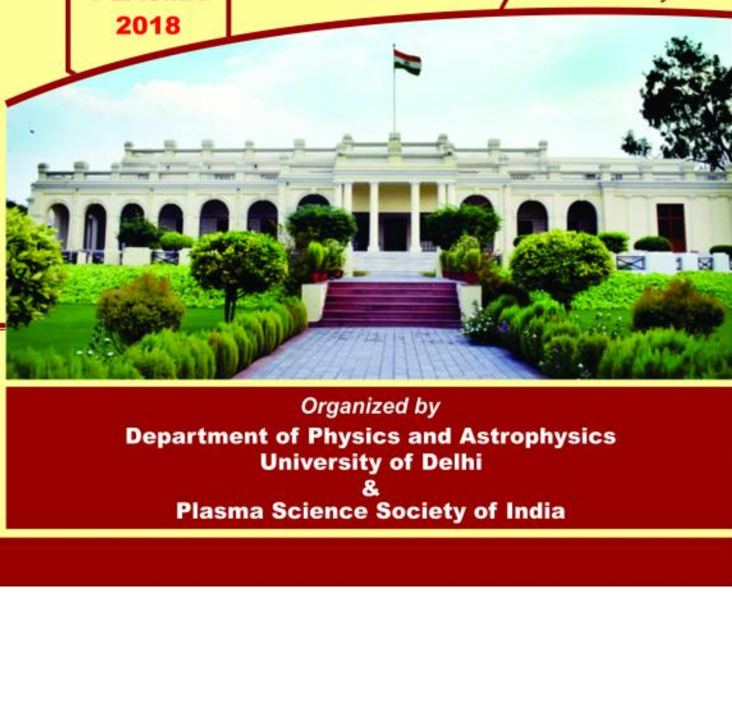
Book of Abstract

33rd NATIONAL SYMPOSIUM ON PLASMA SCIENCE & TECHNOLOGY

PLASMA 2018

4-7 December 2018



Organized by

Department of Physics and Astrophysics
University of Delhi
&
Plasma Science Society of India

33rd NATIONAL SYMPOSIUM ON PLASMA SCIENCE & TECHNOLOGY | PLASMA 2018

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PLASMA- 2018

33rd National Symposium on Plasma Science & Technology

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Book of Abstracts

PLASMA- 2018

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Edited by

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Department of Physics & Astrophysics, University of Delhi
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DEPARTMENT OF PHYSICS AND ASTROPHYSICS
UNIVERSITY OF DELHI, DELHI-110007

PREFACE

The 33rd National Symposium on Plasma Science & Technology (Plasma-2018) is jointly organized by the Department of Physics and Astrophysics, University Delhi and Plasma Science Society of India (PSSI) from 4-7 December 2018. The National symposium of plasma science and technology has been held since 1990s in order to promote the growth and exchange of information in the fields of plasma science and gas discharge physics. The series of this conference is being organized in different parts of India to encourage and involve a large number of Indian researchers to participate in the conference. The conference explores all kinds of plasmas, ranging from low pressure to high pressure plasmas, from thermal to non-thermal plasmas, and their applications.

Progress in science and technology has been strongly contributing to the development of social, economical, intellectual aspects and overall growth in every society. In the recent years, through the PSSI conference series, a strong networking is being established with noted credentials among academicians, industries, researchers, technologists etc. from many diverse fields. One of the major objectives of this conference series is to highlight the inter-connectivity aspects. Special attention is focused on understanding the advancing complex-fundamental issues, technologies and further investigating the interdisciplinary fields. Plasma physics is a very rapidly emerging multi-featured area with widespread approach to applications and technological developments by providing an extraordinary opportunity to the researchers.

At Plasma-2018 conference, 300 registered participants from all over India attended the conference. A keynote address was delivered by Prof. Arnab Rai Choudhuri (I.I.Sc. Bangalore). 14 invited talks, 35 oral talks, and 300 posters were presented in the 7 categories shown in the following contents of these proceedings. Included is a popular talk delivered by Professor M. Krishnamurthy (TIFR).

We would like to express our deep appreciation to a conference sponsor *BRNS, CSIR, IASST, IPR* for their financial support. We thank to the PSSI to give an opportunity to organize the Plasma-2018 conference at Delhi University. We would like to express our deep appreciation to the award committee members and session chairs.

We would like to express our special thanks to the Proceeding Editors, for their tremendous efforts. Finally, but not least, support from the Department of Physics and Astrophysics, University of Delhi was absolutely essential to the conference.

At the end of this preface, we would like to announce that the NAC selected VIT (Chennai Campus) Chennai as the next PSSI conference host and the venue. We look forward to see you next year in Plasma-2019 conference. We wish you all enjoyable stay at Delhi and productive scientific sessions.

Prof. Avinash Khare, Convener (Plasma 2018)
Dr. D. N. Gupta, Co-Convener (Plasma 2018)

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	Institute of Advanced Study in Science and Technology (IASST)
	Institute of Plasma Research (IPR)

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PLASMA – 2018
Conference Schedule (4 - 7 December, 2018)

04-Dec-2018 DAY-01	Time	Time	Time	Time	Time	Hr	Time	Time	Time	Hr	Time	Time	Time
	8:00-9:00	9:00-9:45	9:45-10:15	10:15-11:00	11:00-13:15	2hr 15m	13:15-14:00	14:00-16:30	2hrs 30 m	16:00-16:30	16:30-18:30	2 Hr	18:30-19:30
	Registration	Inaugural Function	High Tea	Keynote Session	Session-1 (BP)	Min	Lunch	Poster Session – 1 (BP+PP) D1 / P1 (BP +PP)		Tea	Buti Award Presentations		Cultural Programme
		Inauguration		Keynote Address	S1-I-01 - Invited	30					BYSA-01	20	
					S1-I-02 - Invited	30					BYSA-02	20	
					S1-O-01 - Oral	12					BYSA-03	20	
					S1-O-02 - Oral	12					BYSA-04	20	
					S1-O-03 - Oral	12					BYSA-05	20	
					S1-O-04-Oral	12					BYSA-06	20	
					S1-O-05-Oral	12							
					D1/S1/BP								

05-Dec-2018 DAY-02	09:00-11:15	2h 15m	11:15-11:30	11:30-13:45	2h 15m	13:45-14.30	14:30-17:00	16:30-17:00	17:00-18:00	18:00-21:00
	Session - 2 (NF)	Min	Tea	Session - 3 (PP + IP)	Min	Lunch	Poster Session – 2 (NF+PU)	Tea	PSSI GBM	Banquet Dinner
	S2-I-01 - Invited	30		S2-I-01 - Invited	30					
	S2-I-02 - Invited	30		S2-I-02 - Invited	30					
	S2-O-01 - Oral	12		S2-O-01 - Oral	12					
	S2-O-02 - Oral	12		S2-O-02 - Oral	12					
	S2-O-03 - Oral	12		S2-O-03 - Oral	12					
	S2-O-04 - Oral	12		S2-O-04 - Oral	12					
	S2-O-05 - Oral	12		S2-O-05 - Oral	12					
	D2 / S2-NF			D2 / S3-PP-IP			D2 / P2 (NF+PU)			

<table>
<tr><td rowspan="10">DAY-03 06-Dec-2018</td><td>09:00-11:00</td><td>2h 15m</td><td>11:00-11:15</td><td>11:15-13:30</td><td></td><td>13:30-14:15</td><td>14:15-16:45</td><td>16:15-16:45</td><td>16:45-17:45</td><td>17:45-19:45</td><td>2 hr</td></tr>
<tr><td>Session-4 (SP)</td><td>Min</td><td rowspan="9">Tea</td><td>Session - 5 (LP + CM)</td><td>Min</td><td rowspan="9">Lunch</td><td rowspan="7">Poster Session – 3 (SA + CM + EP)</td><td rowspan="9">Tea</td><td rowspan="9">Popular Talk (High power laser research)</td><td>Session - 6 (EP + PU)</td><td>Min</td></tr>
<tr><td>S2-I-01 - Invited</td><td>30</td><td>S2-I-01 - Invited</td><td>30</td><td>S2-I-01 - Invited</td><td>30</td></tr>
<tr><td>S2-I-02 - Invited</td><td>30</td><td>S2-I-02 - Invited</td><td>30</td><td>S2-I-02 - Invited</td><td>30</td></tr>
<tr><td>S2-O-01 - Oral</td><td>12</td><td>S2-O-01 - Oral</td><td>12</td><td>S2-O-01 - Oral</td><td>12</td></tr>
<tr><td>S2-O-02 - Oral</td><td>12</td><td>S2-O-02 - Oral</td><td>12</td><td>S2-O-02 - Oral</td><td>12</td></tr>
<tr><td>S2-O-03 - Oral</td><td>12</td><td>S2-O-03 - Oral</td><td>12</td><td>S2-O-03 - Oral</td><td>12</td></tr>
<tr><td>S2-O-04 - Oral</td><td>12</td><td>S2-O-04 - Oral</td><td>12</td><td rowspan="2">S2-O-04 - Oral</td><td rowspan="2">12</td></tr>
<tr><td></td><td></td><td>S2-O-05 - Oral</td><td>12</td><td></td></tr>
<tr><td colspan="2">D3 / S4- Space Plasma</td><td>D3 / S5 – Laser Plasma + Computer Modeling</td><td></td><td>D3 / P3 (SA+CM+EP)</td><td colspan="2">D3 / S6- Exotic Plasma Pulsed Power</td></tr>
</table>

<table>
<tr><td rowspan="11">DAY-04 07Dec-2018</td><td>09:00-11:00</td><td>10:45-11:00</td><td>11:00-11:30</td><td>11:30-13:45</td><td>2 Hr 15 m</td><td>13:45-14:45</td><td>14:45-16:30</td></tr>
<tr><td rowspan="9">Poster Session – 4 (IP + LP + PD)</td><td rowspan="10">TEA</td><td rowspan="10">Guzdar Award Presentation</td><td>S2-I-01 - Invited</td><td>30</td><td rowspan="10">Lunch</td><td rowspan="10">Concluding Session & Award Presentation</td></tr>
<tr><td>S2-I-02 - Invited</td><td>30</td></tr>
<tr><td>S2-O-01 - Oral</td><td>12</td></tr>
<tr><td>S2-O-02 - Oral</td><td>12</td></tr>
<tr><td>S2-O-03 - Oral</td><td>12</td></tr>
<tr><td>S2-O-04 - Oral</td><td>12</td></tr>
<tr><td>S2-O-05 - Oral</td><td>12</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td>D4 / P4 (IP+LP+PD)</td><td></td><td></td></tr>
</table>

DAY-0 1 : 04-DEC-2018							
REG	08:00	09:00		**REGISTRATION**			
INAUG	09:00	09:45		**INAUGURAL FUNCTION**			
TEA	9:45	10:15		**HIGH TEA**			
KN	10:15	11:00	KN-01	Keynote Address		Prof. Arnab Raichoudhuri, IISC, Bangalore	
D1/S-01	**11:00**	**13:15**		**SESSION – 1 : BASIC PLASMA (BP)**		**Session Chair (TBA)**	**Abs#**
S1-I-01	11:00	11:30	Invited - 1	25+5	Prof. R. Ganesh	IPR, Gandhinagar	
S1-I-02	11:30	12:00	Invited - 2	25+5	Prof. H. Bailung	IAST, Guwahati	
S1-O-01	12:00	12:15	Oral – 1	10+2	Mr. Rupak Mukherjee	IPR, Gandhinagar	67
S1-O-02	12:15	12:30	Oral – 2	10+2	Mr. Saravanan Arumugam	Pondicherry Univ.	153
S1-O-03	12:30	12:45	Oral – 3	10+2	Mr. Arghya Mukherjee	IPR, Gandhinagar	182
S1-O-04	12:45	13:00	Oral – 4	10+2	Dr. Divya Ganesan	Modi University	236
S1-O-05	13:00	13:15	Oral – 5	10+2	Ms. Anshu Verma	IIT Delhi	372
LUNCH	13:15	14:00		**LUNCH**			
D1 / P-01	14:00	16:30		**POSTER – 1 (BP+PP)**			
TEA	16:00	16:30		**TEA**			
BYSA	**16:30**	**18:30**		**BUTI YOUNG SCIENTIST AWARD PRESENTATIONS**		**Session Chair (TBA)**	
BYSA-01	16:30	16:50	Buti Award	15+5	Dr. Mridula. N	Space Physics Laboratory, VSSC, Thiruvananthapuram	
BYSA-02	16:50	17:10	Buti Award	15+5	Sandeep Kumar	IPR Gandhinagar	
BYSA-03	17:10	17:30	Buti Award	15+5	Umesh Kumar	IPR Gandhinagar	
BYSA-04	17:30	17:50	Buti Award	15+5	Divya Deepak	Mody University of Science and Technology	
BYSA-05	17:50	18:10	Buti Award	15+5	Prabhakar	IPR Gandhinagar	
BYSA-06	18:10	18:30	Buti Award	15+5	Priti	IIT Roorkie	
	18:30	19:30			**CULTURAL PROGRAMME**		

DAY-0 2 : 05-Dec-2018							
D2 / S-02	**09:00**	**11:15**			**SESSION – 2 : NUCLEAR FUSION (NF)**	**Session Chair (TBA)**	
S2-I-01	09:00	09:30	Invited - 3	25+5	Mr. R. L. Tanna	IPR, Gandhinagar	
S2-I-02	09:30	10:00	Invited - 4	25+5	Dr. Debjyoti basu	IPR, Gandhinagar	
S2-O-01	10:00	10:15	Oral – 6	10+2	Mr. Ram Niranjan	BARC, Mumbai	128
S2-O-02	10:15	10:30	Oral – 7	10+2	Dr. Vipul Tanna	IPR, Gandhinagar	245
S2-O-03	10:30	10:45	Oral – 8	10+2	Mr. Jervis Mendonca	IPR, Gandhinagar	254
S2-O-04	10:45	11:00	Oral – 9	10+2	Ms. Harshita Raj	IPR, Gandhinagar	348
S2-O-05	11:00	11:15	Oral – 10	10+2	Dr. Nitin Kumar	CEERI, Pilani	377
TEA	11:15	11:30			**TEA**		
D2 / S-03	**11:30**	**13:45**			**SESSION – 3 : INDUSTRIAL PLASMA/ PLASMA PROCESSING (IP+PP)**	**Session Chair (TBA)**	
S3-I-01	11:30	12:00	Invited - 5	25+5	Dr. U. N. Pal	CEERI, Pilani	
S3-I-02	12:00	12:30	Invited - 6	25+5	Dr. Vishal Jain	IPR, Gandhinagar	
S3-O-01	12:30	12:45	Oral – 11	10+2	Dr. Onkar Mangla	University of Delhi, Delhi	23
S3-O-02	12:45	13:00	Oral – 12	10+2	Dr. Mukesh Ranjan	IPR, Gandhinagar	37
S3-O-03	13:00	13:15	Oral – 13	10+2	Dr. Alphonsa Joseph Palakel	IPR, Gandhinagar	48
S3-O-04	13:15	13:30	Oral – 14	10+2	Dr. Snehlata Aggarwal	IPR, Gandhinagar	271
S3-O-05	13:30	13:45	Oral – 15	10+2	Mr. Mohammad Afaque Hossain	Academy of Science and Innovative Research	327
LUNCH	13:45	14:30			**LUNCH**		
D2 / PS-02	14:30	17:00	**POSTER SESSION – 02 (NF+PU)**				
TEA	16:30	17:00	**TEA**				
GBM	17:00	18:00	**PSSI GBM**				
DINNER	18:00	21:00	**BANQUET DINNER**				

DAY-0 3 : 06-Dec-2018							
D3 / S-04	**09:00**	**11:00**			**SESSION – 4 : SPACE PLASMA (SA)**	**Session Chair (TBA)**	
S4-I-01	09:00	09:30	Invited - 8	25+5	Prof. M. K. Verma	IIT Kanpur	
S4-I-02	09:30	10:00	Invited - 9	25+5	Prof. N. S. Saini	GNDU, Amritsar	
S4-O-01	10:00	10:15	Oral - 16	10+2	Ms. Archana Patidar	Ujjain Engineering College, Ujjain	50
S4-O-02	10:15	10:30	Oral - 17	10+2	Ms. Yashika Ghai	Gurunanak Dev Univ, Amritsar	158
S4-O-03	10:30	10:45	Oral - 18	10+2	Dr. Navin Chandra Joshi	Udaipur Solar Observatory, PRL, Udaipur	178
S4-O-04	10:45	11:00	Oral - 19	10+2	Mr. Biswajit Ojha	Indian Institute of Geomagnetism	184
TEA	11:00	11:15			**TEA**		
D3 / S-05	**11:15**	**13:30**			**SESSION – 5 : LASER PLASMA + COMPUTER MODELING (LP + CM)**	**Session Chair: Prof. N. K. Jaiman (University of Kota)**	
S5-I-01	11:15	11:45	Invited - 10	25+5	Prof. V. K. Tripathi	Department of Physics, IIT Delhi	
S5-I-02	11:45	12:15	Invited - 11	25+5	Dr. Bobbili Sanyasi Rao	RRCAT, Indore	
S5-O-01	12:15	12:30	Oral - 20	10+2	Dr. Anil Kumar	CCS University, Meerut	321
S5-O-02	12:30	12:45	Oral - 21	10+2	Dr. Krishna Gopal Goswami	University of Delhi	329
S5-O-03	12:45	13:00	Oral - 22	10+2	Mr. Atul Kumar	IPR, Gandhinagar	187
S5-O-04	13:00	13:15	Oral - 23	10+2	Mr. Narayan Behera	IPR, Gandhinagar	214
S5-O-05	13:15	13:30	Oral - 24	10+2	Mr. Varun	CEERI, Pilani	368
LUNCH	13:30	14:15			**LUNCH**		
D3 / PS-03	14:15	16:45			**POSTER SESSION – 03 (SA + CM + EP)**		
TEA	16:15	16:45			**TEA**		
POPULAR TALK	**16:45**	**17:45**			**POPULAR TALK (HIGH POWER LASER RESEARCH)**		
D3 / S-06	**17:45**	**19:45**			**SESSION – 6 : EXOTIC PLASMA + PULSED POWER (EP+ PU)**	**Session Chair (TBA)**	
S6-I-01	17:45	18:15	Invited - 12	25+5	Dr. Pintu Bandyopadhyay	IPR, Gandhinagar	
S6-I-01	18:15	18:45	Invited - 13	25+5	Dr. R. P. Prajapati	Guru Ghasidas Central University, Bilaspur	
S6-O-01	18:45	19:00	Oral - 25	10+2	Mrs. Sita Sundar	IIT Madras	9
S6-O-02	19:00	19:15	Oral - 26	10+2	Dr. Gadadhar Banerjee	University of Eng. & Mangement (UEM), Kolkata	82
S6-O-03	19:15	19:30	Oral - 27	10+2	Dr. Jyotirmoy Pramanik	Kharagpur College, Kharagpur	268
S6-O-04	19:30	19:45	Oral - 28	10+2	Dr. Sunil Rawat	IPR,Gandhinagar	332

DAY-04 : 07-Dec-2018							
D4 / PS-04	09:00	11:00	**POSTER SESSION – 04 (IP + LP + PD)**				
TEA	10:45	11:00	**TEA**				
GUZDAR	11:00	11:30	**GUZDAR AWARD**				
D4/S-07	11:30	13:45	**SESSION – 7 : PLASMA DIAGNOSTICS (PD)**			**Session Chair (TBA)**	
S7-I-01	11:30	12:00	Invited - 14	25+5	Dr. Mukti Ranjan Jana	IPR, Gandhinagar	
S7-I-02	12:00	12:30	Invited - 15	25+5	Dr. Gagan kumar	IIT Guwahati	
S7-O-01	12:30	12:45	Oral – 29	10+2	Dr. Ashutosh SINGH	Bihar University, Bihar	27
S7-O-02	12:45	13:00	Oral – 30	10+2	Dr. Arvind Saxena	IPR, Gandhinagar	103
S7-O-03	13:00	13:15	Oral – 31	10+2	Prof. Rajesh Srivastava	IIT Roorkee	106
S7-O-04	13:15	13:30	Oral – 32	10+2	Mr. Avnish Pandey	IPR, Gandhinagar	197
S7-O-05	13:30	13:45	Oral – 33	10+2	Mr. Arun Pandey	IPR, Gandhinagar	316
LUNCH	13:45	14:45	**LUNCH**				
AWARDS	14:45	16:30	**Concluding Session & Award Presentation**				

Paper Nominated for BUTI YOUNG SCIENTIST AWARD Presentation

PLASMA-2018 (4 December 2018)

16.30 Hrs Onward

S.No	Name	Affiliation	Title
1	Dr. Mridula. N	Space Physics Laboratory, VSSC, Thiruvananthapuram	A Quantitative Analysis On The Roles Of F3 Layers As Well As Solar Flux In Modulating The Topside Ionization Over Indian Region
2	Sandeep Kumar	IPR Gandhinagar	Excitation and dynamics of spiral structures (wave) in strongly coupled dusty plasmas
3	Umesh Kumar	IPR Gandhinagar	High Frequency, Global Geodesic Acoustic-like Mode In A Simple Magnetized Toroidal Plasma: An Experimental Study
4	Divya Deepak	Mody University of Science and Technology	Modelling and Characterization of Atmospheric Pressure Plasma Jet Based on Dielectric Barrier Discharge
5	Prabhakar	IPR Gandhinagar	Study of Plasma Transport due to Electron Temperature Gradient Induced Turbulence in Laboratory Plasma
6	Priti	IIT Roorkie	Electron Scattering from Atoms (Ions) and Plasma Modeling

KEYNOTE ADDRESS

The Origin of the Sunspot Cycle

Arnab Rai Choudhuri

Department of Physics, Indian Institute of Science, Bangalore

Abstract

The 11-year sunspot cycle is produced by a plasma process known as the dynamo process inside the Sun. After presenting the relevant observational data, I shall discuss how we can understand the formation of sunspots on the basis of MHD equations. Then I shall give an introduction to the flux transport dynamo model, the currently favoured theoretical model of the sunspot cycle. I shall end with a discussion of some problems at the present-day research frontier.

Invited Talk

S1-I-01

Novel aspects of 1D Collision-less plasma using a general Vlasov-Poisson Model

Pallavi Trivedi, Sanjeev K Pandey, R Ganesh
Institute of Plasma Research, Ghandhinagar

In the limit of zero correlations and weak collisions, plasmas are well described in their electrostatic limit by Vlasov-Poisson system of equations. Except for a very few special cases, even this simplified Model is hard to solve analytically. More often than not, computer simulations come handy in addressing various fundamental questions related to collision-less plasmas. Considering an Eulerian grid in phase space, a fully nonlinear Vlasov-Poisson solver is developed for a 1D plasma using a Piece-wise Parabolic Convection Scheme where both electrons and ions are fully kinetic species.

After establishing the correctness of the solver in the opposite limits of immobile ions and kinetic electrons as well as fully kinetic ions and highly mobile electrons using well studied examples, an attempt will be made to present a unified picture where both ions and electron respond simultaneously in fully kinetic fashion. Some novel aspects of this combined picture will be elucidated.

S1-I-02

Some new experimental aspects of ion acoustic and dust acoustic waves

H. Bailung, P. Pathak, Y. Bailung, T. Deka and Y. Nakamura
Physical Sciences Division, Institute of Advanced Study in Science and Technology
Garchuk, Guwahati- 781035

Ion acoustic wave is one of the most fundamental wave modes in unmagnetized low temperature plasma. Experimentally most of the linear and nonlinear characteristics of the IA waves are investigated. When mixed with additional negative ion component, however, the IA wave mode is modified. Interestingly, at a critical concentration of negative ion the ion wave mode become modulationally unstable for wide range wavenumbers and thus fulfils the condition for generation of Peregrine soliton –a prototype of oceanic rogue wave. The Peregrine soliton is a doubly localized nonlinear structure described by the nonlinear Schrodinger equation (NLSE).

The dusty plasma on the other hand contains additional micron or sub-micron sized particles in the plasma and supports very low frequency waves namely dust acoustic waves (with characteristics frequency ~ few Hz- tens of Hz) analogous to ion acoustic waves. In the nonlinear regime the dust acoustic waves can be transformed into dust acoustic solitons. Experimentally these waves are visible with laser light scattering and captured in high speed video camera. In laboratory dusty plasma can be made to flow at controllable speed and when allowed to flow past an obstacle can generate nonlinear structures e.g. bow shock, vortex and other complex structures.

Some experimental aspects of linear and nonlinear ion acoustic and dust acoustic waves and nonlinear structures in dusty plasma will be discussed in the presentation.

S2-I-01

Overview on ADITYA Upgrade Tokamak Experimental Progress

R.L. Tanna and the ADITYA Upgrade Team

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Recently, the first medium sized tokamak facility of India named ADITYA (R0 = 75 cm, a = 25 cm), operated over 2 decades with circular poloidal limiter has been upgraded to a tokamak named ADITYA Upgrade (ADITYA-U) for the purpose of having shaped plasma operation with an open divertor geometry with divertor plates without any baffle, to support the future Indian Fusion program. The foremost objective of ADITYA-U is to prepare the physics and technological base for future ITER and DEMO machine by performing the dedicated experiments, such as generation and control of REs, disruption prediction and mitigation studies, along with plasma position control and confinement improvement studies with shaped plasmas. Tokamak experimental research in ADITYA Upgrade has made significant progress since last year. After installation of PFC and standard tokamak diagnostics, the Phase-I plasma operations in ADITYA-U were resumed from December 2016 with graphite toroidal belt limiter [1]. The primary objectives of the Phase-I operation: (1) to achieve first circular hydrogen plasma in ADITYA-U with purely Ohmic discharges assisted by filament pre-ionization (2) to check the overall functionality of the system and (3) study the discharge characteristics of ADITYA and ADITYA-U tokamak. During Phase-I operation, all the subsystem of the machine have performed well as desired and the discharges are very satisfactory in terms of the functionality of the machine. After completion of Phase-I operation by the end of March 2017, the Phase-II operation preparation has been executed. The Phase-II operation preparations includes: (1) Calibration of in-vessel magnetic diagnostics (2) Major Diagnostics installation and (3) Baking heaters installation and vacuum vessel baking. ADITYA-U vacuum vessel has been successfully baked up to ~ 130°C in subsequent baking cycles for the purpose of achieving lower base vacuum. The base pressure of the order of ~ 9 x 10^-9 torr has been achieved after solving all leaks. After all the relevant preparations, the Phase –II plasma operation were resumed in ADITYA-U in February 2018 in a Graphite limiter (toroidal belt limiter) configuration and continued to achieve plasma parameters close to design parameters. Dedicated experiments relevant for plasma operations in large size machines have also been conducted during the Phase-II operation of ADITYA-U. Significant and very encouraging results related to runaway electron generation and loss mechanisms, control of rotation of magnetic islands, radiative improved modes have been obtained. An overview of these experiments has been presented in the paper.

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S2-I-02

Experimental studies of geodesic acoustic mode (GAM) like oscillations in STOR-M tokamak

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The Saskatchewan Tours Modified (STOR-M) is a small, limiter based, Ohmic heating Tokamak, having circular cross-section with major and minor radii 46 cm and 12 cm respectively. This tokamak is well known for achieving many fundamental fusion related results such as ac-mode operation, Compact Torus (CT) injection for plasma fuelling, etc. But, elaborate turbulent related experimental studies have not been done so far. Recently, detailed experimental studies on Geodesic Acoustic Mode (GAM) have been performed as well as online turbulent feedback experiment has been initiated to study the effect on GAM in this machine. A new kind of the quasi-coherent mode was observed in ohmic plasma in the STOR-M tokamak. It is featured with a clear solitary peak around 30-35 kHz in the power spectra of the ion saturation current (Isat) of Langmuir probe as well as poloidal and toroidal mode numbers (m=1, n=0) as per prediction of conventional GAM theory. The dispersion relation of the mode is also similar to GAM and it also shows collisional damping. In contrast to conventional GAM, the floating potential φ of the observed GAM-like mode does not show similar symmetric poloidal and toroidal mode numbers (m=0, n=0), but has (m=1, n=1). The GAM-like mode has also a pronounced magnetic component with mixed poloidal modes (m=3 and m=5; n=1), as observed by Mirnov coils. Recently, detailed Bi-spectral analysis is going on which indicates it is a turbulent driven mode. This mode is suppressed by the application of Resonance Magnetic Perturbations (RMP). All those results will be discussed in presentation.

S3-I-01

Pulsed Power Plasma Technologies and their Applications

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Presently, there is growing concern in pulsed plasma devices and technologies, such as, high power plasma switches (Thyratron and pseudospark switch (PSS)) for different pulse modulator and high energy physics applications; high density and energetic electron beam sources for microwave and surface modification applications; Extreme Ultraviolet (EUV)/X-ray sources for surface modification of polymers, X-ray Crystal Spectroscopy (XRCS) and radiography of small objects for potential biological applications; and plasma assisted compact microwave and THz sources [1-17]. Keeping in view of these applications, CSIR-CEERI has initiated the research activities on pulsed plasma devices and technologies, particularly thyratron switches and pseudospark (PS) discharge devices in early 2000 [3-4]. The talk has covered the recent technological efforts made by CSIR-CEERI for the design, development and characterization of high power plasma switches, such as, Thyratrons (25kV/1kA, 35kV/3kA and 40kV/3kA) and PSS (25kV/5kA, 40kV/10kA and 20kV/100kA) for different pulse power applications of strategic importance [3-8]. Such plasma switches are presently being imported and have always been a subject to import restrictions, causing hurdles in Indian efforts for advancing technologies in high energy research areas. The design, fabrication, processing, development and characterization issues of these plasma switches have been presented. The research work on development of high voltage (≥ 30 kV) and high current (≥ 5 kA) PSS and thyratrons for high energy applications has also been presented. The recent research work on the few PS discharge based plasma cathode electron (PCE) guns for the generation of high energetic, intense and focused electron beams and also their applications for plasma-assisted slow wave oscillator 'Pasotron' will also be presented [9-14]. Discussions have also been made for the areas of further research on novel pseudospark (PS) discharge technologies for the generation of EUV/X-ray radiations for the potential biological, spectroscopy and surface modification applications.

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S3-I-02

Novel approaches in Generating Atmospheric Pressure Non-thermal Air Plasmas for Textile Processing and Bactericidal Applications

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Plasma contains lots of active species which can perform desired chemical reactions catering to the various environment friendly applications in surface engineering. Non-thermal plasma is one such stream of the plasma which is widely researched for its capability to perform desired chemical changes on surface pertaining to the industrial applications such as textile processing etc. without changing its bulk property. These researches are mostly carried out using argon and helium as plasma gen gas which are not affordable in many inline processing applications. Therefore, the technology still remained at nurturing stage and yet to come up for the use in textile industries. There are challenges which limit the use of plasma technology for inline processing applications such as generation of streamer free uniform glow discharge plasma at atmospheric pressure, use of air as plasma gen gas instead of costly gases like helium and argon, cost effectiveness and compactness of the system. Taking all these challenges into account, a system has been designed and developed by Atmospheric Plasma Division in the Institute for Plasma Research (IPR) with the financial support

from Department of Science and Technology (DST), New Delhi. This work includes the design of a novel power supply architecture which generates 0.5 to 3MHz frequency oscillations at 5kVrms. However, this high frequency discharge lasts for 8 to 10 microseconds with the repetition rate at 1 to 100 kHz. The current is of order of 100 to 500mA. These voltage and current characteristics relate to a novel philosophy for generation of nonthermal uniform glow discharge in air at atmospheric pressure in which the energy is controlled by damping the voltage and current oscillations. The species generated in this plasma has shown substantial improvement on the surface properties of various textiles without changing its bulk property. The required plasma exposure time for such functionality improvement is also observed to be very less which can be exploited to meet fast inline speed in the textile industries.

The other category of non-thermal plasma is DBD (Dielectric Barrier Discharge) plasma jet which is also widely researched for its use in various applications such as sterilization, bactericidal applications etc. This plasma can perform the chemical reactions in direct contact and also by indirect contact manner. The direct contact application of DBD plasma jet is widely researched in biomedical applications such as wound healing etc. The indirect contact applications involves the use plasma to modify certain chemical properties of material such as generation of plasma activated water for its use in agriculture, bactericidal applications etc. The work was carried out by institute for plasma research to design and develop a system for producing Plasma Activated Water (PAW). The generation of PAW makes use of a current source power supply with voltage rating up to 5kV and frequency up to 40 kHz for generating underwater DBD air plasma jet. The property of normal water is changed by air plasma jet in terms of its pH value from 7 to 2.7 and oxidation reduction potential (ORP) from 200mV to 650mV to make it PAW. The higher oxidation reduction potential makes the PAW more reactive in terms of its bactericidal properties. The plasma activated water of consistent 650mV ORP has been successfully generated at our lab in IPR and its bactericidal properties have been successfully validated by Gujarat Environment and Management Institute, Gandhinagar. PAW also has potential to stop growth of biofilm for increasing the shelf life of fruits, vegetables etc.


(a)

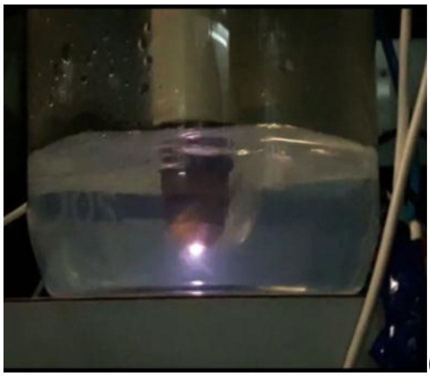
(b)

Fig. a) Inline plasma system for textile treatment at IPR; b) Underwater DBD air plasma jet for producing PAW at IPR.

S4-I-01

Multiscale energy transfers in turbulent magnetohydrodynamics (MHD) and in electron MHD (EMHD)

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In this general talk, I will present the formalism of computing energy transfers mainly energy fluxes---kinetic to magnetic, and magnetic to magnetic. These transfers are useful for understanding physics of magnetofluids, as well as dynamo action in astrophysical objects, such as the Sun and the Earth.

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S4-I-02

Head on collision of multi-solitons in a polarized dusty plasma with non-Maxwellian distribution

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Most of the space and astrophysical observations have revealed the presence of non-Maxwellian distribution of particles in different plasma environments. Nonthermal ions from the Earth's bow shock have been observed by the Vela satellite and in and around the Earth's foreshock. Nonthermal ion populations have also been found to occur in the magnetospheres of Jupiter and Saturn planets. It is believed that dust is an ubiquitous component of space and astrophysical environments and has a wide range of applications in the different fields as well as in the study of astrophysical and space environments. The deformation of the Debye sheath around the dust particulates in the background of non-uniform plasmas makes the occurrence of polarization force [1], which influences different kinds of nonlinear structures. The study of wave dynamics in dusty plasma under the influence of polarization force is an important frontline area of research. This polarization force modifies the characteristics of dust acoustic solitary waves (DASWs) [2,3]. It is interesting to study the head-on collision (HoC) between dust acoustic solitary waves (DASWs) travelling in opposite directions in a dusty plasma with charged particles featuring non-Maxwellian distribution under the effect of polarization force. The extended Poincaré-Lighthill-Kuo method is used to derive nonlinear equations. The Hirota direct method [4] is used to obtain multi-soliton solutions for different KdV equations, and all solitons move along the same direction where the fastest moving soliton eventually overtakes the others. The expressions for collisional phase shifts after head-on collision of two-, four-, and six-DA solitons are derived under the influence of polarization force. It is found that the effect of polarization force and the presence of non-Maxwellian ions have a great influence on the phase shifts after the head-on collision of multi-solitons. The impact of polarization force on time evolution of multi-solitons has also been illustrated. It is remarked that the findings of this investigation may be of significant importance in laboratory experiments and in space/astrophysical environments, especially in Saturn's magnetosphere and Comet tails [5].

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S5-I-01

Parametric instabilities in Laser-driven Fusion

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Parametric instabilities are a major concern in the success of laser driven fusion. Recent experiments on indirect drive fusion failed to ignite mainly due to deleterious Raman backscattering parametric instabilities. 30 to 50% laser energy gets reflected back in the underdense region, while the plasma wave, generated in the process, produces hot electrons that pre-heat the core, putting in jeopardy the D-T pellet compression, mandatory to achieve fusion. High reflectivity is attributed to transition from convective to absolute Raman instability where electron distribution function acquires a plateau, reducing the Landau damping of the Langmuir wave and lowering the threshold for absolute Raman. Two Plasmon Decay is also a potent trouble as it produces hot electrons at the quarter critical layer. The talk will discuss recent experiments and probable scenarios to explain these results.

S6-I-02

Betatron Oscillations of Energetic Electrons and Emission of Femtosecond X-rays In Laser Wakefield Acceleration

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Ultra-short high power laser technology has contributed immensely to the rapid development of laser plasma accelerators in last few decades. Laser wakefield accelerators (LWFA) are now capable of producing stable femtosecond duration electron bunches with acceptable control on beam parameters required for applications. Interestingly, the electrons that are self-injected into the wakefield of a laser pulse undergo transverse oscillations (betatron oscillations) about the laser propagation axis due to the radial force while simultaneously accelerated due to the longitudinal force. The betatron oscillation of energetic electrons results in the emission of femtosecond duration spatially coherent synchrotron-like radiation whose spectrum extends to hard X-ray domain and beyond. Such a source of X-rays from a compact LWFA set-up will be highly desirable for applications in phase contrast imaging, medicine, biology, time-resolved studies in material science, and laser-produced plasmas. Here, we present an experimental demonstration and characterization of LWFA that can deliver quasi-monoenergetic electron beams with energy in excess of 300MeV (from 2.3-mm long helium gas-jet plasma) driven by a 25fs, 150TW titanium sapphire laser. Then, we shall show and discuss in detail on the direct measurement of betatron oscillations of the accelerated electrons and the simultaneous detection and characterization of highly directional hard X-rays emitted in the forward direction from a micron-sized source. These betatron X-rays can be used for non-invasive independent diagnosis of electron beam parameters, apart from exploiting them for applications.

S7-I-01

Experiments in flowing dusty plasma

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A variety of flowing dusty plasma experiments, which have been carried out in a tabletop Dusty Plasma Experimental (DPEx) device is reported. In this pi-shaped apparatus, a DC glow discharge plasma is produced between a disc shaped anode and a grounded long cathode plate by applying a high voltage DC in the background of neutral gas and subsequently a dusty plasma is created by introducing micron sized dust particles that get charged and levitated in the sheath region [1]. A flow of dust particles/fluid is generated by additional gas injection from single or dual locations or by altering the dust confining potential. The flow velocity is then estimated by three different techniques, namely, by super Particle Identification tracking (sPIT) code, Particle Image Velocimetry (PIV) analysis and the excitation of Dust Acoustic Waves (DAWs) [2]. The experimental results suggest that the flowing neutrals are responsible for streaming the dust particles along its direction [3]. An isolated copper wire mounted on the cathode acts as a potential hill to the flow of dust particles. By a visual tracking of the individual particle trajectories, the potential profile around that potential hill is directly estimated by using energy conservation arguments [4]. For the excitation of linear and nonlinear waves, a supersonic/subsonic mass flow of the dust particles over this electrostatic potential hill is initiated. The experimental findings of a variety of experiments e.g., precursor solitons, shock waves, dynamical and stationary structures etc. [5-7] conducted in DPEx device will be discussed in detail.

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S7-I-02

Waves, Instabilities And Structure Formations In Dusty (Complex) Plasmas: Some Astrophysical Applications

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Dusty (complex) plasmas characterized by the presence of micron to nanometer sized charged dust particles into normal electron-ion plasma are ubiquitous in low temperature laboratory plasma as well as in space plasmas. The collective interactions of dust and plasma enabled various kinds of linear and nonlinear waves and instabilities depending upon the considered plasma background. The existence of dust acoustic wave (DAW), dust ion acoustic wave (DIAW) and solitary wave have been experimentally observed with the help of established theoretical results. Moreover the lattice wave approach for strongly coupled dusty plasma (SCDP) in a crystalline state could be of significant interests in the formation of plasma crystal under microgravity conditions [1,3].

In the larger astrophysical systems under some circumstances the gravitational and electrostatic forces may become comparable hence the structure formations in space environment of dusty molecular clouds, interstellar space, planetary nebula and in dense stars are affected by the presence of self-gravitational force which produces fundamental Jeans (self-gravitational) instability. Moreover, in rotating accretion disks, Saturn ring and outer region of galaxies, the various kinds of hydrodynamic instabilities such as Rayleigh-Taylor instability (RTI), Kelvin-Helmholtz instability (KHI) and magnetorotational instability (MRI) are significantly depends upon the dynamics of charged dust particles [4,5].

In this talk the underlying physics of various excited waves and instabilities and their role in structure formations in dusty space plasma environment is presented. The collective dust-plasma interactions are discussed and several novel phenomena observed theoretically have been presented. The influence of various key factors viz. dust charge fluctuations, dust charge gradient force, dust-neutral collisions, radiative condensation, strong coupling effects, polarization force, non-ideal effects etc. on the various waves and instabilities are studied using hydrodynamic approach. The theoretical results are compared with existing observations and these results have been significantly applied to understand the structure formations in dusty plasma environment. The future scope of the work in low temperature laboratory dusty plasma is also presented [6-10].

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S8-I-01

High Power Ion Acceleration System for Tokamak Plasma Heating: The Physics and Technology

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High power ion acceleration is important topic of research and development due to its wide application e.g. Neutral Beam Injection (NBI) system for tokamak plasma heating and current drive. Tokamak is inherently pulsed device. To get a steady state, the current in tokamak is to be driven by non-inductive methods. Profiling of temperature and current needed for improving plasma properties, require local heating and local current drive. This cannot be provided by ohmic heating. For this reason, non-inductive methods have to be provided. Additional heating power in tokamak plasma can be provided by Neutral Beams (NB) power. Production of neutral beam of desired energy has sequence: fist plasma is produced inside vacuum chamber called plasma box. Ions from this plasma are separated, extracted and accelerated to a desired energy by an ion extractor. The accelerated ions are neutralized by passing them through a gas cell called neutralizer. Neutralisation occurs by charge exchange process. Un-neutralized ions are separated and deflected by bending magnet to a dump. The energetic neutrals, uninhibited by the tokamak magnetic field, are injected into plasma for the purpose of heating, current drive, plasma rotation and fuelling. The technology of production of NB is very complex. Steady state Superconducting Tokamak (SST-1) has a provision for positive hydrogen ion based Neutral Beam Injector (NBI) to raise the plasma ion temperature of ~ 1 keV with injection of neutral hydrogen beam (Ho) power of 1.7 MW at 55 kV. Considering neutralization efficiency and beam power loss at different beam line components, to obtain 1.7 MW NB power the required extract positive hydrogen ion beam power from ion source is 5 MW. Therefore extracted positive hydrogen ion current is 90A and is high value. This can be achieved by multi-aperture ion extractor system consists of 3 grid accel-decel system. Ion beam optics simulation code AXCEL-INP is used to design shape of the aperture of 3 grid systems and thickness of each grid. The result shows that single aperture of 8 mm diameter can be extract 116 mA hydrogen ion current. Therefore, total 774 numbers of apertures are needed to obtain 90A ion current at 55 kV. During beam operation extractor grid received heat load of 175 W/cm2 and same is removed by providing dense network of wavy semi-circular (R1.1 mm) cooling channels embedded in between the rows of shaped apertures. Complex technologies are involved in the fabrication of extractor grid. This talk shall describe the physics of generation of high power ion beamlets formation from ion source and transport to SST-1 tokamak plasma for heating and current drive. This talk also highlights the present status of the prototype development of various technologies involved in fabrication of extractor grid in India.

S8-I-02

Terahertz Plasmonics

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The field of terahertz science has been rapidly growing in last few years. It has found applications in a variety of areas ranging from engineering to medical science. Terahertz frequencies using plasmonic structures can potentially lead to the creation of next generation miniaturized high speed communication devices and networks. In my talk, I will speak about this emerging field of science and its significance in making waveguides which can support highly confined terahertz surface plasmon polaritons on a planar surface. The design, fabrication and characterization of planar plasmonic terahertz guided wave devices using plasmonic metamaterials structures will be discussed in length. Further, the significance of these devices in terahertz thin film sensing will be discussed.

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Basic Plasma (BP)

S-1-O-1

Interplay Between Kinetic and Magnetic Energies in Three Dimensional Magnetohydrodynamic Plasma

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Abstract- Unlike hydrodynamic systems the extra degrees of freedom in magnetohydrodynamic systems allow several information (energy, helicity etc.) to flow from one field variables to the other. This interplay has shown several novel phenomena that are absent in hydrodynamic flows for example dynamo, recurrence to name a few. The flow of energy from kinetic to magnetic variables is popularly known as dynamo effect. The dependency of growth rate of magnetic energy for several chaotic velocity field profiles (e.g. ArnoldBeltrami-Childress, Taylor-Green etc) on various parameters will be presented. On the other hand a reverse phenomenon where the velocity and magnetic field variables exchange energies between each other through reconnection process leading to reconstruction of velocity and magnetic field structures in such a high dimensional system will be presented. An analytical outline for the occurrence of such phenomena will also be depicted.

S-1-O-2

Effective Secondary Electron Emission Coefficient in Glow Discharge Plasmas

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Abstract-Secondary electrons (SEs) emitted from material surface which bound the plasma in laboratory have control over almost all the plasma parameters such as plasma density, electron/ion temperatures, power influx to the material etc. There are various species that can eject SEs from material surface such as ions, electrons, energetic neutrals, exited species, photons etc. The ratio of emitted electron flux to the incident ion flux on a metal surface is called ion induced secondary electron emission coefficient (ISEEC, ϒi). However, under abnormal glow discharge plasma condition, the non-ionic cathode directed species such as photons, metastables and energetic neutrals results from ion actively participate in the process of secondary electron emission (SEE) from cathode. The effective number of secondary electrons (SEs) emitted per ion is characterized by the value of effective secondary electron emission coefficient (ESEEC, ϒE) which is normally higher than ϒi. In the present work, we proposed a self consistent model for measurement of ϒE value of cathode material under abnormal glow discharge plasma condition. Using this model, we measured the ϒE value of different cathode (Tungsten (W), Copper (Cu)) material using different operating gases (Nitrogen (N2) and Argon (Ar)) for different pressures (0.15 mbar to 0.45 mbar). In addition to discharge conditions, the results show that possible dependence of ϒE value on the material properties such as work function and Fermi energy of cathode.

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S-1-O-3

Breaking of Nonlinear Plasma Oscillations against an Ion-pulse/Cavity: A Particle-in-Cell Simulation Study

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Abstract-The space-time evolution of nonlinear electron plasma oscillations against an ion-pulse/cavity has been studied in both non-relativistic [1, 2, 3, 4] and relativistic [5] limit using an in-house developed Particle-in-Cell (PIC) simulation code. It is found that for both the cases oscillations gradually start to deform and eventually break at arbitrarily small initial amplitude due to crossing of neighboring electron trajectories (phase mixing) [6]. The variation of phase mixing time (wave breaking time) for different input parameters has been studied and compared with the existing theoretical results [1, 2, 3, 4, 5].

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S-1-O-4

Modelling and Characterization of Atmospheric Pressure Plasma Jet based on Dielectric Barrier Discharge

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Abstract- Non-equilibrium atmospheric pressure plasma jets (APPJs) are of intense interest in current low-temperature plasma research because of their immense potential for material processing and biomedical applications. The plasma jets generate plasma plumes in open space while providing a significant number of active species, such as radicals, electrons, and ions. Thus, they can be used for direct treatment of materials or living tissues. One of the prerequisites to the biomedical applications is that the plume should be near room temperature and carry a low current under moderate voltage. Depending on the jet configuration and the electrical excitation, the plasma characteristics including heat, charged particle, electric field, and chemically active species may differ significantly. Other important parameters of importance in these studies are the kind of utilized working gas and gas flow rate [1-3]. Physically, the breakdown mechanism of APPJs depend strongly on the electron multiplication, which controls the transition from Townsend breakdown to streamer breakdown and finally to glow discharge region. The mobility of charged species in the electric field depend on the gas properties, the gas type determines the electron multiplication and the breakdown mechanism as well as the discharge mode. In addition, different working gases produce different plasma species resulting in different interactions with the targets [4-10]. In this research work, theoretical modelling has been done for ring electrode and pin electrode configurations using COMSOL Multiphysics software under the static argon gas condition and with flowing argon gas [11].The electron temperature, electron density and electrical potential have been calculated using simulation by varying applied frequency (10-25 KHz) and applied voltage (2.5 kV- 6kV). The electrical characterization of these jet devices having ring and pin electrode

configurations have been performed by V-I measurements in argon gas. The electrical characterization has been done for establishing the optimized operating range based on power consumption, peak discharge current and jet length. The experimental results are in agreement with simulation studies. All these jets have been operated in the glow discharge region. It is imperative to operate the device that is used for low temperature applications in the glow discharge region as the temperature of the gas remains at room temperature so that it does not damage the living tissue that is to be treated. If the discharge proceeds to the arc discharge region it would result in increase of gas temperature, the input power being wasted in thermal dissipation which causes the heating of the quartz tube and also leading to more power consumption. The floating helix electrode configuration studied has a novel design feature to understand the effect of floating electrode on the power consumption as well as on the jet length. The floating electrode configuration has been studied experimentally for different gases (Ar/He/Ar+N_2) and consumption of power has been studied under different operating parameters. The comparative analysis of the experimental results of all the above mentioned electrode configurations shall help in operating these devices in the glow discharge region with optimized power consumption. This research work also discusses the most pivotal factor of the developed plasma jet, i.e., jet length. Besides the V-I characteristics of these different electrode configurations for DBD based APPJ, jet lengths have been studied as a function of supply voltage, supply frequency and quartz sleeve put at the end of quartz tube. The jet length has been studied for both with sleeve and without sleeve. It has been observed that floating helix electrode configuration operating with helium consumes least power around few mW and may be a potential device for biological applications. The jet generated using mixture of Ar + N_2 shall be rich in excited active species and may be a useful device for surface cleaning and modifications.

S-1-O-5

Self-Consistent Development of Plasma Potential Drops in Expanding Plasma

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Abstract- The concept of plasma potential arises from the interaction of plasma with a boundary. The plasma potential develops so as to aid the acceleration of ions up to Bohm speed and retard electrons so as to maintain the quasi-neutral nature of plasma. This leads to the development of sheaths at the boundary walls. This dependence of the plasma potential on the confining boundaries has been exploited to trigger nonlinear potential structures in expanding plasma.Electron Cyclotron Resonance (ECR) plasma has been produced in an indigenously built Compact ECR Plasma Source (CEPS) [1] using permanent ring magnets and is allowed to expand into another larger volume of stainless steel (ss) cylinder. The ring magnets provide a diverging magnetic field in the expansion chamber with a peak at z = 2 cm (z = 0 cm corresponds to the mating plane of the two chambers). Systematic measurements of the plasma potential (V_p) have been presented using a movable Langmuir probe from inside the source to the outside in the expansion chamber. The dependency of the plasma potential on pressure (p = 0.05 – 1 mTorr) has been studied. It was observed that the on-axis plasma potential decreases from the source mouth to the end wall of the expansion chamber irrespective of the gas pressure, since such a potential gradient helps the ions to leave the system at the same rate as electrons.
However, there is a distinct difference in the evolution of the plasma profiles at high pressures ($p \geq 0.3$ mTorr) as compared to that at lower pressures (≤ 0.2 mTorr). A major distinction seen is the evolution of the plasma potential (V_p). At higher pressures, for $z > 0$, one observes a gradual linear decaying ambipolar field (*i.e.*, from 40-50 eV at source mouth to 15-25 eV at $z \approx 50$ cm). However, as one goes down in pressures, the gradients becoming steeper and ultimately multiple double layers (DL) are observed along the axis for p = 0.05 mTorr. In fact, V_p is significantly high at the source mouth (100 - 150 eV), *i.e. 2-3 times than that observed at higher*

pressures. This is indicative that the plasma in the source region has evolved to impede the plasma flowing out into the expansion chamber at lower pressures, as indicated in Ref. [1]. Another significant observation is that at high pressures ($p \geq 0.3$ mTorr) the plasma discharge evolves beyond z ≈ 0 cm as a *two temperature population* whereas for low pressures (≤ 0.2 mTorr), *single electron populations* are only observed. At high pressures, the bulk electrons have densities (n_e) ≈ (1 – 2) × 10^{12} cm^{-3} and temperatures (T_e) ≈ 5 - 10 eV near the source mouth. The bulk population density decays rapidly to n_e ≈ (5 – 10) × 10^{11} cm^{-3} at z ≈ 12 cm. Thereafter the decrease is more gradual to about n_e ≈ (2.5 – 5) × 10^{11} cm^{-3} at z ≈ 50 cm. T_e is also seen to decrease almost linearly from the source mouth to ≈ 2 eV at z ≈ 50 cm. The warm population temperature (T_w) is almost constant (≈ 50 eV) along the axis and density (n_w) profiles are almost following the bulk density profiles with n_e / n_w ~ 800-1000.

The distinct difference of the plasma profiles with pressure can be attributed to the evolution of the plasma within the source section along with its leaking out into the expansion chamber following the expanding magnetic field profile of the permanent magnets. This paper will present the experimental results so as to correlate the plasma evolution from the source section to the expansion chamber.

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BP1

Modulational Instability of Ion Acoustic Waves in a Multi-Species Collisionless Magnetized Plasma Consisting Of Nonthermal And Isothermal Electrons

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Abstract -We studied the modulational instability of ion acoustic waves in a multi-species collisionless plasma by considering the effect of uniform (space independent) and static (time independent) magnetic field directed along a fixed direction. A three dimensional nonlinear Schrödinger equation is derived to study the modulational instability of ion acoustic waves in a multi-species collisionless magnetized plasma consisting of warm adiabatic ions, nonthermal hot electrons, due to Cairns et al. [Geophys. Res. Lett. 22, 2709 (1995)], which generates the fast energetic electrons and MaxwellBoltzmann distributed isothermal electrons. The modulational instability of ion acoustic waves propagating along the direction of the magnetic field has been investigated theoretically. The instability condition and the maximum growth rate of instability have been derived analytically. It is found that the maximum growth rate of instability decreases with increasing values of the magnetic field intensity whereas the maximum growth rate of instability increases with increasing cos δ, where δ is directly related to the modulational obliqueness θ by the relation θ+δ=π/2, i.e., δ is the angle between the direction of the modulated wave with the static uniform magnetic field.

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BP2

Bernstein Mode Instabilities In Inhomogeneous Plasma In Presence Of *F* X *B* Drift Wave Turbulence.

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Abstract-The instabilities of Bernstein mode in an inhomogeneous plasma has been investigated on the basis of nonlinear wave-particle interaction process. We have considered an uniform force field ***F*** perpendicular to the magnetic field ***B*** in the direction opposite to the density gradient for which it may cause the ***F***x***B*** drift wave turbulence in the system. Using Vlasov-Poisson's system of equations and Maxwellian type distribution function of particles modeled for density inhomogeneity, we have derived a nonlinear dispersion relation for Bernstein mode in inhomogeneous plasma. This nonlinear dispersion relation is expressed sum of two terms called direct coupling term and polarization coupling term. It is observed that the direct coupling term doesn't contribute to the growth of the Bernstein mode. Only the polarization coupling term is found to be effective in the energy upconversion process due to the external force field ***F*** whose is identified as electrical force. We have also estimated the growth rate of Bernstein mode in the magnetospheric and tokomark plasmas.

BP3

Emission of Electromagnetic Radiation in Burning Plasma Driven By Nonlinear Force

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Abstract-Emission of electromagnetic radiation of whistler mode in burning plasma has been investigated in presence of low frequency kinetic Alfven wave turbulence through wave particle interaction on the basis of a nonlinear force. The nonlinear force arises as a result of the resonant interaction between ion and modulated field has been found to derive the instabilities. We have considered Maxwellian model for particle distribution function to obtained fluctuating parts for ion distributions. Using nonlinear fluctuating parts of ion distribution, a nonlinear force is developed. From ion momentum equation and ion continuity equation, a nonlinear dispersion relation for whistler mode is obtained by involving this nonlinear force. The growth of whistler mode has been estimated using observed data from fusion experiments. This investigation indicates whistler mode instability may be developed in presence of kinetic Alfven wave turbulence field in burning plasma.

BP4

Ion-Acoustic Dressed Solitons in Plasmas with Positrons and Nonthermal Electrons

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Abstract-Propagation of an ion-acoustic soliton in a plasma consisting of ion, positron and nonthermal electron is considered the reductive perturbation. The well known reductive perturbation method (RPM) has been used to derive the KdV equation. This exact solution reduce to the dressed soliton solution when mach number (M) is expanded in terms of soliton velocity. Variation of amplitude and width for the KdV soliton, core structure, dressed soliton and exact soliton are graphically represented [Tiwari 2008] to different values

of positron concentration and nonthermal electron.

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BP5

Quantum Dots Based Klystron Application in Automobiles and Locomotives

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Abstract-Application of Quantum dots based klystron studied theoretically with design for implementation in automobiles and locomotives .ZnS based quantum dots 12 cavity Toroidal klystron are used to study the power generated by using the microwave technique which will power the automobile with instant charging as well as the boosting the power of 72kW which is equivalent to 96.51 BHP, which is sufficient enough for any automobile be it car, bus or truck .another application of ZnS quantum dots based 12 cavity Toroidal klystron is in large scale using such type of 10-12 klystron to generate power of 2000BHP for locomotive engines.

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BP6

Modulation Instability of Obliquely Propagation Ion-Acoustic Waves In Plasma With Nonthermal Electrons And Positrons

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Abstract-The stability of oblique modulation of an ion-acoustic waves in a magnetized plasma consisting of ion, positron and nonthermal electron, using the KBM perturbation method. A nonlinear Schrodinger equation is derived for the system. It is found that the variation of the growth rate and Landau damping rate with obliqueness of modulation and magnetization. The stability region is investigated in the (k, θ) plane. It is observed that in a collisionless plasma, the maximum growth rate for the modulation instability, for large carrier-wave amplitude ($a_0 > 0.1$), exceeds the nonthermal electron Landau damping rate for sufficiently oblique modulation.

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BP7

Large Amplitude Ion-Acoustic Solitons In Plasmas With Positron And Nonthermal Electron

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Abstract-Propagation of an ion-acoustic soliton in a plasma consisting of ion, positron and nonthermal electron is considered the reductive perturbation. The well known reductive perturbation method (RPM) has been used to derive the KdV equation. This exact solution reduce to the dressed soliton solution when mach number (M) is expanded in terms of soliton velocity. Variation of amplitude and width for the KdV soliton, core structure, dressed soliton and exact soliton are graphically represented to different values of positron and nonthermal electron.

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BP8

Transient Solutions of Fokker-Planck Equation in a Paul Trap

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Abstract-Paul trap is a device used to confine charged particles of the same species by using time-periodic spatially linear electric fields. Although the single particle dynamics for such electric fields is well understood, the collective dynamics still has many open questions. The collision-less Vlasov equation for spatially non-uniform time-periodic electric fields is known to have infinitely many solutions, most of which are quasi-periodic in time [1-2]. However, it is usually believed that the solutions of the collisional Fokker-Planck equation for such systems asymptotically reach an equilibrium state of time-periodicity irrespective of the initial conditions [3]. In this work, we have analyzed the Fokker-Planck equation for plasma in a Paul trap in more detail and found two interesting features of the solutions. Firstly, for a time-periodic spatially linear electric field, the Fokker-Planck equation seems to admit solutions only of the form of a Gaussian (quadratic polynomial in the spatial and velocity coordinates raised to an exponential). If we take higher powers of the spatial and velocity coordinates in the exponential, their coefficients turn out to be zero even for the transient state. This is very intriguing since strictly speaking, we should be able to start from any arbitrary initial condition and then reach a particular periodic solution asymptotically. Secondly, for the simple case of a simple harmonic oscillator, when we assume a similar Gaussian solution for the Fokker-Planck equation, we find that the coefficients of the three terms inside the exponential have two fixed points, one of which is the well known stable Boltzmann solution. However, there is another fixed point, which is unstable and there could be special initial conditions in the plasma distribution, for which these coefficients blow up with time.The primary conclusion of our work is that the transient solutions of Fokker-Planck equation need to be carefully analyzed and merely looking at the equilibrium solutions can be misleading.

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BP9

Wave Breaking of Nonlinear Relativistic Electron Plasma Wave in Inhomogeneous Plasma

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Abstract- One of the key applications of relativistically strong plasma wave is to produce ultra-high energy charged particles for the purpose of high energy physics research. In this plasma wake field acceleration process, the highest energy that can be achieved is mainly determined by the maximum sustainable electric field in the plasma system. This limiting amplitude of the electric field is dictated by a process called plasma wave breaking.[1,2] We have performed an extensive analysis to investigate the wave breaking phenomena of high frequency nonlinear plasma modes (Langmuir wave) with the consideration of the effect of the nonlinearities associated with inhomogeneous ion background, relativistic electron mass variation effect, ion motion etc. The onset of such wave breaking has been confirmed by the observed high density spikes in the electron fluid density obtained in investigating the space time evolution (Lagrangian fluid description) of the nonlinear relativistic plasma wave dynamics.[2,3]

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BP10

The Cnoidal Ion Hole Spectrum Due To Trapping Nonlinearity

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Abstract - Phase space vortices are perfect examples of self-organization in plasma and are inherently nonlinear [1,2]. They are formed due to density depletion of plasma species in a certain localized region in phase space. The spectrum of Cnoidal ion holes has been investigated for both continuous and discontinuous distributions for trapped ion. Regular (continuous) trapped ion distribution leads to a continuous spectrum which provides a finite phase velocity and hence termed as "Privileged". By introducing a jump at the separatrix of trapped ion distribution (discontinuous)[3], an extended class of privileged Cnoidal ion hole spectrum can be obtained. Schamel's kinetically upgraded method [4] has been employed for obtaining the set of two microscopic equations viz., the nonlinear dispersion relation (NDR) and the pseudopotential to get the spectrum.

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BP11

Solutions Of Vlasov Equation For Periodically Driven Plasma

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Abstract - Periodic driving is an important tool that is widely used to spatially confine plasmas, especially using RF fields [1]. The dynamics of such periodically driven systems are normally studied through Vlasov equation with the basic assumption that the plasma under study is collisionless and non-radiating [2]. Analytical solutions to the equation in such cases are usually approximated using the standard ponderomotive theory. There have been several attempts made in the past to rigorously solve the Vlasov equation using a basic assumption that the

plasma distribution function is itself time-periodic. Though the solutions obtained through these methods agree well with the conventional ponderomotive theory, they lack insights as to why it has to be periodic. To investigate this problem, we first solve the collisionless Vlasov equation using Hamiltonian averaging theory [3] and show that one of the solutions obtained is indeed identical to the solution predicted by ponderomotive theory. On further comparison of the result with that obtained from the method of characteristics, we obtain that the solution derived using ponderomotive theory is in general very restrictive in nature and heavily depends upon the initial distribution function from where the system evolves. In general, we show that solutions of Vlasov equation for a periodically driven system are aperiodic and that there do exist other periodic solutions different from that predicted by the ponderomotive theory. Lastly, based on the analysis done using the method of characteristics, we propose a conjecture on the structure of the initial distribution needed for the periodicity condition of the solutions of Vlasov equation to be valid. We found that in order to satisfy the condition, the irreducible polynomial corresponding to the initial distribution should have squares of momentum and spatial variables [4].

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BP12

Effect of Ohmic Heating on THz Radiation Emission by Laser Plasma Interaction

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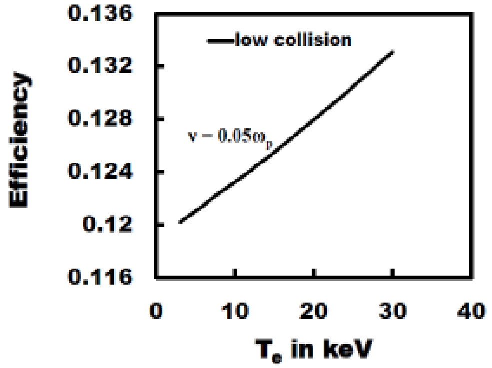
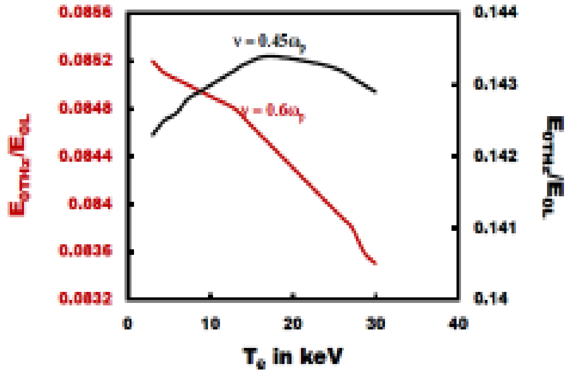
Abstract-These days Terahertz frequency (submilimeter wavelength) domain of electromagnetic spectrum has emerged as an extensive tool of the technology based on their day to day applications. The mechanism of terahertz generation from laser plasma interaction is very interesting topic which also involve nonlinear thermal effects in plasma. The effect of different profile of lasers on the magnitude of beat wave and wakefield is investigated and further theoretical description is presented for emission of terahertz pulses. It is also studied that how electron neutral collisions adverse the mechanism of THz emission. Collisions lead to ohmic heating in plasma through laser which result interesting modifications in the plasma dynamics causing THz emission.





The collisions in a plasma act as a damping force to the plasma electron oscillations and moreover thermal effects in presence of collision become important to THz Radiation generation. The ohmic heating causes temperature anisotropy in plasma that results further redistribution of plasma density and variation of collision frequency. The effect of plasma temperature corresponding to collision frequency is studied on the efficiency of the mechanism and THz field amplitude is seen from appended figures.

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BP13

Ion-Acoustic Wave Modulation and their Stability for Higher Order Nonlinearity

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Abstract- Strongly dispersive plasma waves and wave modulation has been studied through Nonlinear Schrödinger Equation (NLSE) which is derived by a Modified Reductive Perturbation Technique (MRPT). Here the stability and evolution of the modulated nonlinear plasma waves can be studied through the coefficients of the nonlinear and the dispersive terms in the derived equation of NLSE. Results obtained due to the effect of ion temperature and pressure term which are observed in our study. The derivation of an NLSE in our work describes the nonlinearity of the modulated plasma waves and it shows that the higher order nonlinearity can be shown by another evolution equation and pressure term equation in more detailed type.

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BP14

Conceptual Design and Prototyping of 2-D Probe Positioning System for Large Volume Plasma Device

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Abstract-The Large Volume Plasma Device (LVPD) [1] is a large sized, double walled, water cooled, linear plasma system dedicated for carrying out fundamental studies relevant to earth's atmosphere and fusion plasmas. The SS304 vacuum vessel (L = 3m, Ø= 2m) is equipped with 94 radial ports distributed over cylindrical surface. These ports are meant to accommodate various diagnostics needed for plasma characterization. The novelty of this work lies in realizing (r, θ) movement of the probe over a radial extent of 1m without disturbing high vacuum (10^{-6} Torr) conditions inside the device. Currently, 12 numbers of ports in the horizontal plane are equipped with linear automated probe positioning systems[2]. A new probe drive system with (r, θ) movement is required for 06 numbers of vertical ports to obtain cross-sectional information on plasma parameters at different axial locations. The conceived system should have features such as , 1) linear motion (~1m), 2) rotational motion (0-360^o), 3) automated remote operation and 4) mechanical and structural integrity. The mechanical design is being carried out using CATIA software, to design structural model of vacuum vessel, components for (r, θ) movement, vacuum interface arrangement and design calculations. An in-house development has begun for procurement of vacuum seal and fabrication of support structure for integrating the probe drive system with LVPD. This development is meant for LVPD; however it

can also be useful for other experimental plasma devices in general. This paper will discuss requirements, literature survey, mechanical model design and on-going prototype development and obtained results.

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BP15

Synchronization dynamics between three inductively coupled DC glow discharge plasma Sources

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Abstract- Synchronization dynamics is studied between three inductively coupled DC glow discharge plasma sources. For this, DC glow discharge plasma is produced in three glass chambers of same configurations by applying the potential difference between the electrodes. The ratio of the anode to the cathode surface area is chosen to be very small such that an intense anode glow could be formed around the anode surface area which in turn produces the oscillations in the plasma. These oscillations are measured by capturing the floating potential oscillations of plasma via cylindrical Langmuir probes placed in each of the chambers. The discharge voltages in two of the chamber plasmas are adjusted such that the oscillation frequencies in these chambers are close namely 340 kHz and 360 kHz respectively while third chamber plasma oscillation frequency is kept fixed at 55 kHz. The oscillations of 340 kHz and 360 kHz plasma systems are individually inductively coupled via 55 kHz plasma system. The inductive coupling is provided between these systems by connecting the externally wounded copper wires placed outside on top of each of the chambers. It has been observed as the coupling is provided, the oscillations of 340 kHz and 360 kHz plasma systems are synchronized in a in-phase state with a common oscillation frequency of 350 kHz while the third system oscillations went to an unsynchronized state. This is an interesting experimental observation which is previously not seen in the plasma systems. These experiment tal results are numerically modeled using three environmentally coupled van der Pol oscillators and the obtained results are found to be in good agreement with the experimental results.

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BP16

Design and Analysis of Plasma Diagnostic Supports Structure and Mechanisms for Aditya-U Tokamak

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Abstract- Plasma diagnostic is very important tool to determine the different parameters of plasma. These parameters decide the way of operation and improvement to sustain the plasma for the longer duration. At Institute for Plasma Research, two tokamaks namely Aditya-U and SST-1 (Steady-state Superconducting Tokamak) are being regularly under operated to study the behaviour of plasma. Different diagnostics are

installed in the said tokamaks. They are namely bolometer, reflectometry, Langmuir probe etc. Each of these diagnostic requires careful mechanical design and analysis. In this paper, mechanical design, structural analysis, manufacturing and installation of various diagnostics deployed in ADITYA-U tokamak is discussed.

BP17

Dust Acoustic Waves in Plasma with Variable Dust Charge, Nonthermal Ions and Trapped Electrons

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Abstact-A fluid model of unmagnetized dusty plasma containing dust particles with variation of charge [1], nonisothermal electrons and nonthermal ions, is considered. Non perturbative approach is applied to study the large amplitude dust acoustic solitary waves. Solutions of small amplitude waves are obtained under different approximations by deriving the intermediate integral forms of Korteweg-de Vries (KdV) and modified Korteweg-de Vries (mKdV) equations from the Sagdeev potential equation [2]. Spiky and Explosive modes of solitary waves as well as double layers are found to exist [3]. The parameters $\alpha, \beta, M, \sigma,$ and μ, representing the population of nonthermal ions, ratio of free and trapped electron's temperatures, wave Mach number, temperature ratio of ion and free electrons, and the density ratio respectively, are found to play a very important role in the formation of solitary waves.

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BP18

Validation of Smartex-C Vacuum Vessel Heating Results with Fem Analysis and Prospective Conceptual Cooling Design Schemes

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Abstract -SMARTEX-C, the SMall Aspect Ratio Toroidal EXperiment in a C-shaped geometry, is a partial toroidal trap (aspect ratio Ro/a = 1.6, trapping angle Φ~315o) which combines the features of toroidal trap with those of cylindrical one. It routinely creates electron plasmas for ~1s, at 1.0× 10 –9 mbar pressure and toroidal magnetic field ~ 1kG along its minor axis. Vacuum vessel heating/baking during the physics experiments with continuously powered electronsource (hot tungsten filament) on for steady-state conditions (4 hours to say) lead to temperature rise up to 80C and consequential base pressure rise. This increase in pressure leads to the degradation of the confinement time hence need of an efficient cooling to kept the vacuum vessel at lower temperature was felt. Such cooling mechanism needs a validated estimation of rise in vessel temperature and its distribution on its surface.This paper discusses the FEM approach and estimation of the vessel temperature rise due to the source, its validation with experimental results and prospective cooling schemes are summarized.

BP19

Existence And Stability Of Alternative Dust Ion Acoustic Solitary Wave Solution Of The Combined Mkp-Kp Equation In Nonthermal Plasma

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Abstract- The aim of the present paper is to extend the recent work of Sardar *et al.* [Phys. Plasmas, **23**, 073703 (2016)] on the stability of the small amplitude dust ion acoustic solitary wave in a collisionless unmagnetized nonthermal plasma in presence of isothermal positrons. Sardar *et al.* [Phys. Plasmas, **23**, 073703 (2016)] have derived a KP (Kadomtsev Petviashvili) equation to study the stability of the dust ion acoustic solitary wave when the weak dependence of the spatial coordinates perpendicular to the direction of propagation of the wave is taken into account. They have also derived a modified KP (MKP) equation to investigate the stability of the dust ion acoustic solitary wave when the coefficient of the nonlinear term of the KP equation vanishes. When the coefficient of the nonlinear term of the KP equation is close to zero, a combined MKP-KP equation more efficiently describes the nonlinear behaviour of the dust ion acoustic wave. This equation is derived in the present paper. The alternative solitary wave solution of the combined MKP-KP equation having profile different from $sech^2$ or $sech$ is obtained. This alternative solitary wave solution of the combined MKP-KP equation is stable at the lowest order of the wave number. It is found that this alternative solitary wave solution of the combined MKP-KP equation and its lowest order stability analysis are exactly same as those of the solitary wave solution of the MKP equation when the coefficient of the nonlinear term of the KP equation tends to zero.

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BP20

Dust Ion Acoustic Solitary Structures at the Acoustic Speed in Presence of Nonthermally Distributed Electrons and Positrons

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Abstract- The Sagdeev pseudo-potential technique and the analytic theory developed by Das *et al.* [1] have been used to investigate the dust ion acoustic solitary structures at the acoustic speed in a collisionless unmagnetized dusty plasma consisting of negatively charged static dust grains, adiabatic warm ions, Cairns [2] distributed nonthermal electrons and positrons. Several authors investigated small or arbitrary amplitude dust ion acoustic solitary structures in different electron-positron-ion-dust plasma systems. But in all those works dust ion acoustic solitary structures have been considered at the supersonic speed only, i.e., for $U > C_D$, where U is the velocity of the wave frame and C_D is the linearized velocity of the dust ion acoustic wave for long wave length plane wave perturbation. In the present paper, we have studied the dust ion acoustic solitary structures at the acoustic speed i.e., for $U = C_D$ with the help of the existence domains and the phase portraits of the dynamical system describing the nonlinear behaviour of the dust ion acoustic waves in the same plasma system considered by Paul *et al.* [3]. At the acoustic speed, the system supports both positive and negative potential solitary waves, but does not support the coexistence of solitary waves of opposite polarities. The system also supports negative potential double layer at the acoustic speed, but does not support positive potential double layer. Although the system

supports positive potential supersoliton at the supersonic speed, but there does not exist supersoliton of any polarity at the acoustic speed. For the first time, we have introduced the phase portrait analysis of the dynamical system corresponding to the solitary structures at the acoustic speed. Phase portraits of the dynamical system corresponding to different dust ion acoustic solitary structures indicate the difference between the solitary structures at the acoustic speed ($U = C_D \Leftrightarrow M = M_C$) and the solitary structures at the supersonic speed ($U > C_D \Leftrightarrow M > M_C$).

