Plasma Processing Update

A Quarterly Newsletter from FCIPT, Institute for Plasma Research

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TECHNICAL ARTICLE

Effect of chamber pressure on the output properties of a DC plasma spray torch for VLPPS (Very Low Pressure Plasma Spray) application

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In the present work, the effect of chamber pressure on the electrical and thermodynamic characteristics of a low-pressure thermal plasma jet was studied. The work was carried out with the objective of advancement of knowledge in the understanding of thermal plasma jets under low-pressure conditions and their applications across various domains. The major findings have been reported in a series of publications [1 – 3]. The focus of the study lies on the experimental investigation of the current–voltage characteristics, arc voltage fluctuations, plasma jet temperature, electron density, and velocity within the range of 100 – 500 A arc current at chamber pressures of 100 Pa, 1 kPa, and 3 kPa. The electrical characterization reveals the presence of distinct frequencies including restrike, Helmholtz, and acoustic modes through spectral analysis of the arc voltage [1]. These frequencies exhibit varying behaviour under different chamber pressure conditions. An increase in restrike frequency is observed with decreasing chamber pressure, while Helmholtz frequency remains unaffected. The power density of the acoustic frequency diminishes, eventually disappearing from the spectrum. Although there have been several earlier studies carried out by other researchers [4 and references therein] that highlighted various types of fluctuations associated with arc voltage in atmospheric pressure conditions, the current study primarily focuses on the arc fluctuation behaviour under very low pressure conditions. This is because arc root fluctuations play a critical role in determining both the arc voltage and heat transfer to the feedstock (coating material) in a plasma torch and can also affect the temperature distribution and deposition rate. While extensive research has been conducted to investigate the influence of chamber pressure on the properties of the plasma jet, particularly within the higher pressure range [5 – 7], there is a significant knowledge gap regarding the behaviour of the plasma jet within the very low-pressure to low-pressure regime. This study also explores the transition of the plasma jet from a continuum regime to a frozen state with

decreasing chamber pressure, along with the formation of shock structures. Optical emission spectroscopy is employed to map the excitation temperature and electron density profiles along the jet axis. The results demonstrate that the jet temperature and density peak at the compression zone.

Furthermore, Mach probe measurements of the plasma jet velocity at different axial locations,

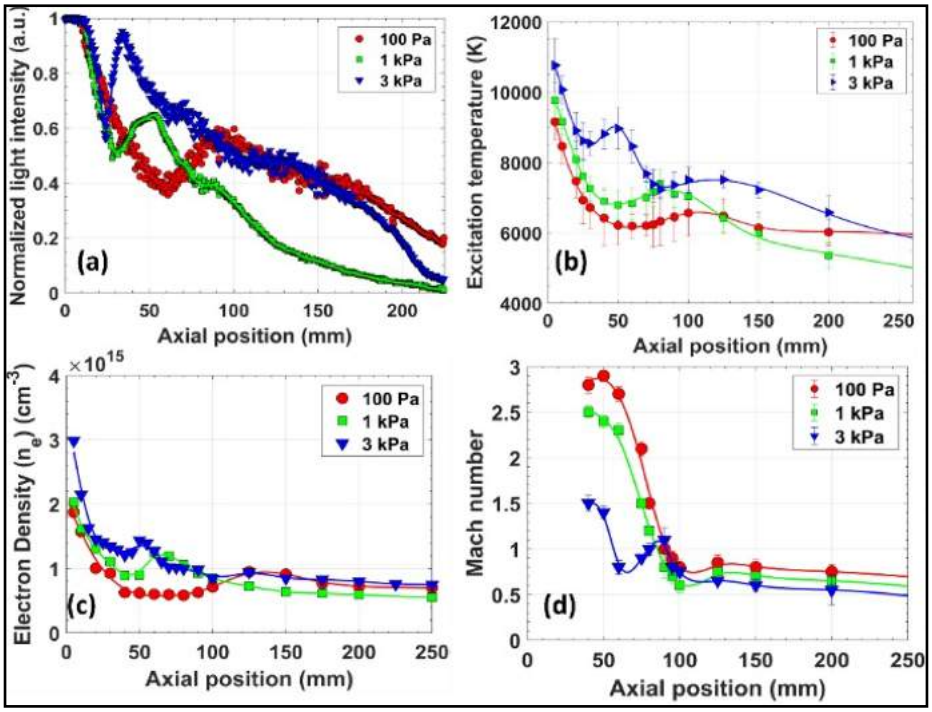


Figure:1 *(a) Normalized light intensity profile (b) Excitation temperature profile (c) Electron density profile (d) Mach number profile of the plasma jet at r=0 and different axial locations, Nitrogen flow rate= 50 LPM, arc power = 30 kW, arc current = 500 A.*

