National Conference on

RECENT DEVELOPMENTS AND EVOLVING TRENDS IN PLASMA SCIENCE AND TECHNOLOGY

&

Pre-conference Workshop on

MODELLING AND SIMULATION OF INDUSTRIAL PLASMAS

BHARATHIAR UNIVERSITY

State University, Accredited with 'A' Grade by NAAC, Ranked 15th among Indian Universities by MoE-NIRF

September 22 - 24, 2022

Organized by

DEPARTMENT OF PHYSICS

Bharathiar University, Coimbatore

&

BEAM TECHNOLOGY DEVELOPMENT GROUP (BTDG)

Bhabha Atomic Research Centre, Mumbai

In Association with

POWER BEAM SOCIETY OF INDIA (PSI)

Navi Mumbai

BOOK OF ABSTRACTS

Editors

Dr. K. RAMACHANDRAN
Dr. SRIKUMAR GHORUI
Dr. G. SHANMUGAVELAYUTHAM
Dr. K. SURESH

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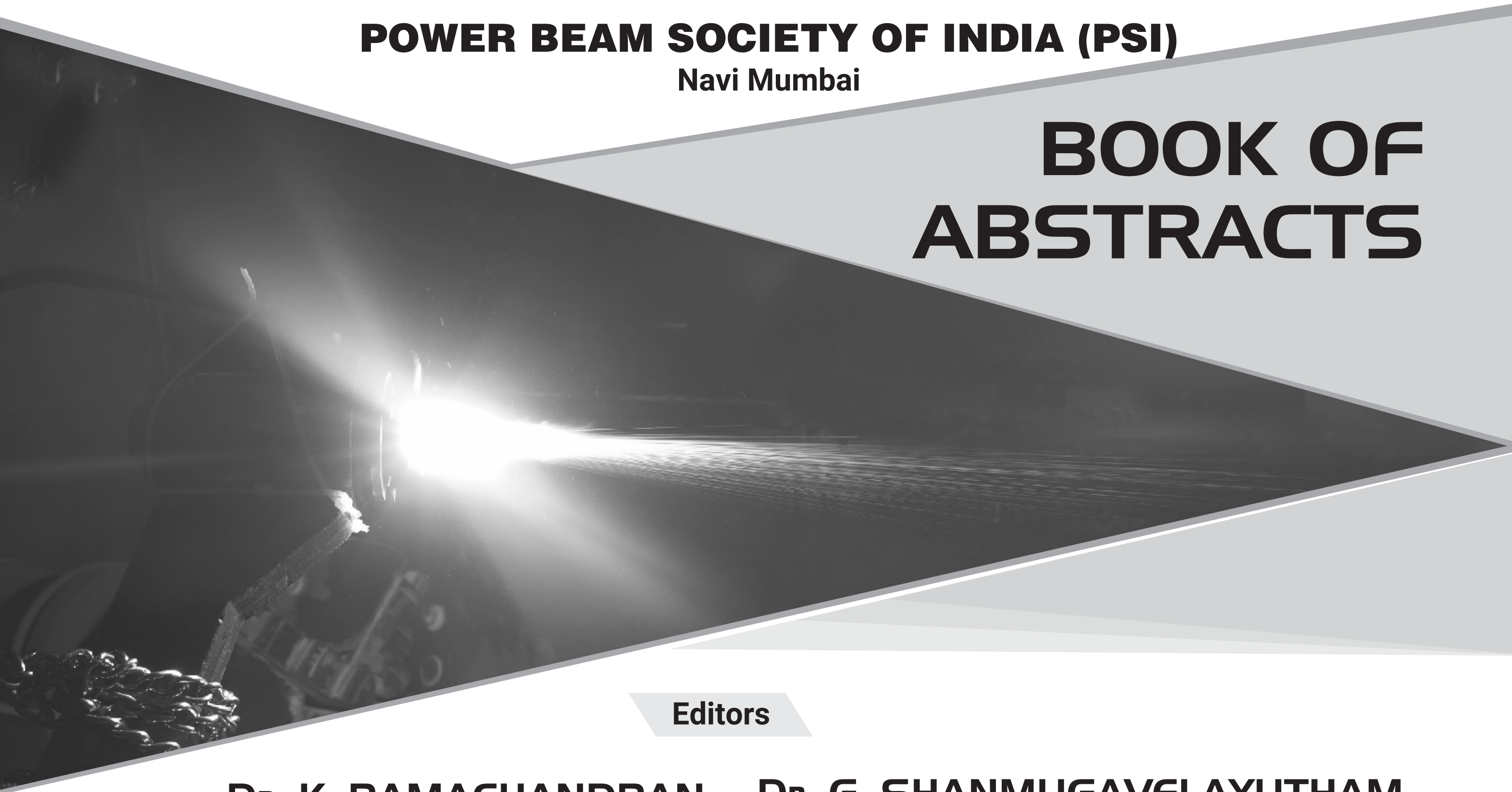

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Coimbatore - 641 046.
Tamil Nadu, India

Date: 14.09.2022

Foreword

Technologies that use plasmas have been emerging in various areas such as waste management, nanomaterials, medicine, agriculture, aerospace etc. I am glad that the Department of Physics of our University and the Beam Technology Development Group, Bhabha Atomic Research Centre, Mumbai are jointly organizing a national level conference on "Recent Developments and Evolving Trends in Plasma Science and Technology and Pre-conference Workshop on Modelling and Simulation of Industrial Plasmas (BU PLASMA 2022)" at our campus during September 22-24, 2022 in association with Power Beam Society of India, Navi Mumbai.

I am happy to learn that this conference aims to bring together around 150 participants from various places of India under the banner of BU PLASMA 2022 to discuss the issues and opportunities in the field of plasma science and technology. This conference will also feature invited talks from eminent scientists both from abroad and India, as well an opportunity for young researchers to share their research works through oral and poster presentations. A pre-conference workshop on Modelling and Simulation of Industrial Plasmaswill be extremely useful for young researchers.

I am sure that this conference will bring together researchers, scholars, and engineers from academic and R& D institutions working in the fields of plasma science and technology and provide a great platform for sharing their knowledge.I would like to greet all the distinguished participants who will be attending this conference.

I congratulate the organizers of the conference for their sincere efforts in organizing this event, and I wish theconference a grand success.

BHARATHIAR UNIVERSITY
Vice-Chancellor's Office
Coimbatore-46

(P. KALIRAJ) 14/09/22

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FOREWORD

The operational adaptability of plasmas over a wide range of conditions including thermal, non-thermal and non-equilibrium regimes have made them technologically versatile. Thermal and non-thermal plasmas are extensively used for surface engineering applications, for adopting new processing routes for material synthesis and for bio-medical applications. The present conference is aimed at providing a common platform for scientists and engineers working in the field of plasma science and technology to discuss their recent research work and suitably plan future course of research.

This National Conference is organized jointly by the Department of Physics, Bharathiar University and the Beam Technology Development Group, BARC in association with the Power Beam Society of India with the objective of evolving useful collaborations and working strategies between academicians and technologists. Papers covering the entire spectrum of Plasma Science and Technology including diagnostics, modelling and simulation studies, plasma applications in the nuclear industry, surface engineering, medical and agricultural applications, ore beneficiation & recovery of precious metals would be presented and discussed during the conference. A Pre-conference Workshop on Modelling and Simulation of Industrial Plasmas is also planned as part of the event.

I am sure this book will serve as a useful compendium of recent research activities in the emerging areas of Plasma Science and Technology and would trigger further advanced research.

Dr. P V Ananthapadmanabhan
President, Power Beam Society of India

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National Conference on
Recent Developments and Evolving Trends in
Plasma Science and Technology
&
Pre-conference Workshop on
Modelling and Simulation of Industrial Plasmas

Department of Physics, Bharathiar University, Coimbatore
September 22-24, 2022

Schedule of the Event

22-09-2022 (Thursday)	
Time	**Session**
09:00 – 09:30	Registration for Pre-conference Workshop & Conference
09:30 – 10:00	Inaugural Function
Plasma Modelling & Simulation - Basics	
10:00 – 11:00	**Lecture 1**: Fundamentals of Modeling & Simulation in Industrial Plasma: Kinetic Theory to Fluid model, Equilibrium to Non-Equilibrium ***Dr. S. Ghorui,*** *Bhabha Atomic Research Centre, Mumbai, India*
11:00 – 11:15	Tea Break
11:15 – 12:15	**Lecture 2** : Spectroscopic Diagnostic of Plasmas using OES Measurement, Modelling and Simulation ***Dr. R.K. Gangwar****, Indian Institute of Technology Tirupati, India*
Modelling of Equilibrium & Non-equilibrium Plasmas	
12:15 – 01:15	**Lecture 3** : Modelling of Thermal Plasma Processes, including Arc Welding and Wire–Arc Additive Manufacturing ***Prof. A.B. Murphy****, CSIRO Manufacturing, Australia*
01:15 – 02:00	Lunch Break
02:00 – 03:00	**Lecture 4**: Modelling of Cold Plasma Systems: Advantages and Opportunities ***Dr. Lakshminarayana Rao****, Indian Institute of Science, Bangalore, India*
03:00 – 04:00	**Lecture 5** : Transient Behaviour of Excitation Frequency Controlled Cold Atmospheric Pressure Plasma Jet (EFCAP): A One-Dimensional Simulation Study ***Dr. V.C. Misra****, Bhabha Atomic Research Centre, Mumbai, India*
04:00 – 04:15	Tea Break
04:15 – 04:45	**Tutorial 1 :** Modelling and Simulation of Non-equilibrium Plasma ***Dr. R.K. Gangwar****, Indian Institute of Technology Tirupati, India*
04:45 – 05:15	**Tutorial 2** : Modelling and Simulation of Non-equilibrium Plasma ***Dr. Lakshminarayana Rao****, Indian Institute of Science, Bangalore, India*
05:15 – 05:45	**Tutorial 3**: Tutorial on Thermal Plasma Modeling of Inductively Coupled Plasma Torch and DC Transferred Arc Plasma System ***Dr. K. Ramachandran****, Bharathiar University, Coimbatore, India* ***Mr. V.R. Barath****, Indian Institue of Technology Delhi, India*

23-09-2022 (Friday)	
TIME	**SESSION**
08:30 – 09.00	Registration
09:00 – 10:20	Inaugural Function
10:20 – 10:35	High Tea
10:35 – 11:15	**Keynote Address**: Tracing the History of Science & Technology of Processing Plasmas : Promises, Hopes and Achievements ***Dr. A.K. Das***, *Odisha State Higher Education Council, Bhubaneswar, India*
Session 1 : Plasma Generation & Plasma Devices	
11:15 – 11:45	**Invited Talk-1**: Propagation Processes of Underwater Streamers ***Prof. T. Sato***, *Tohoku University, Sendai, Japan*
11:45 – 12:15	**Invited Talk-2** : Lighting up the Dark Plasma and Generating the Decoded Information ***Dr. N. Ramasubramanian***, *Institute for Plasma Research, Gandhinagar, India*
12:15 – 12:45	**Invited Talk-3**: Innovative Thermal Plasma Generation for Nanomaterials Synthesis ***Prof. T. Watanabe***, *Kyushu University, Fukuoka, Japan*
12:45 – 12:55	**Oral-1**: Substrate Level Measurements: Semion Made it Easy ***Dr. Anshu Verma***, *Impedans Ltd., Dublin, Ireland*
12:55 – 01:05	**Oral-2**: Compact High Power Terahertz Source for Plasma Diagnostic, Medical Imaging and Spectroscopy ***Dr. Vishnu Srivastava*** *(Rtd. Sci), CSIR Pilani, India*
01:05 – 01:15	**Oral-3**: Investigation on Double Layer in a DC Discharge Plasma ***Mr. Paragjyoti Sut***, *IASST, Guwahati, India*
01:15 – 02:00	Lunch Break
Session 2: Diagnostics, Modelling and Simulation of Plasma	
02:00 – 02:30	**Invited Talk-4**: Mathematical Modelling and Simulations of Thermal Plasma–Nanopowder Fabrication Processes ***Prof. M. Shigeta***, *Tohoku University, Sendai, Japan*
02:30 – 03:00	**Invited Talk-5**: Spectroscopic Diagnostics – its Application to Various Types of Plasma ***Dr. M.B. Chowdhuri***, *Institute for Plasma Research, Gandhinagar, India*
03:00 – 03:10	**Oral-4**: Development Of Monte Carlo Collision Module For Particle-In-Cell Code PASUPAT ***Rashbihari Rudra***, *Bhabha Atomic Research Centre, Mumbai, India*
03:10 – 03:20	**Oral-5**: Porosity Determination in Fe-Al Weld Joints through Optical Emission Spectroscopy ***P.S.N.S.R. Srikar***, *Indian Institute of Technology Tirupati, India*
03:20 – 03:30	Tea Break

Session 3: Plasma Application in Energy, Environment & Protective Coating	
03:30 – 04:00	**Invited Talk-6**: Plasma Spraying of Coatings for Applications in Energy Systems ***Prof. R. Vaßen*** *ForschungszentrumJülich GmbH, Jülich, Germany*
04:00 – 04:30	**Invited Talk-7**: Solution Precursor and Suspension Plasma Spray: Recent Developments on Functional Coatings for Diverse Industrial Applications ***Dr. G. Sivakumar**, ARCI, Hyderabad, India*
04:30 – 05:00	**Invited Talk-8**: Non-Thermal Plasma and Catalysis for CH_4 & CO_2 Conversion ***Prof. Catherine Batiot-Dupeyrat**, Université de Poitiers, France*
05:00 – 05:10	**Oral-6**: Optical Emission Spectroscopic Investigations for Understanding Growth Mechanism of Arc Plasma Synthesized Nanocrystalline Rare Earth Hexaborides ***Shalaka A. Kamble**, Savitribai Phule Pune University, Pune, India*
05:10 – 05:20	**Oral -7**: Thermal Plasma Synthesis of Silicon Carbide from Solar Waste Panels ***E.I. Anjana**, CSIR–NIIST, Thiruvananthapuram, India*
05:20 – 07:00	**POSTER SESSION** with Refreshment
07:00 – 08:00	General Body Meeting of PSI
08:00 – 09:00	Dinner

24-09-2022 (Saturday)

Session 4: Low-pressure and DBD Plasmas, Surface Treatment & CVD	
09:30 – 10:00	**Invited Talk-9**: Capacitively Coupled Radio-Frequency Plasma: From PECVD to Agriculture ***Dr. Rajib Kar**, Bhabha Atomic Research Centre, Mumbai, India*
10:00 – 10:30	**Invited Talk-10**: Magnetron Sputtering Based Thin Films for Solar Cell Application ***Dr. Devendra Bhale**, Bhabha Atomic Research Centre, Mumbai, India*
10:30 – 11:00	**Invited Talk-11**: Plasma Thrusters for Space Applications ***Dr. Vara Prasad Kella**, Liquid Propulsion Systems Centre, ISRO, Thiruvananthapuram, India*
11:00 – 11:10	**Oral-8**: Plasma Spray Coated YSZ for High-Temperature Radiative Cooling ***N.K. Gopinath**, Indian Institute of Science, Bangalore, India*
11:10 – 11:20	**Oral-9**: Cold Plasma Treatment for Extending the Shelf Life of Soya Chunks ***T. Anupriyanka**, Bharathiar University, Coimbatore, India*
11:20 – 11:30	**Oral-10**: Production, Characterization and Application of Plasma for Coriander Seed Germination ***Roshani Dahal**, Tribhuvan University, Nepal*
11:30 – 11:45	Tea Break
Session – 5: Plasma for Medical & Agriculture Applications	
11:45 – 12:15	**Invited Talk-12**: Thermal and Non -Thermal Plasma for Agriculture Application ***Dr. N. Tiwari**, Bhabha Atomic Research Centre, Mumbai, India*
12:15 – 12:45	**Invited Talk-13**: Electron Cyclotron Resonance (ECR) Cold Plasma for Biomedical Applications ***Dr. V.L. Mathe**, Savitribai Phule Pune University, Pune, India*

12:45 – 12:55	**<u>Oral-11</u>**: Cold Plasma to Improve Pearl Millet Seed Germination and Plant Growth ***M. Subash***, *SRM Institute of Science and Technology, Chennai, India*
12:55 – 01:05	**<u>Oral-12</u>**: Antimicrobial, Agriculture, and Aquaculture Applications of Plasma Activated Water ***Vikas Rathore***, *Institute for Plasma Research, Gandhinagar, India*
01:05 – 01:15	**<u>Oral-13</u>**: Self-Organized ordered Nanoparticles Arrays for the SERS Applications ***Sebin Augustine***, *Institute for Plasma Research, Gandhinagar, India*
01:15 – 02:00	Lunch Break
Session 6: Plasma Waste Treatment, Ore Beneficiation & Recovery of Metals	
02:00 – 02:30	**<u>Invited Talk-14</u>**: Thermal Plasma Technology for Difficult-to-Treat Mineral and its Waste ***Dr. K. Jayasankar***, *CSIR-NIIST, Thiruvananthapuram, India*
02:30 – 03:00	**<u>Invited Talk-15</u>**: Decomposition and Decontamination of Industrial Effluents via an Advanced Cold Atmospheric Pressure Plasma Oxidation Technique ***Dr. K. Navaneetha Pandiyaraj***, *Sri Ramakrishna Mission Vidyalaya College of Arts and Science, Coimbatore, India*
03:00 – 03:10	**<u>Oral-14</u>**: High-rate Synthesis of Stoichiometric and Hydrogenated Molybdenum-oxide Nanomaterials by One-step Plasma Techniques, for Dye Adsorption and Treatment of Cancer ***Mizanur Rahman,*** *Centre of Plasma Physics-IPR, Assam, India*
03:10 – 03:20	**<u>Oral-15</u>**: An Experimental Study on Abatement of NOx & VOC using Pulse Powered Dielectric Barrier Discharge Plasma Hybrid Technique ***Dr. N. Jagadisha***, *Department of EEE GSSSIETW, Mysuru, Karnataka, India*
03:20 – 03:30	**<u>Oral-16</u>**: Effect of Air in Submerged Thermal Argon Plasma on Degradation of Pharmaceutical Antibiotic ***Nanditta Nandy***, *Pondicherry University, Pondicherry, India*
03:30 – 03:40	Tea Break
Session 7: Plasma Technology in Nuclear Industry	
03:40 – 04:10	**<u>Invited Talk-16</u>**: Plasma Spray Coatings for Pyrochemical Reprocessing of Spent Metallic Nuclear Fuels Applications ***Dr. Ch. Jagadeeswara Rao***, *Indira Gandhi Centre for Atomic Research, Kalpakkam, India*
04:10 – 04:40	**<u>Invited talk-17</u>**: Plasma Technology in Nuclear Industry ***Dr. S. Bhandari***, *Bhabha Atomic Research Centre, Mumbai, India*
04:40 – 04:50	**<u>Oral-17</u>**: NF_3 Plasma Based Surface Etching Process – An Extended Utilization Towards Nuclear Industries ***H.L. Swami***, *Institute for Plasma Research, Gandhinagar, India*
04:50 – 05:00	**<u>Oral-18</u>**: The Quantum Dusty-Plasma Molecules in Astrophysics and Newer Kinds of Plasmas ***Dr. Kotcherlakota Lakshmi Narayana*** *(Rtd. Prof.)*
05:00 – 05:45	**Concluding Remarks & Valedictory Function**

CONTENTS

ORAL PRESENTATIONS

POSTER PRESENTATIONS

KEYNOTE ADDRESS

Keynote Address

Tracing the History of Science and Technology of Processing Plasmas: Promises, Hopes and Achievements

Asoka Kumar Das

Odisha State Higher Education Council, Bhubaneswar, India

E-mail: asokadas@gmail.com

Abstract

The story of the growth of processing plasmas in the Department of Atomic Energy can probably be matched with the growth of the science and technology of plasma processing in India. The journey of low temperature plasma processing technology in our country started through the building low-temperature thermal plasma systems for air plasma and underwater plasma cutting of thick metal plates for the VEC project at Kolkata. The first plasma torch of 100kW capacity was built and technology transferred to Industry during the very early seventies. From that point onwards, thigh-temperature technology group (later changed to Plasma Physics Division and further to Laser and Plasma Technology Division) at BARC took up development challenges of various aspects of processing plasma technologies leading to the development of the first Indian combustion plasma based MHD generators, first indigenous thermal plasma spray technology in its entirety (Air plasma spray, controlled environment plasma spray, wire arc spray, automated spray etc.), development testing of the first Indian High enthalpy ground based plasma jet simulators for ISRO, RF plasma systems for synthesis of a variety of nanostructured materials, plasma nuclear aerosol generator test facility, High power thermal plasma melter, spectrum of nanomaterials generators, waste treatment reactors as well as plasma chemical reactors. As in all technology development programs in DAE, these technologies were supported by the indigenous design of plasma generating devices as well as development of the entire process flow including product characterization. The work also included plasma diagnostics, modeling through development of computer simulation including inhouse codes for thermochemical properties, transport properties, particle dynamics, plasma fluid dynamics as well as plasma stabilization. On the applications of low temperature non-equilibrium processing plasmas, notable achievements in DAE included inhouse design development of a variety of RF. ECR and microwave plasma systems for synthesizing a large variety of thin film coatings (diamond and DLC coatings) to support the requirements of nuclear fuel cycle. Some of the important plasma processing achievements during the last five decades include Diamond and diamond like carbon coatings, thermal barrier coatings, corrosion resistant coatings, UF6-UF4 convertor, inflight plasma processing reactors for synthesis of micron and nano phase materials, boron coatings for nuclear detectors, plasma DBD jets for nuclear decontamination, plasma assisted waste pyrolizer and a variety of novel nanogenerators. In addition to BARC, work conducted at IPR added plasma arc pyrolizers, large volume plasma ion implantation as well as nitriding systems to this kitty. More recently, research focus has shifted to DBD plasmas for plasma medicine, plasma agriculture, tailoring biological products, toxic waste decomposition and aerospace applications. As a novel and environment-friendly materials processing enabler, processing plasma technology has therefore shown a great amount of potential for industrial applications in India. Of particular hope was smooth integration to the both academic institutions and concerned industries. The talk will trace the five decades of development in this interesting area with critically analyzing the lessons learned and the way forward.

WORKSHOP LECTURES

Workshop Lecture – 1

Fundamentals of Modelling & Simulation in Industrial Plasma: Kinetic Theory to Fluid Model, Equilibrium to Non-Equilibrium

S. Ghorui

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Bhabha Atomic Research Centre, Trombay, Mumbai-400085, India*

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Abstract

Plasma technologies cover a vast variety of industrial applications in numerous advanced technology areas. While nano-synthesis, plasma metallurgy, plasma spray coating, plasma waste processing, plasma CVD, plasma cutting, and plasma welding are some of the important application areas in thermal plasma, surface modification, functionalization, lighting, thin film coating, and numerous biomedical applications are the potential application areas in non-thermal plasma. Modelling associated phenomena to a tractable level to simulate the process is rapidly gaining utmost importance to fully capitalize the potential of the plasma technology as well as to understand the process and making it more economical and more efficient. After a brief overview of the state of the art technological span in thermal and non-thermal plasma, the talk will directly address the standard kinetic theory models and fluid models of plasma for numerical simulation of the associated plasma behaviour. Plasma kinetic equation, energy, momentum and radiation transport, collisional exchange of energy, current continuity, turbulence models, thermal and chemical non-equilibrium are the various aspects that will be discussed with a tight focus on its modelling and simulation perspective. General structure of plasma simulation codes will be discussed accounting the computational fluid dynamic (CFD) part as well as thermo-physical properties that evolve continuously as the simulation proceeds. Important roles of highly nonlinear behaviour of thermodynamic properties like species density, physical density, specific heat, enthalpy and transport properties like electrical conductivity, thermal conductivity, collision frequency, and diffusion coefficients to shape the ultimate behaviour will be discussed. The talk will be concluded illustrating the results of application of the modelling concept and simulation strategies to a real plasma application problem.

References

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[4] S Ghorui, J.V.R Heberlein, E. Pfender, Non-equilibrium modelling of an oxygen-plasma cutting torch, J. Phys. D: Appl. Phys. 40, 1966–1976 (2007)
[5] S. Ghorui, Joachim V.R. Heberlein, E. Pfender, Thermodynamic and Transport Properties of Two-temperature Oxygen Plasmas, Plasma Chem. Plasma Process. 267 (2007)

Workshop Lecture – 2

Spectroscopic Diagnostic of Plasmas using OES Measurement, Modelling and Simulation

R.K. Gangwar

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Abstract

The use of plasma-mediated processing in various applications is growing significantly. It is because plasmas can provide a unique environment composed of neutral atoms, molecules, radicals, excited states, ions, and energetic electrons. Interestingly, the in-situ production of these reactive chemical species (RCS) by plasma does not necessarily require chemical agents. However, a reliable plasma diagnostic is required to achieve and optimize the required processing in a given application. Further, the plasma diagnostic also provides insight into the plasma surface interaction. In this regard, optical emission spectroscopy (OES) based diagnostic approaches are prevalent due to their non-invasive nature and ease of implementation. However, one must couple the OES measurements with suitable population-kinetic models to extract the information from OES measurements. During my talk, I shall give an overview of OES-based diagnostic techniques, including the associated modelling and simulation.