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BP21

Amplification of Energetic Electrons Driven Whistler Mode by Loss Cone Induced Reflected Particles

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Abstract-_Whistler waves are evident in magnetospheric as well as laboratory plasmas. These waves are excited by pressure gradients (∇P), energetic electrons, electron temperature anisotropy ($\frac{T_\parallel}{T_\perp} \neq 1$), loss cone and external antennas etc. Lately, these waves are found to be of more significance in fusion machines that can possibly suppress runaway electrons [1]. In the recent past, we reported excitation of Quasi-Longitudinal whistlers in LVPD by loss cone induced reflected particles [2]. The theory for the reflected particle driven whistlers consider DGH type of distribution ($f_r(v_\parallel, v_\perp) = n_r f_{r\perp}(v_\perp) f_{r\parallel}(v_\parallel)$), where n_r is the reflected particle population [3]. The plasma in LVPD uses a filamentary discharge with confinement provided by a combined magnetic field of axial and transverse components. The axial magnetic field, B_z is provided by a set of 10 coils garlanded to LVPD and transverse field, B_{EEF} by an 2m diameter, solenoid called electrons energy filter (B_{EEF}) accommodated at the axial center of device[4]. This introduces asymmetry in plasma and divides LVPD plasma into three plasma regions of Source, EEF and Target plasmas. The configuration develops a belt like structure, rich with energetic electrons and exhibits enhanced turbulence in the source plasma region. The dispersion relation for the growth of the excited mode suggests that the reflected particle density is directly proportional to its growth. Controlled investigations are initiated to see the role of reflected electrons and strength of loss cone on the plasma instability. Variation in EEF magnetic field controls strength of loss cone and variation in filament current controls population of reflected electron density. This paper will present the experimental results on the amplification of the whistler modes under these conditions and will throw some light on conditions under which mode undergoes transformation from electrostatic to electromagnetic nature.

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BP22

Finite Beta Effect on Turbulent Particle Transport in ETG Plasma

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Abstract-Plasma transport across confining magnetic field continues to bother fusion fraternity; consequently, numerous efforts are dedicated on its experimental, theoretical and computational investigations. Although, problem concerning ion scales is greatly resolved but electron scale contribution to plasma loss still unresolved. The reason may be the inability of carrying out direct measurements in fusion devices because of extremely small-scale length of instability and violent conditions [1].Recent success on unambiguous demonstration of excitation of Electron Temperature Gradient (ETG) turbulence in Large Volume Plasma Device (LVPD) [2] has motivated us to investigate turbulent transport induced by ETG turbulence. We investigated convective particle transport, and compared it's both electrostatic and electromagnetic components with theoretical estimates and found that they are directed radially inward. The EM flux is found finite and non - zero against predicted zero for slab ETG model but its magnitude is extremely small compared to ES flux. We varied plasma beta between (β~ 0.01- 0.4) and observed that despite reduction in density fluctuations with increasing beta, the contribution to particle flux increases, which is surprising. For this, we carried out investigations for phase angle and temperature fluctuations. Detailed results on plasma beta modifications to phase angle and temperature fluctuations contribution to plasma transport will be presented in the conference.

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BP23

Electron Temperature Control using Multi- Grid Biasing System in Prototype Double Plasma Device

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Abstract-A prototype double plasma device is configured for carrying out investigations in understanding the mechanism involved for exerting a control on plasma parameters, especially the electron temperature. This is significant as it allows leverage in understanding the role of plasma profiles in the generation of plasma instabilities and also, their role in carrying out material processing applications [1, 2, 3]. We carried out this exercise in order to find out a better mechanism of electron temperature control than concept based on transverse field diffusion [3]. The prototype device consists of two almost similar cylindrical chambers. The plasma is produced in first chamber which is grounded and allows diffused plasma to enter in target chamber, which is floating and is separated by a gridded assembly. In pursuit of carrying out aimed investigations, we first established double plasma conditions in target chamber of the device before really exercising charging of different extent of grid, spread radially with different potentials.We observed significant reduction in electron temperature and plasma density in the radial center of target plasma. We inspected the role of different grid bias potential and effect of transparency on electron temperature control. Variation in grid transparency is realized by varying the Debye length in realizing a change in plasma density. This has shown that better control in electron temperature is established when the ratio of source to target density is maximum. We

could change the electron temperature by ~ 35%. The temperature value has undergone a change from 4.87 eV to 7.2 eV when the grid bias is varied from 0 to 20 V. The Electron Energy Distribution Function (EEDF) shows the presence of an energetic tail. The detailed results on this will be presented in the conference.

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BP24

Large amplitude ion acoustic double layers in negative ion plasmas

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Abstract: We have studied ion acoustic double layers (IADLs) in multicomponent plasma containing hot negative and positive ions with Maxwellians electrons distribution. We have studied the charteristrics and occurrence of IADLs in negative ions plasmas employing Sagdeev pseudo potential technique. We have investigated the dependence of different parameters on the characteristic of double layers. It is investigated that the positive (compressive) and negative (rarefactive) potential double layers are simultaneously exist in system. It is analysed that by increasing the negative ions decreases the minimum Mach number at fix temperature (σ_1 and σ_2). The effect of ions temperature ratio (σ_1 and σ_2) and negative ion concentration (α) on the double layers are discussed in detail. The present model is applied to study the large amplitude IADLs in the plasmas containing (H^+, H^-), (Ar^+, F^-), (CS^+, Cl^-) and (Xe^+, F^-). This investigation may be helpful to understand the double layers in laboratory and space plasma, where negative ions are present with thermal electrons.

BP25

Injection of Electrons in SMARTEX – C

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Abstract-Electron plasmas have regularly been created, confined and studied in SMARTEX – C which is a toroidal device maintained at an ultrahigh vacuum ~ 10– 9 mbar, has a low aspect ratio and a C – shaped trapping region. The electrons from a thermionic source i.e., a 0.5 mm thick, 30 cm long tungsten filament bent in a ring shape, are loaded into the trapping region using a gated injector. The 'inject – hold – dump' scheme applied in linear traps is followed here too. The trapping region is the major arc of a torus formed by two electrostatic gates viz. injector and collector grids and a toroidal magnetic field BTF. In this paper we present the experimental results of injection of electrons under different physical parameters like tungsten filament current IF, filament bias VB (thermionic current, IS) and BTF. The scheme of investigation is based on charge conservation. The leakage of injected electrons from the trap and methods to reduce their leakage is also discussed.

BP26

Global Particle Balance in a 13.56 MHz Magnetized Parallel Plate Capacitive Discharge

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Abstract - Global models have been extensively used by researchers in predicting the plasma parameters and scaling laws of diverse kind of discharges including the one with complex gas mixtures [1]. The beauty of global model lies in its simplistic approach which enables it to be used readily in the discharges where fluid or kinetic simulation takes an enormous amount of computational time. Electron temperature is one of the plasma parameter commonly estimated by balancing the particles produced by ionization within a plasma volume to the flux of particles reaching the bounding surfaces [1-2]. The flux of the particles lost depends on the ratio of the electron density at the plasma sheath edge (ns) to the density at the center (n0). The factor hl= ns/ n0 has a critical dependence on the pressure and the dimension of the reactor. There are different solutions given in the literature on the basis on the working regime. However, we have used a Heuristic solution for hl, solved for a plane parallel geometry for the unmagnetized case [2]. Due to the presence of transverse magnetic field the expression governing the particle and energy conservation gets modified as compared to the conventional unmagnified discharge model.

In the present work, we have estimated the electron temperature from the global particle balance in a magnetized parallel plate capacitive discharge. To incorporate the effect of transverse magnetic field, the conventional form of hl has been modified and used in the particle conservation to estimate the electron temperature. The electron temperature obtained by particle balance exhibits a direct dependence with the gas pressure. The response of electron temperature to the pressure is found to be in agreement with the electron temperature measured by an rf compensated single Langmuir probe and also with the results obtained from the Comsol Multiphysics software.

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BP27

Envisaging Space Propulsion Experiment in A Helicon Plasma Source

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Abstract- For deep space propulsion, plasma thruster is one of the best options for high specific impulse which allows maximization of mission payload mass and makes electric propulsion attractive [1]. Different thruster-schemes based on plasma are being explored worldwide in recent years. The thruster based on current free helicon double layer (CFDL) has been demonstrated as a potential candidate among them. [1]. In CPP-IPR, a helicon plasma source (HeliPS) has been designed, developed and successfully used to produce helicon plasma in different gases [2, 3]. This system consists of a source chamber made of glass whose inner diameter is 10 cm and length 60 cm, an expansion chamber of diameter 30 cm and length 40 cm followed by an extraction chamber of diameter 30 cm and length 43 cm [2, 3]. Plasma is produced by injecting RF power at a frequency of 13.56 MHz through a half-helical antenna of length 18 cm in presence of a DC magnetic field (**B_0**) along the axis of the chamber which is produced by using six electromagnets. This device provides opportunities to create conditions for formation of Double Layer (DL) [4, 5] at low pressure and high plasma density. Experiments using electronegative gases such as Oxygen (O_2), Chlorine (Cl_2) or mixture of Argon (Ar) and O_2 or Cl_2 will facilitate production of positive-ion negative-ion plasma and our endeavor will be to create conditions for occurrence of nonlinear phenomena such as

formation of Double Layer (DL) [4, 5]. Ion acceleration will result due to the electric field of DL which will also contribute in their extraction. It is worth mentioning that ion-ion plasma propulsion has the advantage that no neutralizer is needed to neutralize the ions detached from the spacecraft, and no space charge build-up problem arises. Therefore, attempt will be made for envisaging space propulsion experiment in HeliPS both in electron-ion and ion-ion plasma.

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BP28

Modeling Metal-Plasma Junction using Energy-Band Diagram

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Abstract- In the present work, the concept of energy-band theory has been adopted for metal-plasma junction to study I-V characteristics. A simplified Energy-Band diagram for metal-plasma junction has been presented. Further, the theoretical predictions of the proposed model have been experimentally validated using two different metal-plasma junctions. Tungsten (W) and stainless steel (SS) metals having different band structure owing to their workfuncitons (Φ_W=4.55 eV & Φ_{SS}=4.30 eV) has been chosen to make metal-plasma junctions. The discharge is produced in a SS chamber at different pressures (0.25 mbar, 0.30 mbar and 0.35 mbar) in air with discharge voltage of -500 V applied between cathode and grounded chamber. The W & SS planar metal probes having identical geometry were exposed to plasma under identical plasma environment. The difference in I-V characteristics obtained for these two planar metal probes is consistent with the proposed energy-band diagram for metal-plasma junction which can't be explained otherwise. Thus, the concept may have wide impact on laboratory plasma and may provide a new method for accurate measurement of plasma parameters experimentally.

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BP29

Sheath Characteristics in Presence of Two Species of Positive Ions and *Q*-Nonextensive Electron Distribution

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Abstract- Tsallis nonextensive particle distribution [1] is successfully applied to explain the statistical properties of systems with long range correlations such as in plasmas with the Coulomb force. In the plasma processing work the presence of a single positive ion is rare [2]. A plasma sheath model comprising of two species of fluid positive ions along with the Tsallis *q*-nonextensively distributed electrons is presented in this work. A modified sheath formation criterion is derived by using Sagdeev potential technique. On the basis of the modified Bohm sheath criterion the

effect of nonextensivity parameter and the two species of positive ions on the sheath characteristics such as, density, potential etc., has been studied. The results obtained for the q-nonextensive electrons are compared with that of Maxwellian electrons in the limit of the nonextensivity parameter tends to one.

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BP30

Solitary Kinetic Alfvén Waves in Quantum Electron-Positron-Ion Plasma with Arbitrary Temperature Degeneracy

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Abstract-In the present study, nonlinear propagation of kinetic Alfvén waves (KAWs) is investigated in a low but finite β (particle-to-magnetic pressure ratio) electron-positron-ion (e-p-i) quantum plasma. The ions are assumed to be cold and non-degenerate whereas the electrons and the positrons are assumed to be arbitrarily degenerate. In order to study nonlinear KAWs we have employed Reductive Perturbation Technique and obtained the KdV equation. The arbitrary degeneracy, effects of positron concentration, plasma β and obliqueness on the characteristics of solitary KAWs are investigated numerically.

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BP31

Axial characterization of a segmented cylindrical capacitively coupled plasma source by triple Langmuir probe

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Abstract-A magnetized argon plasma column is created by two cylindrical capacitively coupled electrodes in a linear vacuum chamber. Each cylindrical electrode is azimuthally segmented in four parts and placed coaxially at different axial positions in a linear vacuum chamber. The four segments in both the electrodes are shorted externally (outside the vacuum chamber) and are driven out of phase with each other with help of a 13.56 MHz power supply through a 1:1 isolation transformer to create a symmetric CCP discharge. A triple Langmuir probe is used to obtain time averaged axial plasma parameters [1] such as plasma density (n) and electron temperature (T_e) of this plasma column. It is found from the results that the plasma density and the electron temperature follow similar trends as observed in a parallel plate discharge [2]; with peaked plasma density at the axial center of both the electrodes and falling densities towards the segmented cylindrical electrodes; while the electron temperature is found to show inverse trend as it peaks near the cylindrical electrodes and falls in the axial center of the discharge. It is also seen that the axially the plasma density increases strongly with axial magnetic field and weakly with RF power while the electron temperature is seen to fall with increasing magnetic fields.The behavior of the plasma source and its performance in presence of magnetic field is obtained by characterizing axial plasma parameters and the obtained discharge characteristics have been qualitatively discussed.

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BP32

Biased Hairpin Probe in Magnetized Plasma Column

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Abstract- Hairpin probe is a microwave resonant structure which used to determine the frequency dependent permittivity of the surrounding medium [1]. In the recent years hairpin probe is used to determine the electron density accurately in low-pressure plasmas. In presence of magnetic field the equilibrium condition of plasma is greatly modified. In case of magnetized electrons, the dielectric constant of plasma becomes anisotropic [2, 3]. The orientation of hairpin about the external magnetic field direction has a minimal effect in its resonance frequency [4]. A biased hairpin in a magnetized plasma can measure the corrected sheath thickness around it for a range of electron density [1]. In this paper the effect of probe orientation about the external magnetic field direction in resonance frequency in presence of magnetized plasma of biased hairpin probe is studied. The resonance frequency of hairpin in magnetized plasma is measured for different biasing voltages with respect to plasma potential and magnetic field strengths. It is observed that by varying the biasing from highly negative value to plasma potential, the resonance frequency of hairpin moves from vacuum resonance frequency to higher value. It is also observed that for a fixed biasing the resonance frequency varies with magnetic field variation. The plasma density is measured by considering electron cyclotron frequency and the experimentally measured resonance frequencies of hairpin and this density is verified by Langmuir probe measured density. The sheath thickness around the biased cylindrical hairpin probe is experimentally verified for different magnetic field range. A theoretical model has been proposed by using hydrodynamic model to verify the experimentally measured sheath thickness around the biased cylindrical hairpin probe.

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BP33

Modulational Instability And Envelope Soliton In A Fully Relativistic Plasma Having Two-Temperature Electrons

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Abstract- It is well known that two-temperature electrons are found to occur both in space and laboratory environments and there exist a large variety of wave modes. The presence of two-temperature electrons in plasma gives rise to many interesting characteristics in nonlinear propagation of waves including the excitation of ion-acoustic solitary waves and double layers. The presence of even a small fraction of lower temperature electrons in the plasma could largely influence the behavior of ion-acoustic solitary waves and other nonlinear phenomena [1]. Since, two-temperature electrons are seen to have considerable impact on nonlinear propagation of ion acoustic waves, in this paper we have theoretically investigated the modulational instability and envelope soliton of ion-acoustic waves in a fully relativistic plasma having inertial cold ions and isothermal two-temperature electrons. We have used the Fried and Ichikawa method [2] to derive the nonlinear Schrodinger equation (NLS). The growth rate of modulationally unstable ion acoustic wave in such plasma is discussed. Moreover, the solution of envelope soliton is obtained from the NLS equation and the profiles of envelope solitons are drawn for different values of the density of two-temperature electrons and the relativistic parameter in plasma. It is seen that both modulational instability and envelope soliton are much influenced by the relativistic ion- stream velocity together with two-temperature electrons. Our results may be applicable for understanding nonlinear waves processes in laser plasma, astrophysical plasma (during solar bursts, pulsar radiation) etc. where the velocities of plasma species are relativistic.

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BP34

Dressed Ion Acoustic Soliton in Electron-Positron-Ion Plasma

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Abstract-In recent years, propagation of waves in electron-positron-ion (e-p-i) plasma are being investigated with much interest since it is believed that positron has important contribution on the physical processes in galactic nuclei , pulsar magnetosphere , polar caps of neutron star etc [1,2]. In this paper, our aim is to study the effects of positrons and nonthermal electrons on the ion acoustic dressed soliton in the plasma. Starting from an integrated form of the system of governing equations in terms of pseudo potential, higher order nonlinear and dispersive effects are obtained for ion-acoustic solitary waves [3]. The solutions of first, second and third order solitary waves are obtained which give the shape of the dressed ion acoustic solitary waves in e-p-i plasma. The profiles of dressed solitons are drawn for different values of positron density, positron temperature, nonthermal parameter of electrons etc. It is seen that positrons and nonthermal electrons can significantly modify the structure of dressed solitons in e-p-i plasma. The advantage of our method used here is that instead of solving second order inhomogeneous differential equation at each order in the reductive perturbation method, we are to solve a first-order inhomogeneous equation at each order.

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BP35

Particle-In-Cell Simulation of Nonlinear Plasma Oscillations in Inhomogeneous Warm Plasma

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Abstract-The effect of electron temperature on the space-time evolution of nonlinear plasma oscillations in inhomogeneous plasma has been studied using an in-house developed 1-Dimensional Particle-In-Cell (PIC) code. In the absence of electron temperature, finite plasma inhomogeneity results in phase mixing (wave breaking) which eventually leads to a singularity in electron density [1,2,3]. It is found that inclusion of finite electron temperature prevents density singularity due to advection of the wave, resulting in a finite electron density maximum. The simulation results are found to agree with previous theoretical findings [1,4].

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BP36

Study of origin of Electron Acoustic Modes in a 1D Vlasov Plasma: A numerical approach

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Abstract-Study of electrostatic modes in an unmagnetized, homogeneous, collision-less plasma is a subject of fundamental interest. For example, by solving the linear electrostatic Vlasov dispersion equation in the background of immobile ions for such plasmas, it was found that, in addition to the weakly Landau damped waves (such as Langmuir waves), there are families of heavily damped acoustic (w~k) like modes, called electron-acoustic waves (EAW) [1] with a dispersion w=1.31k for a Maxwellian 1D plasma. Numerically, by considering a weak local flattening in the electron velocity distribution, features of EAWs were addressed [1]. These waves have also been excited in a two temperature electron plasma using a fluid model [2]. More recently, EAWs were shown to exist by driving a 1D collision-less Vlasov plasma externally in bounded [3] and periodic systems [4,5]. Thus, EAWs are seen either in two temperature plasmas or in driven kinetic plasmas which is perhaps resulting in effective two temperature component. A critical examination of conditions under which in a collision-less Vlasov plasma EAWs arise appears to be necessary.In our present study, using a 1D, collision-less, Vlasov-Poisson solver with stationary ions and kinetic electrons, we address excitation of EAWs. In the first part, we ask ourselves if an EAW may be excited as an initial value problem in a Vlasov plasma for a range of distribution functions using an initial value approach. In the second part, we compare the results obtained from the initial value approach with properties of EAW modes obtained recently [4,5,6] in a driven Maxwellian plasma. Details of this work will be presented.

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BP37

Quantum Effect on the Amplitude Modulation Of Ion Plasma Waves In Dusty Plasma

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Abstract- The quantum effect on the propagation of ion plasma waves in a collisionless plasma containing positively charged relativistic ions and negatively charged non-relativistic dust particles have been theoretically investigated. A linear dispersion relation has been derived by using the method of normal mode of analysis and it has been analyzed for ion plasma wave mode of propagation. Using the standard reductive perturbation technique, a nonlinear Schrödinger (NLS) equation has been derived to describe the nonlinear amplitude modulation of ion plasma waves in dusty plasma. Numerically it is shown that the profile of the ion plasma wave soliton depends significantly on the quantum and relativistic parameters. The results of this investigation are expected to be useful for understanding the envelope solitary wave propagation of ion plasma waves in some laboratory and astrophysical plasma environments such as laser solid plasma experiments, Saturn's ring. Halley's commet etc.

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BP38

Modulational Instability of Electron-Acoustic Waves in Electron Beam Plasma System Featuring Tsallis Distributed Electrons

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Abstract-Electron-acoustic waves (EAWs) exist in plasma having the co-existence of electron populations with different temperatures and are observed in laboratory and space environment. Extensive theoretical studies have shown that particles have non-Maxwellian particle distribution known as nonthermal type having high energy tails or have flattops with pronounced shoulders. This leads to considerable increase in richness and variety of wave motion that exist in plasma wave motion. The amplitude modulation is generic feature of nonlinear propagation, resulting in higher harmonic generation due to self-interacting carrier waves. The paradigm used to study this mechanism is multiple space and time scale technique. This technique leads to the derivation of a nonlinear Schrödinger equation (NLSE) describing the evolution of wave envelope. The NLSE based analysis has been used to investigate a number of physical systems and it is possible to explore the existence of localized envelope solitary structures resulting from the balance of wave dispersion and nonlinearity. In the present research paper, modulational instability (MI) of electron-acoustic waves have been investigated in a plasma system consisting of stationary ions, cold electron fluid, non-extensive hot electrons and an electron beam. Reductive Perturbation Method (RPM) is used to derive dispersion and nonlinear Schrödinger equation (NLSE). The dispersion relation exhibits two modes; slow and fast. The effect of electron beam parameters and nonextensive parameter q on the rogue wave profile has been discussed. It is further observed that the presence of non-extensively distributed electrons and electron beam modifies the MI-profile. The numerical results are presented graphically in the given parameter regimes.

BP39

Plasma Containment by Magnetic field Configurations having good and bad Curvature of Magnetic field lines

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Abstract- A new multi-pole line cusp configured plasma device (MPD) consisting of electromagnets with core material has been constructed at the institute and successfully argon plasma has been characterized in six-pole cusp magnetic field configuration. The magnet system has the capability to produce different magnetic field configuration having good and bad curvature of magnetic field lines and also control the magnetic field values and its gradient by changing magnet current. In this poster, we will discuss the evaluation of plasma parameters in a different magnetic field configuration having good and bad curvature of magnetic field line with changing magnet currents. Moreover, the plasma transport in a good curvature and bad curvature of the magnetic field also still poorly understood and will be discussed HERE.

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BP40

Effect of Radiation Reaction on Charged Particle Motion in a Electromagnetic Wave and a Constant Uniform Axial Magnetic Field.

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Abstract-A continuous energy gain during cyclotron-resonance is a result of the well-known solution of the Lorentz force equation of motion for a charged particle moving in the presence of an electromagnetic wave and a uniform axial magnetic field. Cyclotron resonance occurs due to the self-sustained resonance condition, i.e., Doppler shifted frequency of electromagnetic wave becomes equal to the relativistically correct cyclotron frequency of the particle [1]. It has been recently shown that inclusion of radiation-reaction in the particle equation of motion not only leads to saturation of the particle energy in the resonant case, but also results in net energy gain even in the non-resonant case [2]. These results have been obtained by numerically solving the Landau-Lifshitz equation of motion [3]. In the present work, we have perturbatively solved the Landau-Lifshitz equation of motion and shown that the resonance condition broadens in the presence of radiation-reaction, which ultimately leads to energy gain by the particle even in the non-resonant case.

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BP41

Phase Mixing of Langmuir Wave in a Warm Multi-component Plasma

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Abstract-An analytical study on the space-time evolution of normal electrostatic modes in a warm multi-component plasma is presented. A multi-component plasma can be comprised of electrons, ions, dusts etc. Immobile dust grains can be either positively or negatively charged. [1] In this work, they are considered to be distributed uniformly over space with constant density. In a fluid description, a nonlinear analysis of the basic

fluid-Maxwell's equations confirms that the excited Langmuir wave can break even at an arbitrarily low amplitude when it is phase-mixed. [2] The nature of the dust-charge as well as the amount of dust grains present in the system can significantly influence the phase-mixing process. The phase-mixing time is also found to increase with the temperature.

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BP42

Electron-Hole Instability In Semiconductor Quantum Plasma With Spin-Polarization

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Abstract- In recent years, the instabilities in quantum semiconductor plasma have attracted much attention [1-3]. Due to great miniaturization of semiconductor devices, the thermal de-Broglie wavelength of charge particles can be comparable to the spatial variation of the doping profile. The typical quantum effects like the exchange-correlation and fluctuations due to density correlation, the degenerate Fermi-pressure and the electron spin-1/2 play a crucial role. These will be more significant in the electronic components to be constructed in future. The most popular model to study quantum plasma is the quantum hydrodynamic (QHD) model [4-7], which consists of a set of equations dealing with transport of charge, momentum and energy in plasma and the model has also been used to study semiconductor physics. Till now, the spin of plasma electrons was considered to be macroscopic average and the evolution of spin–up and spin-down electrons was not been accounted for. In the present paper, using the modified SSE-QHD model, we have studied the instability of electron-hole with effects of coulomb exchange interaction and the spin-polarization of the quantum semiconductor plasma. Spin-up and spin-down electrons have been taken to be separate species of particles and spin-spin interaction picture has been developed. The effects of quantum Bohm potential, electron Fermi pressure, exchange correlation and spin have also been taken into account.

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BP43

Particle-In-Cell Simulation Of Bernstein-Greene-Kruskal Structures In A Cold Current Carrying Plasma

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Abstract - Stability of nonlinear stationary structures (Bernstein-Greene-Kruskal waves) formed self-consistently in a cold current carrying plasma with immobile ions [1,2] has been studied using a in-house developed 1-D particle-in-cell simulation code. The profile of these nonlinear structures is governed by the ratio of maximum electrostatic field energy density to the kinetic energy density of the current carrying

species (electrons), i.e., $\kappa = E_m/(8\pi W_0)^{1/2}$, where E_m is the maximum electric field associated with the nonlinear structure and W_0 is the kinetic energy density. These structures have been excited for the values of κ lying within the range $0 < \kappa < \kappa^c$, where κ^c ($\kappa^c = 1/\sqrt{\gamma_0}$; γ_0 is the Lorentz factor associated with electron beam velocity) is the value of κ corresponding to the wave breaking limit. These structures have been found to be stable in the non-relativistic limit ($\gamma_0 \approx 1$), whereas in the relativistic limit ($\gamma_0 \gg 1$), structures become unstable due to phase mixing effects.

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BP44

Ion Phase Space Structures In Driven 1d Vlasov- Yukawa Systems

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Abstract- The study of the formation and dynamics of driven electrostatic phase space vortices (PSV) in a bounded/unbounded collisionless plasma is of fundamental interest, both in astrophysical plasmas as well as laboratory plasmas alike. The PSVs are excited by controlling the frequency of an oscillating external potential. Recently, a small amplitude external drive, when chirped, has been shown to couple effectively to the plasma for both Maxwellian and non-Maxwellian distributions of electrons and stationary background ions, and leading to large, multi-extrema phase space vortices. [1,2,3].In the above studies, the ions have been assumed to be immobile. However, ion motion may significantly change the trapping phenomenon and formation of PSVs. Using a one dimensional Vlasov-Yukawa model, which treats kinetic warm ions and Boltzmannian electrons, we bring out several interesting features of driven phase space structures, in an unbounded Maxwellian plasma, analyzed by means of kinetic Eulerian simulations. The details of which will be presented[4]

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BP45

Enrichment of SMARTEX-C Data Acquisition System

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Abstract- SMall Aspect Ratio Toroidal Electron plasma eXperimental with C-Shaped trap (SMARTEX-C[1]) mimics the inject-hold-dump mechanism of cylindrical Penning-Malmberg traps [2] in the toroidal geometry. It creates and confines the electron plasma for ~1s, at a pressure of ~10^{-9} mbar and a toroidal magnetic field of ~ 400 Gauss [3]. The electrons from a thermionic source *i.e.,* tungsten filament bent in a ring shape, are loaded into the trapping region using a gated injector. The experimental setup acquires data on the PXI, USB and RS-232 based systems [4]. Components of the PXI based system are PXI chassis from NI, 3 data acquisition cards, MAXI card, an optical fiber link, a computer and a trigger circuit. This paper presents the

implementation and integration of the (a) USB based data acquisition to acquire current through the TF coil and voltage thus appearing across it (b) SRS's residual gas analyzer (RGA) and other similar instruments with the operational LabVIEW® interface. It also addresses the issue with synchronization of the trigger–pulses to three data-acquisition cards.

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BP46

Optical Emission Spectroscopy of Atmospheric Pressure Micro Plasmas under the Influence of Strong Magnetic Field

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Abstract- Atmospheric pressure micro plasmas (APPJ) are non-equilibrium plasmas with different electron (~ 0.5 eV) and ion temperatures (~ 0.025 eV). These plasmas have versatile application in many fields such as biomedicine, surface modification and environmental applications, and can be easily created by dielectric barrier discharge inside a quartz micro-capillary, in the form of a plasma jet. The plasma is created inside a capillary tube with an axial needle as the high voltage electrode and a ring grounded electrode. When a high voltage ranging from 1-3 kV is applied to the needle electrode the gas (He) inside the capillary breaks down and the plasma is created. The flow rate ranges from 1-5 LPM. The optical emission spectroscopy (OES) of the jet represent different emission lines [1] of helium, molecular nitrogen, oxygen, including H-α and H-β lines. The electron density has been measured from the stark broadening of the H-α lines [2] and the electron temperature has been measured from the Boltzmann plot [3].When a strong transverse magnetic field is applied to the plasma jet, the electrons get deflected from its original course of path due to the Lorentz force [4]. However, collective effects dominate (as the coupling parameter is ~ 0.1) in the rather high density atmospheric pressure micro plasma (with electron densities ~ 10^{14} cm^{-3}). It would therefore be interesting to investigate the effect of a strong magnetic field and how they affect the optical emissions from the plasma. The effect of strong magnetic field on the temperature and density of the electrons will be investigated.To understand the discharge, an electrical model for the plasma jet system has been developed. We have calculated the capacitance of the system (C_d, the capacitance of the system and C_g, the gas capacitance) which depends on the geometry of electrodes and the capillary tube. The model has been experimentally verified by measuring the discharge current and the gap voltage between the two electrodes.

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BP47

Study of Effect of Magnetic field on Electromagnetic Soliton in Inhomogeneous Plasma Density

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Abstract-Soliton have been studied in various field [1-5]. The simulation of Propagation of non linear electromagnetic solitons in a magnetized weakly relativistic plasma have been examined by using Two-Fluid plasma flow model.In our work we have focused on impact of external magnetic field on electromagnetic solitons in Inhomogeneous plasma. The special structure of an ordinary two fluid plasma having ions and electrons have been used in our simulatons. We have obtained five moment equations for each species (electrons and ions), where we have ignored collisions and viscous terms and assumed local thermodynamic equilibrium, These equations are defined as two fluid plasma equations. These equations empower various temperatures and velocities for electrons and ions disparate ideal magnetohydrodynamics equations. In this article, we have investigated the soliton properties and observed the change occurred in the soliton amplitude, width and velocity by altering the magnetic field in inhomogeneous plasma density.

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BP48

Study of Nonlinear Plasma Oscillations in Quantum Plasmas

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Abstract-The understanding of plasma oscillations and their breaking in quantum plasmas is a crucial and active element of research, contributing to the progress of in high energy density plasma physics (HEDPP), solid state physics, particle physics, and astrophysics [1-2]. Till date, the study of plasma oscillations in quantum plasmas has only been investigated in the linear regime (for small amplitude limit). However, the study of plasma oscillations in the nonlinear regime is still an unexplored area of research. Here we have examined the non-relativistic nonlinear plasma oscillations in a homogeneous quantum plasma using Quantum Hydro-Dynamic (QHD) description of the plasma wave excitations. We have developed a fluid code and employed it extensively by applying sinusoidal perturbations to the system over a wide range of amplitudes and wavelengths. For small amplitude limit, the linear dispersion relation of plasma oscillations in quantum plasmas given by Shukla et al. [1] is verified. In the nonlinear limit, it is observed that, the breaking

of oscillations in quantum plasmas requires much higher amplitude of perturbations than that needed for classical plasmas. It is also found that the wave breaking time for quantum plasma depends on the wavelength of the perturbations. The wave breaks earlier for higher wave length perturbations than that for lower wavelengths for the same amplitude perturbations. We have numerically scaled the wave breaking time for different wavelengths in quantum plasmas.

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BP49

Transport of Test Particle In Magnetohydrodynamics

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Abstract-MagnetoHydroDynamics (MHD) provides a framework wherein fluid degrees of freedom for electrons and ions are coupled to magnetic degrees of freedom using Maxwell's equations. Under ideal conditions, the magnetic field is "frozen-in" such that a fluid element transports the magnetic field along with it. Dissipation (of any kind) allows a relative motion between the fluid and magnetic variables. In fluid dynamics, sheared Eulerian fluid velocity profiles are known to produce Lagrangian transport of test particles with a positive Lyapunov exponent in 2D doubly periodic and in mixed boundary domains [1] as well as in 3D. The effect of magnetic degrees of freedom on the test particle transport in MHD is an interesting question. In this work, using MHD nonlinear solvers and a test particle transport model, we investigate the nature of the test particle transport in a variety of initial conditions. In particular, we consider, for a range of Alfven Mach numbers, periodic fluid flows such as ABC flows, parallel shear flows such hyperbolic tangent profiles and Strauss-like profiles [2] in the nearly in-compressible limit and identify the role of magnetic field dynamics in the transport of test particles. the details of this work will be presented.

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BP50

Fabrication and Characterization of Two Washer Guns for Conducting Experiments on Interaction of Pulsed Plasmas

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Abstract- Content In order to study the behavior of colliding pulsed plasmas, two similar kinds of washer plasma guns [1] and two Guillemin E type Pulse Forming Networks (PFNs) [2, 3] are fabricated and operated successfully inside the SS-curved vacuum chamber. Up to 1.5 kV of direct voltage can be applied to charge the PFN by DC power supply. A high frequency current from PFN is fed to the gun for duration of 140μs to generate pulsed plasma. Argon is used as working gas and is injected into the gun through a 3/2 way solenoid valve. The coil of the solenoid valve is energized along with the PFN discharge to the gun. The discharge voltage and current across each gun are recorded by digital storage oscilloscope using voltage divider network and Rogowski coil respectively. The impedances of PFNs (source circuits) are matched with guns (loads) to achieve maximum power transfer. In this system both head on collision and perpendicular collision of pulsed plasmas can be performed. Different plasma parameters such as the electron temperature Te and the electron density ne of plasma generated by both the guns are estimated individually with applied voltage of 1.4 kV at

base pressure 0.5 mbar. Probe as well as spectroscopy diagnostic techniques are used to measure the plasma parameters. Plasma parameters obtained for each individual gun are found to be in the same order.

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BP51

Rayleigh Instability in a Hall Thruster Plasma with Dust in the presence of Doubly Charged Ions

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Abstract - In spacecraft propulsion, Hall thrusters are better candidates for a long-term mission than other electric thrusters. Unlike chemical and electric rockets, a propellant (usually Xenon) achieves the propulsion thrust in a Hall thruster. The used propellant is ionized and then accelerated by electrostatic forces. Electrons trap in the channel due to magnetic field and then these electrons ionize the propellant. These thrusters also adjust their thrust and impulse by varying the acceleration voltage and the flow rate of the propellant, making them potential candidates for space missions with regard to the spacecraft station keeping and orbit topping applications [1-4]. In the channel of the Hall thrusters, erosion of the wall occurs due to the ion sputtering [5]. Hence, these negatively charged dust particles impede the motion of the ions towards exit of the channel. Therefore, this work is devoted to the Rayleigh instability in the presence of doubly charged ions, which arises due to the gradients in densities, velocities and the fields in the plasma. The doubly charged xenon ions have significant contribution in the plume. In the present work, dust particles as well as doubly charged ions in the thruster plasma have taken. The densities of doubly charged ions have a significant role on the instability. The effect of dust density, dust mass and dust charge number on the Rayleigh instability has been observed. In addition, frequency band condition of the oscillations of Rayleigh instability has been investigated.

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BP52

Suppression of Brillouin and Raman Scattering of Laser-Driven Beat-Wave in Negative-Ion Embedded Plasmas

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Abstract- We propose a way to suppress the stimulated Brillioun and Raman instability at beat-wave frequency incorporating the role of negative-ions in a plasma. This study is more appropriate to know the energy coupling/dissipation in case of multiple lasers are used for plasma processes. Beating of two co-propagating lasers excites non-resonant plasma oscillations. Non-resonant oscillations at twice of the plasma electron frequency are susceptible to generate an ion-acoustic wave and a scattered electromagnetic sideband wave. In the absence of negative-ion species, the growth rate scales as a product of amplitudes of the lasers and maximizes at an optimum scattering angle. The inclusion of negative-ions suppresses the growth of stimulated Brillioun scattering (SBS) as the negative-ions are heavier than the electrons. Also, the phase velocity of ion-acoustic wave increases with the density of the negative-ions, hence, the growth rate of Brillioun scattering reduces significantly. In the same way, the stimulated Raman scattering (SRS) would also be suppressed in a plasma embedded by negative-ion species. Our calculation shows that the SRS competes with the SBS. However, the growth rate of SRS is lower (or roughly equal) than the growth rate of the SBS. Thus, the SBS would then arise after (or at the same time) the SRS has been saturated. This study would be technologically important to have diagnostics in low-temperature plasmas

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BP53

Equilibrium Configuration of Self-gravitating Dusty Plasmas

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Abstract-The equilibrium problem of self-gravitating dusty plasma is studied using the three dimensional molecular dynamics (MD) simulation. The isothermal, spherically symmetric equilibria are constructed which are characterized by three parameters: (i) number of particles in the cloud, (ii) $\Gamma_g\left(4\pi\epsilon_0 G m_d^2/q_d^2\right)$, where Γ_g^{-1} is the short range cutoff of the interparticle potential, and (iii) temperature of the grains. The effects of these parameters on the dust cloud are investigated using radial density profile. The problem of equilibrium also formulated in the mean field limit where total dust pressure (which is the sum of kinetic pressure and electrostatic pressure) balances the self-gravity. The mean field solutions agree well with the results of MD simulations.

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BP54

Investigation of Optical Properties of Metallic Thin Films Irradiated by Plasma Based Low Energy Ion Beams

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Abstract- The optical properties of metallic thin films (MTF) have long been a subject of scientific research [1, 2]. Metallic thin films behave in a different way as compared to the bulk, this is manifested in its various applications such as in perfect lenses, enhanced transmission through holey metal and in mirror coatings for space applications. The low energy ions are embedded into the lattice of the host metal and can substantially modify the surface properties of the MTF, such as electrical properties [3], wettability [4] and optical properties.

The optical properties of the medium are strongly dependent on the refractive index, which in its turn is related to the dielectric constant and therefore the Hamaker constant [5]. Hence, the optical properties of metallic thin film are expected to be modified upon irradiation with low energy ion beams. We carry out experiments to investigate the above, using a wide range of available ionic species (obtained from a microwave plasma based ion source developed in the laboratory), their energies, fluxes and target MTF. The optical properties of the irradiated thin films are investigated by UV-VIS spectroscopy, where we measure the reflection (R), transmission (T) and absorption (A) coefficients. We have investigated the aforementioned optical properties of copper MTF irradiated by low energy (0.5 keV) Ar ions with varying fluence. It is observed that reflection, transmission and absorption coefficients vary with ion beam fluence. Metals are generally pure reflector in the visible and infrared portion of the light. The implantation of foreign impurity in the host metal, increases the dielectric media inside it and provides the path for propagation of light through the metal, which therefore decreases the reflection, and increases the transmission and absorption coefficients (A = 1-R-T), with increase in ion beam fluence. The occupied volume of argon in the metallic medium increases with increase in fluence, and dielectric constant of the heterogeneous (metallic and argon atoms) medium is the function of volume of inclusive media, dielectric constant of both the media and wavelength of incident radiation [6]. In this symposium, the optical properties of various type of metallic thin films such as Au, Ag, Al, and Cu irradiated with varying fluence of low energy ion beams of Argon, Helium and Hydrogen will be presented.

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BP55

An Experimental Study on Different Routes to Chaos in Glow Discharge Argon Plasmas

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Abstract - Glow discharge plasmas exhibit various types of self-excited oscillations. The behavior of such oscillations associated with the positive column has been investigated using nonlinear techniques like largest Lyapunov exponent. In the present work, it is seen that these oscillations go to chaotic state in different ways such as periodic doubling and intermittency routes to chaos according to the change in conditions like discharge voltages, and filling pressures. These results are unique from the other observations wherein the fluctuations have been observed to go from ordered to chaotic state.

BP56

Role of Controlled Leak to Trigger Negative Differential Resistance in Parallel Plate Glow Discharges

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Abstract -In the current (I) - voltage (V) characteristics of coaxial DC discharge, negative differential resistance (NDR), associated with hysteresis have been observed by varying the control parameter (DC bias voltage) [1, 2]. The onset of the NDR has been observed in a DC filamentary discharge with variation of discharge parameters such as discharge voltage, gas pressure and filament temperature [3]. The orientation of magnetic field [4] can also play a

significant role in the threshold condition for appearance of the NDR. M. Agop et al. has observed NDR formation in a plasma diode using an auxiliary bias electrode and correlated with the formation of complex structure at this electrode [5]. Although the NDR has been studied from different perspectives, the role of boundary wall in triggering the NDR has not been investigated yet to the best of our knowledge, especially the comparison of the effect of a dielectric boundary with respect to that of a conducting boundary. This paper reports the characterization and investigation of NDR while changing the boundary enclosure of the discharge. The experimental setup consists of a cylindrical SS chamber having two symmetric electrodes (anode and cathode) separated by a distance of 35mm. The electrode system was covered by dielectric boundaries using a glass tube and mica discs to change the boundary condition of the discharge, viz. from a fully exposed (FE) conducting SS chamber wall to a fully covered (FC) dielectric glass wall. When the discharge was partially exposed to the SS vacuum chamber by making a gap between glass tube and mica disc, an NDR appears in the I-V characteristics which is not observed in for both FC and FE condition. Plasma characterization by Langmuir probe has revealed a higher plasma potential (V_p) with two electron temperature (T_e) in FC condition whereas single T_e with lower V_p has been observed in FE configuration. The details of the characterization of plasma between the electrodes and its role in appearance of NDR in parallel plate DC glow discharge will be presented in the conference.

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BP57

Identification of Low frequency Zonal Flow like mode in IMPED

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Abstract- Bounded plasma is always nonuniform near the boundaries. In presence of magnetic field these nonuniformities act as source of free energy and are prone to generate unstable modes. Large gradients can generate modes with secondary daughter modes. Zonal flow is such a secondary unstable low frequency mode with azimuthally and axially symmetric structure. Potential fluctuations dominate over density fluctuations and propagate radially. Low frequency mode with frequency ≈200Hz ($\ll \omega_{ci}$), is observed in Inverse Mirror Plasma Experimental Device (IMPED). This mode is characterized by measurements of wave parameters such as axial and radial wave number, azimuthal mode number, amplitudes and phases of density and potential fluctuations etc. This low frequency mode is observed to satisfy properties of zonal flow. Control over existence of zonal flow like mode has been presented and further investigation for search of parent mode is done.

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BP58

Rogue Waves In A Fully Relativistic Plasma With Kappa Distributed 89 Electrons

Sailen paul

BP59

Control of electron temperature in presence of electron beam using magnetic filter field

Mrinal Kumar Mishra

BP60

Effect of Non-Uniform Magnetic Field on Plasma Production in a Low Magnetic Field Helicon Discharge

Sonu Yadav,

BP61

On The Characteristics Of Argon Plasma In A Multi-Pole Line-Cusp Variable Magnetic Field

Amitkumar D. Patel,

BP62

Diffusion And Particle Balance In A Plasma Confined By A Dipole Magnet

Anuj Ram Baitha

BP63

Effect Of Secondary Electron Emission On Dust Acoustic Wave Propagation In Presence Of Suprathermal Electrons

Samit Paul

BP64

Effect Of Viscosity On Nonlinear Dust Ion Acoustic Wave Propagation In Lorentzian Dusty Plasma

Raicharan Denra

Nuclear Fusion & Technology (NF)

S-2-O-1

Development and Characterization of a 25 KJ Plasma Focus Device for Various Applications

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Abstract- The pulse neutrons produced using plasma focus (PF) devices [1] have found many applications. An 11.5 kJ PF device developed here, has been used in non-destructive assay of fissile material [2]. A medium energy plasma focus device, "MEPF-25" was developed here for operation at maximum energy of 25 kJ. The MEPF-25 device consists of a capacitor bank (80 µF), a triggerable spark gap switch and a plasma focus load. The capacitor bank is made of eight capacitors (each 10 µF, 30 kV). The plasma focus load is connected to a capacitor bank in a compact geometry using parallel plate and co-axial transmission lines. The PF unit is in the form of a squirrel cage with anode at the center and cathode rods are at the periphery. The anode diameter is 60 mm. The cathode consists of twelve rods placed at a pitch circle diameter (PCD) of 122 mm. The anode and the cathode are separated using insulator (quartz) tube at the bottom.

The short circuit inductance and maximum current estimated to be delivered to the plasma focus load are 90 nH and 674 kA (at 25kV) respectively. The current rise time is measured to be around 4.25 µs. The MEPF-25 device has been operated with pure hydrogen (H_2) and pure deuterium (D_2) gas. Hydrogen is primarily used as the filling gas to check and to get strong plasma focus formation. After sharp and strong dip is observed in current derivative signal with H_2 gas which indicates strong plasma focus formation, the plasma focus is operated with D_2 gas for neutron emission study. The maximum neutron yield observed so far was $(4.5 \pm 0.6) \times 10^8$ neutron/shot at 8 mbar D_2 gas filling pressure and at 19.4 kJ (22 kV). The neutron yield is further estimated to increase by increasing the operation energy to 25 kJ (25 kV). The system can be used in applications like non-destructive assay of fissile materials especially containing Uranium and present as waste in various forms. Some details on design, development and optimization of MEPF-25 device for neutron emission with illustrative applications will be presented.

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S-2-O-2

Highlights and Achievements of Cryogenic System for SST-1

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Abstract-The SST-1 tokamak has sixteen TF superconducting and nine PF superconducting coils.This magnets system has been designed to cool using double phase cooling at1.3 – 1.6 bar (a)and with forced flow supercritical helium cooling at 4 bar (a), 4.5 K using 1.3 kW / 4.5 K helium refrigerator-cum-liquefier (HRL) system [1]. Last several campaigns, TF and PF coils could not be simultaneously cooled to desired temperatures of 4.5 K due to unexpectedly higher heat loads and higher pressure head demands from PF coils. Therefore, separate cooling of TF and PF coils were attempted. We could cool the PF coils separately at the cost of higher pressure head demands,

which was balanced by sacrificing the liquefaction part of cryo plant capacity. Measurement of the helium cryo plant capacity test "As on today" basis carried out to assess the health of the SST-1 cryo system [2]. We have also identified undue heat loads sources acting on the cold surfaces at 4.5 K. Rigorous efforts were made to mitigate those to improve the situation. Even we have upgraded integrated flow distribution and control system to have proper regulation of hydraulic resistances within the PF coils. After successful efforts, we could demonstrate the simultaneous cool down of TF and PF coils (except PF 5(L) coil). This demonstration has given us confidence and pathway to go forward for future experiments in SST-1.

First time, we have achieved the major milestone for higher current (7.9 kA) and longer duration operation (6 ½ hours) of TF current leads system. Still, heat loads mitigation efforts are in progress to get more benefits wherever it is feasible within the SST-1 infrastructure. In this paper, we will focus on main highlights and achievements of SST-1 cryo system.

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S-2-O-3

Two Fluid Simulations of Internal Kink (M=1) Modes

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Abstract-Numerical studies on the internal kink (m=1,n=1) mode have been carried out using the CUTIE[1][2] code to extend our previous Visco-Resistive RMHD studies[3] into the two fluid regime. It is found that two fluid effects are influential in the dynamics of the mode in a significant manner. We find in the linear regime that effects of flow are altered considerably in the two fluid regime as compared to the RMHD case. We have earlier noticed this in the case of tearing modes [4]. This can be attributed to the presence of an intrinsic poloidal flow present in a two fluid system due to diamagnetic effects. We notice particularly that the symmetry in the growth rate and frequency curves as a function of flow is broken in the two fluid regime. This is a direct consequence of the intrinsic poloidal flow being present in the system, and in the case of imposed axial flow, the net effect is a helical flow, and we obtain results similar to those with helical flow in the RMHD case, further confirming our hypotheses. The cases with an imposed poloidal and helical flow also can be understood on these lines, although the detailed explanations are more involved. We have then extended these studies to the nonlinear regime, and obtain a richer dynamical picture than that of the corresponding RMHD cases. In the cases involving an imposed axial flow, we again obtain agreement with that of the helical flow cases in RMHD, serving again as a point of connection with the RMHD model and a point of extension into the two fluid realm which has richer and more complicated dynamics. Collectively, our results both confirm and expand on our earlier RMHD results, and we believe are of considerable importance to tokamaks.

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S-2-O-4

Dynamics of Runaway Electrons in Presence Of MHD Modes In ADITYA-U Tokamak

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Abstract- Runaway electrons are extremely energetic electrons (>100 keV) which escape the Maxwellian (thermal) distribution owing to their high velocity and low collisionality, in presence of high parallel electric field [1]. In large tokamaks like ITER these Res can form intense beams with E > 10-20 MeV, which poses severe threat to plasma facing components. Proper understanding of RE generation and transport is crucial in order to develop effective control and mitigation system for RES, to ensure safe operation and integrity of future fusion reactor. In a large number of discharges ADITYA as well as ADITYA-U tokamak [2], the RE generation and loss has been extensively studied, in relation with MHD activity during plasma flat-top. Periodic gas puffing has been used to modulate drift tearing MHD mode frequency and amplitude for varied time periods and magnitudes. Through these experiments we unambiguously demonstrate that cross field transport and confinement of Res is strongly correlated and dominated by MHD activity in the discharge. Furthermore, it has also been observed that in several discharges increase in amount of Res in plasma leads to increase in drift tearing frequency which further leads to suppression of the MHD modes. In this paper we have presented our experimental results showing dependence of Res loss on MHD, effect of Res on MHD modes and a phenomenological physics model to comprehend the experimental observations.

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S-2-O-5

Generalized Non-linear Theory Based Analytical Design for High Power, Millimeter Wave Gyrotrons

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Abstract- International Thermonuclear Experimental Reactor (ITER) is an international effort in the direction of energy generation by plasma fusion. The similar effort has also been initiated in India for indigenous plasma fusion research in the name of ITER-India. 170 GHz is considered the electron cyclotron resonance heating (ECRH) frequency for ITER and total 24 MW power will be pumped into the fusion chamber to heat the plasma up to the fusion reaction level. Gyrotron oscillators are the only device at present capable to deliver megawatt RF power in the millimeter wave band. Gyrotrons are used as the RF power source in all the plasma fusion reactors including ITER. Considering the importance of 170 GHz frequency, the design and development of the gyrotron oscillator at this frequency with 100 kW or more RF power is targeted. In this manuscript, the design approach for interaction structure based on the generalized nonlinear theory for 170 GHz, 100 kW gyrotron is presented. The beam-wave interaction computation and the parametric optimization are carried out using the generalized non-linear theory.

Based on generalized non-linear theory, a computer code GYCAD is developed for the beam-wave interaction computation and electron beam parameters optimization. Along with the beam-wave interaction efficiency calculation, GYCAD is also used for the mode selection, start oscillation current calculation, and dispersion curve calculation. Various design constraints bound the power generation capability of the device and thus discussed here in detail. The effect of technical constraints on the generalized parameters is also discussed in detail.

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NF1

Erection, Testing and Commissioning of 31.5MVA, 132/11.2kV Power Transformer at 132kV IPR Substation

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Abstract- Electrical Power Distribution System in IPR comprises of 132 kV Substation supplied by dedicated 2 GVA SCC line by the Grid Operator (UGVCL). The 132 kV substation hosts four 132 kV / 11.5 kV main step down transformers of 31.5 MVA, 37.5 MVA and 2 x 15 MVA and one 132kV/22 kV step down transformer of rating 31.5 MVA. The total installed capacity of around 130 MVA caters to both steady/continuous power demand (~6 MW) and pulse power demand (~50 MW) of the Institute. The power demanded by the systems is supplied at 11 kV, 22kV & 415 V voltage levels. This paper covers important procedures, check points, flow charts, testing formats, etc. which are required for installation & erection, testing and commissioning of power transformer for its good performance during operation. The transformer caters mainly for APPS and SST-1 load demands.

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NF2

Operational Experiences of 42 GHz gyrotron system with PXIe based Data Acquisition and Control system

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Abstract- The 42 GHz gyrotron system is used in Aditya and SST1 tokamak to carry out plasma startup experiments. The system consists of a gyrotron, Txline and a launcher. The gyrotron delivers 500kw RF power @42 GHz for 500ms duration.The gyrotron has been operated with VME based Data acquisition and control (DAC) system. The DAC system has been upgraded with PXIe[1] based system for its reliability, robustness and versatility. The PXIe based DAC system has been commissioned with the gyrotron and is now under operation. The Control interface and Graphical User Interface(GUI) software applications are designed

and developed using NI Labview. NI Labview is a data acquisition, measurement and control application development software. PXI express or CompactPCIe (cPCIe - Compact Peripheral Component Interface for Instrumentation) is derived from the cPCI interface bus with new backplane standards. Interactive GUI software is developed on Host PC with all control and monitoring facility. The Client –Server model adopted for software development. The shared variable technique is used to share data between loops on a single diagram or between VIs across the network i.e. data communication between target PXIe system and Host PC. During the testing and commissioning various issues have been picked up, identified and solved. The software of the PXIe system has been further updated and inbuilt digital filter has been incorporated in FPGA based fast interlock logic. It minimizes the spurious fault signals detection and make the systems operation more reliable. Data Plot utility for auto update of current shot data has been integrated for better data visualization and manipulation of data. The ECRH system is now successfully operates with this PXIe based DAC system. The gyrotron has been tested for 250kw of microwave power for 150ms duration without any trouble.

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NF3

100kV Galvanic Isolated Control Power Supplies

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Abstract- All modern equipments essentially have power circuit and a control circuit. Power circuit is responsible to deliver the main output and control circuit optimizes its performance by monitoring and governing the controlled parameters. Galvanic isolation provides necessary barrier between power and control circuits. This essentially means, direct conducting metallic path would be restricted (or absent) and an insulation barrier would limit the leakage path within acceptable limits. Galvanic isolated control power is required for in DC power supplies for processing of monitoring signals where potential divider and shunt are used for the voltage and current monitoring respectively. Galvanic isolated control power is required for various bias power supplies also. Many other un-grounded or floating systems need galvanic isolated control power not restricted to the above applications. In this report a novel method is adopted to produce 100kV isolated controlled power at +15V using artificially lit photovoltaic cells.

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NF4

Interface of Arduino Based PWM Pulse Generation Using Labview for ICRH-DAC Software

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Abstract- High Power ICRH system comprises of RF power generator at various frequencies from 22 to 100 MHz.The RF power generation are controlled, operated and monitored by using ICRH DAC i.e. Data Acquisition Control system. ICRH DAC has three main operations i.e. Acquisition, Monitoring and Data

plotting & analysis. It is needed to synchronize of such interdisciplinary systems. ICRH power has been launched into the SST-1 and Aditya tokamak using pulse mode. Online impedance matching should be required in order to couple maximum power. As a part of this matching system, there is a requirement to make such kind of module for PWM pulse generation to operate motorized arrangement. Arduino microcontroller based pulse generation facility has been developed. This development generates fast digital pulses to control motorized arrangement in order to match impedance for ICRH system. Atmega 2560 microcontroller based Arduino platform has been used for this prototype development. Arduino boards prove extremely useful for acquiring data and/or controlling motors and sending/receiving pulses. In such an implementation Arduino boards in principle can be quite accurate. The scripts are compiled and loaded in the board memory, accurate timing is ensured. This embedded microprocessor has its own clock and has to run the script that has just been compiled and loaded into memory. User interface has been developed in LabVIEW which interfaced using VISA communication to integrate Arduino board.

The combination of LabVIEW programming with Arduino board has been successfully developed and tested with prototype development. Upto 1 kHz PWM pulse output has been generated using Arduino programming after successfully configuring the available timers. LabVIEW GUI allows the user to vary the duty cycle of the generated PWM pulse.

NF5

Commissioning of 12kV Light Triggered Thyristor based

Solid State Crowbar System

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Abstract- Ion Cyclotron Resonance heating (ICRH) method uses Radio Frequency (RF) waves at different frequencies for auxiliary heating of plasma, in tokomaks. High Power ICRH sources are indigenously developed for the experimental use. This high power RF is developed with the help of triode and tetrode based amplifiers. All the high power RF tubes need a DC power supply with fast acting arc fault protection in addition to normal over voltage and over current protections. The RF tubes are vulnerable to arcs that may take place during the operation. The amount of energy that is allowable to be dissipated in these arcs is critical and it is in the range of 10-50 J, beyond which damage of the tube may occur. In order to limit this energy Crowbar (which is essentially short-circuiting of power supply output with a switch) scheme is commonly adopted. This diverts the fault current from Load / arc fault to crowbar there-by protecting the load. Effective and reliable arc fault protection of RF tubes is a challenging task. Ignitron crowbar devices are in use with existing power supplies rated up to 30kV. The Ignitron crowbar systems rugged and reliable but have large quantities of mercury. Hence they are being replaced world over with alternate devices. Efforts are being made to replace the existing 30kV ignitron crowbar with Solid Stage Crowbar (SSC). C-DAC, Trivendrum which is the identified government agency for the development task, proposed to develop 10kV system as proto-type.

The 10kV crowbar system with four light triggered thyristors in series is commissioned for the protection of triode used in 20kW stage amplifier. All electrical tests like insulation test, monitoring signal tests, controls and interlocks signals tests and wire burn test, completed satisfactorily. This report presents results of the commissioning tests. Main specifications, topology, available crowbar system and its limitations are mentioned. Interfacing of this crowbar system with data acquisition and control system is possible. The

Crowbar system has been tested installed and commissioned and is ready for use with power supplies up to 10kV.

NF6

Mdsplus Integration with LHCD DAC Software

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Abstract- (Modal data system) MDSplus is a data management system used in several Nuclear Fusion experiments to handle experimental and configuration data. Several application programming interface (API) for local and remote data access are available with several languages, namely C, C++, Fortran, Java, Python, MATLAB and IDL, and a set of visualization and analysis tools are available for data browsing and display. In this way, it is possible to take advantage of the availability of the local and remote data access layers of MDSplus, widely used in the fusion community to handle large sets of data. The VME based Data Acquisition and Control (DAC) system is commissioned for remote operation of SST-1 Lower Hybrid Current Drive (LHCD) system. The MDSplus system has been successfully adopted in many fusion experiments for data acquisition, storage and access. MDSplus provide the hints to achieve continuous data acquisition during the experiments required to use acquired data in the active control of the experiment. We have successfully installed and integrated MDSplus with LHCD DAC system for LHCD experiment requirement. There are around 160 analog input channels required to acquire at the time of experiment. The requirement of LHCD system is successfully achieved and tested with required parameters. We have used C++ (Application Programming Interface) API adapter classes for integration with user interface program. This paper explains such integration and test results.

This MDSPlus software has successfully deployed on the system as per required functionality. To achieve the target, it’s essential to acquire different system parameters along with calibration and smoothing of the curve while plotting. This software is tested to execute the task of data archiving all required signals with analysis of acquired data takes place in off-shot mode.

NF7

Packed Bed Column Performance and Mass Transfer Characteristics for Hydrogen Isotope Separation Process

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Abstract- In fuel cycle loop of a fusion reactor, separation of hydrogen isotopes is one of the key processes. Cryogenic distillation is a promising method for hydrogen Isotope Separation System (ISS). For separation operations using packed columns, such as cryogenic distillation and stripping processes, the best performance is usually obtained with packing techniques. They involve a low pressure drop, good mass transfer efficiency, and high capacity. Packed columns are a practical solution in situations, like, handling of corrosive chemicals or in case of small column diameter.

In this work, geometrical parameters such as column diameter and height as well as operational variables such as convective mass-transfer coefficients for gas and liquid streams, dry & overall pressure drops and overall mass-transfer coefficient have been estimated for structured and random packing considering counter current contact of gas or vapour with liquid. The influence of feed flow rate on important process parameters (tower

diameter, packing height, gas pressure drop and overall mass-transfer coefficient) has been assessed for the structured and random packings. HETP (Height Equivalent to Theoretical Plate), which is more related to separation efficiency has been evaluated for both types of packing.

NF8

Optics of Aperture Offset For Focusing of High Power Ion Beamlets

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Abstract-High power Neutral Beam Injection (NBI) is work horse for tokamak plasma heating and current drive. Heart of the NBI system is multi-aperture ion extractor and acceleration system. Its function is to separate ions from plasma source, form ion beamlets and accelerates to the energy of interest. SST-1 needs 1.7 MW neutral hydrogen beam power at 55 kV to raise plasma ion temperature to □ 1 keV. To fulfil this requirement, considering neutralization efficiency of 60% for hydrogen ion beam at 55 kV and heat dissipation at different beam line components the extracted hydrogen ion beam power would be 5 MW. This implies that 90A ion current at 55 kV must be extracted from ion source capable of supplying ion current density of 230 mA/cm2. To transport such high power beam to SST-1 plasma center which is 7 m away from ion source the required beam divergence is □ 1o. Ion beam optics simulation code AXCEL-INP predicts that 116 mA hydrogen ion beam current can be extracted from single aperture of 8 mm diameter of 3 grid accel-decel extractor system. Thus to obtain 90A hydrogen ion beam current extractor system must be 774 number of aperture. This sets a challengeable task of focusing multi beamlets originating from multi-aperture extractor system before they gets neutralize at the neutralizer. Previously beam focusing by aperture offset is discussed [1] analytically. This paper shall describe in detail optics involved in aperture offset for focusing of ion beam and results obtained from ion beam optics simulation code AXEL-INP. It is to be noted that aperture offset method has advantages over magnetic focusing where extra power supply, a cost issue and also space for installation of magnet is required which increase the beam line length is also cost issue.

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NF9

Development of Software Analyzers on Modbus for Integration and Commissioning of an Experimental System: An Investigation in Large Volume Plasma Device

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Abstract- The integration and commissioning of an experimental plasma system is an engineering challenge. To solve interfacing issues of heterogeneous instrumentation and control devices, a standardized approach at industrial bus level is required. Typically, the subsystems of the machine are requirement specific, off-the-shelf procured and often require customized interfacing. In such scenario, the bus level debugging becomes essential to understand the system behavior followed by virtual commission which in turn followed by machine integration and testing. Modbus [1] is one of the widely used industrial bus based on client and server

architecture. The open source applications for Modbus level analysis and debugging are too primitive and not useful for large systems test and integration. The Large Volume Plasma Device (LVPD) [2] is a large sized, linear cylindrical plasma system dedicated in carrying out investigations on various physical phenomenons taking place in earth's ionosphere and fusion devices. Presently, it is undergoing up-gradation of its various subsystems and machine control system [3] to improve its capability for automated investigations of long pulsed plasma discharges. In this context, a theoretical and experimental study has been undertaken and works on in-house development of analyzer tools using LabVIEW have been initiated. The work is focused on generic bus analyzer tools development at client level for factory and system acceptance test and server level tools for virtual commissioning and interface testing. Two subsystems namely (a) filament power supply [4] for cathode heating and (b) stepper motor control drives for probe positioning subsystem [5] are used for subsystem specific modification of in-house developed bus analyzers. This paper discusses requirement, literature survey of Modbus, developed code details, results and discussions.

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NF10

Design of Gravity Compensated Remote Handling Arm

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Abstract- In the presented work, attention is mainly focused on design of gravity compensated Remote Handling arm. The articulated arm must meet the functional specifications: long reach with a cantilever length of 2m and high dexterity to move in a Torus-shaped environment and able to carry a payload of 0.5 kg at its end effector. This long reach multi-link carrier has 03 modules and 06 degrees of freedom (03 yaw joints and 03 pitch joints). An articulated robot arm with multiple links will spend most of its energy on carrying its own weight when it works against gravity. A gravitational torque occurs due to the mass of the robot links and the payload, but most of the gravitational torque is caused by the mass of the robot links. This degrades the dynamic performance and ability to withstand external forces. The gravity effect in the manipulator is compensated in large part by a special mechanical structure (i.e. parallelogram) that helps to reduce the size of the actuators. Articulated arm is designed using cable, pulley and tension spring combination to negate the gravitational effects and to verify the feasibility and kinematic properties of the mechanism. Dynamic simulation of articulated arm shows that torque requirement for the pitch joint is effectively reduced by gravity compensation mechanism. Generalized equation for the calculation of required stiffness for counter balance is derived from constant total potential energy approach. Denavit-Hartenberg parameters are used to solve the kinematics of articulated manipulator.

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NF11

Mechanical engineering design, analysis, manufacturing, inspection and testing support for the In-house R&D projects and opportunity to extend the support to other R&D Institutions in India.

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Abstract-The Mechanical Engineering Services Division (MESD) at Institute for Plasma Research, is undertaking the activities conforming to full product cycle which includes concept to commissioning of various systems of the R&D projects being implemented at IPR. The major tasks are design and analysis of the various experimental systems of various projects in IPR, preparation of the engineering drawings, fabrication/manufacturing, inspection, testing and commissioning of various systems. The division comprises of team of experienced mechanical engineers, physicist, draftsman and tradesman. MESD division has four sections namely Engineering Design & Analysis Section (EDAS), Drafting Section, Workshop Section and Inspection & Quality section (IQS). The different kind of design & analysis such as structural, thermal, electro-magnetic and coupled field is being carried out routinely using ANSYS and COMSOL software. The 3D design and modelling is done using CATIA-V5 R13. The Workshop section of MESD is equipped with modern versatile machineries including machining and fabrication (shearing, rolling, TIG welding etc.) facilities Apart from conventional machines, Workshop has 3-axis abrasive water-jet machining facility and CNC machining center to manufacture UHV/HV components. In this paper various tasks involving design, analysis, manufacturing, inspection, testing and commissioning of the various experimental systems of various projects in IPR will be discussed. Also the opportunity to extend the support to other R&D institutions will be also presented in this paper.

NF12

Development of a Fast Response Controller for Ionization Gauge Working In UHV Range

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Abstract-The pressure profile inside the vacuum vessel of Tokamak devices is one of the essential parameter for plasma start-up, breakdown & ramp-up [1]. For the Tokamaks like Aditya & SST 1 (Preliminary experiment) where the complete plasma discharge duration is $\leq$ 1 s, the commercially available Ionization gauges (B/A type) with response time varying from 50ms to 100ms are not technically suitable for control feedback. Hence the gauge with fast response time of ~ 1ms or better is required to get the better pressure profile during plasma discharge. In order to cater such requirement, a fast response controller for ionization gauge [2] working in UHV range with response time ~ 1ms is indigenously developed at IPR to fulfill requirement of Tokamak machine. In this paper, the design details along with the results will be presented.

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NF13

Applications of Magnetic Pulse Welding Technology in Tokamak Fusion Machines

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Abstract- The recent technological advances in welding technologies have introduced newer processes which enable industries to achieve better quality and productivity with merit of environmentally friendly. The present era of advance technologies and severe demand for using light weight and high strength materials for the product, it is not possible to manufacture a product using single material and hence different materials involving joining of dissimilar materials is inevitable. The present keen interest of researchers and Industries is to find a suitable welding process for dissimilar materials. There exists a challenge for the advanced manufacturer to produce high strength joint for dissimilar materials using conventional high temperature fusion process. For dissimilar materials, there are dissimilar physical properties of materials such as melting point, specific heat, thermal diffusivity, co-efficient of thermal expansion etc. resulting into obstacles while performing the conventional welding of such dissimilar materials. Magnetic pulse welding (MPW) is proved to be the solution and is a strong candidate for the welding of dissimilar materials. It is a solid state welding process that is accomplished by a magnetic pressure causing a high-velocity impact between two materials, resulting in a true metallurgical bond. Engineers are discovering a variety of applications for this solid-state welding process. MPW is applicable to high technology areas such as nuclear fission and fusion. Magnetic pulse welding (MPW) enables the fabrication of joints via the harnessing of Lorentz forces, which result from discharging a current pulse through a magnetic coil. In the process, an outer piece (flyer) is accelerated onto an inner piece (parent), and welding is achieved using propagating impact fronts.

In this paper possible MPW technology applications in various systems such as PFC, SC magnets, Cryogenics, and other heat removal systems of Tokamak fusion machine is discussed.

NF14

FPGA based programmable delay circuit for Synchronization studies in the dc-glow discharge plasma system.

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Abstract-Fed-back mechanism is used for doing Synchronization studies in single glow discharge plasma system for either suppressing or enhancing the oscillations of the system. A delay varying from less than a quarter period to almost one period of the incoming oscillations is required to be fed-back to the system which generates a time-varying signal with controlled frequency and amplitude .The oscillations obtained from the system has the lower frequency signal in the range of 100KHz and varying upto MHz range in the upper frequency range. A programmable delay circuit controlled through front panel GUI based on NI LabVIEW is designed and implemented using FPGAs and other high sampling rate digital integrated circuits. As the signal range is in the range of 100KHz and above, high sampling-rate ADC, DAC are being deployed in the circuit. Delay is introduced using FIFO implemented in the FPGA as an IP-core. Front –end is implemented using programmable-high bandwidth instrumentation amplifiers and OPAMP. The output of the DAC is followed by 4-order sallen key filter implemented using high bandwidth dual OPAMP AD823. The system is successfully tested with the experimental-setup with noticeable effect on the system.

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NF15

Study of Vertical Machining Centre and Its Usage in Fabrication of Plasma Experimental Devices

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Abstract- Development of plasma experimental systems is generally done in R&D organization such as IPR. Such experimental system fabrication shall require use of subtractive manufacturing equipment such as milling machine or machining centre. Vertical Machining Centre (VMC) is a version of milling machine, which has computer numerical control (CNC). This is common equipment in most of the research centre / facility workshop. It is versatile equipment and provides excellent results in machining cum drilling of the jobs. However, the right kind of the VMC has to be selected from varieties of machines, as various configurations are available. Selection of viable machine for prototype system manufacturing in research environment requires a well thought effort. Specification of the machining center should be in line with the overall size of the work piece and precision requirements of the work piece. Ease in clamping, convenience in operation etc. also need to be considered. The machine should no longer just be selected by analyzing a spreadsheet that compares spindle horsepower and torque, X/Y/Z travels. It is equally important to look into spindle design, thermal stability, and machine construction etc. The 'perfect' machine is one that matches best of the needs of fabrication for planned experimental set up. In this paper, an extensive survey of existing VMC machines, its configurations, its capabilities, etc has been done and compared with the needs for in-house component/system manufacturing.

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NF16

Design and Development of Permeation Based Gas Mixing Experimental Setup to Prepare Ppm Level of Hydrogen in Helium Gas Mixture

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Abstract- In the fusion fuel cycle, Hydrogen Isotopes Removal System is one of the most important technologies for developing Tritium Extraction System (TES) of Indian Tritium Breeder Blanket (TBB). Hydrogen isotopes are extracted from the breeder zone of TBB using Helium purge gas with 1000 ppm of hydrogen gas in it. Hydrogen gas improves tritium extraction via isotopic exchange reaction [1]. So, it is necessary to prepare the process gas mixture with a composition similar to that of the purge gas composition for Indian Breeder Blanket to test and validate TES. Generally, gas mixtures can be prepared by volumetric method. However, in case of mixing ppm level of gas (hydrogen) with parent gas (helium), as the difference in the flow rate of gases to be mixed is very large, it is extremely difficult to prepare such mixtures using

volumetric method. In our earlier work, we prepared ppm levels (1000 – 5000 ppm) of hydrogen in helium using partial pressure method, while operating in semi-continuous mode [2]. In our present work, an experimental setup for preparing ppm levels (1-1000) of Hydrogen in helium gas has been designed, which can be operated in continuous mode. A capsule shaped permeator developed earlier, made up of pure iron membrane coated with palladium, allows to permeate a known amount hydrogen through it at constant temperature and constant upstream pressure of hydrogen [3]. This permeated hydrogen is swept by helium gas under controlled experimental conditions. This paper describes the detailed design of the experimental set up for permeation based gas mixing system. Parametric analysis of the process parameters, viz., flow rate (1-5 l/min), temperature (100 – 500 C) and pressure (1-2 bar(g)) for achieving the required mixture of ppm levels of hydrogen in helium is also presented in the present work.

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NF17

Conceptual Design and Development of Upgraded Electronics for Bolometer Diagnostic

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Abstract- Bolometer diagnostic is used to measure the total radiated power from Plasma in Tokamak. In Aditya-U tokamak two pin hole camera of absolute extreme ultraviolet photodiodes (AXUVD)array containing 20 elements are installed on Top and radial port . Apart from that 4 single AXUV diodes are also installed on different position of the tokamak. Signal conditioning system and indigenously developed Data acquisition systems [1] for bolometer diagnostic installed in Aditya tokamak are in operation and continuously providing good data during experiments. In Aditya upgrade some modifications have been implemented like inclusion of Data acquisition in same rack, interfacing of detector and front-end electronics is improved for easy handling, testing and troubleshooting. Now our main aim is to make the whole bolometer diagnostic electronics very compact and portable. The present signal conditioning system includes part -1 and part-2.All present Bolometer instrumentation as per the Aditya upgrade requirement consumes two racks space. Upgraded bolometer electronics with data acquisition will reduce this space to half of the rack. The restriction of 16 channel of present system will be removed. Individual channel parameter setting will be implemented which was restricted to 4 channel with same parameter. The poster includes detailed conceptual design and features of upgraded bolometer electronics.