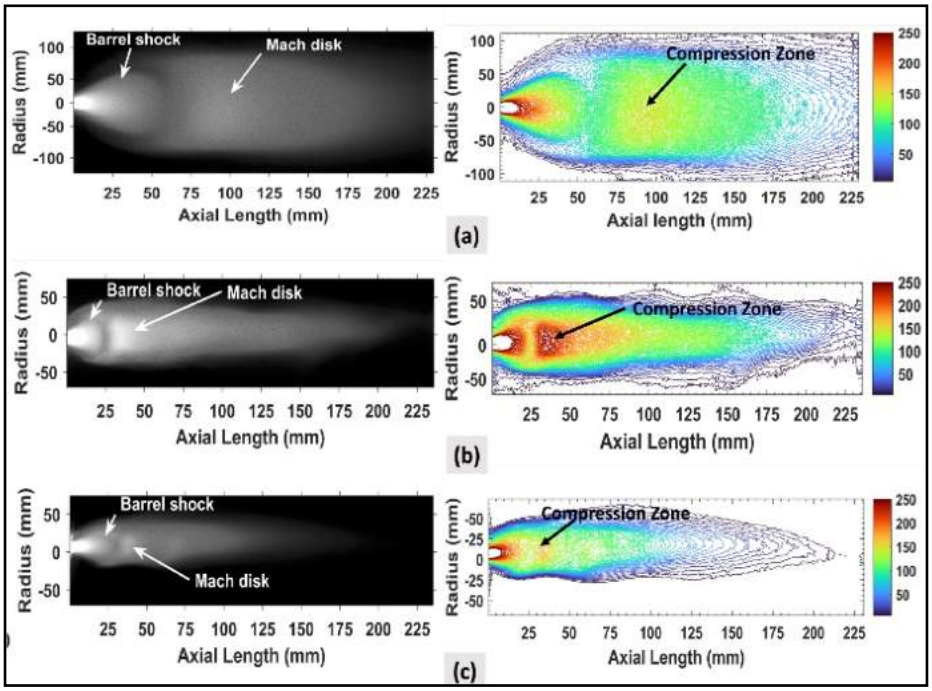


Figure 2: *Evolution of plasma jet images and their respective iso-contour profile for 50 LPM N2 flow rate and 500 A at (a) 100 Pa (b) 1 kPa, and (c) 3 kPa chamber pressure.*

under various chamber pressure conditions, illustrate that the supersonic state of the plasma jet is maintained, regardless of chamber pressure. However, after the formation of a Mach disk, the velocity of the jet becomes subsonic. The highest velocity is achieved at 100 Pa chamber pressure, reaching Mach 2.9 at 50mm from the anode exit. The results greatly enhance our understanding of thermal plasma jets under low to very low pressure conditions, with an emphasis on formation of structured thermal barrier coatings.

References:

1. *R. K. Mohanta and G. Ravi, "Investigation of Subsonic to Supersonic Transition of a Low-Pressure Plasma Torch Jet," IEEE Transactions on Plasma Science, **50** (9), pp. 2941–2951 (2022)*

2. *Ram Krushna Mohanta, Devilal Kumawat, G. Ravi, and Kumudni Tahiliani, "Application of similarity theory to predict operational characteristics of a DC plasma torch under low-pressure condition", Eur. Phys. J. D **77:89** (2023)*

3. *R. Krushna Mohanta, D. Kumawat, and G. Ravi, "Effect of chamber pressure on the output characteristics of a low-pressure DC plasma torch," J. App.Phys., **134** (15), 2023*

4. *V. Rat, F. Mavier, and J. F. Coudert, "Electric Arc Fluctuations in DC Plasma Spray Torch," Plasma Chem. Plasma Process. **37** (3), pp. 549–580 (2017)*

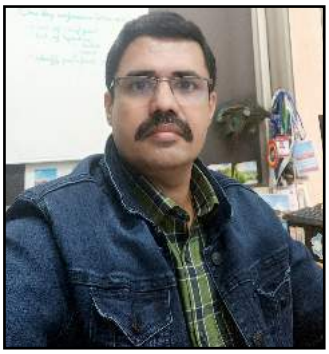
5. *L. Robin, P. Vervisch, and B. G. Cheron, "Experimental study of a supersonic low-pressure nitrogen plasma jet," Phys Plasmas, **1 (**2), pp. 444–458 (1994)*

6. *G. B. M. Gindrat, J. L. Dorier, Ch. Hollenstein, M. Loch, A. Refke, A. Salito et al., "Effect of Specific Operating Conditions on the Properties of LPPS Plasma Jets Expanding at Low Pressure," Proceedings of the Third International thermal spray conference (ITSC), Dec 2014, pp. 459–464*

7. *E. Leveroni and E. Pfender, "Electric probe diagnostics in thermal plasmas: Double probe theory and experimental results," Rev. Sci. Instr. **60** (12), pp. 3744–3749 (1989)*

NEWS - TECHNICAL ACTIVITY

320 kW Plasma Torch System and its successful testing at IPR



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Mr. Bhupendra Patel

Mr.Atik Kumar Mistri

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Plasma torch is a device that converts electrical energy into thermal energy in a very efficiency manner. IPR has indigenously developed a 320 kW graphite electrodes based plasma torch system that has been successfully tested for 16 hours operation. The power supply of this plasma torch system was also tested successfully on resistive load bank for 24 hours, at full load. The electro-thermal efficiency of graphite electrodes based plasma torch system was observed to be 91.6% which is much higher than the conventionally used metal electrode based water-cooled plasma torch system. The graphite electrodes are consumables due to its erosion. The erosion rate of graphite electrodes at 250 kW to 320 kW varying plasma arc power was observed to be 25 mm per hour for two anode electrodes and 50 mm per hour for one cathode electrode during this testing.