References

[1] H.J. Kunze, Introduction to Plasma Spectroscopy, Springer Berlin, Heidelberg DOI: 10.1007/978-3-642-02233-3.

Workshop Lecture – 3

Modelling of Thermal Plasma Processes, including Arc Welding and Wire–Arc Additive Manufacturing

A.B. Murphy

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Abstract

Thermal plasmas are very widely used in industrial applications, including arc welding, wire–arc additive manufacturing (a type of metal 3D printing), plasma spraying, plasma cutting, powder spheroidization, mineral processing, waste treatment and gasification, arc lightning and inductively coupled plasmas for analytical chemistry [1]. Computational modelling is increasingly used to understand, optimize and design such thermal plasma processes.

Computational models of thermal plasmas solve the equations of computational fluid dynamics (CFD) for viscous flow, combined with an energy conservation equation and electromagnetic equations. Source terms describing effects such as the Lorentz force, Joule heating and radiative emission are included. However, solving these equations is rarely sufficient since most applications rely on the effect of the thermal plasma on another substance (e.g., melting the workpiece in arc welding, and melting and accelerating an injected stream of powder in plasma spraying). Therefore, models must consider the plasma's interaction with solids, liquids and/or gases.

In this talk, I will present the fundamentals of thermal plasma modelling. I will then use two examples, arc welding [2] and wire–arc additive manufacturing [3], to illustrate approaches for developing models of thermal plasma processes of industrial interest. In particular, I will consider treatments of the boundary layer between the plasma and electrodes, plasma–particle interactions, vaporization of metal surfaces, and calculation of liquid metal surface profiles, all of which are important in arc welding. Finally, I will present a hybrid approach that couples a CFD arc plasma model with a finite-element model to predict the thermomechanical properties of metal components produced by wire–arc additive manufacturing.

References

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[2] Murphy et al., A desktop computer model of the arc, weld pool and workpiece in metal inert gas welding, Appl. Math. Modell. 44, 91–106 (2017)
[3] Norrish et al., A review of wire arc additive manufacturing: development, principles, process physics, implementation and current status, J. Phys. D: Appl. Phys., 54, 473001 (2021)

Workshop Lecture – 4

Modelling of Cold Plasma Systems: Advantages and Opportunities

Lakshminarayana Rao

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E-mail: narayana@iisc.ac.in

Abstract

Cold plasma technology is extensively used in semiconductor industries under subatmospheric conditions. In recent years, cold plasma chemistry under atmospheric conditions has been extensively researched for its utility in various applications such as food, medicine, hygiene, environmental, materials synthesis, surface modifications, propulsion, flow control, chemical conversion, and combustion. Arguably, most technologies using plasma have been developed empirically and experimentally. Considering the complexity involved in the plasma phenomena i.e., a) defining simultaneous multi-time-scale processes, b) controlling the plasma parameters, such as electron energy distribution function, reduced electric field, and mean energy, becomes essential to achieving desired chemistry. For these reasons, modelling and simulation can make significant support in optimizing the performance and minimizing the cost of experimentation. This talk will focus on the plasma chemistry simulation and the factors to be considered, including the database requirements, the process of building the chemical reaction mechanism, and the choice of tools available to solve the involved chemistry.

Workshop Lecture – 5

Transient Behaviour of Excitation Frequency Controlled Cold Atmospheric Pressure Plasma Jet (EFCAP): A One-Dimensional Simulation Study

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Abstract

Extensive research has been carried out on excitation frequency atmospheric pressure plasma jets (EFCAPs). Different plasma properties, such as the species distribution, density, and electron temperature etc. are very important to understand its suitability for desired application. EFCAP generated Argon-Nitrogen plasmas in particular play an important role to generate reactive oxygen and nitrogen species, very important for biomedical applications. The study develops a 1D simulation model of argon-nitrogen atmospheric pressure plasma using the Finite Element Method (FEM) software COMSOL Multiphysics. The results of a time-dependent, one-dimensional simulation of a non-DBD argon and argon nitrogen discharge between two bare electrodes at atmospheric pressure are presented. The findings may offer framework for designing a plasma source and comprehending the results in the relevant application fields.

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Workshop Lecture – 6

Tutorial on Thermal Plasma Modeling of Inductively Coupled Plasma Torch and DC Transferred Arc Plasma System

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Abstract

Thermal plasma modeling is a multiphysics aspect which involves solving equations that correspond to heat transfer, fluid flow, current channel formation and magnetic field induction in a fully coupled manner. Despite the development of interactive software codes and improved hardware utilities, it always need a little tweak for successful model convergence. In the present tutorial, the usage of commerically available software platform, COMSOL Multiphysics, to model the plasma generated in the Inductively Coupled Plasma (ICP) torch and DC transferred Arc plasma system will be discussed as case studies. The steps involved from the selection of required physics, domain creation, inclusion of temperature dependent material properties, incorporation of required boundary and initial conditions, mesh generation, and solver setup will be briefly discussed. Finally, the various post processing facilities that allows one to visualize the results and also check the model convergence will be explained.

INVITED TALKS

Invited Talk – 1

Propagation Processes of Underwater Streamers

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Abstract

Underwater discharges have been applied to water and medical treatments because ultraviolet rays, high-energy electrons, shock waves, microbubbles, ozone, and OH radicals can be generated. However, the mechanism of formation processes of underwater discharges has not yet been clarified, although both the ionization breakdown theory and the bubble breakdown theory have been proposed. To elucidate the formation process, the authors clarified the initiation and propagation processes of primary streamers in water. When a positive voltage is applied to the tip of a needle electrode placed in water with a voltage rise time of about 100 ns, the current concentrates in the vicinity of the electrode, causing heating and fluctuations in the temperature field. Subsequently, multiple microbubbles are generated at the tip of the electrode over time and grow to form a bubble cluster. When the bubble cluster grows to a certain size and sufficient electric charge is accumulated in the bubble, a protruding bubble is formed at the tip of the bubble cluster. Further concentration of the electric field causes the electric field to exceed the threshold of the electric field for the start of streamer discharge, and a streamer is propagated. The streamer propagates with each pulse of discharge current, forming filamentary gas channels [1, 2].

On the other hand, negative streamers have a small, coral-like propagating region, and the entire region is photographed as a shadow, making it difficult to visualize the internal structure of the streamer. The authors developed a new polarizer shadowgraph method and succeeded in precisely visualizing and analyzing weak pressure waves. The analysis using the visualized pressure wave revealed that the negative streamer propagates with a repetitive progression, stop, and bifurcation of 20 to 50 μm every 20 to 50 ns. The analysis of the phenomena inside the streamer led to the proposal of a bifurcation model based on a local electric field and the discovery that the bifurcation occurs with a time lag, leading to the proposal of a new propagation model for negative streamers [3].

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Invited Talk – 2

Lighting up the Dark Plasma and Generating the Decoded Information

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Abstract

For the continuous operation of a Deuterium – Tritium (DT) fusion machine, it is necessary to monitor the amount of fuel (D, T) available as well as the ash (helium nuclei) produced which can be done only remotely. Usually atomic radiations emitted by a laboratory plasma will have a lot of information about the plasma like type of ions/neutrals, density, temperature etc. But the core of a fusion plasma emits only continuum radiation and it is not possible to decode any information from such radiations. Hence to control the fusion process one needs the amount of ash produced at all times. One of the process proposed for this monitoring is Charge-Exchange Recombination Spectroscopy in which some of the helium nuclei can be 'dressed up' by charge exchange reactions with specific species sent through diagnostic neutral beam injection (NBI). Knowing the beam current of the NBI, the amount of ash can be estimated from the number of the charge exchange reactions, while the charge-exchange reactions itself can be calculated from the light emitted from the 'dressed up' atoms. In this talk, other possible processes will be listed upon after discussing the complexity and importance of the said calculations in detail.

Invited Talk - 3

Innovative Thermal Plasma Generation for Nanomaterials Synthesis

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Abstract

Thermal plasmas have attracted extensive attention due to their unique advantages, and are expected to be utilized for a number of innovative industrial applications such as decomposition of harmful materials, recovery of useful materials from wastes, and synthesis of high-quality and high-performance nanoparticles. Thermal plasmas have advantages such as high enthalpy to enhance reaction kinetics, high chemical reactivity, and oxidation or reduction atmospheres depending on the required chemical reaction, making them effective for s innovative processing. The objective of the study is to investigate the physical and chemical phenomena in thermal plasma processing for industrial application.

The multiphase AC arc is one of the most attractive thermal plasmas because of its advantages for material processing, such as large plasma volume and low gas velocity. It also has the advantages of high energy efficiency and low cost compared to other thermal plasmas [1]. Therefore, multiphase AC arcs have been applied to innovative material processing, such as in-flight glass melting technology and nanomaterials manufacturing processes. The stability of the arc, the temporal and spatial characteristics of the arc discharge, and the electrode phenomena are the most important phenomena to understand. The study of the characteristics of the multiphase AC arc will be useful for industrial applications.

Measurement of excitation temperature of the multiphase AC arc was carried out by the high-speed visualization system [2]. Excitation temperature was estimated by atomic-to-atomic line-ratio method from the obtained intensities at different wavelengths. Excitation temperature of atomic Ar in most of arc region was higher than 7,000 K. This result clearly indicates that the arc temperature is sufficient high to melt glass raw materials and other refractory materials. The high-speed camera with band-pass filters system were successfully applied to the visualization of temperature field of multiphase AC arc.

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Invited Talk – 4

Mathematical Modelling and Simulations of Thermal Plasma – Nanopowder Fabrication Processes

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Abstract

Mathematical models and solution algorithms to simulate thermal plasma – nanopowder fabrication processes are presented and discussed. The processes involve nanometer-scale particles' collective growth by homogeneous nucleation, heterogeneous condensation, and interparticle coagulation and transport by convection, diffusion, and thermophoresis in microsecond to millisecond time scales [1]. The demonstrative simulations were performed to highlight the importance of capturing steep gradients of nanopowder concentration and plasma temperature and 3D dynamic motions of turbulent multi-scale vortices in and around a thermal plasma jet. To obtain the numerical solution, the computation adopted an advanced method (named as Method-III in the literature [2]) which was expected not only to express turbulent features but also to perform numerically stable computation even with a large increment of time steps. Those results depicted that the nanopowder collectively grew up and diffused outside the plasma region. The larger size regions coincided with smaller number density regions, which indicated that simultaneous coagulation decreasing particle number played an important role for the nanopowder growth as well. Furthermore, a different detailed model was developed to numerically predict and analyze a collective growth of binary alloy nanopowder. It could calculate the processes of binary nucleation, binary co-condensation, and interparticle coagulation among nanoparticles with different compositions, even if they occurred simultaneously [3]. The numerical calculation gave information about the binary growth behavior: for example, Mo-rich nanoparticles (but not pure Mo nanoparticles) are generated when the temperature was higher; and subsequently Si vapor condensed on those nanoparticles (Mo vapor was also still condensing simultaneously), because Si had a higher saturation pressure than Mo. It also presented that such nanopowder inevitably had non-uniform sizes and compositions, even though the calculation condition was chosen to be as simple as possible.

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Invited Talk – 5

Spectroscopic Diagnostics - its Application to Various Types of Plasma

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Abstract

Spectroscopic diagnostic is an important non-invasive tool to investigate the plasma. The visible and VUV wavelength ranges are mostly used for plasma spectroscopy when the plasma has a low temperature. This range goes down to hard X-ray for high temperature plasma produced in the tokamak like devices [1]. Then the instrumentation and analysis techniques differ very much depending upon the explored wavelength range to investigate the plasma. Mostly importantly, here, various types of models are used to calculate the molecule, atomic and/or ionic state distribution, simulating the spectrum, and then compare it to the experimentally observed spectrum for inferring the plasma parameters, like electron and gas temperatures and electron density. Not only that, spectral line shapes are also utilised to estimate the neutral and ion temperature as the line shapes are modified in the plasma. The electron and gas temperatures can be obtained through the modelling of spectral lines based on the Boltzman distribution depending on the plasma. Sometimes, collisional – radiative (C-R) model, which includes almost all types of atomic processes to find the atomic state distribution, is applied to infer the plasma parameters. For example, the gas temperature of RF produced plasma can be obtained by applying the Boltzmann technique to the observed molecular band. In the tokamaks, the line intensity ratio based on the C-R model is used to get electron density and temperature. However, the application of the various techniques is a challenging task due to their inherent difficulties and limitations based on the parameter ranges of the plasmas. In this talk, various instrumentation, analysis methods used in spectroscopic diagnostics will be discussed. It will also cover this diagnostic's uses to find out the electron and gas temperature in application oriented plasmas like RF plasma produced in the chamber of plasma assisted chemical vapour deposition (PACVD) technique [2] and penning plasma discharge [3]. Some interesting results from the tokamak plasma, like the nature of the neutral and ion temperatures, will be presented as well, through the spectroscopic investigation.

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Invited Talk – 6

Plasma Spraying of Coatings for Applications in Energy Systems

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Abstract

Plasma spraying is an often used technology to produce coatings for energy applications. The presentation will give a number of examples and will also compare the obtained results with other coating technologies.
One important application are thermal barrier coating systems frequently used in gas turbines. In these systems the bond coat is often produced by plasma spraying, however also high velocity oxygen flame spraying (HVOF) will be described. The top coats are manufactured by different plasma spraying processes as atmospheric plasma spray (APS), suspension plasma spray (SPS), or plasma spray- physical vapor deposition (PS-PVD). These techniques will be compared to physical vapor deposition (PVD) technologies.
Another examples are tungsten/steel graded coatings for fusion reactor applications. Vacuum plasma spraying is here a promising technology, others coating methods will be compared.
As a third example the deposition of chrome evaporation barriers for solid oxide fuel cells (SOFCs) by APS will be described. These coatings lead to low degradation rates. For comparison different type of coatings will also be discussed.

Invited Talk – 7

Solution Precursor and Suspension Plasma Spray: Recent Developments on Functional Coatings for Diverse Industrial Applications

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Abstract

Fine structured coatings developed using liquid feedstock are getting increased attention, mainly due to its unique coating characteristics than the conventional powder feedstock based coatings. Solution precursor plasma spaying (SPPS) and suspension plasma spraying (SPS) and relies upon liquid carrier medium, while the former employs precursor solutions that transform into fine deposits, and the latter uses micron/sub-micron sized, synthesized particle suspensions. Compared to standard powder based spraying, the relatively smaller splats allow diverse microstructure ranging between dense and porous architecture and additionally, the technique facilitates possibilities of tailoring with columnar and vertically cracked features. Such microstructural features are highly desirable for thermal barrier applications. Repeatable deposition of the coating with diverse microstructures involve detailed process parametric understanding and the identification of appropriate feedstock characteristics. In addition to TBCs, the SPPS and SPS technique can be utilized to develop vast range of ceramic and hybrid composite coatings meant for diverse functional applications. An overview of coating mechanism, recent developments using the novel plasma processing approach will be presented.

Invited Talk – 8

Non-Thermal Plasma and Catalysis for CH_4 and CO_2 Conversion

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Abstract

A correlation between chemical properties of metal oxide catalysts and CH_4, CO_2 conversion under plasma discharge was evidenced.

Introduction The coupling of plasma and catalysis was proposed to overcome the main drawbacks encountered in classical catalytic thermal processes such as the high energy required to activate the small molecules CH_4 and CO_2. In this way, plasma assists the catalyst in providing the internal energy of the reactants [1]. In the present study the selected materials were oxides possessing different dielectric constant: from 2.8 to 2903, with surface area from <1 to 312 m^2/g and different acid-base properties. The goal of the study was to find correlations between physico-chemical properties of the solid and CH_4, CO_2 conversion, in a plasma reactor at a fixed deposited power.

Materials and Methods The reaction was performed at atmospheric pressure and room temperature in a coaxial dielectric barrier discharges (DBD) reactor. Helium, methane and carbon dioxide were flown through the plasma reactor at a total flow rate of 40mL.min^{-1}, a ratio $CO_2/CH_4=2$ with a constant concentration in He: 75%, corresponding to a contact time of 1.6s. A sinusoidal supply of power was applied across the electrodes. The discharge power, calculated from the Lissajous figures, was fixed at 8 watts (frequency at 800Hz and voltage at 13.5kV). The oxides used in this study were commercial products for CaO, MgO, BaO, TiO_2, La_2O_3, ZnO, SiO_2, CeO_2, Al_2O_3 and Mesoporous alumina with surface area from 260 to 312m^2.g^{-1} prepared in the laboratory.

Results and Discussion The best results in terms of reactant conversion were obtained using oxides possessing low dielectric constant. It is believed that higher electric field is present locally at the junction of oxide grain when using oxides with high dielectric constant. As a consequence, even if the reactive species density is increased, the volume of efficient discharge is reduced, and the global transformation of reactants is limited [2]. Besides γAl_2O_3 materials, the highest conversions were obtained with the commercial alumina, possessing the lowest surface area: 65 m^2/g, methane conversion reaches 31.3% against 23.4, 22.6 and 25.4 for alumina exhibiting surface area of 312, 301 and 260 m^2/g, respectively. These results suggest that the active sites generated into the mesoporosity of alumina (γAl_2O_3-400) are not accessible to reactants under the plasma discharge. However, a correlation between the number of acid and basic sites and the reactants conversions was clearly shown. The results obtained in the present study confirmed experimentally that the coupling of plasma with catalyst depends strongly on the nature of surface active species (presence of OH) and, to a lower extend, to the amount of active sites located in the small pores of oxides. A deep discussion on selectivity to products (CO, hydrocarbons, oxygenates…) will be performed. Moreover structural modifications of oxides, such as CaO under plasma discharge will be shown and a mechanism of carbonation will be proposed [3].

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Invited Talk – 9

Capacitively Coupled Radio-Frequency Plasma: from PECVD to Agriculture

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Abstract

13.56 MHz Capacitively coupled plasma is one of the most popular technique for deposition of thin films all over the world. Different thin films can be deposited using this particular technique. Here, we have used this facility to deposit DLC-SiOx thin film on TZM alloy to increase the alloy's functionality in high temperature application. The deposited films not only gave the alloy sought after protection against high temperature but additionally increased its hardness and reduced its friction co-efficient. The same plasma CVD system was used for irradiation of rice and mung seeds and the irradiated seeds showed improved germination kinetics and higher stress tolerance. While in the former case, a gas mixture of Ar, CH_4 and Hexa-Methyl-di-Siloxane (HMDSO) was used for deposition, only Ar plasma was used in the latter case. The duration also varies drastically in both cases from 45 mins to 20 seconds.

The talk will give a detailed account of the obtained experimental results and discuss the nuances of deposition and irradiation with this versatile system.

Invited Talk – 10

Magnetron Sputtering Based Thin Films for Solar Cell Application

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Abstract

Physical Vapor Deposition based magnetron sputtering is one of the most popular thin film deposition techniques which have been used for depositing [1] metallic, insulating and composite thin films. This plasma based technology is used in industry and research laboratories for its tremendous advantages including target utilization, high stability and reproducibility of the process, high deposition rate, easy in scaling up etc. [2]. This magnetron sputtering can be used to deposit low-cost, earth abundant, nontoxic Cu_2ZnSnS_4 i.e., CZTS, solar cell absorber layer, which has high optical absorption coefficient (of the order of 10^4cm^{-1}) in solar spectrum and band-gap of 1.5 eV. In literature there are four methods to deposit the CZTS thin film by sputtering which are as follows single step composite CZTS deposition [3]

1. Co-deposition (Cu, Sn and Zn) [4] followed by sulphurization
2. Sequential multilayer deposition [5] of (Cu, Sn and Zn) followed by sulphurization
3. Co-deposition with reactive sputtering [6]

In this work development of a dc/rf magnetron sputtering system capable of depositing CZTS thin film by all above four routes has been described. The system has four 2 inch circular magnetrons arranged in co-sputtering geometry at an angle of 30 degrees from vertical to enable co-sputtering of different materials. DC plasma is used for metallic target and RF plasma is used for insulating target. To maintain the uniformity of thin film the facility for rotation of substrate up to 25 rpm speed is included. CZTS thin films need to be deposited at elevated temperature hence substrate heating up to 600°C has been incorporated. For reactive sputtering several gases need to be allowed in the chamber during the deposition and in argon plasma in a controlled way, so two mass flow controllers are included. This work reports deposition of CZTS thin films of 1000nm thickness from stoichiometric sputtering target. The thin films were deposited at 300°C. The thin films were characterized by several techniques and found to be smooth uniform in both 10mmx10mm and 25mmx 25mm size. The optical band gap was found to be 1.08 eV from the analysis of as deposited CZTS thin films.

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Invited Talk – 11

Plasma Thrusters for Space Applications

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Abstract

Plasma thrusters are the heart of electric propulsion systems used for spacecraft maneuver. Electric power is employed to produce the plasma by ionizing the propellant and to accelerate the charged particles. Due to the unique capability of achieving one or two order higher exhaust velocity than the conventional propulsion systems, electric propulsion gives the mass advantage to the space mission. Gridded ion thrusters and Hall Effect Thrusters are the matured kind of plasma thrusters which comes under the electrostatic thruster category. Thousands of satellites are operating at present using these thruster technologies by various space agencies. [1] These thrusters are effectively used for orbit raising, NSSK operations and interplanetary missions, which produce thrust in the range of few milli-Newtons to few Newtons. Microwave plasma thrusters, Radio-frequency plasma and magneto plasma dynamic (MPD) thrusters are recent developments, which comes under electro-magnetic thruster category. These complex devices shows promising capability of generating higher thrust with higher life. Field-Emission-Electric-Propulsion (FEEP) and Pulsed plasma thrusters are low thrust generating thrusters, which can be used for fine tuning of the thruster orbit. These variety of plasma thrusters are giving solutions to different spacecraft applications from Geo-satellites to CubeSats. However, to catch the ever increasing space commercial demands and scientific goals, plasma thruster technology needs to evolve further. Simulations play a vital role in bridging the gap between concepts and realization.

Reference

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Invited Talk – 12

Thermal and Non-Thermal Plasma for Agriculture Application

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Abstract

Plasmas are used for various industrial, medical and agricultural applications. In this study, nitrogen fixation, one of the major agricultural application of thermal and non - thermal plasma is explored. For the nitrogen fixation, plasma jets emanating from a DC atmospheric air plasma torch and RF non-thermal plasma torch are utilized. Optical emission spectroscopy is employed for identification of different species present in thermal and non-thermal plasma. Emission spectra revealed the presence of emission bands of nitrogen and series of NO bands in addition with the atomic lines of species present in the plasma which are responsible for formation of long lived nitrite and nitrate ions in water through different possible synthesis routes during plasma water interaction. Nitrates and nitrites are the usable form of nitrogen for the plants.

Known amount of water is treated with atmospheric pressure plasma jets and concentration of nitrate and nitrite species are measured using Quantofix test strips. Electrical conductivity and pH of treated water are measured using digital pH meter and conductivity meter respectively. It is found that concentration of nitrates and nitrites increases with time of treatment of water with the plasma jet and pH of the water decreases with time. Reduction in pH may be attributed to formation of HNO_3 in water. Concentration of nitrate and nitrite are measured for both the plasma treated tap water and pure water. It is observed that nitrate and nitrite concentration is almost 8-10 times higher in tap water. Reason behind synthesis of higher concentration of the nitrate and nitrite in tap water for same operating parameter may be attributed to higher concentration of ions present in the tap water. Optimizing the process for maximum synthesis of nitrate and nitrite are under progress.

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Invited Talk – 13

Electron Cyclotron Resonance (ECR) Cold Plasma for Biomedical Applications

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Abstract

Electron Cyclotron Resonance (ECR) plasma is an example of cold plasma characterized by large energy difference between constituent plasma species due to different mass. Electrons possesses sufficiently high energy than that of ions and neutrals, facilitates surface interactions. Such interactions are useful to induce surface modifications, both physical as well as chemical, of polymers. In the work carried out so far, a ECR plasma system has been developed and diagnosed using optical emission spectroscopy as well as electrical probes. Such electrically characterized plasma was used to induce the surface of different polymers such as Nylon – 6, Ultrahigh Molecular Weight Polyethylene (UHMWPE), polystyrene etc. Plasma gas namely oxygen, nitrogen etc. were used to graft function groups such as C-O, C-N at the polymer surface. The grafted surface has been thoroughly examined using analytical techniques such as Scanning electron microscopy, FTIR, X-ray Photoelectron spectroscopy etc. The selected polymers were used for bone tissue engineering. To enhance the biocompatibility of the polymer surface choice of suitable electron energy and plasma density at an appropriate position in the ECR reactor were found to be decisive parameters to facilitate the chemical reaction on the surface. Effect of total plasma fluence deposited induce proper tuning of surface energy, surface functional groups and surface roughness. The biocompatibility was confirmed by the cellular proliferation and differentiation studies with GMSCs and PBMNCs. Such kind of studies involving surface interactions need to paid attention due to an increased demand for the newly developed materials which are synthesized using advanced techniques and possess potential applications in the field of organ regeneration, antimicrobial activity and tissue engineering.