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NF18

Tungsten Deposition on Graphite Substrates Using a Cylindrical Magnetron and High Heat Flux Studies

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Abstract- Tungsten (W) is one of the main candidate materials to be used as plasma facing material both in first wall and diverter components. It is finding applications both in bulk form as well as a coating. Different methods such as plasma spray coating (PS), physical vapour deposition (PVD), chemical vapour deposition (CVD), combined magnetron sputtering and ion implantation (CMSII), electro-deposition techniques have been used for depositing W coatings over carbon/graphite [1-6]. In the present work, PVD based cylindrical magnetron technique was used for depositing W on graphite substrates. Initial experiments were carried out to optimize various 'process parameters' such as discharge power, operating pressure, external magnetic field etc. Thin films with thickness up to 5 μm were successfully deposited. Later, the effect of substrate surface roughness on the coating morphology was studied. Experiments were also carried out to study the effect of discharge power and coating duration on the deposition rate. Further, the W coated graphite substrates were subjected to high heat flux studies with a total absorbed heat flux of around 5 MW/m^2. The W films were studied for their thermal stability. It was also attempted to study the effect of 'initial substrate roughness and thereby the morphology of the deposited coating' on the film's thermal stability under high heat load conditions. The deposited films were characterized using XRD, and high resolution FESEM.

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NF19

Thermo-Structural Analysis of Radiation Shield of SST-1 Cryopump

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Abstract- Radiation shield is placed between higher temperature to cryogenic temperature (<123K)in many devices like cryopump, spacecraft and cryostat etc.in order to reduce the radiation heat load. It plays a vital role for proper cooling and operation of devices, where cryosurfaces is cooled at the cryogenic temperature.In cryopump, cryosurface temperature of ~100 K is required to condense water vapour & hydrocarbons. To pump gases likeH_2, He from SST-1 Tokamak using cryopump, sorbent like charcoal coated to cryosurfacesmust be cooled to the temperature of ~10 K and below. So, shield was designed in such a way that minimal heat flux is acting on the cryosurfaces. Shield model of SST-1 cryopump consists of cylindricallyrolled copper sheet (1mm thick) with SS 304 pipe wrapped on its outer surface using silver brazing and for front shielding, copper louvre baffles was mounted using screws to minimize heat flux with minimum loss of conductance (denoted by transmission probability). In thermal analysis, temperature profile and thermal stresses generated were analyzed on the shield operating at ~80K temperatureto qualify its performance. In structural analysis, various stresses and deflection wereanalyzed on the shield in various possible orientation under gravitational loading conditions to qualify its stability.

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NF20

Effect of Contact Angle on Stress-Strain Characteristics of Nb_3Sn-Nb_3Sn and Nb_3Sn-Copper strands in superconducting cable using FEA

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Abstract- Superconducting cable in Cable In Conduit Conductor (CICC) is manufactured by twisting superconducting strands and copper strands with respect to required design configuration in multi-stage cabling operation. The twisting of strands in various stages is done at appropriate twist pitch with application of torsional forces, resulting in the development of compressive stresses and deformation at contact points between two strands. The developed stresses during twisting of cable, directly affect the performance of individual superconducting strands and its cable as a whole. In this study, the effect of contact angles, compressive forces, as well as strand materials is investigated using FEA, simulating actual cabling scenarios for the Nb_3Sn based superconducting cable. The distribution of compressive stress and plastic strain in Nb_3Sn superconducting strands during cabling is presented. The effect of parametric variation considering contact forces and its angles on mechanical behavior of strands is studied using FEA and discussed in this paper.

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NF21

Ion Dynamics Study in an Inertial Electrostatic Confinement Fusion Device and its Application in Explosive Detection

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Abstract- Inertial Electrostatic Confinement Fusion (IECF) concept was originally conceived by Farnsworth [1] and was first studied experimentally by Hirsch in 1970's [2]. During the last two decades, IECF device has been used as a portable neutron/proton source due to its simple construction and relatively smaller volume which has the capability of providing high fusion rate. The main concept of this device is to accelerate lighter ions such as deuterium, tritium to collide and produce fusion relevant energies by the application of a converging electrostatic field inside a spherical or cylindrical chamber. Seeing the importance of the device in diversified areas, we have already developed a cylindrical IECF device [3] at CPP-IPR. In the present paper, we will discuss on the production of hydrogen plasma inside the device by employing the hot cathode and cold cathode discharges. The plasma parameters such as electron temperature, plasma potential, plasma density and Debye length are evaluated by using different Langmuir probes. A comparative study on ion density profiles and potential profiles have been done at different input potentials starting from -2 kV to -5 kV to the cathode grid. Plasma density of the order of 10^{16} m^{-3} has been achieved. Plasma velocity during Jet mode of discharge is also calculated by using both Faraday cup and Mach probe. The source has also been extensively used to optimize DD neutron emission by operating the device at higher voltage modes i.e. upto 60 kV. The neutrons produced from the device are characterized using various detectors which substantiated

the NPR of 10^6 n/s. This X-rays and neutrons emitted from the device were utilized for demonstrating the radiography techniques and detection of explosives. A detailed discussion on the obtained results would be discussed in the paper.

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NF22

Rise In Input Density Effect on Diffusive Plasma Transport Properties in the Scrape off Layer of Tokamak Aditya

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Abstract- The diffusive plasma transport in parallel and perpendicular to magnetic field direction in Scrape-off layer off tokamakAditya was recently analyzed for old ring limiter and a configuration having three block limiters similar to Aditya Upgrade at constant input density and Power at Last closed flux surface (LCFS) which shows the perpendicular Diffusive transport and recycling flux is high in ring limiter in comparison to block limiter configurations using 3D Plasma-neutral transport model EMC3-EIRENE [1, 2, 3]. In this work the particle transportbehaviour in Aditya ring limiter and a configuration having three block limiters on outboard of tokamakAditya is studied over a range of edge density at constant input Power and constant perpendicular Diffusivity value at LCFS. These set of simulations shows that transport of particle is more in ring limiter than block limiter similar to Alcator-C-Mod results (Having Block and Belt Limiter in Outboard and Inboard) where radial variation of diffusion coefficient additionally observed. The Mach number (M) strength also decreases with rise in Input density as obtained from our simulation results which will have a definite effect of edge transport behaviour in tokamak Aditya [3, 4].

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NF23

DAQ Development for Prototype MgB_2 Current Lead Test Facility

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Abstract- Towards the indigenous development of HTS current lead, experiment test facility developed for the performance and validation of prototype MgB2 based HTS current lead. Test experiment setup is equipped with different physical process parameters measurement instruments like flow, pressure, temperature, level, vacuum and voltage taps, as well as process control element like control valves, heaters, vacuum pumps etc. A reliable data acquisition system is essential for acquiring real time data coming from above mentioned instruments. PLC program is developed in ladder language for acquiring and controlling the process parameters. SCADA applications developed in Wonderware Intouch software for data communication from PLC, Front-end

Graphical user interface (GUI), auto-manual interface, real time trends, history trends, events and alarm pages. The paper describes the developed experiment facility for HTC current lead test.

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NF24

Installation, Testing and Commissioning of Tariff metering Current Transformer at 132kV IPR Substation

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Abstract- The 132 kV Substation at IPR hosts 4 nos. of 132 kV / 11.5 kV main step down transformers of rating ranging 31.5 MVA, 37.5 MVA and 2 x 15 MVA and 1 no. of 132kV/22 kV step down transformer of rating 31.5 MVA. Tariff metering CTs are required at load end (IPR substation) to measure IPR power consumption. The CTs which were installed were specifically procured for metering purpose as per the specifications provided by the grid operator, Uttar Gujarat Vij Company Limited (UGVCL). Erection of current transformer requires great deal of planning and arrangement of resources. It is essential to have erection agency with skilled manpower having experience of EHV class current transformer. This paper covers important procedures, check points, testing formats, etc. which are required for erection, testing and commissioning of current transformers for its good performance.

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NF25

Experience of 12 kA / 16 V SMPS Converter during the Prototype MgB_2 and Brass Current leads Test

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Abstract- As a part of performance validation test of the prototype MgB_2 and Brass based HTS current leads was carried out using very reliable switch mode DC power supply. Dedicated 12 kA, 16 VDC high current, low voltage programmable switch mode power supply (SMPS) is already tested, commissioned and installed to facilities various current lead based tests at IPR. This power supply has special features such as modularity (8 modules), N+1 redundancy, very low ripple voltage (< 8 mVrms), precise current measurements with direct current - current transformer (DCCT), constant current (CC)/ constant voltage (CV) modes with auto-crossover and auto-sequence programming. The lower ripple voltage is essential to minimize the AC loss during the current leads test. Prior to use for the current leads test, the basic functions checks, program checks, basic electrical protocols and procedures were followed. Afterwards, this power supply was used for the testing of the prototype MgB_2 current leads using liquid helium at 4.5 K cooling and applied the maximum current of 1.5kA in different incremental stage. The paper describes power converter operational experience and results obtained from this converter during the current lead test at IPR.

NF26

Performance of Up-graded VME Based Data Acquisition System for Superconducting Magnets Sensors of SST-1

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Abstract- Superconducting (SC) magnet system of SST-1 consists of sixteen Toroidal Field (TF) coils and nine Poloidal Field (PF) coils. These magnets are instrumented with various cryogenic compatible sensors, namely temperature sensors, hall probes, pressure transmitter, venturi meters, displacement transducer, and strain gauges. A VME hardware based data acquisition system has been upgraded for data acquisition, monitoring and control of SC magnets during operation. A java platform based client and server utility has been also developed for this data acquisition system. The signal conditioning electronics has been developed to counter various EMI/RFI interferences and measurement of low amplitude signal in high common mode electromagnetic voltage pickup environment. This poster describes overview of upgraded DAQ system, signal conditioning system scheme and the performances of various cryogenics sensors of SST-1 SC magnets.

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NF27

Suitability of Using Diamond Shaped Aluminum Seals For Evacuated ECRH Waveguide Transmission Line Components

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Abstract- Oversized circular corrugated waveguides are generally employed in transmitting high power RF beams from mm-wave sources like Gyrotrons, as they have been proved to be most efficient (low loss) waveguides for transmitting high power in the mm-wave frequency range [1]. ITER-India, the Indian domestic agency for ITER project, has the responsibility to supply a set of two, high power (1MW), long pulse (3600 s) Gyrotron sources at a frequency of 170 GHz to ITER for Electron Cyclotron Heating & Current Drive applications [2].ITER-India is establishing anITER-India Gyrotron Test Facility (IIGTF) for testing 1MW class Gyrotrons to support ITER deliverables. An evacuated set of corrugated waveguide components of 63.5 mm diameter will be used to transmit the gyrotron output power into a dummy load in the test facility. The vacuum in the waveguide components ensures that there is no RF breakdown occurs while transmitting the RF power of the order of 1MW. As the waveguide components are generally made out of aluminum material, and as the RF joints are to be electrically conducting, the spring loaded metallic seals are employed between the waveguide joints to provide the vacuum sealing and the electrical continuity. Spring loaded seals are tubular in cross-section and have complicated design due to which they are costly and easily not available. In this context, an alternate seal concept, that is low cost and easily machined has been tested for its vacuum compatibility and verified its suitability for aluminum corrugated waveguides.

In order to address the leak tightnesswith this alternate option, aluminum seals with diamond shaped edge on both sides are prepared and tested for vacuum leak tightness of the order of 10^{-10} mbar-l/s and results are illustrated in this paper. Apart from the vacuum compatibility, the other main concern that was to be addressed

by these tests was to ensure that the sharp edge (diamond shape) of the seal does not permanently damage the waveguide sealing surface as the materials of the seal and the waveguide is the same. This paper presents problem identification, approach, test schematic, the leak tightness results and suitability of using diamond shaped aluminum sealsfor high power evacuated corrugated waveguide transmission line components.

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NF28

An Overview of Instrumentation for Mgb_2 Based Current Lead Test

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Abstract- As a development part of current leads (CL) in the SST-1, a cryogenic test facility has been prepared to evaluate the performance of indigenously developed MgB_2 based current leads. During the performance of current leads at cryogenic condition various instruments have been utilized for the precise measurement and control. These instruments include temperature, pressure, mass-flow, liquid helium level, vacuum, pressure drop. Apart from these, different control devices such as regulatory valves, heater and vacuum pumps are also used. This paper describes the selection, mounting techniques and behavior of these instruments for the better output. These instruments have been linked to a dedicated Schneider make PLC system to acquire the signals. During the current lead test, each instrument has been performed satisfactory and reliable in the low temperature (4.5K and 80 K) as well as in the excitation mode.

NF29

Design, Development, Integration And Testing Of Glass Fiber Optic Based Control Signal For Remote Operation Of 30kv-130a Rhvps For Hpa4 Stage Rf-Amplifier.

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Abstract- ICRH system has to be used for interface and antenna conditioning, heating, pre-ionization and current drive experiments in the tokamak 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]. With the conventional HVPS i.e. GPS (30KV, 60A, 1sec) integrated with 1.5MW tube, upto 400kW RF power has been tested some years ago. Further higher power commissioning work (To raise more RF power) from same 1.5MW Amplifier, RHVPS (Regulated High Voltage power supplies) is mandatory. Distance between ICRH lab (RF Amplifier is placed) and Utility building (RHVPS is placed) is around 300 meters, thus beyond to any visual inspection from ICRH control room. Normal Operation and System protection of RF Amplifier & associated Power supply from ICRH lab relies only on the hardware reliability of the control signals. Four types of control and monitoring signals namely Analog Input / Output, Digital Input / Output defined. Digital input/ output are of TTL compatible and analog Input /Output are of 0-10V range. Feasibility study (component costs and its availability, circuit reliability, cables routing and laying, future maintenance and troubleshooting) done with various Hardwire electronics card (V-I cards, FOC and Glass Plastic transmitter /receiver cards) and different type of cables i.e. copper wire, plastic fiber, glass fiber) for signal transmission. Finally, Glass Fiber based Electronics cards is selected. Developed and integrated cards are compatible to carry in / out all type of Plastic / Glass fiber light signals as well as voltage signals with some minor

modification [2]. All electronics card has been tested for continuous operation to check their performance for longer duration operation. Propagation delay is optimized upto 3 μsec. Control signals are successfully implemented for online monitor and control in the VME Processor. Critical signals (Fault, Trip, and Emergency Shutdown) are integrated in the existing system Hardwire Interlock cards and tested .Passive and Active testing of Actual RHVPS operation has been tested by applying High Voltage upto 25KV with 1.5MW tube and wire-burn test has been successfully achieved. This paper would discuss functionality of in-house developed hardware, link performance test, delay optimization and various test results.

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NF30

Baking of the SST-1 Neutral Beam Transmission Duct under Vacuum conditions

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Abstract- Beam transmission duct (BTD) is one of the important components of a neutral beam injection (NBI) system. The BTD is used to connect the injector system with tokamak. The BTD is designed to accept neutral beam power on its walls and also maintain a pressure of ≤1×10-5 mbar during the beam transmission to avoid re-ionization losses. The BTD is expected to be heated up at about 250 C during baking cycles of the SST-1 tokamak. The brazing joints of the BTD need to be checked for vacuum compatibility at high temperatures. A vacuum baking system (4 – 8 kW) was developed in-house to bake the BTD under vacuum conditions to avoid oxidation of its copper panels. The vacuum baking system was made up of 50 number of Nichrome wires (6 ohm each), which were heated up in parallel using an existing variable DC power supply (40 VDC, 500A). The vacuum baking system was able to achieve the steady temperature of 250°C for a continuous period of 4 hours. The temperature measurement was carried out using K-type thermocouples. The design of the vacuum baking system and the results of the test for BTD will be presented.

NF31

Development of Python Based Program to Generate Graphical Output of Fluxes and Reaction Rates from 1-D Radiation Transport Code, ANISNE

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Abstract- Radiation transport calculations are essential for predicting and confirming the nuclear performance of the reactor and, as such, must be an essential part of the reactor design process. Development and optimization of reactor components from the first wall and primary shielding to the breeder blanket must be carried out in a sensible progression. Initial results from 1-D transport calculations are used for scoping studies and are followed by detailed 2-D and 3-D analyses to effectively characterize the overall radiation environment. ANISN code [1] written in FORTRAN IV, is a high-quality deterministic radiation transport code which dates back to the 60s and 70s. ANISN code which treats neutron and gamma transport in the 1-D plane, spherical and cylinder geometry and solves the 1-D linear Boltzmann transport equation is attractive and useful in many possible applications, for fast radiation transport providing a complete flux distribution and reaction rates like tritium production, nuclear heating, radiation damage etc.. As of now the code uses a

text-based input file and generates a text-based output file which contains the desired nuclear responses besides several details. However, it is often a tedious and error-prone exercise to prepare the input files and extract the desired nuclear responses from the set of output files generated during the scoping/ parametric calculations for a nuclear system. This forces the nuclear analyst to spend a lot of his time on the preparation of input file and extracting the desired responses in publishable format. The motivation for this work is to facilitate the use of deterministic transport code, ANISN within a modern user environment/interface and thus bring this closer to nowadays users.

The objective of this work is to make the input and output handling for ANISN code as user-friendly as possible and allowing user tuned viewing of results. To achieve this, an interface program is developed to assist the users in the preparation of input files, rapid modification, execution and extraction of the desired data using a modern Python programming language tool. The interface program developed from this project can also be used to generate the graphical output of the nuclear responses based on the user's requirements. The poster highlights the main features of the developed interface program. It also discusses its application and importance in 1-D radiation transport study for nuclear systems.

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NF32

Dependency of Insulation Resistance of the Magnetic Coils of Aditya-U Tokamk on Changing Weather Conditions

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Abstract- ADITYA-U (R0=75 cm, a=25 cm) is a medium sized air-core poloidal limiter tokamak, recently upgraded for the purpose of having shaped plasma operation with diverter configuration. ADITYA-U is equipped with 20 nos. of TF coils, 9 nos. of Ohmic coils including air-core central solenoid and 4 nos. of BV coils for the generation of magnetic and electric field for the plasma initiation, confinement, Ohmic heating and equilibrium stabilisation of the plasma column in pulse operation. Designed electrical rating for different magnetic coils i.e., Toroidal field (TF) coils is 400V,50 kA, Ohmic Transformer (OT) coils is 2 kV, ±20 kA and Vertical field (BV) coilsis 4 kV, 12.5 kA for their respective power supplies. All the magnetic coils are fabricated with copper with the provision of active cooling with de-mineralised (D.M) water circulated at ~ 1 kg/cm^2. Insulation resistance of every single coil was benchmarked to the required experimental value before installing the magnetic coils in the original experimental setup. New configuration of cooling pipes and adhesives are tested, in-situ installation is performed and water leakage for every single coil.Before the plasma operation, insulation resistance of all the magnetic coils tested routinely, for example TF coils megger at max. 500 V, Ohmic coils at max. 1000 V and BV coils at 1000V. In addition to that Ohmic and BV coils were Impulse voltage tested 10 kV and 6 kV respectively. Moisture of experimental setup is actively-controlled with centralised air-conditioning of ADITYA hall. Fluctuating weather conditions results in different humidity level and results in the degradation of the insulation resistance below the value required for experiment and failure of the impulse test. So, investigation was performed for determining the dependence of insulation resistance values of different magnetic coils on the status of D.M water, air-conditioning effect, internal and external heating of the coils. Various test-setup along with the results has been presented in the paper.

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NF33

Modeling of Experimental VUV Spectra from ADITYA-U Tokamak

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Abstract- The studies of impurities spectral emissions emanating from tokamak are required to be done to understand the radiation loss and fuel dilution in the tokamak plasma. As the electron temperature of the plasma increases, the intense impurity emissions move from visible to VUV and then X-ray regions. In order to understand the impurity behavior, VUV spectra recorded from Aditya-U tokamak have been simulated using one-dimensional impurity transport code. The spectral emission from various ionization stages of low-Z impurities such as oxygen, carbon and mid-Z impurity such as iron, are regularly monitored using a VUV survey spectroscopy system attached with Aditya-U tokamak. This diagnostics is having a 0.3 m VUV spectrometer with three toroidal grating having groove density of 290, 450 and 2105 grooves/mm. The spectral resolution of the system is 0.47 nm when it is operated with 450 grooves/mm grating. This system can acquire spectra at every 7 ms interval. The required photon emissivity coefficients (PEC) of these spectral lines are taken from ADAS atomic database. From the simulated result, radial profiles of impurity emission in visible wavelength range, total radiated power and Z_{eff} have been estimated and these are compared with the experimental observation. The obtained diffusion coefficient has been compared with theoretical predication using neo-classical and fluctuation driven transport.

NF34

Effect of Transverse Magnetic field on the ADITYA-U plasma discharge

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Abstract- ADITYA-U (R_0 = 0.75 m and a= 0.25 m) is a medium sized air-core tokamak recently upgraded to Limiter-Divertor configuration after 25 years of successful operation of ADITYA tokamak. ADITYA-U tokamak was upgraded with the inclusion of new circular vacuum vessel and divertor coils for performing the shaped plasma experiments. All the magnetic coils are assembled at their respective mean positions within the precision tolerance of ±1 mm using meteorological instrument.The first Plasma in ADITYA-U has been initiated with hot filament pre-ionization assisted Ohmic breakdown and hydrogen gas breakdown has been obtained in each and every breakdown without a single failure. The achieved plasma parameters in ADITYA-U for Phase-I operation areIp~80-95 kA and duration of 80-180 ms for the maximum toroidal field of ~1 Tesla. The dependency of radial field corrction directed towards Major axis (R=0) has been observed in Phase-I operation to achieve successful start-up, while discharges were operated with higher toroidal field. This fact was confirmed again with vertical displacement of plasma coloum when plasma position measurment was avilable in Phase-II operation. In a series of discharges, toroidal field was varied in the range 0.75-1.35 T to observe its effect on the vertical plasma position measurement. Different effects have been accounted for the explanation of the vertical shift of the plasma column. Dependence of the transverse field component is experimentally and computationally validated for the ADITYA-U. The simulation results

showed asymmetry in the magnetic field due to busbars connection of TF coils. This transverse fields account to be approximately 0.1 % of the toroidal field at the plasma centre (R= 0.75 m). As it was impossible to change the present configuration of the busbars system of TF coils, an external source of magnetic field was implemented for the compensation of the transverse field on the ADITYA-U. Effect of the external radial field for the mitigation of the vertical position of the plasma column has been observed. Detailed results will be presented in the paper.

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NF35

Design and Development Of Instrumentation & Control System For Lead-Lithium MHD Experimental Loop

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Abstract- The Lead Lithium (Pb-Li) Magneto Hydro Dynamic (LLMHD) Experimental loop is being developed to perform MHD experiments as a part of TBM R&D activities. In presence of strong plasma confining toroidal magnetic field, motion of electrically conducting liquid metal leads to MHD phenomena. These MHD flows needs to be studied for various geometrical elements as present in the LLCB TBM for the design and development of LLCB TBS. This facility consists of Pb-Li main loop and oil loop, here Pb-Li main loop extracts heat from test sections & oil loop extracts heat from Pb-Li through heat exchanger & dumps it into the water. This paper also discusses about detailed Process & Instrumentation Diagram (P&ID) emphasizing the critical Measurements & Control philosophy adopted in the loop. The main measurement and controlling parameters of the loop are flow, pressure and temperature of Pb-Li, Oil & water. The Instrumentation and Control system of the LLMHD Loop has been designed to carry out these measurements and control them. Alarms and Interlocks are provided to protect the facility under abnormal condition. A programmable logic controller (PAC T2550) is used for developing the control system for the LLMHD loop.

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NF36

Thermo-hydraulic analysis of 80 K thermal shield of prototype magnet test cryostat

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Abstract- Prototype Magnet Test Facility towards performance validation of large superconducting magnet is under development at Institute for Plasma Research. The test cryostat (~ volume -100 m^3) and 80 K bubble panel thermal shields (~ 94 m^2, 36 sections, LN_2 cooled) along with its cooling network is the major component of this test facility. The analytical and FEA is carried out as a part of preparation towards performance validation of these 80 K thermal shields. The total heat load, nitrogen flow rate, flow distribution, pressure drop and hydraulic resistance of cooling network of 80 K shield are estimated. The

distribution of thermal stresses on cooling network and 80 K shield supports during cool down has also been carried out. The amount of liquid nitrogen required for cooling of entire cold mass of ~ 2300 kg from 300 K to 80 K, for desired cooling rate and for steady state operation of the facility. The cool down and operation methodology for 80 K thermal shields of test cryostat will be elaborated in this presentation.

NF37

FMCW Reflectometry System Software Integration

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Abstract- A Ka-Band Superheterodyne Frequency Modulated Continuous Wave (FMCW) Reflectometry system is under development to measure the radial density profile of plasma in Aditya Upgrade and SST-1 tokamak.The system consists of the Microwave circuit, ultra-fast sweep generator which can sweep in 5µs to drive the microwave source between 26.5-40GHz and high speed Data Acquisition (DAQ) system to record the results at the rate of 200MS/s. The different parameters of all these instruments needs to be configured and monitored frequently. The system requires remote and automaticoperation during Tokamak plasma shots. It is essential for integrating FMCWReflectometry system in to Tokamak to have a coherent single software application for control and DAQ. It is a tedious task to control the different instruments with different software provided by the manufacturer. So, the main aim is to develop Graphical User Interface (GUI)applicationto integrate different instruments on single GUI and compatible with existingDAQ system of Aditya and SST-1 Tokamak. A GUI application is developed using National Instrument (NI) Lab VIEW for operator interface, monitoring and data logging.The detailed software design, development and testing results will be discussed in the paper.

NF38

Conceptual Design of Automatic Charging of High Voltage Capacitor Bank in Aditya-U Tokamak

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Abstract- Aditya-U Tokomak uses three high-voltage (up to 10 kV) capacitor banks for energizing different magnetic coils to obtain plasma discharges. Each capacitor bank consists of several energy storage capacitors of different capacitance connected in series and/or parallel as per the requirements. These capacitors are first charged and then discharged into the coil to produce desired magnetic fields. The charging of these capacitor banks are carried out by individual transformer and rectifier circuits. At present, the voltage in these banks are raised manually using variacs. The charging of these banks has now been planned to be carried out automatically using PLC based control system. The new control system consists of WAGO make PLC and motorized auto transformer. The Tokamak operator configures required charging voltages for different banks. The PLC control system charges up all capacitor from 1kV to 10kV at recommended capacities from 1 uF and upwards with voltage feedback control and motorized autotransformers.The control system monitors the charge voltage as it builds to the pre-set value and then stops.Besides automatic operation, manual operation is provided by front panel HMI to start the charging.

NF39

ECRH Assisted Helium Plasma Discharge in SST-1

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Abstract- The 42GHz ECRH (Electron Cyclotron Resonance Heating) system is an essential system for plasma start-up and current ramp-up in SST-1 tokamak. This system is suitable to operate the tokamak at 1.5T operating toroidal magnetic field. The fundamental O-mode is launched from the radial port (low field side) of tokamak. This system has been extensively used in SST-1 tokamak to carry out plasma start-up at fundamental and second harmonic. Till now the plasma start-up has been achieved with hydrogen plasma. However, plasma discharges with helium in SST-1 is carried out first time. The tokamak is operated at 1.5T operating toroidal magnetic field. The fill pressure of helium gas is maintained around $1x10^{-5}$mbar. The ECH power in O-mode is launched before the loop voltage. The ECH power is varied from 100kW to 150kW and pulse duration is also varied from 50ms to 150ms. The loop voltage is maintained around 4V, successful ECH assisted plasma discharge is achieved with helium gas. In various plasma discharges, around 50kA plasma current is achieved with plasma shot duration varying from 100ms to 200ms. As the plasma discharges with helium gas is tried first time in SST-1, the successful consistent helium plasma discharges are achieved with ECRH assisted pre-ionization. The paper discusses about the role of ECRH in SST-1 plasma and explains the breakdown and start-up of helium gas with ECRH.

NF40

Indigenous Design and Development of USB Based Data Acquisition System on FPGA

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Abstract- Many of the diagnostic group in Institute for Plasma Research (I.P.R) working for Tokamaks like ADITYA and SST need to acquire data from the sensors up to 200 KSa/s. So, a USB based data acquisition (DAQ) system has been indigenously designed and developed on FPGA by Electronics & Instrumentation Division at I.P.R which can be used to acquire signal up to 200 KSa/s simultaneously from 8 channels with 16 bit resolution. Driver implementation to interface USB module, analog-to-digital converter IC and FIFO is done in Spartan 3E FPGA family from Xilinx. A Graphical User Interface has been developed in LabVIEW through which user can set the sampling rate, number of channels to acquire and samples per channel with or without rising edge of trigger. The application also logs the data for further analysis. The system communicates through USB it can be plug and play so the system very handy. Also USB DAQ system is cheaper than the USB DAQ available in the market. It has a very wide application and can be used wherever there is a need to acquire & log data up to 200 KSa/s. This paper describes hardware and software details along with the results.

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NF41

Experimental program for testing TBM FW mock-up in HELOKA facility

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Abstract- In the Indian Lead-Lithium cooled Ceramic Breeder (LLCB) Test Blanket Module (TBM), PbLi eutectic alloy is used as multiplier, breeder, and coolant for the CB zones, and Li2TiO3 ceramic breeder (CB) is used as a tritium breeding material. The first wall is made of India specific Reduced Activation Ferritic Martensitic Steel (IN-RAFMS) and is cooled by high-pressure (8.0 MPa) and high-temperature (300-500 C) helium gas. During the ITER operation, the First Wall (FW) will face varying values of surface heat flux at steady state and in transient conditions. Further in transients the first wall will face back to back pulses, power excursion for short duration and high power with short duration etc. In view of these operating conditions, to test the performance and integrity of first wall mock-up in steady, transients and postulated accidental events such as LOFA (loss of partial and full flow) a number of test cases and associated test matrixes were prepared. A scale down version of the U-shaped TBM FW mock-up was fabricated and shipped to Karlsruhe Institute of Technology for testing in its high-pressure, high-temperature helium cooling loop. This paper presents the details of the experimental program, test matrixes, mechanical and process interface details between the mock-up and the test facility and the experimental process and instrumentation details. The expected performance parameters are also included in this paper.

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NF42

Conceptual Design of -50 kV DC Solid State Crowbar System

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Abstract- Electron Cyclotron Resonance Heating (ECRH) system at IPR consists of 42 GHz gyrotron, which delivers 500kW power for 500ms duration. This system is used for heating and pre-ionization in Aditya Tokamak and SST1 respectively. This gyrotron needs crowbar protection for its safe operation during fault condition. A series ignitron based crowbar protection is being used in present set-up but it has its' own merits and demerits. So an advance -50 kV solid state crowbar system is under development which would replace the existing series ignitron based crowbar system. This paper presents the conceptual design, evaluation and selection of major components of Solid State crow-bar. It will also be discussed about how twelve series thyristor of 6500 VV_{DRM}, V_{RRM}capacityis diverting the fault current and will not be allowed more than 10J energy within 10 micro second at ≤ -50 kV, its simulation model, calculation of major/ key parameters of semiconductor device, design of snubber circuit and gate triggering circuit in detail.

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NF43

Prospective High Temperature Superconductors Based Applications in Fusion Devices

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Abstract- High temperature superconductors (HTS) are now preferably used in large scale superconducting devices like Tokamak, accelerators etc. for applications such as high current carrying HTS based current feeders and current leads for energizing superconducting magnets [1-3]. This is due to the superior performance of HTS compared to low temperature superconductors (LTS) viz. higher transport current capability, higher critical magnetic fields and higher critical temperatures. Additionally higher operating temperatures for HTS technology in large superconducting magnet applications make them more cost effective due to relatively lower cryogenic investment and operational costs. This work focuses on prospective application of HTS cables for current feeder application and HTS current leads in fusion devices. Commercially available second generation (2G) coated conductors based YBCO/BSCCO tapes and MgB2 conductors are compared for use in these applications. Cooling of the HTS current feeder and current leads is envisaged using cold helium gas, atmospheric liquid nitrogen as well as sub-cooled liquid nitrogen and their respective merits as well as limitations would be pointed out. Cooling scheme would be based upon the duty cycle of operation versus the capital costs investment for HTS tapes. Techno-economical benefits of using HTS current feeders and current leads over existing LTS based counterparts would also be discussed.

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NF44

Development of Precise Electronic Circuit for Liquid Nitrogen Two phase flow Void fraction measurement system

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Abstract- It is always challenge to predict the quality and void fraction in two phase flow especially cryogens like liquid nitrogen and liquid helium. Without establishing these parameters, it is difficult to analyze the pressure drop and related thermos-hydraulic characteristics of the system. In cryogenic two phase flow, void fraction (α) is the ratio of area occupied by the vapour with respect to total area occupied by the liquid and vapour. The quality factor (x) of two phase flow is defined as the ratio of mass flow of vapour with respect to total mass flow of liquid and vapour. Therefore, an effort has been made to indigenously develop the precise electronic system to measure the void fraction accurately depending upon the dielectric constant of nitrogen in vapor and liquid phase. The state-of-art electronics circuit has been developed and tested successfully for the capacitance measurement in pico farad order. Using this circuit, we have conducted an experiment of cryo transfer line to study the two phase void fraction

specific to liquid nitrogen services. In this paper, we will discuss about the design basis and working principle of the specially designed electronics card along with the performance results. A/D conversion and DAQ system has been implemented to display the measurement data in desktop.

NF45

Development of Data Plotting and Analysis Utility for Superconducting Magnets of SST-1

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Abstract- The magnet system of SST-1 tokamak at IPR consists of sixteen toroidal field and nine poloidal field Superconducting(SC) coils, a pair of resistive vertical field (VF) coils, an air core Ohmic transformer with compensation coils for its various magnetic field requirements. SC coils are equipped with temperature, voltage, pressure, flow, displacement, strain and Hall sensors for healthy monitoring during cool down, plasma experiment and warm up. An in house signal conditioning electronics system [1] has been developed to cater the need of various cryogenic compatible sensors of TF and PF coils. VME DAQ [2] system interfaced with JAVA based server client application has been developed for acquisition and archival of sensors' data during experiments in SST-1. Post analysis of data of sensors is our prime requirement, which are necessary for magnet cool down, charging-discharging and magnetic field performance as well as health of magnets during quench if any. The java based offline data analysis tool has been developed to read data from single and multiple H2db files which are created with running acquisition along with CSV files. The offline data analysis tool can conjugate up to 20 continuously created H2db files and plot continuous trend of sensors' data. The data analysis tool can also plot in different nodes which a user can define and save for future applications.

This poster gives overview of the offline data analysis tool, its implemented features, data conjugation and data plotting performances of SST-1 SC coil sensors. It also illustrates specific data plotting cases of SC coils in recent SST-1 plasma campaigns.

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NF46

Optimization of Process Parameters for Tungsten Thin Films

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Abstract- To increase the life cycle and performance of a component or a part, surface treatments by physical vapor deposition process (PVD) and coatings of functional thin films have become prominent. Being high Z-materials, Tungsten (W) and Tungsten based metals are now gaining more attention to metallurgists as one of the Plasma Facing Materials (PFM) in nuclear fusion tokomak [1, 2]. Studies show advantages of Tungsten film over bulk material as PFM materials [3]. RF sputtering process has been considered in this study for the

deposition of thin films on substrate due to its advantages of at low temperatures, compact and relatively smooth deposition of tungsten [4]. In this study, thin films of Tungsten are sputter deposited on to Reduced Activation Ferritic Martensitic steel (RAFM steel) by RF sputtering process has been initiated after optimizing the proper deposition condition. To increase the adhesion property of coating proper consideration of inter layer between the RAFM steel and Tungsten has been developed using proper process parameters like sputtering power, sputtering time and substrate temperature. Structural property of the film has been characterized by XRD and FESEM. Hardness and other important mechanical properties of the coated films are characterized by micro and nano indentation techniques. Finally sketch analyses of the coated films are critically studied to understand the actual adhesive properties as real field applications.

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NF47

Hydrogen Extruder Concept for Repetitive Pellet Injection

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Abstract- Plasma fuelling by pellet injection is an important technological requirement of a tokamak machine. Based on the twin-screw extrusion principle design of a hydrogen extruder system has been carried out. It is aimed for the development of repetitive pellet injector system for Indian tokamaks SST-1 and Aditya-Upgrade. This extruder system will be initially used as an experimental system to attain a hydrogen extrusion throughput of ~ 400 mm^3/s. With a sufficient safety margin we are expecting pellet frequency of 10Hz and pellet size 3mm (L) x 3mm (D) in size. In the present design a counter rotating intermeshing twin-screw geometry with square thread is selected. Each screw will be having 28 mm root diameter, 4 mm screw cavity depth and 10 mm pitch with a screw helix angle of 6.5 degree. In the present work design of screw geometries, their support, thermal link with the cryocooler are discussed along with the thermal and structural analysis. A cuboid shaped chamber is designed to accommodate all the cooling stages and extruder elements. The design of subcomponents and extruder system as a whole is discussed here.

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NF48

Overview of System Design Revision for Instrumentation & Control System Architecture of Neutral Beam Injectors

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Abstract- Neutral Beam Injectors constitute auxiliary heating system for Tokamak Plasma. It is designed for injection of 1.7MW neutral beam power to the SST-1 Tokamak machine. Neutral BeaInjector source is being operated in the test stand mode. Instrumentation and control play an important role for the safe and reliable beam operation. Central Data Acquisition and Control System include the control, monitoring, interlocks, safety and diagnostics signals. Instrumentation, Control and Operation requirements for NBI Sub-Systems includes slow acquisition PLC system, VME, VXI, USB based data acquisition and GPIB based data acquisition along with other diagnostics system. Slow Local mode PLC System with Supervisory Control and Data Acquisition (Wonderware) and HMI Interface (Touch Panel) used for operation, control, acquisition, safety and other interlocks for Sub-Systems. Analog Isolation system integrates with the local mode PLC System. Other Diagnostics System comprises of Electrical Diagnostics System, Calorimetre for Beam and Cryogenics Sensors DAQ System. The diagnostics system measures the beam operational parameters on different potentials by means of the optical communication cards, signal conditioners and USB based DAQ system. The calorimeter system involves measurement of more than 150 channels which includes water as well as surface thermocouples. Dedicated GPIB to Ethernet Data Acquisition System measures more than 100 cryogenics temperature sensor channels. This paper presents the complete revised I&C architecture for Neutral Beam Injector which includes various Data Acquisition and Control Systems along with the related diagnostics system's.

NF49

Integration and Testing Of 15kv, 185A Cryogenic and Vacuum Compatible Feed-Through Inside CFS Chamber of SST-1

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Abstract- The SST-1 (Steady State Superconducting (SC) Tokomak) had been installed and commissioned at institute for plasma research, Gandhinagar, Gujarat. The SST-1 comprises of 16 Nos. superconducting TF coils as well as 9 Nos. of superconducting Poloidal field coils. The terminations of SC coils have been terminated to current feeder system (CFS) chamber of SST-1. The main aim of CFS is to provide interlink between the cryogenic temperature to room temperature. PF coils were initially terminated through feed-through which cannot operate in vacuum and cryogenic environment. As a remedy,custom make vacuum and cryogenic compatible feed-through were procured and installed inside the CFS. Currently, PF coils are terminated through feed-through which are compatible with vacuum as well as cryogenic environment with electrical rating of 15kV, 185A. This presentation illustrates testing, installation and integrated test results of high power feed-through with the CFS.

NF50

Design of LN2Bath Cooled Cryostat For Solenoid Magnet

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Abstract- Magnet systems division is working towards development of bath cooled HTS based solenoid magnet of mass ~ 4 Kg. This solenoid will be bath cooled with liquid nitrogen (LN2). The low loss cryostat

plays a key role in the successful operation of any superconducting (SC) magnet system. The performance of the cryostat used for SC magnet system largely depends on its sub-system such as vacuum system, magnet supports, amount of heat loads due to sensors and current leads and its thermal isolation from external auxiliaries. The various heat loads such as conduction, radiative, and residual gas conduction are estimated towards optimum performance of the cryostat. This presentation describes the thermo-mechanical design of the cryostat to be used for the HTS solenoid magnet, structural loads acting on the chambers of the cryostat and the estimated heat loads.

NF51

Observation and Characterization of Low Frequency Density Fluctuation in ADITYA Tokamak

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Abstract- The gradients in the radial profiles of density and temperature gives rise to various instabilities which aid in the transport of the particles across the magnetic field lines in tokamaks. These instabilities, signature of whose are embedded in fluctuations observed in various physical quantities like plasma potential, density, etc. are required to be understood properly for mitigating them. In typical discharges of ADITYA tokamak, a medium sized air core limiter tokamak, fluctuations in electron density, measured with microwave interferometry, are regularly observed. To characterize the observed fluctuations, the Fourier spectrum analysis has been performed on the time-scale data of density fluctuations. The spectral analysis shows a prominent peak at ~25 kHz apart from other high frequency peaks. It has also been observed that the intensity of this low frequency peak is significantly affected by periodic gas puffs applied in the plasma current flattop. In this paper the observed low frequency (~25 kHz) density fluctuation and its variation with the periodic gas puffing has been characterized thoroughly to identify the GAM like instability causing it.

NF52

Nano fluids: Potential Coolants for Fusion Applications

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Abstract- Nanofluids are colloidal suspension of ultra-fine (nano sized) metallic or nonmetallic particles in a base fluids. The advantages of nanofluids are that it give enhanced thermal conductivity and better response as heat transfer medium compared to the conventional fluids. Numerous research work is going on in application of nanofluids in the field of thermal science and engineering. Research is also underway to use the nanofluids to improve the cooling of high heat flux components in a fusion reactor. Water-based nanofluids have the potential to use as a coolant while retaining all the advantages of water. The stability of the long-term behavior of these nanofluids must be studied before they are considered viable for fusion application. Investigation on stability is an unavoidable issue that can alter the thermo-physical properties of nanofluids, so, it is important to analyze the influential factors to the stability of such suspensions. This paper will discuss about the stability is where powders easily aggregate due to strong van der Walls force among nano particles and the stability enhancement processes

by using suitable surfactants. The different characteristics of various nanofluid contains water Al_2O_3, TiO_2, CuO etc. nano particles in the water base fluid have been studied for the % wt. fraction varied from 1% to 5% for all types of nano particles. The result showed the decrease in thermal resistance with particle inclusion in base fluid. Al_2O_3 - water and CuO - water nanofluid was found to be more suitable than TiO_2-water nanofluids. The pumping power requirement also increases as the particle concentration is increases. This paper is an attempt to address the viability of usage of nanofluid as a coolant for the fusion reactor.

NF53

Overview on ADITYA Upgrade Tokamak Experimental Progress

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Abstract - Recently, the first medium sized tokamak facility of India named ADITYA (R0 = 75 cm, a = 25 cm), operated over 2 decades with circular poloidal limiter has been upgraded to a tokamak named ADITYA Upgrade (ADITYA-U) for the purpose of having shaped plasma operation with an open divertor geometry with divertor plates without any baffle, to support the future Indian Fusion program. The foremost objective of ADITYA-U is to prepare the physics and technological base for future ITER and DEMO machine by performing the dedicated experiments, such as generation and control of REs, disruption prediction and mitigation studies, along with plasma position control and confinement improvement studies with shaped plasmas. Tokamak experimental research in ADITYA Upgrade has made significant progress since last year. After installation of PFC and standard tokamak diagnostics, the Phase-I plasma operations in ADITYA-U were resumed from December 2016 with graphite toroidal belt limiter [1]. The primary objectives of the Phase-I operation: (1) to achieve first circular hydrogen plasma in ADITYA-U with purely Ohmic discharges assisted by filament pre-ionization (2) to check the overall functionality of the system and (3) study the discharge characteristics of ADITYA and ADITYA-U tokamak. During Phase-I operation, all the subsystem of the machine have performed well as desired and the discharges are very satisfactory in terms of the functionality of the machine. After completion of Phase-I operation by the end of March 2017, the Phase-II operation preparation has been executed. The Phase-II operation preparations includes: (1) Calibration of in-vessel magnetic diagnostics (2) Major Diagnostics installation and (3) Baking heaters installation and vacuum vessel baking. ADITYA-U vacuum vessel has been successfully baked up to ~ 130°C in subsequent baking cycles for the purpose of achieving lower base vacuum. The base pressure of the order of ~ 9 x 10^-9 torr has been achieved after solving all leaks. After all the relevant preparations, the Phase II plasma operation were resumed in ADITYA-U in February 2018 in a Graphite limiter (toroidal belt limiter) configuration and continued to acheive plasma parameters close to design parameters. Dedicated experiments relevant for plasma operations in large size machines have also been conducted during the Phase-II operation of ADITYA-U. Significant and very encouraging results related to runaway electron generation and loss mechanisms, control of rotation of magnetic islands, radiative improved modes have been obtained. An overview of these experiments has been presented in the paper.

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NF54

Fabrication and Installation of an additional set of poloidal field coils for Experimental applications in ADITYA Upgrade tokamak

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Abstract- ADITYA - U (R0 =75 cm, a=25 cm), an ohmically heated tokamak, recently being upgraded from ADITYA tokamak with additional divertor coils and toroidal belt limiter. After successful commissioning of ADITYA-U, the Phase –I plasma operation was successful completed with circular plasmas and all the sub-systems functioned well during the operation. Later, the Phase-II plasma operation conducted from February-2018 and continued to achieve plasma parameters close to design parameters. During these experiments plasma operation demands requirement of an additional set of poloidal field coils for generating magnetic field in different configurations for example position control, external radial field, external vertical field etc. Therefore, it is planned to install a set of multi-turns additional poloidal field coils in the outer periphery of vacuum vessel. The fabrication and installation of additional set of poloidal field coils includes manufacturing of base support structure, winding of coils and proper clamping at various locations. The radius of these coils is ~ 1.5 meter and the height from the mid-plane is ~ 0.5 meter. These coils were successfully operated during Phase-II plasma operation with capacitor bank power supply and functioned satisfactorily. The fabrication, installation, electrical parameter measurements and its applications during various experiments will be discussed in this paper

NF55

Fabrication and Characterization of Different Joints for High Temperature Superconducting Tapes for Magnet Applications

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Abstract- The high temperature superconducting tapes are now commercially available for various practical magnet applications. Its higher tensile strength gives rise to strain tolerance and hence can be used for pancake winding of smaller diameter coils. The HTS based magnets usually consist of a number of spiral wound pancake coils that are connected together in pairs on the inner turns to form a double pancake, and each pair of double pancakes joined on the outer turn. The most crucial thing in making a pancake coils is to make inter-pancake joint with minimum electrical resistance. However, joining of two parallel HTS tapes is more complicated because of their structural design. It includes materials which get deteriorated on exposing to higher temperature. In this work, effect of different overlapped lengths i.e. 50, 70,100,150 and 200 mm, with perpendicular and inclined overlapped joints have been studied. Pb-Sn (60% lead and 40% tin) solder material of melting point is 188ºC used for preparation of joints. During joint fabrication temperature is maintained ~ 200ºC to avoid he degradation of HTS conductor. Joints are prepared with and without SS sheath. Two types of joints were prepared i.e. without removing of SS sheath material and after removing the SS sheath material by mechanical/chemical etching. Resistances of these joints were measured using four probe methods, at

liquid nitrogen temperature (77 K). The lowest joint resistance of ~5 nΩ of with overlap length of 150 mm achieved at 77 K, self-field [2]. Now, experiments on joint resistance measurement of other configurations are in progress, and will be reported during conference presentation.

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NF56

Conceptual Design Study of a Laboratory Scale HTS Solenoid

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Abstract- High temperature superconductors (HTS) based magnets have many advantages over the conventional low temperature superconductors (LTS) magnets. These advantages include higher operating temperature, current densities, lower operational cost and compact size. The preliminary design study of a smaller laboratory scale HTS solenoid has been carried out to produce the magnetic field of ~ 0.3 Tesla at its center. The proposed basic conductor for this solenoid magnet is commercial second generation (2G) BSCCO tapes. This solenoid will be a bath cooled type magnet. The tentative outer and inner diameter of the proposed solenoid is ~ 140 mm and 100 mm respectively. The estimation and analysis of electrical parameters, the magnetic field profile along the axial and radial directions, and electromagnetic forces on the solenoid winding with designed operating current will be discussed in this presentation. The outcome of the above mentioned studies will contribute towards design and fabrication for future large scale HTS solenoid for magnetic fusion application.

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NF57

Development of Quench Detection System for PF#3 Coils of SST-1

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Abstract- Steady State Superconducting Tokamak-1 (SST-1) machine at IPR is in operation for the plasma experiments. Superconducting Magnet Systems (SCMS) of SST-1 comprising of sixteen superconducting D-shaped Toroidal Field (TF) magnets and nine superconducting Poloidal Field (PF) magnets together with a pair of resistive VF coils and Ohmic coils.The Toroidal Field (TF) magnet system is routinely operating at

more than 1.5 T. PF3 coils also made superconducting successfully during last campaigns. PF3 coils are also going to be charged in up-coming campaigns. A reliable and fail proof quench detection (QD) system is essential for of the PF#3 coils operation. This QD system needs to continuously monitor all the section of PF#3TB coils, which include 4 pair of layers, bus bars and current leads. In case of any event initiating the normal resistive zone and reaching thermal run-away, the QD system needs to trigger the magnet protection circuits. In the present configuration of quench detection scheme, the voltage drop across each pair of layers of PF#3TB coils are measured and compared with its two adjacent pair of layers for the detection of normal zone and cancelation of inductive couples. During OT discharge, PF coils are coupled to induced voltage (~1 kV), which makes the development PF QD system more challenging. A proposed QD system is developed with single stage low pass filter & voltage divider before the front end of electronics, which comprises of 3.5 kV galvanic isolation, filter, difference amplifier section, comparator & timing logic. This paper describes activity continued towards the development of QD system of PF#3TB coils, precaution taken on during development and challenges and will be updated during presentation.

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NF58

Preliminary Engineering Design Study of Compact HTS based TF Coil

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Abstract- High temperature superconductor (HTS) is a promising candidate for next generation of Tokamak magnet system. It provides higher temperature margin, which in turn could be beneficial for cryogenic requirements for such system. This magnet system consumes less space compare to the conventional low temperature superconductor (LTS) based magnets. This study will provide initial assessment on the engineering challenge associate with HTS coils for fusion magnets applications. The generation of a Toroidal Field (TF) coil profile needed for a small aspect ratio Tokamak, estimation of its radial thickness and expected electromagnetic (EM) forces have been attempted for the operating current of 1-2 kA. The proposed TF coil will have different bending curvatures at multiple locations, hence, the estimation of bending and EM loads needed for HTS based compact TF coil. This work will cover basic aspect TF profile design and related analysis to estimate EM forces. This study will be useful for future compact HTS based TF coil systems design for medium size Tokamaks.

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NF59

Simulation Tool for Designing Safety Relief Circuit of Cryogenic Volume in Fusion Devices

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Abstract- Present fusion devices can't be dissociated with cryogenic helium, which is to be supplied at various temperature levels i.e. 4K, 50K and 80K level to many applications such as magnet, cryo-pumps, fuel pellet injection system, current leads and thermal shields with the help of cryo-lines and cryo-distribution boxes [1]. Approx. 5km of vacuum jacketed cryolines [2] and 7 cryo-distribution boxes will serve the purpose of delivering cryogens to respective applications in case of ITER. Safety of these cryo-lines and cryo-distribution boxes are insured with the installation of safety valves in order to protect the cryogenic volumes from over pressurization during any abnormal events such as loss of insulation vacuum (LIV) and fire case. Safety valves must be sized for the most demanding case scenario in such a way that pressure within the system remains below the maximum allowable working pressure (MAWP). Sizing of the safety valve depends on various factors such as heat load, back pressure, set pressure, relieving temperature and most importantly the length and size of safety circuit pipelines. Various guidelines such as maximum pressure drop, maximum desirable specific volume are specified in ISO-21013-3 [3] and has to be ensured for fire as well as non-fire case for designing the safety circuit at upstream and downstream of SRVs. All these parameters needs to be correctly assessed before finalizing the safety valve capacity and its associated circuit. A numerical simulation tool has been developed which is capable of sizing the safety circuit specifically; upstream and downstream pipe of safety valve, safety valve capacity, and maximum allowed back pressure and relieving conditions. Results obtained from the simulation tool has been validated with the calculation as per the code ISO-21013-3 guidelines with an acceptable agreement.

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NF60

Heat Treatment and Electrical Testing of Superconducting Nb_3Sn Strands

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Abstract- Nb_3Sn superconducting strands are widely used for basic conductors of high magnetic field applications such as accelerator and tokamak magnets. Nb_3Sn strand is one of the most applicable cryogenic superconducting materials and the best choice for high field magnets [1] exceeding 10 T due to its superior performance in high magnetic field. Nb_3Sn alloy (withA15 phase) can only be made superconducting after heat treatment at specific schedule with control temperature ramp rate and dwell time. The heat treatment of multi-filamentary Nb3Sn superconducting strands developed by the internal tin process has been investigated here. Uniformity of temperature and dwell time are the critical parameter to make Nb_3Sn alloy to maintain the Stoichiometry. Electrical testing of heat treated Nb3Sn strands samples carried out at 4.5 K in self-field condition. The details of heat treatment and low temperature testing of Nb3Sn strands will be discussed in this presentation.

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NF61

Effect of Magnetic Shear on $\boldsymbol{E}\mathrm{x}\boldsymbol{B}$ Instability in Collisional Inhomogeneous Plasma

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Abstract- The crossfield instability is pervasive in all electromagnetic system. Here we have considered a sheared magnetic field to study the $\boldsymbol{E}\mathrm{x}\boldsymbol{B}$ instability which is observed in the internal transport barrier of fusion machines like Tokamak etc. The benefits of shear for tokamak is to improve the confinement and also the transport reduction. The fundamental physics involved in transport reduction is the synergistic effect of $\boldsymbol{E}\mathrm{x}\boldsymbol{B}$ shear in the growth, radial extent and phase correlation of turbulent eddies in the plasma.[1] Magnetic shear can extenuate the potentially harmful effects of $\boldsymbol{E}\mathrm{x}\boldsymbol{B}$ shear and reinforced the turbulent stabilization.Here we have investigated the behavior of collisional plasma in the presence of sheared magnetic field $B_0(\hat{z} + \frac{y}{L_s}\hat{x})$ where, L_s is sheared length, with smoothly increasing density profile $n = n_0 \exp(\frac{y}{L_n})$ where L_n is the density gradient length. Magnetic shear stabilization requires a shear length (L_s) comparable to or less than density gradient length (L_n).[2] we have considered three different conditions between y and L_s (where y is the magnitude of the applied magnetic field along x-direction) to estimate the response of the magnetic shear. Dispersion relation is also obtained.

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NF62

Initial Results from a Low Cost Electrostatic Confinement Fusion Device at IPR

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Abstract- Inertial electrostatic confinement fusion (IECF) is a distinctive approach towards the production of neutrons using the fusion reaction. In this configuration ions recirculate due to the application of an electrostatic field, which confines the plasma. IECF at IPR comprises of cylindrical vacuum vessel with cathode grid inside the vacuum chamber made up of stainless steel. The chamber has multiple ports for evacuation, high voltage feedthrough, gas inlet and viewing windows. Diffusion pump is used along with the rotary pump to maintain the base vacuum of order upto 10-5 torr. Purified Deuterium (D2) is used for the experiment and operated at a range of pressure (3-4) x 10-3 torr. High voltage is applied between the cathode

grid and vacuum chamber to produce the D2 plasma. This high voltage power supply is developed indigenously assembling the fly-back transformers in series configuration which is tested upto 50 kV in no-load condition. This low cost high voltage power supply is successfully operated in the range of 20-30 kV with current limit range of 5-10 mA. Successful breakdown of D2 plasma and signature of neutron traces are confirmed using He-3 detector. The dose rate data measured at approximately 16 cm from the chamber centre is 0.02 μSv/hr in several discharges. Neutron production is calculated and it comes around 1000 Neutron/sec.

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NF63

High Temperature Superconductor (HTS) for Fusion Magnets

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Abstract- The conventional magnets used for magnetic confinement of plasma in the contemporary Tokamaks are either made up of copper or low temperature superconductors (LTS). The operational limitations of copper coils are due to huge electrical power requirement and joule heating. The LTS has advantages over the copper coils in terms of power requirements and long pulse operation. However, LTS has limitations in terms of operating magnetic fields and the cryogenic requirements. High temperature superconductors (HTS) could be a viable solution for the future Tokamaks and fusion reactors due to higher operating temperature and magnetic fields. These unique properties of HTS can be utilized to design and build magnets with elevated operating temperature (20-77 K) and magnetic fields greater than 20 T. This is a significant step forward over the convention LTS magnets, which generally operate at a temperature of ~4 K and magnetic fields usually limited up to 13 T. The design and R&D initiatives are required for the feasibility study of HTS based magnets for fusion reactors. The R&D components for HTS based magnets are high current conductors, low resistance joints, quench detection and protection. The R&D initiatives related with HTS for small aspect ratio Tokamak will be discussed in this presentation.

NF64

Pumping Speed Effect on Glow Discharge Wall Conditioning In Aditya Upgrade Tokamak Vacuum Vessel

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Abstract- Hydrogen Glow discharge Wall Conditioning (H2-GDWC) is mandatory and routine operation in Aditya upgrade tokamak to remove Oxygen (O) and Carbon (C) contain impurity. To remove Hydrogen from plasma facing components (PFC) and tokamak vessel wall, Helium (He) GDWC is also carried out periodically. Both H2-GDWC and He-GDWC are performed using constant pumping speed with single turbo molecular pump (TMP) in Aditya. The pumping speed is an important parameter in any wall conditioning techniques, because it affects the removal rate of impurity species with other discharge parameters like plasma temperature and plasma density, fill pressure etc. The chemical reaction of Hydrogen ions with metal oxides and metal carbides generates different volatile impurity species in form of H20, hydrocarbons (CH4, C2H4),

CO, CO2 etc. The residence time of gas species stimulate the chemical reaction and it depends on pumping speed. The longer reaction rate generates more impurity species under low pumping speed. But re-ionization and dissociation of released gas species disturb the impurity removal rate in very low pumping speed. While high pumping speed creates short residence time thus short reaction time and less impurity generation. The controlled and proper pumping speed provides better impurity removal rate from the PFCs and vacuum vessel wall during wall conditioning. The pumping speed control experiments during H2-GDWC and He-GDWC have been carried out to study impurity removal rate in Aditya upgrade tokamak vessel. In these experiments, two turbo molecular pumps have been operated with variable pumping speed from ~ 1000 l/s to 1800 l/s during both H2-GDWC and He-GDWC. In this paper, the experimental results of impurity removal rate during H2-GDWC and He-GDWC are presented with single and dual TMPs under different pumping speed.

NF65

RF Characterization of the Passive Active Multijunction (PAM) Launcher for LHCD System of ADITYA -Upgrade Tokamak

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Abstract- The Passive Active Multijunction (PAM) launcher is designed at 3.7 GHz to deliver 250 kW RF power for 1 second into the ADITYA-U tokamak to drive plasma current non-inductively employing Lower Hybrid Waves (LHW) [1][2]. The fabrication of the launcher, its mechanical qualification and RF characterization is completed. The transmission line components namely the mode converter and the linear taper along with the input bends are characterized for low power RF performance using Vector Network Analyzer (VNA). The transmission line components exhibit a return loss of ~25 dB and the power is divided in three poloidal sections equally (~4.9dB) to all the output waveguides with an insertion loss of ~0.11 dB. The PAM launcher consists of the step phase shifter section and the active and passive waveguides. A special testing kit comprising of bends and transformers is designed and fabricated to aid the RF measurements. The output phase of the active waveguides and the power division are the most important parameters. The measured RF results and the simulated RF results are in good agreement with a return loss of ~26 dB and an insertion loss of ~0.2 dB. Finally, the transmission line components and the PAM launcher are integrated and the RF performance of the complete PAM structure is obtained. The poster reports the low power RF characterization and the performance of the components of the PAM launcher.

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NF66

Joining of Ti coated Graphite to Heat Sink Material

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Abstract- Joining of graphite to heat sink material (CuCrZr) is an interesting area in fusion community. At present in SST-1 like tokamak, graphite joining with CuCrZr (heat Sink) is considered for plasma facing component. However, the graphite tiles are attached to heat sink material by physical and mechanical bolting mechanism. The direct metallurgical joining of carbon with CuCrZr material is a problematic as having the large mismatch of coefficient of thermal expansion (CTE) between the carbon and copper, where the CTE ratio between carbon and copper is reported to be 1:16. To metallize and to improve the wettability of the carbon surface, typically active element coating is done in prior such as Titanium (Ti) coating or chromium coating is done on the carbon surface. In this paper, we chose Ti coating, which is achieved by sputtering technique using RF magnetron sputtering device. Once the carbon surface is being metallized by Ti coating then the joining of copper is employed by OFHC copper casting route at 1125°C for 2 h under Ar+4%H_2 atmosphere. Finally, the vacuum brazing is carried out in Gleeble 3800 system for the joining of copper cast Ti coated graphite with heat sink material at 980°C using TiCuNi70 brazing filler. Characterizations such as NDT-UT, metallography study and micro hardness measurement of the sample have been carried out. The experimental details and results of the characterization are presented in the paper.

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NF67

Study of Fueling Efficiency of Smbi System In Aditya-U Tokamak

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Abstract- Refueling of plasma is necessary in order to maintain the plasma density. In Aditya-U tokamak, the refuelling is done by two methods: 1) SMBI (Supersonic Molecular Beam Injection) and 2) Gas-Puff. Fuelling efficiency of these two methods, routinely implemented, are analysed using various diagnostic signals, such as soft X-ray (SXR), hard X-ray (HXR), H_alpha radiation, Bolometer and Mirnov coil signal. In this study, time delay in SXR, HXR and H_alpha signal is observed after launching SMBI and gas puff. It is found that the time taken by SXR signal to reach its peak after refuelling by SMBI is in range of 6-8 ms, whereas that for GP it is about 2-4 ms. A sharp contrast in the images of discharge evolution, acquired by the fast visible imaging systems, is also seen for SMBI and gas puff. In case of SMBI, the overall intensity of the images increases after a span of ~5 ms while for gas puff the increase in intensity is instantaneous with the puff. This suggests deeper penetration of neutrals and subsequent diffusion outwards of the increased density towards the core. The time delay matches the resistive diffusion time scale in Aditya-U. In many shots, after SMBI puff, HXR signal showed sharp decrease. However, in some of the plasma discharges, same behaviour was not reproducible. While in case of gas puff, such sharp fall in hard x-ray is rarely observed. This study will present statistical analysis of large number of plasma discharges and explain the observed result.

NF68

3-D Design of Inverse Magnetron Injection Gun for 0.24 THz, 1 MW Coaxial Cavity Gyrotron

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Abstract- Inverse magnetron injection gun (IMIG) provides several advantages over simple MIG especially in high-power, high-frequency gyrotron. Sub-millimeter (> 230 GHz), high power (≥ 1 MW) gyrotrons would be required in futuristic plasma fusion machines to fulfill the need of tens of megawatt RF power for electron cyclotron resonance heating (ECRH). Here, in this manuscript, an inverse MIG is designed for 0.24 THz, 1 MW coaxial cavity gyrotron. Coaxial cavity configuration provides better control on the mode competition and space charge compared to the simple cavity configuration. First, the trade-off design equations and technical constraints are used to synthesize the electrodes geometry and electrical parameters of IMIG. This synthesized IMIG model is further simulated to finalize the design using 3-D particle trajectory simulator CST. Simultaneously, the magnet system including the auxiliary gun coils and superconducting magnets (SCM) is also designed and the obtained magnetic field profile is used in the IMIG simulations. This IMIG is designed for a very high order mode ($TE_{46,17}$) based coaxial cavity. A detail parametric and misalignment analyses are also performed with respect to the electron beam parameters, such as pitch factor, velocity spread and guiding center radius spread. These parametric and misalignment analyses would be utter helpful in the fabrication, assembling and testing of the IMIG as well as gyrotron.

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NF69

Corrosion Study of IN-RAFMS With Lead -Lithium

ATCHUTUNI, Sarada Sree

NF70

Software Simulation of Field Devices using Python for ITER-India Gyrotron Test Facility

MANDGE, Deepak

NF71

Thermal Simulations of Microwave Mirror for ECRH Launcher

MISTRY, Hardik

NF72

Performance assessment of Helium cooled First Wall mock-up in HELOKA facility

SANTHARAM, Ranjithkumar

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FEA Investigation for Support Structure towards Installation of Prototype Magnet Test Cryostat

AGRAVAT, Hemang

NF74

Pre-conceptual Structural Design Study of Lab scale HTS based TF coils

GHATE, Mahesh

NF75

Architecture of Neutral Beam Injectors

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Plasma Diagnostics (PD)

S-7-O-1

Effects of Electron Beam Parameters and Velocity Spread on RF Output of a 35GHz Gyrotron Oscillator

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Abstract-In this paper, the effects of electron beam parameters as well as velocity spread on the RF behavior of a 35 GHz gyrotron operating in the TE041 mode has been investigated. The mode competition effects are also observed on the performance of the device. Variation of electron beam parameters like beam voltage, beam current, beam velocity ratio, and magnetic field are considered for determining output power of the device. Moreover, the effect of velocity spread on the output power is also demonstrated. The output power obtained from analysis have been compared with those obtained from commercially available Particle in Cell (PIC) code CST Particle Studio™. The output power for the designed mode as well as all nearby competiting modes are estimated and are found well above 230 kW with more than 33% device efficiency in the designed TE041 mode along with significantly lower values of power output is obtained among all other competing modes.

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S-7-O-2

Optical Emission Spectroscopy of Laterally Colliding Carbon Plasmas

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Abstract-An emission spectroscopic investigation of carbon dimer formation in laterally colliding two carbon plasma plumes is carried out in vacuum and under an ambient gas environment. Under the similar experimental conditions, emission spectra obtained with colliding carbon plasmas are compared with single

plasma plume to find the optimum conditions for cluster formation. Two spatially separated laser pulses from an Nd:YAG laser are used to generate two single plasma plumes in close proximity from a solid graphite target. Emission spectra of colliding plasmas and single plasma plume reveal a significant enhancement in the yield of carbon dimer in the stagnation layer, formed due to the collision of two single plasma plumes, as compared to that observed in single plasma plume. The Spatial and temporal evolution of carbon dimer emission reveals that yield of carbon dimer formation is optimum near the graphite surface, and starts decreasing with an increase in time as well as distance from the target surface. The above observations are correlated with the cooling of ejected carbon species in the collisional regime and the estimated vibrational temperature of carbon dimer.

S-7-O-3

Collisional Radiative Model for Neon Plasma with Relativistic Electron Impact Fine-Structure Excitation Cross Sections

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Abstract-Most of the earlier plasma diagnostic studies have focused on Ar, Kr [1] and Xe but not much attention has been paid to study Ne plasma which is equally important. In the present work, we take up the diagnostics of low temperature Ne plasma through optical emission spectroscopy (OES) technique. In this method, the emission measurements are combined with suitable collisional radiative (CR) model to extract electron temperature, electron density and population of species. A large amount of reliable electron impact excitation (EIE) cross sections data are required for optical-based plasma diagnostic techniques and at present these are not available in accurate and adequate manner for Ne. Therefore, there is need to produce these data first and then resort to a reliable plasma modeling. We calculate the required fine-structure EIE cross sections of Ne using fully relativistic distorted wave (RDW) theory and then incorporate into the CR model for the neon plasma modeling [1]. For the diagnostics our CR model is coupled with the Optical emission spectroscopy (OES) measurements of Navratil et al.[2]. In our CR model we take into account 40 fine structure states of Ne corresponding to $2p^5 3s$, $2p^5 3p$, $2p^5 4s$, $2p^5 4p$ and $2p^5 3d$ configurations along with its ground and ionic state. We calculate the required electron impact excitation cross- sections from the ground and excited states to upper states using fully Relativistic Distorted Wave (RDW) theory. In the calculation, the ground and excited states of the neon are represented through relativistic multi-configuration Dirac–Fock (MCDF) wave functions which are obtained from GRASP2K code [3]. The projectile electron wave functions are obtained by solving The Dirac equations in the field of spherically averaged static potential of the Ne atom. The electron excitation T matrices are calculated and the cross sections for the possible different fine structure transitions are obtained in the electron impact energy range up to 500 eV. Thereafter, these cross sections are incorporated in the CR model of Ne plasma following our earlier work on Kr [1] and coupling our model with OES measurements of Navratil *et al.* [3] where they obtained the intensities of the lines from $2p^5 3p \rightarrow 2p^5 3s$ transitions. In the conference we will present the details of RDW method and the calculated different cross sections as well as CR model of the Ne plasma along with the obtained parameters.

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S-7-O-4

Measurement of Electron Temperature and Negative Ion Concentration Using Biased Hairpin Resonator Probe

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Abstract-The existence of negative ions and its effect on the transport behavior inside the sheath in electronegative plasma is difficult to diagnose directly by the traditional electrostatic probes because of having almost same temperature and mass as the positive ions have. The microwave hairpin resonator probe is a parallel wire transmission line which exhibit resonance depending on the medium surrounding it. When immersed into the plasma, the observed resonance is directly related to electron plasma frequency through the dielectric constant of the medium surrounding the hairpin wire. Therefore the electron density n_e can be found using this technique [1]. In this study a dc biased hairpin probe is used to determine the variation of sheath thickness with power and pressure. On applying positive dc bias to the hairpin, the resonance frequency shifts towards higher values and get saturated at the plasma potential. Knowing sheath thickness the electron temperature can be found using the floating potential condition in an argon plasma and negative ion concentration in oxygen plasma. These results have been validated with a theoretical model of a collisionless sheath around the cylindrical wire of the hairpin probe and show a good agreement with the experiment. It is found that the negative ion concentration decreases with increase in power but increases with increase in pressure, consistence with the previous result [2].

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S-7-O-5

Density Measurement Techniques For Negative Hydrogen Ion Source

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Abstract-Negative hydrogen sources have applications in a variety of fields ranging from the neutral beam heating systems for nuclear fusion devices to particle accelerators. To characterize a negative hydrogen ion source it is imperative to measure the fraction of negative hydrogen ions (H^-) produced in the plasma. Typically, the H^- density is small compared to H^+ ions and this makes their detection difficult and error prone. In a wave heated magnetized rf plasma device[1] (HELEN-I) with no Caesium injection, the negative hydrogen ion production is quantified with a laser photo detachment[2] (LPD) diagnostic. Laser photo detachment method uses a Langmuir probe to measure the current (I_{PD}) due to the photodetachment of electrons from negative hydrogen ions. The Langmuir probe is sufficiently positively biased to draw the electron saturation current I_{es}. When the laser is shot, a sharp increase in the current takes place. This increment in current corresponds to the I_{PD}. A lock-in technique is used to obtain this small I_{PD} from the total current drawn by the probe. This gives more reliable and less error prone results than conventional LPD analysis. The results have been verified with the Optical Emission Spectroscopy, which makes use of H_α, H_β and H_γ lines of the hydrogen spectrum to calculate H^- density.

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PD1

Error Estimation and Measurement for Far-infrared Interferometer of SST-1 Tokamak

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Abstract-This paper focuses on the measurement of phase difference induced due to mechanical vibrations of optical components in the signals detected by the Far-infrared interferometer of SST-1 tokamak. The interferometer employs a multi-channel configuration and heterodyne detection for measuring the plasma density in SST-1. The interferometric measurements are sensitive to vibrations of optical components which lead to unwanted phase change and reduce the measurement accuracy. The error in phase difference due to mechanical vibrations has been measured by the interferometer itself during some selective plasma discharges. The measured phase difference due to vibrations corresponds to fringe counting error of < 0.3 fringe (peak-to-peak). The accuracy of density measurement is improved by deducting the vibration induced phase from the overall phase difference measured by the interferometer. The minimum line-integrated plasma density that can be measured by FIR interferometer is ~ 5 x 10^{18} m^{-2}. The corresponding values of measurable central densities are also given for two tangential channels.

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PD2

Microwave Diagnostic for Electron Density Measurement in Surface Dielectric Barrier Discharge Plasma

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Abstract-The surface barrier discharge (SBD) is the atmospheric pressure glow discharge produced on a planar surface. In such sources, discharge is confined close to the electrode and plasma thickness remains very small. Hence, accurate measurement of plasma parameters i.e. electron temperature, electron density etc. become difficult and challenging. The concept of microwave absorption in collisional plasma layer is well proved. Using this technique, we have tried to measure the electron density from microwave attenuation measurement in SBD plasma. We report the experimental measurements of X-Band (at 10 GHz) microwaves attenuation after interacting with planar surface barrier discharge plasma. Such measurements are found suitable to diagnose the plasma in order to estimate its electron plasma density. We have recorded microwave signals that travel through plasma and reflected from surface discharge panel. The attenuation in the microwave signal is observed following the discharge current variation. The electron plasma density obtained

thorough microwave diagnostics is compared with the spectroscopic measurement. Both the results match well.

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PD3

Reinstallation of ADITYA Thomson Scattering System with Modified Calibration Facility

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Abstract-Thomson scattering is one of the important diagnostics for the measurement of electron temperature (T_e) and density (n_e) of tokamak plasma. Aditya Thomson scattering system (ATSS) [1] which was dismantled for the upgradation of ADITYA is installed back into the Tokomak. ATSS is a single point measurement system operated using a Ruby Laser(694nm,10J,and Pulse duration of 20ns),one meter grating spectrometer(Minutesman Model SMP-310, 1200grooves/mm) for spectral dispersion, photomultiplier tube(RCA make PMT) detectors as the detection system and charge integrator based DAQ system[2].Some essential modifications like modification of viewing ports, calibration methods, and incorporation of UHV compatible retractable arm for illuminating the imaging volume etc. are incorporated to ATSS to make the alignment/operation of the diagnostics easy and accurate. All these modifications along with the relevant calibration results will be discussed in this paper.

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PD4

Role of Ionic Lines in Determining Excitation Temperature Of Microwave-Induced, Magnetically-Confined Plasma Using Optical Emission Spectroscopy

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Abstract-Optical Emission Spectroscopy (OES) is a non-intrusive technique widely used in plasma-assisted processes for in-situ process control and monitoring [1]. For example, in semiconductor industries, it is used to monitor species coming from silicon wafer while in proton sources, it is used for monitoring proton beam and vibrational states of H^{2+} molecule. Optical emission from rare gases present in the plasma can be an effective tool to measure excitation temperature (T_{exc}) using slope of the well-known Boltzman plot [2]. OES can resolve spectral lines in temporal as well as in spatial scale [3] and hence is preferred over the Langmuir probe and Thomson scattering methods.In the present work, T_{exc} of a low pressure (~ 10^{-4} Torr) argon plasma, generated by microwaves (2.45 GHz) and confined within multicusp magnetic field configuration is investigated using OES. The microwave plasmas are non-equilibrium in nature and hence is preferred in various applications [4]. The plasma optical emission is recorded using an optical fibre and a spectrometer

(Ocean Optics USB4000). Assuming the plasma to be in partial local thermodynamic equilibrium, Boltzman plot is generated using spectral data taken from NIST database, to evaluate T_{exc}.

