## Plasma Science and Technology
## Room 315 - Session PS1-TuA

### Atmospheric and Liquid Plasmas

**Moderators: Prof. Michael Gordon**, University of California at Santa Barbara, **Prof. Dr. Mohan Sankaran**, University of Illinois at Urbana-Champaign

2:15pm **PS1-TuA-1 Synthesis of Organic and Inorganic Spatially Differentiated Coatings by Cold Atmospheric Plasma***, Marie Brabant, Celine Dergham,* ***Francois Reniers,*** Université libre de Bruxelles, Belgium

In earlier studies, we have shown that one could immobilize filaments in an atmospheric pressure dielectric barrier discharge (DBD). This setup allows to deposit coatings presenting spatially differentiated chemistries that lead to tunable surface properties, such as, for instance, coatings presenting simultaneously hydrophobic and hydrophilic areas [1].

In this talk will methyl metacrylate (MMA) and hexamethyl disiloxane (HMDSO) are used as precursor to deposit localized PMMA and SiOx coatings, respectively. The chemistry, roughness and thickness of the coatings obtained under the filaments and between the filaments is studied by XPS, FTIR, Raman, profilometry and SIMS. The effect of the nature and flow rate of the plasma gas and the power injection mode on the resulting coating is presented and discussed.

For PMMA deposit, a drastic influence of the plasma gas nature is evidenced: transparent, sticky coatings are obtained with Ar, with excellent preservation of the ester function, whereas well polymerized yellow – orange coatings are obtained with $N_2$. In these last coatings, nitrogen is incorporated.

SiOx coatings deposited under the filaments are much thicker than those deposited between the filaments, with a chemistry depending on the ratio HMDSO/$O_2$. Adhesion of such coatings on glass substrates is superior.

This study highlights the versatility of plasma polymerization for microscale patterning and surface functionalization. Localized AP-PACVD enables micron–scale deposition and controlled chemical tuning without vacuum infrastructure [2], making it a promising technique for advanced surface engineering. The ability to modulate plasma chemistry through gas composition opens new perspectives for designing functional polymer and inorganic coatings with spatially selective properties.

Acknowledgements :

This work was funded by the FNRS (Belgium) (StreamCoat project).

References :

[1] A. Demaude et al, *Advanced Science* Adv. Sci. **9**, 2200237 (2022)

[2] A. Demaude et al, *Plasma Chemistry and Plasma Processing*. **43**(6), 1731–48 (2023)

2:30pm **PS1-TuA-2 Atmospheric Plasma-Induced Surface Modification of Carbonaceous Thin Films***,* ***Thea Ferley,*** School of Physics, Clinical and Optometric Sciences, TU Dublin, Ireland*; Vladimir Milosavljevic,* School of Physics, Clinical and Optometric Sciences, TU Dublin, Ireland & Faculty of Physics, University of Belgrade, Serbia, Ireland

