

PLASMA PROCESSING UPDATE

Issue 104



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EDITORIAL TEAM

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FACILITATION CENTRE FOR INDUSTRIAL PLASMA TECHNOLOGIES (FCIPT)

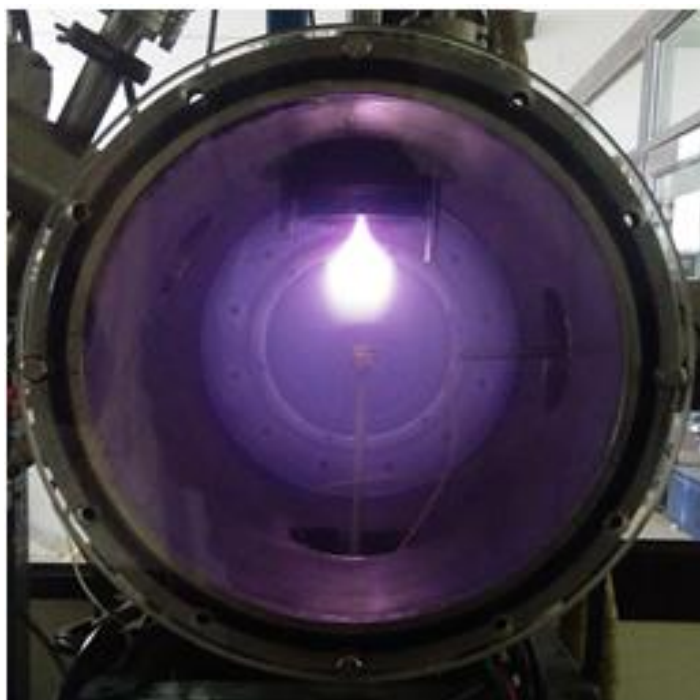
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Plasma Fireball



Superhydrophobic properties of jute originated by synergistic effect of argon plasma and HDTMS coating



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Introduction:

As per the production of natural fibers worldwide, jute is the second most important fiber after cotton. World population review reports (<https://worldpopulationreview.com/country-rankings/jute-production-by-country>) that India produces 1.97-million-ton jute as of 2023. The superhydrophobic fabrics with unique characteristics like self-cleaning, anti-icing, anti-contamination have received tremendous attention which is inspired by the lotus leaf effect^[1]. Superhydrophobic jute could also be used for the production of conventional textile products such as carpets, bags, sacking, dresses etc. The superhydrophobic fabric could be synthesized by various methods for example sol-gel process, dip coating method, Plasma treatment, Radiation assisted method, Acetylation, etc. Out of these, plasma treatment was known to modify various surfaces including textile surface. Anwer et al. studied the low temperature Ar-plasma (50, 75, and 100 W discharge) effect on the jute fibers^[2]. His group observed that the moisture content was reduced due to the surface modification of plasma treated jute. But, plasma treatment sometime creates loss of other important functional groups such as $-CH_2$. Surface chemistry of jute composite treated with atmospheric plasma was studied by Kafi et al^[3]. The wicking properties of jute cotton blend composite was reported by Ullah et al^[4]. There was a 50% reduction in the contact angle for the composite treated for 20 mins. Atmospheric plasma affects the mechanical properties of jute fiber, it generates roughness and increases the mechanical interlocking between the fiber and matrix^[5]. Compared to other processes, it was observed that Ar-plasma treatment to jute improves the de-wetting properties as it reduces the hydroxyl groups present in the jute. However, the effect diminishes with aging, as the surface chemistry of jute changes over time^[6]. Therefore, after plasma treatment, jute is subjected to chemical modification, which can enhance its superhydrophobicity and help mitigate the aging effect.

To tackle the current challenges, the present work proposes an approach to enhance the wettability of jute fabric using RF plasma etching followed by Hexadecyltrimethoxysilane (HDTMS) coating. In this study, jute surfaces have been treated at 30 W, 60 W and 90 W RF plasma (for 5, 10 and 15 mins) and later, treated with the hydrophobic solution of HDTMS in ethanol using the dip coating method. The treated jute and HDTMS modified jute have been further studied by using FTIR and SEM. The superhydrophobic properties of modified jute have been investigated by the contact angle, sliding angle and wetting time measurements. The wetting time was significantly increased after plasma treatment followed by HDTMS coating, indicated improved water resistance of jute fabric. After the plasma treatment and HDTMS coated jute surface was characterized in terms of contact angle, adhesive force analysis, and de-wetting time test.