The technique has already been employed earlier for diagnostics of argon plasmas by considering its atomic lines [2,5-6]. However, it is found that employing atomic lines alone, can lead to considerable amount of error in T_{exc} [2]. The present work demonstrates that by including ionic lines in the Boltzman plot, error in the T_{exc} can be reduced by an order. The results have been further used to study signature of electron trapping along the plasma axis [7].

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PD5

Development of X-Pinch System with Slow Rising (0.1kA/ns) Current Source

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Abstract-An X-pinch is formed when a fast rising current is passed through two or more fine wires placed in letter ‘X’ configuration [1]. The plasma is an intense and short (100ps-ns) duration source of soft X-ray burst from a micron size region. This is at times suited for applications such as studying the dynamics of high energy density plasmas such as exploding wires and Z-pinches through point projection radiography. Although Shelkovenko et. al. have postulated that current required to generate <1 μm size with <1ns source is >1kA/ns [2], in this work an X-pinch device have been developed utilizing a 0.1kA/ns current rate. A 2 μF capacitor is used as a current source which is connected through a spark gap to X-pinch load, which has inter electrode gap of 13 mm. The load is placed under vacuum of 10^{-4} mbar. The system has been characterized using various diagnostics such as voltage divider across electrodes, Rogowaski coil for current derivative and PIN diodes coupled with filters for temporal profile and pinhole cameras for spatial profile of X-rays.The short circuit inductance and rise time of the system is found out to be 200 nH and 1 μs. It can deliver peak current of 105 kA at 38kV operating voltage. Molybdenum wires of diameter 13 μm, were used for the X-pinch having 40^0 vertical angle. The wire burst was observed at ~18ns. Multiple X-ray pulses of energy more than 0.6 keV (6 μm Al filter, 50 μm beryllium (>1keV) and 12.5 μm titanium) were observed after 360 ns of current initiation. The signals from Ti filtered PIN shows that the X-rays are mainly in soft energy range. Although wire burst was observed at almost initial stage of current but the X-ray timings show that the neck hotspot is forming around half of the current peak. The X-ray pulse duration is observed to be 5-10ns and might be still short since the response of PIN diodes is seen to slow as compared to the X-ray pulse itself.

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PD6

Collisional Radiative Model for the Xenon Plasma Using Reliable Cross Sections

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Abstract-Xenon is used nearly in all modern HETs as propellant [1]. Also, xenon is added as trace a gas to characterize the low temperature plasmas. Therefore, it is very important to develop reliable collisional radiative model for xenon. The leading process in the low temperature xenon plasma is electron impact excitation of the various fine structure levels involved from the ground as well as excited states. For the appropriate plasma model, accurate electron impact excitation cross section data are required which at present are not available. Our aim is to obtain highly needed detailed fine-structure resolved cross sections for electron impact excitation of xenon using relativistic distorted wave (RDW) approach and demonstrate the application of the calculated data in modelling of low temperature xenon plasma by developing a CR model following our earlier work on Cs [2]. Various transitions from the ground $5p^6$ state to the excited $5p^5 6s$, $5p^5 6p$, $5p^5 5d$, $5p^5 7s$ and $5p^5 7p$ as well as among these excited states are considered and their corresponding cross sections are reported. In view of this, A C-R model is developed by incorporating our obtained cross sections. Further, coupling the C-R model with the optical emission spectroscopy (OES) measurements of Czerwiec *et al*. [3], diagnostic of the low temperature inductively coupled (ICP) xenon plasma is performed. The plasma parameters are extracted *viz.* electron temperature (T_e) and electron density (n_e) for H-mode transitions of xenon discharge [4].

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PD7

Radial Plasma Column Movement Measurements Using Soft X-Ray Diagnostics in Aditya-U

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Abstract-Plasma column movement in radial and vertical plane highly influences the characteristics of plasma discharges in tokamak. These position movements are routinely measured by various magnetic diagnostics. In Aditya-U, radial plasma column movements have been measured using soft x ray diagnostics. Radial plasma column movements were validated using results obtained from magnetic diagnostics (like, sine cosine coil, magnetic probe measurement) as well as with from the images acquired from visible imagining camera. These results are good in agreement with magnetic measurement of plasma column movement. In this communication we will discuss, diagnostics system, how measurements preformed and its validation with other diagnostics systems in Aditya-U.

PD8

Low cost, User friendly Langmuir Probe Diagnostic System

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Abstract-Langmuir probe diagnostic is a simple tool used for measurement of plasma parameters in low pressure plasmas. PC based low cost Langmuir probe powers supply is designed using Labview platform, Data acquisition hardware, current measurement card and amplifier card. This automatic Langmuir probe power supply measures plasma parameters at different location automatically and saves voltage and current data in different files in specific folder. At the same time we can view the V-I characteristics on the display. On the control panel we can set signal type, signal voltage, measurement distance and no. of measurements. Langmuir probe data analysis software is designed using math script feature of labview in which we have to provide the information like probe area, type of gas used. A detailed report is automatically generated in word report format.

PD9

Measurement of Bp and W_{DIA} of Aditya-U Plasma with a Diamagnetic Loop

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Abstract-Measurements of poloidal beta (β_p = ratio of kinetic pressure to magnetic field pressure) and thermal energy of plasma (W_{DIA}) have been performed on Aditya-Up by a diamagnetic loop installed inside the vacuum vessel in a poloidal plane. This loop encloses the plasma column and measures vacuum toroidal flux and change in toroidal flux, $\Phi_v + \delta\varphi$. For eliminating vacuum flux component Φ_V from diamagnetic loop signal, a compensating loop has been installed along with diamagnetic loop. This compensating loop encircle the plasma column but does not enclose it. These loops may have pick up with current in vertical field coils (I_{VF}). Contribution of vacuum toroidal flux and vertical magnetic flux has been estimated in non plasma shots and eliminated from the diamagnetic signal. In plasma discharges, $\delta\varphi$ has been measured 0.2-0.6 mWb. From measured $\delta\varphi$, poloidal beta (βp) and W_{DIA} have been estimated for various Aditya-Up discharges.

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PD10

Upgrade Design of Detection Sub-system for SST-1 Thomson Scattering Diagnostic

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Abstract-Steady state superconducting tokamak (SST-1) Thomson scattering (TS) system is operated using high power Nd:YAG lasers at its fundamental frequency [1]. As the Thomson scattering cross section is extremely small, the number of scattered photons collected is also very small. Detection of such low flux of photons at 1064 nm (fundamental frequency of Nd:YAG) requires high sensitive detectors with response at this wavelength and equally fast and sensitive signal conditioning electronics (SCE) with sufficient gain and low noise. IR enhanced Si-Avalanche photodiodes (APD) with thermo-electric cooler (TEC) are used as detectors for SST-1 Thomson system [2]. The output signal from these sensors is in nano-amperes (nA) range

at bandwidth of ~ 50 MHz. After a number of trials and actual operations with existing SCE, significant modifications in electronics and mechanical design of detector are made to improve the signal to noise ratio as well as ease in operation and alignment of the detector. The upgraded design of SCE with open board type layout, higher gain and embedded with miniature connectors is easy to operate and is tested with SST-1 plasma operation. A detailed account of the electronic and mechanical up-gradation of the detection subsection along with its preliminary test results will be discussed.

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PD11

Power Balance Studies in the Aditya – Upgrade Tokamak

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Abstract- A bolometric special and temporal study of radiation measurements on the Aditya – Up tokamak shows that for a global power balance impurities plays a major role, in particular when compared the bolometric signals with spectroscopic signals the central region of plasma high-Z elements like iron contributes more, and at the edge region low-Z elements like Hydrogen and Oxygen plays major contribution of radiated power. The total radiated power (line, bremsstrahlung) in the range UV, VUV, Soft X-Ray region of the plasma measured from top port is 20% to 60 % of the input power. For Power balance the radiated power and W_{dia} have been estimated for plasma discharges with and without gas-puff. The detailed discussion is given in the poster.

PD12

Image Analysis of Magnetized dc Plasma Using Singular Value Decomposition

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Abstract- In the present work, dynamics of the thermal plasma inside a dc non-transferred plasma torch is studied using Principle component analysis (PCA) of fast imaging data. The experiments are performed with indigenous plasma torch (TVG-25) for a wide range of gas flow rates (20 to 60 lpm) and currents (70 -120 A) in the presence of a strong axial external magnetic field (100 to 500 G) at atmospheric pressure with nitrogen as working gas [1]. Images are captured using high speed CMOS camera from end-on direction. It has been found that besides arc root rotation and fast re-striking phenomena, various structures are also developed inside the plumes for different experimental conditions. These internal structures are resolved by using Singular Value Decomposition (SVD) of the fast imaging data of arc plume at higher gas flow rates, currents and magnetic fields. The dynamics of different components of plasma plume is discussed and presented.

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PD13

Global Particle Balance and Wall Recycling Study for Aditya – U Tokamak

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Abstract- Global particle balance can determine the exchange of particle between the walls and plasma, this helps to measure how much fuel particle retained in the wall along with this it provides better understanding of plasma density and control. The global particle balance in plasma interacting with Plasma Facing Components (PFC) governed by parameters such as Recycling coefficient, R, the fueling efficiency, *f* and the global particle confinement time τ_p. The wall recycling depends not only the wall condition but also the particle flux out of the plasma. Particle flux out of the plasma may differ during normal fueling and gas puffing. The measurement and understanding of these parameters are essential for fusion plasmas to understand particle and impurity production and screening. In this paper we present the results obtained for Aditya – U tokamak for recycling coefficient measurement, particle confinement time and particle balance. The results are deduced with mainly with spectroscopic diagnostics and Langmuir probe measurements. Particle balance is studied with lithium wall conditioning, as the reduction in Hα emission is significantly reduces after Li coating, this affects the wall recycling [1].

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PD14

Estimation Of Neutral Temperature From H_α Emissions Under The Influence Of Magnetic Fields In Aditya-U Tokamak

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Abstract-Neutral particle temperature in tokamak plasma can be measured through the estimation of Doppler broadening of the spectral line. This measurement is important considering the neutral particle manipulate the plasma edge properties through its interaction with plasma particle. Under the influence of magnetic field in tokamak, the shapes of the spectral lines emitting from the plasma are significantly modified due to the Zeeman splitting, in which a single spectral line splits into multiple components. A single component is having a certain broadening corresponds to value of the neutral or ion temperature. However, when all components added up, the apparent broadening did not reflect the actual temperature of the emitting species. To minimize such effect while estimating the neutral temperature from H_α emission (656.28 nm), a MATLAB simulation code has been developed to incorporate the Zeeman Effect in the temperature measurement. In this code all 48 components of Zeeman splitted spectral lines are considered and neutral temperature was estimated. In this paper we are presenting the simulation of the experimental results measured for recent Aditya-U tokamak experiments and the estimated neutral temperature of the Aditya-U tokamak plasmas under different experimental scenarios.

PD15

Conceptual Design of A Tomographic System For Helicon Plasma Device

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Abstract-An optical emission tomography system has been developed to obtain the 2D radial emission profile of a permanent magnet based helicon plasma source system. The plasma system is a RF driven cylindrical plasma source operating at 13.56 MHz [1]. The technique is based on measurement of line integrated value of optical emission which is the intensity of line emission from a cross-sectional plane using an optical detection system. Inversion of the line integrated data gives the 2D distribution of emissivity over the plane. From this local emission profile, the distribution of the plasma parameters such as density, temperature can be calculated [2]. The detection system having a fan beam geometry primarily consists of a pinhole, a lens and a CCD based linear optical array detector. The light from the plasma after passing through the pinhole is collimated using a precision aspheric lens and allowed to fall on the CCD based sensor. Optical band pass filters for some specific wavelengths are also used to reduce optical noise. The filter module is designed to quickly exchange filters for a particular wavelength within the experimental setup. The whole assembly of these components constitutes a camera. 6 such cameras are proposed to scan the entire plasma system and the cameras are placed symmetrically around the periphery of the cylindrical plasma system. The optical signals are acquired from the camera using software application built in LabVIEW through USB interface with configurable scan and exposure time settings. A tomography algorithm based on maximum entropy concept has been developed to get the local emission profile.

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PD16

Toroidal Plasma Rotation and Impurity Ion Temperature Measurement on ADITYA-U Tokamak Using Visible Spectroscopy

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Abstract-In tokamak plasma, rotation plays an important role in improved plasma confinement and stability by suppressing the plasma turbulence and the magnetohydrodynamic mode (MHD) instability [1] . In many current tokamaks, high rotation velocities are achieved by external momentum supplied through the tangential injection of heating neutral beam (NBI). However, for ITER like future fusion devices, external momentum will not be sufficient to drive the large plasma volume [2]. In such a scenario, the intrinsic rotation observed in many tokamaks, may act as the solution of the aforesaid problem. Hence, the study of intrinsic rotation becomes significant for tokamak plasma. Doppler shift spectroscopy of spectral lines emitted in Visible and UV wavelength range is used to estimate intrinsic rotation velocity of light impurity ions present in a tokamak plasma. Impurity ion temperature is determined by measuring Doppler broadening of spectral line emission.

A high-resolution ultraviolet (UV) and visible spectroscopic diagnostic have been developed and implemented on Aditya-U[3-4] tokamak to measure the spatial profile of toroidal rotation velocity and temperature of impurity ions. Carbon ion is chosen because it remains the main intrinsic impurity in Aditya-U discharges due to the graphite limiters. For the measurement, Passive charge exchange (PCX) line of Carbon impurity was chosen giving emission at 529 nm. The measurements were performed using five lines of sights covering upto ~ 17 cm of plasma minor radius towards low field side. The diagnostic installed on ADITYA-U gives line integrated measurement; localized measurements are obtained by implementing matrix inversion techniques to calculate radial profiles of rotation velocity and ion temperature. In this presentation, initial results obtained will be discussed.

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PD17

Design and Development of a Microcontroller Based Data Acquisition System for Langmuir and Emissive Probes

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Abstract-A microcontroller based data acquisition system for Langmuir and Emissive probes has been designed and developed. ATmega-16 microcontroller has been used in this system. The drive circuit to apply bias voltage and signal conditioning circuits to measure voltage and current have been designed and developed. The system is capable of supplying probe voltage in the range of -80V to +80V and is also able to measure the corresponding change in current in mA range. The measured values are recorded in a PC. The system development includes design of hardware and development of software. Proper signal conditioning circuits for sensing current and voltage in the probe have been designed. Printed circuit board is designed in a CAD tool called DIP-trace and fabricated. Firmware of the microcontroller is developed in C-language in AVR Studio4. The GUI of the data acquisition system is developed in NI-Labview. The system is calibrated by standard resistors. Change in voltage and current of a Langmuir probe (diameter-0.25mm, length-10 mm) have been tested and recorded successfully by producing low-pressure filament discharge argon plasma in dusty plasma experimental setup. In this work, the test results have been presented.

PD18

Uniform Software for Data Acquisition Systems of All SST-1 Diagnostics

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Abstract-Data Acquisition system (DAS) is a very important part of any tokamak operation. Steady State Tokamak (SST-1) DAS has been operated successfully up to recent SST-1 experimental campaigns. PXI and PXIe based DAS cater around 200 no. of DAQ channels ranging from 10KSPS to 10MSPS for various SST-1 diagnostics. The SST-1 DAS are categorized in two groups (1) Slow DAS (sampling rate up to 100 KSPS) and (2) fast DAS (sampling rate from 100KSPS to 10MSPS). Previously, these two categories of DAS were operated with two different sets of software, developed in LabVIEW, one each for slow and fast DAS. For ease of operation & maintenance, it has been realized to make software uniform for both the DAS. At the same time the challenges were to keep their original communication protocol intact with other sub systems of

SST-1 and in particular with SST-1 Central control system to minimize human intervention for smooth and user friendly operation of DAS during SST-1 experiments. To fulfil this requirement LabVIEW based software was developed for slow DAQ channels keeping the software for Fast channels intact to achieve above said objective.This paper describes distribution of various diagnostic channels across all DAS systems i.e. slow and fast channels and its communication interface, the need to make software look and feel identical, software development process for slow channels DAS, its data archival and retrieval.

PD19

In-Situ Probing Of Gas Phase Nucleation Dynamics in Yttria-Argon Plasma System

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Abstract-Theoretical investigation of chemical kinetics in Argon plasma and experimental investigation of chemical kinetics in Ar, Yttria-Argon plasma are presented. Chemical kinetics of plasma species are presented in argon plasma under thermal non-equilibrium parameter (ϴ=Te/Th) ranging from 1 to 20, electron temperature ranging from 0 to 50000K and pressure ranging from 0.1 to 5 Atm. The data will be useful in understanding plasma synthesis processes over wide parametric range. Chemical kinetics behind synthesis of yttria nano-paricles in gas phase nucleation process is explored through in-situ emission spectroscopy and high speed camera. It was observed that as soon as precursor is fed to the plasma argon atomic lines disappears and YI, YII, O lines appear. YO band at the nozzle exit was not observed. It starts appearing after 3cm from the nozzle exit. With increase in distance, the band becomes stronger and stronger up to certain distance and then starts falling. The band is clearly visible up to 6 cm from the nozzle exit. Spectra clearly show one of synthesis mechanism of Y_2O_3 nano powder in a low pressure dc plasma torch system. Image and voltage analysis of the plasma jet show the effect of powder feeding on the plasma jet dynamics.

PD20

Design Of Sectorial E Plane Horn Antenna And Vacuum Window For X-Mode Reflectometry System For ADITYA-U Tokamak

Jagabandhu Kumar

PD21

Pumping Speed Requirements, Calculations and Experimental Observations for Modified Cxd-Npa System Integrated With Aditya-U

Ajay, Kumar

PD22

Observation of Argon Impurity Lines In ADITYA-U Tokamak Using Spectroscopic Diagnostic

Shah, Kajal

Space & Astrophysical Plasma (SA)

S-4-O-01

Propagation of Dust Ion Acoustic Solitary Wave in Weakly Relativistic Dusty Plasma with Non-thermal Ions

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Abstract-The Korteweg−deVries equation is derived to study the dynamics of dust ion acoustic solitary waves in weakly relativistic dusty plasma. The ions are assumed to be non-thermal and the electron species are weakly relativistic. The reductive perturbation method is applied to obtain the Korteweg−deVries equation considering the governing set of basic equation in dusty plasma system. The effect of the variation of nonthermal ion population and weakly relativistic effect of electrons on the properties of dust ion acoustic solitary waves is investigated. The soliton width and amplitude are also studied in weakly relativistic dusty plasma. The obtained result can be useful in the space plasma.

S-4-O-02

Neutrino Driven Instability of Ion-acoustic Waves in a Relativistic Degenerate Plasma

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Abstract-Intense neutrino beams are present in astrophysical plasmas and are considered responsible for various phenomena such as heating of Type II Supernovae. Hydrodynamic instabilities of various kinds have been recognized to occur in the supernova core and to be of potential importance for the supernova explosion, one of these instabilities is the neutrinos-driven streaming instability. Moreover, the confirmation of neutrino masses and flavor oscillations draw attention towards the incompleteness of the standard model and call for a new description of nature. The interaction of neutrinos with plasma may give rise to waves in plasmas, which perturb the plasma and may become unstable due to interaction with the streaming neutrino beam. Since the ion acoustic waves as well as neutrino flavor oscillations are both slow in character, the coupling between neutrinos and ion-acoustic waves is a very interesting phenomenon to investigate. Our aim is to study the neutrino beam driven instability of IAWs in the presence of relativistic degenerate electrons and relativistic neutrino beam exhibiting flavor oscillations. The generation of neutrino beam instability via the interaction of high energy neutrinos with the dense iron core at the last stage of stellar evolution in a supernova progenitor might give interesting insights into the physics of a supernova explosion. Recently reported investigations have illustrated the growth rate of linear plasma instabilities while considering the neutrino mass oscillation model linked to the neutrino-plasma coupling model in usual electron-ion plasma [1, 2]. However, the neutrino beam instability arising due to coupling of slow mode waves and neutrino flavor oscillations in self-gravitating plasma comprising inertial ions and relativistic degenerate electrons has not been scrutinized. Our aim is to remove this lacuna and investigate the plasma instabilities while taking into account the breakthrough discovery of neutrino flavor oscillations. The findings of present investigation may give interesting physical insights into the complex astrophysical phenomenon in dense plasmas of stellar, white dwarf, red giant, and supernova stars.

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S-3-O-03

Successive Stages of Magnetic Reconnection Associated With the Flux Rope Eruption in A Multiple-Ribbon Solar Eruptive Flare

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Abstract-In this work, we present multi–wavelength study of an M8.7 class solar flare that occurred on 2014 December 17 from active region NOAA AR 12242. SDO/AIA, SDO/HMI, GOES and RHESSI data are used to analyses this event. This event consists of three different set of flare ribbons; circular, parallel, and remote ribbons. The event can be expressed by the three phases i.e., pre–eruptive, breakout (or null point) reconnection and standard reconnection phases. Magnetic field analysis reveals the presence of fan–spine type magnetic configuration over the active region. We interpret this event in the following three stages of reconnection. First, the tether cutting reconnection forms the flux rope and allows its slow upward evolution from a bipolar region that exists inside the fan–dome. Second, the reconnection takes place at the magnetic null that results in the formation of the circular ribbon over the outer negative polarity region at the footpoints of the fan dome. Finally, the standard reconnection occurred underneath the erupting flux rope that results in the formation of parallel ribbons on both side of the inner s-shaped PIL inside the fan–dome. For the very first time, we report the formation of circular ribbon prior to the formation of parallel ribbons in such type of flare events, which provides a clear evidence that the breakout type magnetic reconnection at the magnetic null allows the eruption of the flux rope, and hence the standard reconnection in a typical fan-spine magnetic configuration.

S-4-O-04

Electromagnetic Ion Cyclotron Waves Observed By THEMIS Spacecraft in Magnetosphere

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Abstract-Electromagnetic Ion Cyclotron (EMIC) Waves play important role to study the dynamics of magnetosphere. It is generated by temperature anisotropy ($T_\perp > T_\parallel$) and seen at mainly dusk-side plasmapause (around $11^0 - 15^0$ MLAT). These waves are in the range of Pc1 and Pc2 (0.1-5 Hz). EMICs are generated with left handed polarization (LH wave) and propagate almost parallel to the background magnetic field. When they propagate out they make different wave normal angles and thus LH and RH waves couple. At a certain frequency called "cross-over frequency" change of polarization happens. Depending upon the background ion species like H^+, He^+, O^+, we see three bands in EMIC – Proton band (below proton gyro freq. Ω_H) , helium band (below Ω_{He}) and Oxygen band (below Ω_O).We have also analyzed THEMIS magnetic field data for three different events to produce dynamics spectra, where rising (frequency increases for a certain time period), falling and constant frequency bands in EMIC can be seen. The simultaneous rising and falling tone, which we named as 'Bifurcation' phenomena, are also seen. Change in some parameter can provide the anisotropy for this local bifurcation. Stable points become unstable at the bifurcation point and branches develop. Correlation between rising and falling part and also individually Minimum Variance Analysis (MVA) is studied. The ellipticity, polarization and the wave normal angles are obtained by using MVA. It is seen that a single cycles change polarizations from right to left and vice-versa. We have also analyzed the correlations between rising and falling tones and the individual rotated magnetic components which provide information about the scattering efficiency of EMIC waves.

SA1

Ion And Electron Beam Effect On Kinetic Alfven Waves In The Presence Of Kappa Distribution Function In Plasma Sheet Boundary Layer –Kinetic Approach

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Abstract-The kinetic 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, electron beam with kappa distribution function 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, electron beam, kappa distribution function, the ratio of thermal energy density to magnetic field energy densityb and the ratio of ion to electron thermal temperature (Ti/Te) 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.

SA2

Effect of Electron and Positron Trapping On Solitary Waves in Degenerate Dense Plasma In The Presence Of Landau Quantized Magnetic Field

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Abstract-The evolution of solitary wave in an ion beam driven degenerate plasma in the presence of trapped electron and positron with Landau quantized magnetic field is studied by deriving Korteweg-de-Vries (K-dV) equation. Different studies have shown that these trapped charged particles are inevitable in space plasmas which makes the plasma system highly non-linear [1]. Here we have adopted the standard reductive perturbation method is employed to obtain the K-dV equation. The solution of K-dV equation is examined analytically to study the salient characteristics of solitary waves in such plasmas. As like classical plasmas, we encounter three different modes namely, beam driven Fast and Slow modes along with inherent Ion Acoustic mode in such plasmas also. The Landau quantized magnetic field has a great impact in controlling the normalized phase velocity (Mach Number) in such plasmas [2]. Here, we have observed that the Mach Number of the solitons can range from supersonic to hypersonic and also, we have noticed that both type of solitons can co-exist under suitable conditions of quantized magnetic field, degenerate temperature and positron density. The amplitude, width of all the three wave modes are greatly influenced by degenerate parameters and positron density. Moreover, the dispersion of the wave also increases with positron density and decreases with magnetic quantization and ion beam density.

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SA3

Whistlers Observed during St. Patrick's Days Storm at Low Latitide Varanasi.

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Abstract-Whistlers have been used since many decades to study the key parameters of the magnetosphere and ionosphere [1]. To sense/monitor the characteristic parameters and structures of magnetospheric / ionospheric plasma, analysis of whistlers have been used on the basis of the dispersion features of received wave forms [2, 3]. Geomagnetic storm is the temporary disturbances in the Earth's magnetic field which affects the electrodynamics of ionosphere leading to huge fluctuation in ionospheric plasma finally affects the communication and navigation to a great extent and in worst case disturbs the human health and life. In this study, the characteristics of whistlers observed during St. Patrick's Day geomagnetic storm from 17-18 March 2015 have been analyzed and correlated with the causative lightning strikes using data provided by the WWLLN (World-Wide Lightning Location Network). We have computed the dispersions, L-value and the columnar ionospheric electron contents of the observed whistlers during the storm which varies between 12 $sec^{1/2}$ to 15 $sec^{1/2}$, 1.11 ± 0.1 to 1.78 ± 0.1 and 27.42×10^{12} to 50.42×10^{12} el cm^{-2} respectively.

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SA4

Nonlinear Nucleus-Acoustic Wave-Structures in Strongly Coupled Degenerate Dwarf Plasmas

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Abstract-We report on the evolutionary dynamics of nonlinear nucleus-acoustic wave patterns excitable in a strongly coupled self-gravitating degenerate quantum dwarf plasma (QDP). It is composed of strongly coupled non-degenerate heavy nuclei, weakly coupled degenerate light nuclei; and non-relativistic and ultra-relativistic degenerate lighter electrons [1-2]. A weakly nonlinear perturbation analysis is carried out to obtain a conjugated pair of extended Korteweg-de Vries (*e*-KdV) equations. The constructed numerical tapestry, which is framed on the fourth-order Runge-Kutta method [3], shows the collective excitations of a new conjugational pair of nonlinear eigen-mode structures in a new parametric space. The electrostatic potential fluctuations evolve as a distinct family of solitons-antisoliton chains. In contrast, the gravitational potential fluctuations propagate as a unique class of extended oscillatory solitions and dispersive oscillatory shocks. The microphysical influential dependencies of the eigen-structural patterns on various sensible plasma multi-parametric factors are illustratively analyzed in both the non-relativistic (NR) and ultra-relativistic (UR) limits in the electronic dynamics. The applicability of the investigated results to see various wave-kinetic phenomenological processes in the context of compact astro-objects is summarily outlined.

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SA5

Investigation of Rayleigh Taylor Instability and Internal Waves in Rotating Strongly Coupled Magnetized Quantum Plasma

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Abstract-We have investigated the internal waves and R-T Instabiltiy in incompressible, rotating plasma under the influence of quantum effect and magnetic field in strongly coupled plasma medium. In this case the problem is formulated by considering (QMHD) model in weakly coupled degenerate electrons and strongly coupled degenerate ions. The dispersion relation for Rayleigh Taylor Instability and internal waves in incompressible rotating magnetised plasma derived by linearizing the fliud equations. The internal wave can propagate along transverse direction. We solve the unstable RT modes numerically and graphs are plotted in which it is observed that the magnetic field and Quantum fraud number (quantum correction) stabilizes the system. The relevance of these results are useful to understand the suppression of R-T Instability in dense astrophysical system.

SA6

Solitary Kinetic Alfvén Waves in Dense Astrophysical Plasmas with Relativistic Degenerate Electrons and Positrons

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Abstract-Solitary kinetic Alfvén waves (KAWs) are investigated in low but finite β (particle-to-magnetic pressure ratio) collisionless dense plasma whose constituents are nondegenerate warm ions, and delativistic degenerate electrons and positrons. The reductive perturbation technique is applied to derive Kortweg-de Vries equation, which admits small amplitude localized wave solution of KAWs. It is shown that the relativistic degenerate electron-positron-ion (e-p-i) plasma system considered here supports the existence of sub-Alfvénic compressive solitary KAWs. The effects of plasma β, positron concentration, electron relativistic degeneracy parameter, ion thermal temperature and obliqueness parameter on solitary KAWs are studied. The results of this present theoretical investigation are aimed at elucidating characteristics of solitary KAWs in relativistic degenerate e-p-i plasmas found in dense astrophysical objects specifically neutron stars and white dwarfs.

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SA7

Plasma Waves in Unmagnetized Planets – Venus and Mars

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Abstract-Although Venus and Mars are the immediate near neighbours of Earth on its either side, theseplanets are not much studied in terms of plasma waves and a lot in this particular field is there yet to be explored. Out of 42 missions to Mars only 3 and only 4 out of 23 missions to Venus carry plasma wave detection instruments with them. One of the reasons for this could be that unlike Earth, Venus and Mars do not possess a global magnetic field. The absence of an intrinsic magnetic field in Venus is due to the lack of dynamo which is responsible for a strong global magnetic field due to the motion of an electrically conducting and convecting fluid inside the planet. It is believed that Mars had an intrinsic magnetic field is the past but the dynamo stops due to various factors. Despite this, a number of plasma waves are observed in the ionospheres of Venus and Mars [1, 2]. Due to the absence of a global magnetic field in Venus and Mars, the solar wind penetrates deep inside the ionosphere of these two planets giving rise to plasma phenomena which are not observed in any of the other planets with magnetospheres [3]. The plasma waves observed in the ionosphere of Venus and Mars are believed to play an important role in the dynamics of the magnetosphere by controlling the scattering and loss of energetic charged particles. In other cases plasma waves provide an important diagnostic tool by revealing various characteristic frequencies of the plasma, from which quantities such as the electron density can be computed. Due to the limitation of the measuring instruments and the detached missions from one another, all the possible plasma waves that can exist in the ionosphere of these two planets could not be detected. In this paper, the plasma waves observed so far in the two unmagnetized planets - Venus and Mars and the plasma waves that could be present in these two planets but are yet to be observed with possible plasma wave detection instrumentation to achieve this, are discussed.

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SA8

Study of Whistlers in Saturn Magnetosphere in the Presence of Parallel A.C. Electric Field

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Abstract-The electromagnetic whistler waves generated by lightning was observed in the magnetosphere of Saturn through the Cassini Radio and Plasma Wave Science Survey (RPWS). On July 1, 2004, two whistlers were observed as the spacecraft flew over the rings, and the third was observed at a radial distance of 6.19 RS (the radius of Saturn) as it entered the orbit on October 28, 2004. In present work we have investigated those whistlers waves which are pertaining in background plasma propagating in the direction of the magnetic field of Saturn. We use non-uniform, anisotropic, multi-component plasma waves to study linear growth. Using the kinetic approach method, the expressions of dispersion relation and growth rate are derived. A model of magnetic field strength has been used for different latitudes at a radial distance of 8 R_s (1 R_s= 60,268 km). Various parameters affecting the growth of whistler waves with relativistic effect in bi-Maxwellian background has been studied. Parametric analysis inferred that growth rate of whistler waves increases with increasing value of temperature anisotropy and AC frequency, but the growth rate remains same as the angle of propagation with respect to B_o (Magnetic field at equator) increases. We find that temperature anisotropy ($T\perp/T\parallel \sim 1.5$) can account for linear temporal growth rate of whistler mode waves, which provides a majority of the observed frequency-integrated power. Higher frequency chorus emissions differ from lower frequency

whistler mode emissions and are sometimes associated with simultaneously observed low frequency electromagnetic ion cyclotron waves. These electromagnetic ion cyclotrons appear to modulate a slow frequency drift (~15 Hz / s), which develops into a nonlinear growth with much greater frequency drift, only related to high frequency chorus.

SA9

Study of Relativistic VLF Wave for Subtracted bi-Maxwellian Distribution Function for Saturn

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Abstract-We have been studied cold electron beam effect for Whistler mode waves, electromagnetic waves of very low frequency which are produced by lightning strikes, for the relativistic case of subtracted bi-Maxwellian distribution in the presence of perpendicular AC electric field to magnetic field by using the method of kinetic approach to ensure efficiency, consistency etc., The complete derivation and estimations has been done for determining the dispersion relation and variation in growth rate by varying plasma parameters: ac frequency, temperature anisotropy, width and amplitude of loss-cone distribution function, etc., for Saturn magnetosphere at the radial distance $18R_s$. To examine the AC frequency effect on the Doppler shifting frequency (i.e., change in frequency or wavelength of a wave with respect to observer) and relative study are analyzed by doing variation in relativistic dimensionless Growth Rate in relation to $\tilde{k}$ for different values of density ratio n_c/n_w at all remaining plasma parameters being fixed. The obtaining results, found by using subtracted bi-Maxwellian distribution function, noticed that the effective parameters are not depend only on the temperature anisotropy but also on the relativistic factor, AC frequency, density ratio and width of the loss-cone distribution function which would discuss further in results and discussion unit.

SA10

Nonlinear Oscillations in A MRI Induced Turbulent Protoplanetary Disks

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Abstract-An analysis of nonlinear oscillation in a turbulent protolanetary disks is presented in this work. We consider a weakly ionized gas with a considerable presence of neutrals so that plasma particles collide frequently with the neutrals so that the collision can effectively cause a thermal equilibration in the plasma. However, if there is an applied electric field, a part of the gained kinetic energy is converted to random collision energy which heats the plasma. This random energy of the electrons greatly exceeds that of the neutrals when the electric field is above a certain threshold [1, 2]. Such a plasma is characterized by what is known as Druyvesteyn distribution with a break-away electron polulation. This situation is realizable in protoplanetary disks where the applied electric field can be produced through MRI turbulence, as in protoplanetary disks, the MRI can be self-sustained. Our work presents some preliminary results of nonlinear oscillations in such a system.

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SA11

Self-Gravito-Acoustic Solitons and Rogue Waves in Self-Gravitating Degenerate Quantum Plasma

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Abstract-The self-gravitating degenerate quantum plasma systems (SG-DQPSs) are completely different from other space and laboratory plasma systems not only because of their extraordinarily high density [1] (in astrophysical SG-DQPSs, e.g., white dwarfs and neutron stars [2]) and laboratory viz., solid density plasmas and laser produced plasmas formed from solid targets irradiating by intense laser [3], but also because of associated new kind of waves and nonlinear structures [4] (e.g., solitary waves, shock structures, and double layers). A general realistic self-gravitating degenerate quantum plasma system (SG-DQPS) containing inertialess degenerate electron species, inertial degenerate light and heavy nucleus species is considered to study the existence of degenerate pressure driven self-gravito-acoustic (DPD-SGA) solitons in such a SG-DQPS. Reductive perturbation method is employed to study the small amplitude DPD-SGA Solitons [4]. The basic features (polarity, amplitude, and width) of DPD-SGA solitons are found to be significantly modified by the dynamics of heavy nucleus species. Further, the generation of DPD-SGA rogue waves (RWs) has been studied in the framework of rational solution of nonlinear Schrodinger equation. The dependence of the rogue wave profile on the relevant physical parameters has been discussed in detail. The theoretical investigation presented here is so general that it can be applied not only in astrophysical SG-DQPSs (such as white dwarf and neutron star SG-DQPSs), but also in laboratory SG-DQPSs (viz., solid density and laser produced SG-DQPSs) to identify the salient features of the DPD-SGA SWs formed in those environments.

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SA12

Evolution of Solar Magnetic Fields and Large-Scale Reconnection Events in Extremely Complex Solar Active Region NOAA 12673

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Abstract-Solar active region NOAA 12673, appeared from 28 August 2017 to 10 September 2017, produced the largest flare of solar cycle 23 of class X9.3 on 6 September. Surprisingly, this enormously complex and dynamic active region emerged during the minimum phase of the solar cycle. In this work, we explore the magnetic field evolution in NOAA 12673 which produced 4 X-class and 27 M-class flares besides several smaller C-class events. The AR first appeared in the eastern limb of the Sun on 28 August, gradually evolved into a complex network of 'δ-spots' on September 6 and remained so until its disappearance on the western limb. During the peak flaring phase, this unusually north-south oriented active region contained excessively high non-potential energy which fuelled toward its frequent large-flare producing capability. We particularly focus on the triggering and dynamical evolution of an interesting event in which a small fluxrope structure from the northern region of the AR partially erupted in association with two very impulsive M-class flares on 7 September. The ejecting plasma, at first, was collimated and then, strikingly, changed its motion to almost

opposite direction to constitute a coronal mass ejection (CME) with medium speed and angular width. Non-linear-force-free-field (NLFFF) extrapolation clearly indicates the presence of another, larger fluxrope in the active region which remained quiet during the activity whereas the small fluxrope erupted partially. Our analysis suggests that the ejected material from the erupting fluxrope proceeded through a narrow passage of high magnetic decay index which explains its abnormal dynamics. We further present a detailed comparison of the magnetic configuration of AR between 6 and 7 September to explore the circumstances that gave rise to the largest flare (X9.3 flare on 6 September) of the solar cycle 24.

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SA13

Oblique Electromagnetic Waves for Ring Distribution with Parallel A.C. Field in Saturnian Magnetosphere

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Abstract-During the Inbound pass on October 28, 2004, the Radio and Plasma Wave Science (RPWS) instrument on the Cassini spacecraft detected a whistler at a radial distance of 6.18 RS (Saturn radius). The dispersion relation of the obliquely propagating electromagnetic whistler mode wave has been applied to the magnetosphere of Saturn and compared with the observations of Voyager and Cassini. The effects of electron density, temperature anisotropy, A.C frequency and energy on the growth rate of whistler mode emission were investigated. The observation is in very good agreement with the results. The dispersion relation of the whistler mode wave in the Saturnian magnetosphere in the extended magnetic field is derived by using the linear property of the ring distribution function. Analysis shows that an increase in temperature anisotropy, number density, and energy density increases the rate of increase in whistler waves with significant changes in wave numbers. It has been shown that whistler mode waves have increased due to the loss of vertical kinetic energy of the ring electrons. In Saturn's magnetosphere, calculations were made at a radial distance of 6.18 RS. This result is important for the analysis of VLF emissions observed over a broad spectrum of frequencies in the Saturn magnetosphere. The analytical models developed can also be used to study various instabilities in the planetary magnetosphere.

SA14

Effect of Solar Flares on Ionospheric Tec, During Descending Phase of Solar Cycle 24

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Abstract-In this paper, we have analyzed the dual frequency signals from GPS satellites recorded at Varanasi (Geographic latitude 25^0, 16′ N, longitude 82^0, 59′ E) near the equatorial ionization anomaly (EIA) crest region in India, to study the effect of intense solar flares on the variation of TEC, during the years 2015-2017. There are 195 intense storms (M and X class) occurred during this period. The TEC variations during some selected solar flares have been analyzed which were observed during March 9-13, 2015, August 6-8, 2016, July 8-10, 2017, and September 6-8, 2017. The flares induced features in the vertical TEC (VTEC) have been

studied considering the monthly mean VTEC value of quiet days as reference level. It is observed that the solar flare have increased the value of VTEC over Varanasi. Generally it is believed that the sudden increase of VTEC due to impinging solar flares causes various types of structures in the ionosphere, like plasma patches and plasma bubbles.

SA15

Study of Dust Kinetic Alfvén Cnoidal Waves in Nonextensive Plasmas

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Abstract-Alfvén waves are the electromagnetic waves. The restoring force in kinetic Alfvén waves is provided by magnetic tension and inertia is provided by ion mass. Dust is an ubiquitous component in astrophysical and space environments such as planetary rings, cometary tails, interstellar clouds, and earth's mesosphere and ionosphere [1]. The presence of charged dust particles generates new types of eigen modes such as dust acoustic (DA), dust ion-acoustic (DIA), and dust lattice (DL) modes . In the presence of an external magnetic field, dust grains can respond to the perturbations on long time and space scales, and this response to perturbations can generate the dust kinetic Alfvén waves via polarization drifts of dust fluid [2]. The present work focuses on the study of dust kinetic Alfvén cnoidal waves (DKACWs), which has their major applications in transporting and dissipating energy in various space and astrophysical plasma environments [3]. A theoretical investigation is carried out to study dust kinetic Alfvén cnoidal waves containing two temperature superthermal electrons in nonextensive plasma. The nonlinear Korteweg-de Vries (KdV) equation is derived by using the reductive perturbation (RPT) technique. Further, the solution of KdV equation is numerically analyzed to study cnoidal waves. The variation of different plasma parameters has been analyzed on the characteristics of DKACWs. The findings of this research work may have important applications in Saturn's magnetosphere where two temperature superthermal electrons are present.

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SA16

Finite Temperature and Magnetic Shear Induced Stabilization of Multiple Instabilities in Convective Fluid Plasma Transport Scenario.

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Abstract-Simultaneous existence of multiple instabilities has been reported in various linear plasma devices [1-2], toroidal devices [3] as well as in space plasma systems [4-5]. The interplay between these participating modes and the associated wave particle interactions are significantly influenced by dominant drivers as well as

free energy sources/sinks for a given plasma system. The relative suppression mechanism and hierarchy of these instabilities needs to be critically investigated with respect to plasma confinement scenario. In context with it, the collective influence of finite temperature and sheared magnetic field is studied analytically for the EXB (and/or gravitational) and the current convective instabilities (CCI) to visualize local and global fluid flow patterns in slab geometry configuration. Further, global mix-mode potential eigen-mode structure suggests mode localization off the rational surface due to equilibrium parallel dynamics. It turns out that the magnetic shear induced stabilization is more effective at the larger scale sizes whereas finite temperature induced stabilization is more dominant at the smaller scale sizes.

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SA17

Effects of Solar High Energy Protons on Ozone Layer During Super Storms

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Abstract- We are very much known to the importance of ozone without which life on the Earth would not have evolved in the way it has. Strong solar storms carried energetic protons into the Earth's upper atmosphere, where they boosted production of nitrogen oxides which are known as ozone killers. In the present study, we have estimated the effects of solar energetic protons over the total ozone column since last 30 years. To that end, we have selected total seven solar storm events having Dst index < -300 nT and occurred during solar cycle 22^{nd}, 23^{rd} and 24^{th} (for 32 years). We have statistically analyzed the significance of the solar proton events on the quantitative variation of total ozone column during super storm events. Further, we have applied the superposed epoch analysis to verify the impact of storm events on solar protons and ultimately on total ozone content. During our analysis, we have established that the ozone column gets depleted significantly (15 - 20%) as proton density increased with the result of solar storm.

SA18

The Role of Hall-MHD in Magnetic Reconnection on the Sun

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Abstract-Magnetic reconnection is widely believed to be the most important process by which magnetic fields transfer energy to plasmas and, consequently, has been invoked as the explanation for a multitude of phenomena observed in space, astrophysical, and laboratory plasmas. Solar flares and CMEs dissipate the magnetic energy rapidly via magnetic reconnection on the Sun. In order to release magnetic energy via solar flare or CME, one needs to generate small length-scales in sheets or filaments, as the time scale for magnetic

dissipation is 1014 s for the parameters global solar coronal length-scale (L=107 m) and coronal temperature (T=106 °K), while the flares happen on typical time scale of few minutes. At such small scales, the standard MHD is not valid and one may have to include other terms of the generalized Ohm's law. The Hall term comes into play in generalised Ohm's law when the thickness Δ of the Sweet -Parker current sheet becomes smaller than the ion skin depth, i.e., when $d_e < \Delta < d_i$. Hall term may lead to increment in the reconnection rate from Sweet-Parker like (slow reconnection) to Petschek like (fast reconnection). We plan to do simulations to capture the change in reconnection rate by including Hall term and its effect on the large scale reconnections which are responsible for flares and CMEs.

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SA19

Dust Scattering Cross Section in Presence of Magnetic Field

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Abstract-The formation of star and planetary system takes place in interstellar clouds such as nebulas contains region of high temperature [1, 2]. The plasma in this region is normally characterized by dust particles of varied sizes. Particles of 10 nm to 100 µm size distributions are levitated in presence of plasma in a particular condition behave as dusty plasma. To know the behaviour of these charged dust grains in laboratory scale is a challenge and open a new way to study the basics of plasma interaction [3]. In this work a typical laboratory scale dusty plasma setup is modelled using COMSOL multi-physics. Dust particles of uniform size distributions of the order of 10 µm have been considered in this condition. Scattering radius and corresponding scattering cross section area has been estimated from simulated data and numerically calculated value. Conditions like charge of dust particles, applied discharge voltage to produce plasma, collision cross section and external magnetic field have been incorporated to understand the scattering of charged dust particles.

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SA20

Nonlinear Dust Ion Acoustic Waves In Two-Fluid Quantum Dusty Plasma

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Abstract-Micron sized dust particles are present in most of the space and astrophysical plasma environments as well as in laboratory plasmas. These particles get charged and form dusty plasma. The presence of charged dust particulates in plasma influences the nonlinear properties of waves propagating in that plasma medium and give rise to different kinds of wave modes, dust-ion acoustic mode (DIA) is one of such modes. DIA waves can propagate in cosmic plasma environments, in the dusty plasma of Earth's mesosphere and contribute to the low–frequency noise in the F-ring of Saturn. The quantum effects in plasmas become important, when de Broglie wavelength associated with the particles is comparable to the dimensions of the

system. The study of quantum plasma is important due to its applications in solid state physics, microelectronics, quantum dots and quantum wires, ultra cold plasmas and in dense astrophysical environments such as those occurring in the interior of giant planets or dwarf and neutron stars. In present investigation, the nonlinear propagation of dust ion-acoustic waves (DIAWs) is analyzed in quantum plasma whose constituents are electrons, positive ions and negatively charged dust grains. The ions and dust grains are assumed to be mobile, while the electrons are considered to be inertialess. The Quantum hydrodynamic (QHD) model is considered for describing the linear and nonlinear properties of charged quantum particles. We use QHD model to investigate dust-ion acoustic nonlinear waves in two-fluid quantum dusty plasma. The reductive perturbation technique is used to derive the Korteweg–de Vries–Burger (KdVB) equation for DIAWs whose solution has the form of solitary and shock structures. The effect of variation of different physical parameters on the characteristics of DIA solitary and shock structures is analyzed. The results of present investigation shall be useful in the understanding of fundamental plasma phenomenon in a dusty plasma environment containing inertialess quantum electrons, inertial ions and dust particulates.

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SA21

Ultra-Low Frequency Waves by Ion Beam and Velocity Shear

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Abstract-A plasma model for the excitation of the Kinetic Alfvén Waves (KAWs) by the ion beam and velocity shear will be discussed. A three component plasma model consisting of cold background ions, hot electrons and hot ion beams will be presented. The model is very general in the sense that all the three species have drifting Maxwellian distribution, non-uniform streaming and velocity shear and can be applied to magnetospheric regions where velocity shear is present. The effect of plasma parameters such as species temperature, number density, angle of propagation etc. on the growth of the waves is discussed. It is found that the ion beam alone can excite these KAWs. However, in the presence of ion beam along the ambient magnetic field and negative velocity shear or antiparallel ion beam and positive shear, the wave growth is much larger as compared to ion beam case alone. The present model is applied to auroral region of Earth's magnetosphere and it can explain several characteristic properties of the observed ultra low frequency waves.

SA22

Evolution of Nonlinear Electrostatic Waves in the Auroral Acceleration Region

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Abstract-Evolution of nonlinear electrostatic oscillations in a two-component magnetized plasma comprising of cold ions and suprathermal electrons following κ-distribution has been analyzed. The nonlinear electrostatic waves are considered to be propagating at an oblique direction to the ambient magnetic field. A parametric study of the effect of initial driving electric field amplitude, wave Mach number, propagation angle, streaming velocity and κ-index on the evolution of nonlinear waves is carried out. The effect of these parameters on the frequency and the nature of electric field structures (sinusoidal, sawtooth or spiky) is also analyzed. The results from the model are compared with the satellite observations of spiky waveforms in the parallel electric field in the auroral acceleration region.

SA23

Asymmetry of Sunspot Area and their Periodicity during Solar Cycles 22-24

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Abstract-In this paper, we have analyzed the north-south asymmetry of sunspot area on the monthly basis during solar cycles 22, 23 and 24. Asymmetry of sunspot area is dominant in the southern hemisphere over northern hemisphere for the period 2006 (A =-0.85), as well as northern hemisphere over southern hemisphere for the period 2011 (A=0.50). Asymmetry of sunspot area for ~06 months running smoothed has minimum over the period 2006 and oscillatory motion have been found over the interval 1994 to 1998. The ~6 months smoothed (running) variation of the southern hemisphere of sunspot area show, the spline curve for the period 1993 to 1998 and 2003 to 2008. The northern hemisphere is dominated at the very beginning of the solar cycle while the southern hemisphere dominates in the decline phase of the solar cycle 22 to 24. The statistically significant mid-term periodicity between 5.5 years to 120 days of the north-south asymmetry of sunspot area has been investigated using Fast Fourier Transform (FFT) and Morlet Wavelet Transformation (WT). Quasi-biennial oscillation for asymmetry of sunspot area has been seen plateau type for the period 1990 to 1994 and 2014 to 2016.

SA24

Generation of three dimensional magnetic nulls in large Reynolds number plasma

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Abstract-Recent numerical simulations highlight the role of three dimensional (3D) magnetic nulls in initiating solar flares. The flares are important because of their impact on the near earth space weather. A 3D null initiated flare does not follow the standard flare model and it is imperative to explore the underlying physics. Importantly, generation of 3D nulls in naturally existing plasmas, such as the solar corona, is counterintuitive and requires comprehensive research. The focus of the work is to explore the generation of 3D nulls by numerical means. For the purpose, numerical simulations are designed by exploiting the loss of magnetic topology conservation in dissipative magnetohydrodynamic evolution. Specifically, two sets of initial value problems (IVPs) are attempted. The first one utilizes chaotic flow to deform a current-free 3D null and creates a topologically different state by allowing magnetic reconnection. For the second set, the deformation is achieved by perturbing the 3D null with a solenoidal field having---once again---chaotic field lines. Subsequently the plasma is relaxed by allowing energy loss via viscous dissipation and magnetic reconnection. Interestingly, both IVPs generate 3D nulls at the quasi-steady terminal states. The generated 3D nulls are current carrying and hence, are different from the initial nulls which were current-free---signifying the possibility that such nulls are dissipative relaxed states and can ubiquitously be present in the coronal plasma.

SA25

Effect of Polarization Force on Dust Acoustic Kinetic Alfven Waves In The Presence Of Trapped Ions

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Abstract-Most of the space and astrophysical environments have witnessed the presence of dust and have a wide ranging applications in the different fields as well as in the study of astrophysical and space environments. The different observations have revealed the presence of superthermal particles in different kinds of space and astrophysical environments of plasmas. The deformation in the Debye sheath formed by ions around the negatively charged dust grains is termed as polarization force, which is an important frontline area of research in dusty plasma from last few decades. The polarization force is eloquently modified due to the presence of superthermally trapped ions and thus produces the drastic changes in wave dynamics. Kinetic Alfven waves arise when the perpendicular wavelength of ordinary Alfven wave is comparable to the ion Larmor radius. Kinetic Alfven waves play an important role in transporting energy in various space and astrophysical plasma environments, coronal plasma heating, plasma transport in magnetopause as well as in heating Tokamak plasmas, thus heating the plasma to fusion temperatures. Thus, it is imperative to study the dynamics of kinetic Alfven waves in order to understand various energy transport mechanisms in plasmas. The trapping of the particles was shown to be important while investigating the nonlinear characteristics of waves. In the present work, we have discussed the effects of vortex-like distribution of ions on obliquely propagating dust acoustic kinetic Alfven waves in a low β plasma. Using the two potential theory and employing the Sagdeev potential approach, we have investigated the existence of arbitrary amplitude coupled dust acoustic kinetic Alfvenic solitary waves in the frame work of trapped ions distribution. The present investigation may be beneficial in understanding the propagation of nonlinear coherent structures in different space and astrophysical environments where trapped populations of ions have been observed.

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SA26

Characteristics of Equatorial Plasma Bubbles over Indian Region During 2017

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Abstract-Equatorial Plasma Bubbles (EPBs) are ionospheric electron density depletions near the Earth's geomagnetic equator which causes the disruptions in the radio signal, communication and navigation system. In this paper, we have analyzed ground based GPS data during quiet and disturbed geomagnetic condition to study the plasma bubble characteristics which is further confirmed with satellite based observation from C/NOFS (Communications/Navigation Outage Forecasting System). The effect of geomagnetic storm on generation of plasma bubble is also discussed. The characteristics of plasma bubble generated during geomagnetic storms have been compared to that generated during geomagnetic quiet condition. The results of the studied are discussed in accordance with other reported results.

SA27

Parametric instability in strongly coupled degenerate plasma

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Abstract-Parametric instability in strongly coupled degenerate plasma is examined. In this study, the electrons are degenerate and weakly correlated, while non-degenerate ions are strongly correlated. The

dynamics of weakly coupled degenerate electron fluid is governed by quantum hydrodynamics. The quantum forces associated with the quantum diffraction effects and the quantum statistical effects act on the degenerate electron fluid. The strong correlation effects of ion are embedded in generalized viscoelastic momentum equation including the viscoelasticity and shear viscosities of ion fluid. It is shown that strong correlation/coupling effects enhance the growth rate of instabilities, while the quantum effects suppress the instabilities. The results are analyzed for understanding the instability in dense white dwarfs which consist of degenerate electrons and strongly coupled ions.

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SA28

Flux Rope Eruption from δ-Sunspot Region of NOAA 12673 That Produced the Largest Flare of Solar Cycle 24

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Abstract-We present multi-wavelength and multi-point observations of a major X9.3 flare, halo coronal mass ejection, and geomagnetic storm driven by the flux rope eruption from solar active region NOAA 12673 on 2017 September 6. This major flare was recorded as the largest flare of the solar cycle 24 by the GOES satellite. Initial signatures of eruption from solar source region are confirmed by the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory. Observations in hot 94 Å channel reveal the CME to be originated from a coronal sigmoid. The photospheric magnetic configuration displayed a complex network of δ-sunspots with a sharp gradient in magnetic field along the polarity inversion line (PIL). Model coronal magnetic field in the pre-flare phase clearly indicates the presence of a flux rope structure along the PIL which erupted during the impulsive phase of the X-class flare. CME observations within the range of 2 $R_\odot$ to 30 $R_\odot$ (where $R_\odot$ denotes the solar radius) taken by the LASCO coronagraph show its linear speed and acceleration to be 1569 km/s and -0.3 m/s^2 respectively. Dynamic radio spectrum obtained from e-CALLISTO reveals metric type II radio emission which implies the formation and propagation of CME driven shock in the height range of 1.24-2.09 $R_\odot$ with a speed of 928 km/s. The analysis of near-Earth *in situ* measurements indicate the arrival of the CME associated interplanetary shock and magnetic cloud on September 7 at 23:00 UT and September 8 at 12:00 UT, respectively. This CME finally caused a major geo-magnetic storm of Dst ≈ -150 nT. The synthesis of multi-wavelength observations along with magnetic field modeling reveal that the breakout reconnection at relatively lower coronal heights triggered the coronal mass ejection at the solar source region.

SA29

Nonlinear Propagation of Dispersive Alfven Wave in the Presence of Magnetic Islands and Its Role in the Solar Wind Turbulence

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Abstract-We present the numerical simulation of spatio-temporally evolving circularly polarized dispersive Alfven wave interacting nonlinearly with parallel propagating ion acoustic wave in the solar wind at 1AU in the vicinity of magnetic islands. Since a long time, it is alleged that the linear and nonlinear dynamics of Alfvén waves are responsible for some of the key qualitative features of plasma turbulence that distinguish it from hydrodynamic turbulence, including the cascade of energy and the development of current sheets at small scales.[1] In addition, the occurrence of magnetic reconnection in turbulent plasmas and its interplay with a fully-developed turbulent state and vice-versa is another matter of great debate. Recently, Voros[2] et. al (2014) have demonstrated using Wind data that reconnection outflow may generate turbulence in solar wind plasmas. Besides, the turbulence may also be driven by the nonlinear coupling between the counterpropagating waves (i.e., Alfven wave or ion acoustic wave etc), or Hall effect or coherent structures formations that causes cascading of kinetic and magnetic energy to small scales where they are eventually dissipated, adding heat to the plasma.[3] This article reviews the turbulent behavior of solar wind at small scales as a result of the wave coupling with magnetic islands at reconnection sites. We propose that dispersive Alfven waves (DAW) may interact nonlinearly with these magnetic islands at the reconnection sites leading to the development of coherent structures and current sheets. The ultimate goal of the present study of space plasma turbulence is to develop a predictive model with detailed understanding of the physics of the nonlinear energy transfer, the damping of the turbulent fluctuations and the resulting heating of the plasma species, for example the heating of the solar corona.[3] A two-fluid model is used to formulate the dynamical equations of the concerned wave. Numerical simulation is performed to study the evolution of coherent structures or current sheets in the spatial domain. We see that both the mechanisms i.e., reconnection and instabilities support the formation of coherent or localized structures. Power spectral density is obtained to study the fluctuations at small scales. The consistency of these results with the observational[2,4] findings is also discussed.

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SA30

Propagation Characteristics of Waves in Neutrino Magneto-hydrodynamics

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Abstract-Neutrinos interact only weakly with ordinary matter. However, in certain astrophysical

context, such as supernova explosion, the coupled interaction between neutrino and dense, highly ionized plasma contribute significantly to a system's evolution. Neutrino Magnetohydrodynamics (NMHD) has been recently formulated to model such systems. In this approach magnetohydrodynamics (MHD), which treats a plasma's electron and ions as fluid and considers the dynamics of the magnetic field they produce is extended to include weak interaction; which in particle physics describes the coupling between neutrinos and electron. Normal modes analysis is carried out to derive a dispersion relation of waves in such a system. Inclusion of neutrinos and their subsequent interactions with the MHD fluid can prevent flux freezing in such a system, which hitherto has been characteristic feature of all astrophysical plasmas. In the present paper, Friedrich's diagram of the NMHD waves, which are polar plots depicting the variation of phase speeds and group speeds of waves with the direction of propagation (with respect to the direction of the ambient field) are drawn. Using these diagrams, the propagation characteristics of NMHD waves are discerned vis-a-visthe MHD waves in astrophysical plasmas. Incidence of instabilities of NMHD are also pointed out.

SA31

Instability of Gyrogravitating Star-Forming Fluids in Dynamic Environs

HALOI, Archana

SA32

Electron Acoustic and Lower Hybrid Dromions in the Context of Auroral Plasma

Prof. GHOSH, Suktisama

SA33

On the Nature of Extreme Ultraviolet (EUV) Waves

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Abstract - Extreme Ultraviolet (EUV) waves was first discovered by EUV Imaging Telescope (EIT) onboard SOHO satellite. After more than two decades of the discovery of EUV waves, their nature is still controversial. Different models proposed to explain their physical nature, which mainly includes wave, non-wave, and hybrid models. We will discuss here the different features of EUV waves namely fast-mode components, slow-mode components, stationary fronts, their mode conversions. For this purpose, we used the high spatial and temporal resolution data of Atmospheric Imaging Assembly (AIA) onboard Solar Dynamics Observatory (SDO) satellite

Pulsed Power (PU)

S-6-O-4

Coil Optimization to Maximize Projectile Velocity for a Simple Capacitor Bank Parameters

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Abstract- The electromagnetic (EM) coilguns due to their high efficiency, high projectile velocity and long barrel lifetime are of interests in high speed applications [1, 2, 3]. One of the potential applications of EM coilgun is in the long-range guns [4]. Such systems also permit multistage acceleration [5]. The EM coilgun involves a large number of design parameters (e.g. coil length, coil diameter, coil pitch, projectile starting location etc.) which affects the final projectile velocity and hence the coilgun efficiency. One way to obtain the optimum design parameters is to perform a set of experiments but the experiments are time consuming and costly. Hence to cut down the time/cost of the experiments, computer modeling is required for the design and optimization of the experiments. This paper presents the optimization of coil parameters for a simple capacitor bank parameters to achieve maximum projectile velocity.

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PU1

High Intense Pulse Evolution Effect on Critical Temperature of Plasma Generation during Interaction with Photonic Crystals

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Abstract-The present investigation is mainly concentrated on the consequence of ultra-short high intense femtosecond pulse evolution to generate critical temperature of plasma during interaction with photonic crystals. When a high intense ultra-short electromagnetic wave interact with the periodically structured photonic crystals possessing second order susceptibility, the electromagnetic wave impart oscillatory velocities to electrons that generate the temperature for the generation of plasma. The pulse parameters evolution such as normalized energy of the pulse ($E0$), pulse width (T), position of the pulse center ( ) and reflectivity coefficient of the medium (R) is investigated theoretically on plasma generation. The outcome of the theoretically investigated reveals that the increment in the heating rate can be caused by decrease in the pulse width, increment in reflectivity coefficient and the pulse peak power. This work can be helpful into control the critical temperature of the device to generating plasma.

PU2

Plasma Stream Parameter Measurement in Pulsed Plasma Accelerator Using Optical Emission Spectroscopy

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Abstract - A pulsed plasma accelerator, which is driven by a 200kJ pulsed power system, has been developed and installed successfully at CPP-IPR. The device has been operational to produce high velocity (≈ few km/s) plasma stream. The plasma stream is being characterized by using different diagnostics such as triple Langmuir probe for density and temperature, double plate probe for stream velocity and calorimeter for heat flux. The measurement of high density and high velocity plasma stream is useful for studying plasma matter interaction(PMI) relevant to tokamak as well as other applications. In this experiment, Optical Emission Spectroscopy (OES) of plasma stream has been carried out to observe the spectra of different operating gases. For this study, a portable spectrometer was employed, which is responsive to the wavelength range of 350-820 nm with optical resolution of around 0.1 nm. The analyses of the spectra provide the information of different spectral lines, which help to estimate the different plasma parameters. The experiment was carried out with Ar and N_2 as operating gases. Initial analysis of Ar and N_2 plasma stream spectra show spectral lines of unionized atoms, singly and some doubly ionized atoms. Besides, a few impurity lines are also observed in the spectra. Further analysis of the spectra is continuing to estimate different plasma parameters viz. density and temperature of the plasma stream. The velocity of the plasma stream will be estimated by analyzing the spectra for Doppler shift of the spectral lines. The detail analysis of plasma stream parameters with respect to discharge voltage and operating pressure condition will be reported in this presentation. Additionally, a comparative result of different plasma parameters with previously measured electrostatic probes will also be presented.

PU3

2D Transient Magnetic Field Analyses of Linear Induction Motor

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Abstract - A linear induction motor (LIM) has been identified as a key element for electromagnetic launching technology. The stator part of the motor when energized induces a linearly moving magnetic field which consequently produces a thrust force on the rotor part of the motor. Thus it accelerates a projectile to a required velocity in a controllable manner as per the application criteria. Recently a lab scale experiment employing a LIM is carried out in Magnetics and Dynamics section to check the performance of it as launcher. The LIM was earlier being used as electromagnetic stirrer for liquid Pb-Li preparation and was supplied by Institute of Physics of University of Latvia (IPUL). A two –dimensional simulation study has been carried out to compute the eddy current, magnetic field distribution and hence thrust force acting on the projectile using the parameter of the existing LIM. A simplified two-dimensional geometry including stator core region and copper winding in the slots of the core was modelled in FEA analyses (COMSOL, version 5.3 a) as per the actual physical parameters of the motor. The geometrical model of analyses consists of a linear coil assembly of active length of 728 mm excluding the overhang area of winding. Double layer winding is modelled as per the actual coil winding. The winding pattern of the coil has been traced, the three phase current waveform defined in the boundary condition is fed at the winding terminals maintaining pole pitch of the actual winding. An SS plate of length 1010 mm and thickness 16 mm is modelled above the coil assembly

keeping same air gap as used in the experiment performed during the acceptance test of Electromagnetic stirrer at IPUL. A rectangular air domain is modelled which acts as infinite boundary for magnetic field analyses. Time averaged magnetic flux and eddy current distribution on the SS plate are analyzed. The time averaged Lorentz force acting on the SS plate has been estimated and compared with the experimental result. The force on the SS plate is measured experimentally, employing dynamometer anchored with the SS plate. The Lorentz force value in simulation and in experiment matched closely for a particular RMS current of autotransformer and particular number of turns of conductor in the winding.

PU4

Optimization of a Plasma Focus Device, Pulsed Radiation Characterization and its Application in Dosimetry measurements and In Vitro Cancer Cell Irradiation

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Abstract - Plasma focus (PF) devices consist in a co-axial geometry of electrodes, in which the central electrode, anode, is partially covered by an insulator and symmetrically surrounded by cathode bars. On applying high voltage at the anode pulsed plasma is produced which comprises self-constricted pinching action known as ‘pinch’. The signature of the pinch can be seen in electrical signals such as voltage and current derivative. As a consequence of the constriction, pulsed radiation emission such as, low and high energy x-rays, neutrons, charged particles also takes place. The origin of high-energy x-rays is considered targeted bremsstrahlung and for low-energy x-rays it is considered mainly thermal bremsstrahlung. The neutron origin is mainly considered beam-target fusion mechanism with a fraction of thermonuclear origin. The pinch occurs at various fill pressures and it is important to optimize a PF device for a fixed geometry and filled gas. In the present work, we propose a methodology to optimize PF devices. For this purpose a hundred joules plasma focus device, PF-400J, was operated at various pressures of hydrogen gas. Electrical signals like voltage and current derivative were recorded using a fast resistive voltage divider and a fast Rogowski coil. Various electrical parameters were derived using the voltage and current derivative signals. Later the derived signals were used to optimize the device. In addition, pulsed radiation characterization was also carried out. Later, the radiation (x-rays, neutrons) was applied to irradiate colorectal cancer cells in vitro. Experiments were performed for fifty pulses of each type of radiation x-ray and neutron. In the case of x-rays accumulative doses were measured using TLD-100 thermoluminscent dosimeters, which provided doses ~ 0.12 Gy. In the case of neutrons, doses were estimated using neutron fluence and energy at the place of petri dish, in which the cell culture were cultivated. DNA damage and cell death studies were carried out after irradiation at various time points. Fifty pulses of x-rays provided a significant rise in DNA damage at 30 minutes, but cell death was absent. In the case of pulsed neutron irradiation (fifty pulses) cell death was observed at ultra-low doses ~ 3.5 μGy, which is much smaller than the doses obtained for fifty pulses of x-rays. It was found that double strand break (DSB)/dose was higher in the case of pulsed radiation than conventional continuous source. The results will be presented and discussed in detail during the conference.

PU5

Development of Variable Pulse Width, Variable Amplitude, Nanosecond Rise Time, Line Type High Voltage Impulse Generator

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Abstract - A line type high voltage pulse generator has been developed to produce an output pulse of 1-10 kV and pulse duration of sub-microseconds to nanoseconds duration. This source is suitable for pre-treatment of biomass to fuel conversion using Pulsed Electric Field (PEF). PEF involves application of very short pulses of high voltage which results in rapid electrical breakdown of the biomass which facilitates the process of biomass to biofuel conversion. Design and development of a simple, low cost, compact pulse forming line is discussed in this work. The line type source has been developed using RG213 PE coaxial cable. The experimental results has been matched with simulation results using the OrCAD simulation software. The spark gap switch, which is the heart of the system, is designed to comply Rogowski profile i.e. uniform electric field. The electric field profile for the electrode geometry has been observed through FEMM software. This spark gap is specially designed for very fast switching and high current handling. The design, experimental and simulation results will be discussed in the presentation.

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PU6

Design, Fabrication & Testing of Single Sided Linear Induction Motor

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Abstract – Linear motors are coming into lime-light due to applications involving generation of traction force without physical contact. Linear Induction Motor (LIMs) can produce high forces and can accelerate metallic objects to very high velocities, which makes them suitable for various projectile launch applications. In our organization, linear induction motors (LIMs) are being used as non-contact type electromagnetic stirrer for liquid Pb-Li applications. The stator part of the LIM, when energized with three phase input, produces magnetic field moving linearly above LIM. It consequently produces eddy currents that induce motion in the liquid metal. If an aluminum sheet is placed on LIM, a thrust force is generated and the sheet is accelerated along LIM surface linearly. Thus LIM forms a key element for electromagnetic launching applications.

A lab scale experiment employing a single sided LIM (developed in-house) is carried out in Magnetics and Dynamics Section, to check the performance of LIM as launcher. This paper describes the design, simulation, fabrication and testing of a Single sided LIM which is used to accelerate aluminum sheets of various thicknesses and dimensions as projectiles. The fabricated LIM is tested and its results are compared with the simulations. Details of enhanced accelerations obtained with the use of magnetic material sheets above the aluminum sheets are also mentioned.

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PU7

Indigenous Development of High Voltage Plasma Switches for Pulse Power Applications

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Abstract - The paper represents the recent research and technological efforts made by CSIR-CEERI for the design, development and characterization of different kinds of high power plasma switches, like Thyratrons (35kV/3kA) and Pseudospark Switches (25kV/5kA, 40kV/5kA and 50-70kV/10kA) for different pulse power applications. Such plasma switches are presently being imported and have always been the subject to import restrictions, causing hurdles in Indian efforts for advancing technologies in high energy research areas. These high power plasma switches have always been the key components of pulsed power systems including modulators, linear accelerators, synchrotron sources, crowbar circuits, cargo scanning systems, sterilization, etc. [1-5]. Very recently CSIR-CEERI have developed 35kV/3kA thyratrons for their use in line type pulse modulator for linear accelerator applications at BARC, Mumbai. In addition, different prototypes of single gap (25kV/5kA), double gap (40kV/5kA) and triple gap (50-70kV/10kA) pseudospark switches (PSS) have been designed and developed for very high voltage pulsed applications [4-7]. The design, development and characterization issues of these plasma switches have been presented. The research work on design and development of high voltage (≥ 30 kV) and high current (≥ 5 kA) pseudospark switches for low jitter and fast pulse power applications have also been discussed. The switching characterization of the developed thyratrons and PSS prototypes have been carried out at different operating and circuit conditions, such as, gas pressure, voltage, triggering, pulse repetition rate and circuit parameters [4-7]. The testing results of the switching characterizations of the developed Thyratrons and PSS have validated the designed specifications.

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PU8

Pseudospark Discharge Characteristics in Radial Multi-Channel Configuration

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Abstract - This paper gives an overview of research work done on a new kind of low gas pressure discharge (pseudospark) for high current switching. High current densities are achieved within very short time in this special kind of self- sustained discharge hence named pseudo spark discharge. The pseudospark discharge evolution in typical hollow-cathode round hole coaxial geometry has been studied by Frank and co-workers and has shown limitation for high current switching in coaxial geometries.

Some of available literature on radial multi-channel pseudospark indicated that the radial arrangement of discharge channels in direction radial to the axis of switch can provides more diffused discharge and higher charge transfer capability hence higher life time, provided all the discharge channels contribute

simultaneously in the discharge process. The spatial and temporal characteristics of the pseudo spark discharge in radial multi-channel PSS fed through common hollow cathode is investigated in this work. The different phases of the discharge inside the particular geometry have also been analyzed. In the triggering or pre-breakdown phase, each channel in radial setup must receives its respective beam current for ionization of all channels from trigger source placed at central axis of hollow cathode, equidistant from all apertures. After triggering, the breakdown occurs in the form of hollow cathode discharge and further taken by bore hole discharge. In the bore hole discharge current density is confined to the apertures regions and may erode the exposed electrode area if not shifted to other areas, as happens in the coaxial geometry. But in radial geometry, the discharge from all channels shifts from the aperture regions and move in the high voltage gap towards the top of hollow cathode and may pinch depending upon the discharge pulse durations under the effect of Lorentz forces. To reduce the energy density and the erosion around the channel aperture areas, linear apertures are created around the periphery of the hollow cathode instead of round apertures. With linear aperture creation, more discharge channel emission area will be utilized for passing the current for comparable geometrical potential penetration through apertures.

The plasma simulations and post experimental diagnosis of discharge exposed regions of electrodes are showing good co-relation that discharge is equally shared among all channels and moving under the effects of Lorentz forces in the particular geometry.

Exotic Plasma Including Dusty Plasma (EP)

S-6-O-1

Impact of Magnetic Field on a Stationary Charged Grain in Streaming Ions

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Abstract - A systematic numerical study of wake potential and density distribution for a single grain in streaming ions under the influence of the magnetic field applied along flow has been studied. Wake size and strength manifests itself in a variety of forms for weakly and strongly magnetized plasma. Strong magnetic field introduces ion focus depletion behind grain facilitating the entrance of electrons far away in the downstream towards the grain. It has been observed that the magnetic field suppresses the amplitude of wake potential and modifies the ion density distribution substantially. The wake peak potential and position characteristics, and density distribution of plasma constituents in the presence of magnetic field and charge-exchange collisions for the subsonic, sonic, and supersonic regime has also been investigated. In the subsonic regime, simulations demonstrate the accumulation of ions near dust grain in the perpendicular direction (w.r.t. flow) while complete suppression of oscillations in the transverse direction takes place for sonic and subsonic regime. By applying a magnetic field, both the ion density distribution and wake potential changed greatly, demonstrating that grain in plasma system can be controlled by applying a magnetic field. The impact and interplay of parallel magnetic field with collisionality and streaming speed on the wake potential and ion density distribution will be discussed in detail.