Figure 1 (a) shows the red hot graphite electrodes in power off condition. The other images show the power panel and torch system including torch assembly and test chamber. The voltage and current profile on resistive load bank testing is shown in Figure 2 (a). The power supply is a current source power supply. The output power on resistive load bank is shown in figure 2 (b). The voltage and current profile on actual plasma arc load is shown in figure 2 (c) and the power across plasma torch during this testing is shown in figure 2(d). The variation in the power is due to the dynamic impedance of plasma arc load.

Figure 1: *(a) Red hot electrode and chamber; (b) Control Panel; (c) Power supply unit; (d) Plasma torch test system comprising electrodes and chamber*

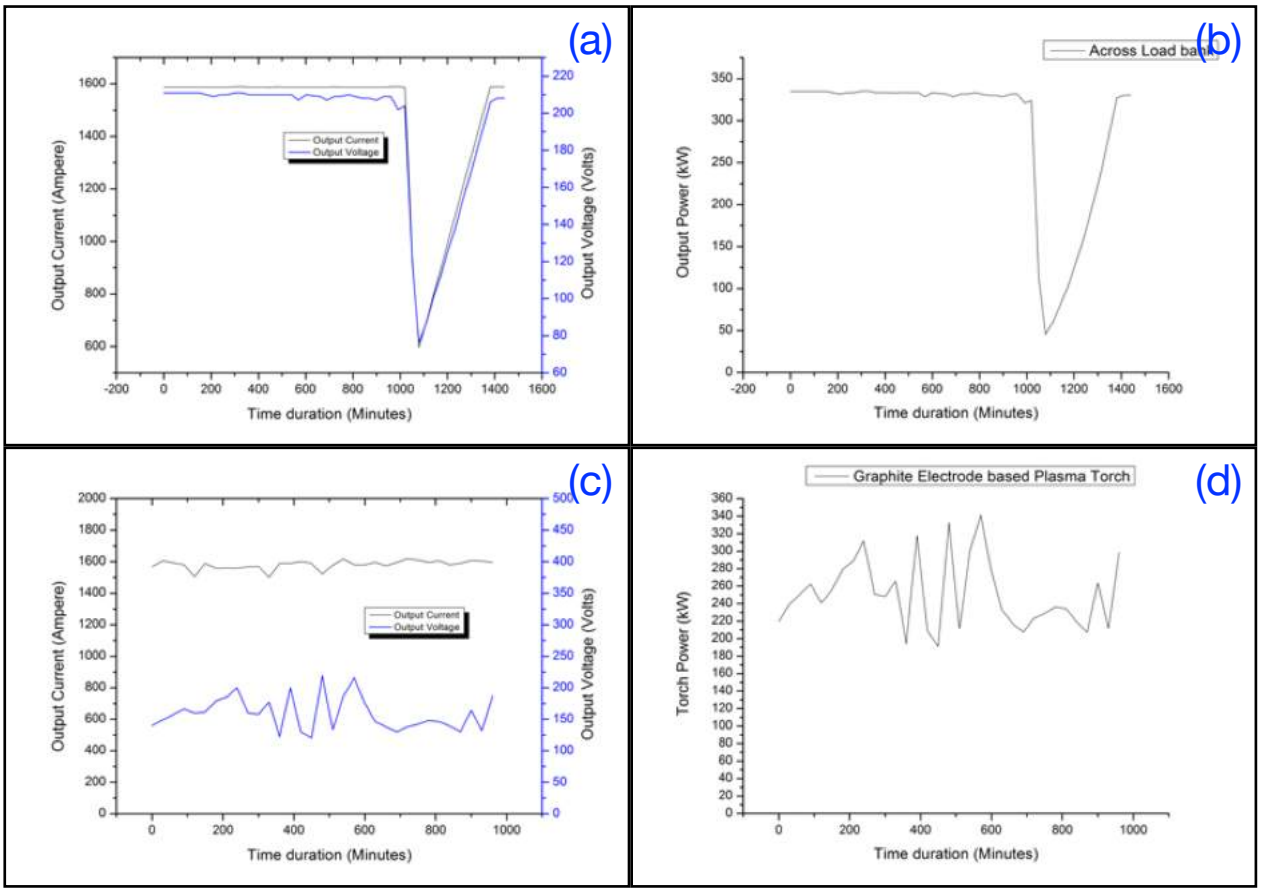


Figure 2: *(a) Voltage & Current profile on resistive load bank testing; (b) Output DC power to resistive load bank; (c) Voltage and current profile on actual plasma arc load; (d) Output DC power across plasma arc load.*

NEWS - TECHNICAL ACTIVITY

Environmental Clearance granted for establishing Common Biomedical Waste Treatment Facility (CBWTF) at Varanasi