This study investigated the influence of operating conditions in a pulse resonance atmospheric pin plasma system on the surface modification of carbonaceous thin films representative of contaminant layers found in fusion environments. The work focused on the effects of applied voltage, pulse frequency, duty cycle, and working gas environment on the wettability, thickness, roughness, and void fraction of the films. Samples were exposed to controlled plasma conditions using ambient air, He and Ar as working gases and were characterised using contact angle measurements and ellipsometric analysis.The results demonstrated that plasma-induced surface modification strongly depends on both the electrical operating parameters and the gas environment. Among the investigated parameters, applied voltage produced the clearest effect on wettability, where increasing voltage resulted in larger reductions in contact angle, indicating an increase in surface energy. In contrast, duty cycle showed limited and inconsistent influence on the measured surface properties, while pulse frequency mainly affected structural properties such as roughness and void fraction through repeated plasma–surface interactions.Statistical analysis confirmed a highly significant effect of plasma exposure on contact angle ($F=115.036$, $P<0.001$), with gas type and the interaction between exposure and gas also being statistically significant ($F=3.476$, $P=0.045$). Ambient air produced a smaller reduction in contact angle (-10.32°), while Ar and He produced larger reductions of -19.30° and -17.27°, respectively, demonstrating stronger surface modification under inert gas conditions. Thickness measurements showed a slight increase in ambient air (+1.4 nm) and reductions for He (-4.3 nm) and Ar (-9.5 nm). Surface roughness decreased for all gases, with the largest separation of 17.5 nm observed between Ar and He conditions. Void fraction measurements further highlighted the differences between gas environments, with He producing the largest decrease (-6.8%) compared to Ar (-1.5%).The observed differences indicate that ambient air promotes chemically driven surface interactions through reactive $O_2$ and $N_2$ based species, whereas Ar and He primarily contribute through physical plasma mechanisms such as ion bombardment and momentum transfer. Overall, the results demonstrate that the pulse resonance atmospheric plasma pin system can produce controlled and measurable changes in surface properties. These findings support the potential of this system as a flexible atmospheric-pressure plasma technology for surface cleaning and conditioning applications in fusion-relevant environments.

2:45pm **PS1-TuA-3 Influence of Pulsed Power Parameters on the Properties of Submerged Argon Plasmas***,* ***Michael Johnson,*** US Naval Research Laboratory*; Mackenzie Meyer,* National Research Council*; David Boris, Scott Walton,* US Naval Research Laboratory

Atmospheric pressure plasmas create a unique chemical and electrical environment that is well-suited for liquid treatment applications, such as decontamination and remediation. These plasmas can operate in a nonthermal regime when driven by pulsed power of sufficiently short duration. However, the influence of pulse power parameters on plasma behavior in gas-liquid systems is challenging to understand given the strong spatial and temporal variations that can arise. In this work, we discuss the use of short duration (< 1 ms), high voltage (> 10 kV) pulses driven at frequencies between 100 Hz and 10 kHz to produce an argon plasma submerged in flowing water. Varying the pulse width, impacts the induced plasma chemistry since excitation of the argon feed is dominant early, while hydrogen emission increases over time as water vapor dissociates. Spatial profiles show uniform hydrogen emission, while argon emission is stronger near the negative electrode. Stark broadening analysis reveals that the lifetime of electrons after the pulse is strongly influenced by the pulse width, as electron density can persist for several microseconds post-pulse. Varying the repetition frequency reveals that higher frequencies decrease the breakdown voltage because residual reactive species facilitate easier plasma reignition. Discharge current rises with frequency until limited by power supply resistances, with energy delivered per pulse peaking near 500 Hz for the present system. Higher water flow rates increase the frequency required for consistent ignition, suggesting liquid dynamics influence the quenching of residual species. Electron density peaks between 800 Hz and 3 kHz, beyond which it decreases as molecular gases like $H_2$ and $O_2$ alter formation conditions. Optical emission spectroscopy also indicates greater electrode erosion at higher frequencies. The implications of these results are discussed in terms of water treatment applications. This work supported by the Naval Research Laboratory base program.

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3:00pm **PS1-TuA-4 Non-Invasive Short-Wave Infrared Imaging for High-Resolution Thermal Mapping of Graphene-Growth Atmospheric Plasmas***,* ***Logan Holler,*** *Mia Sawkik, Brenna Miller, Parker Hayes, Drhuval Patel, David Ruzic,* University of Illinois at Urbana-Champaign*; Michael Stowell,* Lyten*; Dren Qerimi,* University of Illinois at Urbana-Champaign

Atmospheric-pressure plasma synthesis of graphene has emerged as a promising route for scalable carbon nanomaterial production. While it is well established that graphene formation is highly temperature-dependent, the distinction between the formation of graphene flakes versus nodules remains insufficiently characterized within plasmas. A key step forward centers on better mapping the temperatures across our different plasma mixtures. However, conventional diagnostic tools often fall short: most diagnostic systems only provide one-dimensional snapshots, and physical probes degrade rapidly when exposed to atmospheric plasmas.