Contact angle Analysis:

Figure 1 (a-b) show the contact angle image of raw jute and jute treated at 90W for 10 min and coated with HDTMS whereas **Figure 1(c)** show contact angle of each sample. In this graph, each shaded portion represent the power (30, 60 and 90 W RF power) whereas the ball symbol represents the exposure time (5, 10 and 15 mins). The black colour line with dot shows the contact angle of plasma treated jute whereas the red line data shows the contact angle of plasma treated jute followed by HDTMS coating. A 16% enhancement in the contact angle was observed for jute treated at 90 W RF power for 10 minutes, compared to bare jute. With the change in time the contact angle is also increased. This increase in contact angle was due to the interaction of argon plasma with the jute surface that generate the roughness as observed in the SEM image. This interaction creates more complex surface topography which traps the air and leads to an increase in contact angle. Also, the surface chemistry of fiber was altered by plasma treatment as supported by FTIR data. Compared to bare jute, at 90W RF power for 10 mins treated sample shows a 20% increase in contact angle. HDTMS coating also provides durability to the plasma treated sample. To check the stability of the samples, the contact angle of 30W to 90W RF plasma treated sample for 10 mins exposure was studied for 28 days at interval of 7 days. However, the HDTMS coated jute remained stable as the contact angle is unchanged for almost a month.

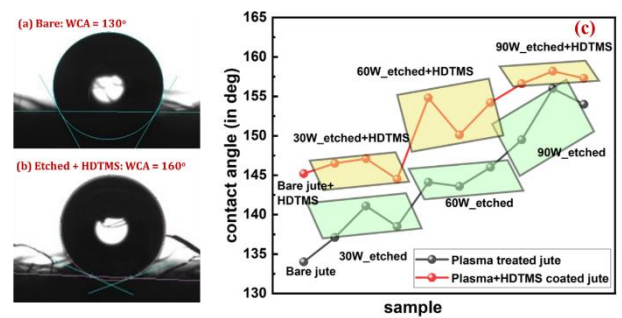


Figure 1: (a-b) Contact angle image of raw jute and jute treated at 90W for 10 min and coated with HDTMS whereas (c) show contact angle of each sample.

Adhesive force analysis:

From **Figure 2**, it is observed that water droplet does not roll from the bare jute fabric; same behaviour is observed for the jute treated at 30 W for 5, 10 and 15 mins. The water droplet starts to roll from the jute surface treated at 60W for 5 mins. It has the highest adhesive force of 161.22 μN which reduced to 114.84 μN for 90W, 15 mins RF plasma treatment. A 40% reduction is observed in the adhesive force after plasma treatment with respect to the jute treated at 30 W for 5 mins. However, after HDTMS coating, the water droplet starts to roll off the raw jute fabric, but the adhesive force remains quite high (183.62 μN). HDTMS reacts with $-\text{OH}$ groups present in the cellulose molecules of the jute, forming a hydrophobic layer on the surface that imparts water-repellent properties to the fabric. An abrupt behaviour is observed in the HDTMS and plasma treated jute. The minimum adhesive force is observed for jute treated at 60W RF power, which is 84.32 μN . A 50% reduction in adhesive force is observed compared to bare jute coated with HDTMS. This reduction in the adhesive force suggests that plasma treated jute with HDTMS coating is highly superhydrophobic in nature.

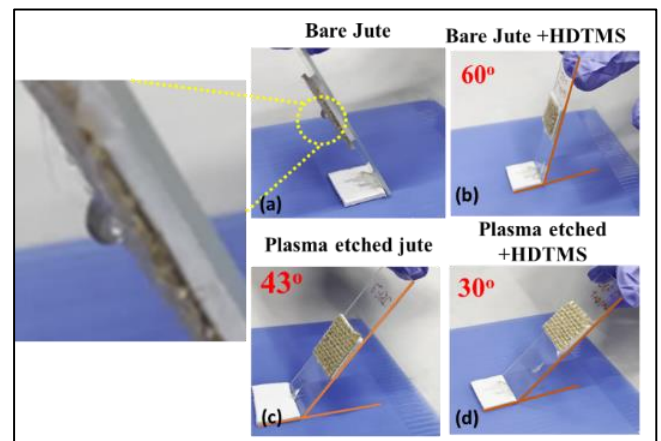


Figure 2: Droplet roll of test on raw jute and plasma treated jute along with HDTMS + Plasma treated jute.

