Facilitation Centre for Industrial Plasma Technologies
Institute for Plasma Research

# Plasma Processing Update

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## Inside this Issue

## Research Focus - Water Repellent Superhydrophobic PTFE Surface Produced by Low Energy Ion Irradiation

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**Highlights**

- Superhydrophobic PTFE
- Low energy ion beam irradiation technique
- Water repellent surface with 150° contact angle
- Low contact angle hysteresis and surface free energy

**Team members**

- Mukesh Ranjan

Over the last two decades, fabrication of hydrophobic and superhydrophobic surfaces has extensively increased due to their superior water repellent property. Further, development of functional surfaces with self-cleaning, anti-scratch, anti-icing, anti-corrosion and fog harvesting properties has turned out to be an emerging field of research with significant technological applications. Superhydrophobic surfaces also have important role in water harvesting, water condensation, and heat transfer. Superhydrophobicity is said to be achieved if water contact angle with the given surface (generally with very low surface energy) is large ($\theta > 150°$). Substantial amount of study has been carried out in the area of modifying surface properties either by surface structuring or by changing surface chemistry. Various fabrication processes are available to obtain hydrophobic and superhydrophobic surfaces including coating techniques like sputter deposition, chemical vapour deposition; and surface structuring techniques like plasma etching, ion beam irradiation, etc. Polytetrafluoroethylene (PTFE or Teflon) is widely used for the fabrication of superhydrophobic surfaces due to its low surface free energy (~20 mN/m at 20° C). Teflon and Teflon-like coatings find number of applications in automobiles, non-stick cookware, and medicine due to their useful properties such as high heat resistance, excellent electrical resistance, and biocompatibility. As Teflon is hydrophobic in nature, many investigations have been carried out to alter its wettability by modifying its surface structures.

In the present study, we attempted to modify the surfaces of Teflon substrates using low energy ion beam irradiation. We have observed that Teflon surfaces become superhydrophobic when irradiated with a beam of low energy (300 - 800 eV) $Ar^+$ ions. Further, it was also observed that by changing the incidence angle of ion beam, from normal to oblique angle, the substrates can become superhydrophobic at much lower ion energies & fluence even without requiring any additional gas. $Ar^+$ ion irradiated Teflon surfaces were investigated, for their superhydrophobicity, by water contact angle measurement, surface free energy calculations, and water drop rolling behaviour. We have observed a systematic increase in water contact angle with increasing energy of the ion beam, even when irradiated for a very short duration of time. From a technological view point, this technique can be helpful in developing superhydrophobic bulk Teflon sheets in very short time duration wherein a specific surface region can be made superhydrophobic by using masking or ion beam writing.

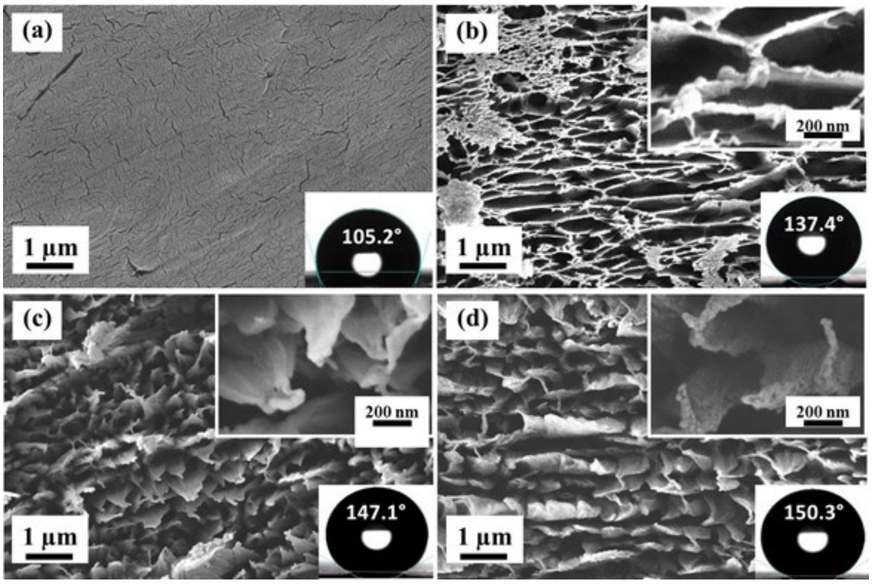


**Figure 1:** FESEM images of pristine and ion beam treated Teflon surfaces at normal angle of incidence. (a) Pristine, (b) 300 eV, (c) 500 eV and (d) 800 eV. High magnification images are shown in insets. Ion beam treatment time is 60 s.

