*INMASTERS LTD, Kharkov, Ukraine*

*\*Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria*

*\*\*\*National Science Centre „Kharkov Institute of Physics and Technology“,  
Kharkov, Ukraine*

*\*\*\*\*Lugansk State Medical University, Lugansk, Ukraine*

Amorphous carbon based coatings have a great potential for biomedical applications due to its high hardness, low frictional coefficient, chemical inertness, high wear and corrosion resistance. These properties match well with the criteria of a good biomaterial for applications in orthopedic, cardiovascular and dentistry. Changing of surface chemistry enables to control wettability of amorphous carbon based coatings and future biomedical response.

The study of **a-C:N** coatings surface chemistry and wettability effect on cell/material response in vitro test was performed. The coatings with different concentration of nitrogen were formed on glass substrates. The deposition process was carried out by adding steam-to-gas mixture in glow discharge plasma generated by DC ion source with different ratio **N<sub>2</sub> : C<sub>7</sub>H<sub>8</sub>** at chamber. The main parameters of deposition process were presented: the ion source power 150W, bias voltage in the range 80-160V, substrate temperature and nitrogen concentration in mixture in the ratio **N<sub>2</sub> : C<sub>7</sub>H<sub>8</sub>** 10:90, 15:85, 20:80, 25:75. Adjustment of deposition conditions and surface chemistry has an important influence on surface structure, morphology and wettability of amorphous carbon based coatings.

The surface structure and morphology of deposited coatings were investigated by means of scanning electron microscopy (SEM) and atomic force microscopy (AFM) methods. The coatings are characterized with respect to their bonding structure at different stoichiometric compositions by photoelectron spectroscopy (XPS) analysis. The wettability was investigated by means of sessile-drop method of dynamic contact angle measurement of distilled water at temperature 20°C. The surface free energy (SFE) was calculated according to Robertson equation. The cytotoxicity and cytocompatibility were estimated in vitro tests. In the process of cell cultivation (fibroblasts) with amorphous carbon coated and control samples the cell cytology, morphology and vital capacity were determined after 24h and 3, 5 days cultivation.

The modification of coatings properties by changing plasma chemistry by adding nitrogen into the plasma mixture in the ratio **N<sub>2</sub> : C<sub>7</sub>H<sub>8</sub>** 10:90, 15:85, 20:80, 25:75 leads to distilled water

contact angles varying in the range of 77°-88° and SFE parameters in the range of 90-70 mN/m, respectively. Furthermore, an additional nitrogen concentration leads to an increase of contact angles and decrease of surface free energy. Generally, the obtained results show that the surface properties are strongly influenced by the coating's deposition conditions and a combination of deposition parameters with optimized plasma chemistry allows to tailor surface free energy parameters.

The data demonstrate that cell adhesive potential and phenotypical characteristics were different on the amorphous carbon based coatings at nitrogen concentration varying. The best results were obtained in the case of coatings with the minimum values of distilled water contact angle and the greater parameters of SFE with the ratio N<sub>2</sub> : C<sub>7</sub>H<sub>8</sub> 10:90 and 15:85. The deposition process controlling allows to control the surface chemistry and wettability of amorphous carbon based coatings and the next biological response.

### OA-525 (I)

#### **Preparation of “Micro-Fluidic Amperometric Sensor (MFAS)” by Integrating Core-Shell Au@Ag Nanocrystals on Carbon Electrode**

Yan-Hsiang Huang, Meng-Jiy Wang\*

*Department of Chemical Engineering, National Taiwan University of Science and Technology, Taipei, Taiwan*

Correspondence e-mail address: mjwang@mail.ntust.edu.tw

#### **Abstract**

This study is comprised of two parts: the first part focused on the synthesis of metallic nanoparticles with polyhedral structure. Metallic nanocrystals have drawn considerable attention in recent years because of their superior optical properties, large specific surface area, and versatile applications in photonics, information storages, chemical/biological sensing, and surface enhanced Raman scattering (SERS)<sup>[1]</sup>. The synthetic parameters for generating the Au nanocluster seeds include pH, reaction temperature, and capping agent were modulated, followed by integrating a thin layer of silver to form Au@Ag nanocrystals. Various analytical tools were employed to verify the physical-chemical and morphology characteristics of the prepared metallic nanocrystals.

For the second part, a custom-made microdevice was applied which mainly plays the role of minimize the required components for reaction and further facilitated the integration, automation, and parallelization for the designated biochemical processes. In addition, the prepared metallic nanocrystals prepared in the first part were incorporated on carbon electrodes for the detection of hydrogen peroxide, which was further combined with microdevice, to form “Micro-Fluidic Amperometric Sensor” (MFAS). The microdevice designed in this study allows the manipulation of small fluid volume, from micro- down to pico- liter, with exceptional accuracy. In summary, the proposed MFAS would have the advantages including low price, rapid response time, high accuracy, and smaller reaction volume that can reduce the thickness of the diffusion layer<sup>[2]</sup> and effectively convey electronic signals between solid-liquid phases when compared with the conventional system, and could be utilized for a wider range of applications.



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## OA-529 (I)

### CONTROL OF VACUUM ARC MACROPARTICLES BY HIGH-FREQUENCY SHORT-PULSED NEGATIVE BIAS APPLICATION

A.I. Ryabchikov

*National Research Tomsk Polytechnic University, 634050, Lenina 2, bldg. 4, Tomsk, Russia*

*Phone (3822) 70-56-94,*

*E-mail: ralex@tpu.ru*

#### Abstract

Paper is devoted to a brief review of the investigation of short negative bias pulse application for aluminium, copper and titanium macroparticles control on the substrate immersed in vacuum arc and gaseous plasmas. It was found that the decreasing of MP surface number density on a negatively biased substrate is determined by the pulse amplitude, pulse duration, pulse frequency, plasma density and processing time. A possibility to reduce the macroparticle number density more than 1000 fold has been demonstrated.

# **SPACE AND ATMOSPHERIC PLASMA**



SA-004

## Jeans Instability of A Self Gravitating Viscous Molecular Cloud Under The Influence Of Finite Electron Inertia, Hall Effect Fine Dust Particles And Rotation

D.L. sutar\* and R.K. Pensia\*\*

\* *Research Scholar Mewar University Gangrar, Chittorgarh (Raj.) 312901*

\*\* *Department of physics, Govt. Girls College, Neemuch (M.P.) 458441*

Corresponding author's E-mail: Devilalsutar833@gmail.com

### Abstract

In this paper we have study the Jeans instability of gaseous plasma in the presence of fine dust particles in incorporating the effect of finite electron inertia, viscosity, rotation, thermal conductivity, electrical conductivity and Hall current. The linearized perturbed equations of the problem we have obtained a general dispersion relation. The general dispersion relation is discussed for different mode of propagation and about different axis of rotations. The stability of the system is discussed by applying Rought-Hurwitz criteria. We hope that our result of the present problem will help to understand the astro physical problems.

**Key words:** Thermal conductivity, Hall-Effect, Finite Electron-Inertia, Suspended Particles, Rotation, Magnetic Field.

SA-006

## Plasma Waves Beyond The Solar System

Vipin K. Yadav and Anil Bhardwaj

*Space Physics Laboratory, Vikram Sarabhai Space Centre, Thiruvananthapuram 695022*

vkyadavcsp@gmail.com, vipin\_ky@vssc.gov.in

### Abstract

Plasma waves are omnipresent and thus are a unique feature of space plasmas as they propagate energy across different space regions. They transport particles and accelerate them to attain high energies. They transmit information about the local plasma properties from regions not accessible for in situ measurements and are specific to the phenomena/instabilities as their properties depend upon the background plasma prevailing at that location.

Plasma waves are observed in planets with magnetospheres viz Mercury, Earth, Jupiter, Saturn, Uranus, and Neptune [1, 2] as well as planets such as Venus and Mars which are deprived of a global magnetic field [2]. Plasma waves are detected in planetary satellites, comets and the interplanetary medium (IPM) [2]. The plasma in Sun itself supports plasma waves which are observed in solar

corona along the solar magnetic field [3]. Alfvén waves, observed in the IPM, are most likely of the solar origin and believed to reach IPM along with the solar wind. Plasma waves are predicted to exist in interstellar medium (ISM) where the Langmuir waves [4], Alfvén waves [5] and Magnetosonic waves [6] are excited by the incoming cosmic rays streaming along the magnetic field lines. The Alfvén waves are also believed to be present in the dusty winds of cooled supergiant stars. An abrupt rise in temperature is observed with the distance from the surface of supergiant stars which can be explained by the mechanical dissipation of these Alfvén waves [7]. In supergiant stars, the Alfvén wave generation mechanism is same as that in the Sun.

In this paper, the plasma wave observation / prediction beyond the solar system shall be discussed.

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SA-011

## On The Characteristics Of Transient Luminous Events (Sprite) Producing Thundercloud/storm Over Indian Region: A Case Study

Ajeet K Maurya<sup>1</sup>, Rajesh Singh<sup>1</sup>, B. Veenadhari<sup>2</sup>,

*Affiliation : <sup>1</sup>KSK Geomagnetic Research Laboratory, IIG, Chamanganj, Allahabad  
<sup>2</sup>Indian Institutes of Geomagnetism, New Panvel, Navi Mumbai*

E-mail : ajeet.iig@gmail.com

### Abstract

Transient Luminous Events (TLEs) are short lived flash of light observed above large thunderstorms in the lower regions of earth's atmosphere and affecting “space plasma” (ionosphere) by providing direct electrical connection between cloud top to ionosphere. Indian region is the part of tropical regions in the world, where two of every three lightning flashes occurs and make this region an important location for TLEs observations. In spite of being lightning active region, TLEs observations in India were lacking due to thought that, TLEs can't be observed over Indian thunder clouds as they do not form Mesoscale Convective Systems (MCSs) which are proposed to produce TLEs (sprite) events. Since the first observations of sprite event on 11 April 2012 over Indian region (Allahabad: Geographic lat.29.36° N, long.79.46° E) [1] and consequently several other event days since April, 2012, hence it has become important to re-examine our present understanding of thundercloud/storm system over these regions. In the present work, we have extensively analyzed various satellites (CloudSat, VIIRS, MTSAT, EUMATSAT etc), lightning detection network (WWLLN, GLD360) lightning data and ground based ELF-VLF data to understand cloud

characteristics. The thunderstorm characteristics studied are cloud type, height, temperature, pressure, lightning characteristics such as type, polarity, energy and effect of TLEs on the lower ionospheric plasma by taking a case study for the October 07, 2013 event day, when, we have recorded unusually more than 30 sprite events within 06 hours activity duration. The final analysis is underway and results will be presented during conference.

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SA-012

### Modeling of 22 July 2009 total solar eclipse effects on the D-region ionosphere using narrowband VLF signal recorded at Indian low latitude stations

K.Venkatesham<sup>1</sup>, Rajesh Singh<sup>1</sup>, Ajeet K Maurya<sup>1</sup>, B. Veenadhari<sup>2</sup>,

*Affiliation : <sup>1</sup>KSK Geomagnetic Research Laboratory, IIG, Chamanganj, Allahabad*

*<sup>2</sup>Indian Institutes of Geomagnetism, New Panvel, Navi Mumbai*

E-mail: kvenkateshphysics@gmail.com

#### Abstract

The Present work focus on the observations and modeling of D-region ionospheric changes during the period of total solar eclipse 22 July 2009. In the study observations of NWC (19.8 kHz) and JJI (22.1 kHz) Very Low Frequency (VLF, 3-30 kHz) narrowband transmitters signal propagating via multiple reflection in earth-ionosphere wave guide and recorded at Indian stations Allahabad (Geographic lat. 25.75 °N; long. 81.85 °E), Varanasi (Geographic lat. 25.25 °N; long. 82.99 °E) and Nainital (Geographic lat. 29.35 °N; long. 79.46 °E) are utilized. Allahabad, Varanasi were located in 100 % totality, where as Nainital was in 85% solar obscuration. For JJI signal amplitude where transmitter receiver great circle path (TRGCP) is parallel to the totality path, showed increase in VLF signal amplitude at totality stations (Allahabad and Varanasi) and decrease at partially eclipsed region (Nainital) when compared to the control day JJI VLF signal amplitude. The NWC VLF signal has TRGCP which is perpendicular or intersecting to totality path, we observed increase/decrease in amplitude for eclipse duration at all three stations. In order to understand eclipse effect on different TRGCP and to derive D-region ionospheric parameters such as electron density, we have applied Long Wave Propagation Capability (LWPC) modeling. The D-region ionosphere electron densities is characterized by two traditional parameters, ionospheric reflection height ( $H'$ ) in km and sharpness factor ( $\beta$ ) in  $\text{km}^{-1}$  are estimated by modeling of the observed VLF signal perturbation using LWPC code. The corresponding values of  $H'$  and  $\beta$  along with unperturbed day values will be used to estimate and model electron density profile for the altitude range of 60-100km. At present analysis are underway and final results will be presented and discussed during the conference

SA-017

## **The Impact Of 22 July 2009 Total Solar Eclipse On Sporadic E-layer Near The Equatorial Ionization Anomaly (EIA) Crest Region, Allahabad**

Prabhakar Tiwari<sup>1a</sup>, Ajeet K. Maurya<sup>1</sup>, Rajesh Singh<sup>1</sup>, S. Sripathi<sup>2</sup>, B. Veenadhari<sup>2</sup>

*Affiliation :<sup>1</sup>Dr. K. S. Krishnan Geomagnetic Research Laboratory, IIG, Jhansi, Allahabad - 221505*

*<sup>2</sup>Indian Institute of Geomagnetism, New Panvel, Navi Mumbai - 410218*

E-mail :<sup>a</sup>pibbal@gmail.com

### **Abstract**

The Total Solar Eclipse (TSE) of 22 July 2009 that occurred during morning time over northern India with totality region as well as with partial eclipse where Sun's obscuration was more than 80% has provided us a unique opportunity to investigate its impact on the low latitude ionospheric electrodynamics. While some investigations have been made in the past to understand impact of total solar eclipse on D layer using VLF observations, however, studies were being made on the sporadic E-layer. In this study, we try to understand the role of total solar eclipse on the sporadic E (Es) layer near equatorial ionization anomaly crest region, Allahabad (25.4°N, 81.9°E, Geomag. lat. 16.05°N) using Canadian Advanced Digital Ionosonde (CADI) and discover the relationship between solar radiation and characteristics of Es layer. Rapid radio soundings (every 1 min) from the ionosonde were made on the eclipse day. The ionograms of 22, 23 and 24 July 2009 were processed and analyzed to identify the characteristics of Es layer during control day and eclipse day. The top frequency of the reflecting/scattering of Es layer (ftEs) and the blanketing frequency of Es layer (fbEs) have been scaled manually from the ionograms. The analysis shows that the intense Es layer was present during and after the eclipse period in comparison to non-eclipse days. It is found that ftEs values increased during the solar eclipse period as compared to the control days. Another interesting feature which is observed during this event is wave-like fluctuations in ftEs showing the signatures of gravity waves generated by solar eclipse. Further analysis of these observations along with other co-located or nearby stations data to understand the characteristic differences between control and total solar eclipse day and will be presented in this paper.

**SA-026**

**Ionospheric TEC Variations Over Allahabad Due To Solar Flares Of Solar Cycle 24**

K Vijay Kumar<sup>1a</sup>, Prabhakar Tiwari<sup>1</sup>, Ajeet K. Maurya<sup>1</sup>, Rajesh Singh<sup>1</sup>, C.D. Reddy<sup>2</sup>

*Affiliation : <sup>1</sup>Dr. K. S. Krishnan Geomagnetic Research Laboratory, IIG, Jhansi, Allahabad - 221505*

*<sup>2</sup>Indian Institute of Geomagnetism, New Panvel, Navi Mumbai - 410218*

E-mail : <sup>a</sup>kvijay@iigs.iigm.res.in

**Abstract**

Solar flares are known to cause perturbations during daytime in the Earth's ionosphere creating density perturbations all the regions of ionosphere from D- to F-region. A solar flare is a huge blast associated with the high magnetic fields in sunspot producing regions of the sun's atmosphere. The radiations of solar flares interact with the constituents of the ionosphere, thus, producing sudden changes in electron density in the ionosphere. Current investigation utilizes data from global positioning system (GPS) receiver installed at Allahabad (25.4°N, 81.9°E, Geomag. lat. 16.05°N ) which is near toequatorial ionization anomaly (EIA) crestregion. In the present study we have delineated the effect of solar flares on the ionospheric Total Electron Content (TEC) using dual frequency global positioning system (GPS) observation at Allahabad for selected events of solar flares of C, M and X-class which occurred during the year 2010-13. It is also to be noted that solar flares under investigation also marked the beginning of solar activity of solar cycle 24 after a prolonged minima. The extent of enhancement in the ionospheric TEC values in response to the various classes (C, M, X) of flares with different intensity ranges, for few groups, during ascending phase of solar activity shall be presented in this paper.

**SA-032**

**Prediction Of Coronal Dynamics Driven By Collisionless Magnetic Reconnection Model**

Visakh kumar U.L ,Bilin Susan Varghese and P.J Kurian\*

*Physics Research Centre, St. Berchmans College, Changanacherry, Kerala 686101*

Email:pjkplasma@yahoo.ca

**Abstract**

The solar corona is a mysterious region due to its enormously large temperature of the order of several million Kelvin existing above the photosphere having a temperature of 6000K. Recent observations reveal that to account for the temperatures and densities observed in the corona, chaotic forces may be at work, regulating the scales of magnetic reconnection in the solar coronal plasma. In



the corona, reconnection takes place between the field lines, which are twisted and braided as a result of photospheric foot point motion.

In this paper we propose a model for the reconnection in which at the initial state, the lower corona is collisional with high resistivity. The collisional coronal plasma cannot release huge thermal energy. As the reconnection starts, reconnection inflow increases the strength of magnetic field in the diffusion region. As a result, the width of diffusion region as well as the resistivity decreases and the corona becomes collisionless resulting in a very fast reconnection rate which can erupt solar flares. Our analytical theory is supported by numerical work.

**SA-033**

## **Energization Of The Solar Transition Region Due To A Microflare Arising From Twisting And Braiding Of Magnetic Field Lines.**

Bilin Susan Varghese, Visakh kumar U.L, P.J Kurian\*

*Physics Research Centre, St. Berchmans College, Changanacherry, Kerala 686101*

E mail: pjklasma@yahoo.ca

### **Abstract**

The Solar Transition Region extends from the upper Chromosphere to the lower Corona. It is an interface between partially ionized and fully ionized plasma which acts as a good natural laboratory for plasma physics. The temperature increases abruptly in this region within a very short distance  $\approx 1000$  km. One of the main proposed mechanisms for the rise in temperature in the transition region is magnetic reconnection. Many authors suggest that the random walk of the field footpoints in the photosphere give rise to twisting and braiding of the field lines as we move up towards the above layers. In our paper, we propose that the twisting and braiding of magnetic field lines undergo reconnection that energizes the transition region in the form of a flare. We have calculated the amount of free energy liberated in the transition region in a reconnection time interval of 17.2s in a cylindrical area of  $1.57 \times 10^{19} \text{ m}^2$ , by varying the angle of magnetic flux tubes with respect to vertical. Our results depict that this phenomenon leads to the generation of huge amount of energy  $\approx 10^{29} \text{ erg}$ , in the form of a microflare. This tremendous energy is deposited in the transition region which helps it to maintain the steep temperature gradient. We have also performed 2D and 3D plots to support our study.

**SA-038**

## **Electron Acoustic Rogue Waves in Electron Beam Plasma**

Shalini and N. S. Saini

*Department of Physics, Guru Nanak Dev University, Amritsar -143005*

E-mail: shal.phy29@gmail.com

### **Abstract**

Rogue waves are now recognized as proper intrinsically nonlinear structures, fundamental research has gone farther the ocean surface problems, in nonlinear optics, in super fluidity, in hydrodynamics, in atmospheric dynamics and in econophysics. In the present investigation electron acoustic rogue waves in an unmagnetized collisionless four component plasma system consisting of inertial cold electrons and inertialess superthermal hot electrons, an electron beam and stationary ions. By using the multiple scale perturbation method, nonlinear Schrödinger equation (NLSE) is derived to study the nonlinear evolution of electron acoustic rogue waves (*EARWs*). The propagation characteristics of electron acoustic rogue waves are strongly influenced by the electron beam parameters and superthermality of electrons/ions. The results of the present investigation may be applicable in auroral zone plasma.

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**SA-039**

## **Ion Acoustic Cnoidal Waves In A Superthermal Plasma**

Papihra Sethi, N.S. Saini

*Department of Physics, Guru Nanak Dev University, Amritsar, 143005*

E-mail: papihra.sethi@gmail.com

### **Abstract**

The study of the nonlinear solitary structures has been an important area of research for the last five decades due to its importance for understanding wave dynamics in space and astrophysical environments. A number of observations confirm the presence of superthermal electrons/ions in most of the space and astrophysical environments, therefore, it is interesting to study the characteristics of nonlinear solitary structures in a plasma with electrons/ions featuring kappa distribution. The propagation properties of ion acoustic cnoidal waves are studied in a plasma containing ion fluid and two temperature electrons (hot and cold) featuring superthermal distribution. Employing reductive

perturbation technique, Korteweg-de-Vries (KdV) equation has been derived. From the cnoidal solution of KdV equation, the combined effects of superthermality, density ratio and temperature ratio are studied on characteristics of ion acoustic cnoidal waves. The superthermality of electrons as well as ions and concentration of electrons significantly influence the characteristics of ion acoustic cnoidal waves. The findings of this investigation may be useful in understanding the nonlinear periodic waves in space/astrophysical environments (Saturn's Magnetosphere) where multi-temperature electrons are present.

SA-045

## The Role of Diffusivity and Viscosity in Solar Plasma

B. K. Kumthekar

*Affiliation: Department of Physics, Nutan Mahavidyalaya, sailu, Dist: Parbhani-431 503 (MS)*

Email: bkumthekar@gmail.com

### Abstract

For diffusive and viscous plasma, the dispersion relation is applied for the North Polar Coronal Hole, where we assumed the angular frequency  $\omega$  to be a real quantity and the wave number  $k$  as a complex quantity. For  $\omega$  we have chosen three values for  $\tau$ . For each value of  $\tau$ , we considered three situations: (i) where  $\nu = 0$ , (ii) where  $\eta = 0$  and (iii) where both the diffusivity and viscosity are present. For the cases (i) and (ii), we get two solutions,  $+(kr + iki)$  and  $-(kr + iki)$ . But for the case (iii), we get two pairs of solutions,  $+(kr1 + iki1)$  &  $-(kr1 + iki1)$  and  $+(kr2 + iki2)$  &  $-(kr2 + iki2)$ . These two pairs correspond to the fast-mode and slow-mode waves.

SA-049

## Ion-acoustic rogue waves in multicomponent plasma In the presence of positrons

Shalini and N. S. Saini

*Department of Physics, Guru Nanak Dev University, Amritsar -143005*

E-mail: shal.phy29@gmail.com

### Abstract

An electron-positron plasma, a fully ionized gas composed of electrons and positrons having equal masses and charges with opposite polarity, is considered not only as a building block of our early universe, but also as an omnipresent ingredient of a number of astrophysical objects, such as active galactic nuclei, pulsar magnetospheres, solar flares, fireballs producing-ray bursts, etc. Most of the space and astrophysical plasma environments show the existence of superthermal electrons/ions, i.e., the particles are obeying kappa distribution [1]. We present an investigation for the generation of

planar and nonplanar (cylindrical and spherical) ion acoustic rogue waves in an electron-positron-ion plasma with two temperature superthermal electrons and superthermal positrons. The reductive perturbation technique is used to obtain a modified nonlinear Schrodinger equation, which includes a damping term that account for the geometrical effect for ion acoustic rogue waves. From the coefficients of nonlinearity and dispersion, we have determined the critical wave number threshold at which modulational instability sets in. This critical wave number depends on various plasma parameters viz. superthermality of electrons (cold and hot) and positron concentration. Within the modulational instability region, a random perturbation of amplitude grows and thus creates ion acoustic rogue waves. Further, it is seen that there is a modulation instability period for the cylindrical and spherical wave modulation, which does not exist in the one dimensional case [2]. The results of present investigation may be applicable in space and astrophysical plasma.

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SA-052

### Localization and turbulent spectrum Of 3-D Inertial Alfvén Wave In Low Beta Plasma

Prachi Sharma<sup>a)</sup>, R. P. Sharma<sup>b)</sup> and N. Yadav<sup>c)</sup>

*Centre for Energy Studies, Indian Institute of Technology Delhi-110016*

\*Email: a) ps5739@gmail.com

#### Abstract

The present poster deals with the nonlinear interaction of Inertial Alfvén wave (IAW) and fast magnetosonic wave in the low beta plasma, where beta is the ratio of thermal pressure to the background magnetic pressure. In this poster, the localization and turbulent spectra of IAW along with the density dips correlated with the fast magnetosonic wave have been investigated. A set of coupled dimensionless equations has been derived taking ponderomotive nonlinearity into account in the fast magnetosonic wave dynamics. These coupled equations have been solved numerically using the pseudo-spectral method of simulation. The obtained results reveal that the Kolmogorov scaling is followed by a steeper scaling in magnetic power spectrum, which is consistent with the observations presented by Chaston et al., 2006 and Kintner, 1976 respectively.