S-6-O-2

Dust Acoustic Solitary Waves in an inhomogeneous Dusty Plasma Having Dust Size Distribution in Presence of Superthermal Electrons and Ions

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Abstract - Observations from different space and laboratory plasmas imply the existence of inhomogeneity in the dust density gradient widely [1, 2]. Also, it has been observed that in real situations, the dust grains are not of uniform in size [3, 4]. Here, both, dust size distribution and dust density inhomogeneity have been taken under consideration. The existence of dust acoustic solitary waves in an inhomogeneous, collisionless, unmagnetized dusty plasma having power law dust size distribution (DSD) with kappa-distributed ions and electrons is reported in this article. Using an appropriate stretched variable for spatially inhomogeneous plasma, the reductive perturbation technique is followed and a variable coefficient deformed Korteweg-deVries (VCdKdV) equation is obtained from the basic set of hydrodynamic equations. A solitary wave solution is derived from the VCdKdV equation by employing the generalized expansion method [5]. It has been observed that dust density inhomogeneity and dust size distribution affect the wave propagation characteristics. Various parametrical and numerical analyses are presented as support to the analytic study using different parameters of DSD, inhomogeneity and superthermal electrons and ions.

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S-6-O-3

Characterization of Carbon Dust Formation and Enhancement of its Growth in a DC Sputtering Discharges

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Abstract – A Direct Current glow discharge argon plasma is produced in between the graphite made cathode and the anode to simulate tokamak plasma environment at some extent. Due to the ion bombardment, the carbon particles are eroded from cathode surface at a particular discharge condition. These carbon particles are then charged negatively by collecting more electrons than ions and levitated in the cathode sheath region by balancing electrostatic force with gravitational force. A red He – Ne laser is used to illuminate the levitated carbon particles. The time evolution of scattered light from the growing carbon particles are captured using a CCD camera (with frame rate ~ 60 fps) and the images is stored in a high-speed computer. IDL based particle tracking code is then used to calculate the pair correlation function, which gives the particle density of the captured images in different plasma parameters [1-2]. In another set of experiments, the cathode is biased negatively with respect to the grounded chamber to study the enhancement of sputtering yield from cathode surface and its variation over a wide range of discharge condition.

The experimental results showed that the more carbon particle erode if the experiments have performed for longer time and higher discharge voltage and background pressure. The sputtering even becomes more efficient when the cathode is biased with negative voltage. We believe, our experimental results will be helpful to fusion community to understand the sputtering from carbon walls of various tokamaks.

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EP1

Staggering transverse shear waves in strongly coupled dust fluid

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Abstract - Excitation and dynamics of staggering transverse shear waves (STSW) in a two-dimensional dusty plasma medium are studied using Generalized Hydrodynamic (GHD) [1, 2] model visco-elastic simulations. These waves get excited by the presence of time-dependent forcing over a small circular patch. Characteristics of staggering structures with varying amplitude and frequency of forcing and strong coupling of the medium have been studied. It is observed that the radial velocity of the STSW increases with increase in the strong coupling of dust fluid. The relevance of work carried out here with other systems such as condensed matter systems, liquid crystals, colloidal suspensions, and active gels has also pointed out.

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EP2

Study of Probe Potential Below and Above Plasma Potential in an Unmagnetised Dusty Plasma

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Abstract- In this experiment, a Langmuir probe1, 2 was used to study various phenomena in un-magnetized cogenerated dusty plasma, produced by bi-polar pulsed DC power supply. The probe was biased positively as well as negatively with respect to the plasma potential. While doing so, we found some distinguished and exciting events. A sharp transition point was observed when the probe potential crosses the plasma potential. One void appeared at negative probe potential whereas two concentric voids appeared at the positive prove voltage. In addition, the region between the inner ring and the larger one is not fully empty as found in the common voids, rather filled up with finer dust grains. So a term was used to describe the bigger void as "Partial-void", in positive potential case. Effect of the biased Langmuir probe inside a cogenerated dusty plasma environment, resulting to different structural instabilities, which was investigated. The variation of void size was also observed as complex phenomena. Explanation regarding the behavior of dust void in light of dust size distribution has been taken into account.

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EP3

Jeans Instability in Dusty Plasma with Charge Gradient Force

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Abstract - In a dusty (complex) plasma the varying dust charge contributes to the charge gradient force which is proportional to the gradient of the particle charge. This force dominates for lower charges and thus it is taken into account for getting the dispersion relation of low frequency dust acoustic wave in weakly coupled dusty plasma [1]. The situation is more interesting when a periodic growing perturbations are observed due to higher charges causing polarization effect on dust particles [1].

In this work, we have investigated the combined influence of polarization force and dust charge gradient force on the Jeans instability of weakly coupled dusty plasma. The electrons and ions are described through Boltzmann relation while gravitational effect of massive charged dust grains are taken into account. Using Fourier transform a linear dispersion relation is derived and condition of Jeans instability is examined which is modified by both polarization and charge gradient effects. The growth rate of Jeans instability is plotted to study the effects of these forces and possible applications of the work are discussed in the context of dense dusty molecular clouds.

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EP4

Collisional Effects on Diffusion of Dust Grains in Magnetized Plasma

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Abstract - A theoretical analysis on the nature of diffusion is investigated for an ensemble of dust grains in plasma. Strong ion neutral collision in presence of magnetic field and ion flow can induce a significant deviation in dust dynamics thereby affecting the transport mechanism. It is mainly due to the modified interaction potential [1] that arises when the system is modeled with different physical effects as mentioned. In our work, the anomalous nature of dust transport is studied using Langevin dynamics simulation [2,3]. The evolution of Mean square displacement (MSD) in different phase states enables us to correlate the phase behavior of the system with the diffusion of dust grains. We also observe an interesting role of Coulomb coupling parameter (Γ) in disorganizing the particles, which is attributed to the asymmetric repulsive interaction that operates between grains. The variation in nature of diffusion coefficient with respect to moderate magnetic field [4, 5] is also determined.

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EP5

Arbitrary Amplitude Kinetic Alfvén Solitary Waves and Double Layers in Dusty Plasma with κ-Distributed Electrons

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Abstract - The arbitrary amplitude wave structure of magnetized plasma with warm ion and negatively charged dust particles are investigated to study the effect of κ- distributed electrons. The kappa distribution (spectral index κ having value >3/2) is a velocity distribution that has a high energy tail but approaches to the Maxwell- Boltzmann distribution when $\kappa \to \infty$. In the nonlinear regime, the energy integral is obtained by a Sagdeev pseudopotential analysis, which predicts solitary waves as well as double potential structures. For different set of plasma parameter, the Sagdeev Potential (SP) has been calculated numerically. It is found that the spatial index κ plays a significant role in determining the shape and size of the solitary waves and double layers. Study has been made related to the transition of the waves and corresponding characters in terms of Mach numbers. The roles of plasma parameters for

existence of double layers are also investigated. This theoretical study may help in understanding the nonlinear structures developed in laboratory as well as space and astrophysical plasmas.

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EP6

Effect of Intermediate Magnetic Field on the Rayleigh-Taylor Instability in a Strongly Coupled Dusty Plasma

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Abstract – In the presence of density gradient, a dense magnetized electron-ion or complex (dusty) plasma can be subjected to develop the RTI when it is supported against gravity. The problem of RTI prevails great interest to the researchers because of its wide applications. We investigate the linear Rayleigh-Taylor instability (RTI) in a strongly coupled dusty plasma (SCDP) where the dust cloud is rotating uniformly. The electron fluid is assumed to be inertia-less as compared to the other constituents. The strength of the magnetic field is such that the electrons and ions are assumed to be fully magnetized, but the dust particles remain unmagnetized. In the presence of magnetic field the ions experience a rigid rotational force with constant angular velocity and drift along the E×B direction. The strongly correlated dust particles are dragged in the same direction by magnetized ions [1]. Thus the dust particles experience a uniform rotational force similar to the Coriolis force [2, 3] mainly due to the drag force of the magnetized ions. The strong correlation between dust particles are considered and hence the dust coupling parameter is much higher than the electron and ion coupling parameters. If any part of the dust cloud experienced a rotational force then the entire dust cloud will rotate rigidly as dust particles are strongly correlated. We formulate single fluid momentum transfer and continuity equation incorporating individual electron, ion and dusty fluid equations [4] for local stability analysis. The slowly varying background density profile make the dusty plasma configuration unstable to the RT mode. The general dispersion relation exhibiting RTI is derived analytically for the considered SCDP and analyzed in the strongly coupled (kinetic) limit. A direct numerical solution is also performed to find the growth rate numerically and the results are compared with analytical results. We use Finite Discretization Method (FDM) to discretize the governing equations in vertical direction and solve the equations to obtain eigenvalues using Octave code.

In the presence of both magnetic field and dust-dust strong correlation, the Alfven mode is coupled with the viscoelastic shear mode. The RTI criterion is obtained which is modified due to the presence of shear velocity comprising strong correlation effects, and Alfven velocity. It is found that the presence of the intermediate magnetic field in SCDP, the dust cloud rotation due to drag force of magnetized ions can also stabilize growth of RTI. The influence of dust cloud rotation, magnetic field and strong coupling effects are studied graphically which show the stabilizing effects on the growth rate of linear RTI.

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EP7

Effects of Radiation Pressure and Polarization Force on Jeans Instability of Magnetized Strongly Coupled Dusty Plasma

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Abstract - The combined effects of radiation pressure and polarization force are studied on the linear Jeans instability of magnetized strongly coupled dusty plasma (SCDP) using the generalized hydrodynamic (GH) fluid model. The electron and ion fluids are assumed to be inertialess and their thermal radiation pressures including gas pressures are considered in the single fluid momentum transfer equation of strongly coupled dusty fluid. The modified dispersion relation is derived which show the influence of dust radiation velocity, shear wave velocity, compressional wave velocity and polarization force. The dispersion characteristics are discussed for transverse and longitudinal modes in both the strongly coupled (kinetic) and weakly coupled (hydrodynamic) limits. The criterion of Jeans instability and critical Jeans wavenumber are obtained and it is found that in parallel propagation of longitudinal mode the Jeans wavenumber is not affected by the magnetic field whereas in transverse mode the critical Jeans wavenumber is modified by the magnetic field. The numerical calculations show that the coupling parameter, dust radiation velocity and bulk viscosity coefficient have stabilizing influence on the growth rate of Jeans instability. The results of the present work have been applied in the dense molecular cloud when both the magnetic field and radiation pressure are dominant.

EP8

Study of Compressible Shear Flows in Dusty Plasma Using Molecular And Fluid Dynamics Simulations

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Abstract - Micron-sized dielectric or conducting grains embedded inside the conventional plasma, named strongly coupled dusty plasma, behave like quasi-two-dimensional system with only a small variation in the direction of gravity. This grain medium exhibits gas-like, liquid-like and solid-like phases. In the past, it has been found that shear flows may be induced by external low power laser- drive in such grain medium [1]. Dusty or complex plasmas are often modelled by Yukawa potential in molecular dynamics (MD) and by a generalized hydrodynamic model (GHD) in fluid dynamics simulations [2, 3].

Far-from-equilibrium questions, such as a transition from laminar to turbulent flows, vortex-vortex interactions, the interaction of embedded coherent structures with the background turbulence etc - for these fundamental questions, even a qualitative comparative study of strongly correlated fluids using fluid model and molecular dynamics have not been attempted yet. In this work, a qualitative and quantitative comparative study of compressible parallel shear flow in the strongly coupled dusty plasma using MD and CFD has been studied [4]. In the present study, the transition from laminar to turbulent flow at a critical value of Reynolds number in both the macroscopic (GHD) and microscopic (MD) simulation, nonlinear saturation in perturbed kinetic energy, an evolution of vortex, vortex-vortex interactions and various interesting phenomena will be presented.

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EP9

Effect of Polarization Force on Interaction of Shocks in a Non-Maxwellian Strongly Coupled Dusty Plasma

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Abstract - A dusty plasma is ubiquitous in nature and is characterized by the presence of massive charged dust particles in addition to the ions, neutral and electrons. Dust plays an important role in laboratory and astrophysical environment [1]. The charged particles interact with each other via the long range Coulomb interactions and the large amount of charge enables dust grains to strongly couple with the neighbouring charged particles, which makes dusty plasma a complex media for fundamental research [2]. Dust grains are subject to additional force such as polarization force occurring due to deformation of Debye sheath around the dust grains in the background of nonuniform plasmas. The interaction of two or more solitary waves is a nonlinear phenomenon and occurs due to propagation towards each other, exchanging their energies and separating off after the collision. The phase shift physically means the energy utilization by solitary waves to preserve their shape and size after collision [3]. The observations of various satellite missions have confirmed the omnipresence of non-Maxwellian particles with suprathermal tails at higher energies in most of the astrophysical and space plasma environments. Such kinds of non-thermal particles are naturally found in solar wind, Jupiter and Saturn environments. Owing to the importance of polarization force, kappa distribution and omnipresence of charged dust, we have investigated dust acoustic shock waves in a strongly coupled plasma with negatively charged dust, Maxwellian electrons and superthermal ions. The effect of various parameters such as polarization force, ratio of temperatures of effective dust to ion, kinematic viscosity on the nonlinear structures and collisions of dust acoustic shock waves is examined. The study may find relevance in space and astrophysical environments.

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EP10

The Effect of Dust Charge Fluctuations on Nonlinear Dust Kinetic Alfvén Waves

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Abstract - The presence of heavy, micron sized and charged (positively or negatively) dust in an electron-ion plasma generates new wave modes in the plasma and modify the existing modes. When the charge on the dust grains varies with time, the characteristics of the dust modes are further modified. These fluctuations can arise due to the electron and ion currents. In a dusty plasma, the dust kinetic Alfvén solitary waves (DKASWs) are one of the modes which are formed when the perpendicular wavelength is comparable to the dust gyroradius. So, in this investigation, by incorporating the dust charge fluctuation effects, the Korteweg-de Vries (KdV) equation has been derived to study the DKASWs in a plasma, comprising of negatively charged dust grains

modeled by the fluid equations, and electrons and ions (positive) both following the Maxwell-Boltzmann distribution. The modulation instability of the DKASWs leads to the formation of dust kinetic Alfvén rogue waves (DKARWs) which are very unpredictable, high amplitude and short lived waves. The DKARWs have been studied by a rational solution to the nonlinear Schrodinger equation (NLSE). By performing the numerical analysis, it is seen that the dust charge fluctuations significantly modify the characteristics of both the DKASWs and DKARWs. Further, we have also studied the combined effects of dust plasma beta and angle of propagation of the wave with respect to the external magnetic field on the characteristics of DKASWs and DKARWs. This study may be useful for the understanding of excitation of nonlinear structures in space and astrophysical dusty plasmas.

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EP11

Effects Of Polarization Force on the Double Layers in Dusty Plasma

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Abstract - In last few years, there has been a great deal of interest in understanding the characteristics of different types of collective modes in complex (dusty) plasmas both in the laboratory environment as well as in space and astrophysical objects [1]. The effects of polarization force are very important in dusty plasma situations in order to understand various propagation characteristics of the dust acoustic waves [2]. In this paper, we report the propagation characteristics of dust acoustic double layers due to the polarization force acting on micron size dust particles in plasma. Following the standard fluid description of dusty plasma for studying low-frequency phenomena in the regime where dust dynamics is important, we treat the electrons and ions as light fluids which can be modeled by Boltzmann distributions for using the hydrodynamic equations for describing the dynamics of dust component in the plasma. The expression of Sagdeev potential is derived for the dust acoustic waves considering the polarization force in dusty plasma. For arbitrary amplitude waves we find the solution of double layers of dust acoustic waves and the profiles of double layers are drawn taking different values of the polarization force due to plasma-particle interaction. The variation of the amplitude and the width of double layers are shown graphically and discussed. It is seen that the polarization force in dusty plasma has significant effects on the formation of dust acoustic double layers.

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EP12

Annihilation of Wake Potential in Dusty Plasma due to Strong Collisional Effect

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Abstract - Strongly coupled dusty plasma exhibits novel kind of behavior in presence of flowing ions, magnetic field and ion-neutral collisions. Ion flow leads to the appearance of attractive wake potential whereas magnetic field brings in an asymmetry to the dusty plasma system [1, 2]. It is shown in the present

work that strong ion neutral collision completely destroys the wake potential arising due to ion flow and instead of this, an asymmetric Debye- Hückel potential emerges [3]. The nature of this potential is governed by the combined effects of ion flow, magnetic field and collision. When this asymmetric potential adds with isotropic inter particle Debye- Hückel potential, drastically different kind of properties appear in dusty plasma. The interaction potential derived on the basis of linear response theory reveals that strong collision distorts the wake structure and the dynamics of plasma particles is guided by modified Debye- Hückel potential. To understand the phase behavior of such systems, Langevin dynamics simulation is performed [4]. Conditions for transition from ordered to disordered fluid state in such environment have been discussed.

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EP13

Synchronization of Weakly Nonlinear Dust Acoustic Waves

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Abstract - Synchronization is a nonlinear phenomenon where an interaction between a driver and a system leads to an adjustment in the system's characteristic frequency to match that of the driver. A few examples from its widespread applicability in nature are collective oscillations of a group of pacemaker cells, spatial patterns formed in flocks of birds in flight, enhanced output of coupled lasers, behavior of power grids etc. [1]. Synchronization phenomenon has been explored in plasmas between ion acoustic waves in two coupled glow discharge plasma sources [2] and for dust density waves in dusty plasma experiments in [3]. A commonly used model to explain these synchronization observations has been a Van-der-Pol oscillator with an external periodic driving force. Such a model ignores dispersion effects an important characteristic of collective phenomena in plasmas.

In the present work, dispersive effects are retained by studying synchronization phenomena in a dusty plasma medium in the framework of a fluid model. In the weak nonlinearity regime, the evolution of dust acoustic waves can be well described by a Korteweg-de-Vries (KdV) equation [4]. We study synchronization in such a model by applying an external forcing term that varies in space and time. Domains of synchronization are identified in the form of Arnold tongues and the spectral distribution of the power for different applied frequencies is explored. Comparisons are also made with results obtained from a Van der Pol model.

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EP14

Characterization Of In Situ Grown Dust Particles in A Capacitively Coupled RF Discharge

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Abstract - Formation of dust particle (nanoparticle) in reactive plasmas is very common in semiconductor fabrication industries, and in other various technological applications [1]. Due to the large variety of phenomena that can be observed in reactive complex plasmas, it has gained interest of the scientific community in the last two decades.

In the present work, Argon (Ar) plasma is produced using RF discharge (2 – 20 W at 13.56 MHz) in a cylindrical glass tube of length ~ 25 cm and outer diameter ~ 3.2 cm. The discharge characteristics as well as plasma parameters have been studied under different discharge conditions. Acetylene (C_2H_2) gas is then injected in Ar plasma which leads to the formation of carbonaceous nanoparticle. C_2H_2 molecules undergo three successive stages to produce nanoparticle: nucleation, coagulation & accretion [2]. The particles acquire high negative charge (depending on their size) by collecting plasma electrons and ions and are confined within the discharge tube due to the boundary wall electric field. The particle cloud is observed by using green laser light. The size of the as grown particles is obtained by analyzing the Scanning Electron Microscope (SEM) images. Here, we have studied the variation in size distribution of the in-situ grown particles under different discharge conditions such as exposure time of C_2H_2 in order to optimize the parameters for controlled particle growth.

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EP15

Observation Of Spontaneous Rotation Of Dust Cloud In An Unmagnetized Dusty Plasma Containing Carbon Nanopowder

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Abstract - Dusty plasma is a medium containing micron and nanometer size dust particles in the plasma background of electrons, ions and neutral gas molecules [1]. The presence of these dust particles increases the complexities of the plasma, creating new wave modes and instabilities. The relatively heavier dust particles have low charge to mass ratio. Hence the spatial and time scales of their motion are suitable for the direct observation of various kinds of waves and instabilities like dust acoustic wave (DAW), dust ion acoustic wave (DIAW), shock and solitons etc. [1,2]. Last few decades, researchers have shown immense interest in the study of the nonlinear properties of waves and instabilities [3,4] in dusty plasma.

The present experimental work is performed in a glass cylinder of diameter ~ 2.8 cm and length ~ 15 cm placed vertically. RF power of 5 – 15 W at 13.56 MHz is applied to produce plasma at a pressure of 0.01 –

0.015 mbar of argon. Carbon nano powder of average diameter 100 nm is injected into the argon plasma by using a piezoelectric buzzer. Typical measured plasma parameters are: ion density ~ 10^8 – 10^9 cm^{-3}, average electron temperature ~ 5 – 7 eV, dust density ~ 10^4 cm^{-3}, average dust charge ~ 75 e [4]. By laser light illumination (530 nm, 50 mW), vertically extended dense dust cloud is observed in the mid portion of the cylinder. At a threshold pressure, spontaneous rotation of the dust cloud about the cylindrical (vertical) axis is observed. The direction of rotation changes from clockwise to anti-clockwise (and vice-versa) and it is aperiodic in nature. The dynamics of the dust cloud is recorded in a high-resolution camera. The rotational speed of the dust cloud is measured to be about 5-6 rotations per sec. The variation of the rotational speed with the rf power is also measured.

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EP16

Dependence of Dust Voids on Probe Potential and Dust Density

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Abstract - Void is a dust free region inside a dust cloud that is frequently encountered in dusty plasma experiments performed under microgravity conditions as well as in ground based laboratory conditions. Spontaneously formed dust voids as well as probe induced ones, have been rigorously studied in the past couple of decades [1-3]. Their study have gained immense importance owing to the various interaction forces associated with it, such as the electric field force and the ion drag force. Moreover, in many dusty plasma experiments, voids have played the role of an obstacle in the path of a dust flow [4, 5]. Morfill et al. performed an experiment of dust fluid flow around a lentil shaped obstacle and observed wake behind it [4]. As such, understanding the dependence of the shape and size of the dust void on various dusty plasma parameters is of utmost importance.

Here, we present the formation of voids by inserting a cylindrical pin into a two dimensional dusty plasma layer. The experiment is carried out in a glass cylinder and plasma is produced using RF (13.56 MHz, 5 W) discharge in argon at 0.5-5 Pa. Gold coated silica particles of 5 micron diameter are injected into the argon plasma using an electric buzzer. Typical values of dusty plasma parameters are: ion density ~ 10^8 cm^{-3}, electron temperature ~ 5-10 eV, dust density ~ 10^3 cm^{-3}, average dust charge ~ 10^4 e. The characteristics of the void around the pin are studied by applying different bias voltages, which changes the sheath structure around the pin. The effect of dust density on the size of the dust void have also been studied and it is observed that with the increase of dust density, void size decreases. The electric field forces and the ion drag forces on the dust particles are investigated at the various positions of the void boundaries and the balance of the two forces accounts well for the experimentally measured boundary positions.

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EP17

Circularly Polarized Modes in Quantum Dusty Magnetoplasma with Two Spin State Exchange Interaction

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Abstract - The study of dusty plasmas is concerned with objects, usually on the micro or nano-scales, immersed in a hot ionised gas known as plasma. These objects, referred to as dust grains, may be either solid or liquid and are ubiquitous in plasmas. As such, the instances and applications of dusty plasmas are too numerous to elaborate ; they include inter-stellar dust, planetary rings, noctilucent clouds, plasma spraying, contamination in semiconductor processing plasmas, impurities in magnetic confinement fusion devices, low-temperature laboratory dusty plasmas devices. The collective behavior of pure plasma is highly complex and depends on the interactions between vast numbers of individual ions and electrons. This complexity is increased further by the inclusion of dust grains; not only do they represent an additional charged species, but they act as sources and sinks for electrons and ions. Therefore, the charge on the dust may fluctuate [1], but this charge depends additionally on non-plasma processes such as thermionic, field-induced and photonic emission of electrons [2]. The shape and size of dust is also variable, as they can grow through aggregation [3] or shrink through evaporation and violent processes such as electrostatic breakup [4]. Recently, a great deal of attention has been paid to quantum effects in dusty plasma. When a dusty plasma is cooled down to an extremely low temperature such that the de-Broglie wavelength [5,6] of the charge carriers is comparable to the dimension of the systems, the ultra cold dusty plasma behaves like a Fermi gas and quantum mechanical effects are expected to play an important role in the behavior of charged dust particles. Till now, the spin of plasma electrons was considered to be macroscopic average and the evolution of spin–up and spin-down electrons was not been accounted for. The spin state of particles is also perturbed by the presence of electromagnetic waves [7,8].

In the present paper, a separated spin evolution quantum hydrodynamic model is employed to study propagation of high intense electromagnetic wave in quantum dusty magnetoplasma having inertia-less degenerate electrons with spin-up and spin-down states. The effects of quantum Bohm potential, electron fermi pressure and difference in spin-up and spin-down concentration of electron caused by external magnetic field have been taken into account. The dispersion relation for electromagnetic waves in dusty magnetoplasma has been setup, the circularly polarized mode has been analyzed and the effect of spin polarization due to spin-up and spin-down concentration difference has been studied both numerically and analytically .

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EP18

Characterization of Carbon Dust Formation and Enhancement of its Growth in a DC Sputtering Discharges

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Abstract - A Direct Current glow discharge argon plasma is produced in between the graphite made cathode and the anode to simulate tokamak plasma environment at some extent. Due to the ion bombardment, the carbon particles are eroded from cathode surface at a particular discharge condition. These carbon particles are then charged negatively by collecting more electrons than ions and levitated in the cathode sheath region by balancing electrostatic force with gravitational force. A red He – Ne laser is used to illuminate the levitated carbon particles. The time evolution of scattered light from the growing carbon particles are captured using a CCD camera (with frame rate ~ 60 fps) and the images is stored in a high-speed computer. IDL based particle tracking code is then used to calculate the pair correlation function, which gives the particle density of the captured images in different plasma parameters [1-2]. In another set of experiments, the cathode is biased negatively with respect to the grounded chamber to study the enhancement of sputtering yield from cathode surface and its variation over a wide range of discharge condition.

The experimental results showed that the more carbon particle erode if the experiments have performed for longer time and higher discharge voltage and background pressure. The sputtering even becomes more efficient when the cathode is biased with negative voltage. We believe, our experimental results will be helpful to fusion community to understand the sputtering from carbon walls of various tokamaks.

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EP19

Study of Non-equilibrium Steady State in Rayleigh-Benard Convection of Yukawa liquids using Molecular Dynamics

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Abstract - Equilibrium Statistical Mechanics is governed by the well known Boltzmann Entropy. When such a system is subjected to an external forcing, the system is driven out of equilibrium. When forcing and dissipation balance, the system relaxes to non-equilibrium steady state. To understand the dynamics of non-equilibrium steady state, a fluctuation theorem based on entropy production rate was proposed which describes the fluctuations in non-equilibrium steady state in open systems[1,2].

In this work, using 2D Molecular Dynamics simulation, we study statistical properties of turbulent Rayleigh-Benard system of Yukawa liquids. The system, when placed under the effect of gravity and subjected to a temperature gradient and implicit viscosity, leads to the formation of Rayleigh-Benard Convection Cells in this driven-dissipative system beyond a critical value of external temperature gradient[3]. If the external temperature gradient is further increased to a very large value, the system becomes highly turbulent. The statistical properties of this system are analysed and results are compared with the predictions of steady state fluctuation theorem[4] based on extremization of entropy production rate, the details of which will be presented.

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EP20

Effect of Two-temperature Electrons on Plasma Sheath in a Collisional Magnetized Plasma

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Abstract – A collisional magnetized plasma consisting of two-temperature electrons has been investigated numerically to calculate the sheath structure and the energy flux to the wall. The low temperature electrons are described by Maxwellian distribution and the high-temperature electrons are described by truncated Maxwellian distribution. It has been observed that high-temperature electrons play a major role in the sheath potential as well as the ion energy flux to the wall. The observations made in this study are quite relevant in Tokamak Divertors.

EP21

Magnetized Plasma Sheath in Presence of Negative Ions

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Abstract - The sheath formation in a collisional weakly magnetized electronegative plasma consisting of electrons, negative and positive ions has been numerically investigated using the hydrodynamics equations. The electrons are assumed to follow Boltzmann relation whereas the negative ions are described using fluid equations. It has been observed that the presence of negative ions has a substantial effect on the sheath structure. The observations made in the present work have profound significance on processing plasmas especially in the semiconductor industry.

EP22

Effect of Ion Temperature on Plasma Sheath in Presence of Oblique Magnetic Field

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Abstract - A collisional magnetized plasma with finite temperature has been studied to find out the dependency of sheath properties on the ion temperature. The plasma flow is assumed to be normal with respect to the surface and primarily controlled by the self-consistent internal electric field. Using single fluid hydrodynamic model the system of equations has been solved numerically. The electrons are considered to follow Boltzmann relation. The outcome of this study will help us to shed some light on the complex dynamics of ions in the processing plasmas as well as in Tokamaks.

EP23

A Dust Particle Based Technique to Measure the Potential Profile in a Plasma

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Abstract - We present the experimental measurement of the potential profile around a wire attached to a grounded cathode in a DC glow discharge Argon plasma by using dust particles as dynamical micro-probes. The experiments are performed in a Π shaped Dusty Plasma Experimental device [2], in which the plasma is produced by applying a DC voltage between a circular anode and a grounded tray cathode. A few Melamine formaldehyde (MF) particles are then introduced in the plasma and are seen to be levitated in the cathode sheath region. These particles are made to move over the grounded wire by suddenly changing the flow rate of argon gas. Tracing the position of individual particles and calculating their velocities, the sheath potential profile is estimated over a wide range of discharge parameters using energy conservation arguments. The potential profiles are found to be Gaussian in axial direction whereas it is parabolic in the radial direction for a given discharge condition. The maximum potential strength increases whereas the width of the potential hill decreases with the increase of the discharge voltage and the background neutral gas pressure [3].

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EP24

Formation of Finite Coulomb Clusters through Controlled Particle Additions

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Abstract - A complex (dusty) plasma [1,2], consisting of electrons, ions, neutrals and charged micro-sized dust particles, offers an excellent medium to investigate many fundamental physics problems in thermodynamics, statistical mechanics and soft condensed matter at a kinetic level. For certain plasma conditions, when the inter-particle potential energy of dust particles becomes much higher than their particle kinetic energy, a dusty plasma system can arrange itself in an ordered fashion to form crystalline structures [3,4]. In this work, we report the formation of small Coulomb clusters of dust grains in the background of a DC discharge Argon plasma. The dynamics and stationary states of these clusters are studied experimentally in the DPEx device [5] through controlled introduction of additional dust grains after a basic triangular structure of three particles is formed. The self-organization of the dust particles as a result of the balance between Coulomb repulsion and external confinement potentials is investigated. Dust particles are found to be stabilized in such a way that the new configuration becomes more ordered and contains more hexagonal cells. The coupling parameter of the finite cluster is estimated using Langevin dynamics and found to be maximum when the cluster is dominated by hexagonal cells. Finally, the structural transition of a single hexagonal cell and a small cluster of 10 particles are investigated by varying the discharge parameters.

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EP25

Study Of Probe Potential Below and Above Plasma Potential in Unmagnetised Dusty Plasma

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Abstract - In this experiment, a Langmuir probe1, 2 was used to study various phenomena in un-magnetized cogenerated dusty plasma, produced by bi-polar pulsed DC power supply. The probe was biased positively as well as negatively with respect to the plasma potential. While doing so, we found some distinguished and exciting events. A sharp transition point was observed when the probe potential crosses the plasma potential. One void appeared at negative probe potential whereas two concentric voids appeared at the positive prove voltage. In addition, the region between the inner ring and the larger one is not fully empty as found in the common voids, rather filled up with finer dust grains. So a term was used to describe the bigger void as "Partial-void", in positive potential case.

Effect of the biased Langmuir probe inside a cogenerated dusty plasma environment, resulting to different structural instabilities, which was investigated. The variation of void size was also observed as complex phenomena. Explanation regarding the behavior of dust void in light of dust size distribution has been taken into account.

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EP26

Study Of Melting Dynamics Triggered By Localized Perturbation In Crystalized Dusty Plasma Layers

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Abstract - Melting transition of crystalized dusty plasma layers induced by an external perturbation has been studied in the presence of neutral damping using Langevin molecular dynamics simulation. In experiments, charged dust particles typically levitate due to the balance of gravitational force and force associated with the sheath electric field. In this work, three-dimensional molecular dynamics simulation has been carried out, where dust particles are considered to interact with each other via Yukawa pair potential. Besides this pair interaction each particle is also subjected to the forces due to gravity (vertically downward) and an external electric field (vertically upward) [1]. Crystalized layers are observed to form and have been characterized by different values of system parameters. These structural layers have been introduced to an externally pulsed perturbation perpendicular to the plane of layers in a localized region of the crystal [2]. Melting dynamics with changing values of external perturbation has been studied in different neutral damping regions. It has been shown in our simulations that single particle effects play a dominant role to melt the crystals in a low damping region.

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EP27

Transient Self-Filamentation of Electromagnetic Beam Propagating in Dusty Plasma

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Abstract - A theoretical model mentioning the effect of dust grains on transient self-filamentation of electromagnetic beam propagating in dusty plasmas has been proposed. Non-linear irradiance of the electromagnetic beam in dusty plasma causes the non-uniform distribution of electron temperature. As a result of which more and more electrons are accumulated on dust grain surface near the axis of the beam which generate distorted electron density passage even after considering the ambipolar diffusion and motivate the self-filamentation of beam. In this analysis, while considering non-linear ohmic heating, dust charge balance, elastic and inelastic collision of constituent particles, accumulation and ionization of electron from dust grain surface, momentum and energy balance equations have been solved simultaneously to govern the relation between the beam width parameter and distance of propagation. The dependence of beam width parameter with dimensionless propagation distance have been evaluated for different values of dust densities and dust charge potential.

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EP28

Quasipotential Analysis for Dust Acoustic Solitary Waves and It Coherent Structures in Dusty Plasmas

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Laser and beam Physics (LP)

S-5-O-03

In-situ Ion Heating via a New Absorption Mechanism with pulsed CO2 Laser in Presence of an External Magnetic Field

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Abstract - The possibility of ion heating directly with short pulse, intense lasers has gained a significant interest in recent years because of their practical applications in a variety of contexts e.g. fast ignition scheme of laser fusion, proton radiography, biomedical applications etc. [1]. Some of the well-known mechanisms in this regard are the RPA (Radiation Pressure Acceleration) [2] and TNSA (Target Normal Sheath Acceleration) [3]. A new mechanism of ion heating with a p-polarized, pulsed CO_2 laser when incident normal to an overdense plasma with sharp interface has been shown to be operative in presence of an external magnetostatic field. The external magnetic fields are chosen so as to restrict the electron motion and the heavier ions be allowed to respond to the laser electric field. The difference of electron and ion dynamics leads to charge separation and drives large amplitude ion plasma oscillations resonantly, thereby transferring the laser energy directly to heat ions (~ MeV). The proposed mechanism has been demonstrated by carrying out Particle-in-Cell (PIC) simulations under OSIRIS 4.0 framework [4] using parameters for nonrelativistic intensities ($I = 3.46 \times 10^{14}$ W/cm^2) of pulsed CO_2 laser for which the requirement of external magnetic field strength is smaller. Furthermore, for a relativistic laser intensity ($I = 7.0 \times 10^{17}$ W/cm^2), Korteweg - de Vries (KdV) magnetosonic solitons have been observed to get excited. These solitons, as expected, propagate stably for several hundreds of ion plasma periods. However, subsequently, they are observed to develop transverse modulations which grow with time. It is important to note that with the recent technological advancements on CO_2 pulsed lasers and the possibility of attaining magnetic fields of Kilo-Tesla order in the laboratory [6], this domain of studies will soon be within the reach of experimental explorations.

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S-5-O-04

Diamagnetism in Expanding Plasma Plume

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Abstract - We have developed a novel experimental technique for two directional imaging of expanding laser-produced plasma across the magnetic field. An Nd:YAG laser (λ = 1064 nm, 8 ns pulse width) has been used to generate plasma plume in the presence of transverse uniform magnetic field, varying from 0 to 0.57 T. The dynamics of the evolving plasma plume along and across the magnetic field lines has been studied by two internally synchronized ICCD cameras, mounted in a direction orthogonal to the plume propagation. For the first time, we have experimentally demonstrated the time-varying structure of induced diamagnetic cavity in laser-produced plasma in the presence of the transverse magnetic field. We have observed an elliptical cylinder-like diamagnetic cavity instead of theoretically predicted spherical one. A theoretical model has also been developed to explain the observed features. The diamagnetism nature of the cavity is verified using an indigenously developed three-axis, high-frequency B-dot probe. Details of development technique and plausible explanation of the observed results will also be discussed.

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S-5-O-01

Terahertz (THz) Radiation Frequency Control by DC Magnetic Field in a Laser Beating with nano-cluster

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Abstract - THz radiation have enormous applications in material characterization, imaging, topography, remote sensing, chemical and security identification[1-5]. Thus, development of new high intensity THz sources and detectors are the crucial area of research. We propose THz radiation generation by optical rectification of CW CO_2 laser in nanoclusters. The effect of laser beam quality and profile on emitted THz radiation is investigated. Presence of DC magnetic field shifts the resonance condition and help in THz frequency tuning.

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S-5-O-02

Laser Wakefield Electron Acceleration by shaped laser pulse in the presence a magnetic field

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Abstract - The effect of temporally asymmetric laser pulse has been investigated on electron beam quality in laser wakefield acceleration (LWFA) in the presence of external magnetic field. An asymmetric laser pulse imparts strong ponderomotive force on plasma electrons due to high velocity gradient. External magnetic field relaxes the trapping threshold for electrons, which influences the wake wave evolution and injection mechanism. Two dimensional particle-in-cell (PIC) simulations have been performed to show the dependency of electron beam quality on pulse asymmetric parameter and transverse magnetic field. The electron beam emittance reduces sharply if the leading edge of the pulse is two-fold sharper in the presence of a magnetic

field of 50 Tesla. The electron energy and charge also affected. These simulation based predictions may be crucial in generation of monoenergetic electron beams, and, therefore combination of magnetic field and pulse asymmetry significantly affects the quality of the injected electron bunch in terms of the injected charge; mean energy and emittance in laser wakefield acceleration.

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LP1

Stimulated Brillouin backscattering of cosh Gaussian beam in collisionless plasma

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Abstract-We present theoretical and numerical analyses of the propagation of cosh Gaussian laser beam in collisionless plasma with relativistic ponderomotive nonliearities and its effect on the excitation of ion acoustic wave (IAW) and stimulated Brillouin backscattering (SBS) process. We also compare the results of cosh Gaussian profile with Gaussian profile. A paraxial-ray approximation has been invoked to understand the nature of propagation of a cosh Gaussian laser beam in plasma, ion acoustic wave and back reflectivity under the influence of only relativistic and relativistic ponderomotive nonlinearity. The numerical results are presented for different values of decentered parameter '*b*' and intensity parameter. It is observed from the results that these parameters play vital role for the self-focusing of the CGLB and the excitation of IAW. The self focusing and significantly reflectivity is increased for higher decentered parameter. Strong self focusing is observed in relativistic-ponderomotive regime as compared to only relativistic nonlinearity.

LP2

Lower Hybrid Wave Aided Laser Second Harmonic Generation in a Magneto Plasma

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Abstract - In laser produced plasmas strong magnetic fields are produced. When a highly intense laser is moving into such plasmas, laser harmonics can be produced with the assistance of electrostatic waves. Electrostatic waves provide phase matching and non-linear coupling for harmonic generation. The process of Lower Hybrid wave assisted resonant second harmonic generation of laser in a magnetized plasma is investigated. The laser of frequency ω_0 and wave number $\vec{k}_0$ travelling across the magnetic field in a plasma, exerts a second harmonic pondromotive force on electrons imparting them an oscillatory velocity $\vec{v}_{2\omega_0,2\vec{k}_0}$. This velocity beats with the density perturbation due to the Lower Hybrid wave to produce a density perturbation at Lower Hybrid wave frequency shifted second harmonic. The Lower Hybrid wave assisted second harmonic has frequency slightly shifted from the laser second harmonic. At normalized amplitude $\frac{eA}{m\omega_0 c} = 0.2$, normalized plasma length=50 and $n_{\omega,\vec{k}}/n_0^0$=0.3 the normalized amplitude value of Lower Hybrid wave assisted second harmonic is found to be quite high near the upper hybrid resonance.

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LP3

Phase-Matched Third Harmonic Generation Via Interaction Of Bichromatic Laser Beams With Plasma

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Abstract - Generation of harmonic radiation is an important subject of laser plasma interaction and attracts great attention due to wide range of applications. In general, linearly polarized laser beams interacting with homogeneous plasma lead to the generation of odd harmonics of the laser frequency [1]. However, even harmonics have been observed by laser beam propagation in plasma having transverse gradient in its density profile [2] and also in plasma embedded in external fields [3]. The conversion efficiency of the harmonics is limited due to the phase-mismatch between the generated harmonics and the fundamental frequency of the laser radiation. Hence, it is important to investigate the conditions under which harmonic generation efficiency can be maximized. Recently, an analytical study of phase-matched second harmonic generation by interaction of linearly polarized laser beams with plasma in presence of a transverse, spatially distributed static electric field has been reported [4].

In the present study, an analytical theory is developed for generation of efficient phase-matched third harmonic radiation by the propagation of bichromatic linearly polarized laser beams copropagating at different angles of incidence in homogeneous underdense plasma. With the help of perturbative technique, in the mildly relativistic regime, the current density oscillating at the third harmonic of the laser frequency has been obtained by simultaneously solving the Lorentz force, continuity and Poisson's equations. The amplitude of third harmonic radiation has been obtained and its variation with the angle of incidence is analyzed. It is shown that phase matched third harmonic radiation may be achieved for an appropriate value of angles of incidence which satisfies the phase matching condition.

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LP4

Relativistic Self-Focusing Of Super-Gaussian Laser Beam In Thermal Quantum Plasma:Higher Order Paraxial Ray Theory

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Abstract - This paper presents an investigation of a self-consistent, theoretical model, which explains the ring formation in a super-Gaussian laser beam propagating in thermal quantum plasma, characterized by relativistic nonlinearity. Higher order terms (up to r4) in the expansion of the dielectric function and the eikonal have been taken into account. The condition for the formation of a dark and bright ring has been used to study focusing/defocusing of the beam. It is seen that inclusion of higher order terms does significantly

affect the dependence of beam width parameter on distance of propagation. Self-focusing of super-Gaussian beam is studied at various values of super-Gaussian coefficient, m and Fermi Temperature.

LP5

Measurement Of X- Ray Emission From Plasmas Produced By Interaction Of Short Pulses Of 1.06μm Wavelength Laser With Metal Targets.

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Abstract - This paper presents the generation and measurement of the x-ray from laser produced plasmas. The x-ray emission depends on input laser intensity and atomic number of the target material [1, 2]. Plane metal targets of Aluminium, Copper, Iron, Molybdenum, Tungsten, Platinum and Gold were used for these studies. A 300mJ, 2 picosesond and 1.06μm wavelength laser pulse from a chirped pulsed amplification Nd: Glass laser chain was used. The laser beam was focussed on the target by a 45 degree off axis parabolic mirror of 100 mm focal length. The best focus intensity on target was in the range of 1.2×10^{14} W/cm^2. The incident laser beam was at an angle of 35 degree to the target normal. Metal targets were placed on a motorised translation stage so that the laser intensity on target could be changed or tweaked. Neutral density filters were placed in the path of the laser beam to vary the input laser energy and therefore the intensity on target.

In one experimental set up, the x-rays produced on the front side of the target were measured with silicon x-ray photo diodes (OSI optoelectronics make XUV-100) covered with thin Aluminium foil. Four such diodes were placed at different points (distance of 50mm from the target) spanning 180^0 of the target front surface. The target and photodiodes were placed inside a vacuum chamber. The thin foil suppresses the visible light created at the target surface and also the infra –red light of the laser that may be reflected from various surfaces inside the experimental chamber. The signal from the photodiodes showed that the X-ray spread was nearly equal in all direction or angle. The scaling of the x-ray signal was of course laser intensity dependent. Therefore the best focussing conditions were maintained for all the target metals. It was found that x-ray production scales with Z, the atomic number of the metal. For gold x-ray emission was maximum and it was minimum for aluminium.

In the next experimental set up an X-ray CCD camera replaced the photodiodes in order to get an estimate of the X-ray spectrum. These were all Bremsstrahlung x-rays that are emitted from laser solid interaction. They were measured with a 2048 x 2048 pixels X-ray CCD camera (Andor Make DO936Z), placed facing the target inside the vacuum (10^{-6} Torr) chamber. The CCD is sensitive to x-rays in the range of 10 eV to 10 keV but with a 60 μm thick Beryllium window, the x-rays detected were above 2 keV. This CCD camera was placed in line with target normal. The measurement shows that x-ray intensity has an approximate power law dependence of 2.27 with laser intensity. The measurements also show that the Bremsstrahlung x-ray emission is more or less the same with in ±1.5mm of the best focused position of the laser pulse on the targets. The number of counts generated for a photon of energy E (eV), at these setting is approximately E/11.68 counts. Though there were some pile up errors, the x-ray energies reached about 6 keV. It was found that higher x-ray energies were from the Molybdnum target and not the Gold target with a higher Z value.

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LP6

Ion Acceleration in Interaction of High Intensity Laser with Mass-Limited Targets

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Abstract - The interaction of intense laser field with matter leads to various interesting physical phenomena [1-3]. Acceleration of plasma ions due to interaction of laser with underdense or overdense targets have been widely studied during last two decades. In the present work, 3D PIC simulation has been performed to understand ion-acceleration for a wide range of parameters, such as, plasma density, target thickness, laser-polarization etc. It is observed that the ion spectrum is the result of competition among different dynamical processes. Depending on the target parameters, ion may be accelerated from the rear surface due to Target Normal Sheath Acceleration (TNSA) [4], or from the front surface due to Radiation Pressure Acceleration (RPA) [5]. Our effort is to identify the optimum parameter range suitable for ion acceleration through various mechanisms.

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LP7

The Parametric Instability Of A Laser Beam In A Ferroelectric Material (PZT) Using QHD Model

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Abstract - In the present paper we shall show that the parametric instability of an intense Laser beams of ferroelectric material (PZT) using quantum hydrodynamic model. We analysis is carried out through the nonlinear dispersion relation of parametric and the threshold value of the pump an electric and magnetic field. An expression for the growth rate of acoustic waves through with the quantum and without quantum effect or also the compared the growth rate between them.

LP8

Effect Of Capillary Inner Diameter on the X-Ray Laser Output

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Abstract - Capillary discharge plasma has great potential to become very compact soft X-ray laser source emitting at 46.9 nm which can be mounted on a small portable trolley. Such a compact soft X-ray laser in repetitive mode operation has tremendous applications in nano-imaging, nano-patterning, dense-plasma diagnostics etc [1] and may find several new potential applications in future. In our laboratory, discharge parameters of capillary discharge X-ray laser system [2] has been optimized for smaller size. As a result, a new ultra-compact version (size ~ 40 cm x 25 cm) has recently been established and operated up to 0.5 Hz repetition rate. The argon plasma in this ultra-compact soft X-ray laser system is driven by 18 - 21 kA current

pulse with half period ($T_{1/2}$) of 190 ns generated from an indigeneously developed Tesla-transformer based pulse-power system at 60 kV. Before the main discharge current, the argon gas in a few centimeters long (typically ~ 15 cm) alumina capillary, is subjected to 20 A pre-pulse current of long duration (typically tens of micro-seconds) to form homogeneous argon plasma. This is uniformly compressed with main discharge current to generate plasma Z-pinch which has suitable density and temperature for soft X-ray lasing at 46.9 nm. It was observed that if a small DC current of ~ 20 - 30 mA is also introduced before the pre-pulse current through the argon filled capillary, then the initialization of the pre-pulse current becomes highly reproducible in time. The lasing depends on various parameters such as main current amplitude and its duration, pre-pulse amplitude and its time delay, initial gas pressure, capillary length and its inner diameter (ID). Experiments have been conducted to see the effect of capillary ID on the laser output with a 15 cm long capillary for a maximum discharge current amplitude (~ 21 kA) available from the ultra-compact system. The duration of the main discharge current is fixed for the system configuration as it is decided from the discharge circuit parameters viz. inductance (L) and capacitance (C). Capillaries of different ID's viz. 2.0 mm, 2.8 mm, 3.2 mm and 4.0 mm were used in these experiments. The pre-pulse conditions and the gas pressures were optimized for each capillary ID in order to maximize the laser output. The soft X-ray laser output was detected by calibrated vacuum diode of larger sensor area and was highly attenuated by 2.4 µm thick Al filter in order to avoid the saturation of vacuum diode. It was observed that as the capillary ID is reduced from 4.0 mm to 2.0 mm, the laser output monotonically increases. The maximum laser energy was seen to be ~ 2.2 µJ per pulse with capillary of 2.0 mm ID. Further enhancement in laser energy is possible by increasing the capillary length i.e. the gain-length of the laser which will be taken up in near future.

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LP9

Guided Acceleration Of Carbon Ions By Laser Irradiated Thick Walled Hollow Nano Cylinder

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Abstract - A scheme of guided acceleration of carbon ions using thick walled hollow nano cylinder is proposed, in which the embedded fragments of low-Z materials are irradiated by an ultrashort intense laser to eject and accelerates the substantial number of electrons. The ultrashort intense laser of pulse duration ~30 fs and intensity surpassing $10^{18} W/cm^2$ at 1 µm wavelength causes the substantial high ionization of gold atoms while full ionization of embedded particles and blown out the free electrons via the ponderomotive force. The charged nanocylinder produces an electric field with axial field outwards and the transverse component of field towards the axis of symmetry. Thus, the embedded particles along with carbon ions confined in transverse direction and accelerated axially.

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LP10

Langmuir Beat Wave Heating of a Plasma

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Abstract - A Scheme of Langmuir beat wave heating of plasma via electron cyclotron damping is proposed and analyzed. Two Langmuir waves, propagating at an angle θ to each other in a plasma, exert a beat frequency pondermotive force on electrons,. The beat wave driven quasi mode suffers Landau damping and cyclotron damping on electrons, heating them efficiently, Electron temperature scaling with plasma density, ripple wave number and Langmuir wave amplitude has been obtained.

LP11

Laser Beat Wave Terahertz Generation on a CNT Embedded Surface

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Abstract - A scheme of terahertz generation employing carbon nanotubes (CNTs) embedded metal surface is proposed. This surface is irradiated by two laser beams incident at angle θ, that induce large excursions on CNT electrons and exert a ponderomotive force at the beat frequency $\omega=\omega_1-\omega_2$. The pondermotive force derives a nonlinear current producing THz radiation. THz field is resonantly enhanced at the plasmon resource, $\omega = \omega_p(1+\beta)/\sqrt{2}$, where ω_p is the plasma frequency of CNT electrons and β characterises the dielectric susceptibility of the CNTs.. Collisions are a limiting factor, and cause the laser induced heating of vacuum-metal intrface.

LP12

Interaction of Intense Laser Pulse with a Thin Flying Plasma Mirror And Generation of High Frequency Radiations

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Abstract - An electromagnetic wave reflected from a moving mirror undergoes frequency multiplication and corresponding increase in the electric field amplitude [1]. This multiplication factor is proportional to the square of the relativistic gamma factor of the mirror. This effect is an attractive basis for the source of a powerful high frequency radiation. In relativistic plasma, the double Doppler effect manifests itself when a fast change in the electric current density leads to the conversion of an incident light into strong compressed pulses of high frequency electromagnetic radiation [2]. Here we discuss intense laser driven high frequency radiation of high intensity as a result of reflection of electromagnetic wave from a relativistic flying plasma mirror. As regards the brightness of reflected radiation we are concerned with the light energy emerging from a portion of the mirror surface [3]. If the mirror surface is opaque, it is reflected light which is considered; if it is transparent or semi-transparent (in which case the light is partly absorbed or scattered), it is the transmitted light which is usually measured. We present our analytical and numerical results on the number of emitted energetic x-ray photons and their possible medical applications.

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LP13

Generation of Quasi-Monoenergetic Electron Beams Through Direct Laser Acceleration Using Ionization Induced Injection In High-Z Mixed Gas Target

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Abstract – Laser wakefield electron acceleration (LWFA) achieved using high-intensity, short-duration laser pulses interacting with underdense plasma has been a subject of considerable interest. Mostly, LWFA experiments are performed using He/H_2 gas targets where self-injection (SI) of electron takes place through the highly non-linear wave-breaking process resulting in uncontrolled injection. However, using high Z gases such as N_2, O_2 etc. as well as mixed gas targets (He+few% of high Z gas), controlled injection of electrons can be achieved with the assistance of ionization induced injection (III) mechanism. Due to continuous injection of electrons in case of III, mostly broad and continuous electron energy spectra have been observed [1]. However, various techniques are recently being proposed to reduce the energy spread. In this context, detail experimental investigation in generation of quasi-monoenergetic (QM) electron beams with III would be interesting.

In this paper, we present an experimental investigation of electron acceleration using Ti: Sapphire laser interacting with He, N_2 and mixed gas targets (He+N_2) of length 4 mm. Laser pulse was focused to ~6.5×6.5μm^2 containing ~38% energy. By varying the pulse duration in the range of ~60-120fs, laser intensity at focus was in the range of ~2-5×10^{19} W/cm^2. Using mixed gas targets (He+N_2) with percentage of N_2 varying between ~2-100%, a threshold density of ~5×10^{18}cm^{-3} was observed for He+2%N_2 which gradually decreased to ~1×10^{18}cm^{-3} for pure N_2 case. It was found that at an optimum composition of He+42-50% N_2 (density ~2.2×10^{18}cm^{-3}) QM electron beams with peak energies ~150-200MeV, maximum energy ~250MeV were observed, whereas for other compositions the spectrum was quasi-thermal. Further theoretical investigation performed suggests the acceleration mechanism could be attributed to direct laser acceleration (DLA) rather than wakefield in a self-modulated LWFA regime where $L>\lambda_p$: L is the laser pulse length and λ_p is the plasma wavelength. Analysis also predicts generation of QM beams at a same density of ~2.2×10^{18}cm^{-3} observed experimentally, as the rate of change of phase was found to decrease with density and attains a minimum at ~2.2×10^{18}cm^{-3} where maximum bunching of electrons takes place and beyond which the rate further increases. Thus we report for the first time experimental demonstration of QM beams accelerated through DLA more so by III by optimization of percentage of mixing of N_2 in He.

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LP14

Study of Radiography Application of Relativistic Electron Beams Generated From Laser Plasma Electron Accelerator

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Abstract - Laser driven plasma based electron accelerators have emerged to be one of the promising candidates for compact and cheap accelerators as it can now routinely generate stable electrons beams with energies ranging from few tens to few hundreds of MeV with different beam properties viz. beam size, beam charge and spectral characteristics accelerated either by laser wakefield acceleration (LWFA) and/or direct laser acceleration (DLA). In such a scenario in which the acceleration mechanisms are comparatively well understood, it would be desirable to consider various applications of these electron beams. Out of many, one important application is the electron radiography. Since there are very few reports on electron radiography using LWFA beams [1] further experimental investigation would be of interest.

In this paper, we present an experimental demonstration of electron beam radiography of plant samples viz. aloe-vera of ~1cm thick and different dense structured targets viz. copper groove of 5cm thick, electronic IC chip, copper wire of ~250µm diameter, copper mesh of thickness of ~600 µm, Al ring with horizontal groove structures of thickness ~4 mm, etc. using electron beams generated from interaction of Ti:Sapphire laser pulses of ~120fs (2×10^{19} W/cm^2) with Ar gas-jet targets of 4mm length. The samples were placed at a distance of ~70cm from source and radiographs were recorded on imaging plates. Stable electron beams ~20MeV with broad continuous spectra, large beam size of ~10 cm at target and high charge of few nC were generated at a density $>1\times10^{19}$cm^{-3}. The minimum resolution of the radiograph was found theoretically to be ~300µm. Further, GEANT4 simulations were performed which could reproduce the experimentally observed radiographs. Further effect of different beam properties on resolution has been studied. Detail simulation studies were performed to further explore the applicability of these electron beams in electron therapy and study of deformation embedded in bulk materials, showing high potential to address such applications. Hence our experimental parameters demonstrate an electron beam source which can address broad range of radiography applications in a low cost set up compared to the RF linear accelerators.

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LP15

Simple Estimation of X-Ray Enhancement Due to Broadband Surface Plasmon Resonance in Micro-Flower Targets Irradiated by Intense Pulses

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Abstract - One of the major applications of intense ultra-short laser pulses is the production of intense, picosecond duration, point X-ray source for probing hot dense matter or Time Resolved X-ray Diffraction [1]. Various exotic structures like Nano-particles and Micro-structures are generally used as targets. One among them is Water Micro- Droplets (Low Z) target which are debris free source but they suffer from inefficient Resonance Absorption (occurring at critical density n_c=1.7X10^{21}/cc for 800nm Ti: Sa Laser) of just 20% in the optimized conditions [2]. It is desirable that the structure of a Micro-Droplet or Micro-Spheres should have features that facilitate electric field enhancement, enhanced absorption and a high resonance density for its candidature to be an efficient X-ray source. One such target is the Copper Tin Sulphide Micro-Flowers. They can be deposited on a large area by electrochemical method and is generally used for Solar cell applications. These Micro-Flowers are 5-7 µm in size and has random submicron (300-900 nm) heterogeneity. Due to unavailability of Simulations for such complex structures their interaction with intense pulses is simplistically modeled analytically in this study to choose the laser and target parameter for efficient X-ray emission. A simple FFT of the SEM micrograph of the Micro-Flowers reveals almost all spatial frequencies of similar

amplitude present in this target. It is well known that Surface Plasmon Resonance (SPR) can be excited in metal/plasma dielectric interface when the incident light momentum is boosted by the surface roughness to excite the SPR [3]. This resonant excitation occurs at a particular density for fixed quasi surface grating/momentum vector ($k=2\pi/d$). Since all possible "k" vector are present in this structure resonance can be excited over a wide range of densities from $2n_c$-100 n_c. This broadband resonance which occurs at densities much higher that than n_c is expected to produce high Bremsstrahlung enhancement due to emission occurring at high density and Temperature (Due to field enhancement effective intensity increases). More than an order of magnitude X-ray enhancement is predicted at SPR depending on the laser wavelength, angle of incidence and sub-micron structures present in Micro-Flowers. The proposed model is in general applicable to other microstructures with submicron heterogeneities revealed through SEM micrographs for estimating SPR resonance densities as well as the intensity and X-ray enhancement.

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LP16

Intense Laser Induced Ion Acceleration and their Applications in Medical Physics

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Abstract - The study of the interaction between an ultra intense laser pulse with a thin dense plasma foil is of fundamental importance for different research fields such as efficient ion acceleration, high frequency intense radiation sources, medical applications, investigation of high energy collective phenomena in relativistic astrophysics [1]. We consider the interaction of ultra-short, ultra-intense laser with ultrathin plasma layer and estimate the feasibility of accelerated ions having a bearing on the cure of oncological diseases. The proton therapy has an advantage of reducing the irradiation of healthy tissues [2]. In the interaction of long laser pulses with thin plasma layer the typical time scale of the hydrodynamic expansion of a micron plasma layer is much larger than the laser pulse duration. However, the electrons respond immediately. On this time scale the ions are assumed to be at rest. The accelerated electrons leave the irradiated surface element instantaneously. The ions respond after a time interval equal to or longer than the inverse of the ion plasma frequency. The ion layer explodes because of the intense Coulomb repulsive electric field.

In this paper we present our analytical and numerical results of laser induced accelerated ions for the possible treatment of oncological diseases [3]. The ion beam is generated as a result of intense laser interacting with plasma. In this reference we estimate laser pulse intensity, its power, pulse duration, pulse shape, number of accelerated ions, the energy gain of the fast ions and their dependence on the parameters of laser and target.

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LP17

Laser Pulse Amplification by Stimulated Brillouin Scattering in Pi Pulse Regime

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Abstract - A theoretical model of laser pulse amplification by stimulated Brillouin scattering is presented. The amplification of laser pulses by plasmas is based on coupling of three waves: two transverse electromagnetic waves, and a longitudinal plasma response. The plasma response via ion-acoustic wave called Brillouin amplification. This process requires that the resonance condition for energy (frequency) and momentum (wave-vector) is fulfilled. The laser pulse interacts with counter propagating seed laser pulse via stimulated Brillouin scattering. The seed pulse takes the energy from the main laser pulse and gets amplified via stimulated Brillouin scattering (SBS) process. The final seed pulse also gets compressed by SBS process. In operating the scheme in optimum parametric window one can develop compact plasma based amplifier which can produce ultra-intense and ultra-short laser. This technique provides damage less amplification of laser pulses. The amplification ratio achieved in this model is 94 and compression is 30. These intensities can be used as a seed intensity and by using the C3 (Cascade conversion compression) technique given by G.A. Mourou et. al.,[Optics Communications 285 (2012) 720–724], one can get the Zetta watt laser pulses. The theoretical results are compared with simulation results which are in good agreements.

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LP18

Dynamics of Confined Laser Induced Plasma: Effect on Shock Waves

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Abstract - Laser plasma induced shockwaves (LISW) in a confined geometry are very useful in understanding the shock tube problems, reshocking of plasma due to shock reflections from boundaries, vorticity production and transport, turbulence, inertial confinement fusion (ICF), etc. [1-2]. Second harmonic pulses of Nd:YAG laser (TITAN-5, 5 J, 5 Hz, 532 nm) with 10 ns pulse width (FWHM) and 200 mJ energy were used to generate plasma inside a hollow glass tube of 12 mm length and 6 mm inner diameter. The temporal dynamics of plasma expansion, shock wave reflections from boundaries and reshocking of plasma are visualized by focused shadowgraphy technique [3, 4]. An expanded and collimated 47 mm beam of He-Ne laser (632 nm, CW) was used as probe. An ICCD (Andor iStar DH-734U) camera of 14μm × 14 μm spatial resolution and 1.5 ns temporal resolution triggered by a photo diode is used to capture the shadowgrams. The shadowgrams are captured from 200 ns to 50 μs with 1 μs step size. The shockwaves emitted from plasma will reflect from both the vertical edges (±y direction) of hollow tube. The reflected shockwaves in turn were observed to interact with the plasma from both sides. The reshocking effect due to the reflected shockwaves is observed to squeeze the plasma along horizontal direction (±z direction). Due to the confinement and multiple reflections of shockwaves from the glass tube boundary, the ejected shock waves are strong and reside along ±z direction for a longer time (50 μs). We have also observed the generation of shock wave vortices at the glass tube edges due to sudden change of pressure gradient. The spatio-temporal evolution of the shockwaves were compared with that observed without any confinement. Optimizing the dimensions of the hollow tube will help us understand the generation and transportation of shockwaves for long distances without attenuation.

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LP19

Numerical Study of Laser Induced Blow-off Shock Wave From 10 µm Al Foil In Glass Confinement And Its Comparison With Experiments

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Abstract - In this work, a one-dimensional numerical simulations [1, 2] of laser induced blow-off from 10 µm Al foil has been performed considering with and without the glass confinement for the input laser energy of 500 mJ. The shock wave evolution in the confined geometry was compared with the experimental results over 0.4 – 2 µs. Experimentally, the shock waves from the rear side of the Al foil have been generated using of second harmonics (532 nm) from Nd:YAG laser having a pulse duration of 10 ns. The simulated results both with and without glass confinement clearly shows that there is a significant enhancement in the shock velocity and pressures with confinement. To understand the nature of the evolution, the simulated shock radius after breaking out from the rear side of the target are compared with the experimental results for three different geometries planar, cylindrical and spherical. The observation estimates that the shock evolves as spherical during these times, as the simulated shock radius compare favourably for this evolution. This comparison enabled to know the initial shock breakout times as well as the maximum velocity achieved by the shock wave from the rear surface. The maximum shock velocity achieved was as high as 12 km/s. Also, in order to know the scaling dependency of the shock velocity and pressure with respect to the input laser energy a parametric study has been performed over the input laser energies from 200 – 2000 mJ. This study has been carried out with particular interest to understand the critical shock conditions that can be achieved for the laser ignition of various materials for the optimized foil thickness.

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LP20

Terahertz Radiation Generation by Two Cosh-Gaussian (ChG) Laser Beams With Graphite Nanoparticles

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Abstract - In this study, terahertz radiation generation by nonlinear photomixing of two cosh-Gaussain (ChG) beams having different frequencies of ω_1 and ω_2 in a spatially modulated medium of graphite nano-particles. Here, we have consider that all graphite nano-particles are in spherical shape and having two different

configurations: (i) the electric fields of the propagating laser beams are perpendicular to the normal vector of the basal plane of the graphite nano-particles and (ii) laser beams are parallel to the normal vector of the basal plane. The electric fields of laser beams exert a nonlinear ponderomotive force due to spatial non-uniformity in the intensity. Under the influence of ponderomotive force the electronic clouds of the graphite nanoparticles acquire nonlinear oscillatory velocity. This ponderomotive force leads to the creation of a strong nonlinear current in the direction of laser polarization and at the beat wave frequency ω_T, which can generate terahertz radiation. We show that, when beat wave frequency (ω_T) ~ ω_p (plasmon frequency of the nano-particles) and the electric field are parallel to the basal plane normal, a resonant interaction of the laser beams causes intense terahertz radiation. The effects of decentered parameter (b) are analyzed for strong THz radiation generation. Analytically results show that the amplitude of THz wave enhances with decentered parameters.

LP21

Generation Of Magnetic Moment Field Due To Resonant Interaction Of Waves In Laser Induced Relativistic Plasma

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Abstract - One of the most important processes that accompany laser–matter interaction is the magnetic field generation. Magnetic fields could have a significant effect on the overall nonlinear plasma dynamics. Particularly, extremely high magnetic fields play an essential role in propagation of laser pulses, laser beam self-focusing, and penetration of laser radiation into over dense plasma. Among the various mechanisms the inverse Faraday effect is responsible for the magnetic field generation from the electron motion in the circularly polarized electromagnetic wave [1]. The original trajectories of the electrons and ions are deviated when electromagnetic wave passes through plasma and there is some gain in angular momentum, consequently magnetic moment field is being generated. During interaction with a circularly polarized laser pulse, plasma electrons absorb not only the laser energy but also the amount of the total angular momentum of the laser pulse. This angular momentum transfer leads to the electron rotation and the generation of the axial magnetic field by the azimuthally electron current [2]. In the present paper, the theoretical investigation is made to find the magnetic moment field generated due to resonant interaction of four waves, two (transverse) electromagnetic waves and two high frequency (longitudinal) electrostatic waves, in a laser induced relativistic plasma. The magnetic field excited in the plasma from a matching of frequencies of first harmonic part of four waves is obtained. The matching condition for the frequencies of electromagnetic and electrostatic waves for the excitation of moment field is satisfied in a small region compared to the largest of the wave length of the involved waves. It is shown that the inclusion of relativistic effect enhances the magnetic moment field in laser induced plasma. The moment field is numerically estimated for high intensity laser beams. This moment field may be of the order of a few mega gauss. This magnetic field may have considerable impact on transport phenomena in fusion plasma.

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LP22

Study of the Variation of Nonlinear Current in Magnetized Hot Plasma

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Abstract - When the high intensity laser interact with the plasma, due to this interaction nonlinear effects occurs and generate a nonlinear current in the plasma. We consider the beating of two lasers in the plasma which provides oscillatory velocity to the electrons. Inhomogeneous oscillating electric fields are responsible for the nonlinearity in the plasma. These nonlinear current are governed by relativistic factor [1], laser profiles [2], and intensity of the lasers [3] and so on.

In our work we have consider beating of two laser profile in magnetised and hot plasma. Cyclotron frequency influences the motion of the electron and hence nonlinear current. Temperature of the plasma provides thermal velocity to the species of the plasma. So we have study the variation of current with the applied magnetic field and temperature of the plasma as well.

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LP23

Generation Of Circularly Polarized Third Harmonic Radiation By Propagation of Two Colour Laser Beams In Plasma

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Abstract - Interest in harmonic radiation generation via laser plasma interaction has grown significantly due to wide range of applications. In general, linearly polarized laser beams interacting with homogeneous plasma lead to the generation of linearly polarized odd harmonics of the laser frequency [1]. In the last few decades significant efforts have been devoted to generation of circularly polarized harmonic radiation due to various applications such as photoelectron circular dichroism spectroscopy [2] and magnetic microscopy [3]. Since a single circularly polarized laser beam cannot generate harmonic radiation, the challenge for generation of circularly polarized harmonic radiation was overcome by using two color laser beams. Harmonic generation by two colour circularly polarized laser pulses interacting with plasma plumes has been experimentally observed [4].

An analytical study of generation of third harmonic radiation by the propagation of two colour circularly polarized laser beams co-propagating in homogeneous underdense plasma has been presented. The electric field vectors of the two laser beams are considered to be rotating in the same direction (co-polarized). Considering the mildly relativistic regime of laser plasma interaction, a perturbative technique is used to obtain the current density components oscillating at fundamental as well as third harmonic of the laser frequency with the help of the Lorentz force, continuity and Poisson's equations. The wave equation is used to evaluate the amplitude of the third harmonic radiation. It is shown that the third harmonic radiation is circularly polarized.

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LP24

Terahertz Radiation Generation by Fs Laser Pulses Propagating In Homogeneous Plasma In The Presence of Wiggler Magnetic Field

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Abstract - The interaction of intense, short two-color laser pulses with plasma can lead to a variety of wave-particle phenomena which includes generation of high order harmonics [1], attosecond laser pulses [2] and Terahertz radiation [3]. THz radiation is of great current interest owing to its ability to nondestructively analyze a wide range of materials in detail and finds applications in the field of medical imaging, material characterization, explosive detection, outer space communication and homeland security. Several simulation, experimental and theoretical analyses have been done to study the generation of THz radiation [3,4]. In the current study, terahertz radiation generation due to the propagation of a mildly-relativistic laser pulse in homogeneous plasma embedded in a wiggler magnetic field, has been analytically studied. A perturbative technique involving orders of the incident laser beam is used to obtain electric and magnetic wakefields generated in weakly magnetized underdense plasma and hence terahertz radiation, generated in the wake of the laser pulse. The wiggler magnetic field is applied along a direction perpendicular to the direction of propagation as well as the direction of polarization of the linearly polarized laser pulse. It is seen that the coupling of the slow velocities with externally applied, transverse, wiggler magnetic field leads to (on-axis) THz radiation generation.

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LP25

Axicon Laser Driven Electron Acceleration under the Influence of Axial Magnetic Field in an Ion Channel

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Abstract - A scheme of electron acceleration due to axicon Gaussian laser is presented in an ion channel under the influence of an external axial magnetic field. Due to an attractive inherent symmetry and strong longitudinal laser field of axicon Gaussian laser profile, the electrons get trapped and accelerated effectively along the propagation direction. The preformed ion channel confines the electron in the accelerating phase and the application of an externally applied axial magnetic field further increases the ponderomotive force on the electron and as a result, the electron energy is raised up to GeV energy level. Laser particle acceleration is a captivating field of research from the past few decades. The concept of plasma based acceleration was proposed by Tajima and Dawson in 1979 [1]. Electron acceleration in an ion channel is employed for imparting a significant amount of energy to electron due to the betatron resonance. The influence of ion-channel on electron energy gain has been studied by a number of authors [2]. The externally applied magnetic field also plays a crucial role in enhancing electron energy. Singh [3] has studied the electron acceleration by employing a circularly polarized laser pulse in the influence of an intense axial magnetic field in vacuum and calculated the GeV-order energy gain with low emittance.

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LP26

Pump Depletion Effects on Stimulated Raman Scattering of X-mode Laser in a Plasma

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Abstract - The saturation of stimulated Raman scattering instability of X-mode laser in magnetized plasma via pump depletion is studied. The laser excites an electrostatic wave and a back scattered side band electromagnetic wave. The coupled mode equations are obtained, including nonlocal effects, and solved numerically to study the saturation of instability via pump depletion. Equations for the action and action conservation have been obtained. Equations for the action conservation are normalized and are solved to obtain the periodic variation of wave amplitude in time.

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LP27

Nonlocal Effects in Weibel Instability in A Plasma

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Abstract - A nonlocal theory of Weibel instability of a relativistic electron beam propagating through a plasma channel, is developed in the slab geometry. For beam density greater than the plasma density ( ), the beam of spot size pushes the plasma electrons out of the beam region ( ). It also imparts return velocity to plasma electrons in the outer region. The relative drift between the inner region beam electrons and outer region plasma electrons drives the electromagnetic perturbation with transverse wave vector comparable to the spot size of the beam. The growth rate increases with the parallel wave number and tends to saturate. For typical parameters the growth rate of the instability acquires values comparable to a fraction of the plasma frequency.

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LP28

Study of Laser Pulse Width Dependence on Ablation of Thin Film and Plasma Plume Propagation

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Abstract - Effect of laser pulse width on plasma plume formation and its expansion into the background gas is investigated for thin film sample under the rear ablation geometry, employing 10 ns, 200 ps and 100 fs laser pulses respectively. The plasma plume is diagnosed with multiple diagnostics like fast imaging, spectroscopy and Langmuir probe. We observe that the plume directionality, splitting and expansion significantly depend on the laser pulse width. The plume expansion behavior is explained by appropriate models. We also observe that the laser pulse width along with the film thickness plays a major role in deciding the nature of plasma plume expansion.

LP29

Enhancement of Terahertz Radiation by Resonance in Arrays of Nanoantennas

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Abstract - The paper presents the theoretical analysis of terahertz (THz) radiation generation in periodic array of metallic nanoantennas. Two laser beams incident normally on the array of vertically aligned carbon nanotubes (CNTs) exert ponderomotive force to generate nonlinear current at THz frequency. Wiggler magnetic field is applied externally, to make this phenomenon resonant. The impacts of various antenna and laser parameters are explored to enhance the power conversion efficiency.

LP30

Terahertz (Thz) Generation by Laser Beating in Ripple Density Magneto-Plasma

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Abstract - Here, we numerically investigate the terahertz pulse generation by propagation of p-polarised laser pulses, having different frequency, incident obliquely on x-z plane in rippled density magneto-plasma. Major process consists of ponderomotive force associated with transverse and longitudinal field excitation and coupling of oscillatory velocity with preformed density ripple. Which produce a non-linear current density at difference frequency. This nonlinear current density urges a wave whose frequency depends on the difference frequency of the lasers is in THz range. The applied magnetic field and density ripple of suitable wave number provides the phase matching which further helps in the efficiency enhancement. Our results show that for a set of plasma parameters the amplitude of emitted THz wave decreases with the THz frequency and increases with plasma frequency for an optimum value of incidence angle. In our case at laser intensity ~7×1014 W/cm2, and 30%, density ripple the maximum normalized amplitude of emitted THz radiation is reached up to 0.045.
Introduction Although plasmas are generally considered as unstable and hardly controllable media, during an ultrashort laser pulse this plasma only expands by a small fraction of the light wavelength, and leading to the high intensity specular reflection. The interaction of an intense laser beam with plasma offers various wide ranging applications of THz in technology and science. These potential outcomes of utilizing THz radiation in THz imaging, spectroscopy, communications technology, food and material sciences, remote identification of explosive, etc. are actively studied by various researchers1–4. The present communication deals with the scheme of generating terahertz radiation by the nonlinear interaction of high power laser beam with rippled density plasma.