De-wetting time test:

The measurements were taken on raw jute, plasma treated jute and HDTMS coated-plasma treated jute (as shown in **Figure 3**). In the case of raw jute, the water droplet was absorbed within 48 seconds. However, after plasma treatment at 30 W RF power for 10 minutes, the de-wetting time increased to 17 min. There is ~ 21 times enhancement for 30 W RF power- 10 mins treated jute compared to bare jute. However, for 90 W RF power-10 mins treated jute with HDTMS ~220-fold enhancement in the de-wetting time is observed

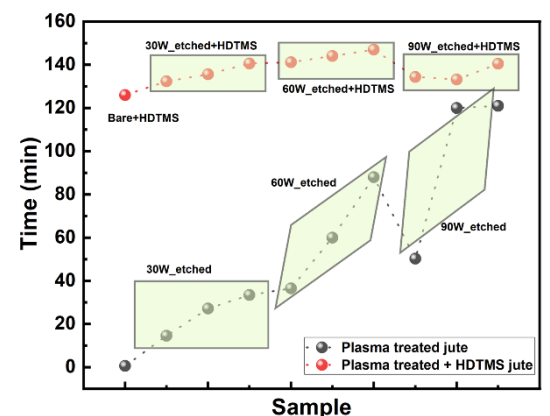


Figure 3: De-wetting time of plasma treated jute and HDTMS coated-plasma treated jute at various power and plasma exposure time.

compared to bare jute. This change is related to the surface polarity i.e., formation of new functional groups on the surface which is correlated with FTIR data. The removal of pectin and the waxy layer from the outer surface of jute fiber is responsible for the enhancement in de-wetting time, as reported in the literature. HDTMS coating provides an additional protective layer, making the jute surface become more durable. The wetting time doubles after the coating and then gradually increases with power and time. Jute treated with 60W RF power for 10 mins and coated with HDTMS shows the highest wetting time. The wetting time then decreases slightly for jute treated with 90 W RF power followed by HDTMS coating, but it remains higher than that of plasma-treated jute samples. This coating improves the wettability and enhances the moisture resistance of jute.

Summary:

This study offers valuable insights how RF plasma can be effectively used for sustainable surface engineering. It highlights the role of plasma in activating natural fiber surfaces, improving chemical grafting, and achieving durable superhydrophobicity without harmful chemicals. The integration of plasma treatment with silane coating demonstrates a scalable, low-energy, and environmentally friendly approach, reinforcing the relevance of plasma in green manufacturing. These results not only validate the practical utility of plasma in material functionalization but also open pathways for industry partnerships, eco-innovation, and interdisciplinary research in advanced textiles and biodegradable materials.

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Plasma Treated Antimicrobial Polymer: A Sustainable and Green Solution for Foodstuff and Healthcare Packaging



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Plasma treated polymer-based antimicrobial packaging embodies a transformative advancement in the arena of active and intelligent packaging. The combination of functionality, chemical free, sustainability, and cost-effectiveness makes this technology particularly appreciable for food preservation and healthcare applications with enhanced product shelf life and consumer safety. Crucial optimization of each plasma parameter may offer a technology transferable recipe with low cost green solution to the food and healthcare packaging industry.

An advanced packaging for food and healthcare appliance require a safe and hygienic technology, with superior material performance and enhanced shelf-life characteristics due to their direct impact on human health [1-4]. Among them, plasma treated surface activated polymer-based antimicrobial packaging has emerged as a promising innovation to enhance product safety and shelf life by controlling microbial growth. In contrast with the conventional polymer packaging, plasma treated antimicrobial material introduces an active protection mechanism, inhibiting pathogenic, spoilage microorganisms and reduce biofilm formation directly from its activated surface. This intelligent approach plays a crucial role in maintaining hygiene, plummeting foodborne illnesses, and supporting sustainability and by minimizing food waste and prevent chemical hazards in terms of solvents or any other preservatives. Plasma activated antimicrobial packaging works through Contact Killing Mechanism (CKM) [4-5] i.e. when the foreign microbes interacts with the polymer surface directly with microbial cell walls, disrupting cellular integrity and metabolic processes. The effectiveness of antimicrobial polymer packaging depends on factors such as the type of polymer/polymer blend used and its nature (molecular weight and its distribution, crystallinity, packing factor, branching, tacticity and crosslinking), its surface properties (including surface charge density, wettability, roughness, topography, and stiffness), and environmental conditions like humidity and temperature.