#### References:

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SA-053

## Localized Structures And Turbulent Spectrum Of Kinetic Alfvén Wave

Anju Kumari<sup>1</sup> and R. P. Sharma<sup>1</sup>

<sup>1</sup>Centre for Energy Studies, Indian Institute of Technology Delhi, Delhi-110016

Email: anju.agrawal0986@gmail.com

### Abstract

The localization of Kinetic Alfvén wave (KAW) caused by finite amplitude background density fluctuations has been studied in intermediate beta plasma. KAW breaks up into localized large amplitude structures when perturbed by MHD fluctuations of the medium which are in the form of magnetosonic waves. Numerical simulation has been performed to analyse the localized structures and resulting turbulent spectrum of KAW applicable to magnetopause. Simulation results reveal that power spectrum deviates from Kolmogorov scaling at the transverse size of KAW, equal to ion gyroradius. Steepening of power spectrum at shorter wavelengths may be accountable for heating and acceleration of the plasma particles. The obtained results are compared with observations collected from the THEMIS spacecraft in magnetopause [Chaston *et al.*, 2008].

### Reference:

1. Chaston, C., et al., Turbulent heating and cross-field transport near the magnetopause from THEMIS, *Geophys. Res. Lett.*, 35, L17S08, (2008)

SA-063

## Arbitrary Amplitude Solitary Structures in Pair-ion Plasma in the presence of Superthermal Positrons and Electrons

Nimardeep Kaur and N. S. Saini

Department of Physics, Guru Nanak Dev University, Amritsar, 143005

E-mail: nimarphy@gmail.com

### Abstract

A number of experimental studies have shown the existence of pair ion plasmas. The pair ion plasma is composed of positive and negative ions having an equal charge to mass ratio, and it does not have any electrons. The pair-ion plasma is expected to be used for the synthesis of the dimers directly from carbon allotropes, as well as for nanotechnology. A high momentum transfer during binary collisions, due to equal mass, is responsible for both species to relax on the same time scale to thermodynamic equilibrium, and hence they acquire the same temperature. Due to wide range of

applications of pair ion plasmas, it is interesting to study the wave dynamics. The large amplitude ion acoustic solitary structures are investigated in unmagnetized plasma comprising positive and negative ions fluid, superthermal electrons and positrons. Using Sagdeev pseudopotential approach, the energy balance equation is derived. From the expression for Sagdeev potential, the effect of the concentration of ions, superthermality of electrons and positrons on the soliton structures is studied. We have also observed the formation of supersolitons. The potential profile of supersolitons is distinguished from the traditional solitons by their electric field profiles, having additional extrema on the wings of the standard bipolar structure. Our results may be of relevance in pair-ion (fullerene) experiments. They may also be relevant in astrophysical environments, in particular in pulsar magnetospheres, where a co-existence of electrons, positrons and ions in plasma may occur.

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SA-066

## Characteristic Features Of Geomagnetic Storms Observed During Solar Cycle 23

Apeksha Tonk, U. P. Verma and A. K. Singh

*Department of physics, University of Lucknow, Lucknow 226007*

E-mail: apeksha.nam.25@gmail.com

### Abstract

A geomagnetic storm is a temporary disturbance of the Earth's magnetosphere caused by a solar wind shock wave and/or cloud of magnetic field which interacts with the Earth's magnetic field. The importance of studying geomagnetic storms is manifold. Apart from academic aspects of earth/atmospheric sciences, it has its impact on mankind as well. In the present paper we have studied various cases of geomagnetic storms observed during the years 1996-2007 i.e. for the solar cycle 23 which was more active in comparison to solar cycle 22 and solar cycle 24. Total 29 cases of super storm ( $Dst \leq -200$  nT) were observed during solar cycle 23. We have considered sunspot numbers, solar wind speed, Dst index and Kp index as various parameters for the detailed study of storms and have presented their various characteristics.

**SA-067**

## **Evolution of Nonlinear Ion-Acoustic Waves in Anisotropic Space Plasmas**

Murchana Khusroo and Madhurjya P Bora

*Physics Department, Gauhati University, Guwahati 781014*

khusroomurchana@gmail.com

### **Abstract**

In this work, we present a comprehensive study of evolution of nonlinear ion-acoustic waves in space plasmas with pressure anisotropy. While the ion component is described with the double adiabatic equations of state, the electron fluid is described by an anisotropic velocity distribution function (VDF). The scenario is relevant in anisotropic space plasmas such as in magnetospheres of planets and also some specific environments such as the plasma torus of Io, one of the Galilean satellites of Jupiter.

We compare our results with different experimental observations and try to map these results with various VDFs, which are believed to be appropriate in describing such plasmas.

**SA-070**

## **ELECTRON DENSITY PROFILING OF LOWER IONOSPHERE USING TWEAK ATMOSPHERICS**

U. P. Verma, Apeksha Tonk, R. Singh and A. K. Singh

*Department of Physics, University of Lucknow, Lucknow 226007, India*

E-mail: upverma001@gmail.com

### **Abstract**

The lightning discharge is an electrical breakdown current which may flow from cloud to ground (CG discharges) or within thunderclouds (intra-cloud discharge). Ground to cloud (GC) discharge are rare, usually occurring from mountain tops and tall buildings. The discharge currents generate transient radio pulses termed 'atmospherics' or 'sferics'. The energy in these pulses vary over a wide frequency range from a few Hz to several MHz, but the maximum radiated energy is confined in extremely low (ELF: 3Hz -3 kHz) and very low (VLF: 3kHz -30 kHz) frequency band. These pulsed signals propagate through the process of multiple reflections in the Earth-ionosphere waveguide formed by the lower ionosphere and the Earth. When escaping from the cavity and propagating in the ionosphere, possibly along ducts, the signal is slightly dispersed, producing a tweek which is basically a sferic that suffers small frequency dispersion when traveling through the ionosphere. Since these waves are reflected by lower boundary of ionosphere (D-region), these are used for probing the D-region ionosphere. This part of ionosphere is important to space weather, as well as the submarine

communication. The measurement of the electron density profiles of the D- region is of great importance. In the present study two weeks recorded during the month of January, 2011 at low latitude ground station Lucknow (Geom. lat.  $17.6^{\circ}\text{N}$ ; long.  $154.5^{\circ}\text{E}$ ) have been analyzed to determine the plasma electron densities of the D- region. The electron density estimated using cutoff frequency of two weeks of each mode varies from  $23.8\text{--}123.7\text{ cm}^{-3}$ .

SA-089

## Equatorial plasma bubbles studied using slant totalelectron content observations over Varanasi, India

V. S. Rathore and A. K. Singh<sup>\*</sup>

*Atmospheric Research Lab., Department of Physics, Banaras Hindu University, Varanasi-221005*

E-mail: abhay\_s@rediffmail.com

### Abstract

Equatorial plasma bubbles (EPBs) are field-aligned depletions of F-region ionospheric plasma density that grow from irregularities caused by the generalized Rayleigh–Taylor instability mechanism in the postsunset equatorial region [1]. The worst source of EPBs is at the equatorial anomaly region ( $\pm 15^{\circ}$  geomagnetic latitude) [2]. Although they have been studied for some decades, they continue to be an important subject of both experimental and theoretical investigations because of their effects on trans-ionospheric radio communications.

In the present work, we have considered the propagation of electromagnetic waves through the irregular ionosphere in the L-band frequency range using dual frequency ( $f_1 = 1.575\text{ GHz}$  and  $f_2 = 1.227\text{ GHz}$ ) GPS receiver. To study the characteristic of plasma bubbles the GPS data recorded at our low latitude station, Varanasi have been analyzed to compute amplitude scintillation index (S4), total electron content (TEC), the rate of change of TEC (ROT) as well as ROTI defined as a standard deviation of ROT during the year 2013. The seasonal and monthly distribution during active solar and geomagnetic period.

### References:

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SA-092

## Synchrotron Emissions From Relativistic Electron Trapped In Jovian Magnetoplasma

SB Singh<sup>1</sup>, Shubha Singh<sup>2</sup>, RP Singh<sup>1</sup> and AK Singh<sup>1\*</sup>

1. Department of Physics, Banaras Hindu University Varanasi-221005.

2. Department of Physics, University of Petroleum and Energy Studies, Dehradun-248007.

Email: sbsingh\_maharaja@yahoo.co.in

### Abstract

The observations of radio emissions from Jupiter have been carried out intermittently over a large radio band from kilometer wave lengths to decameter wave lengths [1-2]. The low frequency part of the radio wave spectrum known as decametric band is attributed to electron cyclotron maser emissions emitted by KeV electrons in Jupiter's auroral regions and the high frequency part, known as decimetric radiation is attributed to thermal radiation from the planet as well as non-thermal synchrotron radiation from relativistic electrons trapped in Jupiter's radiation belt.

In this paper, using recent data, we have computed synchrotron radiated power from energetic electrons gyrating along Jovian magnetic field. The present computations differ from the earlier work in the sense that we have considered radiating electron energy considered from few KeV to hundred of MeV and frequency range considered include decametric to decimetric emissions. The flux density variations of radio emissions with frequency and electron energy have been studied.

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SA-095

## Inertial Alfvén Wave Turbulence And Formation Of Localized Structures In Auroral Regions

M. L. Rinawa<sup>1, 2, a)</sup>, R. P. Sharma<sup>1, b)</sup>

<sup>1</sup>Centre for Energy Studies, Indian Institute of Technology Delhi, Delhi 110016

<sup>2</sup>Mechanical Engineering Department, Government Engineering College Jhalawar, Rajasthan, 326023

E-mail –rinawa.iitd@gmail.com

### Abstract

In the present paper, we have investigated nonlinear interaction of inertial Alfvén wave and ion acoustic wave, for low  $\beta$  - plasma ( $\beta \ll m_e / m_i$ ) where  $\beta$  is the thermal to magnetic pressure ratio. We have developed the dynamical equation of inertial Alfvén wave by considering the finite

frequency as well as finite temperature correction. The dynamical equation of ion acoustic wave, propagating at an angle with respect to the background magnetic field, in the presence of ponderomotive nonlinearity due to inertial Alfvén wave is also derived. Numerical simulation has been carried out to study the effect of nonlinear coupling between these waves which results in the formation of localized structures and turbulent spectrum, applicable to auroral region. The result reveals that the localized structures become complex and intense in nature (quasi-steady state). Further, we have studied the turbulent spectrum which follows spectral index ( $\propto k^{-4.46}$ ) at smaller scales. Relevance of the obtained results has been shown with the observations reported by various spacecrafts like Hawkeye and HEOS-2.

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SA-100

### On the Generation and Propagation of Low Latitude (L=1.08) Whistlers

Sneha A. Goakani<sup>1,a</sup>, Rajesh Singh<sup>2,b</sup>, B. Veenadhari<sup>1,c</sup>

*Affiliation : <sup>1</sup>Indian Institute of Geomagnetism, New Panvel, Navi Mumbai*

*<sup>2</sup>Dr. K. S. Krishnan Geomagnetic Research Laboratory, Jhansi, Allahabad*

E-mail : <sup>a</sup>gokanisneha@gmail.com

#### Abstract

The generation and propagation of Low Latitude whistlers has no definite answers unlike mid latitudes. Solving the propagation path problem requires knowledge of both source as well as ionospheric exit region. In the present study, the source location of whistlers observed at Indian low latitude station, Allahabad (Geog. lat., 25.40° N; Geog. long. 81.93° E; Geomag. lat. 16.25° N, L=1.081) during the year 2011 is examined on the basis of arrival of causative sferics as well as arrival azimuths. To study the propagation characteristics of these whistlers, Power Spectral Density analysis is also carried out. The results are attributed to electron density changes in the top side ionosphere which leads to ducted propagation of low latitude whistlers.

**SA-107**

**Investigations On The Influence Of Extreme Solar Activity Conditions On The Ionospheric Plasma**

Ambily.S<sup>1</sup> and T.E.Girish<sup>2</sup>

*Department of Physics, University College, Trivandrum, Pin-695034*  
pranavrevathy@gmail.com

**Abstract**

We have studied the effects of abnormal increases in solar activity conditions on the earth's ionospheric plasma parameters in both lower and upper layers including the thermosphere. In extreme limits of sunspot activity there may be saturation effects on the ionospheric conditions when solar EUV irradiance increases beyond a threshold. Our model results will be compared with relevant solar-terrestrial data for selected sunspot cycles.

**References:**

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**SA-108**

**Heliospheric Current Sheet Crossings And Intense Geomagnetic Storms Observed During Cycle 23**

Haritha.V.G, T.E.Girish and G.Gopkumar

*Department of Physics, University College, Trivandrum, Pin-695034*

E mail: tegirish5@yahoo.co.in

**Abstract**

Gross associations of geomagnetic activity with IMF sector boundary ( heliospheric current sheet crossings) and sunspot activity are known earlier. In this paper we have studied event by event study of the solar origin of intense geomagnetic storms observed during sunspot cycle 23 ( 1997-2005). Source surface solar magnetic field maps, solar wind and IMF observations and sunspot data are used for the present study. The results of this study suggest that solar wind plasma originating over active solar longitudes with closed magnetic field geometry in the solar corona has high probability of causing intense geomagnetic storms which has predictive value in the medium range scale.

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[2] Eapen.P.E, Some studies on Geomagnetic observations made at the Maharajas Observatory in Trivandrum,PhD thesis,University of Kerala, p174 ( 2009).

**SA-112**

**Influence of Superthermal Electrons On Obliquely Propagating Ion-Acoustic Solitary Waves In Space Plasmas**

Devanandhan, S., Sreeraj, T., Singh, S.V. and Lakhina, G.S.

*Affiliation :Indian Institute of Geomagnetism, Navi Mumbai*

E-mail : devanandhan@gmail.com

**Abstract**

The nonlinear propagation of ion-acoustic solitary waves in magnetized plasma consisting of hot superthermal electrons, fluid heavy ions and protons have been investigated. The hot superthermal electrons are modeled by  $\kappa$ -distribution. The system of basic equations describing the properties of ion-acoustic solitary waves reduced to Korteweg-de-Vries-Zakharov-Kuznetsov by using reductive perturbation analysis. The effects of superthermality, obliquity, temperature etc. on the existence regime of Ion-acoustic solitons are examined in detail. The findings of this study and its application to the space and astrophysical plasmas will be discussed.

**SA-113**

**Ion Cyclotron and Ion Acoustic Waves In Magnetised Plasma With Kappa Distribution Of Electrons.**

Sreeraj, T.Devanandhan, S, Singh, S.V. and Lakhina, G.S.

*Affiliation: Indian Institute of Geomagnetism, New Panvel (West), Navi Mumbai*

Email: sreerajt90@gmail.com

**Abstract:**

A linear study of ion-cyclotron and ion-acoustic waves in three component magnetised plasma, consisting of hot electrons with Kappa distribution and cold protons and heavy ions following fluid description is presented. We have derived a linear dispersion relation for coupled ion cyclotron and ion acoustic waves of this system. The analysis for weakly magnetised and strongly magnetised case

is also carried out. The numerical results and outcome of this work will be discussed in the context of the observations in the solar wind plasmas.

SA-116

## **Solar Wind Interaction with Moon: Observation of Protons in Lunar Wake during magnetic aligned flow by SARA aboard Chandrayaan-1 Mission**

Name(s) of the author : M. B. Dhanya (1), Anil Bhardwaj (1), Y. Futaana (2), S. Fatemi (2,4), M. Holmstrom (2), S. Barabash (2), M. Wieser (2), P. Wurz (3), Abhinaw Alok (1) and R. Satheesh Thampi (1)

*Affiliation : (1) Space Physics Laboratory, Vikram Sarabhai Space Center, Trivandrum, 695022*

*(2) Swedish Institute of Space Physics, Box 812, 98128 Kiruna, Sweden*

*(3) Physikalisches Institut, University of Bern, CH-3012 Bern, Switzerland*

*(4) Department of Computer Science, Electrical and Space Engineering, Lulea University of Technology, Lulea, Sweden*

E-mail : mb\_dhanya@vssc.gov.in

### **Abstract**

Solar wind is a magnetized plasma flow from Sun at supersonic velocities of  $\sim 400$  km/s on average and a typical composition of  $\sim 96\%$  of  $H^+$ ,  $\sim 4\%$   $He^{++}$  and  $<1\%$  heavier ions. Solar wind carries with it (frozen in) the magnetic field of Sun known as interplanetary magnetic field (IMF). During its flow through the interplanetary medium, solar wind interacts with the various objects in the solar system. The resulting dynamical processes varies depending on the size of the object as well as whether the object posses atmosphere and magnetic field.

Moon is planetary body with a surface bound exosphere and without global magnetic field. For more than half of its orbital period around Earth, Moon is exposed to the solar wind in the upstream of Earth's magnetosphere. This enables the direct interaction of solar wind with the lunar surface. Only  $\sim 1/3^{\text{rd}}$  of its orbital period, Moon passes through Earth's magnetotail, a different plasma region. When the solar wind plasma flow past the Moon, it leaves a cavity in the downstream of the Moon known as lunar plasma wake, a region conventionally thought to be devoid of solar wind plasma, until recent plasma observations around Moon by various planetary missions. The limited observations and simulations have shown that the geometry of the wake depends on the orientation of IMF. The SARA (Sub-keV Atom Reflecting Analyser) experiment on Chandrayaan-1, the first Indian Lunar mission, had the scientific objective of studying the interaction of solar wind with the Moon. It had a plasma analyzer namely SWIM (Solar Wind Monitor) which was capable of energy analysis in the 10-3000 eV range and mass analysis. SWIM had a fan shaped field-of-view of  $7^\circ \times 160^\circ$  divided in to 16 angular pixels. SWIM made excellent observations of the plasma environment around Moon at 100-200 km altitude from lunar surface.

Here, we present the first observation of protons in the near and deeper (close to anti-subsolar point) lunar plasma wake when the IMF and solar wind velocity were parallel (magnetic aligned flow). These observations were not supported by the conventional fluid models of lunar wake for magnetic aligned flow. The back-tracing of the observed protons suggested that their source is the solar wind. These protons from the high-energy tail of the solar wind velocity distribution could enter the wake due to their larger gyro-radii even when the flow is parallel to IMF. These protons can significantly

alter the electrodynamics, affect the lunar nightside surface charging, and may even cause sputtering from nightside surface thereby contributing to lunar nightside exosphere. These have implications on similar atmosphereless bodies in the solar system .

## SA-117

### Electromagnetic Ion Cyclotron (EMIC) Waves In The Inner Magnetosphere

Satyavir Singh

*Indian Institute of Geomagnetism, New Panvel (West), Navi Mumbai-410218, Maharashtra*

E-mail : satyavir@iigs.iigm.res.in

#### Abstract

Electromagnetic ion cyclotron (EMIC) waves are low frequency (below the proton gyro-frequency) waves that play an important role in the Earth's magnetosphere. When they propagate parallel to the ambient magnetic field they constitute the low frequency part of the left-hand circularly polarized mode (L mode) but otherwise they are coupled to the right-hand circularly polarized mode (R mode). These waves can resonantly interact with ions and relativistic electrons and can alter their energies and pitch angles and thus, can contribute to precipitation loss of particles from the magnetosphere. The EMIC waves in the terrestrial magnetosphere can primarily be excited by the hot anisotropic protons. The recent observations from Cluster spacecraft in the plasmopause region have shown the rising tone emissions which are believed to be triggered by the EMIC waves. The plasma constituents in this region where these emissions have been observed are electron, cold and hot anisotropic protons ( $H^+$ ), helium ( $He^+$ ) and oxygen ( $O^+$ ) ions. We examine the generation of obliquely propagating EMIC waves in multi-component plasma excited by the hot proton anisotropy in the plasmopause region.

## SA-118

### Multifractal Analysis of the Complex Magnetosphere System

Sumesh Gopinath<sup>1</sup> and P.R. Prince<sup>2</sup>

<sup>1</sup>*Department of Physics, University College, Thiruvananthapuram 695034, Kerala*

<sup>2</sup>*Department of Physics, Govt. Arts College, Thiruvananthapuram 695014, Kerala*

E-mail: sumeshgopinath@gmail.com

#### Abstract

There are many self-organization processes in physics, such as structural first-order phase transitions and spontaneous symmetry breaking, second-order phase transitions at which the system exhibits scale-invariant structures (critical opalescence of fluids at a critical point), structure formation in thermodynamic systems away from equilibrium (Bénard cells), or self-organization of electromagnetic waves or solitons into vortices in a magnetized electron-positron plasma [1]. Space

plasmas often display very complex behavior which includes multiscale dynamics, spatio-temporal chaos, bifurcations, intermittence, self-organized criticality (SOC) etc. The study of self-organization of magnetospheric plasma and its relation with instabilities and turbulence is a subject at the forefront of astrophysics and space research and in particular, it may have relevance in the behavior of the magnetospheric dynamics.

Due to continuous forcing of external driver, the magnetotail plasma sheet is driven into a non-equilibrium self-organized global state which is characterized by criticalities with scale invariant events, self-similar spatial structures, and multi-fractal topology [2]. These are similar to out-of-equilibrium states which are seen to emerge naturally in numerous plasma physics models by sporadic dissipation, through spatio-temporal chaos. The forced self-organized criticality (FSOC) concept was mostly motivated by the physics of magnetospheric substorms, which seems to require a continuous loading process in order to drive it into a critical or near-critical state. Low-frequency stochastic fluctuations of the geomagnetic AE-index with a  $1/f$  spectrum have been interpreted in terms of a SOC system. We analyze in detail the multifractality of the auroral indices such as AE, AL and AU which may give an insight into the existence of self-organization in the magnetotail with underlying complex multifractal accumulation/dissipation dynamics in the plasma sheet.

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- [2] Chang, T., Self-organized criticality, multi-fractal spectra, sporadic localized reconnections and intermittent turbulence in the magnetotail, Phys. Plasmas 6, 4137–4145, 1999.

SA-146

## Amplitude Modulation of Electron-Acoustic Waves in Multicomponent Magnetized Plasma

Ripin Kohli and N. S. Saini

*Department of Physics, Guru Nanak Dev University, Amritsar-143005*

E-mail: ripin.kohli@gmail.com

### Abstract

During last few decades, there has been a great deal of interest in the study of electron-positron-ion plasma. The electron-positron plasmas occur naturally through a very high energy process of pair production in the early universe. Also the electron-acoustic waves have been extensively studied both experimentally and theoretically in different kind of plasma environments. Electron-acoustic waves are high frequency waves that exist in plasma having two temperature electrons (hot and cold). Not only this, observations of astrophysical plasmas indicate that the external magnetic field in space and astrophysical plasmas play an important role in linear and nonlinear plasma dynamics, as well as it affects the stability conditions of various plasma waves. In this study, we have considered four component plasma with cold electrons, non-Maxwellian distributed hot electrons, ions and positrons. By employing multiple scale technique, the nonlinear Schrodinger equation (NLSE) is derived which governs the modulation instability of electron-acoustic waves. Different types of envelope (bright/dark) solitons are observed. Both dispersion and nonlinearity coefficients of the NLSE are

explicit functions of relevant physical parameters that change the critical wave number at which modulational instability sets in. The characteristics of electron-acoustic waves are modified by the non-Maxwellian distribution of hot electrons, ions and positrons.

SA-158

## Magnetospheric Conductivities At Satellite Locations During Solar Cycle 23

Santhoshkumar G.<sup>1</sup> and Prince P. R.<sup>2</sup>

<sup>1</sup>*Department of Physics, University College, Thiruvananthapuram 695034, Kerala*

<sup>2</sup>*Department of Physics, Govt. Arts College, Thiruvananthapuram 695014, Kerala*

E-mail: <sup>1</sup>saswarrier@gmail.com

### Abstract

Earth's magnetosphere is a very complicated plasma system in which many predictable and unpredictable events occur. Different plasma regions existing in the magnetosphere are affected in one way or the other by these processes.

Convective energy dissipations in magnetosphere are well studied phenomena and are proved to be the controlling factors of its thermodynamic behavior [1]. Conductive dissipations in the domain, on the contrary, are not well addressed. The heat conductivity of plasma is determined by energy transfer in collisions between particles with different thermal energies in a region where a temperature gradient exists. The decisive part in this heat transfer is played by the collisions between electrons, since their collision frequency is high. Plasma particles, which execute motions, are susceptible to collisions that induce a resistivity to the sheet. Resistivity is generated in collisionless plasmas too, due to wave-particle interactions.

We, in this study have analysed the thermal and electrical conductivities [2] at different satellite locations in the magnetosphere. Solar cycle 23 has been selected for the study. The impact of conductivity variations on magnetospheric dynamics is investigated. Correlation between the occurrence of substorms and conductivity profiles is also examined.

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**SA-168**

## **Dynamics of Geomagnetic Storms and Substorms using State Space Model**

K.J. Suji<sup>1</sup>, Sumesh Gopinath<sup>2</sup> and P.R. Prince<sup>3</sup>

<sup>1,2</sup>*Department of Physics, University College, Thiruvananthapuram 695034, Kerala*

<sup>3</sup>*Department of Physics, Govt. Arts College, Thiruvananthapuram 695014, Kerala*

E-mail: kjsuji85@gmail.com

### **Abstract**

It is well known that one of the foremost problems in magnetospheric plasma physics is to develop integrated dynamical systems which are able to model geomagnetic storm and substorm activity with the aim of developing advanced space weather forecasting tools. State space models could be used as an external global framework within which to evaluate the implications of the micro-instabilities of collisionless tearing modes and kinetic ballooning modes in the geotail. Such a model could by far consider all magnetotail current physics to be projected onto chosen distributed current systems [1]. We employ a plasma physics based low order dynamical model of the solar wind - magnetosphere - ionosphere system [2] to study geomagnetic storm events during present solar cycle (solar cycle 24) based on the disturbance storm time index (Dst). We analyze whether the model captures global features of the geomagnetic storms/substorms and we also verify the efficiency of the model using metrics such as prediction efficiency, average relative variance, correlation coefficient, log-spectral distance and other related statistical measures.