IPR is working on a project activity to establish a Common Biomedical Waste Treatment Facility (CBWTF) at Varanasi funded by DAE, Government of India. The site for establishing CBWTF is identified and State Environment Impact Assessment Authority, UP (SEIAA) granted and issued the Environmental Clearance for the project in November 2023. In this facility, indigenously designed and developed 5 tons per day (TPD) plasma pyrolysis plant (RAUDRA) will be used to dispose yellow category biomedical waste. The equipment & machineries required for CBWTF to treat other categories of biomedical waste and all mandatory instruments as per CPCB norms are being procured. Various systems such as power supplies, electrode feeding assembly, oxygen and nitrogen generator, autoclave, shredder, ash collection system were procured, delivered and tested successfully. A shed is under construction for testing the procured equipment and machineries. By March 2024, the 5 TPD plasma pyrolysis plant and associated sub-systems of CBWTF will be tested for their functional performance at IPR facility. The isometric graphical view of integrated 5 TPD plasma pyrolysis (RAUDRA) plant, and the facility being developed for housing this system are shown below.

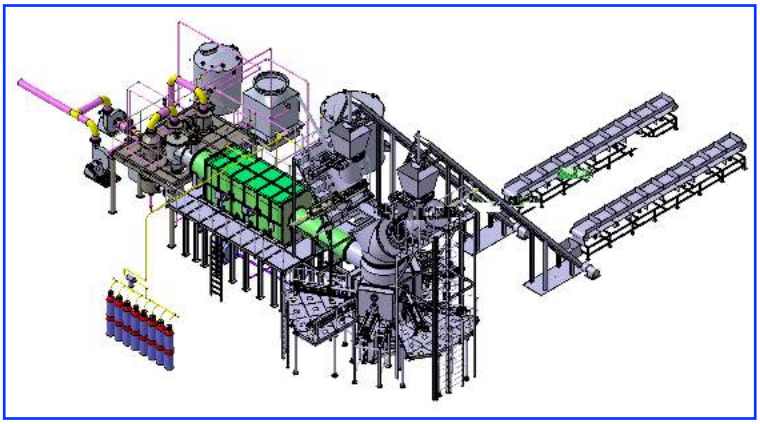


Figure 1: *Isometric graphical view of 5 TPD RAUDRA Plant*

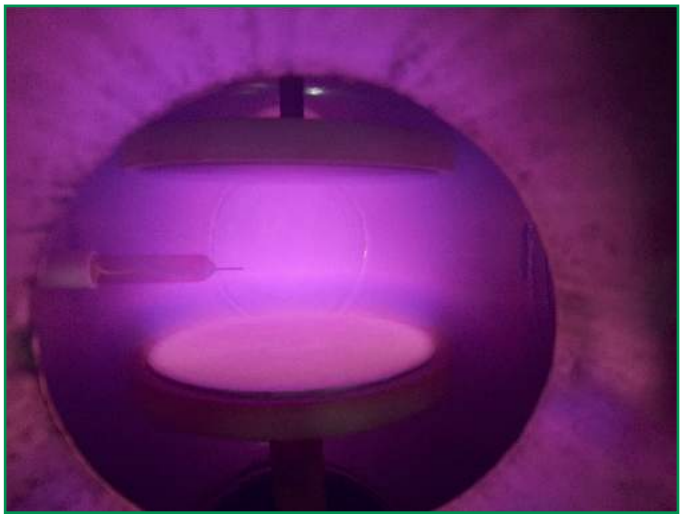
Figure 2: *Construction of the housing facility in progress*

TECHNOLOGY KNOW-HOW AND LICENCE AGREEMENT

GLOW-DISCHARGE SYSTEM ALONG WITH LANGMUIR PROBE DIAGNOSTICS

In India, plasma physics is being taught in most of the universities particularly for post graduate students as an elective subject. The primary objective of teaching this subject is to make the students familiar with the plasma physics, at an introductory level, with emphasis on topics of broad applicability. Hence, to achieve this goal, know-how about making basic prototype glow discharge plasma system along with Langmuir probe diagnostics was developed at FCIPT, IPR; and is ready to be transferred to industries so that colleges and universities can avail these systems and use them for academic purposes.

In this glow discharge system students can carry out experiments to learn about DC discharge production & its diagnosis, Paschen Curve formation, Plasma Striations, measuring plasma density & temperature etc. This know-how has been transferred to M/s Sun vacuum & Plasma engineering, Ahmedabad, in December 2023. Universities, Colleges, and other research institutes in India can contact M/s Sun vacuum & Plasma engineering, Ahmedabad for getting such lab scale plasma system.



Photograph showing a simple DC plasma discharge, and a Langmuir probe in the developed system

Know-how and Licence agreement between IPR and M/s Sun Vacuum & Plasma Engineering

ACHIEVEMENTS

PARVEZ GUZDAR YOUNG SCIENTIST AWARD 2023

Dr. Amreen Ara Hussain, a scientific officer at FCIPT, IPR; has been has been chosen for the PARVEZ GUZDAR YOUNG SCIENTIST AWARD 2023 for her outstanding research contributions in the area of hybrid materials and optoelectronic devices, and plasma technologies. The award was presented to her during 38th National Symposium on Plasma Science and Technology (PLASMA-2023), jointly organised by University of Petroleum and Energy Studies (UPES) and Plasma Science Society of India (PSSI) and held at UPES - Dehradun during December 4-8, 2023. The award consisted of a citation and cash prize. This award was instituted in memory of Dr. Parvez Guzdar by The Parvez Guzdar Memorial Fund.