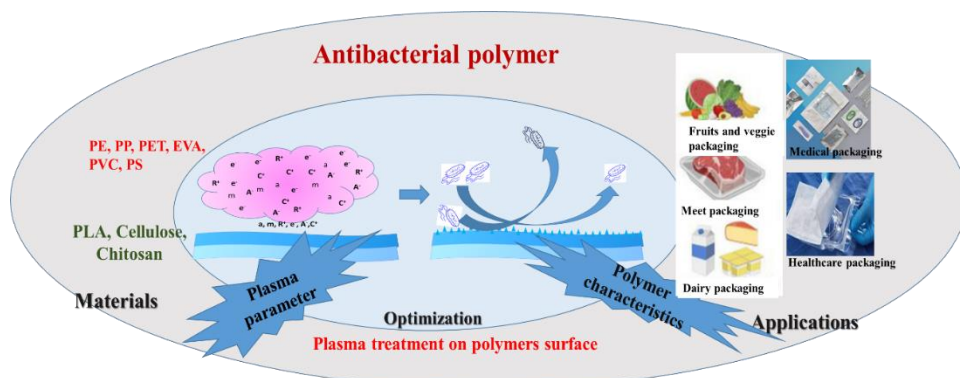


Figure 1: Schematic representation of plasma induced antimicrobial polymers

Both synthetic and biodegradable polymers are used as matrices for antimicrobial packaging, depending on the anticipated application and sustainability goals. Common synthetic polymers include various types Polyethylene (PE), Polypropylene (PP) and their blends are widely used due to their flexibility, durability, and ease of processing.

Polyethylene terephthalate (PET) also offers excellent gas barrier and mechanical properties, making it suitable for beverage

and food packaging. Polystyrene (PS), Polyvinyl chloride (PVC) and their blends are used for specific applications necessitating higher stiffness and optical transparency. Presently, biodegradable polymers with eco-friendliness and compostability such as Polylactic acid (PLA), Polyhydroxyalkanoates (PHA), Starch-based polymers, Chitosan, Cellulose derivatives exhibit superior candidature to develop sustainable packaging technology [3-6].

Plasma exposure can effectively alter the materials and its surface based property. In case of blend, there is another important factor i.e. miscibility which can be very crucial during surface plasma treatment. Large and positive value of Flory-Huggins Interaction Parameter (χ_{12}) indicated antifouling surface coatings with surface phase separation and thus create repulsive surfaces for bacterial adhesion. Depending on plasma parameter and exposure time a tunable, reproducible, up-scalable, low-temperature, low-cost recipe can be developed with bacteria-free, functionalized polymer /polymer blend surface.

There are lot of researches available for solving these issues using plasma treatment as pre activation of polymer surface. In these type of processes, either very low pressure (10^{-6} - 10^{-4} mbar range) or high purity gases (O_2 , N_2 , NH_3 , Ar) [5-6] are extensively used. Owing to various issues such as reproducibility, use of chemicals during or post plasma treatment, lack of crucial optimization of plasma process parameters and standardization etiquette, the process is not fully commercialized. Another big challenge is unavailability of a proper mechanism for bacterial adhesion correlating with surface chemistry, texturing and morphology, study of plasma parameters, temperature, relative humidity, and relative concentration of each gas present in the atmosphere. Especially on Gram- positive bacteria very few researches have been addressed. Our group is presently working on addressing all these challenges collaborating with Nirma University, Ahmedabad.