### **References :**

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**SA-173**

## **Study Of Anomalous Behaviour of Cosmic Ray Intensity During Rising Phase Of Solar Cycle 24**

C. M. Tiwari<sup>1</sup>, Prithvi Raj Singh<sup>2</sup>, Lalji Tiwari<sup>3</sup>, A. K. Saxena<sup>4</sup>

Department of Physics, A.P.S. University, Rewa, M.P.-486004

E-mail: cmtiwari\_2005@yahoo.com

### **Abstract**

The solar parameter and cosmic ray intensity for the rising phase of solar cycle 24 have been analyzed. In this analysis we have used the data collected from Moscow (2.42 GV) neutron monitor

station and Oulu (2.32 GV) neutron monitor stations for the 1996 to 2013. The cosmic ray intensity increases in the solar cycle 24. The cosmic ray intensity and sunspot number shows negative correlation with each other. As for as normal behavior of cosmic ray intensity is concerned when the cosmic ray intensity is at maximum the sunspot number is at minimum and when the cosmic ray intensity shows minimum the sunspot number shows maximum. However, during solar cycle 24, there are quiet some periods during which both cosmic ray intensity and sunspot number increases or decreases simultaneously. From the study it is observed that during the period April, 2003 both the SSN and cosmic ray intensity decreased which shows anomalous behavior of cosmic ray intensity. It is observed that during the period February, 2004 both the SSN and cosmic ray intensity increased which shows anomalous behavior of cosmic ray intensity. It is observed that during the period August, 2005 both the SSN and cosmic ray intensity decreased which shows anomalous behavior of cosmic ray intensity. As we approach towards the solar cycle 24. From the study it is observed that during the period March, 2010, both the SSN and cosmic ray intensity decreased this shows anomalous behavior of cosmic ray intensity. Again it is observed that during the period November, 2011, both the cosmic ray intensity and SSN increased which is again an anomalous behavior of cosmic ray intensity. It is observed that during the period February, 2012, and April 2013 both the cosmic ray intensity and SSN decreased which is again an anomalous behavior of cosmic ray intensity.

**SA-174**

### **Long-Term Variability Of Solar, Interplanetary & Geomagnetic Parameters During Odd Andeven Solar Cycles**

Prithvi Raj Singh<sup>1</sup>, A.K.Saxena<sup>2</sup>, C.M.Tiwari<sup>3</sup>

Department of Physics A.P.S. University, Rewa, M.P.-486004

E-mail:prithvisingh77@gmail.com

#### **Abstract**

The length of solar cycle 23 has been prolonged up to about 13 years. Our studies have speculated that the solar cycle 23/24 minimum will indicate the onset of a grand minimum of solar activity, such as the Maunder Minimum. We check the trends of solar (sunspot number, solar magnetic fields, total solar irradiance, solar radio flux, and frequency of solar X-ray flare), interplanetary (interplanetary magnetic field, and galactic cosmic ray intensity), and geomagnetic (Apindex) parameters (SIG parameters) during solar cycles 21-24. The deep 23/24 solar cycle minimum might be the portent of a grand minimum in which the global mean temperature of the lower atmosphere is as low as in the period of Dalton or Maunder minimum. We have study the modulation of cosmic rays during the solar minimum, including declining phase, of solar cycle 23 and compare the results of this unusual period with the results obtained during the similar phases of previous solar cycles 21 and 22. We also study the relation between simultaneous variations in cosmic ray intensity and solar interplanetary parameters during minimum, including declining phase of solar cycle 23. We then compare these relations with those obtained for two previous solar cycles minima and declining phases. We have observed certain peculiar features in cosmic ray modulation during this deep minimum of solar cycle 23. The focus of our study was to investigate whether this range was associated with a secular pattern in the length of the sunspot cycle the analysis of the long-term behaviour of the Sun, we have analysis archival data of sunspot numbers from 1986 – 2013 and sunspot areas from 1986 – 2013. Long-term

cycles were identified in archival data from 1986 – 2013. The recent paucity of sunspots and the delay in the expected start of Solar Cycle 24 have drawn attention to the challenges involved in predicting solar activity. Our study suggests that the length of the sunspot number cycle should increase gradually, on average, over the next ~27 years, accompanied by a gradual decrease in the number of sunspots. This information should be considered in solar cycle prediction models to provide better estimates of the starting time of each cycle.

## SA-176

### **Comparative Study of Solar Parameters During Odd And Even Solar Cycles**

Lalji Tiwari<sup>1</sup>, C. M. Tiwari<sup>2</sup>, Prithvi Raj Singh<sup>3</sup>, A. K. Saxena<sup>4</sup>

Dept. of Physics, A.P.S. University, Rewa, M.P. - 486004

Email: cmtiwari\_2005@yahoo.com

#### **Abstract**

The solar parameters for the period 1976 to 2013 have been analyzed. The various solar activities, such as sunspot number, grouped solar flare and solar flux during odd and even solar cycles (20, 21, 22, 23 and 24) have been studied. The most of the solar parameters have been found to be different with odd and even solar cycles. The maximum value of sunspot number for solar cycle 22 is greater than the maximum value of sunspot number for solar cycles 21, 23 and 24 upto April 2013. The maximum value of grouped solar flare for solar cycle 21 is greater than the maximum value of solar flare for the solar cycle 22 and 23. In this analysis high correlations are observed between solar flux, grouped solar flare and sunspot numbers. The correlation coefficient decreases slightly from solar cycle 21 to solar cycle 24 upto April 2013. The period of solar cycle 21, 22 and 23 are 10.3 years, 9.7 years and 12.6 years respectively. The period of solar cycle 22 is less than the solar cycle 21 and 23 and the solar cycle 24 is the active solar cycle, and it will complete in 2016. Solar cycle 24 has initially displayed much less active than the previous solar cycles.

## SA-177

### **Solar Wind Turbulence and the Role of Circularly Polarized Dispersive Alfvén Wave**

Swati Sharma<sup>1</sup>, R. P. Sharma<sup>1</sup>, and Nidhi Gaur<sup>1</sup>

*Centre for Energy Studies, Indian Institute of Technology Delhi-110016*

E-mail : swati.sharma704@gmail.com

#### **Abstract**

The physical properties of solar wind turbulence and its evolution have been an intense topic of exploration for decades. The inertial range of Solar wind turbulence can be described by a magnetohydrodynamic model. The dispersive range of the solar wind turbulence likely consists of

several kinds of waves. The obliquely propagating waves, e.g., the kinetic Alfvén wave and whistler wave, are considered to be an important factor in the solar wind turbulence. On the other hand, parallel propagating right(R) and left(L) circularly polarized Alfvén/ ion cyclotron wave in the framework of Hall MHD are also thought to be essential ingredients of the solar wind turbulence. Recently, He et.al[1] have used the magnetic field data from the STEREO spacecraft to calculate the magnetic helicities in the solar wind turbulence. Their analysis indicates the possible existence of Alfvén-cyclotron waves and their coexistence with the right handed polarized fluctuations (kinetic Alfvén waves or whistler waves). In the present article we intend to study the right and left circularly polarized dispersive Alfvén wave (DAW) and their role in the solar wind turbulence. The inclusion of the Hall term causes the dispersion of the AW which, in the present study, is considered on account of the finite frequency (frequency comparable to ion gyro frequency) of the pump wave. The individual left and right polarized DAW dynamics in the presence of the density fluctuations (ion acoustic/magnetosonic) is obtained and simulated numerically. We have also studied the transient evolution of DAW when transverse density perturbations are present in the background. Numerical simulation involves finite difference method for the time domain and pseudo spectral method for the spatial domain. The power spectrum is investigated which shows a steepening for scales larger than the proton inertial length. This is consistent with the recent work by Meyrand et.al[2]. The observations in the solar wind also indicate that L and R modes coexist until the pump wave frequency remains less than or comparable to the ion cyclotron frequency[1]. Therefore, We have also investigated the effect of nonlinear coupling on the localized structures and power spectrum of DAW in solar wind at 1 AU.

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SA-180

## Wavelet Analysis of Grand Episodes in Sunspot Numbers

Jayalekshmi G.L.<sup>1</sup>. and Prince P.R.<sup>2</sup>.

<sup>1</sup>*Department of Physics, University College, Thiruvananthapuram-695034, Kerala*

<sup>2</sup>*Department of Physics, Govt. Arts college, Thiruvananthapuram-695014, Kerala*

Email : <sup>1</sup>jayalekshmi1@yahoo.co.in

### Abstract

Solar activity, as measured by the sunspot number, is characterized by several periodicities. Fluctuating magnetic fields generated by the solar dynamo are responsible for cyclic formation of sunspots in the photosphere. Dynamo process is produced by the action of plasma motions inside the Sun. Sun's long-term behaviour also shows transient dynamics, characterized by striking increase and decrease of solar activity. Grand episodes (Grand maximum and Grand minimum) in sunspot numbers are the periods of extreme solar activity. Local extrema of sunspot cycles are an important characteristic of solar activity cyclic processes. A physical interpretation for the periodicities in solar variability is essential.

The present study analyzes periodicities in sunspot numbers (1090-2013) during grand episodes using wavelet analysis. The well known grand episodes in sunspot numbers include Medieval maximum (1100-1250), Wolf minimum (1280-1340), Spörer minimum (1420-1530), Maunder minimum (1645-1715) and modern maximum (1924-2008) [1]. Wavelet transform is appropriate for analyzing non-stationary time series and is also an efficient tool in time-frequency analysis.

Investigations using wavelet analysis of sunspot numbers reveal a characteristic periodicity of 9.8 years for grand maxima and 10.6 years for grand minima.

#### References:

[1] Eddy J A, Sol. Phys., **89**, p 195-207, (1983)

SA-203

### Analysis of Storms and Substorms of Solar Cycle 23

Seema C.S.<sup>1</sup> and Prince P.R.<sup>2</sup>

<sup>1</sup>*Dept of Physics, University College, Thiruvananthapuram, 695034, Kerala*

<sup>2</sup>*Dept of Physics, Govt. Arts College, Thiruvananthapuram, 695014, Kerala*

E-mail : <sup>1</sup>seemaniran@gmail.com

#### Abstract

Study of geomagnetic storms and substorms forms a major part in understanding space weather. To identify storms, 'Dst' index derived through global processing and averaging of all H-components of various observatories is used. Dst represents the ring current intensity and storms are characterized by rapid growth followed by decay of Dst values.

In the present study, major geomagnetic storms and substorms of solar cycle 23 are identified and statistically analyzed. Storms are classified as severe ( $Dst \leq -200\text{nT}$ ), intense ( $-200\text{nT} < Dst \leq -100\text{nT}$ ) and moderate ( $-100\text{nT} < Dst \leq -50\text{nT}$ ). Occurrence of storms and substorms in each year is studied. Storm time substorms during different storm phases are addressed in detail. It is found that maximum number of storms and substorms occurred 3 years after the solar maximum of 23<sup>rd</sup> cycle. The study also reveals that 98% of substorms were associated with no storms. It is observed that more number of sub storms occurred in the declining phase of the solar cycle. The decay time of storms is also analyzed in the study.

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**SA-248**

**A Case Study On The Occurrence /Non Occurrence Of Equatorial Spread F Over Dip Equator.**

Mridula.N and Tarun Kumar Pant,

*Space Physics Laboratory, Vikram Sarabhai Space Centre, Thiruvananthapuram, 695022*

E-mail: n\_mridula@vssc.gov.in

**Abstract**

**Introduction**

On several days the ionospheric F region plasma thrives with irregularities referred to as ESF (Equatorial SpreadF) during post sunset hours [1]. Even though the background ionospheric plasma conditions remains the same, ESF occurs on one day and is absent on another. In this context, during October- November 2011 it was seen that on all days except November 1, ESF occurred. In the present study the non-occurrence of ESF irregularities on November 1 2011, is examined and the probable factors are discussed in context of the physical processes controlling the generation of ESF. Experimental techniques used.

The data used in this study is obtained using the digital ionosonde operational at Thiruvananthapuram (8.5°N, 76.5°E, 0.5° dip). The data used are for the period October to December, 2011.

**Results:**

The results reveal the following

- a) The altitudinal electron density profiles on November 1, 2011 show a distinctive difference when compared with the same of rest of the days during the reported period.
- b) This modified electron density gradient existing in the ionosphere on this day is able to reduce the ESF irregularity growth rates, thereby leading to the inhibition of the ESF.

**References:**

[1] Abdu, M. A.: Outstanding problems in the equatorial ionosphere thermosphere electrodynamics relevant to spread F, J. Atmos.Sol. Terr. Phys., 63, 869–884, 2001.

## Statistical Relations of Geomagnetic Storms with CMEs and SWP Parameters During Solar Cycle 23

*P.L.Verma<sup>1</sup>A.K.Tripathi<sup>2</sup> and O.P.Tripathi<sup>3</sup>*

plverma2010@gmail.com

<sup>1</sup>*Department of Physics, Govt. Vivekananda P. G. College Maihar (M.P.)*

<sup>2</sup>*Exam Controller, APS University Rewa M.P.*

<sup>3</sup>*Research Scholar, Department of Physics Govt P. G. College Satna (M.P.)*

### **Abstract**

We have studied geomagnetic storms ( $DST \leq -80nT$ ) observed during the period of 1997-2008 with halo and partial halo coronal mass ejections and disturbances in solar wind plasma parameters. We have found that 72.00 % geomagnetic storms are associated with halo and partial halo coronal mass ejections. The association rate of geomagnetic storms with halo and partial halo coronal mass ejections are found 68.06% and 31.94 % respectively. We have also determined positive co-relation between magnitude of geomagnetic storms and speed of associated coronal mass ejection with correlation co-efficient 0.20. In our study we have found positive correlation between the geomagnetic storms and magnitude of jump of SWP parameters with correlation coefficient **0.30** between magnitude of geomagnetic storms and magnitude of associated storms in solar wind plasma temperature, **0.41** between magnitude of geomagnetic storms and magnitude of associated storms in solar wind plasma velocity, **0.39** between magnitude of geomagnetic storms and magnitude of associated storms in solar wind plasma pressure, **0.60** between magnitude of geomagnetic storms and magnitude of associated storms with interplanetary magnetic field (B). It is found that the magnitude of geomagnetic storms is better correlated with the magnitude of associated storm in interplanetary magnetic field than the magnitude of associated storms in T, n, V and P (solar wind number temperature, density, velocity and flow pressure respectively) solar wind plasma parameters ..

**Key Words** - Geomagnetic Storms, Coronal Mass Ejections (CMEs), Disturbances in Solar Wind Plasma (SWP) Parameters.

SA-256

## **A Comprehensive Study Of The Generation And Evolution Of Ionospheric F3 Layer Over The Dip Equator**

Mridula.N and Tarun Kumar Pant.

*Space Physics Laboratory, Vikram Sarabhai Space Centre, Thiruvananthapuram, 695022*

E-mail: n\_mridula@vssc.gov.in

### **Abstract**

#### **Introduction**

F3 layers are the additional layers formed over F2 layers of the ionospheric plasma. The exact causative mechanism of F3 layer formation is still not very clear even though many propositions have been made. Nonetheless, study of F3 layer is important as it would lead to a better understanding of the unique electrodynamical/neutral dynamical processes prevailing in the ionospheric plasma which are thought to be responsible for the formation of the layer. Present investigation involves a comprehensive study of F3 layer over the dip equatorial location of Thiruvananthapuram for two solar cycles (22 years).

#### **Data used**

The occurrence of additional layers in the ionosphere is identified from ionograms obtained from an Ionosonde operational at Thiruvananthapuram for the period 1988 to 2010.

#### **Results**

The results reveal

- a) The prenoon F3 layers have highest occurrence probability during solar minimum while the post noon F3 layers have a maximum occurrence probability during solar maximum.
- b) The occurrence probability is highest during June solstice during maxima, but its occurrence is equally probable during other months during minima.
- c) Interplay between the meridional wind circulation and the electrodynamics is thought to modulate the occurrence pattern of F3 layer during pre-noon and post noon hours.

#### **References:**

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SA-257

## **F3 Ionospheric Plasma Layer and Equatorial Spread F on October 7 2011-A Case Study**

Mridula.N and Tarun Kumar Pant.

*Space Physics Laboratory, Vikram Sarabhai Space Centre, Thiruvananthapuram, 695022*

E-mail: n\_mridula@vssc.gov.in

### **Abstract**

#### **Introduction.**

The ionospheric plasma is characteristically layered into D, E, F1 and F2 layers. On some days additional layers referred to as F3 layers appear in the topside ionosphere above F2 layer. Interestingly on October 7, 2011, the F3 layer was observed during post noon hours in the topside ionosphere and, in the post sunset hours the plasma irregularities referred to as Equatorial Spread F (ESF) got generated collocated with the F3 layer. The present study investigates the physical processes explaining this unique observation.

#### **Experimental techniques**

The occurrence of F3 and ESF irregularities in the ionosphere are inferred from ionograms obtained from an ionosonde operating at Thiruvananthapuram.

#### **Results:**

The present study reports for the first time the near simultaneous development of ESF irregularities at the base of F3 layer as well as in the base of F region. The sharp electron density gradient existing in the base of F3 region provides a conducive environment for the generation of irregularities. Hence ESF irregularities are found to be generated in the bottom of F3 layer in the same way as is occurring in the base of F region.

#### **References:**

[1] Abdu, M. A.: Outstanding problems in the equatorial ionosphere thermosphere electrodynamics relevant to spread F, J. Atmos.Sol. Terr. Phys., 63, 869–884, 2001.

SA-258

## Study On The Ionospheric Plasma Variabilities Over Indian Region Using Tomographic Observations with RaBIT Onboard YOUTHSAT.

Tarun Kumar Pant and Mridula.N.

*Space Physics Laboratory, Vikram Sarabhai Space Centre, Thiruvananthapuram, 695022*

E-mail: n\_mridula@vssc.gov.in

### Abstract

#### **Introduction.**

The ionosphere is a natural plasma laboratory where one can study different plasma processes. In this context, the first Indian radio beacon, the *RaBIT* (*Radio Beacon for Ionospheric Tomography*) was launched onboard India's small satellite YOUTHSAT on April 20, 2011 for studying the large scale plasma processes over the Indian longitudes. This enabled the study of the plasma density changes using ionospheric tomography during the rising phase of solar cycle 24, i.e. May to December 2011 in the Indian region using tomography. The results are presented here.

Experimental technique.

Ionospheric Tomography is a powerful technique which is capable of giving the latitude altitude distribution of plasma density over a wide region of ionosphere [1]. It makes use of Relative Total Electron Content (RTEC) measured by a latitudinal chain of ground based beacon receivers.

Results:

The main outcome of this study is as follows:

- a) A systematic enhancement in topside ionization density (above F peak) with increase in solar activity is inferred through the tomograms.
- b) This enhancement is primarily limited to the dip equatorial region.
- c) This behavior is thought to be due to the change in the vertical plasma scale height and prevailing thermospheric dynamics, especially meridional winds.

#### **References:**

[1]T K Pant, P Sreelatha, N Mridula et al. ,Radio Beacon for Ionospheric Tomography (RaBIT) onboard YOUTHSAT: Preliminary results,Ind. J. Radio Space Phys., 41 (2), 162-168, 2012.

SA-265

## ELECTROMAGNETIC ION-CYCLOTRON WAVES IN SATURN'S MAGNETOSPHERIC PLASMA

Jivan Sharma and G. Ahirwar

*School of Studies in Physics,*

*Vikram University, Ujjain (M.P.)-456010*

E-Mail: [ganpat.physics@gmail.com](mailto:ganpat.physics@gmail.com)

### Abstract

Electromagnetic ion-cyclotron (EMIC) waves have been studied by single particle approaches. The cold plasmadispersion relation, growth rate of the electromagnetic ion-cyclotron waves in a low  $\beta$  (ratio of plasma pressure to magnetic pressure), homogeneous plasma have been obtained. The wave is assumed to propagate parallel to the static magnetic field. The effect of general loss-cone distribution function for different Saturn's Radii on EMIC waves is to enhance the growth rate. The results are interpreted for the Saturn magnetosphere has been applied by Cassini parameters appropriate to the magneto-plasma.

**Key words:** Electromagnetic ion-cyclotron waves, Saturn's magnetosphere, Solar plasma, General loss-cone distribution function.

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## Role Of Circularly Polarized Dispersive Alfvén Wave In Solar Wind Turbulence

Swati Sharma<sup>1</sup>, R. P. Sharma<sup>1</sup>, and NidhiGaur<sup>1</sup>

*Centre for Energy Studies, Indian Institute of Technology Delhi-110016*

E-mail : [swati.sharma704@gmail.com](mailto:swati.sharma704@gmail.com)

### Abstract

The physical properties of solar wind turbulence and its evolution have been an intense topic of exploration for decades. The inertial range of Solar wind turbulence can be described by a magnetohydrodynamic model. The dispersive range of the solar wind turbulence likely consists of several kinds of waves. The obliquely propagating waves, e.g., the kinetic Alfvén wave and whistler wave, are considered to be an important factor in the solar wind turbulence. On the other hand, parallel propagating right(R) and left(L) circularly polarized Alfvén/ ion cyclotron wave in the framework of Hall MHD are also thought to be essential ingredients of the solar wind turbulence. Recently, He et.al[1] have used the magnetic field data from the STEREO spacecraft to calculate the magnetic helicities in the solar wind turbulence. Their analysis indicates the possible existence of

Alfvén-cyclotron waves and their coexistence with the right handed polarized fluctuations (kinetic Alfvén waves or whistler waves). In the present article we intend to study the right and left circularly polarized dispersive Alfvén wave (DAW) and their role in the solar wind turbulence. The inclusion of the Hall term causes the dispersion of the AW which, in the present study, is considered on account of the finite frequency (frequency comparable to ion gyro frequency) of the pump wave. The individual left and right polarized DAW dynamics in the presence of the density fluctuations (ion acoustic/magnetosonic) is obtained and simulated numerically. We have also studied the transient evolution of DAW when transverse density perturbations are present in the background. Numerical simulation involves finite difference method for the time domain and pseudo spectral method for the spatial domain. The power spectrum is investigated which shows a steepening for scales larger than the proton inertial length. This is consistent with the recent work by Meyrand et.al[2]. The observations in the solar wind also indicate that L and R modes coexist until the pump wave frequency remains less than or comparable to the ion cyclotron frequency[1]. Therefore, We have also investigated the effect of nonlinear coupling on the localized structures and power spectrum of DAW in solar wind at 1 AU.

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SA-275

## Density Cavity Formation through Nonlinear Interaction of 3D Inertial Alfvén Wave and Ion Acoustic Wave

Nitin Yadav, R. P. Sharma and Neha Pathak

*Centre for Energy Studies, Indian Institute of Technology Delhi, Delhi-110016*

Email: esz118172@iitd.ac.in

### Abstract

Using numerical techniques density cavity formation in auroral regions has been investigated. These cavities are having transverse scale size of the order of electron inertial length. In the present study, nonlinear interaction of Inertial Alfvén waves and ion acoustic waves has been suggested as a possible mechanism to apprehend density cavity formation in auroral regions. In the proposed mechanism, modification in the density distribution due to ponderomotive force of Inertial Alfvén waves, accounts for density depleted regions. In literature also, it has been demonstrated that these cavities are associated with the ponderomotive forces of inertial Alfvén wave [Bellan and Stasiewicz, 1998]. Our presented model attempts to understand various features of auroral density cavities which are reported in literature from the analysis of data available from FAST satellite [Chaston et. al., 2007].

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**SA-281**

**Kinetic Alfven Waves In A Two Temperature Electrons Plasmas**

N. S. Saini

*Department of Physics, Guru Nanak Dev University, Amritsar-143005*

E-mail: nssaini@yahoo.com

**Abstract**

The space plasmas witness the release of energetic particles from solar wind. The physical mechanism responsible for acceleration of energetic particles from solar wind is still unresolved. Alfven waves (AWs), a low-frequency electromagnetic wave propagating in magnetized plasma, arise from the balance between the magnetic field tension and the ion inertia which seem to play an important role in accelerating the charged particles in the space plasma environments. Therefore, it is believed that AWs are a good agent for energy and momentum transfer in many geophysical and astrophysical phenomena [1]. Alfven waves are very important throughout the solar system. Kinetic Alfven waves (KAWs) can be created when Alfven waves develop a large perpendicular wave number transverse to the ambient magnetic field [2] and may accelerate electrons and ions. The dispersion of the wave perpendicular to the external magnetic field is provided by the averaged ion Larmor radius caused by the pressures of the electrons of two different temperatures acting on the ion via the self-consistent electrostatic field. The balance of the wave dispersive and nonlinear effects can give rise to localized solitary waves. The characteristics of nonlinear KAWs are studied in a plasma consisting of positively charged ions as fluid and two temperature electrons obeying Boltzmann distribution. The Sagdeev pseudopotential approach [3] is employed to drive the energy balance equation. The combined effects of physical parameters, such as concentration and temperature of cool electrons, play a significant role to modify the solitary structures. Findings of this investigation may be useful in understanding the formation as well as properties of large amplitude localized electromagnetic excitations in laboratory, space and astrophysical plasmas.