Congratulations Dr. Amreen.

Dr. Amreen receiving the PARVEZ GUZDAR YOUNG SCIENTIST AWARD 2023

ACHIEVEMENTS

ASM FELLOW AWARD 2023

ASM International, USA (formerly known as American Society for Materials) is a Global Materials Information society with professional members from all across the world. It is popularly known for its ASM Handbooks and for its journals/publications and for its vast materials information database. The society, each year recognizes outstanding work from professionals in the field of materials and metallurgy in the form of Awards. This year, **Dr. Nirav Jamnapara**, a senior scientific officer from IPR has been recognized with the Fellow Award. The award citation reads "*For sustained contributions to the field of plasma materials processing, coatings and promotion of plasma technologies for use by industry and society*". The award was conferred on Dr. Jamnapara during the IMAT 2023 conference at Detroit, USA on 17th Oct, 2023.

Congratulations Dr. Nirav.

Dr. Nirav Jamnapara receiving the ASM INTERNATIONAL FELLOW award

VIP VISITS

VISIT OF EX CHAIRMAN, DAE

Shri K N Vyas, ex chairman, DAE; has visited FCIPT campus on 06.11.2023. He has visited various labs in FCIPT, interacted with the officers & students, and offered valuable suggestions.

STUDENTS' NEWS

THESIS DEFENCE

Ms. Sukriti Hans presented her thesis defence on November 28, 2023, focusing on a detailed examination of ripple patterns on solid surfaces.

The investigation emphasized the role of Ion Beam Sputtering (IBS) in forming patterns at the nanoscale level. The study revealed the formation of triangular features overlaid with ripple patterns on silicon (Si) surfaces using argon (Ar) ions, analysing key factors such as ion beam parameters - energy, angle, and fluence. This analysis provided valuable insights into the intricate details of pattern development.

Additionally, the research explored the thermal aspect of surface pattern dynamics by investigating the impact of substrate temperature. This exploration added a crucial layer to our understanding of how temperature variations influence the evolution of ripple patterns. A significant finding was the exploration of the transition from triangular morphologies to corrugated structures, revealing dynamic processes guiding this transformative shift in surface features. The study also specifically concentrated on the role of xenon (Xe) ions on silicon and germanium (Ge) surfaces, contributing to a deeper comprehension of the complex interactions between ions and materials.

Furthermore, the investigation extended to nanopatterning on compound materials, with a focus on soda-lime glass. By strategically adjusting ion beam parameters, such as energy, fluence, and incidence angle, the study uncovered a clear transition from ripple patterns to terraces. The implications of this research are profound, carrying the potential to drive innovation in nanoscale surface manipulation.

The applications extend across diverse industries, encompassing large-scale manufacturing, anti-reflective coatings, the production of optical devices, electronic components, and more. This research showcases Ms. Sukriti Hans's significant contributions to advancing the understanding of surface patterns and their applications.

Sukruti Hans with the Doctoral Committee after Thesis defence

OTHER ACTIVITIES

INTEGRITY PLEDGE

As a part of the Vigilance Awareness Week during Oct. 30 - Nov. 05, the Integrity pledge was administered at FCIPT campus also on 30th October 2023. The pledge was administered in both Hindi and English.

RASTRIYA EKTA DIWAS

Rashtriya Ekta Diwas is celebrated every year on the birth anniversary of Sardar Vallabh bhai Patel i.e. on 31st October. On 31.10.2023, all employees gathered and a Unity pledge was administered on this occasion.