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Innovation Talks - Expert Lecture Series

The Institute Innovation Council of IPR in association with Homi Bhabha National Institute (HBNI) and IPR's Atal Incubation Centre - Plasmatech Innovation Foundation organized an innovation talk series expert lectures on the following topics:

(a) Talk on "Safeguarding IP for Deeptech Innovations" by Shri P. R. Dani, IP expert on 7th August 2025:

The talk was aimed at safeguarding the intellectual property for deeptech innovations which act as a moat for long gestation innovations and can also act as revenue enabler in future. The talk by Shri Dani showcased what stage patenting should be done and how securing IP based on territorial markets could strategize the country of interest and the procedures and policies so involved. The talk was attended by 40+ participants including students, faculties and researchers.



Shri P. R. Dani delivering lecture

(b) Talk on "Enabling Deeptech Innovations - Experience with AIC- Pi Hub" by Dr. Christ P. Paul, Director & Head of AIC-Pi Hub, RRCAT, Indore on 8th August 2025: The talk was attended by over 50+ participants comprising of Ph.D. students, post-doctoral fellows, researchers and startup enthusiasts. The expert talk explained how deeptech innovation ecosystem has been garnered in RRCAT, DAE and how complex science innovations are enabled through several collaborations ranging from laser based metal 3D printing to sensor technology.



Dr. Christ P. Paul delivering lecture

Celebration of World Entrepreneur Day 2025 at IPR

Institute Innovation Council (IIC) and AIC-Plasmatech coordinated the celebration of the World Entrepreneurship Day 2025 at IPR on 21st August 2025. On this occasion, the guest speaker, Dr. Ravindra Raj, CEO & MD of OmSPACE Rocket & Exploration Pvt. Ltd. presented his entire journey as an M.Tech student in power engineering to CEO. He mentioned that, focusing on his product as well as on the finances are the key aspects of Entrepreneurship. Finally, he gave an overview, how his company is contributing in the launching of Nano-satellites, reusable small launch vehicle (RSLV) and in space technology training program. He is very closely working with various national and international space agencies. In the end of the program, students actively interacted with the speaker and discussed how to become Entrepreneur and face challenges. The program was attended by Dean Academic IPR, IIC coordinators and AIC plasma tech team, PhD/ Postdoc students and IPR employees.



Dr. Ravindra Raj sharing his Professional Journey

Talk at i-Hub Faculty Development Program

A Faculty Development Programme (FDP) on “Empowering Educators through Research and Incubation Experience and NEP Insights” was organized jointly by i-Hub Gujarat, Commissionerate of Technical Education (CTE) - Govt. of Gujarat. The event was organized and hosted by i-Hub Gujarat, a leading incubation centre of Gujarat on 6th June 2025. Dr. Nirav Jamnapara, was invited to deliver a talk on the topic "Translating Deeptech Research into Innovation & Startups" based on the experience and expertise available through the translation of plasma technologies to field deployable knowhow. The talk was attended by more than 160 faculties from all across the state of Gujarat. The valedictory function at the end of the programme included dignitaries such as Commissioner of Technical Education Shri B. H. Talati, IAS; CEO of i-Hub Gujarat, Shri Hiranmay Mahanta, and Head of NITTTR extension centre, Ahmedabad, Professor Nishith Dubey. The event concluded with generation of new interest on how plasma technologies could be brought to the students and more startups could be sensitized. More programmes are being planned in association with i-Hub Gujarat involving plasma technology with IPR's Atal Incubation Centre: AIC-IPR.



Group Photo at i – Hub, Gujarat

MoU signed between AIC-IPR and HBNI

AIC-IPR Plasmatech Innovation Foundation, an Atal Incubation Centre established by Institute for Plasma Research (IPR) as a Section 8 company has been fostering and supporting tech based and Deeptech startups. With an objective to further strengthen deeptech Innovation in the country and encourage Plasmapreneurship within HBNI students, an MoU has been executed on 24 June 2025 by and between HBNI and AIC-IPR at HBNI Council Hall, Mumbai. The MoU was executed by Prof. U. Kamachi Mudali, Vice Chancellor, HBNI and Dr. D. K. Aswal, Chairman, AIC-IPR & Director - IPR (former).

This MoU will open up new opportunities for all the current and past students of HBNI to explore Deeptech entrepreneurship. Both organizations will also conduct joint programmes on innovation, incubation and entrepreneurship involving all ecosystem partners. This MoU marks DAE's commitment towards Atmanirbhar Bharat and Startup India initiatives of Government of India.