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**SA-299**

**Field Aligned Current (FAC) studies during the solar declining phase**

N. Jeni Victor<sup>\*1</sup>, Akhila.J.C.K<sup>1,2</sup>, C. Panneerselvam<sup>1</sup> and C. P. Anil Kumar<sup>1</sup>

<sup>1</sup>Equatorial Geophysical Research Laboratory, Indian Institute of Geomagnetism, Krishnapuram,  
Tirunelveli – 627 011, Tamil Nadu

<sup>2</sup>School of Pure & Applied Physics, Mahatma Gandhi University, Kottayam-686 560  
Kerala

**Abstract**

Field Aligned Current (FAC) studies have been carried out with the aid of CHAMP satellite data during the solar declining phase from 2004 to 2006 of the 23 solar cycle. The study indicates that, the FAC is controlled by quasi-viscous processes occurring at the flank of the earth's magnetosphere. The dawn-dusk conventional pattern enhanced during disturbed days. The intensity of R1 system of currents is higher than the R2 system of currents. Detailed results will be discussed in the conference.

**SA-304**

**Nonextensive Ion Acoustic Solitary Waves And Double Layers In  $\text{Ar}^+$ - $\text{F}^-$  Plasma System**

Honey Arora, Ramandeep Kaur and Parveen Bala

*Punjab Agricultural University, Ludhiana, Punjab-141004*

E-mail : moon.nd.stars@gmail.com

**Abstract**

A solitary wave is a quantum of energy or quasiparticle that can be propagated as a travelling wave in nonlinear systems and is neither preceded nor followed by another such disturbance; does not obey the superposition principle and does not dissipate. A soliton is a nonlinear solitary wave with the additional property that the wave maintains a permanent structure even after interacting with another soliton, i.e. a soliton is a self reinforcing solitary wave that maintains its shape while travelling at constant speed. A soliton is a wave packet in which wavefield is localized in a limited spatial region and absent outside the region. They are travelling waves of permanent form. They exist in the sky as density waves in spiral galaxies, in giant Red Spot of the Jupiter, in plasmas, etc.

Double layer is structure in plasma that consists of two parallel with opposite electric charges. The sheets of charge cause a strong electric field and a correspondingly sharp change in voltage across the double layers. In systems with long interactions are those whose potentials are not integrable at infinity such as in plasmas, non-equilibrium stationary states exist. Systems characterised by the property of non extensivity are systems for which the entropy of the whole is different from the sum of the entropies of the respective parts. Here in this poster the study of the effect of nonextensivity on solitary waves and double layers is undertaken.

## **Ion Acoustic Solitary Waves In A Warm Multi-Ion Plasma With Two Electron Temperatures**

Steffy Sara Varghese and S. S. Ghosh

*Affiliation: Indian Institute of Geomagnetism (IIG), New Panvel, NaviMumbai. 410218*

E-mail: steffystephan28@gmail.com

### **Abstract**

In the earth's magnetosphere, there are many regions which are separated by narrow boundaries. Large gradient in particle properties and field occurs at those boundaries. The instabilities triggered by such gradients often lead to nonlinear wave phenomena, like solitary waves and double layers. Observations of electrostatic solitary waves (ESWs) are reported from the high altitude cusp injections [1], the magnetopause [2], in the magnetosheath [3] and other regions of magnetospheric boundary layers. Characteristics of ESWs are observed by the satellite borne electric field instruments which are recorded as localized bipolar pulses in the electric field (E data). It is observed that the ESWs were often associated with up-flowing ion beams [4] and move with ion acoustic speed [5]. This indicates that such ESWs are possibly governed by ion dynamics and may be interpreted as ion acoustic solitary waves. This motivated us to study ion acoustic solitary waves in detail. It is well known that the magnetosphere is impinged by two temperature electrons and warm multi-ion. . In this context the ion acoustic solitons are investigated in a warm multi-ion plasma with two electron temperatures adopting Sagdeev pseudopotential technique. An exact analytic form of Sagdeev pseudopotential has been derived to study the effect of the presence of warm multi-ions on compressive solitary wave solutions. We have carried out a detailed parametric investigations for a multi-ion plasma and compared its effect with single warm ion case. We intend to apply our theoretical models to the magnetospheric boundary layers.

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SA-319

## Effect Of Post Sunset Vertical Drift And Thermospheric Meridional Winds On The Occurrence Of ESF

Sreeba Sreekumar, S.Sripathi and K. Emperumal

*Indian Institute of Geomagnetism, Navi Mumbai, 410218*

E-mail: sreeba90@gmail.com

### Abstract

The importance of neutral winds and electric fields in controlling the plasma density re-distribution in the E and F region of ionosphere and its role in spread F generation has been recognized and some studies have been made sporadically using some case studies. However, what causes the day-to-day variabilities in spread F occurrence is not yet understood. In this paper, attempts are being made to study the day-to-day variability in Equatorial Spread F (ESF) which are influenced by factors like (a) post sunset height rise and (b) thermospheric meridional winds which plays important role in causing an asymmetry in the equatorial anomaly crests, thereby increasing the low latitude E region conductivity and causing subsequent development or inhibition of post sunset F region height rise. Thus at lower heights increased ion neutral collision frequency leads to the subsequent decrease in the linear growth rate of RT instability mechanism which causes variability in ESF irregularity occurrence. The method adopted in obtaining meridional winds in this study involves the basic principle as adopted by Krishnamurthy et al.[1] that the vertical drift at magnetic equator is purely due to  $E \times B$  drift, whereas for a station slightly away from magnetic equator, meridional wind also affected by the vertical drift in addition to diffusion along the field lines. Thus we use h'F data from two Canadian Digital Ionosonde (CADI) stations located at Equator and low latitude namely Tirunelveli and Hyderabad respectively for the year 2013 for deriving meridional winds and vertical drifts mainly during the equinoctial months March-April. Thus present study aims at studying the influence of evening/post sunset time thermospheric meridional winds and vertical drifts simultaneously and their relation to the ESF development or their occurrence.

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SA-387

## Effect of Rotation and FLR Correction on Rayleigh Taylor Instability of Quantum and Stratified plasma

<sup>1</sup>P.K.Sharma, <sup>1</sup>Anita Tiwari, <sup>1</sup>Shraddha Argal and <sup>2</sup>R.K. Chhajlani  
<sup>1</sup>BUIT, Barkatullah University Bhopal (M.P.)462026  
<sup>2</sup>School of Studies in Physics, Vikram University Ujjain (M.P.)  
Email: - pks\_buit30@yahoo.com

### Abstract

In the present study we examined the effect of rotation and finite Larmor radius (FLR) correction on the Rayleigh Taylor instability of stratified, conducting, rotating, incompressible quantum plasmas. The equations of the problem have been solved by using normal mode method and a general dispersion relation is carried out for the case where the incompressible quantum plasma is confined between two rigid planes  $z = 0$  and  $z = h$ . The dispersion relation of the medium is discussed for various configuration of the Rayleigh Taylor instability. The effect of rotation, FLR correction and quantum mechanism have been investigated and it is found that the FLR correction and quantum effect have stabilizing influence while angular velocity (rotation effect) has destabilizing influence on the growth rate of Rayleigh Taylor instability.

SA-401

## Disturbances in Solar Wind Plasma Parameters and Solar Features in Relation with Shock Related Intense Geomagnetic Storms During the Period of 1997-2012

P.L.Verma<sup>1</sup>, A.K.Tripathi<sup>2</sup> and R.S.Gupta<sup>3</sup>

<sup>1</sup>Department of Physics Govt.Vivekanand P.G.College Maihar Satna M.P.  
Controller A.P.S.University Rewa M.P.,  
E-mail plverma2010@gmail.com

### Abstract

We have studied shock related geomagnetic storms ( $Dst \leq -100nT$ ) observed during the period of 1997-2012 with halo and partial halo coronal mass ejections, X-ray solar flares and disturbances in solar wind plasma parameters. We have found that 87.75% shock related geomagnetic storms are associated with halo and partial halocoronal mass ejections. The association rate of halo and partial halocoronal mass ejections are found 79.06% and 20.93% respectively. Positive correlation with correlation coefficient 0.27 has been found between magnitudes of shock related geomagnetic storms and speed of associated CMEs. Further we have observed that all the shock related geomagnetic storms are associated with X ray solarflares of different categories. The association rate of A-class, B-class, C-class and M-class X-ray solarflares are found 2.04 %, 14.28 %, 20.40%, 51.02%, and 12.24 % respectively. From the study of shock related geomagnetic storms with disturbances in solar

wind plasma parameters ,we have determined positive co-relationbetween magnitude of geomagnetic storms and peak values of associated jump in solar wind plasma parameters with co-relation co-efficient, 0.75 between magnitude of geomagnetic storms and peak values of associated jump in interplanetary magnetic field, 0.19 between magnitude of geomagnetic storms and peak value of associated jump in solar wind plasma temperature, 0.40 between magnitude of geomagnetic storms and peak value of associated jump in solar wind plasma velocity, 0.53 between magnitude of geomagnetic storms and peak value of associated jump in solar wind plasma pressure.

**Keywords** –Disturbances in Solar Wind Plasma Parameters, Coronal Mass Ejections, X-ray Solar Flares, Radio Bursts, Interplanetary Magnetic Fields, Geomagnetic Storms.

**SA-404**

## **DYNAMICAL BEHAVIOUR OF DUST GRAINS WITHIN THE SHEATH IN SPACE PLASMA**

Rinku Deka

*Guahati University, Assam, 781014*

E-mail : rinku.deka@yahoo.in

### **Abstract**

We are working to find the structure of sheath variation in space plasmas (As of when a solid body is immersed in plasma, around which sheath clouds are formed). Our interest is to find the sheath over the Moon's surface. Thereafter, we look for the dynamical behavior of a dust grain with the sheath, causeway thousands of thousands dust grains are likely to be formed stable in the sheath and give a cloud of dust grains, which resembles to the formation of nebulous

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**SA-405**

## **Artificial Neural Network Model for Predicting Horizontal Component Of Earth's Magnetic Field Over Indian Sector**

K. Unnikrishnan

*Department of Physics, N S S Hindu College, Changanacherry, Kerala 686 102*

*School of Pure and Applied Physics, Mahatma Gandhi University, Priyadarshini Hills,  
Kottayam – 686 560, Kerala*

E-mail: kaleekkalunni@gmail.com

### **Abstract**

In the framework of space weather an important role is played by geomagnetic storms, which are comprised of processes occurring in near-Earth space [1].Recently, major efforts have been devoted

to obtain global empirical models of the vertical plasma drifts using radar, magnetometer, satellite, and ionosonde observations [2]. Neural networks (NNs) are a branch of Artificial Intelligence (AI) methods which are proving particularly successful in solar-terrestrial time series prediction and pattern recognition; they appear to be especially effective in modelling the time development of irregular processes.

Present work is the first attempt to predict horizontal component of earth's magnetic field ( $H$ ) and range in  $H$  ( $\Delta H$ ) over Indian sector by considering the stations, namely, Trivandrum, Pondicherry, Visakhapatnam, and Nagpur, using the concept of neural network (NN). Through training procedure, solar flux ( $F_{10.7}$ ), latitude, longitude, day of the year, local time, Ap index, IMF Bz, and ion number density are identified as the optimum choice of input parameters, where as the inclusion of solar wind pressure and velocity has not significantly improved the performance of the model. Thus an appropriate neural network model, NSSHC has been developed with 12 hidden neurons and 500 iterations to predict  $H$  component and range in  $H$  ( $\Delta H$ ) during the period 1996-2001, to capture diurnal, seasonal, latitudinal, magnetic and solar activity effects. It is observed that the RMSE of predicted  $H$  component and range in  $H$  ( $\Delta H$ ) values are slightly greater during geomagnetic storm periods compared to the respective quiet time, irrespective of location. In addition to this, the neural network model developed here, could effectively reflect the solar activity variabilities, as evident from the low RMSEs between the predicted and observed values of both  $H$  component and range in  $H$  ( $\Delta H$ ) values for low (1996) and moderate (1998) solar activity periods for an equatorial station, Trivandrum and for another station, away from equator, Visakhapatnam during low (1996) and high (2001) solar activity periods.

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SA-454

### **Ionospheric Behavior Over Equatorial Region Bhopal During The Total Solar Eclipse Of July 22, 2009**

Varsha Kachneria\*, Prakash Khatarkar, Shweta Thakur, Bhupendra Malvi, and A. K. Gwal

*Space Science Laboratory, Department of Physics, Barkatullah University, Bhopal 462026*

Email: varshakachneria@gmail.com

#### **Abstract**

In this paper we have investigated the variability of ionospheric parameters by using two different techniques GPS and Ionosonde, during total solar eclipse on 22 July 2009, from Bhopal (23.2°N, 77.6°E) which is located under the equatorial anomaly crest. The critical frequency foF2 and virtual heights observed by the ionosondes are good indicators of the true layer heights and electron concentration and may provide information about the equatorial ionosphere dynamics. We have used the Novatel's dual frequency GPS receiver GSV4004A for the TEC values. The deviation in the TEC on the eclipse day from those on reference days show that the TEC value suddenly decreases during

the solar eclipse period. Variation of TEC is studied in correlation with the geomagnetic index Dst, kp, Ap and southward component of interplanetary magnetic field Bz.

**Keywords:** Ionosphere; GPS; Ionosonde; Total electron content; Total solar eclipse; foF2; geomagnetic indices; interplanetary magnetic field.

SA-457

### 3D Solitary Waves In A Five Component Dusty Plasma

Sijo Sebastian<sup>1</sup>, Sreekala G.<sup>1</sup>, Manesh Michael<sup>1</sup>, Noble P. Abraham<sup>1</sup> G. Renuka<sup>2</sup> and Chandu Venugopal<sup>1\*</sup>

<sup>1</sup>*School of Pure and Applied Physics, Mahatma Gandhi University, Kottayam 686 560, Kerala*

<sup>2</sup>*Kerala State Council for Science, Technology & Environment, Sasthra Bhavan, Pattom, Thiruvananthapuram 695 004, Kerala*

\* E-mail : cvgmphys@yahoo.co.in

#### Abstract

We investigate the existence of both positive and negative 3D solitary waves in a five component dusty plasma consisting of positively and negatively charged oxygen ions (dust), hydrogen ions, hotter solar wind electrons and colder cometary photo-electrons. The solar and cometary electrons are described by the kappa distribution functions. The K-dV equation is derived for three dimensional case and the solitary structures for both negative and positive solitons are plotted for different physical variables relevant to comet Halley. It is seen that amplitude of the solitary structures decreases as kappa values and electron temperatures increase. The amplitude of both negative and positive solitary structures increases with increasing ion densities.

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SA-458

## Stability Of Electrostatic Waves In A Five Component Cometary Plasma

Manesh Michael<sup>1</sup>, G. Sreekala<sup>1</sup>, Sijo Sebastian<sup>1</sup>, Amir M.<sup>1</sup>, R. Jayapal<sup>2</sup>, Chandu Venugopal<sup>1\*</sup>

<sup>1</sup>*School of Pure & Applied Physics, Mahatma Gandhi University, Kottayam. 686560, Kerala*

<sup>2</sup>*Department of Physics, Devaswom Board College, Thalayolaparambu, 686605, Kerala*

\*E-mail : cvgmgphys@yahoo.co.in

### Abstract

We investigate the stability of electrostatic waves in a magnetized five component plasma composed of positively and negatively charged oxygen ions and electrons of cometary origin and drifting hydrogen ions and electrons of solar wind origin. Such a plasma composition describes very well the plasma environment around a comet. The expression for real frequencies and growth rate of wave have been derived and computed for typical values observed at comet Halley. It is found that the growth rate increases with increasing hydrogen beam density ( $n_{bH}$ ) of the solar wind and decreases as the density of positively charged oxygen ion ( $n_{o+}$ ) increases. In addition, the variation of growth rate with the drift velocity ( $V_b$ ) of hydrogen ions also studied: as the drift velocity increases the growth is found to be shifted towards lower values of the normalized wave vector.

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## Stability of Kinetic Alfven Wave (KAW) In A Cometary Plasma With Streaming Electrons And Protons

Sreekala G.<sup>1</sup>, Sijo Sebastian<sup>1</sup>, Manesh Michael<sup>1</sup>, C. P. Anilkumar<sup>2</sup> and Chandu Venugopal<sup>1\*</sup>,

<sup>1</sup>*School of Pure and Applied Physics, Mahatma Gandhi University, Kottayam 686 560, Kerala*

<sup>2</sup>*Equatorial Geophysical Research Laboratory, Indian Institute of Geomagnetism, Krishnapuram, Tirunelveli, Tamil Nadu 627 011*

\* E-mail : cvgmgphys@yahoo.co.in

### Abstract

Alfvenic turbulence has been detected at comet Halley by space crafts Giotto [1] and Vega [2] and also at comet Giacobini-Zinner by the ICE space craft [3, 4]. We studied the KAW instability driven by field aligned drifts of solar wind electrons (se), and protons (H) in a cometary pair-ion plasma consisting of cometary electrons (ce), positively and negatively charged oxygen ions with each species being modelled by a drifting ring distribution [with  $V_{dce} = V_{dO^+} = V_{dO^-} = 0$  and  $V_{dH} = V_{dse}$ ]. In the low frequency regime, the dispersion relation is a polynomial equation of order 4. We find that the solar electrons can interact with the cometary electrons to drive the wave unstable with a growth rate proportional to the cometary electron density. Numerical analyses of the general expression for the growth rate show that both  $V_{dH}$  and  $V_{dse}$  can drive the wave unstable. Growth rate also shows linear variations with increase in densities of the ions.

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SA-468

## A Long Term Comprehensive Picture of the Nocturnal Plasma Vertical Drift Over Indian Longitude Sector And Its Implications

Madhav Haridas, M. K, G. Manju and Tarun Kumar Pant  
Space Physics Laboratory, Vikram Sarabhai Space Centre,  
Trivandrum – 695 022, Kerala  
Email: madhavharidas@gmail.com

### Abstract

A comprehensive analysis of the seasonal and solar cycle variabilities of night-time ionospheric plasma vertical drift ( $V_d$ ) over the Indian longitude sector is accomplished using ionosonde data at magnetic equatorial location, Trivandrum (8.5° N, 76.5° E). The analysis extends over a span of two decades (1988-2008). The representative seasonal models, of temporal evolution of  $V_d$ , for high as well as low solar activity period, are arrived at, for the first time. The equinoctial asymmetry in peak  $V_d$  and in time of peak  $V_d$  during high and low solar epochs are significant outcomes of this study. Seasonally, it is seen that maximum post sunset  $V_d$  is obtained in VE, followed by AE, WS and SS for high solar epochs while for low solar epoch maximum  $V_d$  occurs in VE followed by WS, AE and SS. The role of the sunset times at conjugate points in controlling the day to day, seasonal and solar activity variability of the time and magnitude of peak  $V_d$  is an important result obtained from the present study. The sunset times at conjugate points plays a critical role in controlling the time and magnitude of post sunset peak vertical drift in solar maximum. In the present era of GPS based communication and navigation this is an important result which will give a better handle in understanding the day to day variations of the equatorial ionospheric phenomena such as the equatorial plasma irregularities.

**Keywords:** Equatorial ionosphere; vertical drift, sunset time, conjugate point, F region dynamo

SA-472

## A Study on Dust Dynamics on Lunar Surface under Different Plasma conditions Encountered by the Moon.

Rakesh Chandran S.B.<sup>a</sup>, Abraham A.<sup>b</sup>, Renuka G.<sup>c</sup> and Chandu Venugopal<sup>d</sup>  
<sup>a</sup>Sanatana Dharma College, University of Kerala, Alappuzha-688003, Kerala, India  
<sup>b</sup>Christian college, University of Kerala, Chengannur-689 122.  
<sup>c</sup>Kerala State Council for Science, Technology and Environment, Sasthra Bhavan,  
Pattom – 695 004.  
<sup>d</sup>School of Pure and Applied Physics, M G University, Kottayam-686 560.

rakwin@gmail.com

### Abstract

The Moon has a tenuous exosphere and only weak localized crustal magnetic fields, leaving most of its surface exposed to solar UV and X rays as well as solar and magnetospheric plasma, all of which act to electrically

charge the surface. During its orbit around the Earth, the Moon is exposed to highly variable charging currents in the solar wind, terrestrial magnetosphere and during solar energetic particle (SEP) events. The lunar surface charges to a potential such that the currents to it balance locally. On the sunlit hemisphere of the Moon, photoelectron currents usually dominate, and the surface charges to a small positive potential. On the night side, on the other hand, currents from electrons tend to dominate, and the surface charges to a negative potential. Like surface, lunar dust also charges in response of incident currents. Electric field resulting from charging repels like charged dust grains from the lunar surface causing it to levitate above the lunar surface. The electric field of this levitated dust could interact with electric field of equipments in the space craft and may damage its functioning. Here we modeled the dynamics of dust grains with variation of lunar surface potential and electric field. A study on lunar surface charging and electrostatic transport of dust grains assumes tremendous significance while designing a vehicle for safe and reliable operation in the charging environment.  
*Keywords: Charging theory; lunar surface potential; lunar surface electric field; dust levitation.*

SA-480

## Pseudopotential Approach to Ion Acoustic Waves in A Relativistically Degenerate Quantum Plasma

Anay Basak<sup>1</sup>, Saheli Das<sup>1</sup>, Suchandra Mandal<sup>1</sup>, Shoubhik Pramanik<sup>1</sup>, Ravneet Kaur Gill<sup>1</sup>, Sibarjun Das<sup>2</sup>, Basudev Ghosh<sup>2</sup>, S.N.Paul<sup>2</sup>, Himangshu Sahoo<sup>2</sup>, Sreyasi Banerjee<sup>2</sup>, Krishanu Chatterjee<sup>1</sup>, Rakesh Moulick<sup>3</sup>, Swarniv Chandra<sup>1,2\*</sup>

<sup>1</sup>Department of Physics, Techno India University, Salt Lake, Kolkata-700091

<sup>2</sup>Department of Physics, Jadavpur University, Kolkata-700032

<sup>3</sup>CPP-IPR, Sonapur, Guwahati, Assam

E-mail: swarniv147@gmail.com

### Abstract

Using Sagdeev Pseudopotential approach the solitary wave structures in ion acoustic solitary waves in a quantum plasma are investigated by employing Quantum Hydrodynamic (QHD) model and reductive perturbation technique. The results are found out both analytically and verified numerically. It is found that the amplitude and width both vary significantly with change in quantum diffraction parameter and relativistic degeneracy parameter.

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SA-491

## Statistical Study of Some Highly Geo-effective Solar Plasma Events and Their Interplanetary Consequences

Subhash C. Kaushik

*Department of Physics, Government Postgraduate Autonomous College, Datia, 475661*

E-mail : subash.kaushik@gmail.com

### Abstract

In the present study we have analyzed the interplanetary plasma / field parameter, which have initiated the intense and highly geo-effective events in the magnetosphere. It is believed that Solar wind velocity  $V$ , interplanetary magnetic field (IMF)  $B$  and  $B_z$  are the crucial drivers of these activities [1, 2]. However, sometimes strong geomagnetic disturbance is associated with the interaction between slow and fast solar wind originating from coronal holes leads to create co-rotating plasma interaction region (CIR). Magnetospheric plasma anomalies are generally represented by geomagnetic storms and sudden ionosphere disturbance (SIDs) [3]. The study considers 220 geomagnetic storms associated with disturbance storm time (Dst) decreases of more than -50 nT to -300 nT, observed during solar cycle 23 and the ascending phase of solar cycle 24. These have been analyzed and studied statistically. The spacecraft data acquired by STEREO mission and those provided by SOHO, ACE and geomagnetic stations like WDC-Kyoto are utilized in the study. It is observed that the yearly occurrences of geomagnetic storm are strongly correlated with 11-year sunspot cycle, but no significant correlation between the maximum and minimum phase of solar cycle have been found. It is also found that solar cycle-23 is remarkable for occurrence of intense geomagnetic storms during its declining phase. The detailed results are discussed in this paper.

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SA-500

## Simulation of Plasma Layer During Hypersonic Re-entry Vehicles

Eashan Saikia<sup>1</sup>, Siddharth Bhattaroy<sup>1</sup> and S.S. Kausik<sup>2</sup>

<sup>1</sup>Department of Mechanical Engineering, Assam Engineering College, Jalukbari, Guwahati-781013, Assam

<sup>2</sup>Centre of Plasma Physics, Institute for Plasma Research, Nazirakhat, Sonapur-782402, Kamrup(M), Assam

E-mail: esaikia102@gmail.com

### Abstract

Space exploration is the key to unlock the secrets of our universe and the origins of our solar system. An integral part of this process involves the simultaneous development of deep space travel and its subsequent communication technology. Spacecrafts travel at hypersonic speeds, much higher than the speed of sound and hence the fluid flow around the vehicle becomes hypersonic flow. This type of flow is rather difficult to simulate computationally as it is very complex and includes effects of ionization and chemical reactions. An exhaustive study of this type of fluid flow will require a thorough understanding of plasma and its behavioural characteristics. In this work, the plasma layer surrounding a spacecraft will be studied through simulation technique and also to study fluid instabilities in relation to the behaviour of the plasma. Further, the causes leading to a communication blackout will be analyzed and effective measures will be suggested. The study of fluid instabilities in plasma will help to alleviate the detrimental effects of an important phenomenon called the "Re-entry communication blackout".