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LP31

Investigation of Laser Absorption on Self-Focusing and Self-Compression of Ultra-Intense Short Laser Pulses in Magnetized Plasma

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Abstract - In this paper, the effect of laser absorption on the self-focusing and self-compression of an intense Gaussian laser pulses in magnetized plasmas have been studied under relativistic-ponderomotive regime. Nonlinear differential equations have been set up for self-focusing and self-compression of the laser pulse in magnetized plasmaunder laser absorption effect using WKB and higher-order paraxial-ray approximations. These equations have been solved numerically for typical laser and plasma parameters.The results have been compared with paraxial-ray region and only relativistic nonlinearity.The result shows that laser absorption effect significantly mitigates self-focusing and self-compression of laser pulse in magnetized plasma. Moreover, self-focusing and self-compression of laser pulse enhanced when higher order paraxial-ray approximation with relativistic-ponderomotive nonlinearity have been taken into the account. This study may be useful in various laser plasma interaction based applications such as particle acceleration, terahertz generation and high harmonic generation.

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LP32

Self-focusing of Q-Gaussian Laser Beam in Relativistic Magnetized Plasma

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Abstract - In the present paper, we have studied the self-focusing of q-Gaussian laser beam in plasma by taking into account relativistic nonlinearity. The propagation characteristics of the q-Gaussian laser beam is studied while taking into account static magnetic field which modifies the quiver motion of electrons as the natural frequency of the oscillating electron changes on addition to cyclotron frequency as the laser beam propagates in the plasma. The beam width parameter is derived and plotted for the normalized distance of propagation using well known WKB and paraxial ray approximation. Various parameters are studied like q-value, intensity and magnetic field which influence the beam width parameter during its propagation.

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LP33

Channel Formation by a Non-Gaussian Laser in Plasma

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Abstract - A laser pulse propagating through plasma exerts ponderomotive force and creates a low-density plasma channel. The usefulness of the low-density plasma for the main pulse propagation has been investigated. The guided propagation of the main pulse without getting diffracted upto 24 Rayleigh length has been seen[1]. These channels are of great importance for enabling long distance propagation of the laser which is a prerequisit for various laser-plasma interactions [2].

Based on analysis of spot profile of Vulcan Petawatt laser [3], the beam intensity profile is seen to be characterized by a q-Gaussian profile of the form $f(r) = f(0)\left(1 + \frac{r^2}{qr_0^2}\right)^{-q}$,where r_0 is constant beam width. A real parameter 'q' represents the deviation from the Gaussian profile. In case of a nonGaussian profile, the parameter has smaller (finite) values. Long tails are a characteristic in case when 'q' is small. With increase in value of 'q', the intensity distribution gradually converges to a Gaussian profile. In the perturbation approximation $\Delta n << n_0$, where Δn is perturbed electron density; the growth of plasma density is analyzed and an expression has been derived. The effect of tail of intensity distribution has also been investigated.

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LP34

Optical Emission Spectroscopic Studies of Ultrashort Laser Produced Graphene Oxide Plasma

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Abstract -Optical emission spectroscopy (OES) is a reasonably accurate and non-intrusive technique for measuring various plasma parameters. Herein, we report the expansion dynamics of ionic species present in the graphene oxide (GO) plasma generated by an ultrafast laser (120fs, 800nm, 10Hz). Natural graphite powder was used to synthesize graphene oxide (GO) using the modified Hummers' method [1]. The expansion dynamics of the GO plasma was characterised using space resolved optical emission spectroscopy [2]. Plasma parameters like electron temperature (T_e) was measured by Boltzmann plot method and the electron number density (n_e) was estimated using stark broadened profiles of isolated lines of the optical emission spectra

[3,4,5]. These studies have potential applications in multiple areas like ion acceleration, pulsed laser deposition, laser driven plasma accelerators, LIBS etc.

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LP35

Terahertz Radiations from Hollow Sinh Gaussian Laser

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Abstract - The terahertz (THz) radiations (1–10 THz) have enormous potential in biological imaging, remote sensing, material characterization, chemical and security identification [1-4]. We propose a new scheme of Terahertz radiation generation by beating two hollow sinh Gaussian beams having different frequencies, same electric field amplitudes in pre plasma with spatially varying periodic density. Analytical calculations are carried out incorporating the effect of electron temperature and electron neutral collisions. The laser exerts a non linear ponderomotive force on the plasma electrons which impart an oscillatory velocity to the electrons that couples with density ripple to generate non linear current density that results in Terahertz radiations generation.

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LP36

Laser Pulse Propagation in a Plasma under Collisional Absorption effects in Weakly-Relativistic Regime

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Abstract - Absorption of laser energy in plasma has been a curial issue, which has been, attracting continued interest ever since the invention of lasers. Laser absorption is closely related to several applications, namely, the inertial fusion energy research, generation of high energy particles, and creation of high energy density conditions relevant to some astrophysical environments. In the range of laser intensity around 10^{15} W/cm^2, the laser absorption can be dominated by inverse bremsstrahlung or collisional absorption during the laser–solid interaction, where the laser pulse compression is very important in determining the particle energy during acceleration. We investigate the propagation of laser pulse in plasmas to estimate the pulse compression based on collisional absorption under weak-relativistic ponderomotive nonlinearity. The physical mechanism behind it is analyzed theoretically. We have analyzed the longitudinal pulse compression in 1D geometry, assuming a uniform transverse distribution of the irradiance profile. An equation for the dimensionless pulse compression parameter has been derived and the effects of absorption on laser pulse compression have been studied. The laser pulse compression is reduced due to the collisional absorption in plasmas. Fast pulse dispersion is also observed due to pulse absorption, which is obviously associated with the strong energy attenuation in plasmas in this regime. A picosecond pump pulse compression is reduced to about 25% due to the collisional absorption. For large absorption coefficient, the nonlinearity associated

with the laser absorption in plasmas is affected severely and the pulse compression is reduced. The present work is motivated by the need to gain understanding of laser pulse propagation in a collisional plasma and its implications on particle acceleration by high-intensity laser irradiation of targets. The results, in particular the compression of the laser pulse, have taken a further step towards a broad application of laser-plasma interaction in a large variety of fields such as accelerator physics and electromagnetic radiation generation.

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LP37

Terahertz Radiation Generation By Beating of Laser Beam and Its Second Harmonic in A Magnetized Plasma

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Abstract - A scheme is proposed for the generation of terahertz (THz) wave by non linear mixing of laser beam and its second harmonic in corrugated magnetized plasma. Laser exerts a quasistatic ponderomotive force on plasma electrons. Due to this density perturbations arise. These perturbations couple with plasma ripples (wave number q) and generates density oscillations at $(2\omega_1, 2k_1 - q)$ and $(\omega_1 - \omega_2, k_1 - k_2 - q)$ incident on plasma surface couple nonlinearly through the ponderomotive force. Density oscillations couple with oscillatory velocities of electrons at ω_1 and ω_2 and excite terahertz wave at phase matching conditions. The terahertz electric field of value $8\times10^6 V/m$ is obtained at applied magnetic field~175kG.

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LP38

Coherent Radiation Generation by Laser-matter Interaction

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Abstract - We propose a scheme for coherent radiation generation by the interaction of two laser beams in axially magnetized plasma. Plasma-based schemes supersede the other mechanisms, such as semiconductors, due to the higher efficiency of the emitted radiation. When the laser frequency exceeds the plasma frequency, it allows the laser to propagate in a plasma. We here assume two laser pulses enter in the plasma, which beat together and exert a slowly varying force, called the ponderomotive force, on the plasma electrons. Due to the small mass of electrons, the ponderomotive force acts primarily on electrons[1]. Because an electromagnetic wave carries momentum, a force is exerted onto the plasma charged particles whenever the direction of the wave is changed. We revisit the beating mechanism along with the use of spatially periodic density in the plasma where electron-neutral collisions also occur [2]. The transverse component of the force evolves due to

the intensity variation that gives rise to the component of nonlinear oscillating current [3]. This current led to the strong, coherent radiation generation. Through analytical calculations, we obtained that by increasing beating frequency, the efficiency of radiation decreases and intensity of the emitted radiations is found to be highly sensitive to the beam order.

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LP39

Enhanced Terahertz Radiation by Two-Color Laser Pulses in Ionizing Gas

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Abstract - In recent, the rapid growth of terahertz (THz) sources has opened up new frontiers in scientific and technical explorations. The role of THz technology has now gathered tremendous momentum in the fields of medicine, communications, security and many others. All the applications demand a broadband, scalable, table top source of THz radiation. Of all the methods demonstrated so far, the interaction of two colour ultra-short laser produced plasma in ambient air has satisfied most of these demands. Moreover, the concern of material damage has also been completely annulled in plasmas. Though the method is a well-established one, however, recent literature available does not offer a detailed microscopic picture of the underlying phenomena responsible for this observation barring a few attempts.

In this paper, we address the core issue of THz generation from the interaction of ultra-short laser pulses with ambient air. The role of two colour pulse with single colour is thoroughly investigated using 2D-Particle-In-Cell simulationusing ionizing helium gas. We have shown that the terahertz radiation is enhanced when we switch from single colour laser pulse to two colour laser pulses. Generally, terahertz radiation is associated with transverse and longitudinal plasma waves generated by the intense laser pulse. Here, we have incorporated the importance of photocurrent mechanism and used it to explain the enhancement in terahertz radiation. Two colour laser pulses generate asymmetric laser field which leads to non-zero drift velocity and hence a stronger transverse plasma current is produced. The transverse plasma current causes terahertz radiation with polarization same as that of fundamental laser field. The amplitude of terahertz radiation is about ten times greater as compared with the case of single laser pulse. The terahertz radiation can be further enhanced by using mid-infrared laser pulses and their second harmonics. The higher wavelength laser pulses increase the average drift velocity and consequently the plasma current. With two-colour laser pulses, terahertz field strength of GV/m can be generated with laser intensity of around $10^{15}\,W/cm^2$.

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LP40

Study of Bubble Dynamics in Laser Wakefield Acceleration in Pettawatt Regime.

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Abstract - The bubble regime of the laser wakefield acceleration is one of the most recent and promising mechanism for generating quasi-monoenergetic electron beams. In this work, we propose to study the dynamics of bubble (a wake structure devoid of electrons created in underdense plasma by a highly-intense ultrashort laser pulse) in petawatt regime. The dependence of the electron beam energy and the quality of the electron beam on the shape of the bubble is the main motivation behind this work. The bubble length as well as bubble shape have been investigated using PIC simulations. The evolution of bubble with time, and the correlation of bubble length (longitudinal and transverse radius) with the intensity of laser pulse have been revealed in this study. It has been observed that the bubble longitudinal length grows until the dephasing length. The rate of change of bubble dimensions can be estimated by various determining factors such as the laser pulse focusing, the beam loading, the residual electrons, and the bubble velocity. It has also been confirmed that the shape of the bubble cannot be predicted using fixed shape models as spherical or elliptical. Simulations unveil that as the bubble traverses in plasma, it evolves from spherical shape to the highly elliptical shape. And, as it approaches the dephasing length, the eccentricity decreases further. Consequently, the self-injection of plasma electrons in the bubble is seriously affected by the bubble evolution. Comparison of the electron energy gain at different intensities of laser pulse has also been provided. The study has been carried out using two-dimensional Particle-in-Cell simulation code.

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LP41

Laser Wakefield Electron Acceleration in a Preformed Parabolic Plasma Channel by Two Laser Pulses

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Abstract - In laser-wakefield acceleration, an intense laser pulse induces electric field gradient of the order of GV/m. Plasma wave driven by the radiation pressure accelerates energetic electron beams and hence, offers compact electron accelerator in comparison to a conventional radio-frequency accelerator. The interaction distance can be extended using a pre-formed plasma density channel in a compact, high gradient, all-optical laser accelerator. The short propagation distance of the focused laser pulse limits the acceleration distance resulted in low-energy beams with large electron energy spread. Guiding a relativistically intense laser pulse over several diffraction lengths demonstrated using plasma channel, which has a minimum density on the axis of propagation. Simulations are performed using a preformed radial parabolic plasma channel driven by two terawatt laser pulses with a pulse delay of less than recombination time (~ns), which shows a significant increase in laser-driven electron energy. Particle in cell simulations shows the generation of high-quality electron bunch with low energy beam spread. Addition of the second pulse after a delay results in an increment of electron energy and extending the lifetime of the plasma channel.

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LP42

Control on Terahertz (THz) Radiations by Laser Profile Indices

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Abstract - THz radiations have various scientific and commercial applications such as medical imaging[1], topography[2], remote sensing[3], chemical and security identification[4], outer space communication and submillimetre radars[5], spectroscopic identifications of complex molecules, explosive detection, terahertz time-domain spectroscopy (THz-TDS) [6], etc. We report new scheme for bright and efficient THz generation by photomixing of CW lasers with different spatial profile, frequency and wave number in the plasma. The effect of laser beam quality, laser beam profile on field distribution and amplitude of emitted THz radiation is investigated. It is observed the efficiency in this scheme is very high.

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LP43

Terahertz (THz) Radiation Frequency Control by DC Magnetic Field in a Laser Beating with nano-cluster

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Abstract - THz radiation have enormous applications in material characterization, imaging, topography, remote sensing, chemical and security identification[1-5]. Thus, development of new high intensity THz sources and detectors are the crucial area of research. We propose THz radiation generation by optical rectification of CW CO_2 laser in nanoclusters. The effect of laser beam quality and profile on emitted THz radiation is investigated. Presence of DC magnetic field shifts the resonance condition and help in THz frequency tuning.

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LP44

Thz Generation by Asymmetric Laser Pulses in an Inhomogeneous Plasma

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Abstract - This research presents a scheme to generate enhanced THz radiation by two asymmetric laser pulses in a density rippled plasma. Two asymmetric lasers of sharp rising intensity are employed to excite a stronger nonlinear current at plasma frequency in plasmas with longitudinal density ripple. The lasers exert a non-linear ponderomotive force along the transverse direction. The electron oscillatory velocity associated with the asymmetric lasers couples with the density ripple to generate a stronger transient transverse current that drives THz radiation. We provide numerical analysis to optimize the THz conversion efficiency for current laser-plasma parameters. The effect pulse asymmetricity on THz emission is discussed. By optimizing the plasma density and laser intensity, a significant change in magnitude of THz field amplitude and its conversion efficiency is found.

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LP45

Relativistic Laser Plasma Interaction: EM Solitons and Post-Solitons

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Abstract - Laser plasma interaction has been a fascinating field of study for decades and with the invent of super-intense lasers, several new phenomena are being revealed. Electromagnetic solitons and Post-solitons are among them which are created in the plasma in the wake of a high-intensity ultrashort laser pulse [1-2]. Basically they are formed by radiation trapping in the plasma which creates a cavity which on the ion time scale evolves into post-solitons. These post-solitons are bubble or density depleted regions and have been observed to depend upon laser polarization [3].

In the present paper, the evolution of EM solitons and post-solitons have been evaluated for various laser specifications such as polarization, pulse profile, pulse duration with a range of plasma densities. The ion acceleration during the post-soliton evolution has been studied. The effect of negative ions in the plasma during the formation of EM solitons and its evolution has been studied. Both theoretical and Particle-in-Cell (PIC) simulation results have been presented.

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LP46

Variational Theory of Self Action Effects of Cosh-Gaussian Laser Beams in Plasma Channel Created by Ignitor Heater Technique

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LP47

Self Action Effects of Multi-Gaussian Laser Beams in Collisional Plasmas and Their Resembleness to Kepler's Central Force Problem

SANDEEP KUMAR, Sandeep

LP48

INTERACTION OF COSH-GAUSSIAN LASER BEAM WITH WEAKLY RELATIVISTIC-PONDEROMOTIVE COLD QUANTUM PLASMA

KUMAR, Harish

SIMULATION AND MODELING FOR PLASMAS (CM)

S-5-O-05

Generation of High Density and Energetic Electron Beam from Pseudospark Discharge Based Plasma Cathode Electron Source

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Abstract - Pseudospark discharge based plasma cathode electron (PD-PCE) sources are novel way to generate high density ($\geq 10^4$ A/cm^2) and energetic (~20keV) electron beams with fast current rise ~10^{12} A/s and power density ~10^9 W/cm^{-2} [1-2]. The generated electron beams are self-focused and propagated without use of any external guiding magnetic field [1-2]. The exceptional properties of pseudospark discharge based sources make them suitable for plasma switches, electron beam generation, EUV/X-ray radiation, microwave sources etc [1-4]. The PD-PCE sources are primarily comprised of hollow cathode (HC) and/or planner anode and classified in single and multi-gap arrangements [1-3]. The high energy and quality e-beams are generated in a multi-gap PD-PCE source arrangement [5-7]. In fact, electron beam generation is a complex discharge process which is influenced by geometrical and operating parameters [5-7]. The paper presents the complex discharge mechanism for the generation of e-beam with different discharge phases in single-gap as well as multi gap PD-PCE source with the help of 2-D PIC simulation code. The study has been carried out for different HC geometries, seed electron energies, cathode aperture sizes, gas pressures, for applied voltages 20-40kV. It has been observed that operating parameters strongly influence the peak current and size of e-beam. The size of generated e-beam also depends on the potential profile in the PD-PCE source. Increasing the gas pressure, results an early appearance of e-beam at anode surface with higher peak current, while for higher cathode apertures, the peak current of electron beam reduces. Experimental study has also been carried out at different operating conditions to validate the simulated results.

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CM1

Optical Injection Using Colliding Pulses For Laser Wakefield Accelerator

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Abstract - Self-injection of electrons in Laser Wakefield Acceleration (LWFA) is a highly non-linear process which depends on driver evolution which varies from shot to shot. Hence it is difficult to control the electron beam parameters like peak energy, energy spread and emittance. Various novel techniques like ionization induced injection, colliding pulse injection etc. are being explored to achieve better control over the beam parameters. In this paper we show the 2D PIC simulation of colliding pulse injection (CPI) method. In CPI a driver pulse generates the plasma wakefield, but its intensity is lower than the self-injection threshold, another counter-propagating pulse of lower intensity collides with the driver pulse generating a slow beat wave which pushes the background plasma electrons into the accelerating phase of the wake field. Thus the injection is localized, giving rise to nearly mono-energetic beam with enhanced beam parameters.

In this work we show the guiding of the laser pulse in a parabolic radial density plasma channel of the form $n(r)=n_0+\Delta nr^2/w_0^2$, where $\Delta n = n_e(r=w_0) - n_e(r=0)$ is the channel depth and w_0 is matched spot size. Since the driver laser power (a_1~2) is kept less than the critical power for self-focusing to avoid the self-injection, a plasma channel is used to guide the driver pulse over more than 5mm length ($z_R=\pi w_0^2/\lambda$~140 μm). The second pulse (a_2~0.5) was made to collide with the driver pulse at an angle of 15 degrees from opposite direction. For the above laser parameters we could get a few pC charge beam with a mean energy of about 300 MeV with a percent level energy spread. The low energy electrons which formed a major part of the self-injected beam were completely absent in this case. Various parameter scans like the collider pulse intensity, delay, angle w.r.t. the driver pulse were done to optimize the accelerated electron beam parameters. The total injected charge was seen to depend sharply on the parameters of two laser pulses. It was also shown that the peak energy can be controlled by varying the distance at which the collision occurred.

CM2

A Study on Plasma Sheath Formation With The PIC Code

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Abstract - Emission of electrons from the surface contributes to a major role in studying the plasma wall interaction relevant to both laboratory and astrophysical phenomena. Such emission can be attributed to different mechanisms such as photoelectron emission, secondary electron emission (SEE), thermionic emission etc. In any kind of plasma wall interactions, the plasma sheath plays an important role having a highly nonlinear dynamics.

We aim to simulate such a plasma system with the Particle in Cell (PIC) Code and study its characteristics as well as its influence on the plasma sheath formed in the presence of electrons emitted from such surfaces. Here we present the simulation results obtained with our one dimensional electrostatic PIC model that explains the behavior of such plasma system which may be found both in laboratory as well as in space such as the lunar surface.

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CM3

Simulation Of Multicusp Magnetic Field Effect On Hydrogen Plasma Confinement For Rf Based H^- Ion Source

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Abstract - Multi-cusp magnetic field configuration has been found to be the most suitable technique for plasma confinement for generation of H^- ions through volume production in H^- ion sources. It provides sufficient field free region to generate uniform and dense plasma along the extraction axis that can produce high and stable negative ion current with low emittance, in the presence of appropriate filter magnetic field. Multicusp H^- ion source has been developed at RRCAT using a 2 MHz external RF antenna source [1]. This ion source will serve as pre-injector in a high current proton linac for pulsed Spallation Neutron Source (SNS) due to its high operational life time. In this paper, a 3D-simulation of inductively coupled hydrogen plasma discharge in Hexa-pole & Octu-pole multicusp field configurations will be presented. The 3D-simulation has been carried out using FEM based multi-physics COMSOL software [2, 3]. The magnetic field generated due to multi-cusp geometry is simulated using AC/DC module of the software [4]. Subsequently confinement of plasma through the magnetic field is simulated and post-processed using the plasma module of COMSOL. The multi-pole magnetic field and plasma confinement analysis of above configurations are performed considering samarium cobalt(Sm-Co) permanent magnets for optimum design of RF based ion source to get desirable H^- ion beam current [5].

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CM4

Electron Acceleration By Laser Incidence On Grating Surface At Grazing Angle

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Abstract - We have carried out 2D simulation study towards generation of energetic electron bunches by the interaction of a high intensity (>10^{19}W/cm^2) ultra-short (25 f sec) linear polarized laser pulse with “grating”. For grazing incidence angle of less than 10 degrees to grating surface, electrons of energy almost 2.5 times more than the maximum energy obtained by electrons with laser incidence angles closer to the resonance angle is observed. Parametric studies have been carried out to further optimize grazing incidence angle on the grating surface to deduce conditions of maximum energy electrons and flux. As the grazing incidence angle increases from a few degrees to higher value, the electrons maximum energy initially increase with angle and subsequently it starts decreasing, the flux of high energy electrons slightly decreases with increase in maximum energy of electrons. It is found that 5 degree grazing incidence angle is optimum and the corresponding maximum energy of electrons is 63.5 MeV.

CM5

2D Simulation Of Electron Transport In Magnetized DC Glow Discharge Using COMSOL Multiphysics

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Abstract - 2-D COMSOL Multiphysics model of a DC glow in a parallel-plate configuration with and without magnetic is presented. Argon DC glow discharge model has been developed at a pressure (P) ranges from 1–10 Pa, at discharge gap equal to 6 cm and Magnetic field induction B = 0 to 7 mT. The model has been built on the basis of continuity equations for electron and ion fluids as well as anisotropic drift-diffusion equation. The electron mobility became a tensor quantity in presence of magnetic field its value depends on direction of magnetic field [1]. In present research work, COSMOL simulations are focused on calculations of mobility component parallel (**μ||**) and perpendicular (**μ**□) to magnetic field. In absence of magnetic field the mobility is scalar as well as Electron temperature (Te) decreases with increase in pressure (P). In presence of magnetic field the parallel component of electron mobility is remains same but perpendicular component of electron mobility reduced and electron temperature increases with increase in pressure.

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CM6

Quasi-steady States of Toroidal Pure Electron Plasmas: A Numerical Approach

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Abstract - Pure electron plasmas are routinely confined in quasi-stable states in cylindrical Penning-Malmberg traps wherein the radial confinement is provided by the uniform axial magnetic field and axial confinement is achieved by the electric field through the end plugs [1] . Existence of quasi-stable states of pure electron plasmas in an inhomogeneous magnetic field, for example in a toroidal field, is an fundamental question not answered yet. Particle-in-cell (PIC) simulations are known to be handy in addressing such questions [2].

In the present work, a 2D3V PIC code PEC2PIC [2] has been generalized to 3D3V to address the existence of quasi-stable states of pure electron plasmas in a toroidal field at small aspect ratios, preliminary findings of which will be discussed.

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CM7

Implementation of Wave Launching Port in 3D Particle-in-Cell (PIC) code PASUPAT

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Abstract -Electromagnetic wave launching ports are necessary in a Particle-In-Cell (PIC) codes to simulate many realistic problems viz. Laser-Plasma interaction, Flash X-ray source, High Power Microwave devices, scattering of electromagnetic fields from objects etc. We have implemented such wave launching port in our fully electromagnetic three dimensional relativistic code PASUPAT. In this presentation, we shall discuss the algorithm used in construction of port along with validation results and applications.

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CM8

Effect of Intensity on Spatio-Temporal Evolution of Laser Induced Plasma in Air

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Abstract - A two dimensional numerical investigation of laser induced plasma (LIP) in air at ambient pressure of 1.0 atm is performed using FLASH radiation hydrodynamic code [1] for three input laser intensities in the range of $5 – 50 \times 10^9$ W/cm^2. The simulation was performed over a duration of 20 μsec for a laser beam of 10 ns (FWHM) pulse width, excitation wavelength of 532 nm focused to a spot diameter 500 μm. The simulations were compared with that of the experimental results. The plasma expansion is observed to be more in direction opposite to the laser beam when compared to that in the laser propagation direction leading to the asymmetric expansion [2]. The experimental observations of asymmetric plasma expansion and the resultant shockwaves are simulated with reasonable accuracy. The plasma rolling and splitting is observed in the plasma core (PC) because of hydrodynamic instabilities where very high temperatures in the range of 10^3-10^5 K exist. The evolution of mass density and plasma were in accordance with the existing literature [3]. The asymmetric expansion of the plasma, shock velocities and length of plasma expansion is observed to be increasing with the intensity of the laser beam which is due to increase in laser absorption at the focal region [4] and are in tune with the experimental observations [2] and simulations performed using other codes.

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CM9

Numerical Simulation of Plasma Transferred Arc Characteristics Using Fourier Transforms

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Abstract - Nano sized powder of various materials is in great demand due to its varied potential applications such as: Catalysts, Solid Rocket Fuel, Synthetic Bone, Conducting Paste, Magnetic Tapes & Fluid, Targeted Drug Delivery, Metallic Paint, Sintering Aids, and Transparent Polymers. With increasing demand in each of these fields, the necessity for an efficient technique for Nano Powder generation is inevitable. One of the effective methods to produce Nano Powder in large quantities is to evaporate the feed raw material using a Transferred Arc plasma and collect the powder after the vapor condenses losing temperature to the ambient atmosphere. The collection zone plays a vital role in the quality (smaller particle size and narrower size range) of the product. Here, we have reported a numerical simulation to map the temperature profile of the entire nanoparticle generation system. The simulation has been performed over the entire domain taking into consideration: the heat supplied by the Thermal Plasma Arc, the heat absorbed by the material to be evaporated, the heat lost by the evaporated vapor to the ambient atmosphere and the change of plasma parameters due to the presence of evaporated vapor within plasma and so on. This numerical simulation has been performed to solve the Coupled Navier Stokes equation with that of Maxwell's taking into consideration the phase transfers happening while evaporation and condensation. Similar work has been performed and reported by others [1-2] by solving these equations using Finite Volume Methods (FVM). But using Fourier Transform effectively transforms the Partial Differential Equations to simple Numerical Integral equations. These are quite easily solved over the entire domain while not using so much computational power as that of FVM.

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CM10

Numerical Characterization of the Plasma Arc with Ar-CO2 Mixtures

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Abstract - High temperature plasma arcs find its applications in various fields like welding, cutting, metallurgy, waste treatment, nanoparticle synthesis etc. and based on the applications, plasma forming gases (Ar, N_2, He, or mixtures of gases) will be chosen. Arc properties such as temperature, velocity, current density, power and arc heating efficiency depend on the plasma gas used. The main disadvantage of using these gases is either costly or poor heat transfer efficiency. CO_2 gas is cheap and has high enthalpy and thermal conductivity as air. Since utilization of CO_2 to generate plasma will not pollute the environment, the use of CO_2 in the field of plasma material processing has been growing recently. However, it is necessary to understand the characteristics of the plasma arc produced with CO_2 and Ar-CO_2 mixtures for achieving better process efficiency. A 2D axi-symmetric model was developed to study the properties of the plasma arc produced with Ar, CO_2 and their mixture of various ratios at atmospheric pressure. The temperature dependent thermo-physical properties were used to solve governing equations such as energy, momentum, mass continuity as well as scalar and magnetic vector potential equations. The arc properties were studied for different arc currents and Ar-CO_2 mixtures in surrounding air atmosphere. The arc heating efficiency (the amount of heat energy transferred to the anode material from plasma) for all plasma forming gases were calculated and compared. As per the prediction, plasma with 75%CO_2+25%Ar has highest power and 100% CO_2 has highest arc heating efficiency among the other combination of Ar and CO_2 gases in both the arc currents. The present model was validated using already published results.

CM11

In-flight particle behavior in CO2 plasma jet – a numerical study

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Abstract - Generally, the properties of plasma forming gas play a major role in plasma processing of materials. Since CO_2 gas has higher enthalpy and thermal conductivity, it is expected to have higher process efficiency in plasma material processing. Hence, it is necessary to understand and verify the heat transfer process in CO_2 plasma. In this study, a two dimensional axi- symmetric model is developed to simulate the behavior of the particles injected into the CO_2 plasma jet under different operating conditions. Plasma-particle interactions are modeled by coupling the Navier-Stokes equations for plasma flow and Lagrangian equation of motion as well as heat balance equation for particles with one-way coupling between the plasma flow and particle.The temperature and velocity distributions of CO_2 plasma are simulated and compared with the same of Ar plasma. In order to predict the heat transfer efficiency of the CO_2 plasma jet, particles such as tungsten and copper with different particle sizes (20-100 μm) are considered. The particle temperature, velocity and residence time are determined during its in-flight in the plasma. The heating efficiency of the CO_2 plasma is higher than that of Ar plasma under the same operating conditions. In the downstream, CO_2 plasma jet has uniform temperature in larger volume, which is the preferable condition for material processing, than Ar plasma jet.

CM12

Numerical Studies On The Plasma Arc With Central Gas Injection

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Abstract - The transferred arc plasma generated between rod like cathode and crucible anode is used in industries for wide variety of material processes. The gas injection through cathode is expected to transfer more heat energy from plasma to the material through convection. It is important to understand behavior of the arc formed inside the crucible to improve process efficiency. Since measurements on plasma arc inside the crucible are complicated, numerical model is constructed for the study. Two-dimensional axi-symmetric model of transferred are plasma formed between rod like graphite cathode and graphite crucible anode with injection of working gas through the central-hole of cathode is developed. The computational geometry used is similar to the lab scale experimental set-up. The argon arc is simulated for the electrode gap of 10 mm to 25 mm and electric current of 150 -200 A. The set of governing equations is solved simultaneously by finite volume method. It is found that the arc structure depends on the balancing forces (electromagnetic force and gas dynamic forces) as well as configurations [1]. For higher gas flow rates, the gas flow through the cathode is strong enough to push the arc root attachment from the center of the anode bottom and the plasma covers large volume of the crucible. Irrespective of the gas flow rate, arc current, and arc length, the higher arc heating efficiency is achieved when the arc root attachment starts to move away from the center of the anode/arc voltage is minimal [1]. At higher gas flow rates, the anode arc root attachment shrinks and increased arc pressure close to the anode starts to push the plasma flow upstream. For the cases of longer arcs in which the electromagnetic force is strong enough to maintain the arc root at the center of the anode bottom, the gas dynamic force up to certain flow rates cause structural rearrangement on the arc so that all the forces are balanced.

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CM13

Burning Plasma Simulation With Alpha-Particle Heating

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Abstract - To achieve self-sustained ignited operation in a high energy Tokamak, it is important to understand and maximize the energy confinement time, which falls in the domain of transport theory. To analyze and understand dynamics of plasma in Tokamak, performing a one-dimensional transport simulation is still one of the best approaches. In our work we focus on burning plasma simulation and study the alpha particle heating in high energy Tokamaks like ITER. Transport simulations can be performed by solving 1D transport equations using codes such as LCPFCT (Laboratory for Computational Physics Flux-Corrected Transport) [1], which is used to solve 1D generalized coupled continuity, momentum and energy equations along with Maxwell's equations. The transport equations are solved in flux coordinates by coupling with 2-D tokamak equilibrium. In this model, the effects of fusion reactions, coulomb collisional losses, radiation losses, alpha-heating, auxiliary heating and neo-classical Ware pinch are included. This will predict the performance of tokamak based fusion reactor for obtaining the steady state operation. This model is being developed and will be bench marked with published results. This will be use to predict the performance of SST2-like [2] and ITER-like [3] cases and results will be presented in this paper.

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CM14

Simulation Study of High Current Density Miniaturized Pseudospark Based Sheet Electron Beam Source

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Abstract- As the frequency increases, it becomes increasingly difficult (if not impossible) using conventional electron beam sources to focus and form high current density, high quality sheet electron beams through the small size interaction region of the high frequency vacuum electron devices (VEDs) [1]. This is because the sheet-electron beam exhibits disruptive diocotron instability due to E × B velocity shear effect during its propagation through a uniform axial magnetic field. Therefore, plasma based sheet-electron beams are quite useful in generating high power and high frequency microwave signals which eliminates the requirement of external magnetic field [2]. For efficient generation of high frequency microwave signals, geometrical design parameters of electron beam source play an important role. In this paper, design parameters of sheet beam plasma cathode electron gun have been optimized. The diameter (D) to length (L) ratio of hollow cathode as well as beam aspect ratio for efficient sheet electron beam generation has been analysed using COMSOL Multiphysics software in an argon gas environment. The D/L ratio has been varied from 0.1 to 10 while beam aspect ratio has been varied from 5:1 to 12:1 to analyse the beam parameter like beam accelerating potential, beam current density, etc. The results for optimized value of D/L and beam aspect ratio will be presented.

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CM15

Impurity Modelling For The Study Of Start-Up And Burn-Through Phases In Tokamaks With The 0d Code

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Abstract - Plasma start-up in Tokamaks requires high loop voltage (energy source), induced using Ohmic coils, in the pre-filled gas inside the vacuum vessel. This energy needs to be driven through it as quickly as possible in order to minimize the energy loss and assure maximum ionization. Losses can occur in various ways such as transport driven heat and particle loss from plasma, bremsstrahlung radiation, ionization, recombination and equilibration. Thus, in order to achieve a successful start-up, it is essential to maintain energy balance so that the radiation and ionization barrier is successfully overcome during the burn-through phase with minimum possible amount of energy [1]. Start-up failures are mostly due to plasma contamination by impurities originating from first wall. Carbon (C) and Oxygen (O) are the major impurity constituents. Complete ionization of these impurities in the burn-through phase utilizes most of the input energy. A 0D code has been developed in-house at IPR to study plasma start-up and evolution in tokamaks [2]. In this code, a dynamic evolution of impurities has been modeled. Previously, impurity content in the plasma was considered as a constant percentage of the electron density (n_e), irrespective of their ionization states, throughout the plasma evolution. This approximation may lead to serious over/under estimation of major plasma parameters during their evolution, especially in the burn-through phase. Now the 0D code is augmented with a detailed impurity model and it has rendered the impurity content of plasma to be dynamic, governed by the evolution of n_e, temperature (T_e) and the initial impurity influx considered.

Evolution of C and O density and all of their charged states is interrelated and represented by coupled ordinary differential equations (ODEs). Rate of change of impurity densities in the model are coupled through three types of interactions viz. recombination, ionization and charge exchange. Reaction cross-sections [3] depend on impurity densities, n_e and T_e. Solving the energy balance equations for each time step in the 0D code yields the temperature of ions and electrons for the next time step. These are used in the impurity model to calculate the coefficients of all the reactions and evolve data for the next step. Temporal profiles of n_e, T_e and current are compared with experimental profiles from the SST-1 tokamak and a better correlation is obtained with incorporation of the impurity model. Further, time evolution of various charged states of C and O will also be reported.

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CM16

Investigation of Machine Learning Algorithms on Estimation of Neutral Beam Properties

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Abstract - Machine learning algorithms can be used to predict results and optimise systems. Such algorithms are based on deep learning methods where high dimensional data is being trained by neural networks. Data being the sole driver of the machine learning algorithms, complex systems which has many input points, the output of such systems can be predicted by effectively the training neural networks with known outputs. Such trained algorithms can effectively predict and monitor the outputs. This has a huge significance in operating systems where the output cannot be studied and predicted effectively by conventional methods. A typical complex system as such is an ion source for beam extraction. An ion source has many input parameters such as the RF power of the source, grid voltages, pressure in tank and source. The properties of the beam such as the divergence, estimated by Doppler Shift Spectroscopy (DSS), is dependent on the input parameters. In this work, a set of input training data for RF Operated Beam Source in India for Negative Ion Research (ROBIN) beam extraction at various source conditions (40-60kW RF power, 7-25 kV grid voltage) has been trained by supervised learning algorithms. The high dimension training data has been reduced by Principal Component Analysis (PCA) trained by various leaning methods such as Support Vector Machines (SVM), Linear Regression, Logistic Regression, Decision Tree, Naive Bayes, kNN, K-Means and Random Forest in Python. The various models for beam divergence estimation have been studied, and the training data and test data output have been compared.

CM17

2D PIC-MCC Simulations Based Study Of Evolution Of Electron Energy Distribution Function For Understanding Plasma Transport Across Magnetic Filter

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Abstract - Negative ion H^- production in negative ion sources for fusion applications is achieved using electron cooling mechanism using a magnetic filter (B) and depends significantly on the electron energy near the end of the magnetic filter region (beyond the maximum magnetic field (B) after which a negative gradient of B is present). Electron energy distribution function (EEDF) study gives information about the rate of elastic and inelastic collisions in plasma, and therefore a thorough understanding of spatial and temporal evolution of EEDF is necessary for understanding plasma transport across magnetic fields. Two important processes, that is high energy (≥20 eV) electron impact producing ro-vibrationally excited H_2 and low energy (0.14-3.75 eV) dissociative attachment plays important role in effective volume production of H-. This means plasma transport across magnetic field and thereby production of negative ions is highly sensitive to EEDF. EEDF measurement in such experiments is still challenging due to many difficulties such as deviation of plasma parameters in presence of a magnetic field [1][2].

We have developed an in-house 2D-3V PIC-MCC code to study the effects of magnetic filter field on plasma transport in conditions similar to ROBIN negative ion source. Results from our simulations agrees well with the results of first phase of ROBIN (Rf Operated Beam source in India for Negative ion research) experiments without negative ions. Unlike fluid modelling, where a fixed EEDF is assumed, kinetic models such as Particle-in-cell Monte-Carlo-Collision (PIC-MCC) evolves the EEDF during simulation and provides a complete information about the EEDF. In our study, we have focused on analyzing the spatial and temporal

evolution of EEDF throughout the computational domain in our model of negative ion source under condition similar to the ROBIN. Observed EEDF using 2D-3V PIC-MCC simulation is Maxwellian in nature and is in agreement with past experiments [2]. It is observed that, EEDF has longer tail in the source region due to heating, and peak becomes shorter as time progresses. EEDF tail becomes shorter with time in the magnetic filter region due to electron cooling. Analysis of EEDF throughout the computational domain helps us in better interpretation of plasma transport across the magnetic filter as well as the decrease in electron temperature near the extraction region.

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CM18

Formulation and Computation of ICRH antenna-plasma Coupling using Brussels Antenna Coupling Code (BRACC) for the Tokomak Plasma

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Abstract - The ICRH heating (current generation in plasma) delivers the electromagnetic (EM) energy from high-power sources external to the plasma by exciting electromagnetic fields that propagate into the plasma. The coupling between plasma and electromagnetic (EM) waves that dissipate on energy and momentum to charged particle determines the achievable heating. The coupling depends on the antenna impedance, which is a function of frequency and geometry. Motivated by design considerations of a spherical tokomak device, for calculating the antenna impedance with varying geometry and frequency, we have formulated the dispersive field propagation using maxwellian equations in the vacuum (antenna location) and the magneto-sonic wave equations in plasma. This formulation is implemented by the standard antenna-plasma coupling code for computing the field spectrum inside the plasma & subsequently computes the corresponding impedance for an optimal coupling. The numerical procedure is performed using Brussels Antenna Coupling Code (BRACC) to compute the impedance by varying the antenna width and frequency. The resistance of the antenna has been computed with varying the length to width ratio at different frequency for the optimization study. The analytical formulation is to be used as benchmark for the numerical results and its reliable application for the design concept. The above results will be discuss in detail.

CM19

Energy Transfers In Two-Dimensional Turbulent Flow

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S-3-O-01

Plasma-Assisted Deposition of Zinc Oxide Nanostructures in Nitrogen Ambient

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Abstract - Zinc oxide (ZnO) is a wide and direct band gap semiconductor having applications in optoelectronic devices, sensors and protective coating [1,2]. ZnO nanostructures exhibits fascinating morphological, optical and electrical properties which further broadens the range of applications. ZnO nanostructures have applications in light emitting devices, transparent conducting electrodes for flat panel displays, window layers in solar cells [3], cosmetics and purifiers. Several techniques have been adopted for the fabrication of ZnO nanostructures. In this paper, we report the fabrication of ZnO nanostructures on glass substrate using the ions of ZnO generated by the high temperature, high density and extremely non-equilibrium nitrogen plasma in a modified dense plasma focus (DPF) device. Surface morphology is studied using scanning electron microscopy, which show formation of nanostructures of average size ~ 15 nm. Polycrystalline behavior of ZnO nanostructures is obtained in X-ray diffraction patterns. Photoluminescence spectra show emission peaks in visible and UV regions mainly due to oxygen related defect states. The optical band-gap found using Tauc plot is smaller than that of bulk ZnO and lie in visible range. The obtained properties of ZnO nanostructures fabricated in nitrogen ambient are compared with that reported earlier [4], where fabrication is done in argon ambient. The properties obtained in present study indicate possible applications of nanostructures in visible range optoelectronic devices.

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S-3-O-02

Anode Fireball for Making Super-Hydrophobic Nanodot Surfaces

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Abstract - Electron sheath and fireball has been the topic of recent investigations. Electron sheath occurs when the current drawn by the electrode or wall is larger than that which can be provided by the random electron motion. When the sheath potential reaches the necessary potential for excitation of neutral atoms (few eV below ionization potential for Argon), the sheath glows. If this sheath potential reaches above the ionization potential, the sheath breaks down in its own plasma with plasma potential higher than the ambient potential, hence establishing a double layer. This double layer is visually observed as a glow with a sharp boundary, also known as the fireball [1-3]. In the current work using permanent magnets cusp arrangement, effective electrode collection area is reduced by restricting the electron movement to obtain the electron sheath and larger fireball. The anode fireball and the bulk plasma are separated by a double layer visible as a

sharp boundary of the anode fireball. The electrons from the bulk region are accelerated to ionization potential by the double layer. These accelerated electrons produce the glow and plasma inside the droplet shaped fireball. In the bulk plasma, the electron temperature is found to be 3 to 4 eV and the typical plasma density is in the range of $1x10^9$ cm^{-3}. The plasma density in the fireball is about an order of magnitude higher than that of the bulk plasma.

Rapid developments in metal/semiconductor nanofabrication technologies have seen an exciting and emerging trend towards the development of the periodic nanodot structures for Photonics and Magnetism applications [4-5]. In the current work, we have demonstrated a highly economical technique using plasma fireball as explained earlier for making nanodot patterning over large area. This device is not only capable for making nanodot pattern over large area, but also capable to make nanoparticles in another mode. The discharge properties of the device and parameters for making nanodot patterns will be presented [4]. Since fireball has an order higher plasma density, the ion flux plays a very crucial role in pattern formation. Higher plasma flux produces smaller nanodots patterns due to redeposition of the eroded material from the surfaces. Nanodots pattern produced on GaSb surface found to have super-hydrophobic behavior with a water contact angle of 150^o and highly light absorbing in nature [3]. In this way the produced fireball in our device can be used to produce super-hydrophobic nanodots surfaces for various applications like sensing application and photovoltaic [5-6].

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S-3-O-03

Investigation of Mechanical, Structural and Corrosion Resistance Properties of AISI Low Alloy Steel After Incorporating Nitrogen and Carbon in Subsurface by Plasma Assisted Difussion Processes

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Abstract - The use of surface treatments by plasma technology has increased substantially in the recent years for applications where wear and corrosion resistance properties are required. Among the different plasma surface hardening techniques, plasma based diffusion processes like plasma nitriding, plasma nitrocarburizing, plasma carburizing and plasma carbonitriding processes, plasma carburizing processes has yielded good results for low carbon steels. Plasma nitriding and nitrocarburizing are among the great ways to increase corrosion resistance, wear resistance and service life of mechanical components. During plasma nitriding and nitrocarburizing processes, two layers with distinct properties are formed: the outer compound layer consisting of ε-$Fe_{2\text{-}3N}$ and γ'-Fe_4N phase, and the thick inner diffusion layer. Addition of carbon in plasma nitriding process further improves the corrosion resistance properties due to presence of Fe_4N phases. Plasma carburizing on the other hand is considered to be of more advantage over the conventional carburizing process for all low carbon steels mainly due to the reduced time and gas consumption during the treatment and also for its environmentally friendly nature. Moreover, the high temperatures used in the conventional carburizing treatment remain an issue where high degree of dimensional and geometric control is a must. However, with the use of plasma carburizing processes it is possible to achieve better dimensional control even for complex geometry components. This is because, the plasma glow supplies carbon so effectively that the surface of the work is saturated with carbon during the carburizing time and can penetrate the surface irregularities much

better resulting in a more uniform product. Because, plasma carburizing is not limited by the gases ability to supply carbon to surfaces, it saturates the surface with carbon very quickly and this is the reason for plasma carburizing process to attain the same carbon gradient faster than conventional carburizing process. Another variant process of plasma carburizing called plasma carbonitriding has also been recently developed where along with carbon, nitrogen is allowed to diffuse simultaneously into the steel. sIn this paper an attempt is made to compare all the plasma based diffusion processes like plasma nitriding, plasma nitrocarburizing, plasma carburizing and plasma carbonitridng to enhance both surface hardness and corrosion resistance properties of low carbon steel (AISI 1020). The treatments were done at optimized process temperatures for total time duration of 4 h. The surface hardness of all the steels specimens increased by a factor of two compared to the untreated specimens. There was an improvement in the corrosion resistance after these treatments but varied depending upon the nitrogen and carbon incorporation during these processes. This paper also discusses the distortion studies of actual gears after these plasma based diffusion processes.

S-3-O-04

Pulsed Laser Deposition-A Versatile Technique for Depositing Thin Films Of Complex-Oxides

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Abstract - Pulsed laser deposition (PLD) is one of the most versatile and promising techniques to realize high quality thin films of complex oxides. It has emerged as a relatively simple yet advantageous technique as compared to other techniques in terms of, stoichiometric production of films of multi-element compounds, relatively high deposition rate, capability of realizing metastable phases that are difficult to synthesize in bulk form by other deposition methods and growth of multilayered structures without breaking vacuum. After giving a brief glimpse of the technique, the paper discusses the emerging field of magnetoelectric multiferroic materials, in context of perovskite materials. The paper will then focus on the challenges involved in depositing multiferroic magnetoelectric thin films of $PbFe_{0.5}Ti_{0.5}O_3$, which is one of the few multiferroic materials that show magnetoelectric multiferroic properties at *room temperature* [1][2]. The ability of PLD in retaining/maintaining the oxygen stoichoimetry by virtue of optimizing the oxygen partial pressure and hence multiferroicity, is highlighted. The paper summarizes by briefing the advantages and disadvantages of this technique for deposition of these novel multifeorroic (multifunctional) thin films for possible device applications.

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S-3-O-05

Discharge analysis of atmospheric pressure glow discharge in micro-scale dielectric barrier gap

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Abstract-Content Atmospheric pressure gas discharges have widespread applications – ozone synthesis, UV and VUV generation, disinfection, materials processing, etc. Generation of atmospheric pressure plasmas in bare electrode systems encounter instabilities that cause glow to arc transition due to thermionic emissions caused by

ion bombardment on cathodes. To prevent such transition, dielectric barriers are used on the electrodes to limit the ion bombardment which in turn limits the secondary emission and hence the discharge current. Such discharges are called Dielectric Barrier Discharges (DBD). To decrease the voltage requirement of these discharges, one obvious way is to decrease the gap distance, typically hundreds of micrometers. This has a disadvantage of having a low plasma volume – since sheath itself covers few tens of micrometers at atmospheric pressure. An alternative way to create high pressure discharges is micro-hollow cathode structure –where a hollow cathode, an insulator layer and anode (which may or may not be hollow) are sandwiched together. On application of voltage between anode and cathode the electrons start exhibiting pendulum effect because of the repulsion from cathode sheath. This effectively increases the collisions per length, that in turn increases the plasma density but these are prone to electrode erosion due to ion bombardment. A combination of both the advantages of dielectric barrier discharge and micro hollow cathodes –less erosion of the electrodes and high plasma density –has been attempted in a device typically called Dielectric barrier based Micro-hollow cathode (DBMHC). This work aims to analyze different discharge phases in DBD based MHCD device. For this purpose, a cylindrical anode protruding co-axially in a cylindrical hollow cathode structure has been explored who seinner wall sare coated with SiO2. Tosubstantiate, simulations have been carried out in COMSOL 5.3. It is seen that there are three major discharge phases in this device configuration – ignition phase, transition phase and hollow cathode phase. After primary ignition of electrons in the low gap region of the device, ignition and transition phase go hand in hand. During this phase the bulk electrons are trapped in the self-consistent electric field while the fast electrons dump their energy in the hollow cathode discharge region. Also, there is a migratory electron flux which when balancedagainst thefastelectron flux formsthe hollowcathodedischarge. Itis alsoobserved that the hollow cathode discharge once formed is sustained throughout for complete cycle of operation. The metastable and excited species have greater mass fraction than the ionized species. Also, the electron temperature is ˜3.2 eV on an average. The proposed analysis suggests that DBD discharge created in micro-scale can be used for UV/VUV generation and for a range of applications related to it.

IP/PP1

Surface Properties of Plasma Nitrided Inconel 601 Alloy

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Abstract - Inconel alloys are widely used for various applications such as; chemical processing plants, gas turbine, heat exchanger and nuclear industries due to excellent corrosion resistance and resistance to heat properties. Inconel 601 alloy having excellent properties but shows poor wear resistance, lower surface hardness and high coefficient of friction. In this study an effort has been made to modify the surface properties of Inconel 601 alloy by using plasma ion nitriding (PIN) process at low temperature. After plasma ion nitriding, surface properties were investigated by various characterization techniques such as; scanning electron microscope (SEM), X-ray diffraction (XRD) analysis and micro-hardness measurement. It was found that, surface micro-hardness increases after PIN process. A mix peak of epsilon (ε) phase with fcc (γ) phase was detected for all temperature range (350 ^{0}C to 450 ^{0}C), while the chromium nitride (CrN) phase was detected at elevated temperature range ~450 ^{0}C. Average crystallite size of grains were roughly calculated approximately few nanometer using Scherrer formula. It was clearly observed from surface morphology images, the crystallite size of grains increased as process temperature increases.

IP/PP2

Preliminary Design of Primary Chamber of Large Scale Plasma Waste Disposal System

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Abstract - Plasma pyrolysis is a non-incineration process where organic mass is converted in to hydrogen, CO, methane and lower hydrocarbon. It uses plasma torch to produce high temperature where electrical energy is converted in to thermal energy with high efficiency. Unlike conventional incinerators, after combustion of waste, the toxic molecules such as dioxins, furans, etc. are found in negligible quantity using plasma pyrolysis hence, it is environment friendly and an ultimate waste management technology for safe disposal of all kind of organic wastes. Design and development of large scale (4.8 ton per day) plasma waste disposal system is in progress at FCIPT, IPR which comprises of primary chamber, plasma torch system, feeder chamber, ash removal system, secondary (combustion) chamber, gas cleaning cum conditioning system, power supply with automation and control, ID fan, chimney, etc. The primary chamber will be connected with other sub-systems which includes plasma torch system, feeder chamber, stirrer, ash removal system and secondary (combustion) chamber. The primary chamber has cylindrical design with mild steel as structural material along with refractory and insulation lining inside the chamber. Refractory and insulation linings are selected such that it minimise heat loss. The average temperature of refractory lining inside the primary chamber during pyrolysis of waste should be between 1000°C - 1200°C. while, the structural material temperature should be retained between 60°C-70°C. The factors considered for calculating the volume of primary chamber are CPCB guideline, volume of pyrolysis gas liberated form waste fed and factor of safety. In this paper, discussion about preliminary design basis calculation of primary chamber has been discussed.

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IP/PP3

Development of Rotatable Magnetron

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Abstract - Magnetron sputtering is a well-known coating technology for depositing high quality thin films for various applications. Due to its ease of scalability, while maintaining excellent control over crucial layer parameters, it is suitable for large area coatings.[1,2] There are mainly two types of magnetrons with further subcategories as given below:

1. Planar Magnetron
   a. Circular and rectangular Planar Magnetron (circular/rectangular disc shape sputtering target)
2. Cylindrical Magnetron
   a. Static Cylindrical Magnetron (static cylindrical sputtering target)
   b. Rotatable Cylindrical Magnetron (rotatable cylindrical sputtering target)

Circular planar magnetrons are mainly used for small area substrate coatings and lab scale research purposes, while rectangular planar magnetron is mainly used for large area coatings in industries. Disadvantage of any planar magnetron (circular or rectangular) is that it can use only up to 40-50% of target material due to limited sputtering racetrack area and rest of the material remains un-sputtered. Cylindrical static magnetron, on the other hand sputters the complete material in all directions. It is more suitable for the coating on an inner surface of a cylinder (or pipe) where substrate surrounds the sputter target and use the maximum sputtered

material but if the substrate is planar and placed only on one side of the sputter target then rest of the sputtered material deposits on the chamber wall and gets wasted. In rotatable cylindrical magnetron, sputtering happens only one side of the sputter target but as the sputter target is rotated, almost complete material (up to 85-90%) is used even if the substrate is flat (i.e. planar but not cylindrical) and placed at one side of the sputter target.

Here we will be presenting an in-house build rotatable magnetron, which is being reported to best of our knowledge first time in India. Details of rotatable magnetron will be presented along with comparison of planar magnetron.

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IP/PP4

Plasma Nitriding of Maraging Steel C300 for Improvement of Wear Resistance and Tensile Properties

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Abstract - Plasma nitriding of maraging stainless steel C300 was carried out at 425^{0}C, 450^{0}C, 470^{0}C, 490^{0}C, and 500^{0}C for 4 hours using a mixture ratio of N_2:H_2 = 1:4. The modified surface was evaluated for micro-hardness and characterized by optical microscopy, SEM and XRD. Wear resistance and tensile strength tests were also performed on untreated and plasma nitrided samples. The microhardness measurements yield an increase in surface hardness by more than a factor of three for all process temperatures.

As for the case depths it varied from 8 microns (μm) for 425^{o}C to as high as 90 microns for 500^{o}C. Analysis of optical microscopy and SEM images confirm results obtained from micro-hardness measurements vis-à-vis thicknesses of the nitrided layers. XRD results show formation of predominantly γ' (Fe_4N) phases at the surface at all temperatures, however its depth increases with temperature. Dry sliding wear rate was evaluated using a pin on disk wear tester using a load of 10N for the duration of one hour (equivalent distance ~11.95 kilometers). The results show improvement of wear resistance by as much as a factor of 12.28 for the 500^{0}C treated sample when compared to the untreated sample. Tensile properties were measured using a Universal Testing Machine. The tests indicate that the ultimate tensile strength increased by as much as a factor of 2.23 for the 500^{o}C treated sample as compared to the unprocessed one. Other tensile properties also improved for the nitrided samples. 500^{o}C process temperature provided the best results for both the wear resistance as well as the tensile properties.

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IP/PP5

Influence Of Atmospheric Pressure Air Plasma on the Surface Properties of Raw Knitted Cotton Fabric

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Abstract - Raw Cotton or Grey Cotton contains impurities such as natural oil, waxes, pectin and coloring matter, etc. Due to presence of these impurities raw cotton/grey cotton fabric is hydrophobic in nature and is not suitable for dyeing or printing. Conventionally various types of chemicals and reagents are required to remove these impurities. A typical pre-treatment of 1 Kg of Cotton fabric requires about 350 liters of water for pre-treatment . Plasma treatment can be used as alternative dry method for removal of these impurities from raw/ grey cotton fabric and generate hydrophilic groups on its surface. This in-turn makes the fabric suitable for dyeing. [1]. In the present work, we have used a high frequency dielectric barrier discharge in air [2] at atmospheric pressure for the surface modification of grey knitted cotton fabric. The surface properties of plasma treated cotton fabric are studied by using Video-Contact Angle Goniometer (VCA) , ATR-FTIR (Attenuated Total Reflection- Fourier Transform Infrared Spectroscope and FE-SEM (Field Emission Scanning Electron Microscope). The water contact angle of cotton fabric reduces from 135 to 0 (complete wetting) for a plasma exposure of 5 minutes. The water absorption time of untreated fabric is around 2400 seconds to 0.14 seconds. The FTIR analysis on the surface of plasma treated cotton demonstrates removal of wax and pectin as well as formation of hydrophilic groups such as C=O. The SEM analysis reveals the morphological changes induced by plasma treatment.

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IP/PP6

Design and Development of a Power Source for a Novel Electrical Model of Underwater DBD Air Plasma Jet for Generating Plasma Activated Water

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Abstract - Resonant converter based power supplies are used for variable frequency duty cycle control in high frequency inverter system. The configurations of resonant converter are based on the type of load and the range of load variation. In this paper, an electrical model of underwater dielectric barrier discharge (DBD) plasma jet in air is presented as a load for design and development of a series parallel configuration of resonant converter. The load impedance range of DBD air plasma jet varies from zero to R_{max} Ohm. Zero impedance is basically short circuit condition and R_{max} is the operating condition of DBD jet at particular current. The switching frequency is 40 kHz with above resonance operation and it is protected for high voltage surges with a RC snubber across the resonant circuit. A single module of two IGBTs is used for generating a voltage up to 10kV at 1A. However, the air DBD jet is driven at $2.5kV_{rms}$ and 200mA maximum current only. The detailed simulation analysis of this power supply in MATLAB Simulink and its experimental validation is presented in this paper. The simulation of close loop duty cycle control system to achieve a constant current operation is presented here. This is an important operating parameter because the conductivity of water varies during the DBD plasma discharge. The underwater plasma jet in air generates many radicals which get dissolved in the water and thus make it highly active. This activation is generally measured by its ORP (Oxygen Reduction Potential) and pH value. This activated water becomes little acidic with pH value between 2 to 3. The ORP of water is increased from its normal value of 200mV to more than 600mV after the plasma activation using resonant converter based power supply. The plasma activated water (PAW) and air plasma jets characterization results are also presented in this paper.

IP/PP7

Development of Plasma Sterilisation system for medical components

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Abstract - Plasma sterilization is an emerging process that is being used these days for the sterilization of medical components and has specific advantages over the conventional processes for example autoclaving and Ethylene oxide exposure. Plasma sterilization is particularly useful to sterilize medical devices such as endoscope, catheters. In the present study plasma sterilization has been carried out using oxygen and ozone gases. We have used four micro-organisms which are commonly responsible for infection in hospitals. In this study, survival of bacterial species in similar vacuum conditions and when it is exposed to oxygen and ozone gases and their plasma has been compared. Optical emission spectroscopy is also carried out in order to find out the active species produced in oxygen and ozone plasma in the system and to confirm the uniformity of plasma in the system.

Based on the observations it is concluded that as the plasma exposure time increases, there is a decrease in the growth of E-coli, Staphylococcus Aureus, Bacillus Subtilis and other bacterial species selected in the present study. It has been observed that oxygen and ozone plasma effectively kills the bacterial species. It has been observed that ozone plasma is more effective than oxygen plasma and reduces the bacterial load almost to zero.

IP/PP8

The Anode Glow Formation and Its Effect on Thin Film Deposition In A Hollow Cathode Cylindrical Magnetron (HCCM) Discharge

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Abstract - The cylindrical dc magnetron discharge in an inverted (hollow) configuration is used for thin film depositions on cylindrical as well as complex shape substrates. In the present work, the plasma formation near the anode of hollow cathode cylindrical magnetron (HCCM) and its effect on the thin film deposition is studied. The discharge is operated for argon gas in presence of external magnetic field up to 100 gauss. The plasma potential measurement shows a strong anode fall near the anode. The plasma density and electron temperature near the anode is higher as compared to background plasma in the positive column. It is observed that the electron sheath near the anode transforms into anode spot due to the magnetic field of around 10 gauss. The anode spot expands to cover full cylindrical anode with increase in magnetic field. Finally the copper thin film is deposited on silicon substrates with and without anode glow condition. The anode glow formation significantly changes the thin film growth due to locally enhanced ionisation. The copper thin film deposited with anode spot shows oxidised surface due to localised heating caused by extra ionisation near the anode.

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IP/PP9

Comparison Of Conventional Plasma Nitriding And Radical Nitriding Processes On 16mncr5 At Different Process Parameters.

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Abstract - Plasma nitriding process has been widely used by many industries to increase the life of the component by surface hardening. This low temperature, low pressure processes not only increases the surface hardness but also the corrosion and wear resistance of the components. But this process suffers from many limitations like high surface roughness, high capital cost and arcing during the process which may damage sharp edges. In order to overcome these limitations, the aim of this project to bring the plasma nitriding technology to the new advanced level called radical nitriding process where material can be processed under the atmosphere of plasma due to active species rather than producing the plasma directly on the surface of the industrial component. This technology can help the industry for reducing the operating cost of process and retaining the sharpness of the cutting tools which is the very effective factor for the cutting industries. This process will also improve the quality of material processed under plasma atmosphere.

Radical nitriding is based on the use of radicals, so that plasma is not necessarily formed on the surface of the specimen but instead on the screen surface. The process is similar to the conventional plasma nitriding method. It differs, however, in that the screen is placed in the cathodic potential and thus the production of active nitrided species, as well as the heating of the specimens, is conducted by the screen. The plasma generated on the screen (rather than on the specimens) heats the screen, and radiation emitted from the screen supplies the heat required for treatment. Hence, this technique is an advanced level of conventional plasma nitriding technique which has capability to provide same results like conventional plasma nitriding at lower cost by reducing the operating cost. This is because in conventional plasma nitriding process components are biased and current flows from the surface of the component as a result power consumption increases with increasing number of component. Also, as the furnace does not form glow discharge on the surface of the workpiece, uneven modification (edge effect, hollow-cathode effect) due to the shape of the workpiece can be avoided. As, radical nitriding process is a technique where samples are kept at very low or floating potential lower capacity power supply can be used for generating plasma on defined area of cage instead of higher capacity power supply which is required for conventional plasma nitriding technology. In the present work, an attempt will be made to compare conventional plasma nitriding with radical nitriding process on AISI 16MnCr5 at different processing temperature and gas composition. Correlation with structural, mechanical and corrosion resistance along with species formed will be studied after these processes.

IP/PP10

A Study of RF (13. 56 MHz) Air Plasma Treatment Effect on Carbon Fiber to Improve Interface Layer Coating Properties for Carbon Fiber Based Composites Applications

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Abstract - Carbon fiber (CF) reinforced SiC (CF/SiC) composites are sought for high temperature application in areas of automobiles, aerospace and nuclear reactors due to their outstanding properties [1]. However, CF/SiC composites have low durability owing to oxidation of CF upon air-exposure during high temperature applications. The inter-phase layer between fiber and SiC matrix is used in order to protect CF from oxidation during high temperature applications [2].

In this work, we have aimed to study the effect of RF (13.56 MHz) air plasma treatment on CF tow for improvement of SiO_2 inter-face layer coating by dip coating technique. The plasma treatments on CF tows and graphite proxy substrates have been attempted for 20, 40 and 60 min in a parallel plate capacitively coupled setup. The treated CF tows and graphite samples have analyzed by Scanning Electron Microscopy (SEM) and water contact angle measurement, confirmed the change of surface morphology by SEM and wettability increment by water contact angle measurements.

The plasma treated CF tows have been further used for deposition of SiO_2 coating by dip coating method to verify the plasma treatment effect on SiO_2 coating properties. These plasma treated (20, 40 and 60 min) CF tows have been dipped into SiO_2 coating precursor solution prepared from Tetraethyl orthosilicate (TEOS) with fixed dipping parameters such as 3 Nos. of dipping cycles at withdrawal speed of 8 mm/sec with 5 min dipping time, followed by drying up to 100°C after each dipping cycle and then final heat-treated at 500° C for 60 min.

The detailed SEM surface analyses of coated CF tows have confirmed the uniform deposition for 20 min plasma treated CF tows in comparison to untreated, 40 and 60 min treated CF tows. Whereas, Energy Dispersive X-ray Analysis (EDXA) and Fourier Transform Infra-Red spectroscopy (FTIR) measurements have been used to get elemental and bonding information of coating verified the high quality of SiO_2 thin film deposition. At same time, tensile strength measurement demonstrated the enhancement of tensile strength for plasma treated SiO_2 coated CF tows as compare to untreated CF tow, and optimum strength (1449 MPa) has been obtained for 20 min plasma treated SiO_2 coated CF tow with uniform coating properties. Hence, 20 min plasma treatment on CF tow has beneficial effect for SiO_2 inter-face layer coating, to be used for CF based composites processing.

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IP/PP11

Development of Non Thermal Plasma Torch (NTPP) for enhancing surface energy of HDPE

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Abstract - High Density Polyethylene (HDPE) is used in production of plastic bottles and geo-membranes. The surfaces of these polymers are made active by different surface treatments techniques during their applications. The atmospheric pressure plasma treatment is one of the effective and environment friendly techniques to activate the surfaces of such polymers.

In the present work, the Non Thermal Plasma Torch NTPP working at atmospheric pressure has been developed and used for surface treatment of HDPE. The important characteristic of this plasma source is that it operates in air by using a line frequency (50 Hz) power supply. The HDPE polymer is treated with air plasma at different treatment times. The plasma treated surface is analyzed by using Scanning Electron

Microscopy (SEM), Goniometer and Fourier Transform Infrared Spectroscopy (FTIR). The contact angle measurement by using Goniometer shows that the hydrophilicity of the plasma treated sample increases two fold as compared to untreated one. The plasma treated surface is also found to be rougher as well as chemically active compared to untreated sample.

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IP/PP12

Development And Characterization Of Non-Thermal Atmospheric Pressure Plasma Jet Array For Application Of Large Area Treatment

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Abstract - Atmospheric pressure plasma jet is having various applications in the field of surface modification. Mostly single jet is used where at a given time small area can be treated. In order to treat larger area multiple plasma jet is developed which is having array of 72 numbers of jets. The atmospheric pressure plasma jet array is driven by an alternating power supply at tens of kilohertz. The voltage-current of the atmospheric pressure plasma jets array is characterized. The plasma jet array is tested at different voltage, frequency and gas flow level for its optimal condition. It can treat the area of around 40cm^2. In the preliminary experiments, the Polyethylene Terephthalate (PET) is used for the plasma treatment material which is widely used in textile and packaging industry. It is found that wettability of the PET surface enhances significantly after plasma treatment. This array of jet is having advantage that at the given time larger area is treated and also useful to treat those materials having a melting point of below 150°C.

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IP/PP13

Safe Disposal Of Solvent Waste Using Thermal Plasma Technology

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Abstract - One of the greatest challenges of developing countries today are littered with waste in open dumps which are dangerous to health and environmental .Sustainable and successful waste management should be safe , effective ,

environmentally viable. The development and implementation of new technology may make it possible to convert organic waste into energy. Plasma Pyrolysis is one such revolutionary technology for safe disposal of waste in environment friendly manner. Safe disposal of solvent waste is essential since the fact that certain types of solvent such as chlorinated solvents are hazardous and improper disposal can contaminate the environment. High temperature generated by thermal plasma converts organic compounds into valuable by-products. Solvents / Solvent mixture is decomposed /disintegrated in plasma pyrolysis process into small molecular useful gas mixture. The major products in the gas mixture are CO, H_2, CH_4 and other lower hydrocarbons. The reaction products were analyzed by Gas Chromatography. For the identification with both comparisons of retention indices those of standard compounds and literature data and mass spectra were used.

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IP/PP14

Development of High Voltage DC Source for Corona Formation Using Half Wave Cockcroft-Walton Voltage Multiplier Circuit

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Abstract - In the present work a low power high voltage DC source has been devised using Cockcroft-Walton Voltage Multiplier topology. This multiplier provides high voltage DC voltage output from 230V AC input supply. Voltage multiplier is formed using cascading of diode and capacitor. The circuit forms a ladder network of capacitor and diodes and as the number of stages increase the output voltage is also increases. In the proposed work simulation of the multiplier circuit has been done and based on the simulation a multiple stage Cockcroft-Walton multiplier has been developed to generate the low power high voltage DC output.

A needle electrode on the output of the CW voltage multiplier circuit has shown the formation of corona discharge at the sharp tip of the electrode. The corona discharge is formed by ionization of air surrounding the electrode. Corona formation has been confirmed with presence of ozone smell near the needle electrode. This CW VM circuit has advantage that it is low power and small in the size. This has a potential application for in house air purification.

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IP/PP15

Study of Structural, Morphological And Electrical Transport Properties of Ion Irradiated GaAs Nanostructures

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Abstract - This study reports the effect of argon ion beam irradiation on gallium arsenide (GaAs) nanostructures, which are deposited on silicon substrates using GaAs ions generated in a modified dense plasma focus device. Argon ion beam of energy 200 keV having fluences of 1 x 10^{13} ions/cm^2, 5 x 10^{14} ions/cm^2 and 5 x 10^{15} ions/cm^2, is used for irradiation. X-ray diffraction (XRD) studies indicate polycrystalline nature of irradiated nanostructures having diffraction peaks corresponding to [111], [200], [220] and [311] planes with crystallite size of 30-75 nm. Morphological studies through scanning electron microscopy reveal formation of uniform thin film out of as-deposited agglomerated nanostructures. The electrical transport properties are studied using Hall measurements. It was found that carrier concentration decreases and conductivity changes from n-type to p-type. Thus, ion irradiation improves the crystallinity and transport properties of nanostructures, which render them as a potential candidate for fabricating more efficient optoelectronic and electronic devices.

IP/PP16

Plasma Assisted Metal Recovery from Chromium Bearing Waste

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Abstract - Leather and chemical industries generate large quantity of chromium bearing wastes and these wastes are being dumped in open space without necessary treatment. Diffusion of Cr into ground water and soil is a very serious problem. To protect the soil and ground water, it is important that this type of wastes must be treated properly. Plasma processing of wastes is becoming popular since it has several advantages than conventional techniques used for treating wastes. In the present work, plasma assisted aluminothermic process is developed to treat the chromium bearing waste generated from chemical industries. The waste / raw material is characterized using ICPMS, XPS, EDX and XRD techniques. The waste mixed with aluminium metal is treated with air and argon plasmas produced in DC transferred arc system under the atmospheric pressure. In this process, the waste containing mixed oxides is converted into metal / alloy. The recovered metal/alloy, slag and evaporated material are characterized using EDX and XRD. It is found that Chromium Iron Oxide (Cr1.3 Fe0.7 O3) and Magnesium Iron Aluminium Oxide (Mg Fe9 Al1.1 O4) present in the waste get reduced to Chromium (Cr), Iron (Fe) and Aluminium Iron (Al Fe3) metals. On a summary, it can be concluded that there is a potential opportunity for recovery of chromium metal / metal alloy from toxic chromium bearing wastes using plasma assisted aluminothermic process

IP/PP16

Study on Photocatalytic Activity of Thermal Plasma Processed MgO-ZrSiO4 Mixture

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Abstract - Dyes affect the basic nature of the water and they induce toxicity proportional to their concentration. The water diluted by dyes causes allergy, skin irritation and cancer, when consumed by human beings. Several oxides have been reported for synthesizing hybrid composite photocatalytic materials likes

$TiO_2 - ZrO_2$, $TiO_2 - Al_2O_3$, $TiO_2 - V_2O_5$, $Fe_2O_3 - MgO$ and $ZrO_2 - SiO_2$. These hybrid composite photocatalytic materials are used in the degradation of industrial waste water and dye. In the present work, MgO-$ZrSiO_4$ photocatalyst mixed oxide powder was prepared by transferred arc plasma reactor. The influence of the different molar ratio (Mg: $ZrSiO_4$) was studied for photocatalyst mixed oxides (MgO, ZrO_2 and SiO_2) powder. The synthesized powder is characterized by using X-ray diffraction, scanning electron microscopy, energy dispersive X-ray analysis and UV –Vis spectroscopy. The photocatalytic performance of the MgO-$ZrSiO_4$ mixed oxide powder is evaluated by the degradation of methylene blue (MB) and textile dye (Remazol Blue). From the characterization results, it is found that MgO-$ZrSiO_4$ mixed oxide particle exhibit a better visible light response and photocatalytic activity.

IP/PP17

Testing and Development of Cost Effective Microwave Source (1KW, 2.45GHz) Based on Magnetron for Plasma Interaction Experiments

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Abstract - These days microwave controlled radiation is broadly utilized in medical and scientific applications such as plasma generation, hyperthermia, diathermy and as a catalyst in green chemistry. Designing a suitably adapted microwave generator that meets both the scientific and more restrictive medical criteria remains a troublesome assignment. Magnetron is a good choice for that as it is high power, high efficiency and low cost and easily available microwave vacuum electron device. Its working principle is based on the interaction between electron stream and magnetic field. In microwave plasma interaction experimental studies at our lab i.e. **SY**stem for **M**icrowave **PL**asma **E**xperiments **(SYMPLE)**, we need 1KW at 2.45GHz microwave power source for prototype experiments. Microwave interactions with the plasma depend strongly on the magnetron's power supply parameters and the impedance match of the entire microwave circuit. This work presents the development and testing of 1KW microwave source with approx. more than 90% duty cycle (efficiency) at 2.45GHz. The commercially available magnetron is used which is part of the domestic microwave oven. In a microwave oven, the maximum power released from the magnetron is of the order of 1KW. To operate the magnetron, it always requires a high voltage supply in the range of 4KV. For the same, we use two type of voltage supplies: (1) Voltage supply available in the conventional microwave oven, and (2) Self-developed voltage supply. Here, these two types of voltage supplies are tested for extraction of 1KW power. The voltage supply being used in the domestic microwave oven has a half wave rectifier with doubler circuit topology that is directly fed to the magnetron. Similarly, in-house developed voltage supply contains a step-up transformer, high voltage fuse, diodes and capacitors. The output of developed and conventional supply is measured by using Tektronix P6015A voltage probe with Keysight DSO-X-2024A digital oscilloscope. The measured peak to peak voltage available in the conventional microwave oven is 6.8KV while average value is nearly -4.3KV (6.8KV * 0.637) with full wave pulsating DC type. Correspondingly, the output of in-house developed voltage supply for 1KW magnetron source is -4.21KV. This waveform is nearly pure DC waveform. The prototype setup also consists of many components like magnetron, WR340 waveguide launcher, voltage supply, cooling fan, directional coupler, RF-load etc. R&S®FSH8 Handheld Spectrum Analyzer is used to measure the output power of magnetron by reducing the power level with the directional coupler. The measured output power of magnetron is 1288W at ~2.47GHz with 50% duty cycle when employed the voltage supply available in the conventional microwave oven. However, the measured output power of magnetron is 1000W at ~2.46GHz with more than 90% duty cycle when employed the in-house developed voltage supply. The output level of magnetron can be controlled up to 1.5KW by varying the input of developed voltage supply. This RF power is extracted from the cavity of the magnetron and will be used for microwave plasma interaction experiments.