MoU Signing between IPR AIC-IPR and HBNI



Execution of Incubation agreement between Redero Trionics LLP and AIC-IPR Plasmatech Innovation Foundation

AIC-IPR Plasmatech Innovation Foundation is delighted to welcome a new startup, Redero Trionics LLP (Redero Trionics). Redero Trionics is a startup funded by our own students, Mr. Satya Prakash Reddy K (Founder) & Mr. Rosh Roy (Co-Founder). This collaboration marks a proud moment as it reflects the growing spirit of innovation and entrepreneurship within our campus community.

Under the incubation agreement, the startup will gain access to the IPR's state-of-the-art infrastructure, technical mentorship, business development guidance, and networking opportunities. This comprehensive support system is designed to help the startup refine its technology, strengthen its business model, and accelerate its journey from concept to market.

REDERO TRIONICS LLP is a deep tech start-up involved into the design engineering services and prototyping/fabrication of plasma based systems and products and allied fields. Trionics aims to provide specialized engineering design services and end to end solution for design and development of technologies which may include simulations, modelling and fabrication of prototypes and systems.

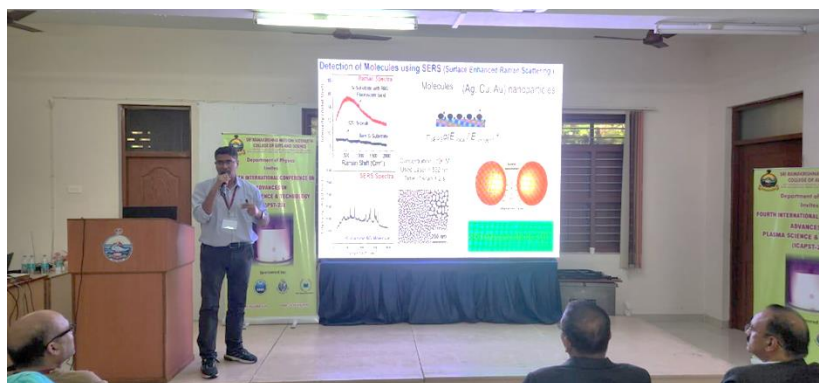
This initiative also reaffirms our IPR's commitment to fostering student entrepreneurship and creating an enabling ecosystem for deep-tech and innovation-driven ventures for development of fusion and plasma technologies. We look forward to witnessing the growth and success of this student-led enterprise in the coming months.



From Left to right: Mr. Rosh Roy (Co-founder), Dr. Tapas Ganguli (Director, IPR), Prof. U. Kamachi Mudali (Vice Chancellor, HBNI), Mr. Satya Prakash Reddy K (Founder), Prof. Naveen Kumar (Associate Dean, HBNI)

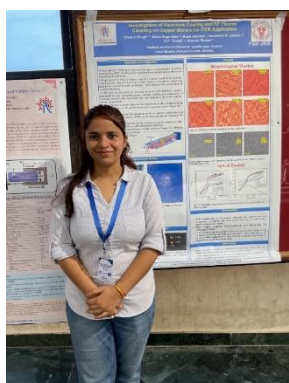
Conference Participations and FCIPT Visits

1. **Dr. Mukesh Ranjan** gave an invited talk about “Plasma Surface Engineering for Sensing and Wettability Application” in FOURTH INTERNATIONAL CONFERENCE ON ADVANCES IN PLASMA SCIENCE AND TECHNOLOGY (ICAPST-25), from July 16-18, 2025,” held at Sri Ramakrishna Mission Vidyalaya College of Arts and Science, Coimbatore, India.



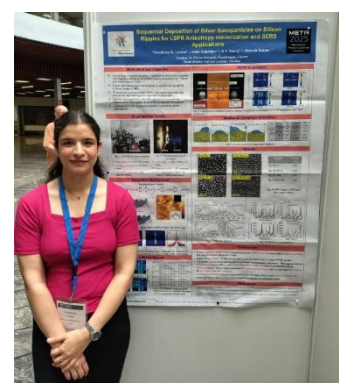
2. **Dr. Rohit Sharma** (IPR postdoc fellow) gave the oral presentation title “Production of surperhydrophoic fabric using argon plasma and HDTMS coating.” In the PSSSI-PSC-25, Indore event

3. **Ms. Sumana Hzara** got the best oral presentation award on her presentation title “Plasma treated BiFeO₃ thin films for the superior Ferroelectric properties” in the 11th Plasma Student Colloquium (PSSI-PSC-2025) held at Centre for Scientific and Applied Research, IPS academy , Indore from 2-4/06/2025. She is working jointly at Saurashtra University, Rajkot and FCIPT/IPR under the Co-supervision of Dr. Mukesh Ranjan.