Figure 1 shows SEM micrographs depicting morphology of pristine as well as ion beam (Ar+) irradiated Teflon surfaces, treated at different ion energies for same duration i.e. 60 seconds. The pristine sample looks very smooth with several cracks on its surface (figure 1a). At 300 eV incident ion beam energy, irregular structures with long cross chains (figure 1b) are observed. At 500 eV, the cross linked chains break and regular sub-micron scale structures start forming with sharp top edges as shown in the inset view of figure 1c. Upon further increasing the beam energy, the structures become more pronounced and sharp. The hierarchical structures are observed with nano-scale roughness on micro-scale structures (inset view of figure 1d).

At lower beam energy (300 eV) and 60 s irradiation time, the energy of Ar+ ions is not high enough to create separated microstructures on the surface and therefore long cross-chains are produced on the surface which is an initiation of structure formation. Since penetration depth of Ar+ ions in PTFE would be higher in case of 800 eV as compared to 300 eV, they can reach deep inside the surface, break the chains, and produce sharp edged microstructures.

Durability of the superhydrophobic Teflon surface thus formed, was studied by exposing the sample to air medium for several months, and measuring the water contact angle at periodic intervals. Figure 2a shows the performance of a superhydrophobic Teflon surface in ambient environment. Teflon surface retains its superhydrophobicity even after five months of exposure to ambient atmosphere, with only a marginal decrease in water contact angle from 152.6° to 150.2°. Figure 2b shows the photograph of the word “IPR” (symbolizing Institute for Plasma Research), constructed using water droplets, on treated Teflon substrates in order to demonstrate that the Teflon surfaces achieved superhydrophobicity after ion beam irradiation.

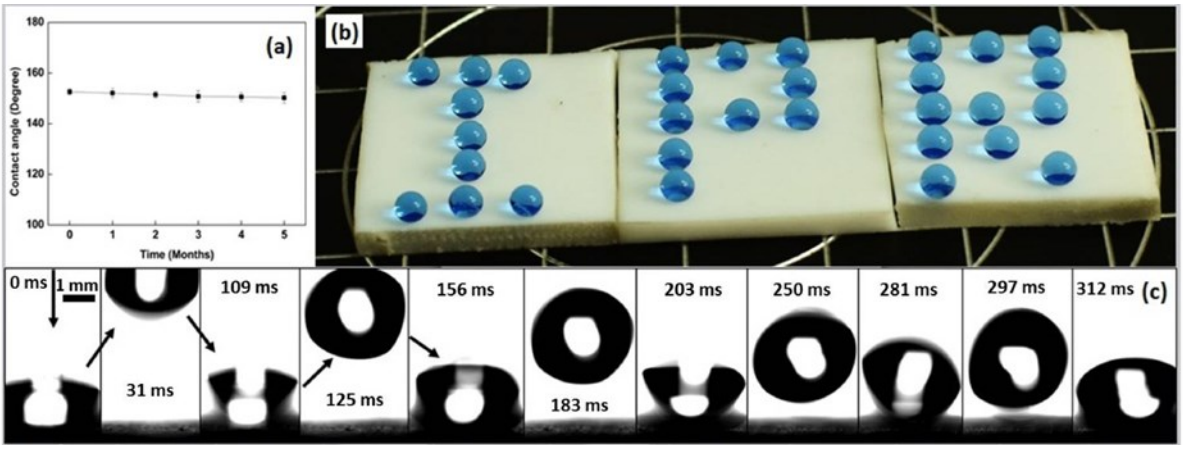


**Figure 2:** (a) Performance of superhydrophobic Teflon surface under ambient environment, (b) Photograph of spherical water droplets resting on superhydrophobic Teflon surfaces and (c) Demonstration of bouncing effect of water droplet which is dispensed from 10 mm above the surface that was irradiated with a 800 eV ion beam (at normal incidence) for 180 seconds.

A blue colour dye was mixed in de-ionized water in order to present the photograph effectively. Further, a water droplet of about 10 µL in volume (radius of the spherical droplet is approximately 1.4 mm) was used for performing the bouncing test, wherein the water droplet was dropped from 10 mm above the testing surface and its immediate consequences were photographed. Figure 2c shows a series of these pictures from a Teflon surface irradiated with an 800 eV Ar+ ion beam at normal incidence, and irradiated for 180 s.