IP/PP18

Design of 14.5 Ghz Multi-Charge Ecr Ion Source

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Abstract - A 14.5GHz, 650 W Electron cyclotron resonance (ECR) is being developed by the Fusion Neutronics Laboratory at Institute for plasma research for ion beam irradiation facility. It will producing multi-charge ion species of elements like Helium, Nitrogen, Oxygen, Neon and Argon. The ion source, is mainly consist of plasma chamber, magnets, RF system, and ion extraction system.

This ion source is proposed to work by heating the neutral gas by microwave of range 12.75GHz to 14.5 GHz in a plasma chamber. The RF system will consist of a Travelling Wave tube (TWT) amplifier feed by a YIG oscillator. The YIG oscillator will produce an mW RF signal of the desired frequency with stable response. This will be feed to TWT amplifier to mW signal to fraction of a kilowatt. The RF system designed in such way that it gives the flexibility for operating frequency selection to optimizing the ion source performance for multi-charge ion production [2]. The minimum-B magnetic mirror structure is designed and optimised by LORENZ3EM code for the confinement of the plasma. The NdFeB permanent magnets is being used to produce the desired magnetic field.

This paper describe simulation result of the magnetic system and RF system of the 14.5 GHz ECR ion source.

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IP/PP19

Estimation of Hydroxyl Radical and Hydrogen Peroxide Formation by Microplasma Discharge on Aqueous Solution

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Abstract - The hydroxyl radical (˙OH) play an important role in environmental chemistry as it has high oxidizing potential over other reactive oxygen species. When the plasma comes in contact with the aqueous medium, it produces reactive oxygen species such as OH radicals, hydrogen peroxide (H2O2) and other short lived species. In the present work, the formation of OH radicals and H2O2 during the interaction of microplasma with the aqueous medium was studied at different treatment periods. The formation of OH radicals was identified using fluorescence method with the help of terephthalic acid which acts as a probe molecule. Further, H2O2 was quantified calorimetrically. The results reveals that OH radicals and H2O2 formation is directly proportional to the treatment time. The influence of plasma generating gas on the production of reactive species was further analyzed.

IP/PP20

First Principle Studies of Multiferroic Pbfe0.5Ti0.5O3

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Abstract - Multiferroics are the materials which have co-existence of ferroelectric and magnetic order in certain range of temperature and there is a coupling between the two orders. $PbFe_{0.5}Ti_{0.5}O_3$ (PTFO) is an important candidate in the class of multiferroics because it is one among very few known room temperature single phase multiferroics [1]. Multiferroic materials show potential for novel device applications, for example in sensors, actuators, memory devices, inductors and microwave devices. Recently, thin films of PTFO were deposited successfully using pulsed laser ablation technique [2]. First principles studies using density-functional theory (DFT) will be useful in giving more insight about the electronic and magnetic properties and in explaining/verifying the experimental observations. Calculations in this work have been done using the Quantum-ESPRESSO Package [3], which is based on density-functional theory, plane waves and pseudopotentials. An attempt is made in calculating the ferroelectric polarization and magnetization in PTFO system. The study will be useful and act as a guide while investigating the effect of epitaxial strain over the ferroic properties in PTFO thin films.

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IP/PP21

Effect Of Atmospheric –Dielectric Barrier Discharge Plasma On The Surface Properties Of Electrospun Silk/PEO Nanofibers

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Abstract - In this work we have functionalized the surface of Silk/PEO eleectrospun nanofibers using atmospheric Dielectric Barrier Discharge (A-DBD) plasma. To evaluate the effects of plasma treatment attenuated total reflectance-infrared spectroscopy (ATR-IR), water contact angle measurements, atomic force microscopy (AFM), stress strain relationships with hemolysis and MTT assay testes has been performed [1, 2].The plasma treatment leads to the formation of hydrogen bonds on the surface of the silk/PEO nanofibers which enhances the mechanical performances of the nanofibers [1, 3]. Increase in surface energy values with improvement of surface roughness has also been observed after plasma treatment as calculated from the water contact angle measurement and AFM analysis [3]. The A-DBD plasma treated silk/PEO nanofibers also exhibits good biocompatibility and cytoxicity which are revealed from the hemolysis and cell viability test. Thus all these findings indicates that A-DBD plasma can be utilized as a potential surface modification technique without affecting polymers biological properties. Also, these mechanically enhanced silk/PEO nanofibers can be used as potential biomaterials for use as wound dressings and drug delivery scaffolds.

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IP/PP22

Effect of Plasma and Beam Parameters on Focal Point and Beam Size Minimization in Plasma Based Focused Ion Beams

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Abstract - Focused ion beams are used in many applications such as creation of micron to nanostructures for studies involving field emission, modification of optical and surface properties of materials [1]. Plasma based focused ion beams are non-toxic [2] and can be used in biomaterials for applications in artificial heart valves. The focal point (FP) of the beam is an important parameter that needs to be determined because the current density at the FP is a maximum, and would imply minimum milling time for substrates kept at FP. Since plasma is a dynamic system, therefore determination of FP for ion beams extracted from the plasma is sometimes difficult, as it depends upon the plasma parameters such as the space potential (V_P), Bohm velocity (v_B), electron (T_e) and ion temperatures (T_i), and ion mass (M). The FP is also controlled by beam parameters such as beam energy (E_B), plasma electrode (PLE) and beam limiter (BL) aperture sizes, and potential applied to different electrostatic lenses. For many applications in the micron to nanometer length scales, the beam size at FP needs to be further minimized by reducing the source size for a constant demagnification factor of the lens, or by employing novel methods such as dielectric capillary guiding [3], for guiding beams with minimized losses [4].

The experimental results on the effect of plasma and beam parameters on FP are verified with beam simulation tools such as AXCEL-INP and SIMION. The focal length (f_l) is found to increase with v_B and V_P, but found to decrease with E_B. f_l decreases with M and is independent of BL aperture size but f_l is found to increase with beam extraction voltage. For reduction of beam size, tapered micro-glass capillaries are employed at the PLE, and the beam current and spot size are measured. Considering the hysteresis area in the I-V plot, charge dissipation from the beam is calculated. Self-focusing of the beam is observed due to smearing of the ions on the inner wall of the capillary, which provide a radial electric field that helps to self-focus the beam. Additionally, particle-in-cell simulations are carried out and the simulation results are found to match well with the experimental results.

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IP/PP23

Investigation of Potential Profile in Electronegative Plasma

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Abstract - Electronegative plasmas are of great interest in both theoretical and experimental physics because of an imperative role in many applications of industry. In the microelectronics industry, they play a crucial role in etching and surface deposition techniques. Oxygen plasma, a well-known electronegative plasma containing both positive and negative ions, used for plasma cleaning. Electronegative plasmas are preferred in surface techniques because of relatively less potential developed, compared to that of electropositive plasma [1]. The examination of surface-plasma interaction in electronegative plasmas, affected by the parameters of plasma, i.e., densities, the temperature of charged species, etc., are necessary to understand these applications. The interpretation of sheath formed surrounding of the metallic conducting probe immersed in the plasma is required to understand surface-plasma interaction. For example, in mass spectroscopy, to have a correct analysis of the results, the study of sheath formation at the front of the entrance hole of the spectrometer is essential [2].

In this work, we investigate the behaviour of potential as a function of radial distance from the electrode for both cylindrical and spherical geometry in collision-less electronegative plasma. We considered the mass of positive and negative ions under different temperatures of positive ion fluids where both positive and negative ions are governed by fluid equations. We encounter that the potential profile is affected by the change in positive ions temperature as potential reduces due to increment in the temperature of positive ion fluids. These results are very useful in plasma-dependent techniques for surface treatments.

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IP/PP24

In-Liquid Plasma Discharge for Synthesis of Copper Oxide (CuO) Nanospindles

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Abstract - Plasma generation inside liquid has been rapidly raising due to its potential application in nanomaterial synthesis [1]. Copper oxide (CuO) nanoparticle is a p-type metal oxide semiconductor having band gap 1.2 eV. Due to its unique electrical, optical, magnetic and catalytic properties, its application also increases in recent years, such as in solar cells, sensors, water treatment, biomedical applications etc. [2-4].

We have developed a liquid plasma discharge reactor. Characterization of the plasma in such a system is very challenging. Plasma is generated by applying a potential difference between two copper electrodes inside distilled water. As soon as, a critical voltage is applied between the two electrodes, the tips of the electrodes become very hot and the water layer on the surface of the electrodes tends to evaporate i.e. a gaseous medium is created, which leads to the formation of a plasma channel between the two electrodes. Copper oxide nanospindles are produced due to the evaporation of atomic copper from the electrodes, followed by the rapid oxidation of the evaporated particles by the reactive radicals present in water medium due to plasma generation. Characterizations of compositional, structural and stability of CuO nanospindle has been carried out by X-ray diffraction (XRD), Scanning electron microscope (SEM) and Dynamic light scattering (DLS) analyzer respectively. UV-Visible spectrometer is used to calculate the indirect band gap of the CuO nanospindles and it is found to be 1.58 eV. Transmission Electron Microscopy (TEM) images demonstrate that the lattice fringe width of CuO nanospindle crystal planes match with the XRD data. Moreover, TEM images shows that the nanospindles have a very strong tendency to aggregate to form CuO nanoflowers.

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IP/PP25

Fabrication Of Tungsten Coated Graphite Tiles For Aditya Upgrade Tokamak

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Abstract - Based on the advancement in current thermonuclear fusion research, it is quite likely that future generation fusion machines, DEMO and beyond, will be operating with tungsten and alloys based on tungsten as the plasma facing material on their walls and targets to dissipate the thermal as well as particle loads under extreme operational conditions. Usage of pure tungsten is not possible because it will substantially increase the manufacturing cost and overall system mass. It is also difficult to machine tungsten in to desired shapes. Hence, tungsten coatings on lighter substrates such as graphite are preferred which essentially reduce the cost and structural weight of the target materials considerably. In this paper, we report the production of tungsten coated graphite tiles for ADITYA-U tokamak and their characterization. Tungsten nano layers have been successfully deposited on limiter tiles of ADITYA-U made up of graphite by plasma assisted reduction of the heavy tungsten hexafluoride gas in hydrogen [1]. Coating thickness of ~ 1 micron has been achieved. Although the uniformity of the coating still needs to be improved the bonding of tungsten on the surface of the graphite tiles seems to quite good. The tiles are made available for insertion into ADITYA-U machine and pre and post exposure analysis of the coated surface will be carried out soon. Details on optimization of plasma parameters for successful coating and characterization and post analysis of the tungsten coated tiles to study the presence of tungsten, thickness of the coating, thermal fatigue etc. will be presented in this paper.

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IP/PP26

Impact of Pre-Sowing Treatment of Seeds With Plasma on Germination And Growth of Soybean And Maize

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Abstract - It is quite well known that the treatment of seeds with plasmas of appropriate parameters leads to significant improvement in germination and growth of seedlings. There have been several studies on the impact of plasma on the seeds demonstrating improved germination of seeds and subsequent growth of the seedlings by plasma treatment [1]. The observations of plasma treatment in the seeds of wheat, soybean,

clover, rye, barley, pea and lup in provide strong evidences of penetration of plasma radicals into the inner parts of the seed which affect the metabolic processes of the seed favorably. In this paper we present the preliminary experiments on plasma treatment of the seeds of soybean and maize using RF plasmas. The RF plasma system used for tungsten coating has been modified to accommodate the seed treatment. The seeds are kept inside the Nitrogen and/or Oxygen plasmas produced at different pressures and RF power and for different durations to optimize the treatment procedure. The shorter exposures lead to no effect and the larger exposures lead to seed damage. Similarly, higher RF power also leads to seed damage. The optimization of plasma exposure of maize and soybean seeds for studying the chemical changes occurring in the seeds will be described in this paper in detail.

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IP/PP27

Estimation of Charge Particle Concentration in Uranium Vapors Produced by Electron Beam Heating

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Abstract - A strip type electron beam is used to get a high throughput of uranium (U) vapor evaporation in electron beam evaporator. When the electrons beam incidents on the metal ingot, it heats the target locally to a high temperature and produces vapors. The vapors near the evaporating surface get partially ionized through Saha ionization at high temperature. When the vapors propagate, they interact with nearly mono-energetic primary electron beam and backscattered, secondary, thermionic electrons which have their energy distributions. The charge particles are produced by electron impact ionization. Thus the ionized vapors form the weakly ionized plasma that is embedded with the neutral vapors. To know the degree of ionization, the e-impact ionization cross section of uranium and its variation with the incident electron energy are calculated. By knowing the incident electron flux, the total ionization yield is estimated. For a given incident electron beam power of 150 kW (i.e. 60 kV x 1.5 A) and cross sectional area of 130 mm x 6 mm, the surface temperature of U target is achieved ~ 2950 K. It is estimated that the yield of Saha ionization is ~ 0.2 % whereas the cumulative contribution of electron impact ionization is ~ 0.3%. The total degree of ionization increases with the incident electron beam power density. The plasma expansion is being studied using particle in cell simulation.

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IP/PP28

Simulation of Plasma Based Chemical Processes

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Abstract - Plasma based chemical processes, especially through plasma etching and chemical vapor deposition, play a vital role in the industrial application of plasma. Microelectronics manufacturing widely utilizes plasma etching and vapor deposition processes [1]. Plasma etching can also be used in the decontamination process of radioactive wastes of nuclear reactor [2]. In order to simulate plasma based chemical processes, a code is being developed which is based on homogeneously mixed gas plasma reactors with chemical gas kinetics. As a first step, a low-pressure

chlorine glow plasma chemical reaction model has been prepared to estimate the plasma and gas species in a reactor. Also, the process is validated with already available plasma kinetic models [3, 4]. The simulations of silicon oxide etching in C2F6 plasma [5] and NF3 plasma [6] etching reactor need a plasma-surface kinetic model and this has been carried out using available plasma surface kinetic models [7-9]. Parametric analyses with variation in flow rate and power deposition are also executed to optimize C2F6 and NF3 plasma reactor etching. Results are compared with published experimental results [5, 6]. This study is being conducted to support the planned RF glow plasma etching experiments.

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IP/PP29

Numerical Modeling of A Circularly Interdigitated Piezoelectric Micro-Actuator Using Comsol Multiphysics

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Abstract - Micromechanical devices that utilize active piezoelectric materials in thin-film form show potential for a wide range of applications, particularly actuation. As the devices become progressively more diverse and sophisticated, the need arises for increasingly accurate and efficient modeling of their behavior for design point of view. The piezoelectric effect manifests itself as a transfer of electrical energy to mechanical energy and vice versa. The electrically active region of the piezoelectric material performs either as a sensor (strain input, electrical output) or as an actuator (electric-field input, displacement output) or both. The design optimization of micro-actuators brings challenges of analyzing inter-dependent physical phenomena, device sensitivity and small scale geometries [1]. The paper describes a method to design, analyze and optimize piezoelectric interdigitated micro-actuators using COMSOL multiphysics finite element analysis (FEA). The simulation requires multidisciplinary software to capture the multiphysical nature of micro-electromechanical devices. The numerical modeling of the circularly interdigitated micro-actuator has been successfully developed and the results are well matched with the published results thereof. The model was further validated by re-producing the results of similar device which were modeled using ANSYS FEA tool. Further, parametric analysis may be carried out to capture a large battery of solutions from a small number of models which will facilitate in optimizing the design parameters of Circularly Interdigitated Microactuators.

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IP/PP30

Formation of Super-Hydrophobic Surface with Hexamethyldisiloxane (HMDSO) Coating by Cold Atmospheric Pressure Plasma Polymerization

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Abstract - Atmospheric pressure plasma jets have received a lot of attention in the last few decades due to their simplicity and low cost operation for surface treatment and polymerization as there is no need of any expensive vacuum pumping system [1]. In this study, we have designed a cold atmospheric pressure plasma jet [2] powered by a 20 KV, 50 kHz sinusoidal power supply to carry out the plasma polymerization process. The plasma is cold because the plasma gas remains at room temperature and highly reactive chemical species are generated by the high temperature plasma electrons which allows the polymerization reactions to occur at a lower temperature. Argon is used as carrier gas and a precursor Hexamethyldisiloxane (HMDSO) is introduced into the plasma through a bubbler at a flow rate of 20 sccm. The discharge is made inside a quartz tube (3 mm inner diameter and 60 mm length) between a hollow live electrode placed inside the tube and a grounded Aluminium strip electrode wrapped on outer surface of the tube. A plasma plume (length $\sim$ 10 mm, diameter $\sim$ 1 mm) blows out into open air with the flow of the gas and is directed towards a substrate for thin film deposition. Optical characterization of the plasma jet is done by using Optical Emission Spectroscopy

(OES). The changes in morphological and chemical composition of the film is analyzed by Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM) and Fourier Transform Infrared Spectroscopy (FTIR). The change in hydrophobicity is investigated by Kruss Drop Shape analyzer. Contact angles greater than 150 degree is achieved for water droplets. The results show that hydrophobicity improves due to increase in surface roughness and introduction of the Silicon containing groups to the coated surface.

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IP/PP31

Oxygen Diffusion Barrier Properties of Plasma Deposited SiOx Films on Low Density Polyethylene

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Abstract- Polyethylene is a promising material for packaging applications due to its good mechanical and sealing properties. Also it is a low cost material. Oxygen diffusion barrier property of polyethylene is not sufficiently good to be used alone as a packaging material. This means the material allows large number of oxygen molecules to pass through which reacts with the packed product and degrades the same. Because of this reason multi-layer (3 – 9 layers) packaging structures are being used for flexible packaging. [1-3].

To address this problem, in the present work we have deposited nano-scale SiOx films on Low Density Polyethylene (LDPE) surface by radio frequency (13.56 MHz) capacitively coupled Oxygen/HMDSO plasma at low pressure. Film properties such as surface chemistry, morphology and oxygen diffusion rate are studied by Fourier Transform Infrared Spectroscopy (FT-IR), High Resolution Scanning Electron Microscopy (HR-SEM) and Gas Transmission Rate Testing machine respectively. Film thickness and surface roughness is determined by contact mode stylus profileometry. Experimental results reveal that oxygen transmission rate reduces from 3300 cc/ m2/day (OTR Value of untreated polyethylene) to 350±100 cc / m2/ day with increase in oxygen concentration in Oxygen / HMDSO gas mixture. Organic-inorganic double layer SiOx film gives better barrier properties compared to single layer film.

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IP/PP32

Discharge analysis of atmospheric pressure glow discharge in micro-scale dielectric barrier gap

Mr. HOSSAIN, Mohammad Afaque

IP/PP33

Characterization and Tribological Evaluation of TiAlN Thin Films Deposited by Reactive Magnetron Sputtering.

Mr. TILAVAT, Parth; Mr. PATEL, Bhargavkumar

IP/PP34

Effect Of Interlayer On Tribological Properties Of DLC Coated Steel/Al Automotive Counterparts

Mr. SAVARIMUTHU, Infant Solomon Vinoth

IP/PP35

Effect of External Magnetic Field on the Absorption of Surface Plasma Wave by Metal Nano-Particles

Deepika Goel, Anshu D Varshney, Suneet Awasthi, Vivek Sajal, Anuraj Panwar, Prashan Chauhan

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Abstract - Study of the absorption of surface plasma wave (SPW) by metal nanoparticles embedded on the metal surface is done in the presence of external magnetic field. In the absence of any external magnetic field, the SPW (propagating in *z*-direction) excites resonant plasma oscillations in the particles incurring attenuation of the wave. For spherical metallic particles with plasma frequency , the resonant plasma oscillations occur at ,where ω is the frequency of the SPW. The absorption of SPW by the nanoparticles enhances significantly in the presence of external magnetic field. Our results shows that the sharp increase in the absorption of SPW by the metallic particles, also depends upon its size, inter-particle separation, magnetic field strength and dielectric constant of the metal occurs.

Papers for BUTI Young Scientist Award

BYSA-04

Modelling and Characterization of Atmospheric Pressure Plasma Jet based on Dielectric Barrier Discharge

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Abstract: Non-equilibrium atmospheric pressure plasma jets (APPJs) are of intense interest in current low-temperature plasma research because of their immense potential for material processing and biomedical applications. The plasma jets generate plasma plumes in open space while providing a significant number of active species, such as radicals, electrons, and ions. Thus, they can be used for direct treatment of materials or living tissues. One of the prerequisites to the biomedical applications is that the plume should be near room temperature and carry a low current under moderate voltage. Depending on the jet configuration and the electrical excitation, the plasma characteristics including heat, charged particle, electric field, and chemically active species may differ significantly. Other important parameters of importance in these studies are the kind of utilized working gas and gas flow rate. Physically, the breakdown mechanism of APPJs depend strongly on the electron multiplication, which controls the transition from Townsend breakdown to streamer breakdown and finally to glow discharge region. The mobility of charged species in the electric field depend on the gas properties, the gas type determines the electron multiplication and the breakdown mechanism as well as the discharge mode. In addition, different working gases produce different plasma species resulting in different interactions with the targets. In this research work, theoretical modelling has been done for ring electrode and pin electrode configurations using COMSOL Multiphysics software under the static argon gas condition and with flowing argon gas. The electron temperature, electron density and electrical potential have been calculated using simulation by varying applied frequency (10-25 KHz) and applied voltage (2.5 kV-6kV). The electrical characterization of these jet devices having ring and pin electrode configurations have been performed by V-I measurements in argon gas. The electrical characterization has been done for establishing the optimized operating range based on power consumption, peak discharge current and jet length. The experimental results are in agreement with simulation studies. All these jets have been operated in the glow discharge region. It is imperative to operate the device that is used for low temperature applications in the glow discharge region as the temperature of the gas remains at room temperature so that it does not damage the living tissue that is to be treated. If the discharge proceeds to the arc discharge region it would result in increase of gas temperature, the input power being wasted in thermal dissipation which causes the heating of the quartz tube and also leading to more power consumption. The floating helix electrode configuration studied has a novel design feature to understand the effect of floating electrode on the power consumption as well as on the jet length. The floating electrode configuration has been studied experimentally for different gases (Ar/He/Ar+N_2) and consumption of power has been studied under different operating parameters. The comparative analysis of the experimental results of all the above mentioned electrode configurations shall help in operating these devices in the glow discharge region with optimized power consumption. This research work also discusses the most pivotal factor of the developed plasma jet, i.e., jet length. Besides the V-I characteristics of these different electrode configurations for DBD based APPJ, jet lengths have been studied as a function of supply voltage, supply frequency and quartz sleeve put at the end of quartz tube. The jet length has been studied for both with sleeve and without sleeve. It has been observed that floating helix electrode configuration operating with helium consumes least power around few mW and may

be a potential device for biological applications. The jet generated using mixture of Ar + N_2 shall be rich in excited active species and may be a useful device for surface cleaning and modifications.

BYSA-01

A Quantitative Analysis on the Roles of F3 Layers As Well As Solar Flux in Modulating the Topside Ionization over Indian Region

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Abstract - The earth is surrounded by a region of plasma referred to as the ionosphere. The behavior of ionization in the upper ionospheric region (topside) is quite different from the lower ionosphere owing to the different processes operational there. This paper presents a comprehensive study on the topside ionosphere and brings out quantitatively the role of F3 layer as well as solar flux in modulating the topside ionization. Data used comprises of the electron density obtained from COSMIC satellite for the period 2007 to 2012 as well as RaBIT tomograms for the period May to December 2011. This study clearly shows that the ionization in the height region of 300 km to 400 km is affected by the presence of F3 layer while above 450 km ionization is not significantly altered by the formation of F3 layer during the solar minimum period. The important factor which affects topside ionization above this altitude is the solar flux. The present study has generated an empirical relationship between the topside electron density and F10.7 cm solar flux during the rising phase of solar cycle 24. This empirical relationship is compared using tomographic observations obtained from RaBIT (Radio Beacon for Ionospheric Tomography) data over Indian region**.**

BYSA-06

Electron Scattering from Atoms (Ions) and Plasma Modeling

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BYSA-02

Excitation and dynamics of spiral structures (wave) in strongly coupled dusty plasmas

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Abstract - Spiral waves are ubiquitous structures observed in variety of natural and laboratory scenarios including Saturn ring, spiral galaxy, Belousov-Zabotinsky reaction, coupled oscillators, liquid crystal and cardiac tissue [1]. Strongly coupled dusty plasma offers a model system to study generic phenomena such as self-organization and transport at individual particle level. For the first time in the dusty plasma medium, we have excited spiral waves using rotating electric fields (REFs). Both fluid [2] and molecular-dynamics (MD) [3] simulations have been carried out to study these waves. Characteristics of spiral waves with varying strength and frequency of REFs and strong coupling of the medium have been studied. It is found that the spiral structure gets determined by an interplay between the frequency of REF and acoustic speed of the dust medium. Comparative study of fluid and MD simulations reveal that single particle dynamical effects also play a crucial role in the formation of spiral pattern. Interestingly in the crystalline state of dusty plasma, the

spiral wavefront becomes hexagonal in shape which is understood by the difference in the phase velocity in directions associated with the crystal lattice (viz., lattice axis and lattice diagonal).

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BYSA-03

High Frequency, Global Geodesic Acoustic-like Mode in a Simple Magnetized Toroidal Plasma: An Experimental Study

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Abstract - In our recent work [1], for the first time we have reported the excitation of a high frequency Geodesic Acoustic-like Mode in a nearly collision less, magnetized simple toroidal plasma experimentally. The observed mode is found to be a discrete, global mode with frequency nearly three times the theoretical GAM frequency. The observed mode exhibits (m=1, n=0) symmetry for density fluctuations and ($m \geq 0, n = 0$) symmetry for potential fluctuations, where m,n are toroidal and poloidal mode numbers respectively. In the present work, a detailed experimental study of the variation of the frequency of the observed mode with the ion mass has been performed. Moreover, an experimental study of dependency of the GAM-like mode on the topology of the toroidal magnetic field has also been performed. It has been observed that for a particular topology of the toroidal field line for which the parallel pathway along the field line is shorter, the GAM-like mode can be observed. The frequency of the observed Mode linearly scales with $1/\sqrt{M_i}$, where M_i is the ion mass.

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BYSA-05

Study of Plasma Transport due to Electron Temperature Gradient Induced Turbulence in Laboratory Plasma

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BYSA-04

Modelling and Characterization of Atmospheric Pressure Plasma Jet based on Dielectric Barrier Discharge

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Abstract: Non-equilibrium atmospheric pressure plasma jets (APPJs) are of intense interest in current low-temperature plasma research because of their immense potential for material processing and biomedical applications. The plasma jets generate plasma plumes in open space while providing a significant number of active species, such as radicals, electrons, and ions. Thus, they can be used for direct treatment of materials or living tissues. One of the prerequisites to the biomedical applications is that the plume should be near room temperature and carry a low current under moderate voltage. Depending on the jet configuration and the electrical excitation, the plasma characteristics including heat, charged particle, electric field, and chemically active species may differ significantly. Other important parameters of importance in these studies are the kind of utilized working gas and gas flow rate. Physically, the breakdown mechanism of APPJs depend strongly on the electron multiplication, which controls the transition from Townsend breakdown to streamer breakdown and finally to glow discharge region. The mobility of charged species in the electric field depend on the gas properties, the gas type determines the electron multiplication and the breakdown mechanism as well as the discharge mode. In addition, different working gases produce different plasma species resulting in different interactions with the targets. In this research work, theoretical modelling has been done for ring electrode and pin electrode configurations using COMSOL Multiphysics software under the static argon gas condition and with flowing argon gas. The electron temperature, electron density and electrical potential have been calculated using simulation by varying applied frequency (10-25 KHz) and applied voltage (2.5 kV-6kV). The electrical characterization of these jet devices having ring and pin electrode configurations have been performed by V-I measurements in argon gas. The electrical characterization has been done for establishing the optimized operating range based on power consumption, peak discharge current and jet length. The experimental results are in agreement with simulation studies. All these jets have been operated in the glow discharge region. It is imperative to operate the device that is used for low temperature applications in the glow discharge region as the temperature of the gas remains at room temperature so that it does not damage the living tissue that is to be treated. If the discharge proceeds to the arc discharge region it would result in increase of gas temperature, the input power being wasted in thermal dissipation which causes the heating of the quartz tube and also leading to more power consumption. The floating helix electrode configuration studied has a novel design feature to understand the effect of floating electrode on the power consumption as well as on the jet length. The floating electrode configuration has been studied experimentally for different gases (Ar/He/Ar+N_2) and consumption of power has been studied under different operating parameters. The comparative analysis of the experimental results of all the above mentioned electrode configurations shall help in operating these devices in the glow discharge region with optimized power consumption. This research work also discusses the most pivotal factor of the developed plasma jet, i.e., jet length. Besides the V-I characteristics of these different electrode configurations for DBD based APPJ, jet lengths have been studied as a function of supply voltage, supply frequency and quartz sleeve put at the end of quartz tube. The jet length has been studied for both with sleeve and without sleeve. It has been observed that floating helix electrode configuration operating with helium consumes least power around few mW and may be a potential device for biological applications. The jet generated using mixture of Ar + N_2 shall be rich in excited active species and may be a useful device for surface cleaning and modifications.

I. INTRODUCTION

Dielectric barrier discharge (DBD) based atmospheric pressure plasmas have been used in numerous applications.[1–4] Atmospheric pressure plasma jets (APPJs) have received significant attention in recent time because they widen the plasma application range for biomedical purposes.[5,6] Different types of plasma jets have already been researched, relying on different excitation means from DC to microwave, and discharge mechanisms, such as capacitively coupled plasma discharge (CCP) and corona discharge,[7–10] but DBD based plasma jets have not been thoroughly explored. Koinuma et al.[11] obtained a plasma jet at atmospheric pressure in a micro-beam plasma generator, which was later termed as "a 'cold' plasma torch" by Schütze et al.[12] In 2005, Laroussi and Lu[13] proposed a plasma jet with a cylindrical configuration fed by inert gases. They found that by confining the glow discharge in a tubular geometry with dimensions usually less than 1 cm in diameter, a stable discharge can be generated. Furthermore, APPJ is also investigated by Teschke et al.[14] by use of an intensified charge coupled device (ICCD) camera to capture photos of the jet with exposure time in 100 ns range. They have found that the presented plasma source acts like a "plasma gun" blowing small "plasma bullets" out of its mouth. Nie et al.[15] generated an argon plasma jet using a pair of tungsten pin electrodes, out of which only one was at floating potential. Nevertheless, a limited jet length is achieved despite working at higher operating voltage. Jiang et al.[16] studied the effect of electrode configuration and discharge behavior on the helium plasma jet but have not conducted power consumption analysis of the device. Lei and Fang[17] analyzed the effect of gas flow on neon based APPJ generated using two planar electrodes which could be used for medical sterilization purposes. Xu et al.[18] fabricated a non-thermal plasma jet source, which produced helium plasma with an oxygen-rich atmosphere in a theta-shaped tube, and its potential was investigated for use in the topological alteration of plasmid DNA. This device consumed a peak power of 27 W at 7.5 kV/32 kHz discharge operation.Recently portable plasma jet devices like jet needle and plasma pencil have also been constructed for their effective operation, and often molecular gases, such as oxygen or methane, are added to the inert carrying gases.[19–30] However, the electrical characterization of such discharges has not been carried out. In this paper, an effort has been made by developing an APPJ using a new electrode arrangement consisting of the floating helix and end ring electrode. These two floating electrodes have been used to propagate the plasma jet to greater lengths at lower operating power. Peak power consumed by the developed APPJ is only of the order of few mW. The electrode configuration implemented shows low voltage operation and also high stability. The electrical characterization has been carried out for floating helix electrode[31] using Ar/He/ mixture of Ar+ N_2 gas and for ring electrode[32] and pin electrode[33] only argon gas was used. The developed APPJ has been studied with respect to the peak discharge current, jet length, and power consumed. The optimum power for maximum jet length is achieved for the helium gas in the proposed novel geometry of floating helix electrode configuration. In this thesis work, simulation has been done for two electrode configurations (pin and ring electrode) with Ar gas. Theoretical modelling has been done using COMSOL Multiphysics software under the static argon gas condition and with flowing argon gas. Three electrode configurations (ring electrode, pin electrode, floating helix electrode) have been studied experimentally and only floating configuration has been studied with different gases such as Ar/ He/ or mixture of Ar +N_2 (50% each). For Ar + N_2, supply voltages in the range 6.5 to 9.5 kV have been used.

II. GEOMETRY AND EXPERIMENTAL SETUP

The developed APPJ in a floating helix electrode configuration is shown in Fig. 1. The floating end ring may be removed in another case to study its effect on jet length (see Fig.1). The applied voltage and currents are measured by using a high voltage probe (Tektronix P 6015 A; bandwidth 0-75 MHz) and Rogowski-type Pearson current monitor (Model 110; 0.1VA–1, 1 Hz–20 MHz, 20 ns usable rise time) connected to a digital storage oscilloscope (Tektronix DPO 4054; bandwidth 500 MHz).

The main body of the jet consists of a quartz tube of diameter 4 mm, which is used as a dielectric barrier between the electrodes. In this geometry, a pin electrode of diameter 1 mm and length 88 mm is used as a cathode, which is hermetically sealed with the quartz tube (see Fig.1). The effective length of the pin electrode inside the quartz tube is 40 mm. The quartz tube is glass blown in L-shape, so as to make an effective length of 123 mm for plasma discharge. The one end of the tube having length 30 mm is used for the gas connection whereas the other open end is used for a cold plasma jet outlet. A conductive epoxy silver foil tape of width 2 mm and 0.1 mm thickness tightly bound to the quartz tube at the gas inlet end is used as an anode, which is grounded. A fourteen turn helix of the same silver foil tape having pitch 5 mm has also been used as a plasma jet guiding rail. The pitch of the helix electrode in the guiding rail has been optimized experimentally based on the diffused discharge to occur between the successive helix pitches, and the number of turns has been decided to facilitate the propagation of the plasma jet out of the quartz tube. The floating helix electrode causes charge accumulation on the dielectric surface around the helix and provides a subsequent discharge path for the plasma jet. Nevertheless, this floating helix electrode geometry electrode has provided a distortion in the plasma jet. So, to focus the plasma jet, another electrode of the same conductive epoxy silver foil tape has been used at the end of the quartz tube outlet after a gap of 25 mm from the helix. To understand the role of the floating end ring electrode on the plasma jet extraction for the same applied conditions, the end ring electrode has been removed in another case. The experiments have been performed using three different gases, such as argon, helium, and Ar + N_2 mixture blown with 1 l/min gas flow rate for all the experiments in an airtight arrangement in the atmospheric pressure environment.[30]

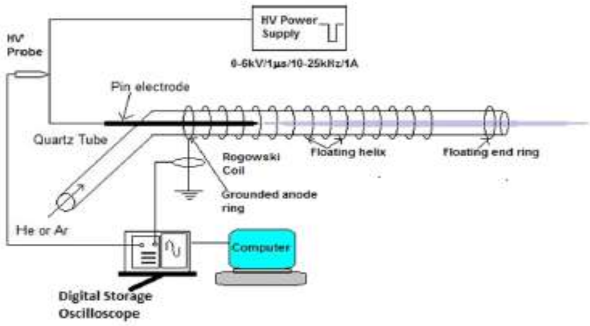

Fig. 1. Experimental setup of the floating helix electrode configuration but with/without floating end ring.[31]

Fig. 2. Argon jet generated using the floating helix configuration. [31]

Fig. 3. Helium jet generated using the floating helix configuration. [31]

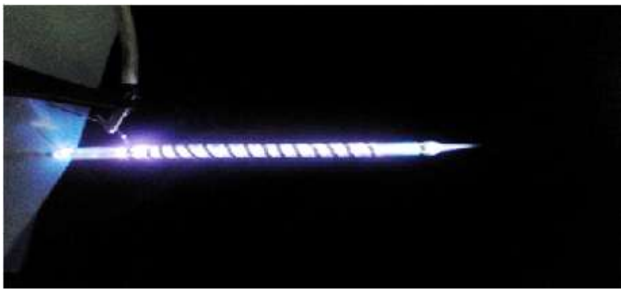

Fig. 4. Cold plasma jet of (Nitrogen and Argon gases) using floating helix [31]

The plasma jets generated using the floating helix configuration along with the floating end ring for argon and helium gases and mixture of $Ar+N_2$ are shown in Fig.2, 3 and 4, respectively. In the discharge experiments, a plasma jet length up to 42 mm has been achieved from the open end of the quartz tube for the helium gas. The maximum effective length obtained in this configuration from the cathode tip is 122 mm. The gas discharge in this geometry has been studied for a range of supply frequency 10-25 kHz and supply voltage 2- 9.5 kV operation. Accordingly the effect of jet length enhancement at optimum operating parameters has been analyzed for the aforementioned two APPJ configurations. Further in this research work the electrical characterization of double ring electrode configuration has also been done [31] which consists of a quartz tube with a nozzle is shown in Fig.5.

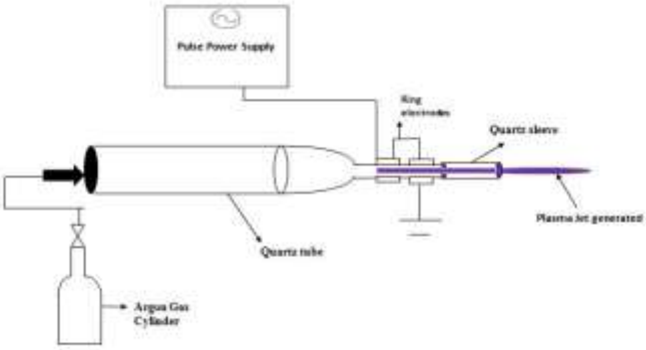

Fig. 5. Schematic diagram of double ring electrode configuration with quartz sleeve [32]

Fig. 6. Plasma jet generated using ring electrode configuration [32]

On top of the nozzle, two metal sleeves are put which act as the ring electrodes. Out of these, one of the metal sleeves is connected to the supply and other is grounded. Ar gas flows through the inlet of the quartz tube (see Fig.5) and its diameter is 22 mm. The diameter of nozzle outlet is 3 mm. The length and outer diameter of the quartz tube are 155 mm and 25 mm, respectively. The thickness of the quartz tube is 1.5 mm. The axial length and diameter of ring electrodes are 18 mm and 4 mm respectively. The ring electrodes are separated by a distance of 3 mm. A quartz sleeve of 4 mm diameter and 15 mm length was placed on the nozzle of the quartz tube to observe the length of plasma jet without the effect of surrounding air. Jet length has been observed with and without the sleeve. Fig. 6 depicts the plasma jet generated using ring electrode configuration.

Further, electrical characterization of pin electrode has been done [32], which consists of a quartz tube of length and outer diameter 155 mm and 25 mm, respectively, which serves as a dielectric barrier between the electrodes. The argon gas flows through the inlet of the quartz tube in the geometrical design as shown in Fig.7. Similarly, the diameter of nozzle outlet is 3 mm. The thickness of the quartz tube is taken 1.5 mm. The pin electrode is connected to a pulse power supply (anode) and ring electrode on top the nozzle is grounded (cathode) (see Fig.7). In the one set of experiments a quartz sleeve of 4 mm diameter and 15 mm length was placed on the nozzle of the quartz tube to observe the variation in the length of plasma jet. Fig. 8 shows the plasma jet generated using pin electrode configuration.

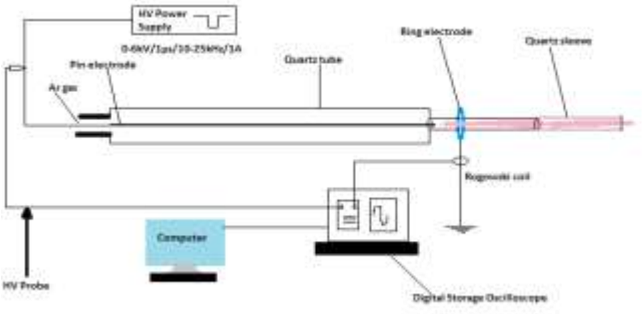

Fig. 7. Experimental set up of atmospheric pressure plasma jet using pin electrode configuration (with quartz sleeve) [33]

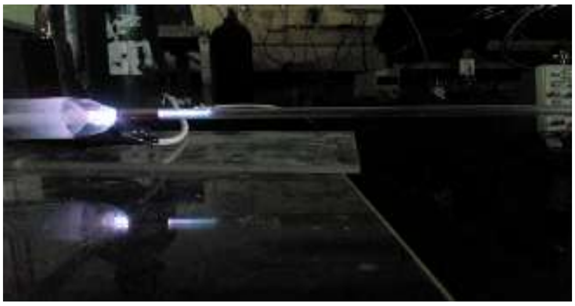

Fig. 8. Cold Plasma jet generated using pin electrode configuration [32]

III. GOVERNING EQUATIONS FOR DISCHARGE SIMULATIONS

The mean electron energy and electron density are computed by solving a pair of drift-diffusion equations for the mean electron energy and electron density.

$$\partial/\partial t(n_e)+\nabla.[-n_e(\mu_e\bullet.E)-D_e\bullet\nabla n_e]=R_e \tag{1}$$

$$\partial/\partial t(n_\varepsilon)+\nabla.[-n_\varepsilon(\mu_\varepsilon\bullet E)-D_\varepsilon\bullet\nabla n_\varepsilon]+E.\Gamma_e=R_\varepsilon \tag{2}$$

$$\Gamma_e=-(\mu_e\bullet E)n_e-D_e\bullet\nabla n_e \tag{3}$$

Here n_e is the electron density, n_ε is the electron energy density, μ_e is electron mobility , μ_ε is the electron energy mobility, E is electric field, R_e is the electron rate expression, R_ε is the energy loss/gain due to inelastic collisions, D_e is Diffusion coefficient of electrons, D_ε is electron energy diffusivity, Γ_e is electron flux.

Plasma chemistry using rate coefficients is used to determine the source coefficient in the equations mentioned above.. In the case of rate coefficients, the electron source term is specified by,

$$R_e=\sum_{j=1}^{M}x_j k_j N_n n_e \tag{4}$$

Here, M denotes the reactions that contribute to the growth or decay of electron density

The mole fraction of the target species for reaction j is given by x_j, The rate coefficient for reaction j is given as k_j and total neutral number density is N_n. The electron energy loss is obtained by summing entire collisional energy loss over all reactions and written as:

$$R_\varepsilon=\sum_{j=1}^{P}x_j k_j N_n n_e\Delta\varepsilon_j \tag{5}$$

where $\Delta\varepsilon_j$ is the energy loss from reaction j and P denotes the inelastic electron-neutral collisions. In general P >> M. The rate coefficients can be computed from cross section data by the following integral

$$k_j = \gamma \int_0^{\infty} \varepsilon \sigma_j(\varepsilon) f(\varepsilon) d\varepsilon \tag{6}$$

where $\gamma = (2q/m_e)^{1/2}$, m_e mass of an electron, ε is energy (V), f is the electron energy distribution function, and σ_j is the cross section of collision. A Maxwellian electron energy distribution function (EEDF) is assumed for this case. The electron diffusivity, energy mobility, and energy diffusivity are calculated from the electron mobility using following equations:

$$D_e = \mu_e T_e \ , \mu_\varepsilon = (5/3)\mu_e \ , D_\varepsilon = \mu_\varepsilon T_e \tag{7}$$

where T_e is the temperature of the electron.

Mean electron energy $\bar{\varepsilon} = n_\varepsilon / n_e$ (8)

Electron temperature $T_e = (2/3)\bar{\varepsilon}$ (9)

and electrostatic potential is given by the expression, $-\nabla \varepsilon_0 . \varepsilon_r \nabla V = \rho$ (10)

Where ρ is the space charge density, V is the applied sinusoidal electrical potential [34].

IV. GOVERNING EQUATIONS FOR FLOW SIMULATIONS

In this simulation study, the effect of argon gas flow rate has been analysed with respect to the electron density and electron temperature again using COMSOL 5.2a. The fluid dynamics module contains equations, volume forces, and boundary conditions that are essential for modelling freely moving fluids by means of the Navier-Stokes equations, and solve for pressure and the velocity field. The laminar flow interface is used primarily to model flows of comparably low Reynolds number. The interface solves the Navier-Stokes equations, for incompressible and weakly compressible flows [34]. The single-phase fluid-flow interfaces are computed using Navier-Stokes equations, as mentioned below:

$$\partial \rho / \partial t + \nabla.(\rho u) = 0 \tag{11}$$

$$\rho \partial u / \partial t + \rho (u.\nabla) u = \nabla.[-pI + \tau] + F \tag{12}$$

$$\begin{aligned} &\rho C_P (\partial T / \partial t + (u.\nabla) T) = -(\nabla.q) + \tau : S - \\ &(T/\rho).(\partial \rho / \partial T)(\partial p / \partial t + (u.\nabla) p + Q \end{aligned} \tag{13}$$

$$S = 1/2(\nabla u + (\nabla u)^T) \tag{14}$$

$$\tau = 2\mu S - 2/3 \mu (\nabla.u) I \tag{15}$$

Here density is given as ρ, τ is the viscous stress tensor, u is the velocity vector, p is pressure, I is the identity matrix, F is the volume force vector, T is the absolute temperature, C_p is the specific heat capacity at constant pressure, q is the heat flux vector, S is the strain-rate tensor, Q contains the heat sources. A contraction between tensors (S & τ) is denoted by operator ":" and is denoted as,

$$S : \tau = \sum_n \sum_m S_{nm} \tau_{nm}$$

V. RESULTS AND DISCUSSION

From the comparative analysis of the results (floating helix electrode) of the above experiments, it is clearly seen from Fig.9,10 & 11. that the maximum power consumed by this helix electrode configuration with end ring is 19 W for ($Ar+N_2$) mixture as compared to only 12mW for Ar and 8 mW for He gas (With end ring), this is due to low ionization potential and lower breakdown voltage of Ar/He in comparison to N_2.

Furthermore, maximum jet length of 42 mm has been obtained is for He gas (With end ring) at 6 kV/25 kHz due to penning ionization process in comparison to jet lengths of only 32 mm for Ar gas (With end ring) and jet length of only 26 mm for Ar+N_2 mixture (With end ring) for the same applied conditions.[35-37]

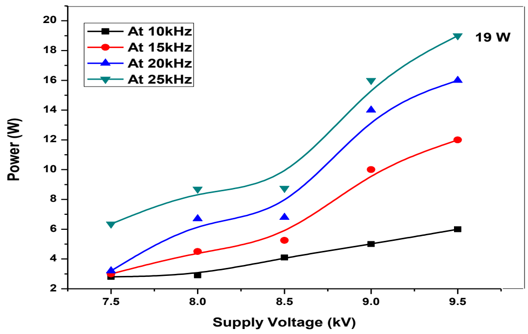

Fig. 9. Variation of power consumed at different frequencies and at different applied voltages with floating helix electrode

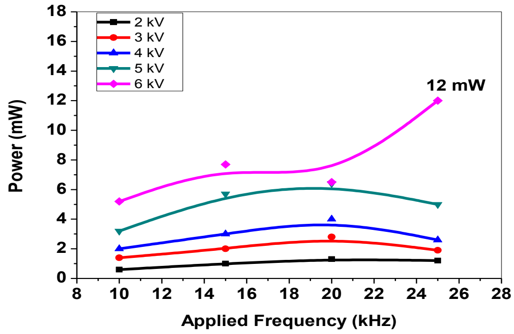

Fig. 10. Variation of power consumed at different frequencies and at different applied voltages with floating helix electrode (Argon gas)

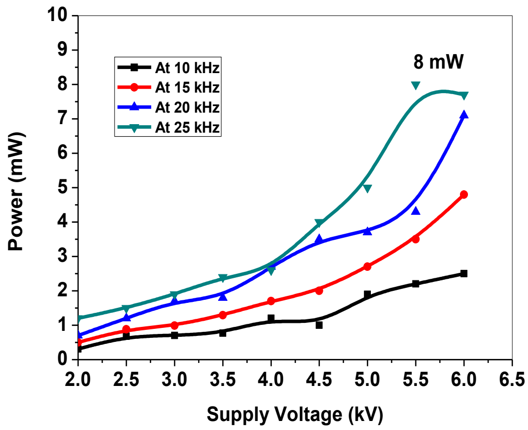

Fig. 11. Variation of power consumed at different supply voltages and different supply frequencies for floating helix and floating end ring electrodes (Helium gas)

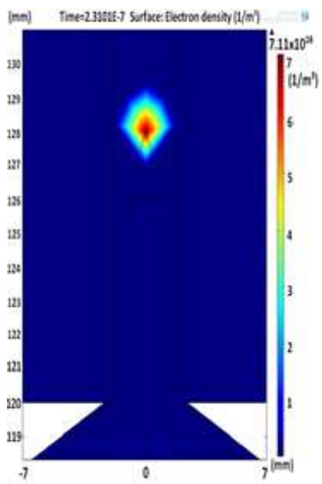

Fig. 12.a. Electron density (with flow)

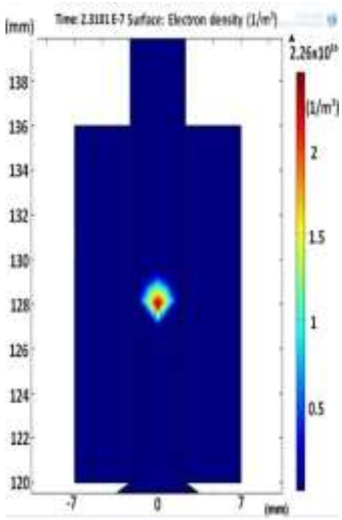

Fig. 12.b. Electron density (static mode)

Both simulation and experimental results of the developed dielectric barrier discharge based argon plasma jet in pin electrode configuration [33] shows that the plasma parameters (i.e., electron density, electron temperature, electrical potential) increases with increase in supply frequency and supply voltage for both cases of with and without flow of argon gas (see Fig.12.a, Fig.12.b, Fig.13a, Fig.13.b, Fig.14.a, Fig.14.b). Our experimental results support this fact by indicating power consumed in the discharge increases with the increase in supply frequency. It is also observed that at all supply frequencies (10–25 kHz) there is more consumption of power, occurring for applied voltage between 5.5–6.5 kV (see Fig.15). This fact is supported by the increase in peak discharge current value from 232 mA at 5.5 kV to 416 mA at 6.5 kV. Hence at combinations of higher supply voltages and frequency the power consumed reaches a highest value of 1.06 W at 6.5 kV, 25 kHz, which could occur due to multiple streamer formation[38-42]. As a consequence the supplied power is lost in thermal dissipation of the dielectric tube leading to heating. It is concluded that for this kind of cold plasma jet generation with an average power consumption of ~ 0.65 W, the tube should be operated between optimum range of 4.5–5.5 kV and 15–25 kHz. Fig 12.a & b shows electron density of plasma jet in pin electrode in both conditions of static and with flow condition. Fig.13 a & b shows the electron temperature of plasma jet in pin electrode configuration in both static and with flow condition. Fig.14 a & b shows the electrical potential of plasma jet reached at the instant of discharge in pin electrode configuration in both static and with flow condition.

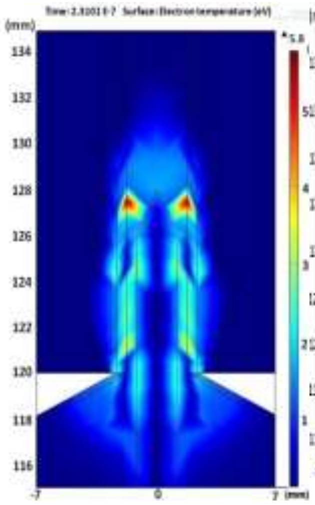

Fig. 13.a. Electron temperature at 4.5 kV/25 kHz (static condition)

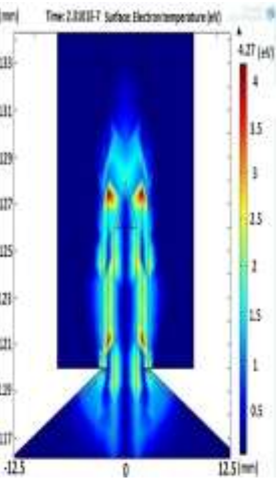

Fig.13.b.Electron temperature at 4.5 kV/25 kHz (withflow)

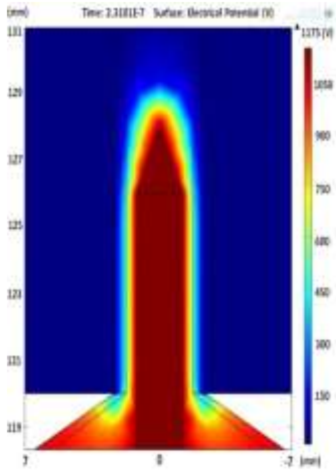

Fig. 14.a. Electrical potential reached at 4.5 kV/ 25 kHz (static mode)

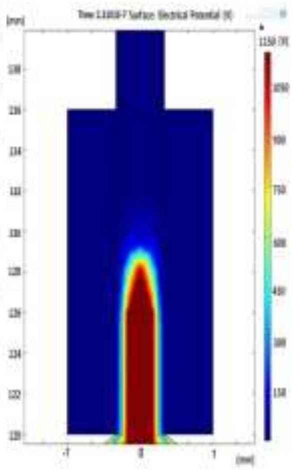

Fig. 14.b. Electrical potential reached at 4.5 kV/ 25 kHz (With flow)

Both simulation and experimental results of the developed dielectric barrier discharge based Ar plasma jet in ring electrode configuration [32] shows that the plasma parameters (i.e., electron density, electron temperature, electrical potential) increase with increase in supply frequency and supply voltage for both static condition and with flow of Ar gas.(see Fig.16,17 & 18) From the simulation results of electron density, electron temperature and electric potential with respect to supply voltage and frequency clearly indicates discharge is progressing in the glow discharge region (see Fig.16, 17 & 18) under both static discharge condition and with flow of Ar gas. However the electron density and electron temperature is lower for with flowing Ar gas due to the lesser availability of electrons compared to the static mode at all supply frequency and applied voltages.[43-44] Consequently the inherent collisions between electrons is lesser with flow of Ar gas resulting in lower electron temperature values compared to static condition at all supply frequencies and voltages.

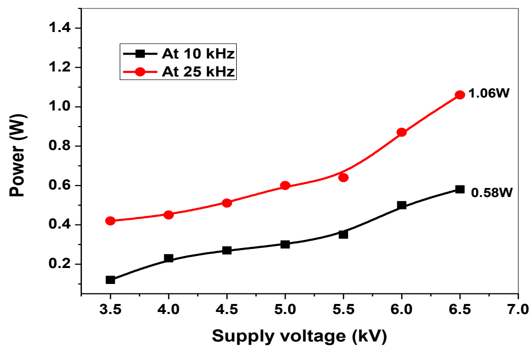

Fig.15. Power Vs supply voltage at 10 kHz & 25 kHz,

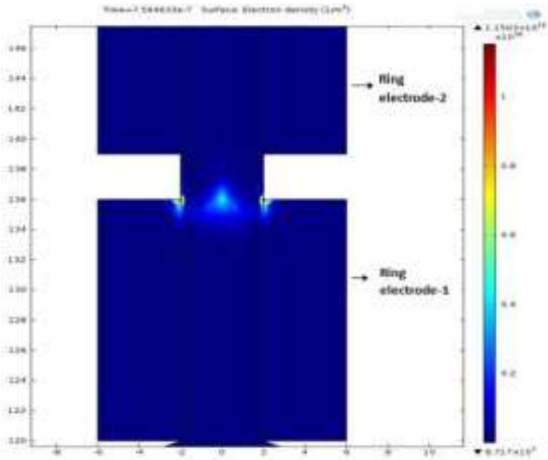

Fig.16. Electron temperature 2.7 eV at 4.5 kV/10 kHz (static discharge condition)

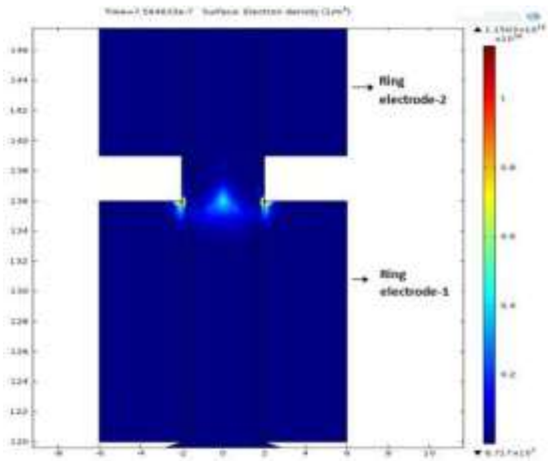

Fig.17. Electron density 1.15×10^{16} at 3.5 kV/25 kHz (static discharge condition)

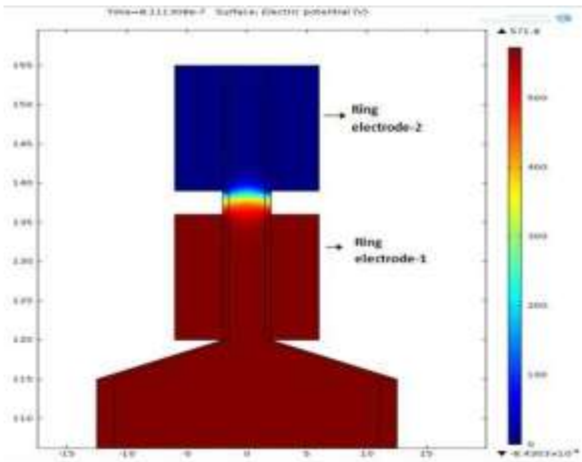

Fig.18. Electrical potential 490 V at 3.5 kV/25 kHz (with flow of Ar gas)

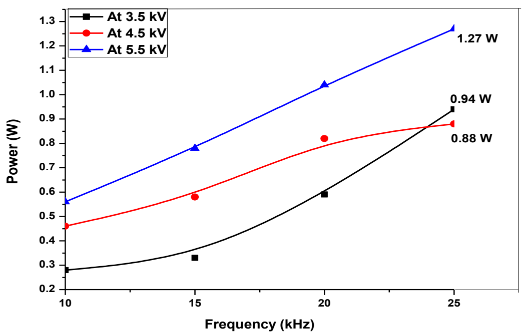

Fig. 19. Power consumption in the jet for different frequencies and 3.5 -5.5 kV applied voltage

From our experimental results it is observed at combinations of higher supply voltages and frequency the power consumed reaches a highest value of 1.27 W at 5.5 kV, 25 kHz, with minimal peak discharge current of 144 mA (see Fig.19). It is also found from experimental results that for the tube to be operated in glow discharge region without arcing, it should be operated between optimum range 3.5-4.5 kV & 15-20 kHz.

V. SUMMARY

From the comparative analysis of the results of the floating helix and floating end ring electrode experiments with Ar/He/Ar+N_2 gases, it is clearly seen that the maximum power consumed by this helix electrode configuration with end ring is 19 W for (Ar+N_2) mixture (see Fig.9) as compared to only few mW for Argon or Helium gas (With end ring) (see Fig.10 & 11). This may be attributed to lower breakdown voltage of Ar/He in comparison to molecular gas N_2 which needs higher input energy for dissociation of nitrogen molecule to nitrogen atoms. It has been experimentally observed that for this kind of cold plasma jet (Ar+N_2) generation, average power consumed is~ 6.5 W with peak discharge current value of ~ 1 A. The optimum range of operation of such a device is 7.5–8.5 kV at applied frequency of 15–25 kHz. Since the current is in the range of Ampere so this Ar+N_2 based plasma can be used for surface modification applications and not for biomedical applications as it could damage the living tissue. Both simulation and experimental results of the developed dielectric barrier discharge based argon plasma jet in pin electrode configuration shows that the plasma parameters (i.e., electron density, electron temperature, electrical potential) increase with increase in frequency and supply voltage for both static condition and with flow of Argon gas. Our experimental results support this fact (see Fig.15).

It is also found from experimental results of ring electrode that for an average power consumption of 0.5W-0.9 W the tube should be operated between optimum range of 3.5-4.5 kV & 15-20 kHz (see Fig.19). It is further observed the power is lost in heating of dielectric material & heating of Argon gas atoms beyond a supply voltage of 5.5 kV irrespective of supply frequency.

We have also studied the most pivotal factor of the developed plasma jet, i.e., jet length, which is related to the input supply frequency, voltage, and quartz sleeve for all the above mentioned electrode configurations. In floating helix electrode configuration, maximum jet length of 42 mm has been obtained for Helium gas (With end ring) at 6 kV/25 kHz due to penning ionization process in comparison to jet lengths of only 32 mm for Argon gas (With end ring) and jet length of only 26 mm for Ar+N_2 mixture (With end ring) for the same applied conditions.

The jet length has been studied for both with sleeve and without sleeve for pin electrode and ring electrode. The maximum jet length obtained for ring electrode and pin electrode configurations with quartz sleeve are 29 mm and 26 mm respectively. The presented analysis in this thesis may help in establishing optimum range of operation for a cold plasma jet without arcing and without any physical damage to the electrodes. Furthermore, experimental results establish the significance of type of working gas on the power consumption as well as on the jet length obtained. These developed cold DBD based APPJ's of larger lengths may be useful to diverse biological applications and surface treatments. [45-50]

The developed novel electrode design of double floating electrode helix electrode configuration which has helped in reducing the power consumption in the range of mW instead of Watts. The jet length has also been enhanced using this novel double floating electrode configuration. The practical applications of the developed floating electrode DBD with longer jet lengths and lower power operations may be realized for the direct plasma treatment on skin and other suitable biomedical applications. The mixed gas APPJ may be useful for surface cleaning and modification and other technological applications.

ACKNOWLEDGMENTS

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A Quantitative Analysis on the Roles of F3 Layers As Well As Solar Flux in Modulating the Topside Ionization over Indian Region

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Abstract - The earth is surrounded by a region of plasma referred to as the ionosphere. The behavior of ionization in the upper ionospheric region (topside) is quite different from the lower ionosphere owing to the different processes operational there. This paper presents a comprehensive study on the topside ionosphere and brings out quantitatively the role of F3 layer as well as solar flux in modulating the topside ionization. Data used comprises of the electron density obtained from COSMIC satellite for the period 2007 to 2012 as well as RaBIT tomograms for the period May to December 2011. This study clearly shows that the ionization in the height region of 300 km to 400 km is affected by the presence of F3 layer while above 450 km ionization is not significantly altered by the formation of F3 layer during the solar minimum period. The important factor which affects topside ionization above this altitude is the solar flux. The present study has generated an empirical relationship between the topside electron density and F10.7 cm solar flux during the rising phase of solar cycle 24. This empirical relationship is compared using tomographic observations obtained from RaBIT (Radio Beacon for Ionospheric Tomography) data over Indian region**.**

I Introduction

The terrestrial ionospheric plasma is generally stratified into different layers called as the D, E and F regions. The F region further splits into F1 and F2 layers. During some days in addition to these normal layers, some additional layers also occur in the ionosphere. The layers which appear above F2 layer is referred to as F3 layers. The behavior of ionization in the topside ionosphere above F2/F3 region peak is quite different from the lower ionosphere owing to the different processes operational therein. Understanding the ionospheric plasma/electron density distribution is important for the estimation of propagation delays involved in the satellite to ground communication systems and their corrections. F3 layers were first observed by Bailey et al., (1948) and afterwards many studies have investigated various aspects regarding F3 layers in detail. Many significant observations regarding their formation and evolution have been brought in the past (Sen, 1949; Balan et al., 1998, Ramarao et al., 2005; Uemoto et al, 2007, 2011; Mridula and Pant, 2015 and references therein). Through a modeling study Balan et al., (1998) had shown the vertical component of meridional winds in addition to the ExB drift, played an important role in the generation of F3 layer over low latitudes. A detailed review on F3 layers and their generation mechanisms is given in Klimenko et al., (2012).

Once formed the F3 layers, especially in the pre noon hours are found to drift to the higher altitudes [Mridula and Pant, 2015]. As F3 layer peak ionization density becomes lower than the F2 peak density, it disappears from the ionogram traces. Hence it is difficult to study the topside ionization characteristics once F3 layer has disappeared. Once the F3 layers move to the topside, they will exist as ledges or they will merge with the ambient ionization. In either scenario, they contribute to an enhancement in ionization in the topside region. This aspect of topside ionization density, in context to F3 layers has not been looked into so far. The present paper deals with the change in topside ionization density caused by the upward drift of F3 layer in conjunction to those days when F3 layer was absent. The extent of influence of F3 layers on topside ionosphere during the solar minimum period when F3 layers are more prominent is identified first. The ionization at altitudes much above this region is then considered to be modulated by solar flux as input from F3 layer is very less. Next, the response of ionization at these high altitudes to the increasing phase of solar cycle 24 is characterized. An empirical relationship between the ionization and F10.7 solar flux for this increasing phase is arrived at.

II Data and methodology

The present study attempts to understand the manifestations of F3 layer on topside plasma density observations from COSMIC [Constellation Observing System for Meteorology, Ionosphere, and Climate] radio occultation [Hajj and Romans, 1998; Schreiner et al., 1999, , Rocken et al., 2000,Schreiner et al., 2007]. Zhao et al., [2011b] using COSMIC Electron Density Profiles (EDP) have shown that F3 layers can be identified unambiguously through the detection of double peaks from the differential Electron Density Profiles (DEDP), i.e. dne/dh. This method by Zhao et al., [2011b] is used to identify F3 layer in the current study. COSMIC EDP's for the year 2007 to 2012 are taken for this study. Only those profiles between 9:00 IST to 12:00 IST are taken, as pre noon F3 layers form predominantly in this local time sector. Profiles from 8^o North to 20^o North are taken as representative of northern hemisphere. RaBIT was India's first beacon onboard YOUTHSAT, dedicated for ionospheric studies. It was launched successfully on 20 April 2011 and was in orbit till December 2011 [Pant et al., 2012]. It had a sun synchronized polar orbit with equatorial crossing time of 10: 30 LT and had a repeativity of 24 days. RaBIT employed the technique of down conversion to 150MHz and 400 MHz from a common oscillator of 1.024 GHz, for coherence. The TEC obtained using RaBIT was inverted using tomography technique to obtain tomograms which are the latitude altitude maps of electron density. The F10.7 cm solar flux is obtained from SPDF OMNI website.

III Observations and discussions

The COSMIC electron density profiles are plotted to identify the presence of F3 layers. Based on technique proposed by Zhao et al., [2011 b], all the profiles during 2007 to 2010 were analysed and categorised into F3 and non F3 days as beyond this the solar activity began increasing. The profiles had been categorised into four periods representing northern winter solstice, vernal equinox, summer solstice and autumnal equinox respectively. The exact time of formation as well as the stage of evolution of F3 cannot be discerned completely on a given day, since only one EDP is available in the time bin taken. The ionization in the topside is higher on F3 days compared to non F3 days except during vernal equinox.

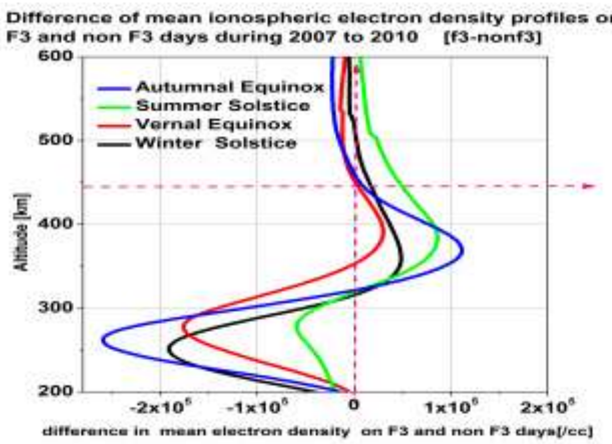

Figure 1: Depicts the difference of mean ionospheric electron density profiles on F3 and non F3 days during 2007 to 2010.

The ionization density is high at altitudes, below 300 km on non F3 days compared to F3 days (the difference is negative), while ionization is more in the altitude region of 300 km to 400 km on F3 days when compared to non F3 days (difference is positive). Above 450 km, no considerable difference is observed between F3 and non F3 days, indicating that F3 layer does not affect the ionization at these altitudes. When F3 layer forms in the equatorial latitude, it drifts up due to the additional electric field [Mridula and Pant,2015] , and over low latitudes it is caused due to the combination of ExB drift and the vertical component of meridional wind. Ionization is transported from lower altitudes to higher attitudes in the form of F3 layer as it moves to higher altitude. As a result, the ionization at lower altitudes will be low on F3 day as compared to a non F3 day, as seen in figure 1. In addition, a part of this ionization is lost due to the magnetic field line aligned diffusion. This explains why the enhancement in ionization density in the altitude region of 300 to 400km is not as high as the lowering in the same in 200 to 300 km region.

Now, the altitude region of 500 km and 600 km is taken for the analysis as it is above the influence of F3 layers and their contributions will be low. The COSMIC as well as RABIT derived electron densities are used to understand the response of topside ionization to solar flux changes. The advantage of RaBIT observations was that the time of Indian crossing i.e. 10:30 IST in the morning was near simultaneous with the peak pre noon F3 formation time. The RaBIT observations made during the period of May to December 2011 which marked a gradual change in the solar flux levels were used to understand the topside ionization response to increasing solar activity. This aspect is made clear in figure 2 which shows electron density as well the F10.7 cm solar flux variation during the period of May to December 2011.

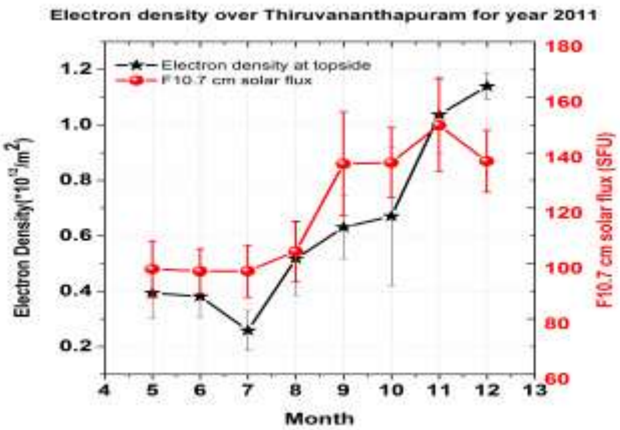

Figure 2: Depicts electron density as well the F10.7 cm solar flux variation during the period of May to December 2011.

The monthly mean F10.7 cm solar flux shows a gradual increase from 90 SFU to 140 SFU during the period. The monthly mean electron density over Thiruvananthapuram at 600 km altitude as obtained from RaBIT data also shows an increase in accordance with the increase in solar flux. It must be mentioned here that during this particular period, the number of F3 layers observed over Thiruvananthapuram during the month of May was 4 while the same for December was zero. The number of F3 layers is very small to reflect as topside ionization change seen in the mean electron density. So the enhancement in topside can be attributed to the flux related changes.

In the present analysis, the relationship between topside ionization and F10.7 cm solar flux has been established using the COSMIC RO EDP for the period of 2007 to 2012, which encompasses periods of low, medium phase of solar cycle 24. The seasonal mean electron densities have been estimated from EDP for local time bins of 2 hours each at 500 km altitude for the whole period. A correlation analysis is carried out between the ionization at these latitude regions at 500km and 600 km altitude with F10.7 cm solar flux for the period 2007 to 2012. Each of these scatter plots are linearly fitted, the slope of which depicts the change in ionization with a concurrent change in F0.7 cm solar flux. The correlation is not 100%. This can be due to the factors like presence of F3 layer; the field aligned diffusion as well as chemical loss affecting the ionization budget.

The slopes obtained for different latitudes and different local times are plotted in Figure 3. The slope represents the rate of change of electron density with F10.7 cm solar flux. Panel a represents the slope at different local times for the altitude of 500 km and 600 km at 0 ^{o} dip, while panel b and c depicts the same for -10^{o} and +10^{o} dip latitude respectively. It is seen from panel a that the slope shows clear local time dependence with the rate of change of electron density being low in the morning hours i.e. around $2*10^3$ electrons /cc/SFU and increasing to around $1.2*10^4$/cc/SFU during 12.5 IST. This remains nearly same till 18.5 IST after which the rate falls down. The rate is almost same at dip equator and +/- 10 ^{o} dip latitude. The slope estimated at 600 km as shown in panel a is smaller than that at 500 km, but the diurnal pattern remains the same. An enhanced slope is seen at 18.5 IST for both 500 km and 600 km. This is probably due to PRE associated upward drift of ionization.

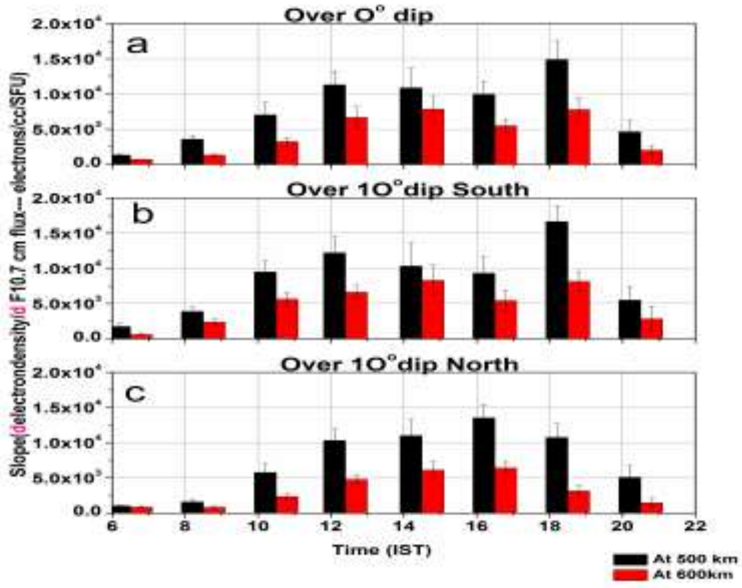

Figure 3: Depicts the slopes obtained for different latitudes and different local times

The slope indicates that as local time advances, with smaller enhancement in F10.7 cm, more ionization will be available. In addition to production, the field aligned diffusion and low loss rates determine the overall ionization in these altitudes. An empirical relationship between the ionization and the solar flux is arrived at and can be used to estimate the change in existing ionization associated with a change in the solar flux values at different local times. These slopes and intercepts can be used to a get a seasonal mean picture. The slopes thus estimated using COSMIC EDP are compared with that estimated using RaBIT observations and are found to be in good agreement (not shown here).