The development of Short-Wave Infrared (SWIR) imaging has allowed time-averaged spatially-resolved temperature profiles to be developed for these systems. SWIR imaging leverages thermal radiation emissions to determine temperature by integrating spectral radiance over the detectable range of our camera. Provided that the camera's solid angle to the plasma remains fixed, changes in the integrated spectral intensity can be used to derive temperature ratios emitted by heated graphite. By calibrating the system

using a known temperature, SWIR snapshots can correlate image intensity with absolute temperature. Within the capacity of pure plasma imaging, this allows for dynamic temperature mapping throughout the plasma, which is limited only to the refresh rate of the SWIR Camera.

Graphite was chosen for these experiments due to its capacity to survive exposure in these plasmas, while also having a near-blackbody emissivity. Having developed a calibration curve for each rod, it is then possible to map the full temperature profile of the plasma by incrementally raising the rod through the plasma. A snapshot is taken at each point once the rod is in thermal equilibrium with the plasma. Stitching these images together forms a complete spatial map to better show thermal gradients across the plasma. A future development of this system aims for a plug-and-play plasma temperature profiling of unobstructed, in-situ plasma temperatures. This would allow for graphene growth modules to be better correlated to the different temperature profiles within the atmospheric plasma. This diagnostic provides a pathway toward in-situ, non-invasive plasma thermal profiling to better understand graphene growth morphology.

3:15pm **PS1-TuA-5 Spatially Resolved Spectroscopic Imaging of Plasma in Contact with a Liquid Interface***, **Robert Pierrard**,* University of Illinois at Urbana-Champaign*; Shurik Yatom,* Princeton Plasma Physics Laboratory*; Davide Curreli, Sean M. Peyres, Mohan Sankaran,* University of Illinois at Urbana-Champaign

Atmospheric-pressure plasmas (APPs) are highly effective at driving complex chemical reaction pathways. When coupled with a liquid interface, these plasmas deliver reactive species directly to a solution, enhancing chemical kinetics and enabling new reactions. Plasma-liquid systems have found applications across diverse fields, including nanomaterial synthesis, wound healing, environmental remediation, and sustainable agriculture via nitrogen fixation. Here we discuss the application of optical spectroscopy to provide deeper insight into plasma-based nitrogen fixation.

Our investigation focuses on a low-temperature APP formed in contact with liquid water, where gas-phase electrons are injected into solution to generate solvated electrons, the strongest known chemical reducing species, capable of reducing molecular nitrogen ($N_2$) to ammonia ($NH_3$). However, competing radicals are simultaneously created, yielding concurrent reduction and oxidation pathways and a wide range of chemical products.

To unravel this complex system, our work was divided into two phases. In the first, we constructed a simplified experiment without a liquid interface, introducing controlled concentrations of water vapor into a nitrogen plasma to isolate its effect on reaction pathways. Using optical emission spectroscopy (OES) with an argon actinometer and laser-induced fluorescence (LIF), we measured steady-state densities of intermediate species to validate a global chemical kinetic reaction network. We found that increasing water vapor dramatically suppresses atomic nitrogen density by quenching two key excited states of $N_2$. Moreover, the oxidative pathway toward NO and $NO_2$ was strongly favored over the reductive pathway toward $NH_3$ due to kinetic bottlenecks, explaining the enhanced oxidative species production commonly observed in the literature.

These findings informed our second phase, where we transitioned to the targeted plasma-liquid system. We extended our OES measurements to spatially resolve the plasma, enabling mapping of gas temperatures, electron temperatures, and key radical species. Measurements revealed striking variation in temperature and species profiles along the discharge, localized either near the metal electrode where the plasma emanates or near the liquid water surface. These results indicate that plasma properties are not uniform, and resolving the inhomogeneities is critical to understanding plasma-liquid processes.

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