Invited Talk – 14

Thermal Plasma Technology for Difficult-to-Treat Mineral and its Waste

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Abstract

Industrial mining waste generated by developing and developed countries pose a major threat to the environment. No serious efforts are made for its disposal. Storage in landfills has been used most often in the past, but as more and more of these wastes are being declared hazardous and landfill cost have risen significantly, an environmental friendly method has to be found for treatment of these wastes. The high cost of present disposal is a strong incentive for developing such a process with minimum environmental hazards. Further with the depletion of natural industrial mineral resources and the increasing emphasis on the protection of the environment from the expanding waste generation, it is critical that sustained effort is necessary to develop processes to recover some of the valuable resource from these waste as well as to make secondary products from these for the benefit of mankind. It is with the above theme in mind a systematic approach has been undertaken to find suitable treatment of the large amount of hazardous solid waste generated.

A detailed presentation on thermal plasma process in various fields especially in the field of difficult to treat ores/minerals will be presented. a) Thermal plasma processing of iron bearing waste fines (red mud, over burden, ilmenite, slimes) for recovery of metal values. b) Plasma smelting studies of solid waste effluent from dichromate plants for recovery of metal values c) Plasma smelting studies on sulphide based minerals d) Thermal plasma synthesis of pigments from RE carbonates.

Invited Talk – 15

Decomposition and Decontamination of Industrial Effluents via an Advanced Cold Atmospheric Pressure Plasma Oxidation Technique

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Abstract

Owing to the significance of rapid industrialization, our nation faces a serious environmental problem is the contamination of natural resources especially water bodies. The contamination of water bodied are mainly caused by discharge of dye and pharmaceutical industries waste water into the water resources which contains enormous amount of harmful compounds. Most of the compounds are highly hazardous/ toxin which leads to produce deleterious effects on water ecosystems and adversely affects human health. Hence it is essential to remove the same from their environment [1-2]. Recently various water treatment techniques such as biodegradation, photo-catalysis, electrochemical degradation, UV/H_2O_2 oxidation, membrane processing, ozonation, and plasma treatment etc have been involved to remove the toxic/ hazardous compounds from the wastewater [3]. However, toxin removal is insufficient by means of the above-said water treatment techniques other than plasma. The main intention of the work was to examine the influence of plasma treatment on the mineralization of textile dye and pharmaceutical compounds in the simulated effluents through a novel cold atmospheric pressure plasma reactor. Moreover, various catalysts were also coupled with plasma treatment to enhance the degradation efficiency. Furthermore, demonstrated the inactivation of microorganisms like *Escherischia coli (E-coli)* in water. The treated water will be investigated by various characterization techniques such as gas high-performance liquid chromatography (HPLC), total organic carbon (TOC), UV spectrometry and pH measurements, etc. The toxicity of the plasma-treated water was also examined by in vitro analysis and germination of seeds. Finally, the plasma plasma-assisted technique is essential in various industries as a highly efficient treatment of the waste water before discharging.

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Invited Talk – 16

Plasma Spray Coatings for Pyrochemical Reprocessing of Spent Metallic Nuclear Fuels Applications

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Abstract

The use of metallic fuels is anticipated in future sodium-cooled Fast Breeder Reactors (FBR's). Pyro-processing technology of reprocessing used spent metallic fuels from FBR's using molten salts is suitable for treating advanced metallic fuel cycle with reduced proliferation risk and radioactive waste. Pyrochemical reprocessing is a non-aqueous reprocessing method, which uses high temperature molten salts, LiCl-KCl eutectic, and molten metals at temperatures ranging from 500 to 1500°C in inert atmosphere glove boxes and hot cells. Since pyrochemical reprocessing is a batch process, the structural materials for various unit operations should withstand several batches. The structural materials must be tested for molten salt and molten metal for their applications at high temperatures. Most of the existing metals and alloys are less corrosion resistant in molten salts, and alloys directly cannot be used for molten metal applications due to interaction with the fuel elements. Hence, high-temperature ceramic coatings on the structural materials are essential for applications in molten salts and molten metals. Plasma spraying has been used to develop ceramic coatings on different substrates for pyrochemical reprocessing applications. Yttria stabilized zirconia coating developed by plasma spray for molten salt applications and Yttria coating with suitable interlayer coatings developed for uranium melting applications. This talk discusses the plasma sprayed ceramic coatings developed on graphite and alloy substrates for molten salt and molten metal applications.

Keywords: Plasma spray coatings, Pyrochemical reprocessing, Yttria.

Invited Talk – 17

Plasma Technology in Nuclear Industry

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Abstract

Indian nuclear power program is expected to grow at rapid rate to meet country's ever-increasing demand of electricity. As conceived by Dr. Bhabha, India follows unique sequential three stage nuclear power program which is based on judicious utilization of nation's own nuclear resource. Indian nuclear program encompasses many complex chemical processes which demand a uniform high temperature zone inside the reaction chamber. Because of the availability of electrons, ions, radicals and highly concentrated heat flux thermal plasma technology offers appropriate thermo-chemical environment for any high temperature chemical processes. Availability of ultra-high temperature and enormous heat flux make plasma a powerful tool for any complex chemical conversion process. This paper presents various state-of-the-art thermal plasma assisted processes applied in the field of nuclear science and technology. Of these, one of the important technologies is solid waste management using thermal plasma. Management of solid waste has been regarded as one of the most pressing issues all over the world. Air plasma gasification technology is considered to be the most advanced and efficient technology for processing all types of solid wastes including municipal, hazardous, bio-medical and radioactive waste. One of the vital applications of plasma technology in nuclear industry is the development protective coating using plasma spray process. While, high temperature processing of uranium metal is an important unit operation in nuclear industry, structural materials during processing are exposed to extremely corrosive molten uranium metal. Plasma sprayed novel ceramic coating protects the structural material from the attack of molten uranium. This paper presents comprehensive investigation that has been done in authors' lab over last few years on the development of various novel plasma sprayed coating on graphite and refractory metals for the containment of molten uranium.

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ORAL PRESENTATIONS

Oral – 1

Substrate Level Measurements: Semion made it Easy

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Abstract

Ion bombardment on substrate plays a crucial role in most plasma processing of materials. For instance, in etching process, the etch rate and etched profile are strongly correlated with the total ion energy flux incident on the wafer surface. Therefore, a better process control can be achieved if one can monitor the ion energy flux in a real-time manner to obtain a desired etch profile. Again, the energy delivered to the surface during all kinds of thin film deposition processes including magnetron sputtering, PECVD, ALD etc should also be measured and analysed as they become crucial for the precise control of the structure and related properties of thin film.

Impedans Ltd. offers a smart sensor called Semion for real time measurement of ion flux and ion energy distribution functions (IEDF) impinging on a substrate from plasma. It is a four grid Retarding Field Energy Analyzer (RFEA) and has been extensively used in various plasma processing devices operated with conventional dc, pulsed dc, RF and microwave plasmas. This talk will review the status of Semion sensor applications in diverse plasma processing devices.

Reference

[1] RF Plasma Measurement and Diagnostics - Impedans Ltd.

Oral – 2

Compact High Power Terahertz Source for Plasma Diagnostic, Medical Imaging and Spectroscopy

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Abstract

Terahertz (THz) frequencies (0.1THz to 10THz) that fall between the microwave and the infrared regions of the electromagnetic spectrum are being explored world over for plasma diagnostic in nuclear fusion, spectroscopy and medical Imaging. The molecular resonances of many bio molecules and materials are within THz frequencies and therefore THz spectroscopy provides distinct spectra of such bio molecules and materials. The energy quanta of THz frequencies are much less (tens of micro eV) compared to X-rays, and therefore THz-rays cause no ionization hazard to the biological tissues unlike X-rays that cause cancer. Because of these unique properties of THz waves, i.e., non-ionizing radiation with reduced health risks, molecular resonances that occur in this frequency band and strong absorption of T-rays by water molecules, THz imaging is highly promising for medical diagnosis like early detection of cancer, osteoarthritis, blood test, etc. THz system is also helpful during surgical operation as it provides high resolution and safe imaging. THz spectroscopy is being explored for scientific studies related to many materials and chemicals. Interaction of a broadband THz pulse with plasma is used for measuring plasma parameters such as temperature and density. The most critical component for plasma diagnostic, spectroscopy and medical imaging is the requirement of a compact, high power, high efficiency, broadband, coherent THz source. In recent years, a remarkable growth in the THz technology is carried out world over. Many organisations in our country are also working in this direction. There are many devices for THz generation but these devices fall into three broad categories: (i) laser and photonic (quantum cascade laser, optically pumped molecular laser, etc.), (ii) solid state (harmonic frequency multiplier, monolithic microwave integrated circuit, etc.), and (iii) vacuum (BWO-backward wave oscillator, TWT-travelling-wave tube, gyrotron, etc.). Vacuum devices like BWO, magnetron, gyrotron, TWT are compact sources for generation of THz frequencies with power level from mW to hundred watts and are tuneable over wide band. They use high energy electron beam passing through a special RF structure, for generating coherent THz waves. At CSIR-CEERI, I was working on design and development of a planar 0.22-THz vacuum tube amplifier (TWT) and oscillator (BWO), of RF power output varying from 100mW to 100W and bandwidth more than 30GHz with sheet beam of beam voltage 20kV. Because of the small size of the RF components of a vacuum device at THz frequencies (dimensions in hundreds of microns), micro- and nano-fabrication technologies like UV-LIGA, DRIE, nano CNC machining are used for fabrication of the RF circuits with high precision in better than 1μm and surface roughness less than 10nm. Nano composite high current density cathodes are used for generating rectangular sheet electron beam of size in few hundred μm and beam current up to 100mA. Therefore, these vacuum devices are named as vacuum microelectronic / nano-electronic devices. Details of a micro fabricated THz BWO as a compact source for plasma diagnostic, THz spectroscopy and medical imaging system will be presented.

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Oral – 3

Investigation on Double Layer in a DC Discharge Plasma

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Abstract

An electric double layer (DL) in plasmas is a nonlinear potential structure consisting of two adjacent layers of positive and negative charges which sustains a large potential jump within a small spatial distance. In DL, there exists a strong electric field that causes acceleration of both the electrons and ions [1]. The DLs have been widely studied because of their importance in space propulsion and astrophysical phenomena. These have also been investigated in numerous laboratory experiments using different types of laboratory plasma systems [2].

One of the special ways to produce a DL in a laboratory is near a fireball boundary. A fireball in a plasma is an additional discharge phenomenon that occurs in front of an immersed electrode which is biased far above the plasma potential [3].

In this work, we produce a fireball in a double plasma device to study the double layer structure that is formed at the boundary of the fireball and the background plasma. Plasma is produced in the chamber using filamentary discharge and a planar electrode (~ 1.5 cm in diameter) is used to produce the fireball. The electrode is biased ~ 50-80 V above the plasma potential. The axial potential profile from the bulk plasma towards the electrode is measured with an emissive probe using the inflection point method. The measured potential structures clearly indicate the formation of the double layer at the boundary of the fireball and the background plasma. Characteristics of the DL under different plasma discharge as well as different electrode biasing conditions will be presented.

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Oral – 4

Development of Monte Carlo Collision Module for Particle-In-Cell Code PASUPAT

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Abstract

Particle-In-Cell (PIC) method is a powerful and popular method for simulation of Charged Particle Beams and Plasma. PIC fully accounts for interaction among the charged particle lying outside a computational cell. Inside the same computational cell, however, the force between charges is underestimated in PIC. Thus charged particles located inside same computational cell or charged-particle and neutral interaction needs to be modeled using Monte Carlo method[1]. This approach is popularly known as PIC-MCC[2] method. PASUPAT[3] is PIC code developed at Bhabha Atomic Research Centre, Mumbai. We have developed a software package using Monte Carlo Collision called MCCM for electron interactions to handle collision of electrons with neutral gases/materials. This package is being integrated as a module in PASUPAT. It processes cross sectional data available from IAEA and Plasma Data Exchange Project[4] (LXCat). The module provides application programming interface (API) to electron transport simulation code. A driver code to validate the package was developed and Swarm Parameter (drift velocity) for electron transport under applied electric field in Argon gas was calculated. The simulated results have shown good agreement with the published data[1].

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Oral – 5

Porosity Determination in Fe-Al Weld Joints through Optical Emission Spectroscopy

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Abstract

The manufacturing and automotive industries have significantly benefited from the usage of lightweight metals like aluminum and magnesium in recent years. The necessary strength can be achieved by combining iron with lighter metals. Different metals, such as Fe-Al, provide unique challenges when attempting to forge a suitable connection due to their varying physical and chemical properties. It is essential to understand and quantify the defects that arise during the welding process of dissimilar metals. In this light, we employed noninvasive optical emission spectroscopy (OES) based techniques to quantify the Zn vapor-induced porosity in a welded Fe-Al joint. The study was performed by varying operating parameters such as welding current, welding speed, and electrical waveform. In each case, the OES measurements were recorded using a spectrometer in the 400-800 nm range. Line emissions were observed from Zn-I at 460 nm to 640 nm and Ar-I at 680 nm to 800 nm. The Zn vapor density was estimated using the OES-actinometry technique based on Zn-I emission lines with Ar as the actinometer gas. There was good agreement between OES-estimated actinometry's Zn population density and porosity data produced from an independent technique based on X-ray radiography pictures. A detailed description of the experimental setup, OES measurements, modeling, and data analysis will be presented at the conference.

Keywords: Optical emission spectroscopy, GTAW process, Fe-Al joints, Zn-induced porosity, X-ray radiography.

Oral – 6

Optical Emission Spectroscopic Investigations for Understanding Growth Mechanism of Arc Plasma Synthesized Nanocrystalline Rare Earth Hexaborides

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Abstract

Optical emission spectroscopy (OES) is one of the important tools for investigating the nature of evaporated species as well as temperature of the plasma [1].In the present work nanocrystalline rare earth hexaborides (RB_6) have been synthesized using arc plasma gas phase condensation route. Effect of variation of plasma forming gas on the synthesized nanocrystalline RB_6 was observed and thoroughly investigated with the help of OES [2]. The nanocrystalline RB_6 shows different crystallographic signatures when synthesized using nitrogen and argon plasma respectively keeping all other synthesis parameters identical. Temperature of the nitrogen plasma was found to be around 11000 K whereas it was around 7000 K for Ar plasma. OES investigations show presence of distinct lines for evaporated species of rare earth element and boron which suggest dissociation of precursor microcrystalline RB_6. In addition, variation of particle size was also observed which is attributed to different evaporation and diffusion rates in N_2 and Ar plasma caused due to different temperature profiles of N_2 and Ar plasma columns. Furthermore, electron emission properties of these synthesized nanocrystalline RB_6 were investigated to explore them for electron emission applications.

Acknowledgement:
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Oral – 7

Thermal Plasma Synthesis of Silicon carbide from Solar Waste Panels

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Abstract

The generation of electronic waste has increased dramatically due to the quick development of technology, urbanisation, and shorter life spans of electronic equipment. An environmentally friendly and resource recovery methodology is critically required for existing scenario to recycle electronic waste. Recycling, reuse and recovery of discarded or dysfunctional equipment represents secondary sources of metals that can be used in the manufacture of the same or similar products, thus avoiding landfilling. Solar panels waste and compact disc (CD) are the key components among e-waste and is considered to be the most problematic waste to recycle due to their heterogenous combination of metal, polymer, and ceramics. This study confirms a sustainable and clean new approach for synthesizing SiC from non-metallic fraction of end-of-life solar panel waste and compact discs (CDs) as reductant carbon resources to produce silicon carbide hybrid using plasma arc melting process. The non-metallic fraction of solar panel indicates 35% of silicon and CD char shows good quality (20%) of carbon. The synthesis is based on carbothermal reduction at 1550 °C. The synthesized product was characterized using XRD, FTIR, SEM and EDS analysis. Results indicated that the silicon carbide hybrid silicon and carbon. Results of this study indicate that plasma arc technology can be effectively applied to convert solar panels and CD waste to silicon carbide hybrid powder and it’s a sustainable solution for recovering resources from solar panel waste and minimizes the utilization of nonrenewable traditional raw materials.

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Oral – 8

Plasma Spray Coated YSZ for High-Temperature Radiative Cooling

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Abstract

External airframe structural segments of high-speed aerospace vehicles are exposed to extreme thermo-mechanical loads arising from turbulent flows, shock waves, viscous dissipation, etc. [1]. One way to mitigate the extreme temperature (>1000 °C) in the external airframe is by applying a coating with high thermal emissivity (ε). High emissivity coatings reduce the surface temperature of the airframe by radiating the heat energy to the freestream atmosphere [2]. Air plasma spray (APS) is a relatively cheap, scalable technique for coating deposition that does not require a secondary heat treatment [3]. However, there is limited focus on ε measurements/improvements of thermal barrier coatings developed using the APS method. In this study, a topcoat of yttria-stabilized zirconia (YSZ) with a thickness of ~350 µm is deposited on Ni-superalloy (35 mm x 35 mm x 2 mm) with a NiCrAlY bond coat (~50 µm) by APS. The thermal emissivity of the as-deposited coating is measured using a Fourier transform infrared spectrometer and an emissometer operated at 82 °C. The bond coat improves the ε of the substrate from 0.34 to 0.42, and the topcoat further enhances the ε to 0.85. Also, the bi-layer coating stack exhibits excellent phase and thermal stability without considerable variation in ε when annealed at 1100 °C in air. Thus, the developed coating shows potential for radiative cooling in the airframe of high-speed aerospace vehicles. The results indicate an opportunity for further increasing the emissivity by optimization of plasma spray parameters.

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Oral – 9

Cold Plasma Treatment for Extending the Shelf Life of Soya Chunks

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Abstract

Microbial contamination of food causes social and economic burdens on health care. So food safety remains to be a critical health issue today. The fungal decontamination occurs in dry food systems with low water activity. Among several approaches cold plasma treatment act rapidly against molds without affecting the quality of the food product. Thus non thermal plasma treatment is a promising intervention in food processing to boost product safety and extend the shelf-life. The proximate composition analysis of untreated and plasma treated soya chunks were studied to improve the shelf life of soya chunks.

Oral – 10

Production, Characterization and Application of Plasma for Coriander Seed Germination

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Abstract

Coriander is the most used kitchen item in Nepal which has high health benefits. It is used in the kitchen due to its fragrance and taste it gives to food. Gliding arc discharge air plasma and dielectric barrier discharge (DBD) has a high range of application in diversified field. An AC power source with a 10 kV potential difference and a 30 kHz frequency is used to produce the plasma. Plasma is characterized by optical emission spectroscopy and I-V characteristics. The average value of excitation temperature of electron calculated for gliding and DBD using Ratio method is 7.98 eV and 5.11 eV respectively. The density of the electron in gliding is 9.60 ×1020 cm^{-3} and DBD is 1.05 × 1016 cm^{-3}. Coriander seeds are treated by both DBD and gliding arc. It is seen that temperature of seed increases with the treatment time. Moreover, on weighing the seeds, it is observed that weight of seeds goes on decreasing with the increase in treatment time. That means weight loss is increased with treatment time. Further, wettability is also measured from which it was concluded that seeds become more hydrophilic after the seeds are treated. Seeds were cultivated after treatment by plasma in different time. Germination rate is calculated on sixth and ninth day when treated with gliding arc. Germination rate is found to be high for 8 minutes treated seeds in both days. In addition, shoot length and root length of the coriander plants are measured with the ruler in the 12th day of germination. Shoot length is found to be longer for 8 minutes treated seeds while root length is found to be longer for 10 minutes treated seeds. Additionally, this time when the seeds are treated using DBD, there is no germination seen of untreated seeds until 22nd day. Germination rate is same for 2 minutes, 3 minute and 5 minutes treated seeds in 22nd day. But for 29th day, germination rate is high for 5 minutes treated seeds.

Oral – 11

Cold Plasma to Improve Pearl Millet Seed Germination and Plant Growth

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Abstract

In this work, we investigated the impact of atmospheric pressure dielectric barrier discharge (DBD) on water activation and pearl millet seed germination/plant growth. For water activation, a cylindrical double dielectric barrier discharge (D-DBD) reactor was utilized. And for seed treatment, a cylindrical DBD reactor was used. We evidenced that 30 min plasma treated pearl millet seeds have exhibited higher germination rate than the control seed. The HR-SEM study revealed that the plasma treated seed surface has been significantly modified at room temperature. Moreover, it was observed that the water contact angle decreased for plasma treated seeds (50%) and the water uptake also increased considerably. These finding indicate that the seed surface has turned more hydrophilic. The 20 min of plasma treatment in water the pH decreased to 4.5, and leads to production of moderate amounts of nitrate (NO_3^-) and hydrogen peroxide (H_2O_2). Interestingly, the plasma activated water (PAW) had shown considerable influence on germination and plant growth as compared to tap water (TW) and distill water (DIW). Remarkably, when PAW and plasma-treated seeds (20 and 30 min) were combined, a beneficial impact in seed germination (95 ± 2%) and seedling growth have been evidenced. These findings demonstrate that the proposed cold plasma reactors might be utilized to boost seed germination and plant growth.

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Oral – 12

Antimicrobial, Agriculture, and Aquaculture Applications of Plasma Activated Water

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Abstract

The present work discusses the applications of plasma-activated water (PAW) produced using a dielectric barrier discharge pencil plasma jet (DBD-PPJ). The air plasma produced in DBD-PPJ is characterized using a voltage-current waveform. The generated plasma species/radicals are identified using optical emission spectroscopy. The PAW is characterized by studying the physicochemical properties and reactive oxygen-nitrogen species [1]. The antimicrobial efficacy of PAW is studied on bacterial species (*Staphylococcus aureus* and *Pseudomonas aeruginosa*) and fungi species (*Candida albicans* and lemon spoilage fungi). The results reveal that interaction of PAW with these microbes substantially reduce their growth. The morphological study, fluorescence microscopy, and UV visible spectroscopy show that PAW exposure to microbes rupture the membrane integrity of these microbes due to which their growth inhibition occurs [2,3]. The agriculture and aquaculture applications of PAW are explored on pea (*Pisum sativum* L.) and freshwater algae (*Chlorella sorokiniana* and *Chlorella pyrenoidosa*). The interaction of PAW with pea seeds enhances the germination rate, plant growth, agronomy traits, nutritional value (soluble sugar and protein) and antioxidant enzyme activities. This is due to removal of waxy structure that naturally occurs on pea surface and as results improve the wettability of pea seeds [4]. The PAW is used as a nitrogen source in Bold's Basal medium to study its effect on algae growth. The results confirm that PAW-grown algae have high growth, chlorophyll content, soluble sugar and protein, and low antioxidant enzyme activities compared to control. Hence, it can be concluded that PAW has enormous potential to be used for antimicrobial, agriculture, and aquaculture applications.

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Oral – 13

Self-Organized Ordered Nanoparticles Arrays for the SERS Applications

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Abstract

Ion beam extracted from the plasma sources have various applications in nanofabrication technology. By providing energy to the Argon ions in the plasma Ar^+ ion can be extracted and can be used for ion irradiation applications. Ar^+ Ion-induced nanopatterns are useful for plasmonic applications as they can be used for making condensed nanoparticle arrays as low as 20nm by varying ion energy and fluence. Changing the array's periodicity and interparticle gap plays a vital role in Surface Enhanced Raman Spectroscopy (SERS), as the electric field (due to the light interaction) between the nanoparticles increases drastically with decreasing interparticle gap [1]. Thus, the electric field enhancement enhances the Raman signal of the probing molecule lies in between nanoparticles and helps in its detection. In this work, we present a two-stage process for the growth of highly dense nanoparticles on nano-rippled templates. The first one is the fabrication of self-organized ripple patterns on Si surfaces using low-energy ion beam irradiation. The next step is the PVD growth of metal nanoparticles at glancing angles on ripple patterns. We prepared Ag, Au, and Ag-Au core-shell nanoparticles grown on these nanoscale ripple patterns for SERS-based sensing of various complex analytes molecules including dyes and pesticides using 532 nm and 785nm excitation lasers [2,3]. Using these SERS substrates, we have successfully detected the dichlorvos pesticide up to 1 ppm concentration which is below its recommended level [3]. We will also present the detection of some adulterants in food using these ordered nanoparticle arrays. Our experimental results are qualitatively compared with FDTD (Finite Difference Time Domain) based simulations where the effect of interparticle gap and Au-Ag layer thicknesses SERS enhancement are explored. This study can be useful in the SERS-based detection of ultralow concentrations of analytes molecules [4].