In conclusion, we have observed that ion irradiation leads to structure formation on originally smooth Teflon surfaces, and the same is observed to improve with increasing ion energy and irradiation time. Increase in the surface roughness with improved structures is a result of stretching of the protrusions, and not due to sputtering and re-deposition of the material. Due to this phenomena, higher beam energy irradiation results in nicely separated high aspect-ratio structures, which are the basis for the formation of superhydrophobic surfaces. The air pockets created between the microstructures prevent the water droplet from spreading completely on the surface. The irradiated Teflon surface becomes so superhydrophobic that the water droplet just rolls off even from a horizontal surface. The superhydrophobic surfaces are also characterized by the "Lotus Effect", derived from the lotus leaf, in which hierarchical structures have been observed.

**References:**

[1] V. Pachchigar, et. al., Scientific Reports, 9, 8675 (2019).

[2] Wenzel, R. N, Ind. Eng. Chem. 28, 988–994 (1936).

[3] A. Atta, et. al., Nucl. Instruments Methods Phys. Res. Sect. B, 300, 46–53 (2013).

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**Highlights**

- High efficiency solid state RF generators
- Wide application range
- Minimum harmonic distortion

**Team members**

- N.P. Singh
- Dishang V. Upadhyay

# Technology Focus - Solid State RF Generator for Plasma Applications

Radio Frequency (RF) generators are used for various applications such as AM Transmitters, metallurgical applications, wireless power transfer etc. These generators also have significance importance in the field of plasma, especially for plasma production by inductively coupling the RF power for use in processing of materials. Solid state design has an edge over conventional topologies due to its compact size, modularity, high efficiency and better control feasibility. We have developed 5 kW and 40 kW solid state RF generators operating at 1 MHz in collaboration with industry. This was implemented in a phased manner as part of a collaborative program. The generators have been integrated with an experimental setup for plasma production and power coupling beyond 90% has been achieved. Studies related to their behavior and stability have also been successfully completed. The generators developed can support the requirements of a bench-top experiment on one side of the spectrum to high power (~200 kW) facility on the other. RF Generators are widely used as radio transmitters and thus can be promoted as important replacement for present installations at radio stations (e.g. All India Radio). They also find applications in marine communication, induction heating processes like tube welding, annealing, melting, crystal growing, heating etc. Typical characteristics of the generator(s) are shown in the table below:

| Sr. No. | Specifications | Parameters |
|---|---|---|
| 1 | Input Voltage | 3ph, 415V 50Hz |
| 2 | Rated Output Power | **40kW** Continuous on 50 Ohm |
| 3 | Output Power Range | 10 -100 % with increment **in steps of 500W** |
| 4 | Power Accuracy | **1kW** |
| 5 | Operational Frequency | **(1 ± 0.1) MHz** |
| 6 | Frequency Accuracy | **± 10kHz** |
| 7 | Frequency Tuning Step | **Steps of 10kHz** or lesser. |
| 8 | RF Harmonic Distortion | < 1% at rated power |
| 9 | RF Power Control | Preset Power as given by Local or Remote Control<br>• Open Loop control<br>• Close Loop control |
| 10 | Rise Time at Rated Power | < 0.3 ms |
| 11 | Fall Time at Rated Power | < 0.3 ms |
| 12 | Output Impedance | **50 Ω** |
| 13 | Output Connector | 3 1/8" |
| 14 | Efficiency | **> 90%** |
| 15 | Cooling | **Air cooled** |
| 16 | Power Supply Control | • By HMI<br>• Via Dedicated Links<br>• Via Profibus |

**Figure 3:** Solid State RF Generator

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**Highlights**

- **Plasma for treatment of fruits and vegetables**

**Team members**

- **Ramakrishna Rane**
- **Vijay Chuahan**

## System Focus - Development of glow discharge set up for Anand Agriculture University

FCIPT, IPR in collaboration with Anand Agriculture University (AAU), Anand, Gujarat is working for various plasma applications in the field of agriculture. In order to study the effect of plasma on degradation of pesticides present in fruits and vegetables, a glow discharge system has been developed at FCIPT and installed & commissioned at AAU. The system will be used for studying the effect of plasma on degradation of various pesticides present in different concentrations in fruits and vegetables. Figure 4 shows the glow discharge plasma system in which a tomato is being treated.