4. **Ms. Sheetal Singh** (IPR JRF) presented a poster title “Investigation of Al Coating and RF plasma cleaning on Cu Mirrors for ITER Application ” In the PSSSI-PSC-25, Indore event.

5. **Ms. Tarundeep Kaur** (IPR JRF) presented a poster title “ Sequential Deposition of Ag Nanoparticles on Si ripple for LSPR anisotropy minimization and SERS application” in 15th International Conference on Metamaterials, Photonic Crystals and Plasmonics, Malaga, Spain, 22 - 25 July, 202





6. **Dr. Mukesh Ranjan** gave an invited talk title “Low energy ion surface modification for water harvesting” in 25th International Workshop on Inelastic Ion-Surface Collisions (IISC-25), held in September 14-19, 2025 at Steinschaler Dörfel in Frankenfels, Austria. Communities of ion solid interactions, plasma material interaction and ion beam centres participated in the event.

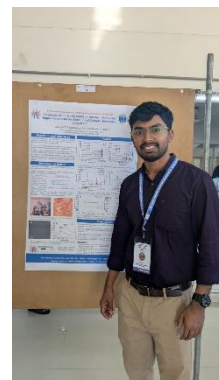


7. **Dr. Mukesh Ranjan** co-organized an International Conference on Nanostructuring by Ion Beams (ICNIB-25) as Co-Convenor in collaboration with Saurashtra University, Rajkot (Gujarat) and Inter University Accelerator Centre (IUAC), New Delhi from 7-9/10/25. Around 200 researcher from India and abroad participated in the event. Dr. Mukesh Ranjan also gave a talk and chaired the session.



8. **Ms. Tarundeep Kaur** got the **best oral presentation award**, given by Director IUAC Prof. Avinash C Pandey.

9. **Mr. Sooraj K. P.** presented his work on ‘Plasmonic Nanoparticle Arrays on Ion Beam Produced Nanopatterns for the Detection of Complex Molecules Using Surface Enhanced Raman Scattering.’ By poster presentation at ICNIB-25



10. **Mr. M. Paramesh** gave the oral presentation on “Plasma-Assisted Thin Film Deposition of Copper Using DC and High Power Impulse Magnetron Sputtering (HiPIMS)” at the Fourth International Conference on Advances in Plasma Science and Technology (ICAPST – 2025) organized by Sri Ramakrishna Mission Vidyalaya College of Arts and Science, Coimbatore.

11. **Mr. Rohit Parihar** gave the oral presentation on Atmospheric pressure plasma treatment of tomatoes for the reduction of pesticides residue and enhancement of shelf life] at FOURTH INTERNATIONAL CONFERENCE ON ADVANCES IN PLASMA SCIENCE AND TECHNOLOGY (ICAPST-25).



12. **Dr. Mukesh Ranjan** gave a motivational talk to the students of Institute of Advanced Research (IAR), Gandhinagar and also introduced them about societal application of Plasma. Director IAR Brigadier P.C. Vyas felicitated Dr. Ranjan at this occasion.

13. **Dr. Ranjan** gave a keynote lecture title "**Plasma Surfaces Modification for Water Harvesting**" in 3rd Biennial International Symposium Fluids and Thermal Engineering (FLUTE) -2025, organized Department of Mechanical Engineering Amity School of Engineering & Technology Amity University, Noida, Uttar Pradesh, India. IPR and Amity University jointly worked on a water harvesting device development under BRNS project.



14. Dr. Mukesh Ranjan gave an outreach activity talk about **Plasma Processing for Nanotechnologies** at Amity Institute of Nanoscience and Nanotechnology (AINN), Noida. Prof. O P Sinha (Director AINN) felicitated Dr. Mukesh Ranjan at this occasion.