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Oral – 14

High-rate Synthesis of Stoichiometric and Hydrogenated Molybdenum-oxide Nanomaterials by One-step Plasma Techniques, for Dye Adsorption and Treatment of Cancer

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Abstract

High-rate synthesis of molybdenum-oxide nanomaterials with controlled phase structure and stoichiometry, by a clean and single step technique, is still considered to be a challenge. We here report a plasma method, where an expanded plasma jet populated with atomic oxygen radicals engulfs a large molybdenum target, leading to rapid surface oxidation and sublimation of the oxides [1], from which grey coloured, hierarchical, well-crystalline nano flake/ribbon like α-MoO_3 is produced maximum up to 750 g/h. This as-synthesized nanomaterial characterized with a large negative Zeta potential (-53 mV), adsorbs cationic methylene-blue dye from an aqueous solution maximum up to ~1044 mg/g. During a second experiment, dark blue coloured, nano flake/ribbon like, non-stoichiometric, plasmonic molybdenum-oxide (MoO_{3-x}) is generated by a one-step, combined plasma synthesis and hydrogenation process, up to 194 g/h. In-situ hydrogen injection into the plasma chamber produces low energy but highly reactive H radicals that intercalate in to the nucleated oxide crystals, leading to creation of controlled surface oxygen vacancies. They are stable against oxidation under atmospheric exposure, perfectly dispersible in a solution even without a surfactant, and characterized with intense absorption of light over the near-infrared attributed to the localized surface plasmon resonance (LSPR). Surface oxygen vacancy in α-MoO_3 and the controlled hydrogenation in photonic MoO_{3-x} endow these nanomaterials with robust room-temperature ferromagnetic behaviour (Maximum saturation-magnetization 6.58 emu/g). Being ferromagnetic, the nanoadsorbents may be separated from wastewater by a simple magnet after adsorption process. *In-vitro* experiments confirm that the photonic, hydrogenated molybdenum oxide nanomaterials may be most ideal for treatment of superficial cancer through the NIR photothermal therapy. They are perfectly compatible in physiological environments, and can be manipulated with a magnetic field for targeted delivery to a tumour. Their degradation behaviour ensures that the nanomaterials are easily excreted, avoiding long term toxicity to other body parts.

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Oral – 15

An Experimental Study on Abatement of Oxides of Nitrogen (NOx) & Volatile Organic Compounds (VOC) using Pulse Powered Dielectric Barrier Discharge Plasma Hybrid Technique

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Abstract

A detailed experimental study is conducted at laboratory level to simultaneously treat NOx, Volatile Organic Compounds(VOC) & CO present in stationary diesel engine exhaust using pulse powered Dielectric Barrier discharge Plasma hybrid Technique(PDBDH). The main objective of the present research is to investigate the effect of type of reactor, electrode configuration & exhaust composition on abatement of NOx, VOC & CO using pulse powered Dielectric Barrier discharge. Experiments are carried out with different dimension of reactors, rod and wire electrodes and filtered and raw exhaust. Two types of plasma hybrid configurations have been studied. In the first hybrid configuration materials like activated alumina, alumina coated with silver nitrate and redmud in the form of balls are packed inside the plasma reactor. This configuration is used for NOx treatment. In the second hybrid configuration VOC is treated first by plasma & then by red mud acting in cascade. The Packed bed reactor filled with activated alumina coated with silver nitrate shows a high NOx removal performance of about 95% while the cascade plasma configuration shows a VOC removal of about 80%.Finally results were tabulated & a comprehensive comparison of NOx/VOC removal by different configurations/techniques is made and further the effect of type of reactor, electrode configuration & exhaust composition on abatement of NOx & VOC is discussed.

Keywords: pulse powered Dielectric Barrier discharge Plasma hybrid Technique (PDBDH), NOx, VOC & CO

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Oral – 16

Effect of Air in Submerged Thermal Argon Plasma on Degradation of Pharmaceutical Antibiotic

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Abstract

Pharmaceutical waste especially antibiotic residues have become potential pollutants that are being detected in waterbodies all over the world [1]. They are toxic, persistent, and bio accumulators whose continuous exposure can have an adverse effect on human health as well as aquatic life. Their presence even in small quantities in the waterbodies can disrupt the microbial population, leading to genetic mutations and an increase in their antibiotic resistance [2]. Therefore, this is the need of the hour to effectively eliminate these antibiotic residues from the water waste before discharging them into the environment. Over the past few decades, submerged thermal plasma has emerged as an effective technology for the degradation of organic pollutants [3]. In this study, the effectiveness of the submerged thermal plasma generated from a non-transferred arc plasma torch is studied for the degradation of a widely used antibiotic ciprofloxacin. Effect of introducing air into the argon plasma on the degradation of ciprofloxacin in aqueous medium was studied in detail. The electron density, plasma temperature and various reactive species generated in the plasma jet are studied from the optical emission spectroscopy. The degradation efficiency and the mineralization percentage are evaluated using UV-Vis spectroscopy and the total organic carbon (TOC) analysis respectively. Detection of various intermediate compounds formed during the degradation process is done from Liquid Chromatography-Mass Spectroscopy (LC-MS) analysis. The degradation efficiencies of CIP in submerged thermal plasma for different ratios of Argon/Air plasma gas compositions such as ArA (25:0 slpm), ArA5 (20:5 slpm), and ArA15 (10:15 slpm) are 67%, 90% and 84% respectively within 15 minutes of treatment time. The addition of Air in thermal Argon plasma increased the degradation efficiency. Mineralization efficiency of ArA5 (31%) is greater than both ArA (16%) and ArA15 (25%). Results reveal that the submerged thermal plasma is a potential tool for the effective degradation of toxic pharmaceutical pollutants in wastewater.

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Oral – 17

NF_3 Plasma Based Surface Etching Process – An Extended Utilization towards Nuclear Industries

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Abstract

Plasma based etching process are utilized in various technological purposes such as integrated circuit formation, chamber surface impurities cleaning, vertical nanostructure arrays formation, etc. [1-3]. The further utilization of plasma etch process can be extended to the nuclear industries for removal of uranium from surface of transuranic steels rad-waste which resultant in the ultimate reduction in the classification of the rad-waste [4]. The plasma treatment reduces the rad-waste storage cost drastically since it depends on the classification. Institute of Plasma Research is also working on the material etch process using the NF_3 glow plasma. The work included here is covering the NF_3 based plasma process for surface etching. The experimental and simulation of NF_3 plasma etching process using the silicon wafer samples has been included here. The silicon etch process are quite similar to the uranium etch process both generates the volatile species which will bring the silicon or uranium atom from the surface. The entire plasma chemistry model generated for the silicon etch process using the CHEMKIN tool has been covered here. All probable species generated in the NF_3 plasma and their reactions with silicon samples are modelled in the tool. The thermodynamic properties and rate constants are included to develop the etch process model. The etch rate results are compared with the experimentally observed results. The work will gives the more control and reliance on the process for the further applications. Moreover, the chemical model of volatile species formation on the uranium oxide contaminated surface using the NF_3 plasma has bene also included. The work will support in futuristic enhancement of plasma etching for the transuranic radioactive waste treatment.

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Oral – 18

The Quantum Dusty-Plasma Molecules in Astrophysics and Newer Kinds of Plasmas

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Abstract

The Cosmic Rays flung out of exploding gigantic stars as dusty-plasmas have an impact on our Earth and, a new research from Denmark found that Supernova releases ions which rain down on Earth's atmosphere seeding the atmospheric clouds.

In fact, in my suggestion, that the Astrophysics Quantum Dusty-Plasmas are remarkable that in their interactions play a role to produce, ordinary Plasmas of degree of ionization of order 10^-6 to 10^-7 in the terrestrial Atmospheres.

I find that the magnetic fields present in the universe (Highest in Neutron Stars of 1.6 Billion Tesla) and celestial bodies, utilize the low-temperature Plasmas to develop "Plasma Molecules" and these metastable particles that endure enough time to react, with normal designated molecules. The Quantum Plasmas of Astrophysics, the Condensed Matter Physics evolves the motions of Spinning Quantum Plasmas and Quantum Dusty-Plasmas. These Complex plasmas, play an important role in Astrophysics, and in intergalactic matter, as well in Science and their Applications in Technology.

POSTER PRESENTATIONS

Poster – 1

Generation of Ion Acoustic Wave Instability by a Gyrating Ion Beam in a Plasma

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Abstract

A Gyrating ion beam propagating through a magnetized plasma containing electrons, positive ions (K^+) and heavy negative $(C_7F_{14}^-)$ ions drives ion-acoustic waves to instability via Cerenkov interaction. Two ion-acoustic (IA) wave modes: a fast (K^+) mode and a slow $(C_7F_{14}^-)$ mode in the presence of positive and heavy negative ions are observed in the plasma. Numerical calculations of the phase velocity of the sound wave, unstable mode frequency and the growth rates for both the modes have been carried out for the typical existing laboratory parameters. It is found that the growth rate and unstable wave frequencies for both the IA wave modes increase with the increase in relative density of heavy negative ions. Moreover, the growth rate scales as one-third power of the beam density and the phase velocity of the fast mode increases with the increase in the concentration of heavy negative ions. There is a considerable effect of increase in magnetic field and the azimuthal mode numbers on the growth rate of unstable modes. The growth rate of fast (K^+) mode increases more rapidly with magnetic field as compared to the slow mode $(C_7F_{14}^-)$. Our work may find applications in the space, laboratory as well as in astrophysical plasmas.

Keywords: Gyrating beam, Growth rate, Cerenkov interaction, Astrophysical plasma.

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Poster – 2

Effect of Magnetic Field on the Dissociation of Nitrogen Molecules in Radio-Frequency Discharge

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Abstract

Optical emission spectroscopy (OES) is performed in pure nitrogen RF plasma which is produced by a half helical antenna at a driving frequency of 13.56 MHz. The detailed variation of vibrational temperature (T_V) is calculated by taking Boltzman plot of selected peaks from N_2 second positive system [C $^3\Pi_u$ (ν′) → B $^3\Pi_g$ (ν″)] as well as the rotational temperature (T_r) measured by analyzing N_2 first positive (2–0) system, are compared with respect to applied RF power and external magnetic field (up to 400 G). The vibrational temperature (T_V) shows a distinct jump when the magnetic field is changed from 0 G to 200 G. This jump of T_V is almost twice of its value measured at 0 G field. But when the magnetic field is varied from 200 G to 400 G, this jump in T_V is negligible with respect to the applied RF power varied from 400-1500 W. The rotational temperature (T_r) however, shows almost an opposite behaviour with its value being maximum at zero magnetic field and thereby decreases with the increase in the magnetic field values. As T_V increases from nearly 1500 K to 3000 K with the application of the magnetic field, it is estimated from our calculation that the dissociation fraction, which is the ratio between the number of nitrogen molecules that are split to the initial number of nitrogen molecules, decreases almost similarly with its maximum value being 0.95 at 0 G field and 0.57 at 300 G field at an RF power of 1500 W. This result therefore, portrays that for application oriented work where atomic nitrogen is highly desirable, the nitrogen RF plasma with no magnetic field suits the purpose most effectively.

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Poster – 3

Understanding the Evolution of Cross Field Diffused Plasma across a Transverse Magnetic Field in LVPD-U

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Abstract

Moderate density (~ 2- 6x10^{11}cm^{-3}), low temperature plasma (~ 2-5 eV) is produced in LVPD-U by making use of a large area multi-filamentary plasma source. The LVPD-U [1] embeds a solenoidal shaped magnetic filter, called electron energy filter (EEF) at its axial centre. The EEF produces a strong, uniform transverse magnetic field of ~ 150G [2]. It divides LVPD-U plasma into three distinct regions of source, EEF and target plasmas. The plasma produced in LVPD-U is radially confined by an axial magnetic field of 6.2G, produced by a set of 10 coils, garlanded to LVPD-U. The activated EEF develops an interesting scenario of cross-field transport of magnetized plasma due to its uniform transverse magnetic field. The physical presence of EEF not only provides a capacitive sheath to the interacting plasma but also, imposes a barrier to high energetic electrons with a strong transverse field once activated [3]. The paper will discuss various characteristics of evolved plasma under two imposed conditions on EEF namely; 1) different radial extent of EEF activated and 2) the ratio of EEF field to ambient field is varied. Various characteristic features of evolution of cross-field diffused plasma under the imposed conditions will be discussed.

Poster – 4

Compact Dense Plasma Focus Device as Multi-radiation Source for Applications

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Abstract

A compact Dense Plasma Focus (DPF) device (0.5m × 0.5m × 1.2m, weighing ≈100 kg) that is driven by 2.5kJ/200kA pulsed power system has been developed at ESDS, Pulsed Power & Electromagnetic Division, BARC Facilities, Visakhapatnam. When fuelled with Deuterium gas, this device produces D-D fusion neutrons having energy of 2.45MeV in 4πsr for the typical pulse duration of 35-50 ns. This fast pulsed neutron generator has been built and operated at much lower cost and less shielding requirements when compared to accelerator based neutron sources and it is an attractive alternative for analyzing bulk materials by Neutron Activation Analysis (NAA). An average neutron yield of $(2.5\pm0.5) \times 10^8$ neutrons per shot is routinely obtained from this device and it is being frequently used for testing and calibration of wide range of fast and thermal neutron detectors. This device is not only a source of high density ($\approx10^{25}$ m^{-3}) and high temperatures (≈1keV) plasma but also a rich source of high energy ions, electron beam and X-ray that are being used for surface modification of materials, thin film deposition and flash-radiography applications. Material/thin-film deposition using DPF device has a unique feature of higher deposition rate than other deposition techniques. For these applications, DPF is fueled with Argon/Hydrogen gas with typical pressure in the range of 1-5 mbar. Thin films (of Al, C and Ti) were deposited on silicon substrate with corresponding solid materials capsulated on top of the central electrode (anode) of this device. Multiple plasma focus shots were performed with Argon gas to reveal the thin-film deposition growth with subsequently increasing number of shots. The scope of this paper is to showcase the potential usage of DPF device as pulsed energetic multi-radiation source for nuclear and non-nuclear applications including nano-technology.

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Poster- 5

Experimental Observation of Non-Planar Dust Acoustic Solitary Wave

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Abstract

Solitary waves have been successful in arresting the attention of mankind ever since its first observation in water and its subsequent observations in variety of nonlinear dispersive media. However, so far all of the experimental observations of this long-standing wave in dusty plasma have been confined to a single plane [1, 2] which might not be a realistic situation as waves are seldom confined to one dimension. Here we report the observation of stable non-linear waves of such kind in a non-planar geometry. The experiment is performed in a strongly coupled dusty plasma that contains monodisperse micron sized dust particles. The massive dust particles are levitated (by balancing gravitational and sheath electric field force) above an electrically grounded stainless-steel plate inside a vacuum glass chamber. For the excitation of the non-planar waves, a cylindrical conducting pin is placed at the center of dusty plasma medium. On application of the negative excitation pulse, the dust particles surrounding the pin moves away creating a dust void. From the void boundary, a outward moving density perturbation propagates which finally evolves as a nonlinear cylindrical dust acoustic solitary wave. The propagating non-planar wave fronts are video recorded using a high-speed camera (30-100 fps) under laser illumination. The videos are converted into frames at constant time interval for analysis. The velocity, width and amplitude of the wave are measured as a function of excitation parameters. It is observed that with increase in wave amplitude (controlled by the excitation voltage) the velocity of the wave increases and simultaneously the width of the wave decreases. This confirms one of the characteristics of the solitary waves.

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Poster – 6

Characterizations of Non-Thermal Deuterium Ions Produced in 3.1 kJ Plasma Focus Device

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Abstract

Plasma focus (PF) device is a copious source of high energetic radiations including ions, electrons, X-rays as well as neutrons. They have been characterized for use in many applications and to understand the dynamics of its emission [1]. Mechanism behind acceleration of ions to high energies (up to several hundred keVs) at a low input voltage of a few kVs are yet to be fully understood. An indigenously developed 3.1 kJ PF device [2] has been operated to study ion emission characteristics and its correlation with plasma pinch characteristics such as pinch voltage, pinch time etc. Ion characteristics such as peak ion density, ion fluence, most probable ion energy etc. were calculated using ion pulse registered in Faraday cup, placed axially at 6 cm from the anode tip. The pinch characteristics were studied through measurements of pinch voltage and discharge current using aqueous copper-sulphate solution based voltage divider and Rogowski coil respectively. The 3.1kJ PF device was filled with deuterium gas at different pressures and operated at 2.0 kJ (10 µF, 20 kV). Typical peak ion density and ion fluence were calculated be 8.6×10^{18} per m^3 and 1.2×10^{18} per m^2 respectively at 4 mbar of D_2 gas filling pressure. Most probable deuterium ions energy was calculated to be typically around 15 keV. Moreover, maximum ion energy was measured to be in the range of 500 to 700 keV. The pinch voltage was measured to be typically around 25 kV with typical FWHM of 15 ns. Higher experimentally observed deuterium ion energy than that of calculated using pinch voltage i.e. 25 keV could be due to acceleration of ions by some additional mechanisms such as instability enhanced high electric field post plasma focus disruption. Details about the experimental set up and experimental observations will be presented and discussed.

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Poster – 7

Indigenous Development of RF Source for Plasma Generation

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Abstract

ACnD, BARC has indigenously developed an automatic impedance matching & auto-igniting 200W plasma source tunable from (2-30) MHz.The system has been integrated and tested with hollow cathode type atmospheric pressure cold plasma device at L&PTD, BARC. The auto-matching system which had to be imported at a premium cost has been developed in house including the high power components.

The system consists of a (2-30) MHz, 200W wide band RF Power source integrated with automatic impedance matching network. RF input signal to RF source has been generated by Direct Digital Synthesis, which has a dynamic range of 31.5dB. Wideband RF power amplifier has been developed so that plasma can be generated at both **13.56 MHz** and **27.12 MHz**. Adequate protection has been provided for the RF source against over drive, over temperature and high reflected power. The important parameters of RF source are displayed on the local panel, including forward, reflected power, temperature, drain voltage and current. These parameters are accessible remotely using ethernet controller.

The automatic impedance matching network is realised by an indigenously developed tunable LC network. The high power RF air core variable capacitors and inductor have been developed in house. The value of the capacitors are varied by driving geared stepper motors. An algorithm has been developed for the measurement of load impedance and control of matching network which ensures matching to a 50 ohm load. The control algorithm for auto-impedance matching may be tuned for other potential applications also.

The system was integrated with three different hollow cathode atmospheric pressure plasma devices, having effective plasma generation area of ~16 cm^2, ~ 50 cm^2 and ~ 80 cm^2 at L&PTD, BARC and it was seen that, the generated plasma remained stable against load variations. This paper discusses design and development details of the RF source for plasma devices.

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Poster – 8

Effects of Toroidal Magnetic Field Strength on ECR Plasma in Small Aspect Ratio Device Starma

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Abstract

The characteristics of the electron cyclotron resonance (ECR) produced plasma is reported here in a low aspect ratio device STARMA. The plasma has been produced using a 2.45GHz magnetron source. The 2.45GHz source requires magnetic field of 875G for fundamental mode breakdown[1]. The toroidal magnetic field is varied temporally and the ECR produced plasma is studied as the radial location of ECR region also varies temporally.

The diagnostics employed in these studies mainly comprises of Langmuir probes (LP) and visible fast camera. The single LP is used to measure I-V characteristics of the plasma at a fixed radial location, using which electron density and temperature of the plasma is estimated. Triple Langmuir probe is also used to measure the temporal evolution of electron density and temperature at a given radial location. The probes are moved radially to measure the radial profile of the plasma parameter from shot to shot

Experimental results shows formation of ECR plasma with peak plasma density of ~ $7 \times 10^{16}\ m^{-3}$. The temperature of the plasma is around 10eV. The radial profiles shows that the peak density is not at the ECR layer location but shows a spreads between upper hybrid resonance (UHR) and the ECR layer. These radial profiles confirms mechanism of plasma production employing the O–mode to X-mode conversion[2,3] and further from X-mode to EBW mode conversion. The equal density contours plot in the poloidal cross section, shows the substantial increase in the density, more towards the inboard side (a<0) and our studies indicate that it may be attributed to the density scale lengths (L_n) in the radial locations where it is observed that L_n is much lower at high filed side compared to low field side.

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Poster – 9

Design & Development of Large Area Atmospheric Pressure Hollow-cathode Cold Plasma: Parametric Variation of Etching Studies Aimed at Radioactive Decontamination

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Abstract

Large area atmospheric pressure cold plasma is in serious demand for several applications ranging from materials science to medical industry. Among the large area atmospheric pressure cold plasma sources, dielectric barrier discharge (DBD) and hollow-cathode (HC) type of sources are popular ones. Although DBD might have gained more attention due to its design simplicity and sturdiness for large area plasma generation, HC type of sources produce more uniform plasma over large area due to absence of streamers. Here, we have designed and developed a radio-frequency hollow cathode (RF-HC) plasma device with an aim of large area plasma based chemical etching. We have already used a similar type of device for deposition of carbon nanostructures and sterilization of surfaces [1, 2]. The main design perspective in this case was to make the electrode design simpler compared to the earlier model used and make the device free of any cooling requirement [1, 2]. The present device used an electrode with 0.5 mm holes instead of 0.25 mm spiral groove used in the earlier version and it does not need any water cooling.

This device has been used in experiment of parametric variation of plasma etching on Ta substrates. Ta substrates specifically chosen as it is a surrogate of actinide Pu. Ar gas was used for initial plasma generation in three separate flow rates (15, 20 and 25 LPM). $Ar/CF_4/O_2$ plasma has been used in these experiments for etching where $CF_4:O_2$ ratio was kept fixed at 1:1but their %flow rate was varied as 0.07, 0.1 and 0.13 with respect to the Ar gas flow rate. Each experiment was conducted for 15 minutes and etching rate was calculated as ($\mu g.cm^{-2}.min$) by measuring area and weight loss of Ta substrate. It was seen that etching rate ~ 83 $\mu g.cm^{-2}.min$ was routinely observed in most of the cases, during experiments. Etched substrate was also studied by scanning electron microscope (SEM) and plasma was characterized by optical emission spectroscopy (OES) for further understanding. SEM shows formation of pits, crevasses in the substrate surface as expected due to aggressive chemical etching. The OES study did not find any signature of F in the plasma; probably meaning that F_2 / F generated due to dissociation of CF_4 inside plasma undergoes collisional de-excitation instead of radiative one due to abundance of Ar (> 99.86% in every case) inside plasma.

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Poster – 10

Study of Multi-component Plasma Sheath in Presence of Charged Dust Species and External Magnetic Field

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Abstract

Study of the plasma sheath dynamics containing nano sized dust species along with two species of positive ions (He^+ and Ar^+) [1,2] is reported in presence of a finite external magnetic field. The impact of charged dust species on ions densities and velocities inside the sheath are investigated. The dynamics of sheath potential and space charge are also investigated in presence and absence of dust species. A Multi-fluid model is used to study the above mentioned sheath parameters in presence of external magnetic field. The numerical results show that, in presence of dust species both the species of ions are accumulated/peaking near the sheath edge. Further, with the increase in magnetic field strength, the peaking of ion densities near the sheath edge are observed to be intensified. It is also noticed that, the space charge accumulation become sharper when charged dust particles are present inside the sheath and the sharpness of the peak increases with the presence of magnetic field. The sheath potential is also behaving in a similar way. A brief explanation of the phenomenon that occurs due to presence of charged dust species will be present.

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Poster – 11

Discharge Modes Sustained in a Surface Microwave Generated Plasma in the Presence of Dielectric Beads

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Abstract

MW plasma utilizes the vibrational excitation of CO_2 levels, also called as ladder climbing process, in which only 5.5 eV energy is required to dissociate the C=O bond [1]. Various experiments suggest that employing plasma alone for applications like CO_2 conversion show limitations such as inferior by-products and low efficiency [2]. It is observed that introduction of the dielectric beads in the quartz tube changes the electric field profile in the discharge system and hence may increase the efficiency of the plasma source to some extent [2, 3].
The present study simulates the electric field and discharge modes in a surfaguide plasma tube with the help of COMSOL Multiphysics v5.6 [4]. Microwaves (2.45 GHz) is allowed to pass through a straight WR340 waveguide (guide wavelength, λ_g= 174.2 mm) followed by a tapered waveguide (TW) that carries the plasma tube, made up of quartz (length 250 mm and thickness 6mm). The results suggest that the introduction of dielectric beads change not only the local electric field and hence plasma density but changes the discharge mode as well. A thorough investigation of the effect of dielectric bead density, dielectric constant and the gas flow rate on the discharge mode has been carried out and it is found that ferroelectric beads creates discharge mode suitable for CO_2 conversion applications where there is always a compromise between the energy efficiency and the conversion efficiency of CO_2. This paper discusses recent advances in the use of plasma processes for carbon dioxide conversion, along with the future outlook of this technology and the impact these techniques could have on the chemical and energy industries. [1]. At 1 torr of gas pressure, the electron density increases from 1.1×10^{18} m^{-3} to as high as 8×10^{18} m^{-3} while electron temperature decreases from 1.78 eV to about 1.66 eV, with the inclusion of $BaTiO_3$ beads in the plasma tube – both of these conditions are favorable for efficient CO_2 conversion [5].