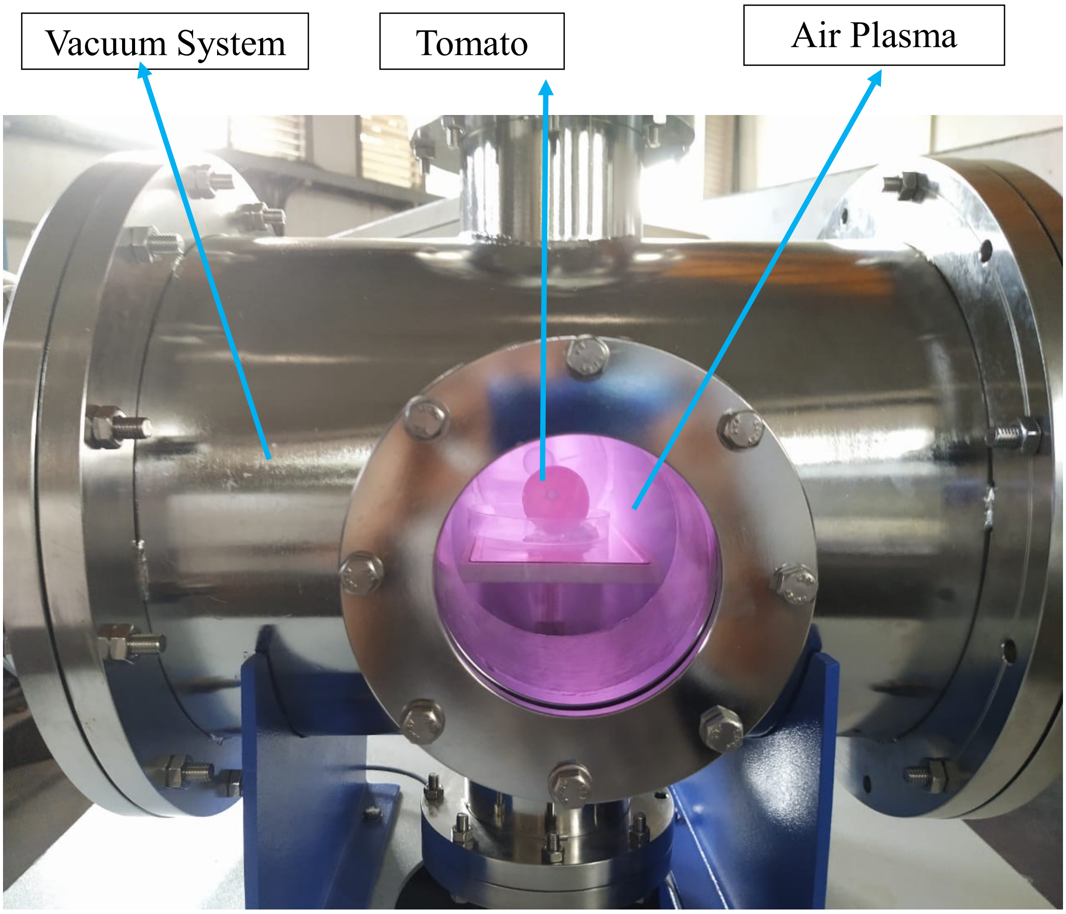
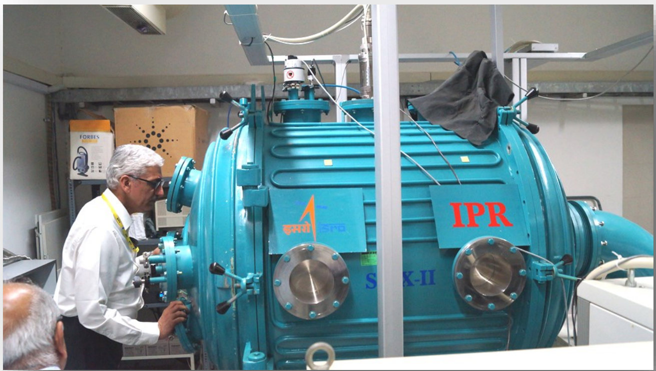



**Figure 4:** Glow discharge plasma system with tomato under treatment

# Past Events

## *Visit to FCIPT by*
## Shri. K. N. Vyas, Chairman, AEC

Chairman of Atomic Energy Commission and Secretary, Department of Atomic Energy, Shri. K. N. Vyas, visited FCIPT and had discussions with scientists and researchers working on different plasma technologies for societal and industrial applications. He also visited the laboratories and facilities at the FCIPT campus. He was accompanied by Dr. M. R. Srinivasan, ex-Chairman AEC, Dr. S. Banerjee, ex-Chairman AEC and DAE Homi Bhabha Chair Professor at BARC, Dr. U. Kamachi Mudali, Distinguished Scientist and Chairman & Chief Executive of Heavy Water Board, Dr. R. B. Grover, Director & Senior Professor, Homi Bhabha National Institute, Dr. S. Chaturvedi, Director IPR and scientists from the IPR main campus. Here are some photographs taken during the occasion:




**Group photo taken during the visit**

# Upcoming Events

One Day Seminar

on

## Plasma Technologies for Health Sector

**(PTHS-2019)**

Date: 29th Nov 2019

*Venue*

Institute for Plasma Research
Bhat Village, Near Indira Bridge
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