Journal Publications & IPR Research /Technical Reports

- [1] **Investigation of Ag-NPs/Graphene hybrid structure on nanoripple silicon for SERS application,**
Tarundeep, Rohit Sharma, M.Ranjan,
Applied Surface Science (2025).

- [2] **Tunable Titanium and Tantalum oxide coatings as highly efficient antibacterial agents,**
Kartikey Chaturvedi, Mittireddi Ravi Teja, Mayank Dotiyal, Radhe Shyam, Mukesh Ranjan, Emila Panda,
Ceramic International (2025).

- [3] **Thickness-dependent charge transport across CdO/La_{0.3}Ca_{0.7}MnO₃ n–n junction interfaces**
Nisarg Raval, Himritri Trivedi, Mayur Parmar, C.M. Panchasara, Bharavi Hirpara, Keval Gadani, Sukriti Hans,
M. Ranjan, Sanjay Kosara, Dhiraj Bhatia, Bhargav Rajyaguru, K.N. Rathod, Davit Dhruv, P.S. Solanki, N.A. Shah
Materials Science in Semiconductor Processing 200 (2025).

- [4] **Multifunctional CuO/NiO Nanocomposites: A Study of Structural, Spectroscopic, Antibacterial and Antioxidant Properties,**
Nensi Bhimani · Urjitsinh Rathod · Ashish Ravalia · M. J. Kaneria · K. D. Rakholiya · Ankit Faldu · Sooraj K. P ·
Mukesh Ranjan · Savan Katba,
Journal of Nanoparticles Research (2025).

- [5] **Effect of heating rate on secondary phase formation and grain size of CZTS thin film,**
Sagar Agrawal, Takafumi Miyanaga, Hiroyuki Ikemoto, C. Balasubramanian, Subroto Mukherjee,
Physica B (2025)

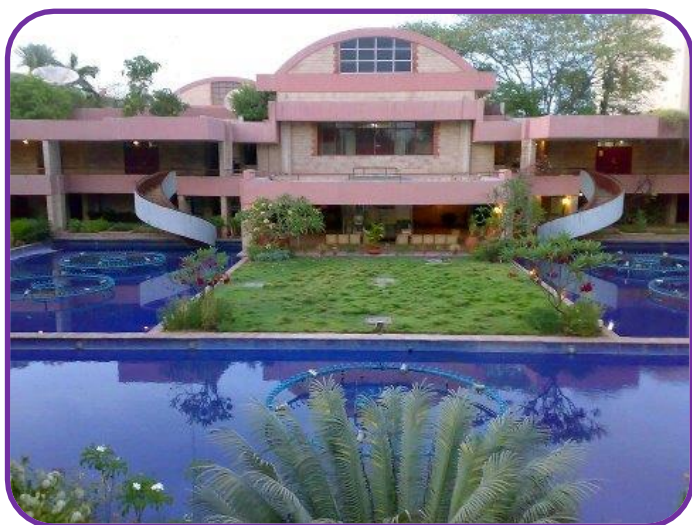
AIC-PLASMATECH

The Department of Atomic Energy (DAE), through its units and aided institutes, has been transferring and deploying several advanced technologies for the betterment of society. In support of the Government of India's initiatives on Atma Nirbhar Bharat and Start-up India, the DAE proactively launched incubation centres at BARC Mumbai, IGCAR Kalpakkam, RRCAT Indore, IPR Gandhinagar, and VECC Kolkata. This step aims to make the expertise, sophisticated infrastructure, and technologies of DAE available to industries and society at large. Additionally, the DAE initiated the recognition of such incubation centres with the Atal Innovation Mission, NITI Aayog, New Delhi, as 'Atal Incubation Centres'.

Based on this initiative, the Institute for Plasma Research established an Atal Incubation Centre as a special purpose vehicle under Section 8 of the Companies Act 2013 in December 2023, with 100% ownership by DAE. The Atal Incubation Centre, popularly known as 'AIC-Plasmatech' and 'Plasmatech Innovation Foundation,'

AIC-PLASMATECH OFFER

The Atal Incubation Centre (AIC Plasmatech) offers not only office space to startups but also essential mentoring by IPR's scientists, along with access to cutting-edge technologies and infrastructure. Additionally, it provides business mentoring from experts and external mentors, as well as support in areas such as intellectual property/patenting, marketing, and branding.



Plasma Pyrolysis System

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