SA-505

## Kinetic Alfven instability the presence of ion beam in magnetospheric plasma

G. Shrivastava<sup>1</sup>, G. Ahirwar<sup>1</sup> & J. Shrivastava<sup>2</sup>

Vikram University, Ujjain (M.P.)<sup>1</sup>,  
Dronacharya Group of Institution<sup>2</sup>, Greater Noida

E-mail: jayashrivastava2007@gmail.com"

### Abstract

The particle aspect approach is adopted to investigate the trajectories of charged particles in the electromagnetic field of kinetic Alfven wave. Expressions are found for the dispersion relation, damping-rate and associated currents in the presence of ion beam in homogenous plasma. Kinetic effects of both electrons and ions are included to study kinetic Alfven wave because both are important in the transition region. It is found that ion beam, the ratio of thermal energy density to

magnetic field energy density ( and the ratio of ion to electron thermal temperature ( $T_i/T_e$ ) affect the dispersion relation, damping/growth-rate and associated currents. The treatment of kinetic Alfven wave instability is based on the assumption that the plasma consists of resonant and non-resonant particles. The resonant particles participate in an energy exchange process, whereas the non-resonant particles support the oscillatory motion of the wave.

**SA-509**

### **Kinetic Alfven instability in magnetospheric plasma**

J. Shrivastava<sup>1</sup>, A. Yadav<sup>1</sup>, G. Ahirwar<sup>2</sup> & G. Shrivastava<sup>2</sup>

<sup>1</sup>Vikram University, Ujjain (M.P.), <sup>2</sup>Dronacharya Group of Institution I, Greater Noida

E-mail: jayashrivastava2007@gmail.com

#### **Abstract**

Kinetic approach is adopted to investigate kinetic Alfven instability in magnetospheric plasma. Expressions are found for the dispersion relation, damping-rate and associated currents in homogenous plasma. Kinetic effects of both electrons and ions are included to study kinetic Alfven wave because both are important in the transition region. It is found that ion beam; the ratio of thermal energy density to magnetic field energy density ( and the ratio of ion to electron thermal temperature ( $T_i/T_e$ ) affect the dispersion relation, damping/growth-rate and associated currents.

**SA-511**

### **Waves and Instabilities in the Propagation of Cosmic Rays in the Interstellar Medium**

Subhash Kumar<sup>1</sup>, Sukanta Deb<sup>1</sup> and Harinder P. Singh<sup>2</sup>,

<sup>1</sup>Acharya Narendra Dev College (University of Delhi), Govindpuri, Kalkaji, New Delhi-110019

<sup>2</sup>Department of Physics & Astrophysics, University of Delhi, Delhi-110007.

E-mail<sup>1</sup>: skumar@andc.du.ac.in

#### **Abstract**

The propagation of cosmic rays in the interstellar medium is modeled as a composite system wherein the cosmic rays are described as an anisotropic ultrarelativistic ( $kT \gg mc^2$ ) magnetohydrodynamic (MHD) fluid moving at relativistic speed with respect to the background non relativistic anisotropic inter-stellar plasma. The cosmic rays are assumed to follow the double adiabatic equations of state. The pressure components of the anisotropic nonrelativistic background plasma are given by the generalized polytropic laws, which allow the model to reduce to variety of situations. The analysis is carried out in the linearized framework and the dispersion relation is derived using the usual normal mode technique. The various propagating modes are discussed both analytically and numerically for parameters appropriate to the astrophysical situations. This composite model allows an additional

mode - the suprathermal mode whose propagation characteristics are sensitive to the relative speed of motion between the two components of the composite system. For large enough value of this relative speed, the phase speed vanishes in the direction perpendicular to the ambient magnetic field. Polar group speed plots are drawn to show that the system does not allow transport of energy in directions transverse to the magnetic field. The free energy associated with the relative motion leads to the onset of fire hose and mirror instabilities in the system whose conditions are derived within the framework of relativistic anisotropic magnetohydrodynamics (RAM).

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# **BUTI YOUNG SCIENTIST AWARD PRESENTATIONS**



**BA-001**

**Generation of Terahertz Radiations by Flat Top Lasers in Modulated Density Plasmas**

Divya Singh<sup>1,2</sup>, Hitendra K. Malik<sup>1</sup>

<sup>1</sup> *Department of Physics, PWAPA Laboratory, IIT Delhi, New Delhi - 110016, India.*

<sup>2</sup> *Department of Physics & Electronics, Rajdhani College, New Delhi -110015, India.*

E-mail- divyasingh1984@gmail.com

**Abstract**

Here we present a mechanism of THz radiation generation by excitation of nonlinear currents due to two flat top laser pulses of same intensities but different frequencies and wave numbers in a plasma of modulated density. In this process, the ponderomotive force is developed which leads to nonlinear current density that resonantly excites the radiation in the THz frequency range. The effect of beam width and density ripples is discussed for these currents and THz generation and comparative studies are made for flat top beams with Gaussian one.

**I. Introduction**

EM radiations have been a part of all walks of life based on their application. Of the EM spectra the range 0.1–10.0 THz rapidly had become an important area of research since last decade due to its diverse applications in material characterization, medical imaging, topography, remote sensing [1], chemical and security identification [2, 3], etc. In order to develop high-power and efficient sources, several schemes [4–25] have been proposed, such as tunable THz generation by superluminous laser pulse interaction with large band gap semiconductors and electro-optic crystals viz. ZnSe, GaP, and LiNbO<sub>3</sub> [4–7]. THz radiation generation also has been reported by the nonlinear interaction of an intense short laser pulse with a semiconductor and dielectric [8–14]. Due to the material damage and low conversion efficiency, it is difficult to obtain powerful THz emission from the THz emitters, such as electro-optic crystals, semiconductors, synchrotrons, etc. Therefore, many experiments use plasma as a nonlinear medium for THz generation using subpicosecond laser pulses [15], as plasma has advantage of supporting very high fields and shows very strong nonlinear effects [16]. Malik et al. [17] have analytically investigated the THz generation by tunnel ionization of a gas jet with superposed femtosecond laser pulses impinging onto it after passing through an axicon. Yoshii et al. [18] theoretically and Yugami et al. [19, 20] experimentally have demonstrated the THz radiation generation when the Cerenkov wake is excited by a short laser pulse in a perpendicularly magnetized plasma. Cook and Hochstrasser [21] considered the THz generation when the fundamental and second harmonic lasers are simultaneously focused into the air. Sheng et al. [22] proposed a scheme in which a short laser pulse excites a large amplitude plasma wake field, which, in the presence of an axial density gradient, produces radiation at the plasma frequency ( $\omega_p$ ) via mode conversion. Antonsen et al. [23] have proposed the employment of a corrugated plasma channel for phase matched THz radiation generation by the ponderomotive force of a laser pulse. So far many schemes have been discussed employing plasma as a medium for THz generation but none of them is for flat top lasers while shape of the lasers pulse is an important ingredient to cause effective THz radiation generation.



## II. Mechanism and nonlinear current

In the present mechanism, two flat top lasers are taken to propagate along z direction in the presence of a plasma having periodic density modulation of wavenumber  $\alpha$  such as  $N=N_0+N_0e^{i\alpha z}$ . Due to the spatial intensity variation of laser fields in the transverse direction, i.e., along y axis, force known as ponderomotive force arises in the direction of propagation of lasers and perpendicular to it. This force gives rise to current that oscillates at the beating frequency of the lasers. At resonance, when

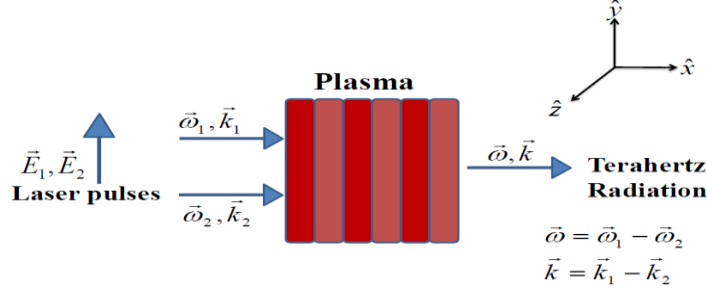


FIG. 1- Schematic

wave number and frequency match, maximum amount of nonlinear currents are generated and these currents are responsible for the generation of THz radiation.

We consider two ultra-short *fs* (femtosecond) flat top lasers (shown later in Fig-4) of frequencies  $\omega_1$  and  $\omega_2$  and wave numbers  $k_1$  and  $k_2$ , respectively, co-propagating in the z direction and polarized along the y direction. We also consider laser produced plasma of modulated density ripples (Fig-1). As the laser fields have space variation along the y axis, a transverse component of the nonlinear ponderomotive force is realized in the y direction at frequency  $\omega = \omega_1 - \omega_2$  and wave number  $k = k_1 - k_2$ .

The laser fields are chosen as  $\vec{E}_1 = E_0 \exp\left[-\left(\frac{y}{b_w}\right)^8\right] e^{i(k_1 z - \omega_1 t)} \hat{y}$ ,  $\vec{E}_2 = E_0 \exp\left[-\left(\frac{y}{b_w}\right)^8\right] e^{i(k_2 z - \omega_2 t)} \hat{y}$  (1)

In the above expressions of flat top lasers,  $b_w$  is the beamwidth of laser pulse. The nonlinear ponderomotive force imparted by lasers is given by

$$\vec{F}_p^{NL} = -\frac{m}{2e} \vec{v}_1 \cdot \vec{v}_2^* = -\frac{e^2 E_0^2}{2m\omega_1\omega_2} \exp\left[-2\left(\frac{y}{b_w}\right)^8\right] \left[ \frac{2p}{b_w} \left(\frac{y}{b_w}\right)^7 \hat{y} - ikz \right] e^{i(kz - \omega t)} \quad (2)$$

Under the effect of this ponderomotive force, electron oscillations are modified and some nonlinear perturbations in plasma density are created those are evaluated using equation of continuity as

$N^{NL} = -\frac{n_0}{m\omega^2} \vec{\nabla} \cdot \vec{F}_p^{NL}$ . Due to this nonlinear perturbation in electron density, some local electrostatic fields  $\phi$  are developed which further introduces some kind of linear density perturbations given as

$N^L = -\frac{N_0 e \vec{\nabla} \cdot \vec{\nabla} \phi}{m\omega^2}$ . We use Poisson's equation under combined effect of densities perturbations

$\vec{\nabla} \cdot \vec{\nabla} \phi = 4\pi e (N^L + N^{NL})$  to find out resultant electrostatic field which is used further to evaluate resultant nonlinear velocities of plasma electrons. Hence the nonlinear oscillatory current is obtained as

$$\vec{J}^{NL} = -\frac{1}{2} Ne \vec{v}^{NL} = -\frac{1}{2} N_{\alpha} e \frac{i \omega \vec{F}_p^{NL}}{m[\omega^2 - \omega_p^2]} \quad (3)$$

Transverse component of nonlinear oscillatory current is

$$\vec{J}_y^{NL} = \frac{1}{4} \frac{i \omega N_0 e^3 E_0^2}{m^2 \omega_1 \omega_2 [\omega^2 - \omega_p^2]} e^{\left[-2\left(\frac{y}{b_w}\right)^8\right]} \frac{2p}{b_w} \left(\frac{y}{b_w}\right)^7 e^{i\{kz - \alpha t\}}$$

here  $k = k_1 - k_2 + \alpha$ ,  $\omega = \omega_1 - \omega_2$ . This condition should be met for generation of THz radiations.

### ELECTRIC FIELD OF EMITTED THz RADIATION

Wave equation governing emission and propagation of THz radiations within plasma is as follows

$$-\nabla^2 \vec{E} + \vec{\nabla}(\vec{\nabla} \cdot \vec{E}) = -\frac{4\pi i \omega}{c^2} \vec{J}^{NL} + \frac{\omega^2}{c^2} \varepsilon \vec{E} \quad (4) \quad \text{Here } E$$

represents the THz field, wherein we symbolize as  $E_{THz}$ . Thus the magnitude of emitted THz is calculated by taking the divergence of the above equation,

$$E_{THz} = \frac{p N_{\alpha} e E_0^2 \omega^2 \omega_p^2 e^{-2\left(\frac{y}{b_w}\right)^8}}{2 N_0 m b_w \omega_1 \omega_2 (\omega^2 - \omega_p^2)^2} \left(\frac{y}{b_w}\right)^7 \quad (5)$$

The given amplitude of THz is obtained only if the following phase matching condition is satisfied

$$\frac{c \alpha}{\omega_p} = \frac{\omega}{\omega_p} \left[ \left( 1 - \frac{\omega_p^2}{\omega^2} \right)^{1/2} - 1 \right] \quad (6)$$

Since quality of emitted THz radiations is determined by their amplitude, band width and efficiency, these are the key factors those are required to be achieved. Therefore, following analytical studies are made to study the nature of emitted THz radiations while flat top laser pulses are co-propagating in a modulated density plasma and further adequate optimization of laser and plasma parameters are done.

### III. Results & discussion

We examine the profile of the field amplitude of emitted THz radiation through Fig-2 for Gaussian laser (GL) and flat top laser (FTL) for the parameters  $\omega/\omega_p = 1.05$ ;  $\omega_1 = 2.4 \times 10^{14}$  rad/sec and  $\omega_2 = 2.0 \times 10^{13}$  rad/sec. From the following Fig-2 it is evident that the THz field amplitude increases and acquires a maximum value for a particular value of  $y/b_w$  i.e. critical transverse distance ( $y_0$ ). For FTL pulse  $y_0 = 0.8$  and for GL pulse  $y_0 = 0.5$ . The reason for the highest magnitude of THz field for a specific value of  $y/b_w$  can be understood based on the magnitude of  $y$  component of the ponderomotive force  $F_{py}^{NL}$ . Actually, for a small but particular value of  $y/b_w$ , the component  $F_{py}^{NL}$  acquires maximum magnitude and, hence, generates the highest nonlinear current  $J^{NL}$ , This in turn, results in the emission of the highest amplitude THz radiation.

A. *Effect of beamwidth  $b_w$*

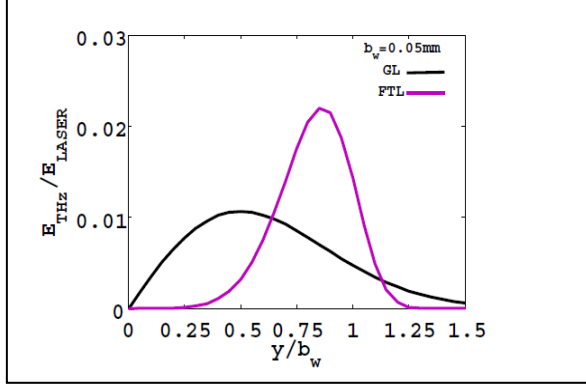


FIG. 2. Profile of electric field of THz radiation flat top laser (FTL) and Gaussian (GL) laser .

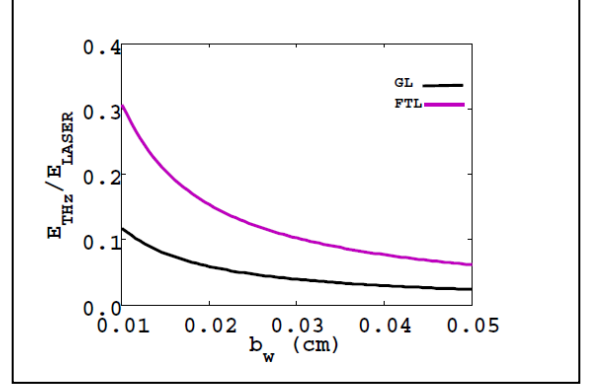


FIG. 3. Variation in the normalized THz field with beam width of FTL & GL profiles.

From Fig-3 the amplitude of THz is found to fall with increasing beam width but both Figs - 2, 3 shows that for  $y_0 = 0.8$ , FTL pulses gives better amplitude of THz fields than GL pulses. From Fig-2 it is also very obvious that for modulated density plasma the profile of normalised amplitude of emitted THz when GL pulses used is unsymmetrical about  $y/b_w$  whereas for FTL pulses we get more symmetric profiles i.e. more synchronised highly focussed emitted THz radiations. Thus small, beam width flat top laser pulse provides highly focussed and collimated THz radiations than Gaussian pulses.

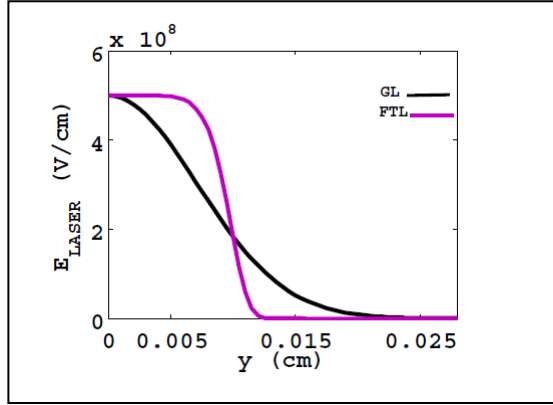


FIG. 4. Profiles of flat top and Gaussian laser

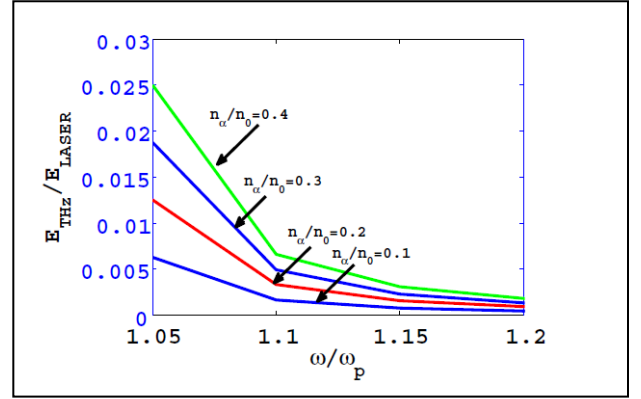


FIG. 5. Variation in the normalized THz field with normalized beat frequency of different density ripples.

The explanation why flat top lasers are better than the Gaussian lasers for THz generation can be understood with the help of Fig-4 that clearly depicts the half beam profile of Gaussian and flat top lasers. The latter has nearly rectangular shape of beam having high value of intensity gradient than Gaussian lasers, therefore FTL gives large ponderomotive force and nonlinear currents. Hence this leads to higher amplitudes of THz radiation along with symmetric profile.

### B. Effect of density ripples on phase matching

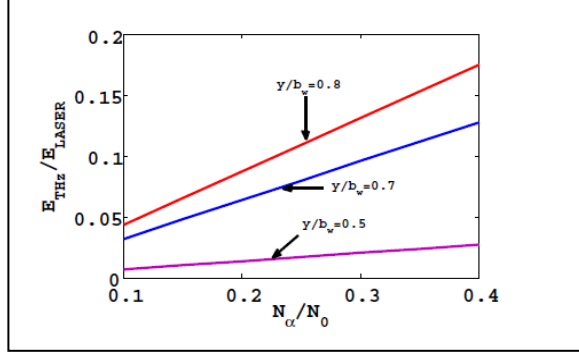


FIG. 6. Variation in the normalized THz field with amplitude of density ripples.

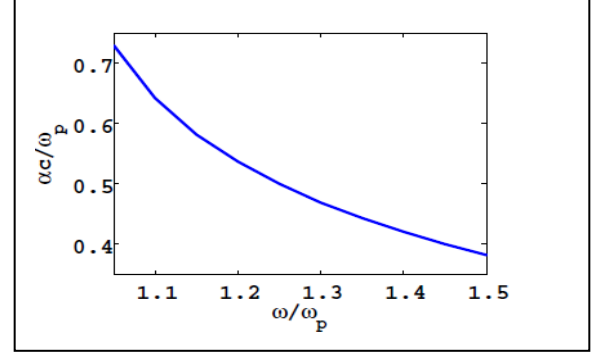


FIG. 7. Variation of the normalized wave no. of density ripples with normalized beat wave frequency.

Figs-5,6 explain that the density ripples help in achieving high amplitudes of THz radiation, resonance condition is also shown to be close to  $\omega = \omega_p$ . As beating frequency varies, the resonance condition departs leading to a mass reduction in the amplitude of THz fields. The resonance condition can be achieved by proper phase matching of wave numbers using density ripples in plasma. The large number of density ripples attributes to the high contribution of electrons in the generation of nonlinear currents. Fig-7 clearly explains that ripples must be formed closer for achieving best condition of phase matching, which leads to resonance and maximum transfer of energy to get enhanced amplitude of emitted THz radiation.

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## BA-002

### **Spatio-Temporal Imaging Of Laser Induced Shock Waves And Plasma Plume From Ambient Air, Metals, Periodic Structured Surfaces And Sub-Micron Sized Compacted Powders**

Leela Chelikani

*Advanced Centre of Research in High Energy Materials (ACRHEM), University of Hyderabad, Prof. C. R. Rao Road, Gachibowli, Hyderabad 500 046, India*

Email: leelachelikani@gmail.com

#### **Abstract**

The scope of the thesis is to characterize the Laser Induced Shock Waves (LISWs) and plasma plume from different materials in solid, liquid and gas phases. A standalone experimental facility capable of imaging spatio-temporal evolution of laser induced shock waves, hot core plasma dynamics, contact front dynamics and imaging of laser induced plasma plume from neutral and ionic species is developed. Results obtained using three different optical techniques namely defocused shadowgraphy, laser induced plasma plume and interferometry imaging under controlled laboratory environment is presented.

## Thesis overview:

**Chapter 1 (Introduction and motivation)** When a short laser pulse is focused in a medium (solid, liquid or gas) due to the associated high electric field, the medium ionizes resulting in production of free electrons which gains energy interacting with residual laser electric field and yield to further ionization resulting in an avalanche breakdown of the medium. This catastrophic ionization of the medium results in plasma formation which expands with supersonic velocities. The plasma while trying to reach equilibrium with surroundings releases energy in the form of an electromagnetic radiation and also in the form of a Shock Wave (SW) travelling into the ambient media. The laser-matter interaction has acquired attention in the fields of optics, material science engineering, nuclear and plasma physics [1]. SWs generated from laser induced optical breakdown of materials have found many applications like laser spark ignition for fuel-air mixtures, internal combustion engines, pulse detonation engines etc., laser shock peening [2], surface cleaning, laser ablation propulsion (LAP) [3], spectroscopic applications like laser induced breakdown spectroscopy (LIBS) [4], understanding the formation of atmospheric oxides in the natural lightning, gas dynamic flow [5], laser ablation of surfaces, spray and microjet formation from liquid droplets[6] to name a few. Biological applications involve SW lithotripsy [7], gall bladder diseases, treatment of pancreatic and salivary stones and also in orthopedics. Also, cavitation bubble (CB) plays an important role in understanding laser produced plasma formation in tissues in ophthalmic surgery as the plasma formation results in the SW and CB formation which can produce undesirable collateral damage to the tissue. The crucial issue involved in all these applications is efficient conversion of optical energy into kinetic energy during the interaction of high energy laser pulses with materials, which is an intriguing field of research owing to the nonlinear optical properties coming to the fore during laser-matter interaction.

**Chapter 2 (Diagnostic techniques and analysis)** describes the standalone experimental facility setup to monitor the energy release characteristics of different materials using optical probing techniques such as defocused shadowgraphy, laser induced plasma plume and interferometry imaging [8,9] with the aim to understand the LISWs, hot core plasma (HCP) dynamics, contact front dynamics and atomic emissions from the reacted species. Also, this chapter discusses the propagation of LISWs into the ambient atmosphere using the Counter Pressure Corrected Point Strong Explosion Theory (CPC-PSET) [10] based on theory of Sedov-Taylor [11] to understand the evolution of SW due to laser energy deposition in the focal volume. Laser pulses from second harmonic of Nd:YAG laser (532 nm, 7 ns, 10 Hz) is used to generate laser induced plasma launching SWs from the materials into the ambient atmosphere. An expanded He-Ne laser beam (632.8 nm, CW, 25 mW,  $2\omega_0 \sim 15$  mm) is used as a probe beam to capture the evolution of expanding HCP and SWs from different materials used in the study. An Intensified Charge Coupled Device (ICCD) camera with 1.5 ns temporal resolution is used as the main diagnostic tool for imaging.

**Chapter 3 (Dynamics of laser induced micro-shock waves, hot core plasma in quiescent air and from a static 2 mm size water droplet)** The dynamics of SW and HCP dynamics studied using time resolved shadowgraphy imaging technique are presented. The existing literature considers the LISWs in air emanate from a single point source in space. In most of the studies, though different

wavelengths from UV (193nm) to IR (1053, 1064 nm) were used to generate LISWs, the diagnostic used to capture the SW is a gated ICCD with a minimum gate width of 10 ns. Although several authors have observed the jet formation and HCP dynamics, during the vibrant laser-plasma dynamics of air. However, study of the complete dynamics from the initial breakdown of the medium to the time scales of 1200  $\mu$ s are sparsely available. This chapter focuses on the novel aspects of (a) the presence of two distinct dominant sources of ionization along the laser propagation direction (Z) modifying the nature of SWs and (b) the interaction of these two sources leading to the transition of HCP analogous to that of a CB observed in fluids. Also, the position of shock front at different delays from the laser pulse allowed us to experimentally measure the shock velocity and estimate the nature of the SWs using CPC-PSET [10]. Initial plasma formation and expansion of plasma is observed to take approximately 0-2000 ns, SW formation and evolution is observed during timescales of 200 ns – 12  $\mu$ s and HCP formation, expansion and oscillation is observed till 1.5 millisecond timescale. Although, the existing models explain the expansion of LISWs from a single source, our experimental observations show the need to consider the LISW problem as a two or a multi-center problem to account for the asymmetric evolution of SWs in different directions. Each of the two sources independently led to a spherical SW following Sedov-Taylor theory along Z-axis with a maximum velocity ( $V_{SW}$ ) of 7.4 km/s and pressure ( $P_{SW}$ ) of 57 MPa behind the shock front. While the interaction of SWs from the two sources led to a planar SW in the direction normal to Z direction. The SW detaches from the HCP and starts expanding into the ambient air at around 3  $\mu$ s indicating the onset of asymmetric expansion of the HCP along the Z-axis [12]. The other part of this chapter focuses on the measurements of LISWs and CB from a static water droplet of 2 mm diameter using time resolved shadowgraphy. The laser energy deposited inside the water droplet launches SWs and CB from the water droplet which further propagates into ambient atmosphere. The generated SWs are found to be spherical with the velocity behind the shock front to be 2 km/sec. The initial collapse of the CB was observed to be at 4.7  $\mu$ s with a maximum radius of 1.22 mm at 12 mJ laser energy. Higher deposition of laser energy is observed to generate stronger SWs.