OTHER ACTIVITIES

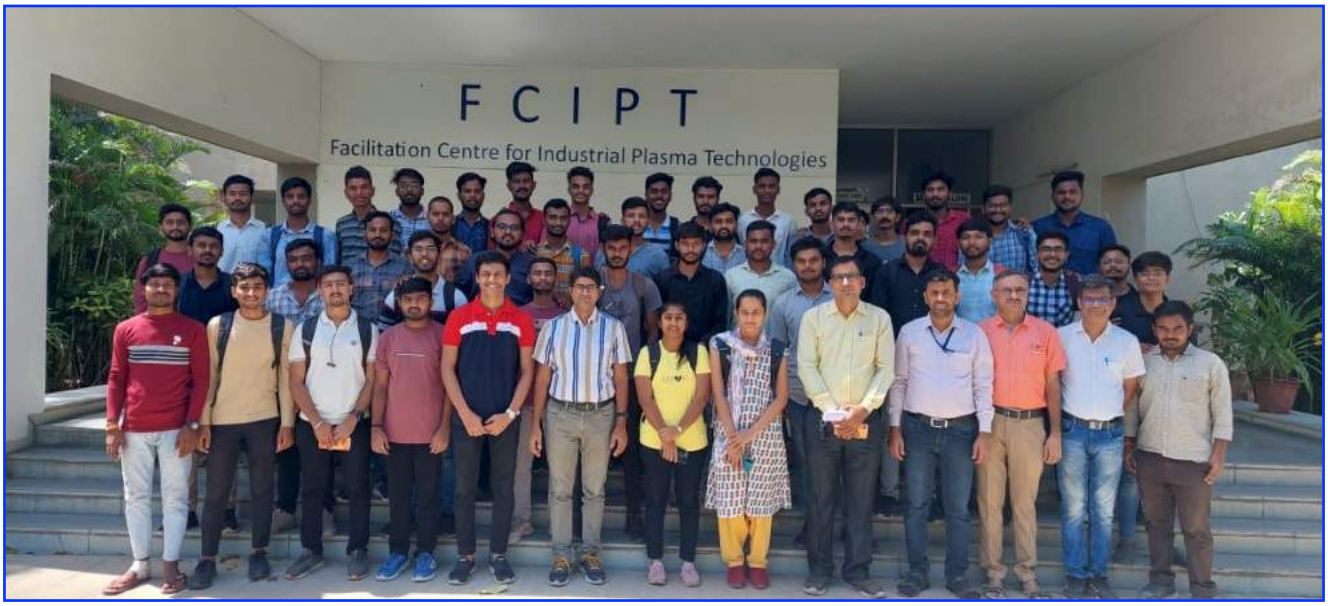
HINDI PAKHWADA

HINDI PAKHWADA was organised in IPR from 18-29 September 2023. Various competitions were conducted and FCIPT staff also actively participated in the same. Pictures of winners in some of the competitions are presented below.

Mr. Satyaprasad, Dr. Mukesh Ranjan, Mr. Akhtar Jamal receiving prizes from Director, IPR

OUT-REACH ACTIVITY AT FCIPT

51 students studying B.Tech. final year (Materials Science and Metallurgy) at Government Engineering College (GEC), Gandhinagar visited FCIPT as a part of industrial visit.



Group photo of the visiting students and faculty, with officers of FCIPT

PATENTS / PUBLICATIONS / TALKS DELIVERED

Patents applied / granted:

1. System and Method for Air Disinfection
   Alphonsa Joseph Palakel, Ramkrishna Satyavan Rane, Akshay Vaid, Anand Visani, Taslimarif Saiyed, Kaushik Choudhury, Paresh Patel,
   Provisional Indian Patent App. No. 202341063140 (Sept 2023)

2. A method for increasing the life of cutting tools
   Alphonsa Joseph, Ghanshyam Jhala, Akshay Vaid and S. Mukherjee
   Granted final Indian Patent : 488119 on 22 December 2023

Publications in peer reviewed journals:

1. Plasma Sterilization for Bacterial Inactivation: Studies on Probable Mechanisms and Biochemical Actions. Plasma Chem Plasma Process
   Tejal Barkhade, Kushagra Nigam, G. Ravi, Seema Rawat, S.K. Nema
   Plasma Chem Plasma Process (2023) *https://doi.org/10.1007/s11090-023-10429-5*

2. Effect of chamber pressure on the output characteristics of a low-pressure DC plasma torch
   Ram Krushna Mohanta, Devilal Kumawat, G Ravi
   J. Appl. Phys. 134, 153302 (2023) *https://doi.org/10.1063/5.0160624*

3. Initial Effects of Plasma Treatment on Maize Seeds: A Laboratory Study
   Kundan Viliya, Uttam Sharma, Manisha Thakur, Jayshree Sharma, K N Guruprasad, **R Rane** and J Ghosh
   Journal of Physics: Conference Series (2023)

4. Investigating the Role of Plasma-Activated Water on the Growth of Freshwater Algae Chlorella Pyrenoidosa and Chlorella Sorokiniana.
   Vikas Rathore, S.K. Nema
   Plasma Chem Plasma Process (2023) *https://doi.org/10.1007/s11090-023-10372-5*

5. Applications of Plasma in Metallurgy and Vice-Versa: Indian Context
   Alphonsa Joseph, Sudhir K. Nema,Amit Sircar,Paritosh Chaudhari, Upendra Prasad, Sameer Khirwadkar, Nirav Jamnapara
   Book chapter in Indian Metallurgy, Indian Institute of Metals Series,Springer, Singapore; ISBN no. 978-981-99-5059-1; pages 07-19; 16 November 2023

6. High-Temperature Wear and Frictional Performance of Plasma-Nitrided AISI H13 Die Steel
   Ashish Kumar, Manpreet Kaur, Alphonsa Joseph, Ghanshyam Jhala, Tarun Nanda, Surinder Singh
   Lubricants, Vol. 11, Issue 10, P 448; October 2023

7. Penicillin Antibiotic (Ampicillin and Cloxacillin) Degradation Using Non-thermal Pencil Plasma Jet.
Vikas Rathore, Akanksha Pandey, Shruti Patel, Jignasa Savjani, Shital Butani, Heman Dave & Sudhir Kumar Nema
Water Air Soil Pollut 235, 44 (2024). *https://doi.org/10.1007/s11270-023-06846-z*