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Poster – 12

Implementation of 3D Monte-Carlo Simulations in the Inboard Limited Aditya-U Scrape-off Layer Plasma

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Abstract

The charged plasma particles show distinct properties in open field line region i.e. scrape-off layer region and plasma transportation needs to be understood in SOL for stable operation of magnetic confined fusion devices constituting complex geometries. The 3D coupled plasma-neutral stochastic Monte-Carlo code EMC3-EIRENE [2] is being used for plasma transport study. The Aditya Upgrade version has an inboard belt limiter providing an inboard limited circular plasma. The fresh implementation of the code to simulate coupled plasma-neutral transport provides some interesting features of the SOL plasma relevant to recent observations on the device [4] including a high recycling zone at radial approach to the limiter. At high enough power the configuration supports high SOL density resulting in an inverted parallel pressure gradient and corresponding up-down antisymmetric far-SOL plasma flows directed away from the targets.

Limiter geometry with higher curvature is simulated exploring the relation of this flow to trapping of the plasma by the limiter at larger anomalous radial diffusivity and higher toroidal magnetic fields. While the two effects provide the same sense of plasma rotation they are found to be independent indicating the high ionization to be the possible origin of the far-SOL flows. These results with the first 3D simulation setup for inboard limiter configuration will be discussed.

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Poster – 13

Study of Dust-Charge Fluctuations in Three-Fluid Model of Plasma

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Abstract

We investigate the evolution of ion-acoustic (IA) waves with an admixture of dust in a one-dimensional three-fluid model of plasma consisting of – electrons, ions and dust grains, using a finite difference numerical simulation. The effect of dust particles in the IA wave is incorporated through the dust-charge fluctuations and the dust density is approximated to remain constant in the limit of IA regime. Fluid equations for the model along with the dust-charging equation are derived and simulation for the effect of dust-charge fluctuations is done with relevant parameters for space and astrophysical plasma. The results from the simulation with a comparison to analytical results are reported.

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Poster – 14

Calculation of Electron Impact Excitation Cross Section of Sn II for Plasma Modelling Application

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Abstract

Laser produced Sn plasma is the most promising choice for the next generation extreme ultraviolet (EUV) light source utilized in semiconductor lithography for the fabrication of microchips. Since LIPs are having non-equilibrium nature, suitable population kinetic models must be employed for their characterization. This necessitates the calculation of electron impact excitation cross sections (EIE) of Sn^+ ions as these are required to develop plasma population-kinetic models. No such calculations have been reported yet. The present work calculates the electron impact excitation cross sections for the fine structure resolved transitions in the Tin ion (Sn-II) from the ground states to higher lying states to $5s5p^2$, $5s^26s$, $5s^25d$, $5s^26p$, $5s^27s$, $5s^27p$, and $5s^26d$. The present calculations are performed using the multi-configurational Dirac-Fock (MCDF) wavefunctions and the relativistic distorted wave (RDW) approximation. The calculated oscillator strengths and transition probabilities are compared with the NIST atomic database to validate the reliability of the obtained cross sections. The detailed results, along with methodology and discussion, will be presented at the conference.

Keywords: Laser induced plasma, Electron impact excitation cross section, Relativistic distorted wave approximation, Multi-configurational Dirac-Fock wave functions.

Poster – 15

DC Glow Discharge Plasma with Magnetic Field – Numerical study

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Abstract

DC glow discharge plasma has been used widely for etching, surface treatment, sputtering etc [1]. Various studies have been carried out on DC glow discharge both experimentally and theoretically to understand the discharge mechanism and plasma processes. It is well known that the plasma characteristics can be controlled by the application of magnetic field. Though literatures on the effect of magnetic field on the behaviour of the DC glow discharge plasma are available, the complete understanding on the same is not achieved. In this study, a 2D axisymmetric non-thermal plasma model is developed based on the drift diffusion approach to study the effect of magnetic field on the behaviour of DC glow discharge. To simulate the influence of magnetic field configuration on the plasma behaviour, magnetic fields generated from two current carrying coils are simulated and incorporated in the plasma model. The direction of the coil current is changed to generate magnetic mirror and cusp configurations. Since the charged species are influenced by the magnetic field, the effect of magnetic field on the transport coefficients of charged species is included in tensor form. The behaviour of the DC glow discharge is simulated for two different magnetic field configurations with different coil pitch distances and coil currents. The effect of the magnetic field on the number density of charged species, electron temperature, electrostatic potential and ionization rate is discussed. The effect of magnetic field on the distribution of electrons is not significant in the mirror configuration and electrons are distributed uniformly over a large volume of the plasma, when coils are enclosing the anode in the cusp configuration. From the result, it can be confirmed that the plasma confinement in between the electrodes is stronger in case of cusp configuration.

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Poster – 16

Modelling and Simulation of Ion Extraction System from Laser-Induced Plasma using 2D- Electrostatic PIC code

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Abstract

The present article, explains all the modelling aspects of the ion extraction system from the laser-induced plasma in an electrostatic field using 2D-electrostatic particle-in-cell (PIC) code. The PIC code is a collection of numerical algorithm, which traces the evolution of macroparticles in an electromagnetic field. The macropaticles are weighted particles that curate plasma computationally. In this work, 2D-PIC codes are specifically developed to simulate the ion extraction system. These codes are designed in an object-oriented framework and written in a C++ programming language. The PIC code is not only capable to recreate the experimental result as well creates some additional results, which are impossible to create experimentally. Conventionally, to extract the ions from the plasma using electrostatic field, a parallel plate electrode configuration is used. However, losses in this system is appreciable. Therefore, over the years to improve the performance of ion extraction system, other electrode arrangements are also investigated that are non-parallel plates, wire-type, M-type, Π-type and plate-grid-plate electrode configurations. The objective of these electrode configurations are to create the spatial variation in an electric potential by using electrostatic field. To simulate the ion extraction system using these configurations, one need to model the plasma as well as different physical systems. Modeling of plasma include, assigning weight to the macroparticles, designing of computational mesh, defining particle boundary conditions, defining boundaries for the Poisson's solver and deciding computational step-size. These parameters decides the accuracy and numerical stability of the simulation. Whereas, to model the different electrode configuration one need to tune the Poission's solver as well as particle boundaries as per the physical dimension of the electrode configurations. To understand this, the spatiotemporal evolution of hydrogen plasma of size *1cm* x *1cm*, density $n_0=1\text{x}10^{10}cm$, electron temperature $T_e=0.1eV$ and ion temperature $T_i=0\ eV$ is investigated in an electrostatic field using the above listed electrode configurations. This work can be utilized to understand the ion extraction process, which can be further utilized to design an efficient extraction system.

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Poster – 17

Computationally Efficient Way to Incorporate Electromagnetic Boundary Conditions in Thermal Plasma Modelling

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Abstract

Solving electromagnetic equations with a better description of the magnetic and electric potentials at the boundary is essential in a plasma model, as it provides information regarding the Joule heating and Lorentz force, which are responsible for the actual thermal and flow fields associated with the plasma. The choice of appropriate boundary conditions used for solving the magnetic vector potential equations has become a topic of interest, as it affects the characteristics of the self-induced magnetic field associated with the thermal plasma flow fields. The conventional Dirichlet and null flux boundary conditions imposed on the magnetic vector potential are not ideal for formulating the self-induced magnetic fields in thermal plasma modeling. The magnetic vector potential calculated using the Biot & Savart law is found to provide better description of the electromagnetic and velocity fields associated with the plasma flow. However, the application of magnetic vector potential boundary condition derived from Biot & Savart law is time consuming as it involves numerical integration at each boundary mesh. In the present work, we propose appending an extended domain, where only the electric and magnetic fields are solved, at all boundaries in order to model the self-induced magnetic fields. The self-induced magnetic field and velocity field thus obtained are compared with those acquired from using the boundary condition based on the Biot & Savart law formulation. Finally, relevant implications on the improved computational efficiency are discussed.

Poster – 18

Ion-Acoustic Double Layers in Negative Ion Plasmas with Two Temperature Superthermal Electrons

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Abstract

Ion-acoustic double layers are investigated with two temperature superthermal electrons in an unmagnetized negative ion plasmas. In this study, we have considered the plasma contains two cold ion species with different masses, ion concentration and charge multiplicity, and two superthermal (non-Maxwellian) electrons. The energy integral equation has been derived by using the Sagdeev pseudopotential technique. We have investigated that both negative and positive potential double layers can exist in the domain of Mach number. The formation of compressive and rarefactive double layers (both polarity) is analysed by phase portrait of the dynamic of the plasma system. The present study is focused on large amplitude ion-acoustic double layers in the D-and F-regime of Earth's ionosphere. Present investigations may be helpful to understand the nonlinear behaviour of double layers in space and laboratory plasmas, where negative ions are present with superthermal electrons at two temperatures.

Poster – 19

Spot Measurement of Electron Temperature and Temperature Fluctuations using a Specially Designed Electrostatic Probe

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Abstract

Laboratory plasma devices dealing with investigations of fundamental plasma physics problems requires very handy, easy to fabricate, replaceable diagnostics, which facilitates measurement of plasma parameters viz., plasma density (n_e), electron temperature (T_e), potentials (ϕ_p, ϕ_f) and their AC counterparts. So far, electrical probes e.g. Langmuir probes (single, double and triple), emissive probes [1] are being used extensively in plasma systems to measure and characterize the plasma. Mostly these diagnostics are employed on individual basis for the parametric investigations. In this paper, we will present a new design of diagnostics, developed primarily from the perspective of making spot measurements of electron temperature and its fluctuations. In this diagnostic, we have employed a combination of center tap emissive probe (CTEP) [2] and a single Langmuir probe (SLP) [3], accommodated very closely on a single ceramic mold. The experimental results obtained have validated the proof of principle for direct estimation of electron temperature and temperature fluctuation for a Maxwellian plasma. The paper will discuss the advantages and disadvantages associated with the method and the measurement made for the estimation of electron temperature and temperature fluctuations.

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Poster – 20

Experimental Estimation of Transport Parameters using Microscopic Density Fluctuations of Dusty Plasmas

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Abstract

Motivated by the seminal observation by Landau-Placzek that the variation of density fluctuations in time can be described by the equations of irreversible thermodynamics, we report an experimental method to calculate the transport coefficients of 2D dusty plasma from the microscopic density fluctuations using the analytically derived density autocorrelation function. The experiments are carried out in the capacitively coupled radio frequency Argon plasma. The dusty plasmas are produced by introducing the mono-dispersive micron sized Melamine Formaldehyde particles in the background plasma. The dynamics of dusty plasma are described in the framework of generalized hydrodynamic (GH) model that incorporate strong coupling and viscoelastic memory effects. A hydrodynamic matrix for Dusty plasma systems is derived in the GH framework. An autocorrelation function of the quantities such as density and current can be derived analytically from the hydrodynamic matrix which can be used in various Green-Kubo relations and MD simulations. In the present work, we show a method to obtain the density autocorrelation function (DAF) for Yukawa fluids from the hydrodynamics matrix. We record the space and time dynamics of Dusty Plasma using high speed imaging systems and obtain the Density Autocorrelation functions experimentally. The experimentally obtained DAF is compared with the analytical and numerical results to estimate the important thermodynamic parameters of dusty plasmas. The potential extension of present approach to other fluids has also been discussed along with applications of analytically obtained DAF to Molecular dynamics simulations to estimate thermodynamic parameters of the system.

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Poster – 21

Measurement of Plasma Frequency and Collisional Frequency of Plasma based Microwave Absorber using Microwave Diagnostics – A Simulation and Experimental Approach

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Abstract

Plasma has found its importance in many fields through the understanding of its parameters. Among others, plasma density (plasma frequency) and electron temperature are very important. For using plasma as an efficient microwave absorber, it is imperative to have a measurement of collisional frequency along with above mentioned important plasma parameters. The present work is a two-fold study of plasma parameters i.e., simulation and its experimental validation. A simulation model is designed in CST, Microwave studio to simulate the S-parameters of the plasma tube. Using the simulated S-parameters, permittivity (εr) and permeability (μ) of plasma is calculated. These quantities are then used to calculate the plasma frequency and collisional frequency of the given plasma by using Appleton's equation. A similar experiment is designed to measure the actual S-parameters using a Vector Network Analyzer (VNA). The S-parameters follow the propagation characteristics of the microwave transmission in plasma and measuring the attenuation and phase shift of these waves gives a qualitative information of plasma frequency and collisional frequency. According to the experimental results a plasma frequency of the given plasma system is of the order of 1010 rad/s and collisional frequency is in the order of 1010 Hz which are also consistent with the simulation results.

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Poster – 22

Refractive Index Measurement of Electrically Exploding Wire Pulsed Plasma Using Laser Shadowgraphy

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Abstract

Optical diagnostics like interferometry, shadowgraphy are commonly used to infer electron density of plasmas. Laser shadowgraphy is a simple experimental technique to get qualitative as well as quantitative information about various parameters of plasma like electron density, expansion profiles, and shock wave profiles [1] etc.. To diagnose pulsed plasmas; laser shadowgraphy technique is developed for measuring refractive index of exploding wire plasma. Shadowgraphs have been obtained using an ICCD camera with exposure time of 2 ns and a laser of wavelength 532 nm. A Fortran program is written for calculating spatial profile of refractive index and hence electron density from intensity profile values of images. A capacitor bank with energy of 256 J is used to electrically explode metal (Cu) wires with diameter in range of 25-50 µm. Electron density in 25 µm exploding copper wire with 31 mm length is observed to be around ~$9x10^{26}$ m^{-3}- $4x10^{27}$ m^{-3} at 300 ns; after the start of current in wire; along the length with maximum near anode electrode and minimum around the center of wire. Shadowgraphs are taken at various instants to observe the trend of electron density profiles. Shadowgraphs for 50 µm thick exploding copper wire is also taken and compared with 25 µm thick exploding copper wire; keeping other experimental parameters same. Their electron density profiles and expanded diameters along the wire length are compared using their shadowgraphs. Electron density is found to be higher near anode then at near cathode electrodes whereas it is lowest at center in 25 µm Cu wire in comparison to 50 µm Cu wire at 500 ns. Electron density in these copper exploding wires is found to be in the range of 10^{26}-10^{27} m^{-3}. Apart from observing shadowgraphs at one instant, temporal profile is also observed using streak camera. Expansion profiles of exploding wire plasmas of Cu and W with 25 µm are observed. Expansion velocity is found to be maximum in range of 6-7 km/s initially after ~150 ns of burst which decreases with time in both the metals to around 2-3 km/s after ~2 µs. Developed system is capable of observing spatial profiles of refractive index in exploding wire plasmas along with temporal profiles of exploding wire plasma.

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Poster – 23

Effect of Connection Length on Plasma Dynamics in a Simple Magnetized TORUS

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Abstract

A simply magnetized device (SMT) is a device in which plasma is confined purely by toroidal field. The cross-field drift of particles arising from the charge polarization is the major loss channel in the device, together, the lack of rotational transform prevents the system to be in MHD equilibrium. Whereas a quasi-stationary equilibrium can be realized by applying a vertical field together with the toroidal field or in other words, reducing the connection length $L_c = 2a\left(\frac{B_\varphi}{B_z}\right)$ from infinity to finite values. Different regimes of operation is identified when the applied vertical field was raised above 4 G and below 4G. Dynamics of plasma state under different connection length or applied vertical field is analyzed using time averaged measurements and conditional averaging techniques. Effect of vertical field on intermittent turbulent fluctuations or generally known as blobs are analyzed.

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Poster – 24

Application of Multiple Sensors for Investigating Real-Time Faults during the Smelting Process in an Arc Plasma

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Abstract

Arc plasma is an important technological application for smelting of low grade minerals, melting of scrap metals, synthesis of oxide nanoparticles. During smelting process numerous spontaneous reaction takes place, which often lead to arc fluctuation, arc extinction, and spurt out of molten metal. In this study, smelting of Ilmenite is carried out in an open atmospheric condition at 5lpm argon gas flow rate to investigate any fault occurrence. During smelting process, a sudden burst of molten metal is distributed out of the furnace. The catastrophic action is captured by different sensors equipped around furnace to monitor real-time smelting process. The equipped sensors around the furnace are photodiode, RGB camera, Linear Variable Differential Transformer (LVDT), sound recorder, along with voltage and current acquisition. The statistical features of captured signals are examined to witness gradual change in smelting condition which finally lead to disastrous condition. The statistical analysis includes variation of pixel intensity of captured images, variation in light intensity through photodiode, fluctuation of arc in terms of voltage and variation of sound intensity from the sound recorder. All these processed signals provide sufficient evidence to differentiate the normal process and fatal action occurred during smelting operation. This experimental investigation is the first of its type and was done to track, record and identify any faults as they occurred in real time during the smelting process.

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Acknowledgement

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Poster – 25

Development of Retarding Field Analyzer (RFA) for the Measurements of Atomic Oxygen Ion Energy in an Electron Cyclotron Resonance (ECR) Plasma Chamber

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Abstract

Electron Cyclotron Resonance (ECR) plasma is a cold plasma, in which the plasma species generated due to interaction of microwave radiations with plasma forming gas and resonating magnetic field. Further the plasma species so generated are subjected to magnetic field gradient. It is interesting to identify and analyze energy of individual species. Electron energy analysis of the plasma species generated in a ECR plasma reactor has already been reported by our group [1]. In the present study an emphasis is given on identification and analysis of atomic oxygen ion plasma species. The atomic ion energy distribution of the plasma species generated in an ECR plasma, have been measured by using retarding field analyzer (RFA). An indigenously designed RFA was used for the ion energy analysis. RFA consists of grounded aperture, electron repelling grid, ion retarding grid, secondary electron suppressor grid and collector. The microwave radiation source frequency of 2.45 GHz, resonating magnetic field of 875 G and operating pressure of 0.007 mbar were used during actual measurements. The atomic oxygen ion energy and distributions were determined by changing the axial position of RFA. The experimental data indicates the energy of atomic oxygen ion is greater than 5 eV which agrees with literature [2-5].

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Poster – 26

Estimation of Plasma Parameters by Using a Lock-In Amplifier and Comparison with Compensated Langmuir Probe in a 13.56 Mhz RF Discharge

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Abstract

Capacitively Coupled Plasmas (CCPs) are commonly used in microelectronic industries because of their ability to produce directed ion flux on a silicon substrate for atomic scale modifications such as etching, deposition and sputtering of thin films [1]. The electron population inside the discharge directly impact the impinging ion flux on the substrate due to ambipolarity. However, due to lack of information about anisotropy in the electron distribution, the impinging ion flux and hence the characteristics of the grown film on the substrate cannot be fully understood. The remedy is to obtain the information regarding the electron energy distribution function (EEDF) [2].

In this work, a lock-in amplifier has been used to obtain the EEDF in a 13.56 MHz cylindrical CCRF discharge with the help of a cylindrical Langmuir probe. It is found that the single Maxwellian electron population in the discharge splits in to bi-Maxwellian when an axial magnetic field is applied. The density & temperature obtained from the EEDF has been compared with that measured from the semi-log plot of I-V characteristic of a RF compensated Langmuir probe. The above study has been further carried out for varying gas pressure and RF power. The plausible explanations are given to explain the observed effect.

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Poster – 27

Comparative Study of Positive and Negative Chirp on Stimulated forward Raman Scattering in a Magnetised Density Rippled Plasma, with Application to Inertial Confinement Fusion

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Abstract

Stimulated Raman scattering (SRS) is one of the mechanisms limiting the power scaling in inertial confinement fusion (ICF). In this work, we demonstrate effective suppression of SRS by the combined effects of static density fluctuations and an azimuthal magnetic field with a propagating chirped laser pulse. In the presence of an azimuthal magnetic field, chirped laser pulse propagates through a density rippled plasma and undergoes stimulated forward Raman scattering (SFRS), resulting in two radially localized electromagnetic sidebands waves and a lower-hybrid wave. Absolute and growing modes saturate due to ion density fluctuations, which then suppress instability growth through mode coupling. The modes modified by the combined effect of chirp and azimuthal magnetic field are effectively damped after saturation. As a result, the overall growth rate of the instability reduces. Based on nonlocal theory, we have analyzed the growth of the SFRS for positive and negative chirp and estimate it for ICF relevant parameters and observed the effect of the growth rate.

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Poster – 28

Plasma Assisted Ignition and Combustion of Pulverized Coal

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Abstract

In coal fired power plants, initially the furnace is preheated (startup) up to coal ignition temperature using oil fired burners. These oil fired burners consume fuel oil / light diesel oil which release particulate matter, NOx etc and pollute the environment. Plasma Assisted Coal Combustion system (PACC) can ignite and combust pulverized coal in environment friendly manner and can replace the oil fired burners used in the furnace startup. Replacing oil fired burners by PACC system in coal based power plants can eliminate the usage of costly fuel oil / LDO and hence reduce the expenses substantially. Further, PACC system has potential to reduce environment pollution. A laboratory scale PACC system consisting of thermally insulated chamber, pulverized coal feeder, air feeder, graphite electrode based plasma torch system along with instrumentation & control was developed to conduct study on coal ignition and combustion. In this work, a study conducted on self-ignition and combustion of coal using Indian as well as imported coal is reported.

In PACC, the burner cavity was preheated using thermal plasma arc system of power 25-30 kW to the temperature of coal's self-ignition point. Pulverized coal of size in range of 75-100 µm mixed with air was injected from one end of a cylindrical chamber and the mixture is allowed to pass through plasma arc zone. As the mixture passes through the arc zone, coal particles get activated due to high temperature density and ionic species of plasma and releases volatile compounds which initiates the combustion process. The ignition of pulverized coal thereby gets initiated and combustion takes place in the burner cavity. The hot efflux gases from burner cavity were found to be at temperature of 1060^{O}C. It was observed that the carbon left in the process is less 1% and approximately 10% of the total coal powder fed remain in burner cavity which is converted into ash.

Keywords: Coal combustion, coal burner, thermal plasma arc, pulverized coal ignition, coal fired power plant.

Poster – 29

Vacuum Conditioning of Graphite Tiles of Aditya Upgrade Tokamak

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Abstract

Graphite is widely used as armour material for plasma facing components in Tokamaks. High thermal shock resistance and low atomic number of carbon are the most important properties of graphite for its application as an armour material in many Tokamaks. Aditya Upgrade Tokamak has a major radius of 0.75m and minor radius of 0.25m. Plasma Facing Components (PFC) is one of the major sub-systems of Aditya Tokamak Upgrade. Aditya Upgrade Tokamak has both the limiter and divertor configurations. Aditya-U tokamak has different set of limiters and divertors, such as (1) Safety limiter, (2) Toroidal Inner limiter, (3) Toroidal outer limiter, (4) Upper and lower divertor plates. Initially graphite will be used as plasma facing material (PFM) in all the limiter and divertor plates. The dimensions of the limiter and divertor tiles are decided based on their installation inside the vacuum vessel as well as on the total plasma heat load falling on them. Shaped graphite tiles are fixed on specially designed support structures made out of SS-304L inside the torus shaped vacuum vessel. About 200 graphite tiles and 240 graphite caps are installed before the commencement of phase-1 plasma operation. PFCs are designed and fabricated to be Ultra High Vacuum (UHV) compatible and high temperature compatible for plasma operation. IG-430 grade graphite is chosen as first wall armour material in Aditya Upgrade Tokamak. Graphite, because of its porous nature absorbs water vapour and other gasses from atmosphere. Generally graphite tiles are given a high temperature bake-out treatment prior to installation inside the tokamak to reduce the in-situ wall conditioning time. All the graphite tiles were given a high temperature bake-out at 1000 ^{o}C to remove the entrapped gasses, under high vacuum (<1.0×10^{-5} mbar) in a vacuum furnace before installation inside the Aditya Upgrade Tokamak vacuum vessel. Residual Gas Analyser (RGA) was used to measure the outgassing at various temperatures during the entire vacuum baking process. RGA analysis shows that water vapour seems to be the dominant impurity. The remaining outgassing species are N_2, CO and H_2. In this paper, we will discuss about the vacuum conditioning procedure and residual gas analysis of Aditya-U Tokamak graphite tiles in high temperature vacuum baking process.