**Chapter 4 (Laser induced shock waves from flat and 1-D periodic structured surfaces)** presents the LISWs from different solids with varying density profile into the ambient air using shadowgraphy technique. Laser interactions with variety of flat and periodic structured surfaces that have been studied for various applications like generating table top particle (electron, ion) sources [13], increasing plasma temperature and electron density by varying the cavity aspect ratio, patterning of laser induced periodic surface structure in liquid crystal displays for molecular orientation to name a few [14]. Though the aspect ratio of the cavities is observed to play a crucial role in modifying the plasma temperature, known to be the source of SWs, the effect of simultaneous ablation of periodic cavities on the evolution of SWs are barely studied. Initially, the flat surfaces (FS) of bulk metals/alloys were studied to understand the plasma plume evolution. Metals include Aluminum (Al), Copper (Cu) and alloys include 304 SS (304 grade Stainless Steel), Brass. The SW parameters were explained using Sedov-Taylor theory. The contact front dynamics between the shocked ambient air and the ejected mass were studied. Among the four different solid targets, the SW properties are observed to be higher for Al and lower for Cu. Also, the effects of different input laser energies on SW propagation were studied. The studies from flat targets were extended to one dimensional Periodic Rectangular engraved Cavity (1-D PRC) in 304 SS surface of  $30 \pm 2$   $\mu$ m depth (d) and of

240 ± 20 μm width (W) respectively giving rise to an aspect ratio of (d/W) of ~ 0.12. The cavities were separated from each other by a flat surface which is made of 304 SS surface itself. The evolution of the shock front from the 1-D PRC is observed to be faster due to the interaction of multiple ablative shock sources from the periodic modulated surface owing to higher SW pressures. The shock front from FS is observed to evolve spherically, while that from PRC is observed to deviate from spherical nature and follow planar evolution. The SW properties are observed to be higher for PRC compared to that from a FS due to the interaction of the localized higher plasma temperature regions closer to the target surface. The dynamic interaction of the plasma from PRC during the overall evolution process indicates a possibility of SW tailoring by varying the periodicity and dimensions of the surface modulations. The studies were further extended to (a) triangular shaped periodic structured surfaces with Al coating which comprises of 1200, 600, 300, 100 lines per mm with periodicity of 0.83, 1.6, 3.3, 10 μm, respectively, and (b) sinusoidal shaped periodic structured surfaces with Al coating which comprises of 2400, 1800, 1200 lines per mm with periodicity of 0.41, 0.55, 0.83 μm, respectively. The effect of density variations on the LISW is presented. As the periodicity approaches excitation wavelength (532 nm), the SW parameters are observed to be higher. The SW properties are observed to increase with periodicity.

**Chapter 5 (Laser induced shock waves from compacted micron, nano-sized powders and Poly Vinyl Chloride (PVC) film)** focuses on the LISWs from compacted micron and nano-sized powders characterized using shadowgraphy technique. Due to the large surface area, nano-sized powders can be used to increase the absorption of laser light to medium. These properties were used to study enhanced X-ray emission from nanoparticle surfaces. The studies from micron-sized powders were compared to nano-sized powders to understand the challenging aspects of laser-powder interactions to explore their application potential for LAP. The study focuses on the effect of micron-sized powders such as Boron Potassium Nitrate (BKN), Ammonium Perchlorate (AP), Potassium Bromide (KBr) and nano-sized powders such as Aluminum (Al), Amorphous Boron (B) and also the effect on coating on the nano-sized powders such as Nickel coated Aluminum (Ni-Al) and Lithium Fluoride coated Boron (LiF-B). Both micron and nano-sized powders of 1 gram each were taken and compacted to a pellet of 1 inch diameter and 1 mm thickness. Among the four different nano-sized powders in pellet form, the SW properties are observed to be higher for Al and lower for B. The specific impulse ( $I_{sp} = V_{sw}/g$ ) obtained from Al and Ni-Al indicate that these potential candidates for LAP applications. Among micron and nano-sized compacted powders, the SW properties are observed to be higher for nano-sized compacted powders when compared to micron-sized powders. The laser based characterization techniques have potential to reveal the applications of the energetic powders in an environmental friendly way [15]. Also, the SW studies were extended to study the LISWs from polymer (Poly Vinyl Chloride) film in both laser ablative and blow-off modes.

**Chapter 6 (Atomic emission lifetimes of different materials from nanosecond laser induced plasma plume imaging vis-à-vis LIBS)** focuses on the study of atomic emission lifetimes of different species measured from spatio-temporal imaging of plasma plume during ns-laser induced breakdown of different materials. A tunable filter in the visible spectral region (± 5 nm bandwidth) was used to capture the emission line of interest and was compared with that of the traditional Laser Induced Breakdown Spectroscopy (LIBS) data. LIBS, an atomic emission based technique has



become an attractive and a versatile technique for the detection of hazardous and prohibited substances, including remote detection capability, constraint of a very small amount of material and high detection speed. The main physical process that forms the essence of LIBS technology is the formation of high-temperature plasma, induced by a short laser pulse (typically of ns duration). Each element in the periodic table is associated with unique LIBS spectral peaks. By identifying different peaks for the analyzed samples, chemical composition of the material can be rapidly determined. Based on the spectral intensities and certain analysis stoichiometry of the compound under study can be determined accurately [16,17]. With proper selection of diagnostics in the required spectral region, this method can be extended to the study of reaction kinetics and has a potential application in the pollution monitoring during the combustion process/ reaction of energetic materials. An ICCD is used to obtain the 2D plasma plume images. The captured images were processed using MATLAB to extract the integrated photon count at different delays and generating the emission intensity profile of a given emission line. Emission profile from prominent lines over the visible spectral region like

- [1]. H $\beta$  (486.1 nm), N II (568.6 nm) and O II (720.2 nm) from ambient air,
- [2]. Al II (466.3 nm) from Aluminum, Cu I (521.8 nm) from Copper, Cu I (521.8 nm), Zn I (481 nm) from Brass and Cr I (520.4 nm), Fe I (438.3 nm) from 304 SS respectively,
- [3]. Na I (588.99 nm), Na II (635.28 nm), H I (656.27 nm) from Ammonium perchlorate (AP) and Na II (635.28 nm) and H I (656.27 nm) from Ammonium Nitrate (AN) respectively,
- [4]. H I (656.2 nm) and O II (720.2 nm) from Poly Vinyl Chloride (PVC) tape

were captured. Atomic line emissions from LIBS data was collected using a combination of Mechelle spectrograph (ME-5000) and an ICCD camera (DH-734, ANDOR). The details of the analysis and results were discussed.

**Chapter 7 (Conclusion and Future direction)** In summary, the results of the experimental studies of LISWs from different materials using defocused shadowgraphy and laser induced plasma plume imaging were presented. The novel aspects of interacting plasma plumes in air and from periodic density modulated surfaces leading to modified SW properties has a potential to tailor the SWs for specific applications either by accelerating or decelerating by controlling the plume dynamics. Also, results on the atomic emission lifetimes calculated by imaging the ns laser induced plasma plumes vis-à-vis the lifetimes obtained using a standard LIBS spectrograph are presented.

As a future scope, this thesis focuses on the measurement of interference fringe displacement produced by a Mach-Zehnder interferometer which gives an accurate quantitative value for the density itself. Mach-Zehnder Interferometer also reveals the information about the two dimensional (2D) spatial distribution [18] of electron densities and temperature. Shadowgraphy technique gives the information about the propagation of shock front, velocity and pressure behind the shock front where as interferometry gives the density information. With the help of this information, one can get the Hugoniot of given material under shocked condition. In addition, the possibility of Radio Frequency (RF) [19], acoustic emissions from laser produced plasma was initiated.

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## BA-003

### Enhanced Laser Energy Absorption And X-Ray Emission From Nano-Structured Targets Irradiated By Ultra-High Intensity Laser Pulses

U. Chakravarty, P. A. Naik, V. Arora, J.A. Chakera and P. D. Gupta

*Laser Plasma Division, Raja Ramanna Centre for Advanced Technology, Indore 452 013*

E-mail : uday@rrcat.gov.in

#### Abstract

A detailed study on the absorption of ultra-short, ultra-high intensity laser pulses in planar and various nano-structured targets, and the corresponding x-ray emission from these targets, has been

carried out. As the absorption of the ultra-short intense laser pulses in smooth, planar targets is low, it is important to devise new techniques for increasing the laser energy coupling to the plasma produced. We have identified the conditions for maximizing the absorption of intense ultra-short laser pulses in nano-particles formed *in situ*. The absorption was observed to exceed ~70% in silver clusters produced *in situ* by sub-ns pulses. The high absorption resulted in a higher x-ray yield (in the >1 keV region) with a conversion efficiency of  $8.5 \times 10^{-2}$  %. This scheme further led to an order of magnitude enhancement of the x-ray emission in the water window spectral region (x-ray conversion of 0.54 % /sr) utilizing the *in situ* formed carbon clusters, as compared to that in a planar graphite target. Using various nano-structures like spherical nano-particles, nano-fibers, nano-rods, nano-tubes, and nano-holes, high laser energy absorption has been demonstrated, with near complete absorption in carbon nano-tubes. The theoretical treatment of the laser absorption by nano-particles has helped in understanding the role of target geometry in the enhancement of the electric field, occurrence of resonances, and the dynamics of the laser nano-structure interaction. It is found analytically in hollow nanostructures that there are multiple resonances, which can facilitate continued occurrence of resonance.

## Introduction

In the recent times, there is a wide spread interest for enhancing the absorption of high intensity, ultra-short laser pulses in their interaction with matter [1]. The enhanced absorption is manifested in the observation of energetic electrons [2], MeV protons and ions [3], and x-rays [4]. The x-rays are useful as a micron sized point source. Such a source has many potential applications like time resolved x-ray diffraction studies, imaging of live biological specimen, mammography, radiography, and x-ray lithography [5]. Since the absorption of the high intensity ( $\sim 10^{17}$  W/cm<sup>2</sup>), ultra-short (~100 fs) laser pulses by planar solid targets is low [6], various types of targets like gratings [7], structured targets [8], pre-deposited metal clusters, gas clusters, snow clusters [3] etc. have been used to enhance the coupling of the laser energy in matter. The interest in the nano-particles stems from the fact that the electric field inside them is highly enhanced at resonance [9]. Recently, intense femtosecond laser irradiation of solid targets has been proposed as a simple means of synthesis of clusters [10]. If the cluster formation can be done by an ultra-short laser pulse and then these generated clusters in the plasma plume are irradiated by a time delayed intense ultra-short laser pulse, it offers a lot of advantages as an x-ray source. First and foremost, this gives an access to a wide range of materials from which clusters can be formed, and it also has the advantage of being a high rep-rate source. In the work reported here, we have identified the conditions for maximizing absorption of intense ultra-short laser pulses in nano-particles formed *in situ*. We have also studied experimentally and theoretically the dynamics of laser nanostructure interaction of various targets like spherical nano-particles, nano-fibers, nano-rods, nano-tubes, and nano-holes. High laser energy absorption has been demonstrated in such nanostructures, with near complete absorption recorded in carbon nano-tubes.

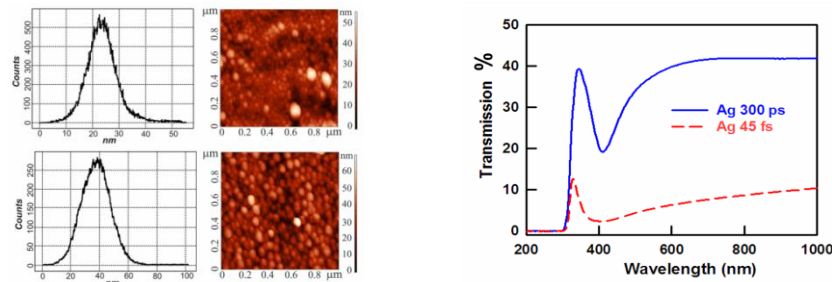
## Experimental Setup

First, a study of nano-particle formation by fs and sub-ns pulse was carried. Ti:sapphire laser pulses ( $\lambda=795$  nm,  $E=30$  mJ, 10 Hz pulse repetition rate) were focussed on planar Ag and Cu targets. The deposition was collected on glass slides, silicon wafer, and Al foil. The presence of nano-particles was inferred by analyzing the spatial characteristics using an atomic force microscope (AFM : SOLVER PRO, NT-MDT) and the spectral analysis of the deposited material was studied using a spectrophotometer (CARY 50). The absorption measurements of intense femtosecond laser pulses in the *in situ* produced silver clusters, formed by the stretched 300 ps laser pulse, was done by measuring the transmitted laser energy (70 mJ, 45 fs) after the laser - cluster interaction. A pyro-electric detector (Gentec, sensitivity 3V/J) and a sensitive calorimeter (Gentec, sensitivity 164 V/J)

were used for the absorption and scattering measurements. An x-ray p-i-n diode (Quantrad) filtered with two aluminized polycarbonate filters having cut-off (1/e transmission) at 0.9 keV, was used to measure the x-ray radiation emitted by the laser irradiated clusters. For absorption measurements and studying the dynamics of nanostructures like nano-fibre, nano-hole and nano-tubes, the plasma was produced by focusing 90 mJ, 45 fs (FWHM) Ti:sapphire laser pulses ( $\lambda = 790$  nm). The laser energy absorption was estimated by collecting the reflected laser light using a large aperture collection lens. Water window x-rays were measured using a transmission grating spectrograph and hard x-rays in 2-20 keV range were measured using an x-ray CCD working as a dispersionless spectrograph. Nano-ripple formation from ultra-short laser pulse irradiation of semiconductor materials of different band gaps was also studied. Semiconductor materials of narrow band gap ( $< 1.5$  eV, which is the energy of the incident 800 nm photon) and wide band gap ( $> 1.5$  eV) materials were used. Multiple laser shots from a Ti-sapphire laser with 8 mJ energy, 45 fs pulse duration, and 800 nm wavelength were focused in air on the semiconductor wafers at a fluence in the range of  $\sim 100$  mJ/cm<sup>2</sup> – 1J/cm<sup>2</sup>. The spatial features of the laser treated semiconductors were characterized using SEM (Philips XL30CP).

## Results and Discussion

The experimental study on the generation of nano-particles of various sizes using Ti:sapphire laser pulses was carried out. Nano-particle formation in plasma plumes of metals like Ag and Cu, expanding in vacuum, has been studied using sub-ns stretched pulses and compared with that generated with the 45 fs compressed laser pulses [11]. The description of the structural analysis of the nano-particle was done through AFM and SEM. Also, the visible light transmission and reflection from the nano-particle film of Ag and Cu on glass substrate showed surface plasmon resonance [12]. As shown in Fig.1, the 45 fs pulses form smaller sized nano-particles, whereas on using the sub-ns pulses, larger nano-particles are produced. The focused laser energy in both the pulses was 30 mJ, with a fluence of  $10^3$  J/cm<sup>2</sup>. Transmission of the Ag nano-particle films formed by the fs and sub-ns pulses shows a dip at  $\sim 410$  nm due to surface plasmon resonance, as seen from Fig.1 (right).



*Fig.1: Ag nano-particles formed by 45 fs pulses with size of 25 nm (Top) and with sub-ns pulses (Bottom) with size of 40 nm. Transmission of Ag nano-particle films formed by fs and sub-ns pulses*

A high absorption of the intense 45 fs laser pulses and efficient x-ray conversion in both soft (water window) and hard x-ray region ( $> 1$  keV) is observed from *in situ* formed clusters. Silver clusters produced by a sub-ns laser pulse were irradiated by 70 mJ, 45 fs laser pulses. We have also carried out experiments for determining the laser parameters and other factors for maximum x-ray yield. The laser absorption and x-ray emission were studied as a function of pre-pulse intensity, main pulse intensity, main pulse duration, and the delay between the pulses. An absorption of the laser light exceeding 70% was observed, resulting in an x-ray yield ( $>1$  keV) of  $\sim 60$   $\mu$ J/ pulse, which corresponds to a conversion efficiency of  $8.5 \times 10^{-2}$  % [13].

Using the same method, the *in situ* formed carbon clusters were used as the target [14]. The water-window x-ray spectral measurements were done using a transmission grating spectrograph. Optimisation of the x-ray yield as a function of the delay and the main pulse duration was done. The pre-pulse intensity was  $10^{12}$  W/cm<sup>2</sup>, and the main pulse intensity was  $3 \times 10^{17}$  W/cm<sup>2</sup>. As seen from Fig. 2 (left), in the no delay case, the enhancement in the x-rays is due to laser interaction with long scale length plasma, and at 8 ns delay, it is due to laser-cluster interaction. It is seen that the technique leads to an enhanced water window x-ray emission (23-44 Å). The conversion efficiency of the laser energy converted to the water- window x-ray emission was also measured and the effect of laser pulse duration on the x-ray yield was also studied, as shown in Fig.2 (right). For a 110 mJ, 45 fs laser pulse, the conversion efficiency in the water window was  $5.8 \times 10^{-2}$  % /sr from planar graphite. For a dual pulse configuration with 8 ns delay between the cluster forming pulse and ultra-short high intensity main pulse, the conversion efficiency from carbon clusters was estimated to be 0.54 % /sr. This x-ray source is an efficient, high repetition rate, and low debris x-ray generation alternative.

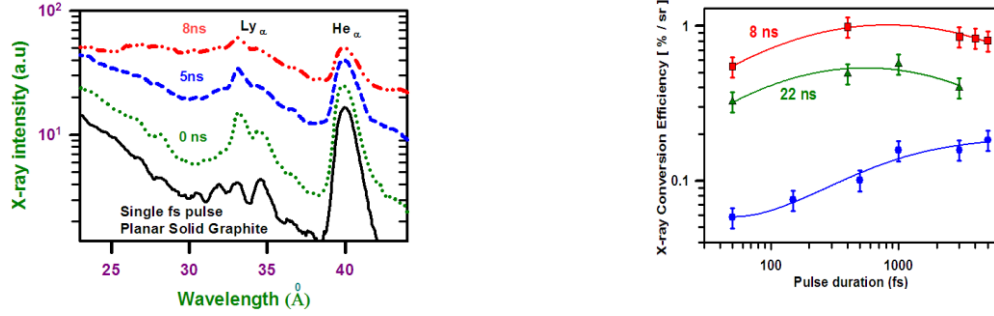


Fig. 2 : X-ray emission spectra from plasma produced from single fs pulse and using dual pulses at a delay of 0 ns, 5 ns and 8 ns. Variation of x-ray yield with main laser pulse duration for : no pre-pulse (closed circles), and dual pulses with a fixed delay of : 8 ns (squares) and 22 ns (triangles).

Next, an experimental study on various sized nano-hole alumina (Fig.3 left) irradiated with intense short pulses was carried out. The effect of laser pulse duration, chirp, and hole size on the hard x-ray yield was studied [15]. The theoretical studies of laser nano-hole interaction were also done. The x-ray yield enhancement from the nano-holes shows an increased coupling of the laser energy to the target. The effect of laser pulse duration on the x-ray emission was also studied, where a peaked behavior was observed. The x-ray peaking pulse duration was found to be proportional to the hole diameter as seen from Fig. 3 (right). The results can be explained by considering the hydrodynamic expansion [16], field enhancement, and void closure on plasma expansion in the nano-holes.

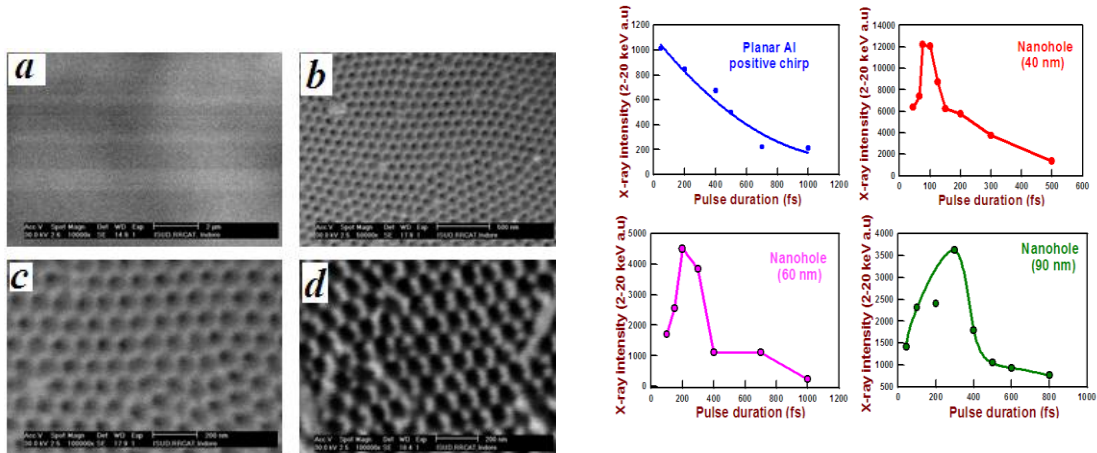


Fig.3 : SEM image of a) Planar Al, rest are nano-hole alumina showing hole size b) ~ 40 nm, c) ~60 nm, d) 90 nm. X-ray intensity vs. pulse duration for various nano-holes of various diameters

We have also observed nearly complete absorption and hard x-ray emission from carbon nano-tubes (CNT) irradiated by intense ultra-short pulses [17]. Absorption studies in CNTs show near complete absorption of the energy of intense ultra-short laser pulses (45 fs, intensity  $\sim 1.6 \times 10^{16} - 2.5 \times 10^{17} \text{ W/cm}^2$ ) in carbon nano-tubes deposited on a planar molybdenum substrate (Fig.4 a, left) which results in enhanced  $K_\alpha$  emission of Mo at 17.5 keV (Fig.4 b) left). The hollow structure of the nano-tube plasma facilitates resonant electric field enhancement at two densities depending on the degree of hollowness ( $a_0/b_0$  the ratio of inner and outer diameter of the nanotube) as shown in Fig 4 a, right. The resonantly enhanced localized field at a density much larger than the critical density  $n_c$  leads to efficient hot electron generation. We identified theoretically a target with a geometry which causes high field enhancement and supports many resonances [18]. The electric field in a nano-tube plasma is shown to be resonantly enhanced at multiple densities (Fig.4 b, right) during the the ionization phase. It is further shown that by a proper choice of hollowness of the nano-tubes resonance can occur right at the solid density and also a continued occurrence of the resonance over a longer time can be achieved.

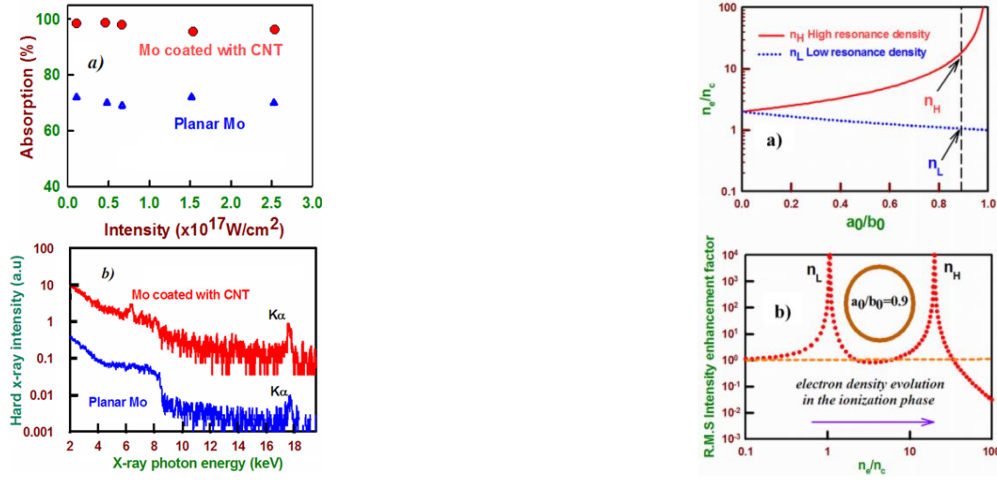


FIG. 4: Left a) Absorption of 45 fs laser pulse in planar Mo (triangles) and Mo coated with CNTs (circles); b) X-ray spectrum from planar Mo and Mo coated with CNTs, (intensity  $\sim 8 \times 10^{16} \text{ W/cm}^2$ ). Right a) The variation of high and low resonance density with degree of hollowness. The dashed vertical line is for the class of CNTs used in our experiments with  $a_0/b_0 = 0.9$ ; b) The r.m.s. intensity enhancement factor inside the nano-tube, compared to the incident intensity of the laser (the inset shows a top view of CNT with a hollowness factor of 0.9).