Research / Technical Reports :

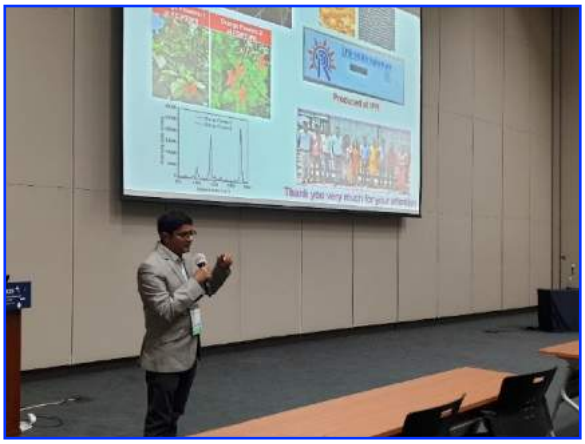
1. Spectroscopic & Microscopic Studies on Inactivation of Staphylococcus aureus and Salmonella abony Exposed to Direct Current Plasma
Tejal Barkhade, Kushagra Nigam, G. Ravi, Seema Rawat, S.K. Nema
IPR/RR-1546/2023

2. Establishment of a new research and development facility for exhaust gas treatment
Kushagra Nigam, Biswaranjan Sahoo, Abhijit Boruah, Chirayu Patil, G Ravi
IPR/TR/776

Talks delivered :

1. **Dr. Mukesh Ranjan** gave an invited talk on "Hydrophobic to surperhydrophoic transitions in Ar plasma irradiated PTFE surfaces for self-cleaning application" during the 13th Asian-European International Conference on Plasma Surface Engineering **(AEPSE-2023) at Busan, South Korea** from 5-8 November 2023**.** Dr. Ranjan **also chaired the session on Plasma coatings and Surface Properties**.
2. **Dr. Mukesh Ranjan** gave an invited talk on "Low energy ion beam for nanostructuring of PTFE bulk and thin film for surface wettability and nanoparticles arrays for sensing applications" during the 7th International Conference on Nanostructuring by Ion Beams (ICNIB-2023) at UPES, Dehradun 2-4/11/23.
3. **Dr. Mukesh Ranjan** gave an invited talk on "Nanoparticles arrays for SERS based sensing" during International Conference in condensed matter and Device physics conference (ICCMDP-23) held at PDEU, Gandhinagar from 27-29 October 2023.
4. **Dr. Mukesh Ranjan** gave an invited talk in 3rd International Conference on "Growth of Surface features through Plasma Material Interaction" during Plasma Theory and Simulations (PTS-2023) organized by the School of Physical Sciences, Jawaharlal Nehru University (JNU), New Delhi, India from 21-23 September 2023
5. **Dr. Alphonsa Joseph** gave an invited talk on "Fundamentals of Corrosion" at NITTTR, Gujarat Extension Center Ahmedabad on 20th October 2023
6. **Mr. Ram Krushna Mohanta,** a DDFS-Ph.D. research scholar working at Plasma torch lab, FCIPT presented an oral talk on the "Effect of chamber pressure on the output properties of a DC plasma spray torch for VLPPS application", at the 12th edition of Asian Thermal Spray Conference (ATSC) held at IIT Madras from 2-4 November 2023. ***The talk was selected for Best paper award.***
7. **Dr. Sukriti Hans** gave an oral presentation on "Facet evolution on Si surfaces under low energy Xe ion irradiation: Influence of ion beam parameters" during 7th International Conference on Nanostructuring by Ion Beams (ICNIB 2023) held at UPES, Dehradun on 2 Nov 2023.

7. **Dr. Sukriti Hans** gave an oral presentation on "Evolution of Triangular Features on Si Surfaces under Low-Energy Ar Ion Irradiation" during 28th International Conference on Nuclear Tracks and Radiation Measurements (ICNTRM 2023) held at Gurugram University on 8 Nov 2023.
8. **Dr. Ramkrishna Rane** gave an invited talk on "Plasma surface modifications for biomedical applications" during 38th National Symposium on Plasma Science & Technology (PLASMA 2023) held at UPES Dehradun on 4-8th December,2023.

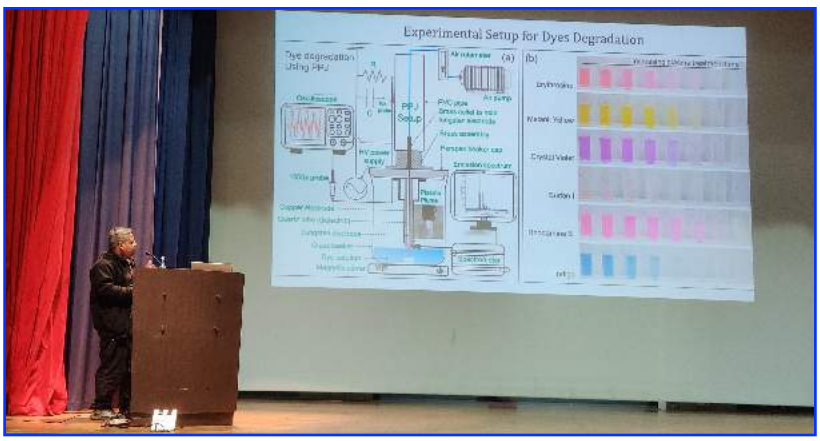


Dr. Mukesh Ranjan at Busan, South Korea. (AEPSE-2023)