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Poster – 30

Microplasma Synthesis of Spinel Co_3O_4 Nanoparticles as Electrode Material for Supercapacitor Application

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Abstract

Spinel Co_3O_4 nanoparticles (NPs) have wide attention due to numerous electrochemical applications at relatively low cost. Co_3O_4NPs can be synthesized in a number of ways like sol-gel, co-precipitation, hydrothermal, solution combustion, and thermal decomposition etc possessing multi-steps and pro-longed reaction time. Here, the synthesis of Co_3O_4 NPs was done through a single step microplasma discharge method [1] in a solution precursor ($Co(NO_3)_2.6H_2O$) with Argon gas of flow rate 1 slpm. In this approach, the plasma plume containing high energetic electrons and OH radicals reduces the precursor solution and produced spinel Co_3O_4NPs at about 90 minutes. The XRD spectrum indicatedthat the NPs have spinel structure and amorphous nature. The characteristic peak at 680 cm^{-1} in Raman spectra and the peaks corresponding to Co^{2+} states in XPS analysis emphasize that the formed particles are Co_3O_4 NPs. The FE-SEM and HR-TEM analysis depicts the formed NPs have spherical shapes with narrow size range of ~5-10 nm. The electrochemical investigation on the synthesized Co_3O_4 NPs revealed reasonable specific capacitance of 234 Fg^{-1} at a current density of 1 Ag^{-1} with good retention capacity in 1M KOH electrolyte. The results affirm that spinel Co_3O_4 NPs unequivocally a suitable electrode material for electrochemical applications. Furthermore, the synthesis of Co_3O_4 NPs by microplasma array discharge method is a novel, facile and eco-friendly method without extraneous chemicals, prolonged synthesis period, high energy and temperature consumption.

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Poster – 31

Formation of Mn-MnO system using Thermal Plasma Route Suitable for Supercapacitor Application

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Abstract

Manganese oxide based materials have wide range of applications in energy storage such as electrode materials in supercapacitor and batteries [1-2].

In view of these applications, in the present work one step synthesis of metal-metal oxide composite nanoparticles namely Mn-MnO has been carried out by transfer arc thermal plasma route. For synthesis of these nanoparticles commercially available microcrystalline Mn Powder is used as precursor and synthesis was carried out in presence of Argon Plasma. It has been observed that the oxygen present along with commercial argon is sufficient to produce Mn-MnO nanocomposite systems besides this the change in ambient environment from argon to oxygen results in formation of Mn_3O_4 nanoparticles irrespective of variation in plasma parameters such as pressure and ambient oxygen flow rate.

Further experiments were carried out using Argon Hydrogen plasma in view of minimizing oxide phase of Mn. The Mn-MnO powder were used to form thick films and used to investigate supercapacitor application.

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Poster – 32

Single-Step Synthesis of Mn_3N_2 Nanoparticles by Thermal Plasma Arc Discharge Technique for Supercapacitor Application

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Abstract

Supercapacitors are regarded as useful devices for storing electrical energy because of their high power, energy densities and enhanced charging-discharging capabilities. The demand and consumption of energy are increasing day by day. One of the main concerns in modern civilization is the necessity for effective energy storage and renewable energy options. Based on their durability and storage capacity, all of these energy storage technologies were employed. In the present study synthesis of single-phase manganese nitride (Mn_3N_2) nanoparticles (NPs) using the thermal plasma arc discharge (TPAD) method were discussed. The experiments were carried out using nitrogen (N_2) and ammonia (NH_3) gas atmospheres at different plasma powers are 2, 4 and 6 kW. The phase and elemental compositions of the prepared nanoparticles were examined using X-Ray Diffraction (XRD) and Energy Dispersive X-ray Spectroscopy (EDX) analysis. Mn_3N_2 NPs have nearly spherical morphology, which is observed by Transmission Electron Microscopy (TEM) analysis. The Mn_3N_2 NPs exhibits superior storage properties with an outstanding specific capacitance of 508.4 F/g at 1 A/g with pseudocapacitive behavior, which exhibited higher cycling stability with 84.2% capacitance retention after 5000 cycles at a current density of 5 A/g. These results demonstrated that the plasma-prepared Mn_3N_2, which is used as a potential electrode material for supercapacitor applications.

Keywords: Plasma arc discharge, nanomaterials, manganese nitride and supercapacitors.

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Poster – 33

Synthesis and Characterization of Magnetic Cobalt Nanoparticles through Plasma arc Discharge for Waste Water Treatment

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Abstract

Water is one of the most important elements of life on earth. Therefore, the contamination of water directly affects the lives on earth on a large scale. Pollutants like oil, industrial waste and dyes are the main reason for water contamination. Water pollution causes diseases like typhoid, cholera etc. Among the known pollutants industrial wastes or effluents plays the main role in water contamination or pollution. Secondarily, the textile dyes also contaminate the water on a measurable scale and compromise the water bodies. Some of the dyes are highly toxic and therefore promote toxicity, mutagenicity and carcinogenicity in the water. Nanoparticles can be used for the degradation of this polluted water by adsorption because of their increased surface properties. In this experiment, pure cobalt nanoparticles were synthesized via the DC thermal plasma arc discharge method which is found to be effective and efficient for the production of pure metal nanoparticles. The crystal structure and morphology of the synthesized cobalt nanoparticles were studied by X- Ray Diffraction (XRD) and Field Emission Scanning Electron Microscopy (FESEM). The synthesized nanoparticles were used for the adsorption of Methyl Orange and Effluent. The treated water is studied and the efficiency of the nanoparticle is investigated using UV- Vis Spectroscopy.

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Poster – 34

One-Step Thermal Plasma Synthesis of Meta-Stable Bismuth Oxide and Composite Nanoparticles for Photocatalytic Applications

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Abstract
Bismuth oxide (Bi_2O_3) exhibit six different polymorphs at atmospheric pressure out of which α (monoclinic) and δ (FCC) are stable phases at room temperature and high temperature (above 730°C) respectively. It is possible to obtain meta-stable β (tetragonal) and γ (BCC) phases by quenching the high temperature δ phase at 650°C and 640°C respectively[1-2]. However, it was observed that while intending to synthesize meta-stable β phase, there is formation of mixture of other phases commonly α-phase and sub-stoichiometric $Bi_2O_{2.3}$ phase. Now, the band-gap of Bi_2O_3 is found between 2.0 eV-3.9 eV ranges. The β-phase of the bismuth oxide has narrow band gap (~2.3 eV) and performs better than α-phase as evident from literature [3-4]. For photocatalytic applications, typically, the nanocomposites perform well due effects introduced by other materials such as band-gap tuning. Bismuth ferrite (BFO) is a ferroelectric material possessing perovskitic rhombohedral crystal structure having band-gap in between 2.1 eV to 2.8 eV often used for photodetector devices [5]. The nano-composite of Bi_2O_3-BFO may help tuning the band-gap if the heterojunctions or core-shell structures are formed thus enhancing the photocatalytic efficiency.
Focusing on above said points, in this study we report single-step formation of β-Bi_2O_3 nanoparticles (S1) using the DC transferred arc thermal plasma synthesis route. Thermal plasma nanoparticle synthesis method offers higher cooling rates thus allowing the formation of β-Bi_2O_3 nanoparticles. Furthermore, an attempt is made to synthesize the β-Bi_2O_3-$BiFeO_3$ nano-composite (S2) in order to tune the band-gap of the said powder. The identification of the different phases formed in as-synthesized S1 and S2 nano-powder is carried out by X-ray diffraction technique. Further, the supplementary results of spectroscopic technique confirm the formation of nano-crystalline β-Bi_2O_3 in S1 without any secondary phase. Similarly, the formation $BiFeO_3$ in S2 is also confirmed by these techniques. The morphology plays an important role when catalytic applications are considered. Hence SEM and back scattered SEM images was used to identify the morphology of as synthesized nanoparticles. The elements in S2 sample was identified by Energy dispersive spectroscopy confirming the presence of iron in the sample. The UV-visible spectroscopy in DRS mode was used for finding the absorption-edge and band gap of the material. The band-gap is found to be decreasing in the S2 sample as compared to pure β-Bi_2O_3 nanoparticles which is beneficial for UV-visible photocatalytic applications.

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Poster – 35

Synthesis of High Entropy Oxide (HEO) Nanoparticles through DC Thermal Plasma Torch

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Abstract

High entropy oxide (HEO) nanoparticles (NPs) exhibit superior performance in energy storage, conversion, and catalysis due to the wide range of elements that were incorporated in the material compositions, which enhances thermal and chemical stability. Scalability and synthesis of phase pure HEO NPs are still challenging tasks in most of the physical and chemical routes. In this study, an attempt is made to synthesize a single phase (Mn, Fe, Ni, Cu, Zn)$_3O_4$ HEO NPs using DC non-transferred thermal plasma torch at atmospheric pressure. Argon and carbon dioxide (CO_2) gases are used as a plasma forming gas and methane (CH_4) is used as secondary gas for this process. Structural information and molecular vibration behavior of synthesized HEO NPs were analyzed using X-ray diffraction and raman spectroscopic analyses. The results confirmed the presence of spinel structure without any secondary phases. Surface morphology, particle size, and elemental compositions of the synthesized HEO NPs were studied using SEM and EDX analyses. The chemical oxidation states were investigated using X-ray photoelectron spectroscopy. The obtained results reveal that the thermal plasma route is a single-step approach for the bulk production of phase pure nanostructured HEO powders.

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Poster – 36

Influence of Partial Pressure of Atmospheric Oxygen on Thermal Plasma Synthesized Fe Nanopowders and its Degradation of Commercial Dyes by Ultrasound Assisted Fenton Process

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Abstract

Atmospheric oxygen plays a key role in determining the composition of oxide in the synthesis of metal/metal oxide nanopowders. As a result of a change in the composition of oxide in the synthesized nanopowder, various properties of the same are altered. The present work elaborates on the processing of Fe nanopowders by Arc Plasma Discharge and the variation in phase of the processed nanopowders by varying the base pressure inside the vacuum chamber. The base pressure determines the concentration of oxygen present in the atmosphere of the plasma vacuum chamber. Experiments are done by varying the operating current while keeping the voltage constant at 40 V. Each set of experiments is done with 50 A, 100 A and 150 A under base pressures of atmospheric pressure, 1×10^{-3} mbar and 3×10^{-5} mbar respectively. The above-mentioned parameters are repeated with N_2 and He atmospheres. The processed nanopowders are subjected to phase analysis which shows increased oxide content for air atmosphere and least oxide content for Fe nanopowders processed at 50 A under He atmosphere.
Further, the processed Fe nanopowders are used for the degradation of commercial dyes like methylene blue and methyl orange using ultrasonic waves assisted Fenton process. Maximum degradation for both dyes of > 97% was obtained when nanopowders were processed in He atmosphere at 150A.

Keywords: Arc Plasma Discharge, Degradation, Fenton process

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Poster – 37

Indigenous Development of High Frequency Power Supply for Production of Plasma Activated Water

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Abstract

A 20 kW, 400 V, 20 kHz high frequency power supply (HFPS) was indigenously developed at The Institute For Plasma Research (IPR), which was used for the production of air plasma in the dielectric barrier discharge plasma device. This plasma device is used for the production of plasma activated water. The effect of different dielectric material, electrode type and electrode material were studied on air plasma produced in plasma device. The key features of the power supply includes a smooth control of the output voltage over a wide range from 5% (20 V) to 100 % (400 V) of the rated output, a pulsed mode operation through external trigger command and a programmable output frequency up to 20 kHz [1]. A buck-voltage-fed full-wave bridge topology was adopted, necessitating a judicial choice of LC filters and semiconductor devices for requisite operational competence [2]. The single-phase inverter operates at 20 kHz yielding a quasi-sine wave output voltage. The IGBT control boards are equipped with overcurrent protections for tripping the power supply in µs. Aluminum heat sink of swaged fins with high fin-density was used, facilitated with forced air cooling for effectual heat dissipation inside the panel. The HFPS was coupled with a high voltage high frequency (HVHF) transformer for generation of output voltage up to 5 kV as per the load conditions.

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Poster – 38

Improvement on Surface Properties of Polycarbonate Using DC Glow Discharge for Food Packaging Application

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Abstract

The hydrophobic polycarbonate film (PC) surface was modified by using O_2 plasma. The operating parameters such as input power, treatment time are varied and the pressure is kept constant. After the plasma treatment, the modified PC surface with different conditions are analysed by static contact angle to identify the hydrophilic properties. The structural and chemical properties were evaluated by SEM, ATR-FTIR. The surface modified samples were further investigated using Anti-bacterial activity for food packaging applications. The result shows that after O_2 plasma treatment, the surface energy of the PC film was gradually increased with treatment time as well as discharge voltage. The ATR-FTIR results detected the hydroxyl groups on O_2 plasma treated PC film surface. The antibacterial testing results indicated that the O_2 plasma treated PC film surface showed strong antibacterial activity against both *S.aureus* & *E.coli*.

Keywords: Polycarbonate, Oxygen plasma, ATR-FTIR, Antibacterial activity

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Poster – 39

Study the Characteristics of Plasma Discharge Current in Atmospheric Pressure Plasma and Low Pressure Plasma Using the High-Voltage Medium-Frequency Power Source

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Abstract

The increasing applications of cold plasma in the field of surface treatment, pollution treatment, water activation, microbial inactivation, food preservation, seed germination and plant growth, etc. created the necessity to develop plasma power supplies as per specific application. Above mentioned applications of cold plasma mainly use high voltage medium frequency power supplies. The present work shows the design and development of high voltage medium frequency power supplies that can be used in applications like water activation, surface treatment, and pollution treatment, etc. This plasma power source used to generate various types of non-thermal plasma and determine the characteristics of plasma discharge current. The presented plasma power source is capable to produce 0-8kV voltage at 15 kHz to 30 kHz variable frequency with a minimum pulse width of 1µs. It is a compact, light in weight power supply working on a digitally controlled switching mode, full bridge inverter topology. The high voltage power is applied to the dielectric barrier discharge atmospheric pressure pencil plasma jet, plasma device, and low-pressure vacuum plasma setup to study the VI characteristics and plasma discharge behaviour at 20 kHz to 30 kHz with a variable duty cycle. The plasma produced using this power source has been used to produce plasma activated water and treatment of lemon.

Keywords: Plasma power source, high voltage supply, atmospheric pressure plasma generation, VI characteristic of atmospheric pressure plasma, plasma jet

Poster – 40

Characterization Study of Dielectric Barrier Discharge (DBD) Plasma Surface Modified Ethylene Vinyl Acetate (EVA) Film for Medical Applications

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Abstract

Plasma treatment is one of the emerging ways used for the surface modification of polymer films, cotton, fabrics and nanoparticles etc. In this research work, the effects of Dielectric Barrier Discharge (DBD) plasma in the presence of argon and helium for the Poly (ethylene-co-vinyl-acetate) (EVA) polymer surface treatment is investigated. EVA, a thermoplastic biomedical polymer along with curcumin, an anti-cancer drug is incorporated into a polymer film [1]. Structural analysis and the chemical state of the drug-loaded film were carried out by static contact angle measurements and FT-IR respectively. The surface roughness of the treated films was evaluated by Atomic Force Microscopy (AFM). According to the results, the hydrophilicity of the polymer films increases for both the argon and helium plasma was observed. The surface roughness increases after the argon plasma treatment compared to helium plasma. In the future, EVA polymer can be used as a base drug reservoir for drug delivery applications and can provide a controlled drug release system.

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Poster – 41

Agricultural Wastes as possible NO_2 Adsorbents in Post-Plasma Treated Diesel Exhaust

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Abstract

This paper compares several agricultural wastes for their possible reuse as NO_2 adsorbents in polluted diesel exhaust which is pretreated with non-thermal plasma [1-3]. Through this, an avenue for managing the solid agricultural waste has been shown and a possible alternative for commercial expensive adsorbents can be thought of. In the current study two new wastes namely areca nut husk and wheat husk have been studied for the first time for their adsorption properties. The other wastes comprise of coffee husk, rice husk, sugarcane bagasse and mulberry husk. The raw wastes were processed and made into pellets form before being used as adsorbents. Studies were carried out on a 5 KW diesel engine exhaust which was first exposed to cold or non-thermal plasma in a dielectric barrier discharge reactor energized by high voltage repetitive pulse/AC. Plasma being an oxidative environment many of the gaseous pollutants get oxidised and one such example is conversion of NO to NO_2. Since the critical temperature of NO_2 is close to the ambient temperature it gets easily adsorbed in the waste-based pellets by capillary action. Helical wire fitted inside a borosilicate glass tube acted as corona electrode while an aluminum foil wrapped around the glass tube acted as ground electrode. The corona electrode was adhering to the inner surface of the glass tube to get surface discharges. The NOx reduction efficiency (DeNOx) was compared amongst the agricultural wastes for various specific energies (J/L). It was observed that plasma cascaded with wheat husk showed maximum NOx removal efficiency of about 75% at 184 J/L when the reactor was AC energized. On the other hand, with plasma alone (pulse/AC), it was about 18-23% DeNOx efficiency indicating that oxidation of NO is dominant compared to reduction of NO. Further, this oxidized NO gets adsorbed in the waste-based pellets enhancing the DeNOx efficiency. Through this work, an economically feasible and abundantly available agricultural wastes can be considered as a competitive alternative to the commercial adsorbents such as alumina, molecular sieves etc.

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Poster – 42

Exploring Catalytic Properties in Lignite Fly Ash and Bauxite Residue through Plasma Catalysis in a Multi Needle-Plate Reactor: A Case Study in NOx Removal

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Abstract

Experiments were conducted on plasma treatment of diesel engine exhaust under laboratory conditions. Given the oxidative environment of non-thermal plasma it was necessary to go for additional technique to enhance the gas treatment and in the current study a plasma catalytic approach was employed. Instead of using expensive commercial catalysts, two solid industrial wastes namely red mud from alumina industry and lignite fly ash from lignite thermal power plant have been used to explore the effect of metallic constituents, that are present in these wastes, on the pollutants in the presence of plasma at room temperature [1, 2]. In the plasma catalysis mode, the design of the corona electrode and the type of energization play a crucial role as they affect the production of the charged species which in turn affect the pathways of various chemical reactions. Keeping this in mind a new plate type electrode embedded with multiple needles was designed and incorporated in a duct type reactor geometry. Further, this rector was filled uniformly with one of the industrial wastes and then subjected to three different types of high voltage energization namely unipolar repetitive pulses (80 Hz), power frequency AC and high frequency AC (1.2 kHz). Plasma catalysis in lignite ash is being reported for the first time. Significant NOx removal (DeNOx) efficiency in plasma catalysis approach has been observed at all energizations. To substantiate catalytic based reactions in the presence of plasma, additional experiment was carried out by treating the exhaust with plasma alone and then allowing the treated exhaust to flow through a reactor filled with industrial waste and the NOx removal, which was mainly due to adsorption of NO2 in the waste-based pellets, was studied. Red mud exhibited better catalytic properties in the presence of plasma when compared to lignite ash. Further, high frequency AC plasma resulted in good plasma catalytic reaction, in presence of red mud, bringing out about 78% DeNOx efficiency at about 260 J/L. In contrast, when this plasma cascaded with red mud resulted in 12 % DeNOx efficiency. Detailed discussion on reaction pathways is discussed in the paper. Through this study, room temperature-based plasma catalytic interaction with metal constituents of industrial wastes have been shown to be a promising and economical approach for NOx removal in diesel exhaust. Further a new way of managing solid industrial waste can be thought of through this study.

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Poster – 43

Studies on Plasma Sprayed Multi-layered Ytterbium Silicate - Based Environmental Barrier Coating

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Abstract

In recent years, there is a lot of pursuit in replacing the hot sections of gas turbine engines made of heavy cobalt- or nickel-based superalloys with SiC/SiC ceramic matrix composites (CMCs). Nevertheless, a major concern is the sensitivity of Si-based ceramics to the combustion environment as the protective silica scale greatly interacts with hot water vapor to form gaseous silicon hydroxides, leading to catastrophic erosion of CMCs [1]. Moreover, the CMCs suffer from severe hot corrosion in molten salt and calcium magnesium aluminum silicate (CMAS) attack. To protect the CMC based turbine materials from the above issues, silicate based environmental barrier coating coatings (EBCs) possessing corrosion-resistant properties at high temperatures followed by a CMAS resistant coating must be enforced on them. The present study reports the preparation and characterization of plasma sprayed multi-layered EBC coating containing $Yb_2Si_2O_7$ and Yb_2SiO_5 layers followed by yttrium aluminum garnet (YAG) as the CMAS layer. The main emphasis is on the synthesis of $Yb_2Si_2O_7$, Yb_2SiO_5 and YAG flowable powders and plasma spraying of the powders and characterization of the coating.

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Poster – 44

Effect of Oxygen Partial Pressure on Copper Thin Film Deposited by Planar Magnetron Sputtering

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Abstract

Copper is well known for its conductivity, ductility and antibacterial behavior over decades. Ancient people have been using copper as a core material for architecture [1]. Later, researchers started coating copper for getting antimicrobial surfaces in selective areas. However, its tendency to form various oxide phases is uncontrollable. And then nanotechnology has arrived and various attempts have been made to produce copper oxide nanoparticles which lead to enormous replacement of metallic copper by incorporating the synthesized nanoparticles onto fabric surfaces [2].

With further development of plasma coating technology, depositing a thin layer of metals, oxides, nitrides etc. became possible and it is an emerging field in the surface engineering at present. In this work copper and its oxide coatings have been deposited on polypropylene fabrics using physical vapor deposition method using argon and partial oxygen medium in the chamber. It reduces the lengthy chemical synthesis processes and use of hazardous reactants and products. In addition, it is feasible for large area applications [3].

This work emphasizes the effect of oxygen partial pressure on formation of various copper oxide phases, which can be extended to diverse applications of copper oxide coatings in future. The coatings have been deposited with and without oxygen presence in various partial pressures to enhance the copper oxide formation. The oxide formation has been confirmed by Micro-Raman analysis which is also observed in the surface topography (SEM). The samples were studied for their elemental and phase compositions using EDX and XRD. Varying oxygen partial pressure found to help formation of cupric and cuprous oxides in varying quantity. Further detailed analysis has been performed using XPS and selected samples have been subjected to leaching process and quantified using ICP-MS analysis. The results have been correlated to find the optimum oxygen partial pressure for enhancing particular oxide phase.

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Poster – 45

Influence of Operating Parameters on Development of Amine Rich Functional Coating on the Surface of PCL Scaffolds through Cold Atmospheric Pressure Plasma

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Abstract

In spite of its wide use for tissue engineering applications, polycaprolactone (PCL) does not exhibit the desired cellular interactions, which has led to the development of a number of surface modification strategies. In this study, we aimed to develop amine coating on PCL scaffolds via the cold atmospheric pressure plasma polymerization technique. In order to attain high retention of monomer functionalities, plasma polymerization of Diethylenetriamine was performed on PCL scaffolds at different operating conditions. The amendments in surface properties were examined by various characterization techniques. The surface chemistry and topography of the surface-modified films were assessed by X-ray photoelectron spectroscopy (XPS) and atomic force microscopy (AFM). The variation in hydrophilic properties was investigated by contact angle measurements. XPS analysis clearly unveiled that the high retention of monomer functional groups are incorporated on the surface of PCL scaffolds. The incorporation of amine functionalities was found to be increased with an increase in monomer concentration. AFM unveiled that the surface-modified films exhibited different surface topography and the same was influenced by operating parameters. Furthermore, the plasma polymerized PCL scaffolds exhibited excellent hydrophilic properties verified by contact angle measurement. In conclusion, the incorporation of characteristic functionalities on the surface of the scaffolds highly depends on the operating parameters.

Keywords: Cold atmospheric pressure plasma, Amination, PCL scaffolds, surface analysis, cell compatibility

Poster – 46

Understanding the Degradation of Plasma Sprayed Ceramic Thermal Barrier Coatings in the Presence of Natural Volcanic Ash

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Abstract

The operational threat posed by $CaO–MgO–Al_2O_3–SiO_2$ (CMAS) and volcanic ash (VA) attack over YSZ based thermal barrier coatings is a serious functionality concern. YSZ is highly vulnerable to CMAS and VA attacks, whereas rare earth cerates arrest the infiltration by forming the interaction layer. Doped lanthanum cerate (RE-$La_2Ce_2O_7$) ceramic coatings are found to exhibit good thermal cycling performance and also, reduces the sudden decrease in thermal expansion mismatch found in lanthanum cerate ($La_2Ce_2O_7$, LC). Along with the standard qualification studies meant for TBCs such as thermal cycling and oxidation resistance studies, it is essential to study the VA infiltration behaviour of the any newly proposed coatings. In the present study, composite coatings containing LC + YSZ and yttria doped LC + YSZ were chosen in the ratio of 50-50% and, the respective composite coatings are generated by atmospheric plasma spraying. The effectiveness in mitigating the microstructural damages against naturally occurring VA is studied. The thermochemical interactions and damage mechanisms are discussed.