Experiments have shown that grating targets when irradiated with intense laser pulses lead to enhanced absorption, x-ray emission, and high energy collimated electrons generation. Such grating-like surface structure may also be produced by ultra-short laser pulses on interaction with a solid surface and they are called nano-ripples. Nano-ripples can be another candidate of *in situ* formed nano-structured target. We have explored the possibility of forming nano-ripples on semiconductors with different band gaps and identified conditions which control the width of nano-ripples by varying the laser parameters as seen from Fig 5 (left). Wide band gap material, shorter wavelength, and a dense ambient forms form smaller ripple width [19]. The critical role of the surface plasmons and surface plasma electron density in deciding ripple period is identified to help in controlling the ripple period as seen from Fig.5 (right). The surface plasmon interferes with incident laser light leading to the nano-ripple formation [20].



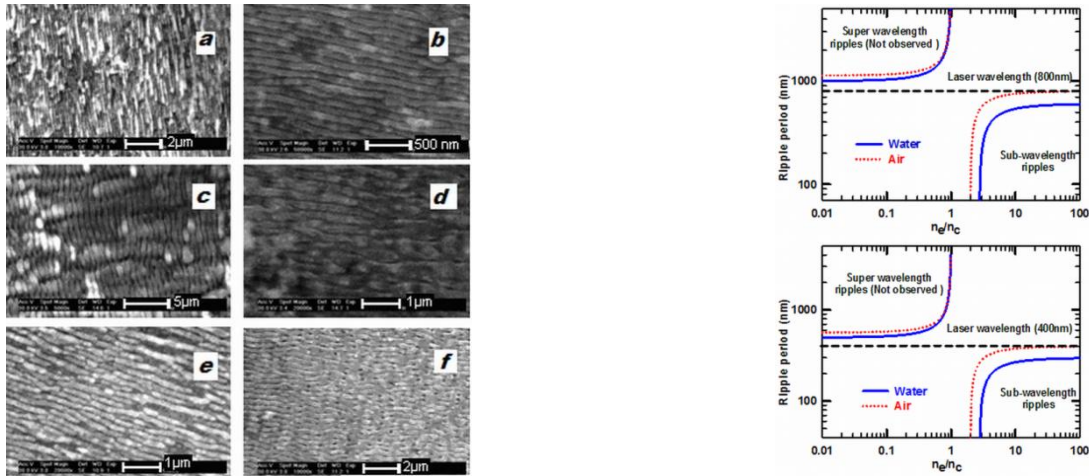


Fig.5 : Nano-ripple formation using 800 nm and 400 nm pulses respectively in wide band gap semiconductors : SiC a) and b); GaP e) and f); and in narrow band gap semiconductor InP c) and d). (The length of the horizontal bar is 2 μm in a), 500 nm in b), 5 μm in c), 1 μm in d), 1 μm in e), and 2 μm in f)). The curves on the right depict the theoretical calculation of nano-ripple period as a function of the electron density for air (dotted line) and water (continuous line), using a) 800 nm pulses and b) 400 nm pulses

## Summary

A detailed study on the absorption of ultra-short, ultra-high intensity laser pulses in planar and various nano-structured targets, and the corresponding x-ray emission from these targets, has been carried out. A new scheme of utilizing the *in situ* formed clusters as targets has been demonstrated. Using various nano-structures like spherical nano-particles, nano-fibers, nano-rods, nano-tubes, and nano-holes, high laser energy absorption has been recorded, with near complete absorption occurring in carbon nano-tubes. The theoretical consideration of the nano-particles has helped in understanding the role of target geometry in enhancement of the electric field, resonances, and the dynamics of the laser nano-structure interaction.

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## BA-004

### Observation Of Poloidal Dust Rotation In Stationary Toroidal Structures

Manjit Kaur, Sayak Bose, P. K. Chattopadhyay, Devendra Sharma, J. Ghosh and Y. C. Saxena

*Institute for Plasma Research, Gandhinagar, 382428, India*

E-mail: angel.manjit@gmail.com

The dust particles are omnipresent in our universe and play a very important role in the formation of planets, stars and solar systems. When kept in plasma they can acquire large negative charge (due to the high mobility of electrons) which enables them to interact with their neighbours very strongly and result into many new phenomena. Stationary self-organized poloidal dust rotation in toroidal structures have been obtained experimentally in parallel plate DC Glow discharge using mono-dispersed MF micro-particles in the absence of any external magnetic field. For exploring the reasons behind the formation of these structures, a thorough mapping of plasma parameters has been carried out using electrical probes. The presence of stationary rotation of dust particles in these structures indicates that the difference between the drag force and repelling electric force is continuously being compensated by the dust friction on neutral gas. The role of the density gradient as one of the major determining factor behind the formation of the rotating structures has been verified experimentally in different ways such as: 1) shifted the overall gradient, 2) reversed the direction of the gradient and 3) generated an additional density gradient.



## I. Introduction

Dust is ubiquitous in nature; comets, interplanetary space, planetary rings (such as Saturn rings, dust streams ejected from Jupiter, etc.) asteroids and aerosols in atmosphere are the few examples where dust exists. When these (micron or sub-micron sized) dust particles are kept in cold plasma, they get charged [1]. The charge on the dust particles is generally negative due to higher mobility of electrons compared to ions. Depending upon the size of the dust particles, their charge can vary from  $10^3 - 10^5 e^-$ , where  $e^-$  represents an electronic charge. The presence of these highly charged particles in the plasma increases the complexity of the whole system. Their presence not only modifies the existing waves and instabilities, but also supports the formation of crystalline structures, voids and self-organized structures, low frequency waves and rotation of dust particles etc.

Dust rotation or so called “vortices” is an interesting fundamental phenomenon which has been observed in many laboratory experiments. Reporting’s on rotation of dust particles and convective vortex motion in the absence of magnetic field in laboratory plasmas as well as plasma under microgravity conditions have been done by many researchers. These vortices may occur in experiments under microgravity conditions [2, 3]. They can also be excited in laboratory experiments by making use of different sized particles (micro-particle size dispersion) [4], by using lasers [5], by generating charge gradients [6], by using biased probe [7] and by creating a gas flow inside the system [8, 9].

We have observed the poloidal dust rotation in self consistently formed stationary toroidal structures in dc glow discharge. But in our case these structures are found to be originating due to the spatial gradient present in the plasma density. The direction of the rotation in these structures depends upon the direction of the spatial density gradient. In this article, we are presenting the observation of poloidal dust rotation and the experimentally determined cause behind their formation. In Section II, a brief description of the experimental setup is given. Experimental results and probable causes for the rotational motion of dust particles are discussed in Section III. The estimation of different forces acting on the dust particles is given in Section IV and their velocity profile analysed with the help of particle image velocimetry (PIV) technique are provided in section V. Finally a brief summary is given in Section VI.

## II. Experimental SetUp

The experiment has been carried out in a cylindrical vessel of 31 cm diameter and 50 cm length as is shown in Figure 1(a). The discharge is produced between two horizontal parallel plate electrodes separated by 4 cm; upper electrode is anode (diameter 10 cm) with edges covered by an insulator and lower electrode is a grounded cathode disk (dia 13 cm). A metal ring with inner diameter of 63 mm and outer diameter of 82 mm has been kept concentrically on the cathode surface. The cathode has provisions for water cooling and a thermocouple is used for monitoring its temperature during experiments.

The discharge voltage is varied from 270 V to 470 V with discharge current ranging from 1 mA to 50 mA. The rotary pump allows a base pressure of 1 Pa. Argon gas pressure is varied between 20 Pa to 350 Pa using a needle valve. No magnetic field is used in these experiments. Mono-dispersed Melamine Formaldehyde particles of diameter  $6.48 \mu\text{m}$  and mass density of  $1.51 \text{ g cm}^{-3}$  have been kept on the lower electrode inside the ring. The levitated dust particles are illuminated by a vertical laser sheet from a 100 mWatt green laser through a cylindrical lens introduced in the system through one of the horizontal radial ports. The laser sheet illuminates the dust torus in the middle section enabling us to see diametrically opposite dust-torus cross sections which look like two vertical dust vortices. The scattered light is captured by an sCMOS camera which has been installed on one of the axial ports. The camera has a resolution of  $2560 \times 2160$  pixels and frame rate of 100 fps. Additionally a DSLR camera is used for viewing as well as taking pictures of the dust-torus through the other axial port. To determine radially resolved floating potential, electron temperature, plasma potential and ion density

profiles at different heights from the cathode surface, a single Langmuir probe of radius 62.5  $\mu\text{m}$  radius and length 5 mm has been used. A representative of the coordinate system for the electrode geometry as well as dust vortex is shown in Fig 1 (b). The direction of gravity is in the negative z direction;  $r$ ,  $\theta$  and  $\phi$  represent the usual toroidal coordinates.

### III. Experimental Results

Discharge is initially produced at low pressure ( $p = 20\text{Pa}$ ) with low discharge current (few mA) and then the pressure is steadily increased to 100 Pa. In a typical sequence of observations at 20 Pa pressure, the levitated dust particles are found to oscillate vertically in the central region inside the metallic ring with the cathode sheath at this pressure being more than 1 cm thick. When pressure is increased to 50 Pa, cathode sheath thickness decreases and a stationary three dimensional crystalline structure is visible at the centre and thick dust clouds of very fine particles are visible above the metallic ring surface. As we increase the pressure up to 69 Pa, cathode sheath thickness decreases further and the mono-dispersed dust particles form slanted horizontal sheets above the sheath, formed above the metallic ring surface in addition to stationary three dimensional crystalline structures at the centre. Up on increasing the pressure ( $\sim 70\text{ Pa}$ ), the dust particles start showing mild rotation in the vertical plane. With further increase in pressure (76 Pa), the dust number density as well as the extent of vertical rotation in the cloud increases; the central three dimensional crystalline structures disappear. At 100 Pa, we see a clear vertical rotation of the dust particles in the clouds shown in Fig 2. When the laser light is scanned in the horizontal plane, the positions of two rotating dust clouds get closer and closer and finally merge. The toroidal nature arises because of the circular symmetry of the electrode and the metallic ring.

To determine the cause behind the formation of these structures, the plasma conditions are determined at different horizontal as well as vertical locations using a Langmuir probe. The results show a peculiar behaviour of the plasma density at the locations where the rotating dust structures get formed as shown in Fig 4. It is found that the radial plasma density profile in presence of dust particles differs significantly from the radial density profile in the absence of the dust particles inside the system. Presence of dust particles (which are dielectric) inside the ring makes the discharge even more concentrated near the metal ring and results in a sharper density gradient near the metallic ring towards the centre. Also the density is high at fewer heights above the cathode surface and decreases as the height from the cathode surface increases. One more thing which is very interesting is that the dust clouds get formed only at the locations where the density gradient is present. Under the experimental conditions we do not get any levitation of the dust particles other than the rotating clouds. Thus we find it to be very interesting to know whether plasma density gradient plays any role in the formation of rotating dust structures.

### IV. Different Forces

As it has been discussed in the introduction, the dust rotation can occur as a result of different forces acting on the dust particles when kept in plasma. So to precisely find out the cause behind the formation of these vortices, the different forces acting on the dust particles under experimental condition is discussed. One of the main dominating forces is the force due to gravity which comes into picture because of the finite mass of the dust particles. The force due to gravity on the micro-particles is of the order of  $2.15 \times 10^{-12}\text{ N}$  and acts downwards. The charge on the dust particles is estimated to be around  $4.0 \times 10^4\text{ e}^-$  for Argon discharge. To levitate these micron sized particles, minimum sheath electric field of the order of  $3.36\text{ Vcm}^{-1}$  is required. Other than gravity and sheath electric field, ion drag force is another dominant force which the dust particles experience. The directed ion flow towards the cathode surface drags the dust particles present in their way. For an ion density of  $5 \times 10^8\text{ cm}^{-3}$  and electron temperature 3 eV its value can be estimated as to be  $1.1 \times 10^{-12}\text{ N}$ .

Since the ion drag force is proportional to the plasma density which has a sharp radial density gradient, it also has a strong radial gradient.

Cathode heating takes place due to the ion bombardment on cathode surface and it increases with the discharge current. Presence of finite temperature gradient can give rise to thermo-phoretic force which may affect dust motion depending on its relative magnitude compared to other forces. In our experiments, the cathode temperature can attain a value from 40°C to 65°C depending upon the discharge current without water cooling. We observe it takes more than an hour for the cathode temperature to increase up to the maximum temperature depending upon the discharge current; for example, it takes more than two hours to reach 65°C for a discharge current of 25 mA at a pressure of 120 Pa. However, we do our experiment within a short time after producing the discharge and observe the rotation of dust cloud. We even do active water cooling of cathode sometimes and don't let the cathode temperature go above 28°C. There also we observe the dust rotation. Active water cooling would not produce any significant temperature gradient. Even if a temperature gradient of  $\nabla T \approx 1 \text{ K cm}^{-1}$  is present at all, the thermophoretic force comes out to be much less compared to the other plasma forces and this fact devoid its importance as the cause of dust rotation. For our experiments, the working pressure range is too high for the existence of thermal creep flow and too low for the existence of free convection.

Motion of dust particles can also be affected by neutral flow. In order to avoid neutral flow from affecting the dust motion, Argon gas is fed through the bottom port which is connected also to the rotary pump via a gate valve for evacuating the system. So we expect only diffused gas to enter the system. During the experiments, on closing both the gate valve at the mouth of the rotary pump and the needle valve (being used for feeding the gas) simultaneously, we do not observe any significant effect on the dust cloud formation and rotation. This observation rules out the presence of any directed flow of gas inside the system and any effect of gas flow on the dynamics of the dust cloud. Due to the diffused gas entering the system, the neutral gas particles can be assumed to be at rest (with no directed flow) and acting as frictional background on the dust particles resisting their motion, then the value of the neutral drag (which is proportional to the instantaneous velocity of the dust particle) can be estimated as  $7 \times 10^{-13} \text{ N}$  for dust velocity of  $2 \text{ cm s}^{-1}$  and neutral gas density of  $3 \times 10^{16} \text{ cm}^{-3}$  at a pressure of 130 Pa.

Thus after considering all the forces, we can conclude that the main forces responsible for dust rotation in our system are downward directed sheared ion drag force and neutral drag force along with the force due to sheath electric field and gravity. The dust particles in the clouds are observed to be flowing towards the cathode surface against the sheath electric field where the ion density and hence the ion drag force is maximum. But due to diffusion of ions towards lower density side (centre), the dust particles do not simply go towards the cathode surface but they also move towards the centre, where they experience the strong sheath electric field and hence get repelled upwards.

In other words, the above observations of dust cloud motion can be interpreted in the simplest form as follows. The levitated dust cloud is confined effectively by a combination of the non-uniform electrostatic space potential present above the bottom electrode and the gravitational field acting downwards. This is subjected to additional non-conservative forces, e.g., the ion-drag force, neutral friction, etc. In the conditions where a spatial gradient is present, the non-conservative force fields across the dust cloud dimensions, the dust cloud must experience a torque in the regime where the dust cloud behaves like a condensed medium. In an alternate regime where the dust cloud behaves like a fluid, the dust fluid interacts with the vorticity of the dragging fluid (ions, neutrals in the present set up). Both these mechanisms can produce an effective rotation of the dust cloud similar to what is observed in the present experiment.

The role of the density gradient as one of the major determining factor behind the formation of the rotating structures is verified experimentally in different ways. The position of the density gradient is shifted radial which resulted into a shift in the position of the dust cloud. Then the direction of the

density gradient is reversed which then resulted into the reversal in the direction of rotation of the dust particles in the cloud. An additional density gradient is created which resulted into the generation of an additional rotating dust cloud. All these results strengthen the explanation provided by us for the cause of the rotation of the dust particles.

## V. Particle Velocity Profile

A snap shot of the particle image taken with the help of digital camera is shown in Fig 4 (a). Under same conditions, a number of sequences of images are stored with the help of sCMOS camera. From these images using PIV, particle streaming velocity is measured. The velocity profile can be reconstructed by performing cross-correlation between two consecutive images. PIV analysis is carried out using MATLAB based free software called openPIV. A two-dimensional velocity profile of the rotating dust cloud in the r-z plane measured using this software is shown in Fig 4 (b). The particle motion is recorded at a frame rate of 200 frames/sec. Here the interrogation window size is taken as 32x32 with a 50% overlapping. Flow velocity is seen to be rotational as indicated by the velocity vectors. It has been observed that the dust velocity is not uniform throughout the cloud rotating poloidally. As the dust particles move towards the bottom their velocity increases and attain a peak value at the bottom. Incidentally these are the regions where ion drag force (which depends upon the plasma density) is also more. From the variation of plasma density shown in Fig 3, it is seen that plasma density is maximum close to the cathode (at a height of  $\sim 7$  mm from cathode surface) and it decreases as the height from the cathode surface increases. As the dust particles move towards the cathode, the ion drag force on the dust particles increases and hence the velocity of dust particles also increases. As the dust particles start moving in the upward direction, their velocity starts decreasing and reaches a minimum value towards the top position of the dust cloud and again increases in going towards the regions of high ion drag. Thus dust particle velocity profile is also in consideration with the sheared ion drag force as its originating factor. In the presented observation the dust particles are moving in the vertical plane with a velocity of around 4 cm/sec towards the bottom electrode as shown in Fig 4 (b). The dust velocity has been found to be varying radially too in the cloud. It is minimum at the centre of the cloud and increases as one moves away from the centre and maximum at the edges of the cloud.

## VI. Summary

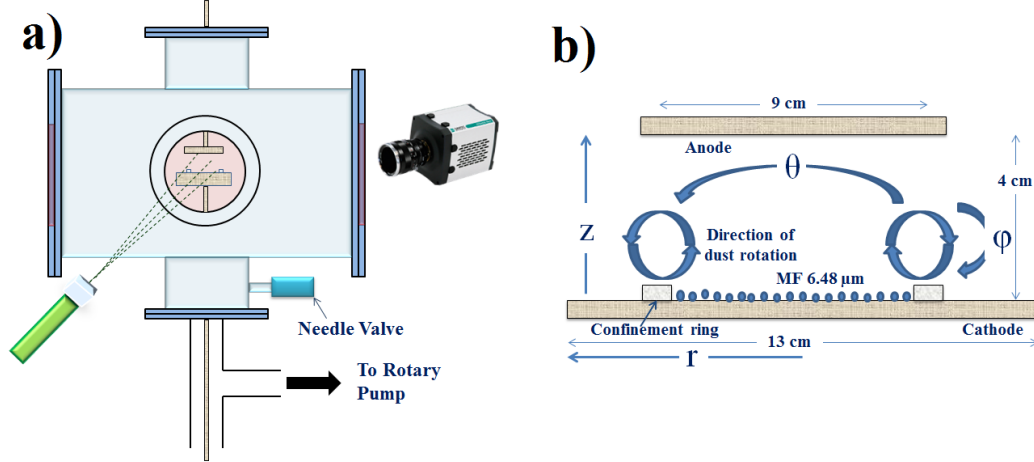
In dc glow discharge plasma we observe and study of the vertical rotation of dust particles in absence of any external magnetic field. A concentric circular ring is placed on top of the lower electrode, the cathode and dust particles are placed on the cathode within the metallic ring. We have been able to observe a stable dust cloud rotation in vertical plane which is toroidally continuous. Plasma behaviour is analysed with 2D profile measurements of plasma density, temperature and floating potential with the help of electrical probes. Probe measurements reveal that the plasma density has a sharp radial density gradient which causes a shear in the ion drag force pushing the dust particles downwards against the sheath electric field in the regions of high ion drag force and upward in the regions with low values of ion drag force because of finite torque experienced by the dust cloud. PIV analysis is also performed to estimate the velocity field profile of this of vortex rotations.

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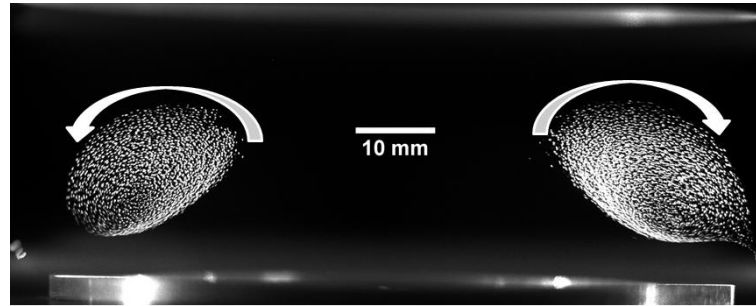
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## Figures

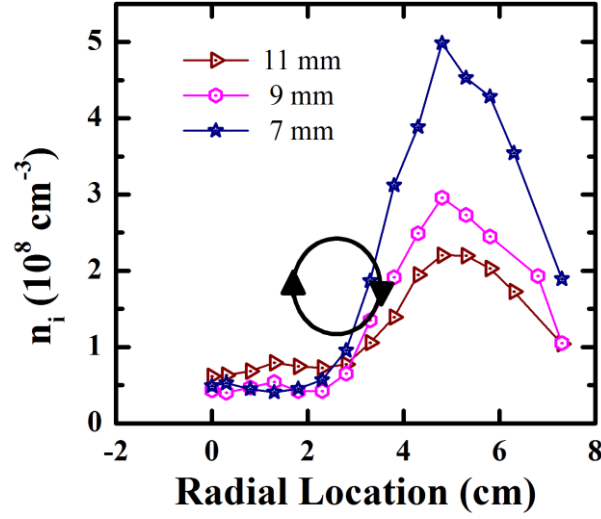


**Fig 1 :** (a) Schematic drawing of the Experimental set-up.

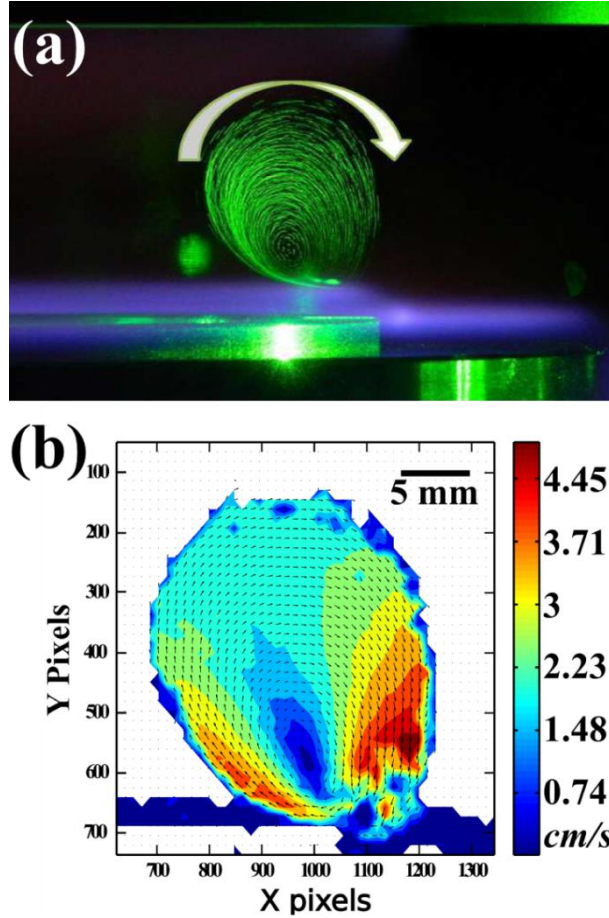
(b) Schematic of the co-ordinate system. Here  $z$  represents the direction opposite to  $\vec{g}$ ,  $r$  is directed in the direction of the radius of the electrodes from its axes,  $\theta$  represents the toroidal/azimuthal direction and  $\phi$  represents the poloidal direction (direction of rotation of the dust particles).



**Fig 2 :** Image of the cross section of the dust torus at 110 Pa. The laser sheet is passed along the diameter of the cathode through the side radial port and the camera is placed perpendicular through the axial port.



**Fig 3 :** The radial profile of the ion density at different heights from the cathode surface in the presence of the dust.



**Fig 4 :** (a) The image of the poloidal cross-section of the dust torus taken using a DSLR camera while the laser sheet is passed along the diameter of torus and (b) Velocity vectors show the direction of rotation of the dust particles. The colourbar shows the value of dust velocity in  $\text{cm s}^{-1}$ .

**BA-005**

**Dielectric Barrier Discharge Based Plasma Excimer Sources For Water Sterilization Application**

Pooja Gulati, U N Pal, M. Kumar and Ram Prakash

<sup>1</sup>*CSIR-Central Electronics Engineering Research Institute (CSIR-CEERI), Pilani,  
Rajasthan-333031*

<sup>2</sup>*Banasthali University, Banasthali-304022, Rajasthan*

E-mail: pgulati1512@gmail.com

Non-equilibrium and non-thermal plasmas generated by dielectric barrier discharge (DBD) are widely used as ultraviolet (UV) and vacuum ultraviolet (VUV) light sources. Such light sources are especially applicable in biological sterilization, material deposition in microelectronics, plasma display panels, destruction of pollutants, lighting, etc. The broad research has been focused on the efficiency enhancement, cost effectiveness and novel applications of the DBD devices. The present research is devoted to the electrical and optical analysis of a few innovative volume discharge (VD) configuration of the DBD based light sources to characterize the discharge parameters and optimize the VUV/UV light efficiency so as to apply the prototype source for water treatment application. Three DBD geometries, i.e., parallel plate geometry, capillary source and a single barrier source have been designed and developed. The electrical and spectroscopic characterization along with particle-in-cell (PIC) simulations have been performed to characterize them. The number of experiments have been performed with different gases at various operating conditions in order to enhance the VUV/UV sterilization efficiency. Eventually, a DBD source with binary mixture of rare-gas and fractional halide has been optimized for water sterilization application and 100 % deactivation of E-coli bacteria has been achieved in less than 1 minute UV exposure.