IV Conclusions

The current study has brought out an important factor contributing to the ionization density in the topside ionospheric region, the drift of additional ionization in the form of F3 layers. It is shown that the most prominent manifestations of F3 layer in the topside ionization are in the height region of 300 km to 400 km above which the solar flux contribution dominates. The solar flux contribution to the topside ionization can be estimated using the slope and intercept parameters derived based on correlation analysis between topside ionization and solar flux. The empirical relationship between the topside electron density and F10.7cm solar flux generated in this study can be used for fine-tuning of topside option of IRI over the Indian region. Comprehending the ionospheric plasma/electron density distribution is important for the estimation of propagation delays involved in the satellite to ground communication systems and their corrections.

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Electron Scattering from Atoms (Ions) and Plasma Modeling

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I Introduction

For the diagnostics of any plasma, optical emission spectroscopy (OES) is one of the most straightforward and non-invasive techniques. As the OES based plasma diagnostics have great advantages over the traditional way to measure the plasma parameters via Langmuir probe as in contrast to probe measurements it provides the plasma parameters without perturbation in any plasma conditions. In such experiments, the intensities of the emitted lines from the plasma are recorded which give the information about the local environment of the plasma. Therefore, combining the emission intensities to an appropriate collisional radiative (C-R) model provides the plasma characterization parameters such as electron density and temperature. However, the proper inclusion of all the relevant processes occurring in the plasma is necessary to develop a reliable C-R model [1– 3]. Therefore, the primary challenge to develop a reliable plasma model is the requirement of both accurate and large atomic data set such as transition energies, transition probabilities and cross section for various collisional and radiative processes occurring in the plasma[1,3–7]. Since electron impact excitation is one of the dominant collision processes, the availability of its reliable and detailed cross section data for all various fine structure transitions in the wide range of energy is necessary to get the correct plasma parameters.

The electron collision experiments are quite sophisticated and have thus provided very limited set of e--atom collision data for only selected electron impact energies. Also the available experimental studies have mainly focused on the electron excitation from ground level to few excited levels. While for plasma modeling, there is a requirement of large set of collision data for several fine structure transitions in the wide range of electron energies. Consequently, available reliable theoretical methods have to meet such requirements. On the theoretical front, largely available theories are the nonrelativistic approaches which have been found totally inadequate to describe the fine structure transitions. However, the relativistic distorted wave approximation has proved to be very reliable and practical to adopt considering the need of large-scale production of atomic data for modeling of plasmas.

In the light of the present context, the work of the thesis has focused on the development of various collisional radiative (C-R) models to diagnose low temperature plasmas which are useful in many applications such as for neutral beam injectors of ITER and in the studies of different industrial aspect. For reliable modeling, the required electron impact excitation cross section of various transitions from ground as well as from the exited states are obtained in the wide range of electron incident energies for neutral atoms *viz.* cesium, argon and xenon using relativistic distorted wave (RDW) theory and incorporated in the C-R model. Further, these cross sections are also fitted through analytical formulae for further use in plasma models. For the modeling of high temperature ITER fusion plasma thereby assisting in the design and development of ITER, another set of calculation have been performed to obtain the electron impact excitation cross sections and polarization of emitted photon by the subsequent decay of the excited tungsten ions. The thesis has seven Chapters including introduction and conclusion. A brief overview of the main work of the thesis is presented through five chapters as given below.

II. Modeling of Low Temperature H2-Cs Plasma with Reliable Electron Impact Fine structure Excitation Cross Sections

For the heating of plasma in ITER it is planned to install high performance neutral beam injection (NBI) systems and two sources of high-frequency electromagnetic wave systems externally [8–10]. Deuterium neutral beam injectors of power 16.5 MW with particle energies of 1MeV and a diagnostic beam of 100 KV are anticipated for the ITER [11]. The acceleration of negative hydrogen or deuterium ions in the fusion device can be achieved through the formation of negative ions by surface effect[12]. Surface with low work function will transfer electrons to generate negative hydrogen or deuterium ions [13]. Cs-seeded negative ion source is expected to fulfill the requirement of ITER project [10,14]. For high performance, achieving the low work function with cesium layer is a crucial aspect as it is highly dependent on the injected Cs amount and also on its population distribution inside the plasma [15–17]. Thus, an accurate numerical population model to simulate the population of Cs atom in ground as well as excited states is highly needed for the optimization purposes. In literature, for the pure Cs plasma, various collisional radiative (C-R) models have been proposed [18,19]. However, these models are not applicable to the hydrogen-cesium plasmas relevant to ITER NBI systems as the mutual neutralization of Cs+ ions with H- ions has not been included which is an important channel for the production of Cs atom in the different states along with the hydrogen atom. Recently Wünderlich *et al.* [20] developed a proper C-R model for the low pressure hydrogen–cesium plasma. Their C-R model includes the channel of mutual neutralization in addition to the other populating and depopulating mechanisms for the excited Cs atom. However, in their model, electron impact excitation and ionization processes from the ground and the excited states have been considered in the framework of non-relativistic Born-approximation or used input data which are available in literature with some scaling and extrapolations [21,22]. Therefore, the existing electron impact data of Cs were not adequate and sufficient for a reliable modeling. For this purpose, first a complete set of electron impact excitation cross sections and rate coefficients have been calculated using RDW theory for several fine-structure transitions from the ground as well as excited states of cesium atom in the wide range of incident electron energy. Thereafter, the calculated detailed cross sections are used to construct a reliable collisional radiative (C-R) model to characterize the hydrogen-cesium plasma.

In this work a C-R model has been developed using reliable electron impact excitation cross sections to characterize the low pressure hydrogen-cesium plasma which is relevant to the negative ion based neutral beam injectors for the ITER project. The model includes the ground state and various finestructure levels of Cs leading to 84 transitions. In addition to these levels of Cs, singly charged Cs+ ion is also considered. All these levels are interconnected through collisional and radiative transitions occurring in the plasma [23]. The present model includes various population transfer mechanisms among fine structure levels such as electron impact excitation, ionization, radiative decay along with their reverse processes viz. electron impact de-excitation and three body recombination. Another important process which has also been included in the present hydrogen-cesium plasma model is the mutual neutralization of Cs+ with H- ion. Since the mutual neutralization cross sections are expected to be quite large, it will considerably affect the population of the ground and excited states of cesium. The particle balance equation for an excited level *j* can be expressed as follows;

formula expression will go here

Here, all the positive terms in the equation represent production and negative terms represent the destruction channel for state *j*. n_i represents the population density of i^{th} level, T_e is the electron temperature. n_e and n_+ are the electron density and ion density, respectively and *Aij* is the transition probability for spontaneous decay from any upper level to *j*. n_+ and n_{H} - represent respectively the Cs ion and H- ion densities. ki_j is the rate coefficient for the electron impact excitation from level $i \rightarrow j$ and obtained from our calculated cross sections. $k_{mutual\ neut.,j}$ is the rate coefficient for the mutual neutralization of Cs+ ion with negative H- ion. The plasma parameters obtained from the best match of the calculated densities of 62P, 72P and 72D states with the OES measurements at the IPP negative ion source prototype for ITER NBI. Details of the cross section calculation, C-R Model and respective results can be seen in reference **[Priti *et. al. J. Quant. Spectrosc. Radiat. Transf.* 187, 426 (2017)].**

III Collisional Radiative Model for the Ar-O2 Mixture Plasma

One of the most commonly used mixture plasma is Ar-O_2 which is often utilized as a source of atomic oxygen. In such plasma the production of atomic oxygen can be influenced by the excited states of argon. It is interesting to study Ar-O_2 mixture plasma as the available studies on population of 1s excited state led to conflicting conclusions. Therefore, a suitable C-R model has been developed for Ar-O_2 mixture plasma and the variations of the plasma n_e and T_e with addition of O_2 is studied by using the reliable complete set of relativistic electron impact excitation cross section data. The model was coupled to the optical spectroscopic measurements reported by Jogi *et al.* [*J. Phys. D: Appl. Phys. 47, 335206 (2014)*]. It is found that as the content of O_2 in Ar increases from 0%–5%, *Te* increases in the range 0.85–1.7 eV while the electron density decreases from 2.76e12–2.34e11 cm-3. The Ar-3*p*54*s* (1*si*) fine-structure level populations at our extracted plasma parameters are found to be in very good agreement with those obtained from the measurements. Details can be found in **[Priti *et. al.* Phys. Plasmas 25 043517 (2018)].**

IV Modeling of Inductively Coupled Xenon Plasma with Reliable Electron Impact Excitation Cross Sections

The xenon gas discharge is used in various plasma applications such as mercury-free light sources [24,25], plasma displays [26] and space propulsion i.e. Hall-effect thrusters (HET) in space craft [27,28]. In particular, xenon is used nearly in all modern HETs as propellant. Also, mixture of inert gases including xenon are added to characterize the low temperature plasmas [29]. Most of the earlier studies have focused on the electron impact transitions in Ar and Kr inert gases and reported their cross sections in detailed manner [30–32]. Not much attention has been paid to study similar transitions in Xe which are also prominent in Xe plasma. From the literature on the electron excitation cross sections of xenon atom, one observes that there is still lack of sufficient cross section data for the fine structure excitations from the ground and among the excited states for a reliable plasma modeling. Even more recent results for the electron impact excitations are only from the ground state of xenon. Also the available data are not reported in the wide range of incident electron energies. Therefore, for the sake of providing sufficient consistent cross section data, detailed calculations are carried out for the excitation cross sections in xenon involving various transitions from the ground state to the excited as well as among these excited states using the RDW method. As an application, using the obtained cross sections, a collisional Radiative (C-R) model coupled with an optical emission measurement from the inductively coupled xenon plasma [33] has been developed and the extracted plasma parameters are obtained. Population densities are found within the range reported in various previous studies which shows that our model is well optimized. This work is submitted in in Plasma Source Science and Technology (PSST) and in under publication.

V Electron Impact N-Shell Excitation of Tungsten Ions and Polarization of their Photon Emission

Atomic data corresponding to different tungsten ions have been in great demand in the last decade due to their application in fusion devices[34]. Special physical properties of tungsten such as its highest melting point and lowest metal pressure amongst metals make it a potential candidate in fusion engineering where tungsten can be used as a potential plasma facing material. Various charge species of tungsten are predicted to be present in the high-temperature and low-density divertor plasma of the International Thermonuclear Experiment Reactor (ITER) tokomak [34–36]. Since electron induced processes are anticipated to be among the dominant ones, it is likelihood that tungsten ions will get excited by collision with plasma electrons and will decay by emitting radiation. Thus information on the electron impact excitation cross sections as well as the polarization of the radiation emitted due to decay of the excited state will facilitate a thorough understanding of the spectra for plasma diagnostics. For example, the ion temperature of the ITER core plasma can be assessed with the help of such diagnostics. Polarization studies play an important role in understanding the plasma properties, as X-ray polarization spectroscopy is a useful diagnostic tool for measuring the velocity distribution of hot electrons propagating in plasma created with a high intensity laser pulse [37]. It has also been employed to measure the energy component associated with the cyclotron motion of the beam electrons in the Livermore electron beam ion trap (EBIT) [38]. The understanding and modeling of such plasma rely on the knowledge of accurate atomic data for ion species encountered in the plasma. The initiative taken by IAEA has led to extensive experimental and theoretical investigations related to emission spectra, energy levels, transition rates, ionization, excitation, radiative recombination and dielectronic recombination etc., of highly charged tungsten ions. As a coordinated effort to cater the need of atomic data of various ionic stages of tungsten, thereby assisting in the design and development of ITER, our aim is to provide reliable cross section data for excitation of various tungsten ions by electron impact.

Therefore, a systematic study of the electron impact N- and M-shell excitations of highly charged Rblike through Br-like (W37+-W39+) and K-like through Ne-like (W55+-W64+) tungsten ions have been done using fully relativistic distorted wave theory. The cross sections are calculated and reported for various transitions in the electron impact energy range from the excitation threshold to 20 keV. Analytic fitting of the calculated cross sections are also provided so that these can be directly used in any plasma model. Linear polarization of the emitted photons, due to decay of the different electron excited states of the tungsten ions has also been obtained and reported. Detailed results can be seen in reference **[Priti *et. al.*, *Eur. Phys. J. D.* 71: 100 (2017), Priti *et. al. Atoms* 3, 53 (2015)].**

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Excitation and dynamics of spiral structures (wave) in strongly coupled dusty plasmas

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Abstract - Spiral waves are ubiquitous structures observed in variety of natural and laboratory scenarios including Saturn ring, spiral galaxy, Belousov-Zabotinsky reaction, coupled oscillators, liquid crystal and cardiac tissue [1]. Strongly coupled dusty plasma offers a model system to study generic phenomena such as self-organization and transport at individual particle level. For the first time in the dusty plasma medium, we have excited spiral waves using rotating electric fields (REFs). Both fluid [2] and molecular-dynamics (MD) [3] simulations have been carried out to study these waves. Characteristics of spiral waves with varying strength and frequency of REFs and strong coupling of the medium have been studied. It is found that the spiral structure gets determined by an interplay between the frequency of REF and acoustic speed of the dust medium. Comparative study of fluid and MD simulations reveal that single particle dynamical effects also play a crucial role in the formation of spiral pattern. Interestingly in the crystalline state of dusty plasma, the spiral wavefront becomes hexagonal in shape which is understood by the difference in the phase velocity in directions associated with the crystal lattice (viz., lattice axis and lattice diagonal).

Frequency, Global Geodesic Acoustic-like Mode in a Simple Magnetized Toroidal Plasma: An Experimental Study

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Abstract - In our recent work [1], for the first time we have reported the excitation of a high frequency Geodesic Acoustic-like Mode in a nearly collision less, magnetized simple toroidal plasma experimentally. The observed mode is found to be a discrete, global mode with frequency nearly three times the theoretical GAM frequency. The observed mode exhibits (m=1, n=0) symmetry for density fluctuations and (m$\geq 0, n = 0$) symmetry for potential fluctuations, where m,n are toroidal and poloidal mode numbers respectively. In the present work, a detailed experimental study of the variation of the frequency of the observed mode with the ion mass has been performed. Moreover, an experimental study of dependency of the GAM-like mode on the topology of the toroidal magnetic field has also been performed. It has been observed that for a particular topology of the toroidal field line for which the parallel pathway along the field line is shorter, the GAM-like mode can be observed. The frequency of the observed Mode linearly scales with $1/\sqrt{M_i}$, where M_i is the ion mass.

I. Introduction

Geodesic Acoustic Modes (GAMs) are plasma oscillations in a toroidal magnetic field supported by plasma compressibility where geodesic curvature provides restoring force. GAMs do not show any variation along the toroidal direction. GAMs exhibit poloidal anti-symmetry for density fluctuation and poloidally symmetric for potential fluctuations [1]. GAMs were first predicted as oscillating zonal flows [2] and are believed to regulate turbulence in Tokamaks [3]. GAMs in Tokamak can be driven unstable by non-linear Reynolds Stress [4], parametrically driven by drift waves [5] and linearly driven unstable by suprathermal ions [6].

In our recent work, we have reported the observation of a high frequency, discrete and global GAM-like mode in a simple magnetized torus, BETA, perhaps the first time. BETA is a simple magnetized torus (SMT), in which plasma is confined only by the application of toroidal field; it is vulnerable to the radial loss of the plasma due to the $E_z^{res} \times B$ drift, where E_z^{res} is the residual electric field generated due to the charge separation caused by gradient and curvature of the magnetic field. This E_z^{res} can be minimized by mounting a limiter [7, 8] and it can be further reduced by the application of an external vertical field [9].

We have observed that a GAM-like mode was driven unstable by the non-linear interaction of drift-interchange mode with itself [1]. The real frequency of the GAM-like mode is found to $f_{GAM-like} = Af_{GAM}$, where scaling factor $A \sim 3$, $f_{GAM} = \sqrt{2}c_s/(2\pi R)$, $c_s = \sqrt{(\bar{T}_e/M_i)}$ is the ion acoustic speed, R is the major radius, $\bar{T}_e$ is mean electron temperature. Moreover, the frequency upshift may be attributed to the interaction of GAM-like mode with background fluctuations [10].

In the present experimental work, we varied ion mass to study the variation of the frequency of the observed mode with the ion mass. For this purpose, we have used three different gases namely, Neon, Argon and Krypton with atomic masses 20 amu, 40 amu and 82 amu respectively. The findings strongly suggest the acoustic nature as frequency scales linearly with $1/\sqrt{M_i}$ [1].

II. Device description and diagnostics

Experiments were carried out in a simple magnetized toroidal device, BETA [11]. The major radius of BETA is 45 cm and minor radius is 15 cm; the toroidal field can be applied up to 0.1 T using 16 TF coils, 3 turns each using a 5 kA DC power supply. Base pressure of around 4.0×10^{-6} torr is achieved using two diffusion pumps. Then Argon gas is filled up to a working pressure of 1.0×10^{-4} torr. As discussed, the $E_z \times B$ drift causes transport of plasma radially outward. A circular conducting limiter placed at a toroidal location is seen to partially short circuit the vertical electric field E_z which in turn reduces the loss of plasma. The limiter is a ring made up of SS-304 with open aperture of 18 cm mounted 180^0 away from the filament. In the present study the toroidal field used is 750 G at the minor axis by passing the current of around 3.4 kA through TF coils. The direction of toroidal field is anticlockwise from top. BETA also has one set i.e., 2 vertical magnetic field coils, which produce vertical magnetic field vertically upward or downward depending upon the direction of current.

Plasma is produced by injecting Microwave of frequency of 2.45 GHz, with average launched power of 1 kW, launched in "O" mode from the outboard side. As the toroidal field at the minor axis is 750 G, therefore electron cyclotron resonance (ECR) occurs at r=-6 cm. The vertical field (VF) current has been varied over a range of values and it has been observed that GAM-like mode excites only for 160 A of VF current corresponding to 12 G of vertical field at the minor axis. For this value of VF current the toroidal field lines are widely opened and have a very short connection length [12].

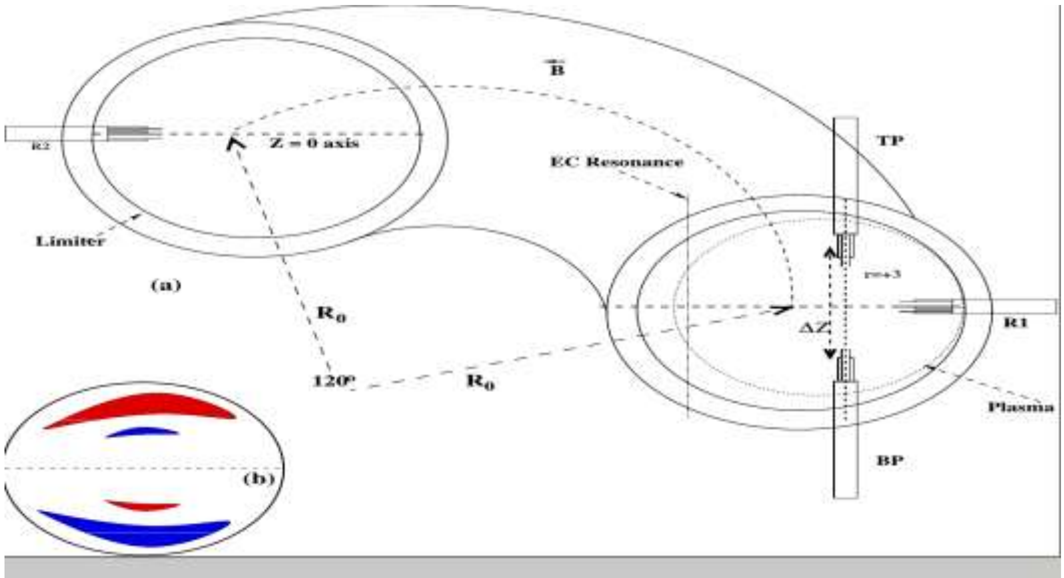

Fig. 1: (a) A schematic showing BETA device and diagnostics. TP and BP are movable across Z-axis measures poloidal mode number. The probe assembly R_1 and R_2 are separated by $\mathbf{120^0}$ angle and measures toroidal mode number. (b) A schematic of GAM-like instantaneous density fluctuation in poloidal cross-section of a toroidal device is shown. Here red and blue colors indicate compression and expansion of plasma due to GAM phase velocity respectively.

To measure the GAM-like characteristics, we mount a pair of two tips Langmuir probes as per the arrangement shown in Fig. 1. The two tips in each of the Top Probe (TP) and Bottom Probe (BP) are separated by 4 mm. While the first tip of each probe measures the floating potential fluctuation with respect to the grounded wall, the second tip provides density fluctuation. Plasma center is shifted from the vessel center, as shown in Fig. 1, by approximately 3 cm towards the outboard side. Therefore probes TP and BP are mounted at r=+3 cm from the vessel major radius R_0. Probes TP and BP can be moved along the equatorial plane. To measure toroidal mode number "n", two radial probes R1 and R2 are mounted at Z=0 plane at nearly similar radial location and are separated toroidally by almost 120^0 simultaneous measurement of density and potential fluctuation are obtained at two toroidal locations. The tip length for each probe is nearly 4 mm and probe separation is also 4 mm.

Using this probe assembly we measured GAM-like characteristics in BETA, the results are summarized as follows.

III. Experimental profiles

In the recent work [1], the detailed experiments have been carried out for Argon gas and observed global GAM-like mode. Some of those results are discussed below.

Fig. 2(a) shows the density and electron temperature profile for Argon gas at VF current of 160 A. It clearly shows that from r=0 cm to r = 8 cm, the gradients in both density and temperature profiles are weak. The plasma potential (not shown) is also nearly flat indicating the absence of any poloidal rotation of the plasma.

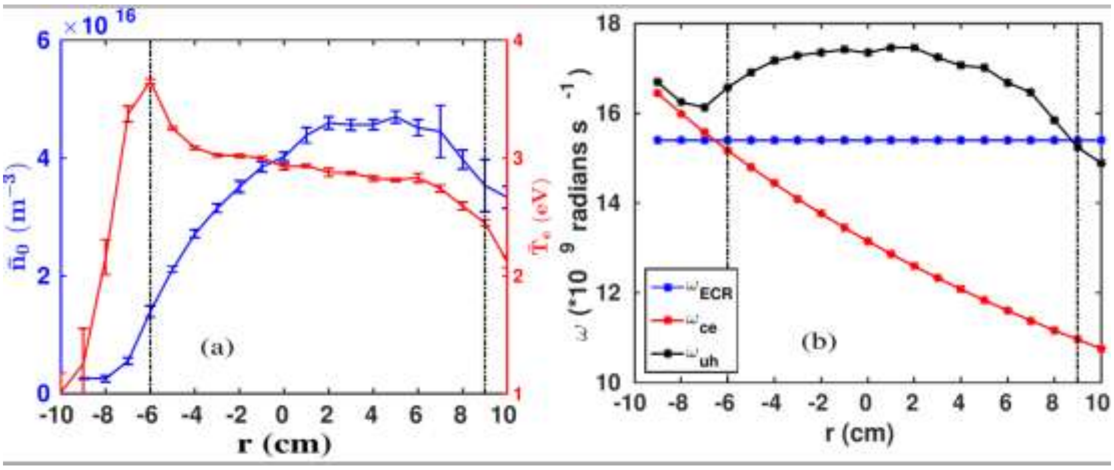

Fig. 2: (a) The radial profile of mean density ($\bar{n}_0$) and mean electron temperature ($\bar{T}_e$) and (b) the upper hybrid frequency $\omega_{UH}^2(r) = (\omega_{ce}^2(r) + \omega_{pe}^2(r)$ for VF current of 160 A is shown. The electron gyration frequency and plasma frequency are denoted as ω_{ce}(r) and ω_{pe}(r) respectively. The EC resonance is shown by a vertical line at -6 cm.

Fig. 2(b) shows the secondary ionization of upper hybrid frequency $\omega_{UH}^2(r) = (\omega_{ce}^2(r) + \omega_{pe}^2(r)$, where ω_{ce}(r) and ω_{pe}(r) are electron gyration frequency and plasma frequency respectively.

The spectrogram of the density fluctuation at r = +5 cm shown in Fig. 3(a), demonstrates that there are two strong frequencies in the density fluctuations corresponding to two discrete modes. The dominant mode is found to be at 1.7 kHz and the second mode is 3.4 kHz. It has been clearly shown earlier [1], that 1.7 kHz mode is found to be due to interchange mode and 3.4 kHz mode exhibits GAM-like characteristics [1]. The GAM-like mode i.e, 3.4 kHz mode is found to be generated by the non-linear interaction of the 1.7 kHz mode with itself [1]

In the present work, we varied ion mass to vary the acoustic speed to verify the acoustic nature of the observed mode. We have used three different gases namely Neon, Argon and Krypton to study the variation of the frequency of the GAM-like mode with the ion mass. Fig. 4 shows the spectrogram for (a) Neon, (b) Argon and (c) Krypton gases. In all the three cases, two dominant modes are found, a low frequency interchange mode and a high frequency GAM-like mode. It can be observed that the frequency of two modes varies with the mass of the gas. To establish GAM-like properties of the second dominant mode, the toroidal and poloidal mode numbers are measured for Neon and Krypton plasmas using the Top-Bottom probes assembly shown in Fig. 1. From Fig. 5, it can be observed that a strong GAM-like property exists for density fluctuations for different masses. However, for the potential fluctuations shown in Fig. 6, the GAM-like nature becomes weaker with an increase in the ion mass. The toroidal mode number is found to be close to zero for both density fluctuation as well as for potential fluctuation for all the cases.

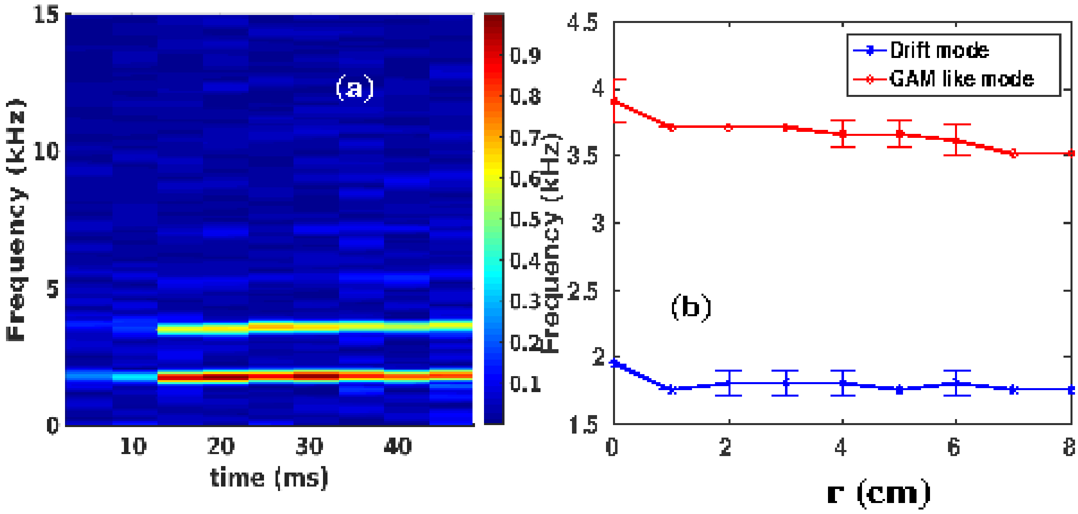

Fig. 3: (a) Spectrogram of density at +5 cm and (b) radial variation of two dominant modes. The spectrogram in (a), shows existence of two dominant modes and it can be clearly observed that second mode is excited after first mode has reached its peak. The radial variation of mode frequencies in (b) is shown from minor axis to the edge of the limiter on outboard side.

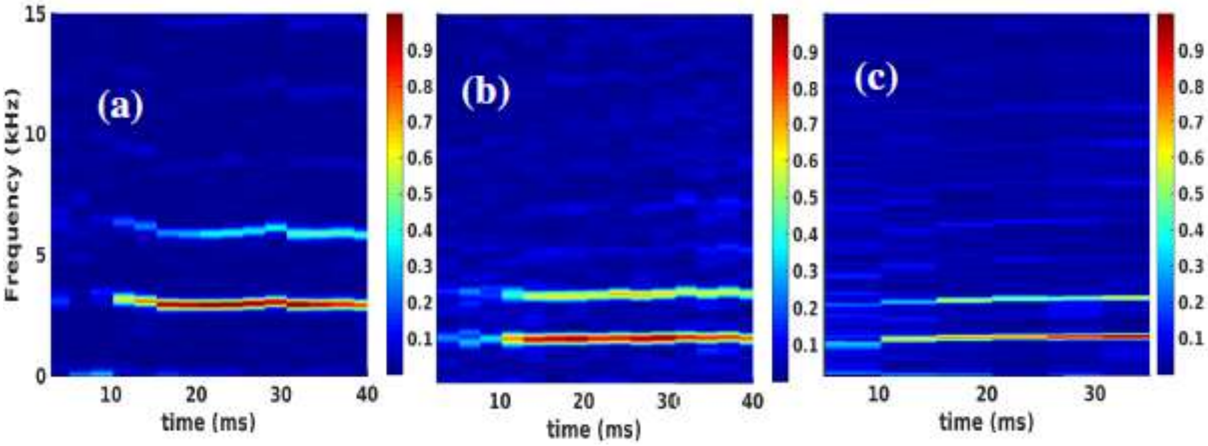

Fig. 4: A spectrogram of density fluctuations for (a) Neon plasma (M_i = 20amu), (b) Argon plasma (M_i = 40 amu) and (c) Krypton plasma (M_i= 82 amu) at r=+5 cm. It can be observed that the similar modes exist for all three different gases, however, frequencies vary with the ion mass. The sampling frequency is around 400 kHz, the plots are zoomed to 15 kHz for better representation.

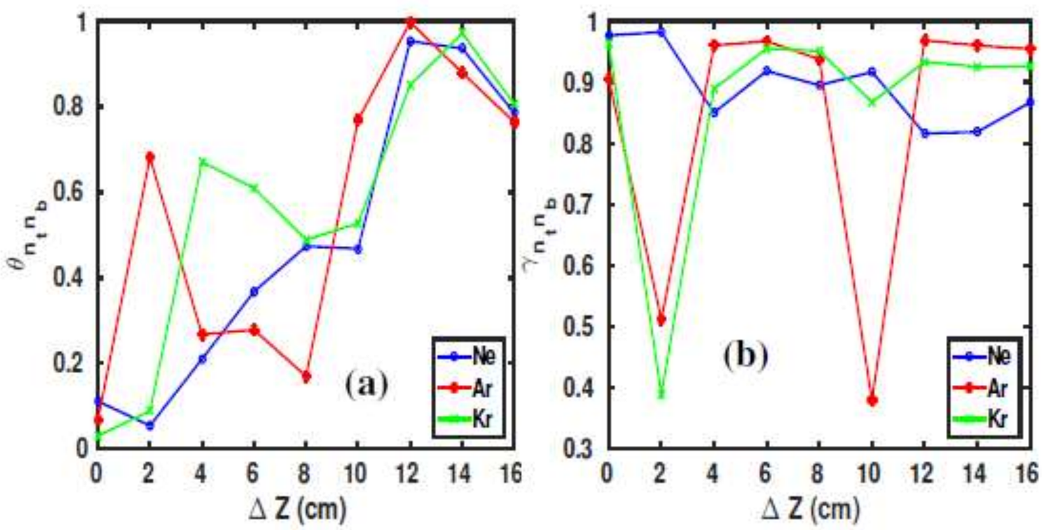

Fig. 5: Variation of the poloidal (a) phase and (b) coherence of the GAM-like mode of density fluctuations with the vertical separation of the top-bottom probes. The poloidal phase of the density fluctuation is close to $\boldsymbol{\pi}$ for $\boldsymbol{\Delta Z} > \mathbf{10}$ cm for every species of the gas. It demonstrates that there exists a strong GAM-like property for density fluctuation.

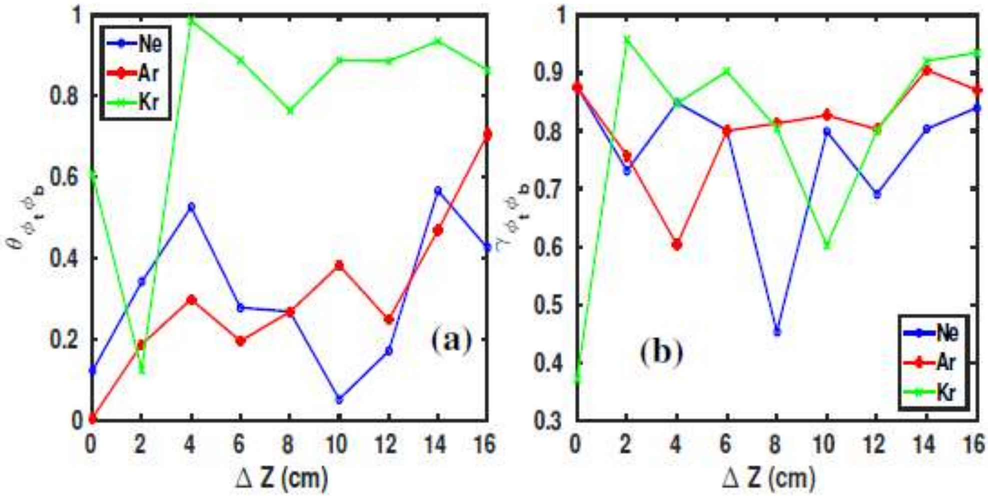

Fig. 6:- Variation of the poloidal (a) phase and (b) coherence of the GAM-like mode of potential fluctuations with the vertical separation of the top-bottom probes. The poloidal phase of the potential fluctuation increases with an increase in the ion mass. It indicates that there exists a weak GAM-like property for potential fluctuation, which gets weaker with an increase in the ion mass.

As shown in Fig. 7, the observed frequency of the GAM-like mode is found to scale linearly as $1/\sqrt{M_i}$, where M_i is the ion mass.

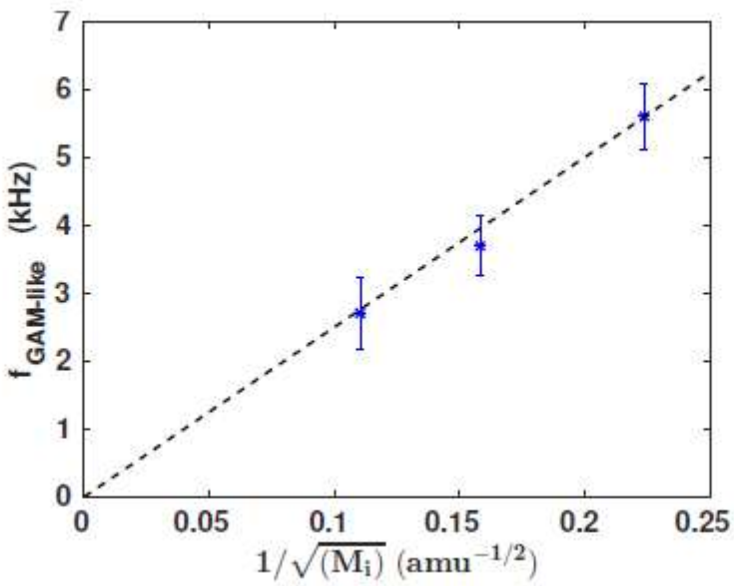

Fig. 7:- Variation of the frequency of the GAM-like mode with ion mass. The error-bars are the resultant of the frequency resolution and shot to shot variation in the frequency and a dashed black line has been added to aid the view. The fitted line has been extrapolated to origin to confirm that no intercept exists for the curve. Thus demonstrating that the frequency of the GAM-like mode, $\boldsymbol{f_{GAM-like}} \propto \mathbf{1}/\sqrt{\boldsymbol{M_i}}$, thus confirming the Acoustic-like nature of the mode.

IV. Discussion and Conclusion

In continuation of our recent work [1] on observation of a high frequency, GAM-like mode in an SMT, we performed experiments to study the variation of observed mode frequency with the ion mass. We observed that the observed is driven unstable by an unstable drift-interchange mode. Measured frequency of the GAM-like mode is found to be independent of the plasma radius, thus demonstrating the global, discrete nature of the mode. For three di_erent ion masses, the observed frequency of the GAM-like mode is found to scale linearly with $1/\sqrt{M_i}$.

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Study of Plasma Transport due to Electron Temperature Gradient Induced Turbulence in Laboratory Plasma

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The Large Volume Plasma Device (LVPD) has successfully demonstrated excitation of Electron Temperature Gradient (ETG) driven turbulence in finite beta ($\beta \sim 0.01-0.4$) plasma, satisfying threshold condition of ETG, $\eta_{ETG} = L_n / L_T > 2/3$ [Mattoo et al,[1]]. The observed mode follows scale length and frequency ordering ($k_\perp \rho_e \leq 1 << k_\perp \rho_i, \Omega_i < \omega << \Omega_e$), where $k_\perp$ is the perpendicular wave vector, ρ_e, ρ_i are Larmor radii of electron and ion, respectively, and Ω_i, Ω_e and ω are the ion, electron gyro frequencies and the mode frequency respectively. Simultaneous measurement of fluctuations in electron temperature, $\delta T_e \sim (10-30)\%$, plasma density, $\delta n_e \sim (5-12)\%$ and potential $\delta V_f \sim (1-10)\%$ are obtained. Strong negative correlation with correlation coefficients $C_{\delta n-\delta\phi} \sim -0.8$ and $C_{\delta T-\delta\phi} \sim -0.7$ is observed between density and potential fluctuation and temperature and potential fluctuation, respectively. These correlated density, temperature and potential fluctuations gives the information of turbulent heat flux. The measured heat flux is compared with estimated heat flux with obtained expression of heat flux for ETG model equations.

I. INTRODUCTION

Plasma confinement and control of plasma transport remains a significant challenge towards achieving fusion power. Plasma confinement is determined mainly by collective modes, arises due to the presence of gradients in density, temperature , magnetic fields, etc. These gradients works as a free source of energy and leads to the generation of different instabilities, enabling anomalous transport of plasma particle and energy. Although, it is well known that during L-mode operation, both ion and electron thermal transport remains anomalous in nature but in high confinement (H-mode) scenerio, due to the presence of internal transport barrier, ion heat transport no more remain anamolous in nature whereas electron thermal transport still remains the same. Focus is thus shifted to the understanding of physics of anamalous electron heat transport across the confining magnetic field, well envisaging its implications for ITER and advanced Tokamak discharges[2]–[4].

In the past, extensive work has been reported on measurements of micro instabilities driven turbulence because of their possible role in causing anomalous particle and energy transport in fusion devices[5]–[9]. Outcome from these investigations suggest that transport by ion scale turbulence is largely understood but the Electron Temperature Gradient (ETG) driven turbulence, which is considered presently a major source of anomalous transport in fusion devices is still not properly understood. Available literature on numerical and theoretical approaches shows significant advancement in contribution on ETG turbulence and transport but experimental investigations provide no direct evidence of its existence in tokamaks. The reason for no direct measurement of ETG may be due to the extremely small scale length in high magnetic field environment of fusion devices ($k_\perp \rho_e \sim 1$ when$\rho_e \sim \mu m$). The ETG mode is a short wavelength, low frequency mode, $k_\perp \rho_e \leq 1 \ll k_\perp \rho_i$, $\Omega_i < \omega \ll \Omega_e$ where $k_\perp$ is perpendicular wave-vector, ρ_e and ρ_i are the larmor radii of electron and ion, respectively, Ω_e $(= eB/m_e)$, $\Omega_i(= eB/m_i)$ and ω are electron, ion gyro-frequencies and mode frequency respectively. Theoretical models for slab ETG predicts that ETG is a fast growing mode driven by electron temperature gradient with characteristic growth rate $\gamma \approx k_y \rho_e (c_e/L_{T_e})$ where c_e, is the electron thermal velocity. Past investigations does provide indirect evidences of its existence during auxiliary heating investigations, carried out in devices like Tore Supra, JET[10], DIII-D[11] etc. but direct measurement of it is shown only in NSTX[12], where Mazzucato et al.[13], have shown its successful excitation. In recent times, linear devices like CLM, LVPD etc. have demonstrated results supporting existence of ETG turbulence. Different mechanisms are used to meet the threshold condition of ETG in these devices. In CLM, this is done by heating electrons using a multi grid arrangement, while in LVPD, cross field diffusion concept is used by magnetic field of large electron energy filter. This makes plasma devoid of energetic electrons. Presence of energetic electrons could have poisoned plasma and subsequently, led to excitation of beam plasma instabilities. In LVPD, wave length of ETG mode is brought to the scales of $\sim mm$ which can be easily measurable by conventional probes.

Introduction of Electron Energy Filter (EEF) divides LVPD plasma into three distinct regions of Source, EEF and Target plasmas. Unambiguous, identification of ETG turbulence is successfully demonstrated in core region of target plasma ($x \leq 45cm$)[1], [14]. As explained by Sushil et al., possibly, following two mechanisms might be responsible for ETG excitation in two different plasma beta regimes. In low plasma beta, the slab mode is primarily driven by parallel compression of electron motion along the magnetic field. The compression effect in electron parallel motion will generate temperature and density perturbations. The density perturbation is out of phase to potential perturbation via ion Boltzmann shielding effect. The potential perturbation creates $E \times B$ drift, which brings cold electrons in a compressed region and thus lowering the pressure. The lower pressure attracts more electrons, further increasing the compression. This positive feedback loop leads to instability. While in high plasma beta, $\beta \geq 0.2$, ETG mode becomes unstable similar to toroidal ETG by whistler wave and coupling of it to ETG play important role in making mode unstable[15].

We present experimental observations on plasma transport due to Electron Temperature Gradient (ETG) turbulence in the finite beta laboratory plasma of Large Volume Plasma Device (LVPD). Recent results reveal that ETG turbulence is probably, the most likely candidate responsible for anomalous transport in fusion plasma. The small scale nature of ETG mode inhibits its direct measurement in fusion devices but basic plasma devices on the other hand offer suitable conditions by bringing the scale length of the mode to measurable limits. Unfortunately, plasma in them also suffers from the very source, which produces it. Because of the presence of ionizing hot and non-thermal electrons, unambiguous identification of ETG becomes difficult. This is where plasma in LVPD assumes significance as dressed plasma in target plasma here realizes control in radial gradient scale length of electron temperature by making use of a large Electron Energy Filter (EEF).

The electromagnetic ETG instability is investigated in the core plasma of the target region. We have established the turbulence by measuring the fluctuations (density, magnetic field, temperature and potential), power-spectra, correlation, phase angle, propagation, wavenumber-frequency spectrum and beta scaling in suitable equilibrium plasma conditions for two EEF configurations. The observed turbulence exhibits broad band spectra in the lower hybrid range of frequencies. Experimental results detail on various characteristic features and nature of the observed flux.

The experimentally observed particle and heat flux due to ETG turbulence is compared with theoretical predications of ETG model equations, taking values of fluctuation level, frequency, correlation properties, phase velocity, and mode characteristic from experimental data are found in good agreement with electrostatic ETG turbulence. In addition to electrostatic particle flux, the electromagnetic radial particle flux is also measured. A theoretical model for electromagnetic ETG driven EM flux is obtained considering role of parallel ion dynamics. The experimental results obtained in LVPD are interesting and hence suppliment in developing a better understanding of ETG turbulence induced turbulent transport.

This paper is organized as follows: the details on experimental setup are discussed in section II. The Plasma parameters and fluctuation characterization is presented in section III. Estimation of particle flux and heat flux from fluctuation data is discussed and its comparison with theory is presented in section IV. Finally, paper will conclude with summary and discussion in section IV.

II. EXPERIMENTAL SETUP

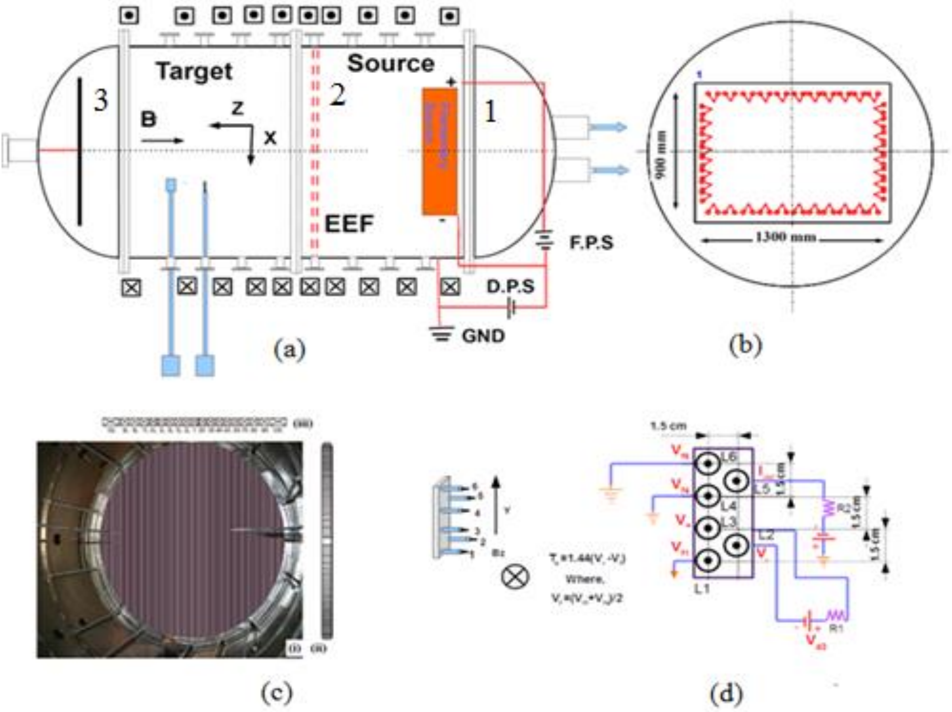

Figure 1: Schematic of experimental Device (Large Volume Plasma Device) showing in (a) top view of Large Volume Plasma Device,(b) the front view of filament assembly in the source side of device, (c) the photograph of EEF mounted within the vessel. The top side bar serves as coil identifier and RHS side bar defines extent of aspect ratio of each of the 19 coils of EEF and (d) Langmuir probe assembly for simultaneous measurement of potential fluctuation and temperature fluctuations for heat flux measurement. Items marked as 1 and 3 represents the cusped back and end plates.

The investigations on energy flux measurement are carried out in target region of Large Volume Plasma Device(LVPD)[16]. The LVPD is a cylindrical device containing plasma within it by using a combination of radial and axial confinement schemes. The radial confinement is provided by a set of 10 garlanded coils producing axial magnetic field, $B_z \sim 6.2G$ along its length and axial confinement by a pair of cusped($\sim 4\,kG$, surface fiueld) back and end plates. These plates are mounted behind the plasma source and the other aial end of plasma column. The plasma source contains 36 numbers of hairpin shaped tungsten filaments($\phi \sim 0.5mm, and\ L = 180\ mm$), distributed in the periphery of a rectangle of size($130cm \times 90cm$). The pulsed Argon plasma of duration, $\Delta t_{discharge} \sim 9.2\ ms$ is produced by appliying a discharge voltage of -70 V between one leg of filament assembly and the anode(device). The radially confining ambient field of garlanded coils is modified by the strong transverse magnetic field produced by a Electron Enery Filter(EEF), mounted almost at the axial centre of the device and partitioning the device into two halves[17]. Few objectives in consideration has led to the development of rectangular shaped EEF solenoid.

Some of the important isues are that 1) it should be highly transparent so that it should not present itself as a large loss surface 2) it should not allow cross field diffusion of eneregtic elctrons into the other region and 3) it should enable introduction of radial gradient in electron temperature. Magnetic field within a long solenoid is largely uniform except near its edges for a constant turn current density. As electron temperature of the target plasma is solely determined by the plasma transport across the transverse magnetic field of the EEF which in turn is determined by the value of magnetic field produced in the solenoid. It was envisaged that a solenoid with uniform turn current density will not introduce gradient in electron temperature hence current density in each turn of the solenoid system is to be made non uniform. The EEF is a rectangular shaped solenoid made up of 155 number of turns and is divided into 19 discrete set of coils being controlled independently from outside the device. The role being played by the EEF is to trap the energetic electrons in the source and EEF plasma and allows only the low energy electrons into the target plasma region. The target plasma, where ETG turbulence is excited develops by the diffused plasma from EEF and is devoid of energetic electrons. The core region of target plasma, axially 1m away from EEF, produces radial equillibrium profiles, predominantly exhibiting a uniform density and a sharp gradient in electron temperature satisfying ETG threshold condition.

Beside using conventional Langmuir probe diagnostics for measuring plasma parameters and Centre Tapped Emissive Probe(CTEP) for plasma potential measurement a specially designed Triple Langmuir Probe(TLP) diagnostics is developed for real time, temperature fluctuation measurements in pulsed plasma of LVPD. It offers salient features namely, 1) bandwidth $\leq 300\,kHz$, 2) galvanic isolation $\geq 250V$, 3) input impedance for voltage measurement exceeding $\sim 10M\Omega$ and current measurement with shunt resistor $\sim 300\Omega$ respectively. The probe assembly shown in figure 1(d), consists of two sets of three Langmuir probes. Each probe is cylindrical in shape and has dimension $(W, \phi = 1mm, L = 8mm)$. First vertical array has 4 numbers of probes (L1, L3, L4, and L6) with separation, $\Delta y = 15\,mm$, while second vertical array consists 2 probes(L2 & L4), vertically displaced, $\Delta y = 30\,mm$. Axially the two arrays are separated by $\Delta x \sim 15mm$. Probes numbering, L1, L2, L3 and L4 are used for electron temperature measurement. Probes are placed at different magnetic field lines and are transverse to the ambient magnetic field in order to avoid influence of shadowing effect and magnetic field. The probe array assembly is mounted on a radially movable probe drive. The TLP measurements are calibrated against single Langmuir probe measurements and TLP configuration is confirmed by obtaining I/V characteristics of double probe. The pair of L2 and L3 are used in double probe configuration and are fed power by floating, battery based power supply. It has characteristic features viz., variable voltage, negligible capacitance with respect to ground. The ion saturation current is obtained across 500 ohm resistance using a floating, battery biased current measurement circuitry. The poloidally separated probes L1, L4 and L6 are used to measure floating potential. The potential (V_+)of positively biased probe L3 is also measured. The Langmuir probe L5 measures ion saturation current and is biased at high negative potential with respect to plasma potential to estimate mean and fluctuations density of plasma. By choosing suitable value of bias voltage between L2 and L3, one calculates electron temperature, T_e by using expression $T_e = (V_+ - V_f)/Log(2)$, where V_f is the average value of V_{f1} and V_{f4} [18].

The probe arrangement ensures that the parameters V_f, $and\ I_{isat}$ are measured by probes placed in close vicinity of each other to avoid the phase delay error. For investigation of fluctuations, data is recorded during the steady state of plasma current. The fluctuating E_θ can be obtained by poloidally separated probes using $\widetilde{E_\theta} = -\partial\phi/\partial y$ where δV_r is derived from $\delta E_\theta \times B$ drift. The radial velocity fluctuations are responsible for conductive ($n_o < \delta T_e \delta V_r >$) and convective heat flux($T_e < \delta n_e \delta V_r >$) having correlation to temperature and density fluctuations respectively. The fluctuations in electron temperature, δT_e, density , δn_e and potential, $\delta\phi$ are measured for the complete duration of plasma evolution $10\,ms$ with a smapling rate of $1MS/s$. The data is acquired with a 12bit digitizer based PXI data acquisition system. Typical ensemble of 100 shots from the steady state window is used for carrying out spectral analysis viz., correlation, coherency, phase , power spectra and joint wave number frequency psctrum, S(k,w)[19].

III. EQUILLIBRIUM PROFILES AND FLUCTUATION CHARACTERIZATION

The plasma discharge pulse ($\Delta t \sim 9.2\ ms$) is produced and data from steady state region ($4ms \le t < 9ms$) is captured from the onset of discharge. Radial profiles of basic plasma parameters and their fluctuations are shown in figure 3 for EEF OFF and ON conditions. Target plasma in LVPD is divided into two distinct regions namely, 1) core ($x \le 40cm$) and 2) edge ($x > 40cm$) respectively. In the core region, figure 2(a) shows hollow plasma density profile for EEF OFF plasma but nearly flat profile for EEF ON plasma with typical gradient scale length, $L_{n_e} \sim 300\,cm$. Figure 2(b) shows nearly flat electron temperature profile for EEF OFF plasma but radial electron temperature gradient exists for EEF ON plasma with typical gradient scale length, $L_{Te} \approx 50cm$. On the other hand, edge plasma exhibits finite gradient in plasma density and nearly flat electron temperature for EEF ON condition. Although, finite electron temperature gradient exits in the edge region for EEF OFF plasma and satisfies the gradient scale length threshold condition of ETG but due to the presence of energetic electrons, loses relevance for carrying out unambiguous ETG studies [22].

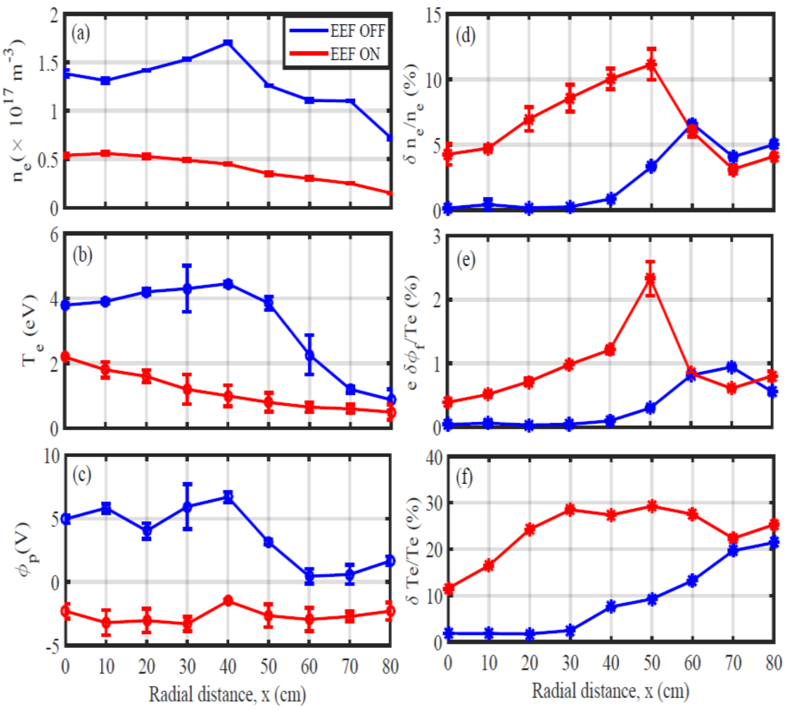

Figure 2: Comparison of radial profiles of mean plasma parameters is shown for , (a) plasma density, n_e , (b) electron temperature, T_e, (c) plasma potential, ϕ_p and fluctuations in d) density, $\tilde{n}_e = \delta n_e / n_e$, e) potential , $\tilde{\phi}_f = e\,\delta\phi_f / T_e$ and f) electron temperature, $\tilde{T}_e = \delta T_e / T_e$ for EEF OFF and EEF ON cases.

Figure 2(c) shows plasma potential profiles for EEF OFF and ON cases. EEF ON plasma shows negligible radial gradient in core region, suggesting absence of radial electric field ($E_x \approx 0$). Hence, $E \times B$ rotation in the core region can be safely neglected. A detailed characterization of the plasma with EEF was reported by S. K. Singh et al. [23], where various plasma scenarios satisfying ETG threshold condition for different imposed operational conditions of EEF are discussed.

The fluctuations in different plasma parameters, in the core region maximizes for EEF ON case. Observed fluctuations are subjected to various statistical techniques before investigating fluctuation induced particle flux in the core region of target plasma. Normalized fluctuations are measured radially for n_e , ϕ_f and T_e with typical values obtained for EEF ON plasma are $5\% - 10\%$, $0.5\% - 2.5\%$ and $10\% - 30\%$ respectively [figure. 2(d-f)] but for EEF OFF plasma, they are reduced to near noise level. Edge region on the other hand exhibits enhanced level of fluctuation for both plasma conditions.

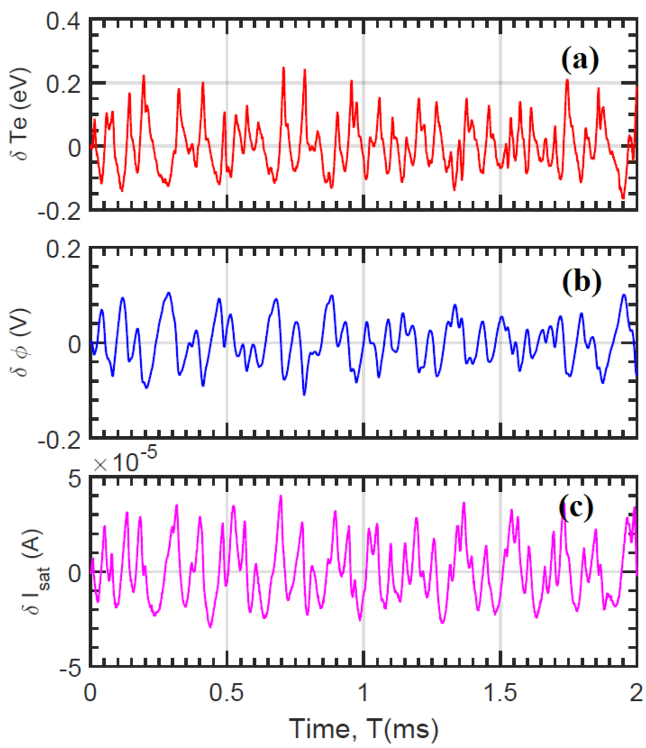

Figure 3: Typical time profile of fluctuations in (a) electron temperature, $\boldsymbol{\delta T_e}$ *(b) floating potential,* $\boldsymbol{\delta\phi}$ *and (c) ion-saturation,* $\boldsymbol{\delta I_{sat}}$ *at R=20 cm.*

Figure 3 shows the snap shot of typical saturated fluctuations in δT_e, $\delta\phi_f$ and δI_{sat}

.Turbulent data is collected for 100 plasma discharges in the core region and concocted for its charcterization. Time profile shows in phase correlation between density and temperature fluctuations and both are found out of phase to the potential fluctuations.

The power spectra of the observed fluctuations shows broadband nature with significant power residing between $f \leq 1 - 15\ kHz$ and it follow a power law of $1/f^{1.8}$ for $f \leq 10 - 80\ kHz$. Mode frequency lies in the lower hybrid range of frequency $\Omega_{ci} < \omega << \Omega_{ce}$, where wave-number satisfies the condition, $k_y \rho_e \leq 1$ and $k_y \rho_i > 1$, suggesting that the instability driving the turbulence is associated with ETG mode. The wave number-frequency spectrum, $S\ (k_y, \omega)$ exhibits peak power for both δn_e at wave number, $k_y \sim 0.1 - 0.5\ cm^{-1}$ and frequency, $f \sim 1 - 10\ kHz$ [figure 4(b)].

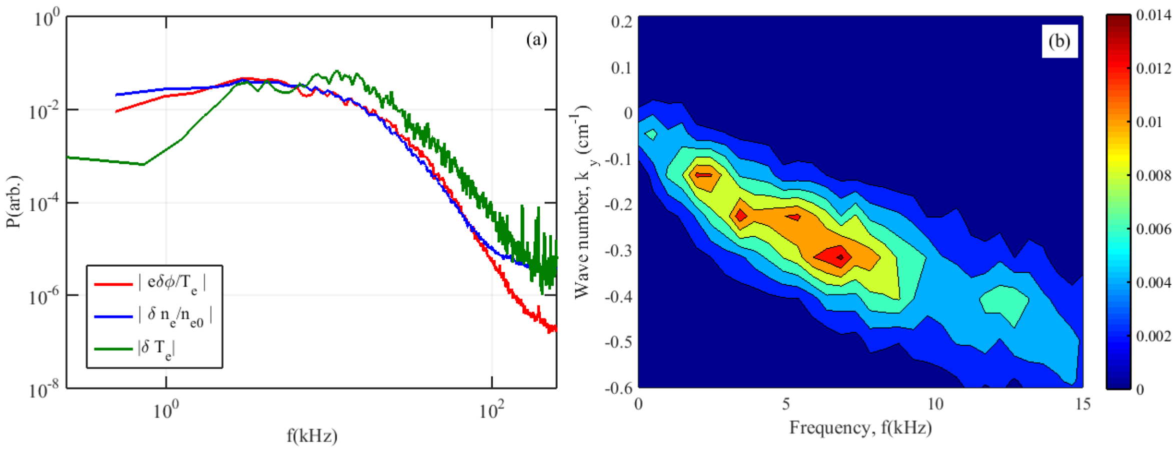

Figure 4: Spectral characteristics of fluctuations (a) the auto power for density (n_e) ,potential (ϕ) and temperature fluctuations, (b) The joint wave number- frequency spectra for density fluctuations. The mode exhibits peak power for frequency between, $f \sim 1-15\,kHz$ for wave number, $k_\perp \approx (0.1-0.4)\ cm^{-1}$.

The fluctuations cross-correlation functions which are strongly negative for density fluctuation $(\delta n_e/n_e)$ and temperature fluctuations, $\delta T_e/T_e$with potential fluctuations, i.e. -0.8 and -0.9 , respectively justifying the fluctuation of ETG turbulence [figure 5].

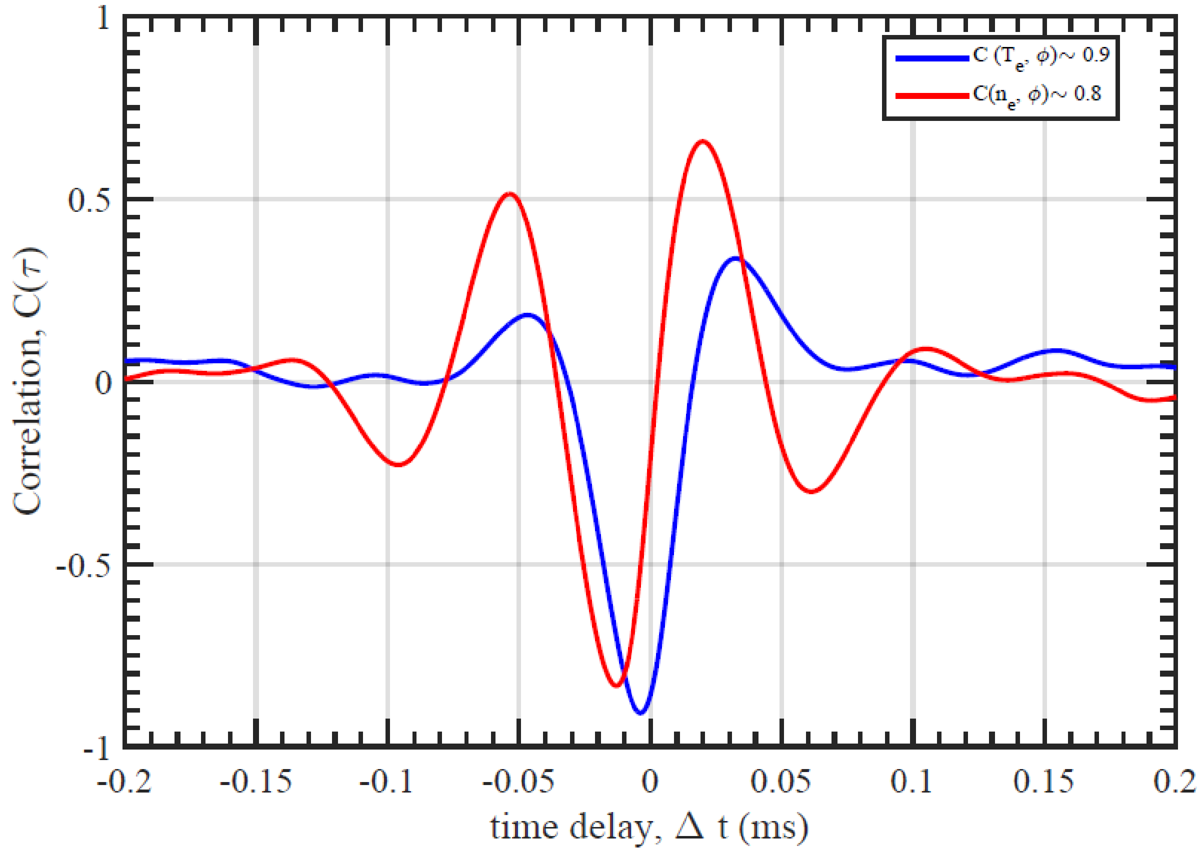

Figure 5: Cross-correlation between density and temperature fluctuations with potential fluctuation in core plasma of LVPD.

IV. MEASUREMENT OF PARTICLE AND HEAT FLUX AND COMPARISON WITH THEORETICAL ESTIMATION

The collective oscillations due to ETG turbulence is responsible for the particle and heat transport. The typical particle and heat flux due to broad band fluctuations can be estimated by simulatneous measurement of density, temperature and potential fluctuations. A theoretical expression is formulated for the radial particle and heat flux due to ETG scale fluctuations to verify our experimental measurement of radial heat flux. The theoretical expression for heat flux due to ETG fluctuations is obtained by use of ETG model equations since density and temperature fluctuations are related with potential equations in the following manner [1]

$$\tilde{n} = -\tau_e^* \tilde{\phi} \tag{1}$$

and

$\tilde{T} = \left[\left(\eta_e - \frac{2}{3}\right)\frac{\hat{k}}{\hat{\omega}} - \frac{2}{3}\, \tau_e^*\right]\tilde{\phi}$ (2)

Where $\tilde{n} = \frac{\delta n_e}{n_e}$, $\tilde{\phi} = \frac{e\delta\phi}{T_e}$, $\tau_e^* = T_e/T_i(1 + i\delta_k)$, $\widetilde{T_e} = \frac{\delta T_e}{T_e}$, $\eta_e = \frac{L_n}{L_{T_e}}$, $\hat{k} = k_y\rho_e$and $\widehat{\omega} = Z\omega/c_e$, $T_e(T_i)$ is electron(ion) temperature, $L_n(L_{T_e})$ is density (temperature) scale length , k_y is poloidal wave number, ρ_e is electron larmor radius, Z is axial length of device , ω is turbulence frequency and c_e is electron thermal velocity. Here δ_k is taking care of ion non - adiabatic response[20] which is $\delta_k = \sqrt{\pi}\frac{\omega}{k_\perp V_{thi}}\exp(-\frac{\omega^2}{k_\perp^2 V_{thi}^2})$.

Experimentally, electrostatic particle flux (Γ_{es}) is measured from the correlated density (δn_e) and radial velocity (δv_x) fluctuations. The velocity fluctuations are estimated from fluctuating poloidal electric field ($\tilde{E}_\theta$) and by cross product with ambient magnetic field, $\tilde{E}_\theta \times B_z$, where $\tilde{E}_\theta$ is estimated from the floating potential fluctuations measured by a pair of poloidally separated Langmuir probes, ($\tilde{E}_\theta = -(\tilde{\phi}_2 - \tilde{\phi}_1)/d$). The electrostatic particle flux is calculated as, $\Gamma_{es} = <\delta n_e.\delta v_x>$.

The particle flux is given by

$$\Gamma_n = <\tilde{v}_x\tilde{n}> \sum_k \tilde{v}_{xk}\tilde{n}_k^* = -\sum_k \frac{k_y}{B}\left|\tilde{\phi}_k\right|\left|\tilde{n}_k\right|\sin\theta_{n\phi} \qquad \text{--------(3)}$$

Where $\theta_{n\phi} = \theta_n - \theta_\phi$ is the cross angle between density and potential fluctuation. The particle flux expression for ion response is given by eqn. (1) becomes

$$\Gamma_n = \sum_k \pi^{1/2}\tau_i n c_e k_y \rho_e (\frac{\omega_r}{k_\perp^2 v_{thi}^2})[\exp(-\frac{\omega_r^2}{k_\perp^2 v_{thi}^2})]\left|\tilde{\phi}_k\right|^2 \qquad \text{-------(4)}$$

Where, $c_e = \sqrt[2]{T_e / M_e}$, ρ_e is the electron Larmor radius and ω_r is the real frequency. This shows that the particle flux can become negative when $\omega / k_y < 0$ that is, when the mode is propagating in ion diamagnetic drift direction. The flux is finite in flat density region indicating that it could be a thermo-diffusion rather than the usual density gradient dependent diffusive flux.

The turbulent heat flux due to fluctuations can be written as

$$q_{cond} = n_o < \tilde{T}_e \tilde{v}_r > = -\sum_k \frac{k_y}{B} n_o |\tilde{T}_{e,k}||\tilde{\phi}_k| sin\theta_{T_e\phi} \text{ ,where } \theta_{T_e\phi} = \theta_{T_e} - \theta_\phi$$

This expression suggests that the heat flux depends on the level of fluctuations and phase relation between temperature and potential fluctuations. The using model equation of ETG turbulence viz., equation (1)-(3), the estimated heat flux is as follows;

$$q = \frac{3}{2} n_0 c_e T_{e0} \Re \sum_k [(\eta_e - \frac{2}{3}) \frac{c_e \gamma_k (k_y \rho_e)^2}{L_n |\omega_k|^2} \left|\frac{e\delta\varphi_k}{T_{e0}}\right|^2 + \frac{2}{3} \frac{\delta n_{ek}}{n_0} i k_y \rho_e \frac{e\delta\varphi}{T_{e0}}] \qquad (5)$$

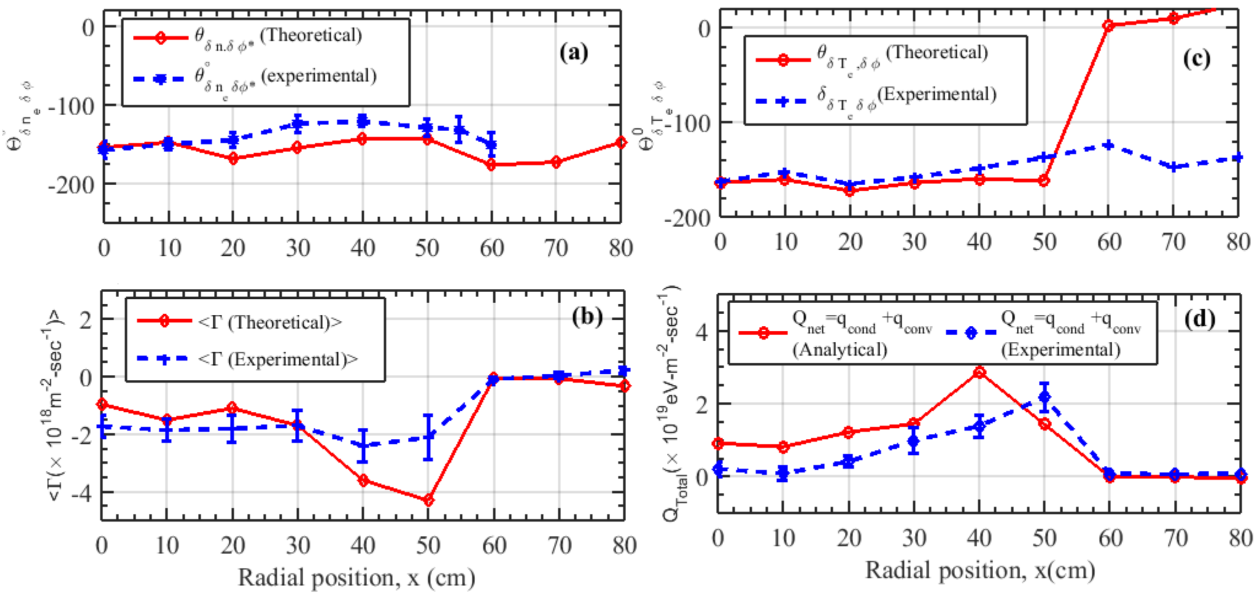

Figure 6: Radial variation of experimentally observed (blue color) and theoretically estimated (red color) values of (a) phase angle between density and potential fluctuations, $\boldsymbol{\Theta_{\delta n_e,\delta\phi}}$ *(b) particle flux due to electrostatic fluctuations,* $\boldsymbol{\Gamma_{es}}$*, (c) phase angle between temperature fluctuation and potential fluctuations,* $\boldsymbol{\Theta_{\delta T_e,\delta\phi}}$ *and (d) total heat flux due to convective and conductive heat loss processes.*

The experimentally observed phase angle between density and potential fluctuation, phase angle between temperature and potential fluctuations , particle flux and heat flux are compared with theoretical estimations obtained by using ETG model equations (1)-(5). The comparison plot is shown in figure (6), shows a good agreement between theoretical predications and experimental observation. It is also observed that the particle flux is highly negative in ETG region of LVPD whereas heat flux is always positive in our case.

V. SUMMARY AND CONCLUSION

We studied fluctuation induced particle and heat transport in LVPD in the background of ETG turbulence. The source of the underlying turbulence has been established as ∇T_e in the core of target plasma. Experimentally observed density-potential and density –temperature cross-correlations and turbulence power spectra along with frequency and wave number ordering confirm that the observed turbulence is driven by ETG. Experimentally observed fluctuation driven electrostatic particle flux is negative i.e., radially inward and is of the order $\Gamma_{es} \sim -10^{18} m^{-2} s^{-1}$. A net particle flux results from the phase difference between the density and potential fluctuations other than $180°$ for ETG driven modes. Turbulence intensity maximizes roughly at the location where particle flux maximizes. The experimental cross phase angle and flux has been compared with the cross phase and flux resulting due to the non-adiabatic ion response due to the resonant interaction of the ions with the ETG mode $k_\perp V_{thi} \sim \omega$. The experiment and theoretical results quantitatively follows the same trend across the radius and matches within 20% with each other.

The conductive heat flux, originated from finite temperature and potential fluctuations also measured experimentally and compared with theoretical expression of ETG heat flux expression. The role of temperature fluctuations in the measurement of conductive heat flux is estimated. The total heat is outward, thus supports thermodynamically, entropy production which is definitive positive.

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