Keywords: $CaO–MgO–Al_2O_3–SiO_2$, volcanic ash, composite coatings, rare earth cerate

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Poster – 47

Deposition of Carbon Nanotubes and Graphene Nanowalls by Microwave Plasma CVD: Understanding & Insights

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Abstract

Since the discovery of Carbon Nanotubes (CNTs) by Ijima in 1991 and discovery of Graphene nanowalls in 2002, these two nanostructures have been in news for their exciting possible applications ranging from supercapacitor to drug delivery. Deposition of these nanostructures can be achieved efficiently by Microwave Plasma CVD method. In past, we have deposited these two nanostructures by this plasma CVD method and studied their performance as field emitter and found a window for their co-deposition. In the present work, we have deposited these two nanostructures in catalyst free method on Inconel 600 substrates with variation of heat treatment conditions and applied bias. In each case, a gas mixture of H_2 and N_2 was used for plasma ignition while C_2H_2 was used as the precursor for the deposition. Microwave power was kept fixed at 1kW for 1 hr during deposition. The deposited nanostructures are then investigated by Raman spectroscopy and scanning electron microscopy. Combining these two techniques in unison, insights about the deposition mechanism under different conditions have been found out. It is seen that heat treatment; microwave attenuation and external electrical bias play a very prominent role in deposition.

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Poster – 48

Effect of Heating Rate during Sulfurization Process on Growth of CZTS Thin Layer

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Abstract

Cu_2ZnSnS_4 (CZTS) is a well-known absorber layer that has demonstrated its potential in thin film solar photovoltaic by achieving an efficiency of 11% [1]. High absorption coefficient of 10^4 cm^{-1}, an optimum bandgap of 1.4-1.5 eV, natural abundance, and non-toxic ingredient of CZTS [2, 3] are some unique features of CZTS that make it a suitable absorber candidate for light harvesting. Process parameters plays important role in achieving desired properties of CZTS layer.

In this work, CZTS layer of thickness up to ~900 nm was prepared by sulfurization of a thin film precursor prepared using plasma assisted magnetron co-sputtering deposition of Cu, Zn and Sn on soda lime glass. Heating rate during sulfurization process was varied to study its effect on the growth properties of the CZTS layer like secondary phase formation, optical and structural properties, etc. XRD, SEM, EDX, Raman-Spectroscopy, UV-Vis spectroscopy were used to analyse the film properties. It is found that the higher heating rates are better to reduce the undesired secondary phase formation.

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Poster – 49

Plasma Assisted Chemical Vapor Deposition and Characterization of SiO_x Thin Films on Polyethylene Napthalate (PEN) Substrates: Effect of RF Power

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Abstract

SiO_x thin films are deposited on Silicon (100) and polyethylene napthalate (PEN) substrates using radio-frequency plasma enhanced chemical vapor deposition (RF-PECVD) process for their potential optical display screens applications. A 1, 2-bis (triethoxysilyl) ethane (BTESE) precursor is used for these depositions. The films were deposited using Argon/BTESE and oxygen/BTESE capacitively coupled plasma discharge under varying influence of RF power levels (15-125 W) during deposition. Depositions are carried out on substrates kept on the grounded electrode. BTESE vapors were fed in the process chamber by keeping the precursor bubbler temperature at 100˚C. Operating pressure during the deposition was ~ 4×10^{-2} - 8×10^{-2} torr. The deposited films are characterized by Fourier transform Infrared (FTIR) spectroscopy to identify the presence of various types of bonding present in the films. Thickness of the films was measured using optical profilometry. The mechanical properties were characterized using Nanoindentation technique. A gradual increase in the hardness was observed with increase in RF power. Optical transparency was measured using UV-Visible spectroscopy. Apart from that in-situ plasma diagnostics was carried out using emissive probe. Plasma potential measurements were found to show decreasing trend with RF power. A substantial decrease in the film optical transmittance with increase in the RF power level is observed. Deposited SiOx films on PEN substrates exhibited transmittance >90% in the visible wavelength range for films deposited at 15W and 25W RF powers. The optical transmittance decreases with increase in RF power beyond 25 W. Comparison of FTIR spectra taken on films deposited with Argon/BTESE and oxygen/BTESE plasma indicate a clear variation in the carbon containing species and Si-O-Si content in the films with RF power levels. Results of these investigations indicate that there is an optimum plasma process parameters window for deposition of optically transparent thin films. This paper will discuss the experimental details and characterization results.

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Poster – 50

Deposition of Titanium Interface on Stainless Steel using Magnetron Plasma Sputtering for Adhesion Improvement of Back Contact Layer

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Abstract

CZTS absorber based thin film solar cell is emerging as a future potential technology for solar photovoltaic. Development of such a device on Stainless steel foil for flexible solar cell application is a challenging task due to the adhesion issues. Adhesion of the Molybdenum back contact layer on Stainless steel foil is the first and most important requirement for such developments. A thin Cr layer was tried in the past for adhesion improvement but the diffusion of Cr into the absorber or back contact during the high temperature processing for crystalline absorber growth is an issue for the device performance [1]. Ti is a better option for this interfacing layer to improve the adhesion which acts as a barrier layer for such diffusions [2]. A thin Ti layer is being deposited using plasma assisted magnetron sputtering process on a SS foil to improve the adhesion of Mo with stainless steel. And being tested for the sequential growth of all the layers (SS/Ti/Mo/CZTS/CdS/ZnO/ZnO:Al) of the device and is demonstrated.

Keywords: Titanium thin film; Adhesion; Stainless steel foil; Barrier layer

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Poster – 51

Experimental Validation Study to Improve Thermal Performance of an Updated Design of Plasma Pyrolysis Chamber using CFD Analysis

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Abstract

Plasma pyrolysis technology safely disposes biomedical waste without generating any toxic by-products. Before feeding waste, the primary chamber is preheated to a high temperature of around 800-1000°C using plasma arcs and subsequently bio-medical waste is fed. The waste disintegrates into gaseous products such as hydrogen, CO, CH_4, etc. along with soot particles. These gases are combusted in the secondary chamber and CO_2, particulate matter are further treated using standard gas cleaning system to meet emission norms set by Central Pollution Control Board, India before releasing to environment. This technology has been indigenously developed at Institute for Plasma Research (IPR) using the patented graphite plasma arc technology. The primary chamber of plasma pyrolysis system has been upgraded to improve its thermal performance, heat confinement and improved preheating time. The upgradation has been done in terms of improved refractory and insulation materials and their thickness to reduce the heat losses to outer walls. The transient temperature profile of system and preheating time is evaluated using CFD analysis in ANSYS CFX. CFD analysis of the updated system has been performed considering the experimental conditions and certain assumptions to estimate the temperature profile of the chamber during preheating. The results of the CFD simulation were compared with the temperature profile of the chamber that was measured using thermocouples during the experiment. The comparison shows that the experimental and CFD simulation are in close agreement with maximum 10% deviation. The results reveal that significant improvement in the thermal performance, heat confinement and faster preheating time in updated chamber even at lower input power as compared to old chamber design. The details of CFD simulation and its experimental validation will be discussed in this paper.

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Poster – 52

Degradation of Congo red dye by Micro Discharge Plasma

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Abstract

Single step degradation without catalyst is the need of the hour to manage enormous quantity of complex organic wastes in waste water treatment. The present study utilizes micro discharge plasma (MDP) method, which is one of the advanced oxidation processes to degrade the highly toxic and carcinogenic dyes like Congo Red (CR) present in aqueous medium. A relative investigation was done using two plasma gases, air and CO_2. The CR dye was completely decolorized in 35 min and 40 min of CO_2 and air plasma treatment, respectively. The optical emission spectrum of the MDP showed that the CO_2 plasma produce more number of OH● radicals during interaction with aqueous medium which led to high CR dye degradation efficiency than the air plasma. The degradation percentage and energy yield of CO_2 plasma was greater than air plasma in CR dye degradation, which was determined using UV-Vis spectroscopy and high-performance liquid chromatography (HPLC) analysis. Mineralization percentage of plasma treated solutions were determined by total organic carbon (TOC) analysis. The results shows that CO_2 plasma produced high mineralization and energy yield of 72.5 mg/kWh than air plasma, which offer a new window for the effective utilization of CO_2 gas as a plasma forming gas in wastewater treatment.

Keywords: Micro discharge plasma, CO_2 plasma, Wastewater treatment, Degradation.

Acknowledgement

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Poster – 53

Atmospheric Pressure Plasma-Induced Rapid Crystallization of Amorphous Titanium oxide: An Efficient Adsorbent of Cationic Dye

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Abstract

Atmospheric pressure plasma (APP) assisted material fabrication, as well as surface modification of materials, is a recently growing interdisciplinary research field in the interface between plasma and material science. Presence of a wide range of reactive species in the plasma zone, results in an intrinsic high chemical reactivity compared to ordinary chemical reaction media. The high chemical reactivity leads this process to be quite rapid. Despite this well-known process of plasma-assisted material preparation, one aspect of plasma synthesis technique that is still poorly understood is plasma-induced crystallization of materials. It is believed that heating of the particles due to collision between energetic short-lived and long-lived reactive species with the material is responsible for the crystalline phase.
Herein, we have developed a plasma-liquid reactor so that the APP is produced above the liquid surface, which is then transferred to the liquid medium. This work demonstrates rapid phase transition of amorphous to phase pure anatase TiO_2 using titanium butoxide (TTB) as the raw material. Upon hydrolysis of TTB, white color precipitation is observed which results in amorphous titanium oxide. XRD spectra reveal that the crystallization process of TiO_2 is very fast compared to the conventional annealing process for crystallization. 10 minutes of plasma treatment is sufficient for the phase transformation of TiO_2. As in the conventional annealing process that is used for crystallization of material particles, the formation of phase pure anatase TiO_2 is difficult to achieve, therefore, this plasma-induced crystallization can be regarded as an efficient alternative tool for crystallization of material. These plasma-treated TiO_2 can be used as a good candidate for adsorption of cationic dye molecules. Within 5 mins, up to 80% dye molecules can be adsorbed on the surface of the catalyst. In addition, to investigate the plasma properties such as gas temperature and to confirm the formation of various reactive species in the plasma zone, OES spectra have been recorded.

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Poster – 54

Thermal Plasma Treatment of Coconut Shells for the One-Step Synthesis of Graphene-Like Structures

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Abstract

Treatment with the use of thermal plasma is regarded as one of the ideal way of treating many toxic wastes due to its high temperature, energy density, less emission of the pollutants, etc. Coconut shell is a type of bio-waste that has been studied widely because of its ability to yield various carbon based products such as activated carbon and graphene like structures [1-4]. In this work we have treated coconut shells with high temperature thermal plasma in arc plasma set-up. Arc plasma setup is an indigenously developed reactor which in brief consist of two electrodes namely, cathode and anode. In this study, tungsten rod with graphite cap acts as cathode and graphite crucible containing coconut shells acts as anode. On characterizing with XRD, Raman and FE-SEM, results indicated presence of graphene like structure in the remains of the coconut shell ash. As treatment of coconut shell with thermal plasma yields graphene-like structures which can be used for many applications such as in high power supercapacitors, it can be considered as the ideal way to deal with large amount of coconut shell wastes which are generally burned in open atmosphere in many areas as it is considered as cheap and simple way to manage the coconut wastes by many farmers.

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Poster – 55

Preparation of CuO Nanoparticles through Thermal Plasma Route and Its Application in Dye Degradation

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Abstract

In recent years, metal oxide nanomaterials has drawn much attention due to its wide range of applications in chemical, biological and environmental sciences. In particular, copper oxide nanoparticles have gained more interest because of its wide range of applications such as solar energy conversion, electronics, magnetic storage, catalysis, gas sensors and antimicrobial agents. In the present work, copper oxide nanoparticles (NPs) were synthesized from copper scrap using plasma arc discharge method since this method is contamination free, single step and eco-friendly. The synthesized NPs were confirmed by using X-ray diffraction (XRD), Energy dispersive spectroscopy (EDS) and UV-Visible spectroscopy. High resolution transmission electron microscopy (HR-TEM) was performed to study the morphology and average particle size of synthesized NPs. The synthesized CuO NPs was utilized for catalytic oxidative degradation and it exhibit significant catalytic performance for both cationic (methylene blue) and anionic (methyl orange) dye pollutants.

Poster – 56

Studies on Synthesis of Fe-TiO_2 Composite Powder from Ilmenite by Carbo-thermal Reduction Process through Transferred Arc Plasma Reactor

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Abstract

Ilmenite ($FeTiO_3$) is abundantly available in the beach sands of India and is an important source of titanium dioxide production and titanium bearing compounds. Titanium dioxide (TiO_2) has a wide range of applications in industries as a pigment in paint, paper and plastic production [1]. TiO2 mixed with Fe was used in the photocatalytic degradation of harmful dyes in visible light region. [] This work discusses the carbo-thermal reduction of ilmenite to form Fe- TiO_2 composite powder through transferred arc plasma processing. Transferred arc plasma system has been developed in-house and uses argon as plasma-generating gas. Transferred arc plasma is used in this reduction process because of the various advantages like high temperature, high enthalpy and shorter processing time [3]. Here, graphite was used as a carbon source for carbo-thermal reduction process and reaction was studied by processing ilmenite at a fixed plasma input power and gas flow rate with varying amounts of carbon (without carbon, 1C and 2C). Free energy minimization technique was used to predict the favorable temperature and other processing conditions for the formation of Fe and other Ti-bearing phases such as TiO_2, Ti_2O_3, Ti_3O_5, Ti_4O_7 and TiC. Different phases present in the plasma processed products were characterized using x-ray diffraction.EDS analysis also carried out to find the elemental composition of the product. XRD results confirmed the formation of Fe along with TiO_2 and titanium sub-oxide phases when processing of ilmenite was carried out with lower carbon contents (up to molar ratio of 2C). By analyzing the experimental results on the basis of free energy minimization technique, ideal conditions for formation of titanium oxide by transferred arc plasma processing of ilmenite has been optimized.

Keywords: Ilmenite, carbo-thermal reduction, transferred arc plasma reactor, titanium dioxide

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Poster – 57

Study of High Voltage Surface Flashover in Electron Gun for Application in Low Pressure Plasma Generation

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Abstract

High voltage surface flashover is one of the major issues when operating an electron gun for generating low pressure plasma. At low pressure in the range of 10^{-5} – 10^{-6} mbar, there is initiation and development of surface charge over insulator surface leading to electric field enhancement and ultimately surface flashover. This has an adverse effect on the functioning of the electron gun at low pressure. In order to ensure continuous and reliable operation of electron gun for generating low pressure plasma, it is of utmost importance to incorporate certain remedial measures. In the work reported here, a detailed study has been carried out on a practical 270 degree bent, high power (60 kV, 60 kW) indirectly heated cathode-based electron gun to investigate major factors affecting surface flashover at low pressure. These majorly include energy of impinging electrons, insulator material, surface gases, temperature and magnetic field effects. Investigation on relevant experimental results reported in the literature incorporating remedials actions has been presented here. These include implementation of various insulator designs, use of ferrite beads, metal oxide coatings on insulator surface and use of metal shield electrodes. The results of this study indicate that the insulator surface and the design of triple junction have an immediate effect on the surface flashover performance of the electron gun. This study will be very helpful to find out the optimized electron gun design that caters the problem of high voltage surface flashover and provides an improved and reliable electron gun performance for generating low pressure plasma.

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Poster – 58

Application of Cold Plasma Discharge on Catalysts Surface Engineering

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Abstract

Quality of environment is severally depleted due to ever increasing population. Scientists are designing methods to monitor or eliminate contaminants as the environment faces problems. One of the topics that researchers have encountered is catalysis. In this study, we propose Non-thermal Plasma (NTP) discharge as an effective technique for the synthesis of nanoscale catalytic material. The magnetically active nanoparticles (MANps) were prepared by Co-precipitation method. Interestingly the application of NTP with external heating at 200 ºC provides an effective alternative route for high-temperature material synthesis. The process is about six-fold energy efficient in comparison to the conventional synthesis method. In addition to that upon calcination of catalyst at higher temperatures, the catalyst tends to form agglomerated particles that are less susceptible towards catalytic reaction. However, the plasma discharge effectively brings surface modification and induces the crystallization on the catalyst surface with high magnetic susceptibility at low temperatures. About 30 min of plasma treatment, at 200 ºC, leads to enhancement in crystallinity, and about 12 nm crystallite size is achieved. Nevertheless, calcination at the same temperature has not induced any crystallinity was confirmed by XRD. Furthermore, the MANps was characterized via Scanning electron microscopy (SEM) for investigation of morphological details, vibrating resonance magnetization (VSM) for magnetic properties, of plasma-treated, untreated material and high temperature calcined material. The prepared MANps have a magnetization (Ms) of 91.77emu/g and a coercivity (Hc) of 882.8Oe at low temperature along with plasma, whereas the high temperature calcined material has a magnetization (Ms) of 64emu/g and a coercivity (Hc) of 1279Oe. As a result, the catalytic activity and reusability of MANps for the synthesis of organic compounds via eco-friendly mechano-chemical synthesis were investigated. Notably, the catalyst recyclability and reusability could be enhanced by plasma treatment.

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Poster – 59

Nano Carbon Incorporated Calcium Silicate Bio-Glass Ceramics by Non-Thermal Plasma Technique

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Abstract

The bio-glass is the most widely used ceramic biomaterial used in this century as they resemble the mineral composition of natural bone. They are widely used for the bone implantation, dentistry, bone regeneration, drug delivery etc. We have modified the surface of hydrothermally synthesized Calcium Silicate nano bio-glass material by the impregnation of nano carbon using the DC low-temperature plasma technique using the acetylene plasma. This was done by varying the time for the exposure in plasma for each of the sample at a constant voltage and gas concentration. The structural, morphological, chemical state, functional groups and thermal profile were studied using the X-Ray Diffraction (XRD), Field Emission Scanning Electron Microscope (FESEM), Fourier Transform Infrared Spectroscopy (FTIR), and Thermo Gravimetric- Differential Scanning Calorimetric (TG-DSC) analysis respectively. The FESEM images shows the flake like nano structures and the nano-carbon present on the top of the bio-glass material and the EDX results show the growing rate of carbon in the material. The results have shown the effect impregnation of nano-carbon into the bio-glass can result in the surface morphology and hence increasing its thermal properties.

Poster – 60

Surface Engineering and Characterization of S-Phase formed in AISI 304 Austenitic Stainless Steel by Plasma Nitrocarburizing

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Abstract

AISI 304 is known for its corrosion resistance which comes from Cr that forms passive Cr_2O_3 on the surface. But its poor hardness makes it unsuitable for applications where the steel also requires high wear resistance. This can be improved by surface hardening using nitrocarburizing processes, which form ε-$Fe_{2-3}N$, $\gamma^{'}$-Fe_4N, nitrides, and carbides of Cr and Fe on the surface and subsurface. These formed phases give the surface greater hardness but the corrosion resistance drops because of the lack of Cr_2O_3 passivation as a result. To overcome this problem plasma nitrocarburizing processes are being developed where the process temperatures are kept below 723 K to avoid Cr-N precipitation [1]. In the presented work low-temperature pulsed-DC plasma nitrocarburizing utilizing a discharge of N_2-H_2-C_2H_2 at 500 Pa with varying N_2:H_2 ratios was conducted on AISI 304 samples at 673 K. The process durations were also varied and the samples were characterized by microindentation using Vicker's hardness tester and corrosion resistances were established from electrochemical impedance studies, and corrosion potentials and corrosion currents were obtained by potentiodynamic polarization testing. XRD revealed S-phase, which is a supersaturated solid solution of N and C in the γ phase. The S-phase was observed to be composed of the expanded phases of γ; γ_N and $\gamma_{C,}$ and $\gamma^{'}_N$ and $\varepsilon^{'}_N$ phases. Significant improvement in surface hardness was achieved after every process which is attributed to the S-phase. Corrosion resistance was also found to improve after the processes. The samples were also characterized by XPS, SEM, and GDOES.

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Poster – 61

Hydrothermal Preparation of Surface Modification of Calcium Silicate Nano Bio-Glass Ceramics by Argon Plasma

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Abstract

Bioactive glasses have been used as artificial bone materials for the past few decades. Calcium Silicate bio glass were successfully synthesized by hydrothermal method without any acid catalyst. The obtained white color calcium silicate powder undergoes low pressure Argon plasma processing with different processing time and constant plasma voltages and gas concentration. The structure, functional groups, morphology and thermal analysis were investigated by XRD, RAMAN, FTIR, FESEM and TGDSC analysis respectively. Predominantly FESEM image shows flake like nano structure which is processed under Argon (Ar) plasma, the calcium silicate nano bio-glass ceramics has become highly porous nature. This acts as an excellent bioactivity and osteogenesis and it may be suitable for bone repair and implants.

Poster – 62

Effect of Surface Modification on Titanium Plate by DC Non-thermal Plasma Processing

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Abstract

Titanium (Ti) plate undergoes carbon coatings which is admitted through low pressure DC glow discharge plasma and the acetylene as the source of carbon. Ti is a well-known corrosion resistant material with well bonded osteoblast and excellent biocompatibility. The surface oxide layer still induces the reaction with calcium and phosphate ions to produce proteins with apatite layers, which is key function of osteointegration process. Addition of carbon plays a vital role to perform the metal-tissue functionalities to the implant processing. Titanium plates were cut into ~1x1 cm in size undergoes the DC glow discharge plasma processing with stabilized input voltage and gas density and various processing time. nano carbon was coated on the surface of the titanium plate. The structural, morphological and functional group observations through XRD, RAMAN, FESEM and FTIR respectively. Plasma processed samples were more often effective to admire the work and better biocompatible response than unprocessed samples are expected.

Poster – 63

Experimental Facility Development of NF_3 Based Plasma Etching System

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Abstract

A Facility of NF_3 RF glow discharge plasma system is developed at Institute for plasma Research. Plasma etching system is generally utilzed for various technologies like IC fabrication, chamber cleaning, material surface modification etc[1]. A typical 13.56 MHz radio-frequency (RF) glow discharge plasma drives highly mobile electrons to collide with neutral gas atoms and molecules, resulting in ionization and dissociation of a reactant gas. In NF_3 plasma etching system, the substrate is placed in a vacuum chamber on the cathode of the plasma generator and gases are introduced to produce the reaction. NF_3 gas in plasma generates many Flurine atoms (free radicals), which are highly reactive and spontaneously react with substrate (Si or SiO_2) to produce volatile product (SiF_4) which will be pumped away by the vacuum pump[3]. NF_3 is selected as reactive gas because bond dissociation energy of various dissociative reactions in NF_3 is much lower than other fluorinated gases like CF_4, SF_6 etc. The basic operating parameter of this facility are pressure (5 to 80 Pa) and RF power from 50-150 Watt. Moreover, it could be utilised for radwaste removal form the metallic surface such as Uranium Oxide cleaning from stainless steel surfaces[2].

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Poster – 64

Effect of Nano-Carbon Incorporated Superhydrophobic PET Films for Medical Application by Using Non-thermal DC Plasma Technique

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Abstract

Polyethylene Terephthalate (PET) was incorporated by Carbon, acetylene plasma as a source. The transparent PET film becomes yellowish to grey in colour due to the effect of carbon impregnation over the polymer surface, in the meantime the analysis with respect to structural, optical properties, and hydrophobic activities. In this work, the 2D peak of incorporated carbon and modes which exist the effect of progression was derived by Raman spectroscopy and the presence of functional groups with respect to the stretching and bending modes described by Fourier Transform Intra-Red spectroscopic analysis. The incidence of UV absorption and emission bands were observed via UV-Visible spectroscopy and Photoluminescence Spectroscopy respectively. The water droplet flows over the pure and plasma processed PET samples are justified by using contact angle measurement and the maximum processed samples shown at 179° contact angle between water and solid reveals the superhydrophobic activity of plasma processed PET sample. Plasma processing brings unique properties applies to the medical arena showing the blood storage devices and liquid medicines flow tubes due to high anti-microbial and non-toxic behavior to human cell tissues.