## **1. INTRODUCTION**

The DBD discharge finds number of industrial applications, such as, ozone generation, CO<sub>2</sub> lasers, production of Ultraviolet (UV)/ Vacuum Ultraviolet (VUV) radiations from excimer lamps, etc. The UV/VUV emission from the DBD is the root of the mercury free sources like flat panels, fluorescent lamps, etc. [1]. It also promises to develop mercury free water purification sources. The impure and polluted water produce many waterborne diseases. Each of existing technologies suffers from various limitations that have precluded their adoption for small scale water purification. The sterilization effects of UV radiation are well known, and low-pressure mercury vapor lamps are commonly used for water purification at the industrial level. The UV radiation causes germicide as a result of photochemical damage of DNA and RNA that prevent reproduction of the organism.

At present the mercury lamp based systems use UV light radiation at peak germicidal wavelength (254nm) for water purification. However, the mercury lamps sometime lead to catastrophic explosion and the toxic mercury mixing with the water causes serious health problems. Hence the development of new generations of mercury free disinfection and sterilization light sources for water purification is the key challenge at present.

The DBD based excimers are the best alternative for the generation of UV/VUV radiation either with rare gases or with rare gas mixture of halogens [1]. Furthermore, the DBD plasmas have potential adoptability for industrial applications because of their simplicity or the geometric freedom, high efficiency, low cost, etc. In this work an effort has been made to show mercury free DBD based water

sterilization system. We have reported that the DBD plasma has considerable impact on Escherichia coli (E-coli) bacteria, which is the most lethal range of bacteria for human health. Prior to this work, two geometries of DBD sources that includes parallel plate geometry and capillary source have been developed and analyzed for the measurement of the basic plasma parameters. Based on the results obtained from the discharge parameter characterization, a more practical DBD source has been developed for water sterilization application, which has shown 100 % deactivation of E-coli bacteria in the water in very short time.

## 2. EXPERIMENTAL ARRANGEMENT

### *Parallel plate double barrier DBD*

The DBD geometry of the discharge consists of two parallel plate electrodes which are covered by the dielectric barriers made of quartz discs with 1 mm thickness and 20 mm in radius. The quartz discs and the metal electrodes are in immediate contact with each other. The space between the discharge electrodes has been varied by connecting the motion feed-through with one of the electrode. The upper and lower electrode sub-assemblies are covered by Teflon (TFE) to avoid long path arcing in the vacuum chamber shown in fig. 1(a).

### *Capillary DBD source*

In this DBD cell, the gas gap is 2 mm. This cylindrical capillary source is made from quartz. Two strips made of Cusil alloy having width 1.5 mm are pasted over the diagonally opposite portion of the tube. The quartz tube of 100 mm length is fabricated with the 16 CF flange arrangement as shown in fig. 1(b).

### *Single Barrier DBD configuration*

It consists of a quartz tube, which acts as a dielectric barrier with thickness 1.5 mm, inner dia. 19 mm and outer dia. 22 mm along with length 150 mm. The titanium gold linear strips of 2 mm wide have been grown on the diametrical opposite portions of outer surface by using magnetron sputtering process. A helical tungsten electrode of thickness 0.75mm and dia. 10mm has been used as cathode for the application of high voltage whereasthe outer striped electrodes are grounded (see in fig. 1(c)).

### *Experimental Setup:*

The schematic diagram of the experimental system is shown in fig.2. A high voltage unipolar-pulse varying from 1 kV to 5 kV with variable frequency and variable pulse width has been used to strike the discharge in the DBD.

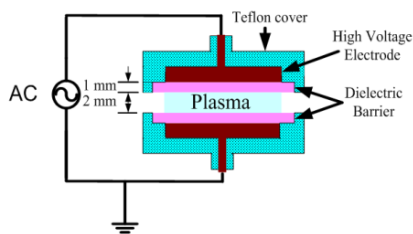


Fig. 1(a) Schematic view of Parallel plate arrangement

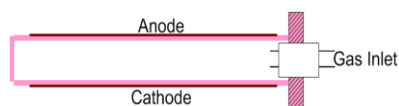


Fig. 1(b) Fig. 2.1. Schematic view of Capillary DBD source



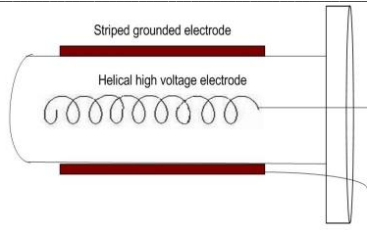


Fig. 1(c) Schematic front view of single barrier DBD source

The developed individual DBD source has been placed inside the ultra-high vacuum chamber for its characterization. The chamber has been pumped down to  $10^{-5}$  mbar and the base pressure is kept at  $\sim 1 \times 10^{-5}$  mbar. At room temperature, the operating helium and combination of xenon and chlorine of 99.9% purity has been filled in the DBD sources and flushed few times from the chamber to mitigate the background gases effect. The total current and applied voltage waveforms are visualized by means of a four-channel Tektronics DPO 4054 digital oscilloscope. The visible, UV and VUV spectrometers have been mounted separately with the experimental chamber for the spectroscopic observations of the discharge.

### 3. Results:

In all the three developed DBD sources *in-situ* diagnostics are not possible due to very thin and small geometries. So, the most obvious choice is to go for electrical and spectroscopic characterization and particle-in-cell (PIC) simulations. The electrical circuit modeling [2] has been utilized to measure internal electrical parameters, such as, discharge gas voltage, dielectric barrier voltage, memory voltage, discharge current, discharge impedance, etc. from the I-V characteristics of the discharge. The discharge current and gas gap voltage obtained from the electrical analysis have also been utilized for electron plasma density measurements using discharge resistivity method [3]. The estimated electron plasma density for the parallel plate DBD and capillary DBD is found to be in the range of  $10^{10}$  -  $10^{11}$   $\text{cm}^{-3}$  whereas in case of the single barrier DBD it is  $\sim 10^{12}$   $\text{cm}^{-3}$  [4-5].

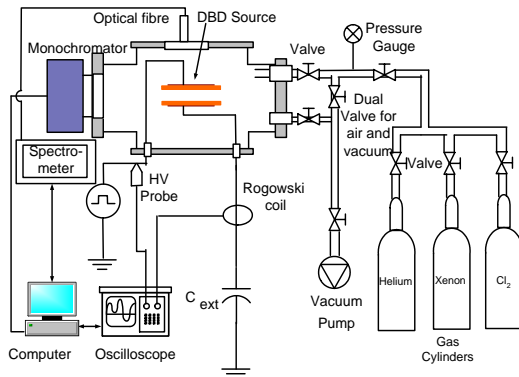


Fig. 2. Schematic view of the experimental set-up

The physics behind the excimer formation to develop an efficient VUV/UV DBD source also require understanding of some of the basic plasma parameters, which are not possible to measure using electrical analysis. Hence OES diagnostic measurements and PIC simulations have been carried out.

A glow discharge observed from the parallel plate geometry and capillary structure of the DBD is fed to the spectrometer. To estimate the electron plasma temperature and density, the collisional-radiative (CR)-model based line-ratio technique has been used. The line-ratios  $7281.3\text{\AA}$  ( $2^1\text{P}-3^1\text{S}$ ) /  $7065.1\text{\AA}$  ( $2^3\text{P}-3^3\text{S}$ ) and  $6678.1\text{\AA}$  ( $2^1\text{P}-3^1\text{D}$ ) /  $7281.3\text{\AA}$  ( $2^1\text{P}-3^1\text{S}$ ) are identified and used for plasma parameter measurements from the experimentally obtained ratios. It is to be emphasized that the line ratio HeI  $6678.1\text{\AA}$  /  $7281.3\text{\AA}$  is more sensitive to electron density and insensitive to temperature in the density

range  $10^{11}$  to  $10^{13}$   $\text{cm}^{-3}$ . The results of the obtained electron plasma temperature and density at different working pressures are shown in figs. 3(a) and (b), respectively, for parallel plate geometry and the similar patterns are observed for capillary source.

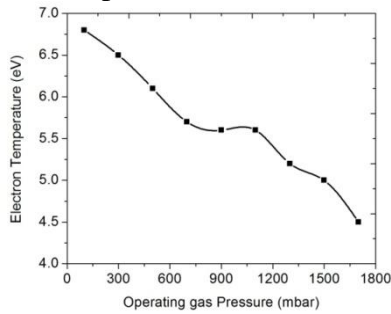


Fig.3(a) Variation of the electron temperature with varying gas pressure helium at constant applied voltage and frequency

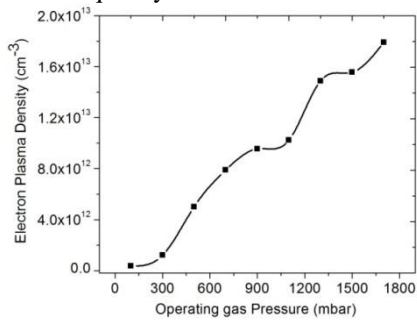


Fig.3(b) Variation in electron density with varying gas pressure of helium at constant applied voltage and frequency

For the PIC simulations the symmetrical 2-D geometry has been designed for the parallel plate and capillary source. To begin the simulation, some seed electrons  $\sim 10^3 \text{ cm}^{-3}$  have been taken into account that is due to the basic fact that most gases under normal temperature and pressure condition contains  $\sim 10^3 \text{ cm}^{-3}$  electrons and ions due to ultraviolet, cosmic radiations, radioactivity, etc. It is found that when the applied potential reaches to the ignition voltage or breakdown voltage, the discharge occurs and it remains there for some nano-second time scale. The PIC simulation provided an opportunity to predict the electron plasma density during the discharge and every point in the discharge space that is usually not measurable during the experimentations. The simulated axial electric field patterns at the same operating conditions as per the experimentations are shown in fig. 4(a) and (b) at different working helium gas pressures. These have been further analyzed using ICCD imaging to predict the transient discharge to compare with the simulations.

Additionally, the obtained average densities of electrons inside the gap through simulations are compared with the spectroscopic line ratio measurements and discharge resistivity method measurements at the same operating conditions which are found to be in close agreement with each other [5].

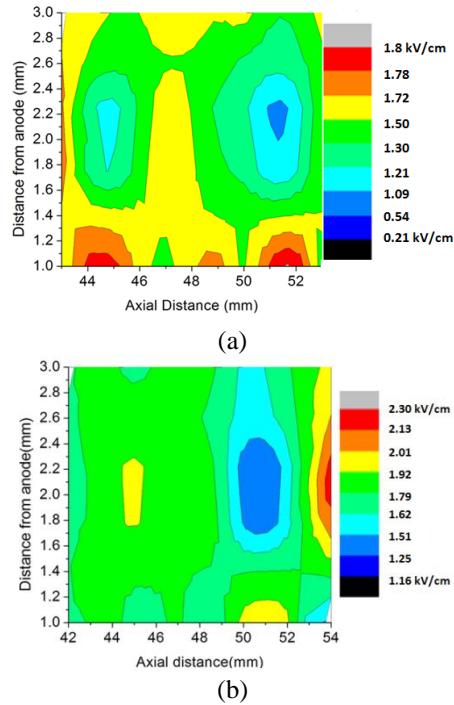
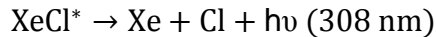
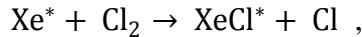


Fig. 4. Axial electric field at different working pressure.  
(a) at 400 mbar. (b) at 800 mbar.

On the basis of the basic discharge and plasma parameters study a more practical single barrier excimer/exciple source has been developed for water purification application. The active plasma discharge zone area is 11122 mm<sup>2</sup>. Different compositions of the gases (Xe, Cl<sub>2</sub>) and (Xe, Cl<sub>2</sub>, Air) have been introduced in the exciple source. The discharge has been operated in the working pressure range 100 mbar to 260 mbar at applied pulse voltage 1-5kV with pulse width 2 μm and operating frequencies 10-30 kHz. There are many atomic and molecular processes involved in the DBD discharge considering rare gas and halides. The production of UV/VUV radiation starts with the excitation, ionization and dissociation process of the rare gas atom and the halogen molecule while they make excited dimmers either purely from rare gas or admixture with halides. The observed exciple molecule XeCl\* is dominantly produced by the so-called Harpoon reaction and 3-body reaction and transition is expressed by,



The Harpoon reaction is expressed as,



whereas 3-body reaction is expressed as,



Here M is collisional third partner, which is basically an atom or molecule of working mixture.

To optimize the composition of the gas mixture of the rare gas and the halogen contents, the number of experiments has been carried out. Research grade xenon with a stated purity of 99.999% as a base gas and fractional chlorine has been introduced for dimer formation. The exciple of XeCl\*(308 nm) is promptly observed during the discharge and is shown in Fig. 5.

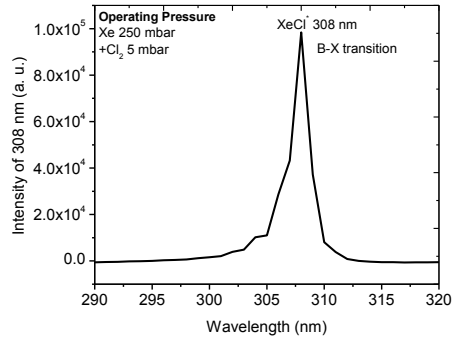


Fig. 5. Observed emission spectrum for the XeCl\* (308 nm) excimer with a gas mixture of xenon at 250 mbar and 2% of chlorine.

It has been observed that the radiation is maximum at 2% chlorine and with the increase in chlorine content, the UV-B radiation decreases continuously. It is because at higher concentration of the chlorine, quenching mechanism of XeCl\* excimer becomes dominant (see fig. 6).

For cost reduction in the VUV/UV excimer/excimer source, the experiments have also been carried out with the admixture of air and to elucidate the effect in the experiment, varied amount of air has been added stepwise in the less pressure of binary mixture of xenon and chlorine. It is significant to note that at around 47% of air admixture in the working pressure of Xe and chlorine keeping total pressure ~165 mbar (see Fig.6.), the level of UV-B photon radiation is same as measured for binary mixture of xenon and chlorine separately with operating pressure ~250 mbar [6].

The enhancement in the radiation is mainly due to the hydroxyl molecular band peaking at wavelength 309 nm ( $A^2\Sigma^+, v=0-X^2\Pi, v'=0$ ) generated from the moisture present in the air. After the optimization, the DBD lamp has been pinched-off at optimized working conditions and has been used for the germicidal studies in the UV water treatment.

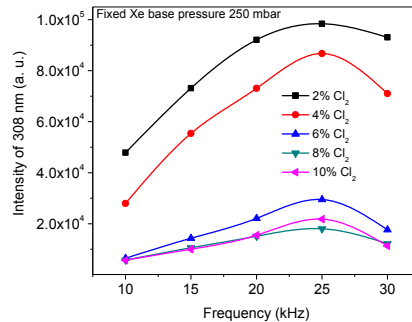


Fig. 6. Intensity variation of 308 nm line at 105 mbar Xe/Cl<sub>2</sub> pressure & then air admixture

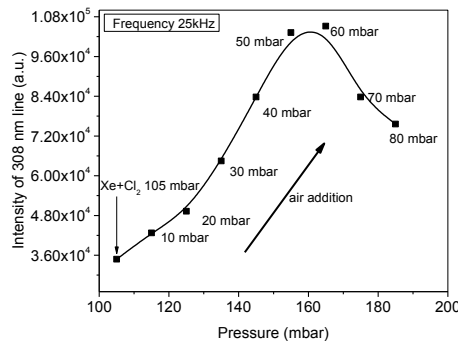


Fig. 6. Intensity variation of 308 nm line at 105 mbar Xe/Cl<sub>2</sub> pressure & then air admixture

The sterilization studies for water has been carried out using UV exposure of UV-B (308 nm) radiation to the water from the developed VUV/UV excimer/exciple DBD source. For the experiment *E. coli* has been chosen for the study. In this study, stock culture with  $25 \times 10^4$  CFU/ml (serially diluted culture ( $10^{-5}$ )) is selected and diluted it to a final volume of 600 ml (to make bacterial water) in experimental unit. After a plasma exposure time of five minutes, the reduction of three orders of magnitude in the population of *E. coli* is observed. A plasma treatment of 15 minutes of sample reduces the population of *E. coli* to approximately 30 CFU/ml, i.e., reduction of four orders of magnitude. It is also found that in 20 min. the samples underwent complete sterilization and no bacteria cells were left alive. The observed efficiency of the *E. coli* deactivation using the developed UV-B excimer/exciple VUV/UV source is more than 99 % even at 5 minute exposure time. More recently we have developed UV-C XeI\* (253 nm) excimer source and more than 100 % deactivation of *E. coli* bacteria has been achieved in less than a minute of UV exposure.

### Conclusion:

A few new methodologies have been worked out to estimate the plasma and electrical parameters from the PIC simulations and the results obtained from the line-of-sight average spectroscopic measurements and electrical analysis are found to be in close agreement with each other. Ultimately, two application oriented DBD based exciple sources are developed. Hundred percent deactivation of *E. coli* bacteria has been achieved in less than a minute of UV exposure, which gives us great motivation to establish this as an environment friendly technology in place of mercury based UV light sources.

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## Studies on Laser Produced Transient Photo-Plasma in Electromagnetic Field

Biswajit Jana

*Laser and Plasma Technology Division, Bhabha Atomic Research Centre, Mumbai-400085*

E-mail : biswajit@barc.gov.in

### Abstract

Plasma produced through resonant photoionization method by shining laser pulses onto a collimated atomic beam is known as photoplasma. The photoplasma is a special class of plasma having unique

characteristics different from the conventionally produced thermal plasma and discharge plasma. It plays an important role in applications like laser based isotope separation through atomic route, purification of materials in nuclear and medical applications, laser based ion source etc. Usually the photoplasma is generated within a time scale of nano-sec (i.e. laser pulse duration  $\sim 10$  ns) while it lasts for few tens of microseconds ranges from 10-100  $\mu$ s. During its decay under the external electric field, the photoplasma passes through the various transient stages. The present work mainly focuses on evolution of the finite-sized transient photoplasma in an electrostatic field. It investigates the various physical processes involved in the transient decay of the photoplasma and studies the process of photoion extraction from the photoplasma in the electrostatic ion-extractors. Starting from the atomic beam generation and photoplasma production through resonant photoionization, the evolutions of photoplasma in the electrostatic ion-extractors has been investigated in details.

Both experiments and numerical simulations have been carried out to study the motion of barium photoplasma in the electrostatic field. The entire works are broadly divided in two parts. The first part describes about the generation of the finite-sized barium photoplasma inside the long wedge-shaped atomic beam through two-step resonant photoionization method. The second part discusses the motion of finite-sized photoplasma over a wide density range from  $10^{12}$  m<sup>-3</sup> to  $10^{16}$  m<sup>-3</sup> under the electrostatic field in different field configurations. In experiments, barium element was chosen because of two reasons. The barium has reasonable good vapor pressure and the atomic beam of high neutral atom density is easily generated at an elevated temperature of  $\sim 1000$  K. Its low lying electronic energy levels have large excitation cross-sections that are readily accessed by the wavelengths of the commercial lasers to produce the photoplasma through two-step resonant photoionization.

For the study of photoplasma in the applications of laser isotope separation and material purification, a long wedge-shaped high atom density effusive atomic beam is requisite for better throughput of the process. A linear array multichannel atom source is designed to produce a long collimated atomic beam. Based on the design parameters, the crucible lid has been fabricated with the collinear array of multi-channels. The crucible containing small pieces of barium is heated by a resistively heated furnace and generates the long wedge-shaped collimated atomic beam. The vapor flow through the channels under collision free region is studied using a set of analytical expressions. At a height of  $\sim 70$  mm from the crucible lid (i.e. at the laser atom interaction region), the various parameters of the atomic beam like its length and width, the neutral atom density and its distribution along the length are calculated. An optical absorption set-up based on hollow cathode lamp is developed and integrated with the existing experimental system. With this setup the line of sight integrated average barium atom density in the atomic beam is measured at different crucible temperature. The measured values are compared with the theoretically calculated number density and they agree in well.

The barium photoplasma has been generated by shining laser pulses onto the collimated atomic beam of barium through two-step resonant photoionization method. In first step, the Ba atoms get resonantly excited from their ground state ( $6s_2: ^1s_0$ ) to the excited state ( $6s6p: ^1p_1$ ) by 553.5 nm radiation. In second step, the excited atoms are subsequently ionized from the excited state ( $6s6p: ^1p_1$ ) to continuum by the 355 nm radiation of Nd: YAG laser. The two laser beams are propagated collinearly and overlapped with the wedge-shaped atomic beam to generate the photoplasma. A rate equations based model is developed to study the kinetics of two-step photoionization process in the optically thick atomic medium of barium. Numerical simulations are carried out to estimate the ionization yield for the time varying Gaussian shaped laser pulses. The required energy density of the laser pulse to saturate the excitation transition throughout the thick medium of barium is estimated. The effect of the optical delay between the laser beams on the ionization yield is also simulated. The

calculated ionization yields from the simulations are compared with the experimentally measured values. The value matches in good agreement and it validates the model.

The photoplasma is transient or pulsed in nature. To study its transient decay in an electromagnetic field, a one dimensional model based on PIC (particle-in-cell) technique is developed. The photoions and electrons of the photoplasma are replaced by super-particles. Their motions are simulated within the computational volume (i.e. a linear box in one dimension) which is discretized into grids by sets of uniformly spaced points. At grid points, the charge densities are calculated from the particle's positions. Poisson equation is solved to get the potentials at different grid points using the charge densities. The forces on the particles are calculated using the Lorentz equation. The velocity and position of the particles are estimated by solving Newton's equation of motion using the leap-frog integration method. The iterative execution of the above steps selfconsistently calculates the electric field and describes the evolution of photoplasma in the electromagnetic field. Thus the 1d PIC model is developed to understand the transient response of the photoplasma to the externally applied field.

Though the plasma is a collection of charge particles, but it shows a complex behavior under the external electric field that is completely different from that of a single charge particle. To understand the transition of the plasma behavior from its independent particle motion to its collective effect, the motion of a low density photoplasma has been studied in a linear electrostatic potential well created by plate-grid-plate geometry. The results obtained from the PIC model is compared with the experimentally observed photoionization signal. The observations shows that for density range  $\sim 1 \times 10^{13}$  to  $5 \times 10^{14} \text{ m}^{-3}$ , the applied electric field  $\leq 10^4 \text{ V/m}$  is sufficient to remove all the electrons from the photoplasma within a time of few ns leaving behind a photoion bunch. The photoion bunch evolves in the potential well created by the plate-grid-plate geometry. A damped oscillation is observed on the current signal recorded on grid electrode. The structure is explained by the single particle behavior of the photoion bunch. For densities  $> 3 \times 10^{14} \text{ m}^{-3}$ , the oscillation frequency depends on both the externally applied electric field and the internal field produced by space charge interactions among the charge particles. As the plasma density increases, the collective behavior of the plasma dominates and its dynamics is governed by the space charge interactions.

During its transient decay in an electrostatic field, the photoplasma passes through various physical processes which are investigated with the help of 1d PIC model. The mono-energetic electrons in the photoplasma get equilibrated through the electron-electron collisions. The plasma space potential initially oscillates and attains a stable value which is near to the anode potential. Within a few cycles of plasma electron interactions, an electron sheath is formed between the anode and the plasma boundary. The plasma is polarized in a fashion so that the internal field due to the space charge interactions shields the applied external field. The entire applied potential drops between the plasma and the cathode. Towards the cathode, the photoions move and form an ion sheath. The photoion motion is governed by the space charge limited Child-Langmuir law. At the plasma-sheath boundary, the Child-Langmuir flux in the sheath region is supplied by the Bohm flux in the plasma region. The difference between the Bohm flux and the Child-Langmuir flux at the sheath boundary governs the motion of the plasma-sheath boundary. Towards the anode, the finitesized plasma expands due to the ambipolar diffusion. As the photoplasma decays with time, its density decreases. The plasma sheath boundary moves towards the plasma region i.e. in opposite direction of the photoion motion to balance the Child-Langmuir flux. Initially the sheath boundary moves fast, stagnates and again moves slowly away from the cathode surface. As the density further decreases with time, the plasma (collections of charge particles) is unable to shield the external potential and hence it behaves like single charge particle.

As the density in photoplasma increases, the finite-sized photoplasma expands in two dimensions. To know the two dimensional features of photoplasma evolutions under the electric field, its motion has been studied in the electrostatic ion extractor produced by parallel plate geometry. The distributions of photoions are measured using a series of Faraday cups placed behind the cathode along the central vertical line. The ions audit at different locations are also examined both experimentally and using 2d PIC model. Several processes like bulk motion, ambipolar diffusion, bounded diffusion, Coulomb repulsion and Child–Langmuir flux involved in the process of photoion extraction from the photoplasma are identified. Their relative contributions are also quantified with the help of photoionization signals recorded on electrode and Faraday cups. The results has compared with the 2d PIC simulations. These processes are superimposed and their relative magnitudes decide the evolution of the photoions. When the external field dominates, a significant fraction of photoions reach the cathode with negligible vertical spread and the plasma motion can be considered as one-dimensional. However, when the plasma collective effects are dominant, then the different mechanisms become comparable and the photoplasma expands in two dimensions. The spread of photoions at different locations in the electrostatic ion-extractor has been determined as a function of plasma density. The details will be discussed in the presentation during the symposium PLASMA 2014.