Mr. Ram Krushna Mohanta, at IIT, Madras (ATSC)

Dr. Ramkrishna Rane at UPES, Dehradun. (PLASMA-2023)

Ms. Sukriti Hans at UPES, Dehradun (ICNIB-2023)

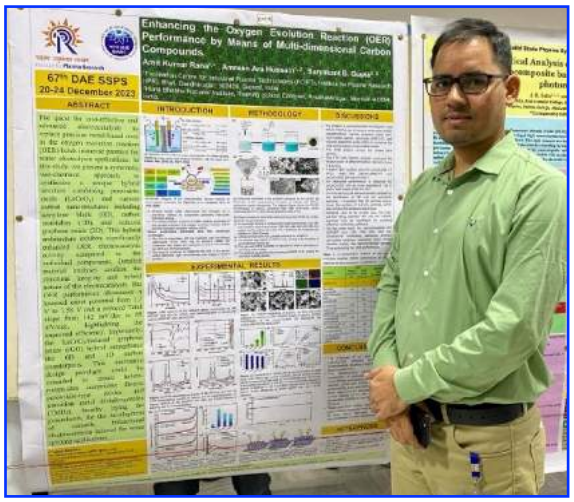


Dr. Vikas Rathore at UPES, Dehradun (PLASMA-2023)

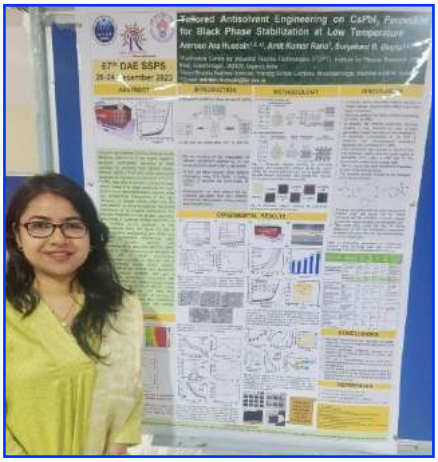
Poster Presentations:

1. A poster was presented by **Dr. Amreen Ara Hussain** on "Tailored Antisolvent Engineering on CsPbI3 Perovskite for Black Phase Stabilization at Low Temperature", during 67th DAE Solid State Physics Symposium (**DAE SSPS 2023**) organized and sponsored by BARC and DAE BRNS; held at GITAM, Visakhapatnam, 20-24 December 2023.
2. A poster was presented by **Dr. Amit Kumar Rana** on "Enhancing the Oxygen Evolution Reaction (OER) Performance by Means of Multi-dimensional Carbon Compounds" during 67th DAE Solid State Physics Symposium (**DAE SSPS 2023**) organized and sponsored by BARC and DAE BRNS held at GITAM, Visakhapatnam, 20-24 December 2023.
3. A poster presentation was given by **Mr. Kushagra Nigam** "Parametric study of microwave field distribution in plasma sterilization chamber" during 3rd International Conference on Plasma Theory and Simulations (**PTS 2023**) organized and sponsored by Jahawarlal Nehu University, held at New Delhi, on 21-23 December 2023.
4. Posters on various topics were presented by Mr. Satyaprasad, Mr. Akshay Vaid, Mr. Anand Visani at **PLASMA-2023**, held at UPES, Dehradun, during 04-08 December 2023

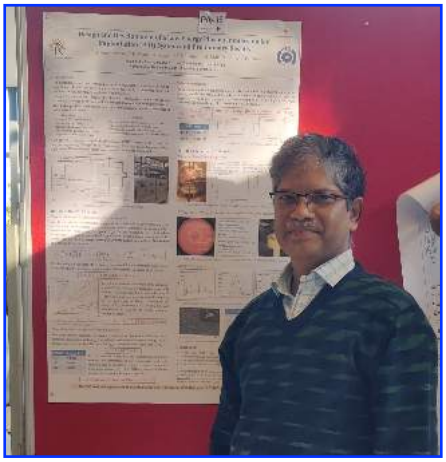
Mr. Kushagra Nigam



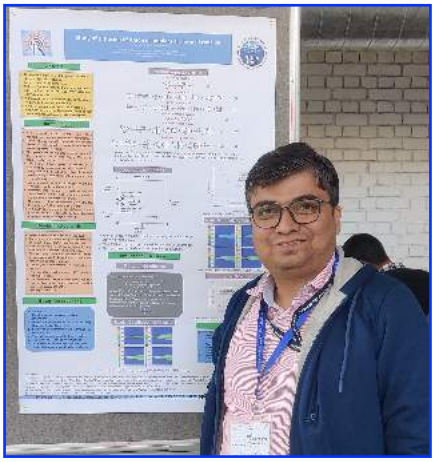
Dr. Amit Kumar Rana



Dr. Amreen Ara Hussian



Mr. Satyaprasad



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