Poster – 65

Comparison of Air and Nitrogen Gliding Arc Plasma for Production of Ammonia with Water

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Abstract

Gliding arc plasma synthesis of ammonia is one of the most promising approaches since it consists of both thermal and non-thermal properties. Electron density of gliding arc plasma generally ranges from 10^{13}-10^{15} cm^{-3} which is higher than other non-thermal plasmas. This work compares the formation of ammonia in gliding arc discharge plasma exposed to the water surface using air and nitrogen as the plasma-forming gases at a fixed discharge power. Optical emission spectrum of the plasma medium revealed the presence of species like NO, N_2^*, N_2^+, O_2 and N atoms in air gliding arc plasma. Similar species are present in the nitrogen gliding arc plasma except for the NO and O_2 species. The vibrational temperature of nitrogen and air gliding arc plasma near the interface of water was determined by the intensity ratio method and was found to be 3778 K and 4780 K, respectively. The concentration of ammonia in water varied with the plasma exposure time (5, 10 and15 minutes) in both the gases and it was in the range of 3.45 to 10.29 ppm for nitrogen gliding arc and 3.07 to 7.04 ppm for air gliding arc plasma. The ammonia production rate of nitrogen and air gliding arc plasma varied from 0.83 to 0.82 mg $h^{-1}$and 0.73 to 0.56 mg h^{-1}, respectively. Results imply that the nitrogen species formed in the air plasma get oxidized to form high concentration of NO_3^+ ions. Energy efficiency of the nitrogen and air gliding arc plasma varied with respect to the treatment time in the range of 0.032 to 0.031 g-NH_3 KWh^{-1} and 0.025 to 0.019 g-NH_3 KWh^{-1}, respectively. Experimental results show that the gliding arc plasma produced by nitrogen is more favorable than air for the generation of ammonia with water.

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Poster – 66

Thermal Plasma Synthesis of Magnetic Nanosystems as MRI Contrast Agents

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Abstract

Magnetic Resonance Imaging (MRI) is a medical imaging technique based on Nuclear Magnetic Resonance (NMR) [1]. The relaxation time of water protons inside the body is evaluated during MRI scans [2]. It is a non-invasive, non-radiative tomographic tool that can provide satisfactory resolution of the organs [1]. However, it has the disadvantage of delivering very low contrast images. Therefore, MRI Contrast Agent (CA)s are used during MRI scans [3]. These CAs are divided into two types: T_1 CA and T_2 CA. The former enhances spin–lattice relaxation of protons delivering brighter MR images while the latter triggers faster spin–spin relaxation of protons leading to darker MR images. Most of the commercially used CAs are gadolinium (Gd) based as Gd has a high magnetic moment leading to significant contrast. However, Gd is linked with the risk of nephrogenic systemic fibrosis (NSF). Therefore, various other chemicals are being studied to obtain MRI contrast enhancement [2].

Manganese based nanomaterials have been gaining a lot of interest as new class of MR imaging agents among researchers due to their impressive contrast ability. In this study, we have developed manganese oxide (Mn_3O_4) and manganese ferrite ($MnFe_2O_4$) nanoparticles as T_1 and T_2 based MRI contrast agent respectively via a gas phase condensation route using a dc thermal plasma arc reactor. Successful formation of the nanomaterials was confirmed by various characterization techniques. Incubation of B16-F1 cells with the as synthesized nanomaterials did not result in any noticeable decrease in cell viability even up to a concentration of 1 mM, establishing their biocompatibility.

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Poster – 67

Investigation of Microwave Produced Plasma at Low Pressure

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Abstract

Microwave produced plasmas are used for a wide variety of applications such as cold plasma jets, plasma thrusters, coal combustion etc., mainly due to the ubiquitous 2.45 GHz commercial microwave source seen commonly in ovens. On the other hand, low pressure applications are limited due to the multi-physics nature of the problem. In recent years, it has evoked much interest due to the availability of advanced simulation tools and greater understanding of the microwave-plasma interaction. Some of the areas are plasma sterilization and, MPCVD for diamond formation etc. In this work, we have explored the characteristics of microwave plasmas produced at sub-atmospheric pressures of the order of 10^{-2} mbar with a view to use it for plasma sterilization application. The microwave produced plasma has been investigated using single and double Langmuir probes to estimate the density and electron temperature and their profiles. We have also investigated the surface mode to volume mode transition at cut-off electron density of 7.45×10^{10} cm^{-3} for different gas pressures and input powers.

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Poster – 68

Cold Plasma Modeling for *Callosobruchus* Disinfestation and Chlorpyrifos Removal from Soybean Seeds

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Abstract

Soybean is a protein rich plant produce for human and animal diet. However, the quality of the seeds often affected by *Callosobruchus* sp. infestation which lead up to an annual loss of $10 million. To control this, pesticides like chlorpyrifos is used in excess amount on soybeans in many countries. However, due to the neurotoxicity of this pesticide, the application of chlorpyrifos is restricted in many countries. This led a situation where we need a technology to reduce infestation and pesticide residue simultaneously from soybeans. In this regards, cold plasma (CP) can act as diverse technology to address both infestation and pesticide contamination issues of soybean. To determine the treatment effect, CP (1.0 kV-2.0 kV) was applied on soybean seeds that are either infested by *Callosobruchus* or contaminated by chlorpyrifos. The mortality results of this study indicated higher mortality in adults (100.00±0.00%) than in pupa (98.89±1.92%) and egg (37.33±8.08%) stages. While pesticide degradation results showed more than fifty percentage reduction in the chlorpyrifos after 6 min of CP treatment at higher voltage level. Both these results were interpreted with the reactive species concentration produced during the treatment and showed linear relationship with mortality and pesticide degradation effects.

Keywords: Cold Plasma; Soybean; *Callosobruchus;* Disinfestation, Chlorpyrifos; Pesticide Degradation

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Poster – 69

Effect of Plasma Activated Water on the Growth of Maize and Tomato Plant

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Abstract

The growing population and globalization have leveraged the application of various technologies in increasing production and yield of crops. Among them cold plasma emerges as a promising technology on the crop production by contributing to soil remediation, seed germination, plant growth, insect control and, quality management. The formation of reactive species, ultraviolet radiation and charged ions aids its application in agriculture. In this study, we focused on the use of plasma activated water rich in nitrate and nitrite as a green fertilizer for the growth of maize and tomato seedlings. 2.5 litres of tap water were taken and activated for 5 hours by pin to water discharge resulting in pH of 3.4 which was further diluted to neutral pH. The growth of seedling was done with 3 water types: tap water, high concentration PAW (120 ppm nitrate) and low concentration PAW (60 ppm nitrate). The plants were grown for 49 days and the physical and chemical parameters like height of plant, number of leaves, shoot and root length chlorophyll a and b were analysed. The results indicated that high concentration PAW possessed 1.5 times higher shoot and root length, higher number of leaves and higher chlorophyll content in both the plants compared to tap water. The content of chlorophyll a and b was also higher in comparison with tap water. The results we reevident in both the maize and tomato plant suggesting that the concentration of nitrate present in PAW is responsible for the growth of plants. Therefore, PAW stands as a sustainable alternative for the growth of plants in increasing the crop yield.

Keywords: Plasma activated water, agriculture, fertilizer, plant growth and sustainability.

Poster – 70

Micro Plasma Activated Water for Growth of Algae: *Chlorella vulgaris* and *Arthrospira plantensis*

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Abstract

Micro algae are healthy food supplements and active ingredients of pharmaceutical and bioenergy products. Hence, it is cultivated worldwide. Nitrogen is an essential nutrient for the growth of algae. The possibility of plasma activated water (PAW) as a nitrogen supplement for the growth of two beneficiary algae chlorella (*Chlorella vulgaris*) and spirulina (*Arthrospira plantensis*) was investigated in the present study. Tap water was activated (45 min) using micro plasma technique with three different feed gases: air, nitrogen and carbon dioxide. The concentration of nitrates (NO_3^-) for air and nitrogen was 250 mg/L, and 50 mg/L for CO_2; whereas nitrites (NO_2^-) concentration was 40, 20 and 5 mg/L for air, N_2 and CO_2, respectively.

The conventional nitrogen source of Walnes and Zarrouk culture medium of chlorella and spirulina was replaced with PAW. Cell count, biomass, chlorophyll and carotenoid content were monitored daily throughout the experimental period of 6 days. The parameters were found to increase with maximum cell count of 568×10^4 cells/mL chlorella obtained in PAW-air, and 492×10^4 cells/mL for spirulina in PAW-N_2 on final day. The biomass and pigment content illustrated the same trend of hike. Highest chlorophyll and carotenoid content was found in PAW-air cultured chlorella, and PAW-N_2 cultured spirulina. The biochemical constituents of algae lipid, carbohydrate and protein estimated on the final day revealed that maximum protein and carbohydrate was found in PAW-air for chlorella, and PAW-N_2 for spirulina. From the results, PAW water could be effectively used as a nitrogen source to grow algae.

Acknowledgement

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Poster – 71

Mechanical Assisted Plasma Synthesis of ZrC/ZrO_2-SiC Ceramic Composite from Zircon Mineral

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Abstract

Ultra high temperature ceramics has found its use in thermal protection system (TPS), Hight temperature coatings etc. Zirconia and zircon carbide belongs to this type of ceramics. Introduction of sircon carbide can increase their oxidation resistance. We have synthesised Zircon Carbide/Zirconia silica carbide ceramic composite from Zircon mineral by mechanothermal method with the help of planetary ballmill and plasma arc furncae. Initimate mixing of zircon and composite mixture was done by using high energy horizontal planetary ballmill with a powder to ball ratio 1:1 for different time intervals, upto 5 hrs. 3hrs milling time was efective in mixing zircon and carbon which has been confirmed by XRD and Raman studies. Composite mixture was seperated into parts and heat treated in 40kW plasma arc reactor. The complete phase trnasformation of ZrC-SiC ceramic composite has been obtained at 20mins at a power output of 9kW. The ZrO_2-SiC ceramic composite was formed by when the amount of carbon was reduced in the initial milling process. Formation of $ZrC\backslash ZrO_2$ – SiC cermaic composites were confirmed by XRD and SEM-EDX.

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Poster – 72

Comparative Study of Efficiency of Terahertz Using Laser Plasma Interaction: Effect of Different Laser Field Profiles

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Abstract

Today the demand of compact/portable THz (Terahertz) radiation devices which can work at room temperature are needed for the purpose of medical imaging, remote sensing as well as outer space communication. Terahertz is the frequency band lies in between microwaves and infrared waves band with a frequency range 0.1-10 THz. For the purpose of usages, it is necessary to increase the efficiency of THz production and for that scientific community is working. And the best suited way to produce THz using highly intense laser is Laser-plasma interaction technique. Due to variation in laser profile the efficiency of THz changes. There are many theoretical methods to derive the efficiency of the terahertz wave under the effects of different laser profiles. In this paper, we have compared the field and efficiency with different laser field profiles.

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Poster – 73

Interaction and Decomposition of Stationary Magnetoacoustic Structures in Magnetospheric Plasma

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Abstract

In this paper, we consider a dense astrophysical plasma consisting of predominantly electrons, positrons and ions under the action of magnetic field of a star or planet. We have derived the KdV-Burgers equations by using PLK method and obtained shock and solitary wave solutions for magneto-acoustic waves. We have further studied the mutual interaction of such stationary formations and the breakdown mechanism. The possibility of rogue wave like structure are also discussed. We have used a newly designed code to study the time evolution of wave wave interaction and the breakdown mechanism. The results will be helpful to interpret magnetoacoustic wave formations in solar corona, or other stellar entities and can help in under- standing the study of inhomogeneous plasmas in laboratory and fusion reactors.

Brief introduction: Magnetic reconnection is at the heart of many spectacular events in our solar system. The breaking and reconnecting of oppositely directed magnetic field lines in a plasma is referred to as magnetic reconnection (henceforth referred to as "reconnection"). In the process, magnetic field energy is converted to plasma kinetic and thermal energy. The magnetic field lines inside plasmas do not break or merge with other field lines under typical circumstances. However, as field lines approach each other, the pattern shifts and everything realigns into a new configuration.

We have studied magnetosonic soliton interactions formed around the region of magnetic reconnections in the magnetosphere of planets. We have used data from Magnetospheric Multiscale (MMS) mission to identify shocks and solitons in observed magetoacoustic waves in the earth's magnetophere. We have made use quantum-magnetohydrodynamic model (QMHD) and employed Poincare-Lighthill-Kuo (PLK) approach to study behaviour of two oppositely propagating magnetosonic waves as is what happens during magnetic reconnection. We have predicted from our results that the phenomenon of magnetic reconnection causes the formation of shocks in the region and compared with the Magnetic field data provided by the MMS. This work will help theoreticians to model many magnetospheric phenomena.

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Poster – 74

Stimulated Raman Scattering of Self Focused Cosh – Gaussian Laser Beams in Collisionless Plasma: Effect of Density Ramp

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Abstract

Stimulated Raman Scattering (SRS) of intense cosh-Gaussian (chG) laser beams interacting with axially inhomogeneous plasmas has been investigated be incorporating the effect of self-focusing of the laser beam. An intense laser beam with frequency propagating through plasma gets coupled with a preexisting electron plasma wave (EPW) at frequency ω_{ep} and produces a back scattered wave at frequency. Semi analytical solution of the set of coupled wave equations for the pump, EPW and scattered wave has been obtained by using variational theory under W.K.B approximation. It has been observed that SRS reflectivity of plasma is significantly affected by the self-focusing effect of pump beam.

Poster – 75

Modelling of Plasma-Metal Junction

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Abstract

The concept of plasma-metal junction (PM Junction) is presented. Like metal-semiconductor junction, PM Junction is a new kind of hetero-junction where electrons and holes in the semiconductor are compared with electrons and ions in the plasma. This PM Junction can be produced in laboratory plasmas. The electrons in the plasma are free to roam throughout the plasma with no physical boundary to limit their motion while the electrons in the metals are bound within the surface of the metal. The plasma metal junction is a special kind of interface between plasma where the electrons obeying classical statistics follow the Maxwell-Boltzmann Distribution andthe metal electrons distributed quantum mechanically follows the Fermi-Dirac Distribution. The main motivation is to understand the electron behavior at the boundary of the hetero-junction where both plasma and metal have different electron densities and different temperatures. The distribution of charge carriers, current-voltage characteristics, and the potential profile at the quantum-classical junction can be studied from the well-established distribution function of charges on both sides of the interface. The concept of PM Junction may simplify the complex plasma-material interactions in laboratory plasmas including fusion plasmas which is now an emerging field for energy production.

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Poster – 76

Electron – Hole Instability in Spin Polarized Quantum Plasma

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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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Poster – 77

Ion Erosion Study of $BNSiO_2$ (Borosil) Related to Plasma Thruster

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Abstract

$BNSiO_2$ (borosil) is used in stationary plasma thrusters as discharge chamber material due to its lower erosion rates. $BNSiO_2$ composite materials are of specific importance due to their good thermal stability, chemical inertness and low erosion behaviour [1-3]. In this study, we have developed a UHV compatible heating arrangement to externally heat the borosil specimens and observe the changes in their erosion rates with the help of in-situ quartz crystal microbalance sensor. We have presented the erosion rate and the morphology changes on the borosil surfaces at elevated temperatures (100°-700°C) using Xe ions. We observed a linear increase in the sputtering yield with temperature and it remains stable during long duration irradiation. The higher erosion rate at higher operating temperatures is proposed to be due to the thermal spike nature. The morphology changes show periodic nanoscale elevations and depressions (nanoripples) in the range of 70-190 nm. Local curvature dependent erosion plays significant role in such pattern evolution [4].

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Poster – 78

Analysis of Breakdown Characteristics of Various SF_6 Admix in Non-uniform Fields for High Frequency RF

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Abstract

As a traditional insulating gas, SF_6 has a serious greenhouse effect and there has been ongoing research into more environmentally friendly alternative gas as a replacement to SF_6 in HV equipment. The research into alternative gases has shown that SF_6 admixtures have a promising dielectric property as comparable to pure SF_6. In this work, breakdown characteristics of various SF_6 admixtures such as SF_6/N_2, SF_6/dry-air and SF_6/Ar has been tested with 20kHz sinusoidal voltage in a strong divergent field (i.e., Point-Point topology). The experimental work was performed with 5%, 10%, 25%, 50% and 100% by vol of SF_6 at 14.5 psi for a gap length of 0.5 mm. The insulation level with 5% mole fraction of SF_6 was found to be ~30%, 60% and 64% of pure SF_6 in SF_6/Ar, SF_6/N_2 and SF_6/dry-air respectively. In SF_6/Ar admix, growth rate of breakdown voltage was found to be increased from 30% to 60% of pure SF_6 as concentration of SF_6 was varied from 5% to 50%. However, in the case of SF_6/N_2, growth rate in the insulation level got saturated even at lower SF_6 concentration ratio. Our experimental results evidenced that utilization of SF_6 and dry-air/N_2 admixture gas may appropriately substitute usage of pure SF_6 gas thereby reducing greenhouse effect.

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Poster – 79

Study of Standard and Hybrid X-Pinches of Cu on Microsecond Current Driver

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Abstract

The x-pinches [1] found their importance in point projection radiography of high energy density plasma due to formation of point and short-lived x-ray source. In the standard x-pinch (XP) configuration, the jitter in the x-rays is few ns in fast current (>1kA/ns) and tens of ns in slow current (<1kA/ns) drivers. The hybrid x-pinch [1] is formed when a wire is mounted between two conical electrodes separated by a few mm. Although there are numerous reports in the literature available on x-pinches developed on the slow current, however development of hybrid x-pinches (HXP) in these drivers is still unexplored.

We have carried out a direct comparison of x-ray properties of standard and hybrid x-pinch made of copper wires using a 1 µs rise time and 110 kA pulsed power generator [2]. The copper wires of 15 µm dia with 2.5 µm polyamide coating for XP are mounted in between the anode-cathode gap of 13 mm and the angle of the wires from the central vertical axis was 40^0. For HXP a Cu wire of same dimension was mounted in between the gap of 2 mm with similar structure (cone angle of 80^0). PIN diodes in combination with Be (50 µm) and Al (6.5 µm) were used for measurement of timing and yield of soft x-rays.

The onset of soft x-rays in XP and HXP configuration is observed at 561±14 ns and 680 ns respectively. The width of the single soft x-rays burst in the XP and HXP is observed to be 5-15 ns and ~10 ns with the total emission time of x-rays being 60 ns and 40 ns respectively. The number of x-ray bursts in both configurations is 3-5. The maximum soft x-ray yield in a shot in XP and HXP is observed to be 570 mJ and 32 mJ respectively. The energy of the x-rays in HXP is also found to be comparatively lower than the XP. Despite the lower (17.4 µg/cm) linear mass density of HXP plasma, it pinches at a higher current (88kA) than the higher (45.4 µg/cm) linear mass density XP which pinches at 79±2 kA and the former configuration results in to lower yield of soft x-rays. In addition to this, the pinch in the HXP is not found to be consistent i.e. the success rate of HXP in this current regime is observed to be <25% as most of the shots do not result in to pinch, which could be due to formation of coronal plasma at lower current. This study provides a direct comparison of the x-ray characteristics of XP and HXP for their use as an x-ray backlighting source in small laboratory scale applications.

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Poster – 80

Effect of Work Function of Different Metals on the Current-Voltage Characteristics of Langmuir Probe

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Abstract

Langmuir probe is a simple instrument to measure the characteristics of the laboratory plasmas as well as the astrophysical plasmas. The I-V Characteristics of the Langmuir probe depend on the work function of the metal we have taken. Langmuir probes are nothing but bare metal and different metals contain different work functions. The difference in the band structure of the metals leads to the change in I-V characteristics and all metals have different properties. Usually, many satellites along with the Langmuir probes are used to measure the thermal plasma characteristics and the metals used for the probes can be chosen considering their properties. The I-V characteristics measured are not the same for the different metals. The current measured is high, for the metals with less work function. But, the work function is not considered previously in the I-V Characteristics equation of the Langmuir probe. So, the equation of the current includes the dependence of the work function of the metal and plasma potential. These can have many applications in Astrophysical plasmas, where Langmuir probes are installed on satellites and sounding rockets, and also in Laboratory plasmas.

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Poster – 81

Submerged Liquid Plasma Processing of Nitrogen Functionalized Mxene

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Abstract

Recently, a new family of two-dimensional materials called MXene was discovered. MXenes are derived from the MAX phases, which are a class of conductive, layered ternary carbides and/or nitrides composed of an early transition metal M, an A-group element and carbon and/or nitrogen noted X, with the general formula Mn+1AXn. MXenes are synthesized by selectively etching out the A layers from the MAX phases. MXenes have quickly attracted the attention as promising candidates for energy storage applications because they have good conductivities, hydrophilic surfaces, a variety of surface chemistries. Ti_3C_2 Mxenes are produced by etching monoatomic layer of metal specifically Al from Ti_3AlC_2 by initially etching in a hydrofluric acid.

In present study, we are using a unique process ''submerged liquid plasma (SLP)'' for the nitrogen doped/substituted of Mxenes in acetonitrile solution at ambient condition. In the plasma experiments, an mechanically sharpen tungsten needle (0.5 mm diameter) was used as a point high voltage electrode and a Pt sheet was used as a planar ground electrode. The electrodes were immersed into the acetonitrile solution and separated by a distance of ~75 µm. Submerged liquid plasma discharge generates free electrons, these free electrons collisions with acetonitrile solution produce ·H and $\cdot CH_2CN$ radicals. The Mxenes powder reacts with ·H and $\cdot CH_2CN$ radicals produced by acetonitrile solution in submerged liquid plasma resulting highly dispersed nitrogen functionalized Mxenes leads to excellent electrochemical performance. The morphological as well as chemical surface modifications were investigated by XRD, Raman spectroscopy, SEM, and XPS. The presences of nitrogen are confirmed by X-ray photoelectron spectroscopy. The electrochemical charge storage mechanism was investigated. The results indicate that the nitrogen functionalized Ti_3C_2 Mxene displays improved performance compared to non-functionalized Mxene.

Poster – 82

Anode Arc Attachment Behavior inside the Plasma Torch – A Numerical Induction Approximation

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Abstract

We present the modelling of interaction between the plasma and the influence of vapour produced by the anode material, in particular to take into account of the electromagnetic properties of the arc on the material and the Joule heating of the anode. The mentioned arc plasma torch consists of three main parts namely, cathode, anode and plasma containing zone. An electric arc is generated in between the electrodes with the help of a DC power supply. An inlet gas is fed via tangential port to create a gas flow, as it enters the plasma containing zone, where it get ionized due to joule heating to produce a hot plasma and create a Gaussian shaped plasma plume travel across the anode as a superheated jet stream.

The aim of the work is to develop a three dimensional, axi-symmetric, chemical non-equilibrium model for the oxygen torch plasma and results are obtained for the spatial distribution of temperature, velocity profiles, pressure, potential, current density and species densities inside the plasma torch for an arc current of 200 A. The mathematical model for the transferred arc plasma can be approximated to a fluid, the Navier-Stokes equations are used to describe the plasma column, to which we add the electromagnetic equations such as current conservation equation and resolution of potential vectors for magnetic induction calculation to take into account of the electromagnetic properties of the arc. In this regard, a 3-D solver has been developed using the available solvers in the open source toolbox Open FOAM. The temperature distribution inside plasma reveals the arc root attachment at anode is constrictive and diffusive at lower and higher currents respectively. The gas flow rate has shown a great impact on arc attachment behaviour on the anode surface. Diffusive arc mode is favourable with low gas flow rates, whereas localized arc attachment is observed with increase in gas flow rates.

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Poster – 83

Effect of External Magnetic Field and Gas Ambient on Iron oxide Nanoparticles Prepared by Arc Plasma Process

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Abstract

Nanoparticles, in general, have applications ranging from opto-electronics to cosmetics. Magnetic materials like iron oxide when reduced to nanosize have applications in hyperthermia and other biomedical process. Iron oxide nanoparticles have earlier been prepared by thermal plasma process and studied for morphological, structural and magnetic properties as a function of macroscopic plasma parameters [1].

The size, shape and magnetization of resultant iron oxide nanoparticles greatly depends on the nucleation, growth and cluster dynamics within the plasma while synthesizing. The particle dynamics and trajectories are expected to be vastly different when the plasma is under the influence of an external electric or magnetic field. This change, in turn, is expected to change the nanoparticle's shape and size and effectively affect its magnetic properties.

In this work we report on our preliminary results on the changes in morphology and crystalline structure of iron oxide nanoparticles prepared by arc plasma under the influence of external magnetic field. Experiments were done with and without the presence of permanent magnets of ~ 100 gauss. The resultant nano powders were analyzed by techniques like XRD, SEM/TEM, VSM etc. It is observed that in the presence of magnetic field the crystallite size decreases significantly. We also observe changes in the magnetization. The results will be presented and discussed during the conference.

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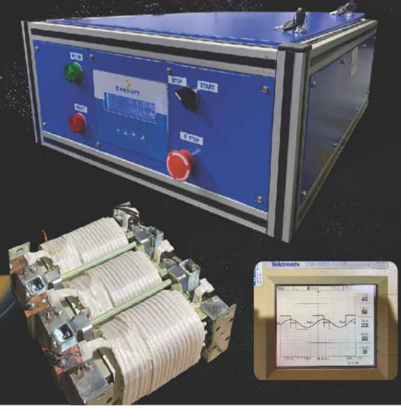

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