Plasma Science and Technology
Room 124 - Session PS2-MoM

Atmospheric Plasma Processing

Moderator: Michael Gordon, University of California at Santa Barbara

11:00am **PS2-MoM-12 Adapting Atmospheric Pressure Plasma Sources to Fit Diverse Applications**, ***Michael Johnson,*** Naval Research Laboratory, USA **INVITED**

Atmospheric pressure plasma technology offers the potential to utilize plasmas in applications occurring outside the confines of a vacuum chamber, opening many new, exciting opportunities. However, generating a plasma at atmospheric pressure comes with challenges that limit its viability. In particular, large electric fields are needed to break down air (~30 kV/cm) while the generated plasma volumes are comparatively small, and energy can be quickly lost to gas heating. This presentation describes novel approaches to nonthermal plasma generation at atmospheric pressure that address these key hurdles to their wider adoption. Piezoelectric transformers are solid-state transformers that create large voltages via electromechanical conversion, providing a small form factor, high gain alternative for generating atmospheric-pressure plasma jets. These transformers enable the production of plasma jets with characteristics similar to those driven by standard high voltage power supplies while only requiring tens of volts. Given the low input voltages, multiple jets can be operated in parallel to facilitate a synergistic increase in plasma volume and enhanced control over species production. Alternatively, gas management can be used to expand the functional volume of jets without an increase in applied power. Additionally, nanosecond pulsed power approaches improve the energy efficiency of plasma production, which can be advantageously used to improve water remediation in a plasma-liquid reactor. Example systems will be discussed and described through a variety of plasma diagnostics to illustrate how the approaches to applied power and plasma generation impact the plasma properties and applications, with an eye on developing more sustainable and versatile plasma sources.

This work was partially supported by the U.S. Naval Research Laboratory Base Program.

11:30am **PS2-MoM-14 Atmospheric Plasma Deposition of Bio-Based Composite Coatings for Enhanced Functional Properties of Paper**, ***Kamal Baba,*** *F. Loyer, N. Boscher, P. Choquet,* Luxembourg Institute of Science and Technology (LIST), Luxembourg*; I. Husić, A. Mahendran, J. Sinic, C. Jocham, H. Lammer,* Wood K plus - Kompetenzzentrum Holz GmbH, Austria

Functional coatings on paper surfaces often rely on low-recyclable synthetic feedstock and wet chemistry techniques, leading to extended processing times and increased material usage. In this work, we address these challenges by the development of functional bio-based composite coatings reinforced with sustainable fillers using atmospheric pressure plasma as sustainability-oriented coating technology.

Various low viscosity acrylated biobased monomer, including Vanillyl Alcohol Methacrylate (VAM), Eugenyl Methacrylate (EM) and Isosorbide Methacrylate (IM), were used as resin to form the polymeric coating. while seashell particles (SS) or cellulose nanocrystals (CNC) were used as sustainable additives. The targeted applications of these formulations are the enhancement of release function, water vapor barrier and antimicrobial properties of paper substrates.

The polymerization of these different monomers was possible thanks to a liquid assisted dielectric barrier discharge approach with either Argon or Nitrogen as plasma gases, and ultrasonic nebulization as monomer injection method. The plasma polymerization of coatings with a thickness ranging from 0.5 to 2 µm on Si wafers, Glassine and Barrier 60g paper was evidenced by FTIR, showing a successful conversion of vinyl double bonds. . The degree of conversion was calculated from the FTIR spectra to assess the effect of the plasma parameters on the polymerization and coating properties. Notably, the polymerization degree increases with the applied plasma power yielding longer polymer chains, as evidenced by high resolution mass spectrometry analyses. This technique revealed the possibility of favoring the formation of polymer compositions rich in organic mono- or di-methacrylate chains in a plasma-polymer matrix by adjusting the plasma power. SEM imaging confirmed the homogeneity of the coatings and a uniform distribution of the particles.The addition of SS and CNC particles to the VAM or EM coating affects both hydrophobicity and surface energy, likely impacting the release properties of the coated surface. The VAM composite coating exhibited the best release function for coated Glassine paper (<250cN/25mm according to Finat10/TESA 7475 test), whereas the lowest water vapor transmission rate for barrier paper was achieved with the EM composite coating (<50g/m^{2}day/bar).

On the other hand, antibacterial properties were achieved through plasma coating with isosorbide methacrylate alone, effectively targeting the E. Coli bacterial strain without the incorporation of any additional additives.

11:45am **PS2-MoM-15 Atmospheric Air Plasma Pre-treatment of Plastics**, ***Aunic Goodin,*** North Carolina State University*; R. Walker, J. Alcala,* University of Michigan, Ann Arbor*; T. Das,* California Institute of Technology*; S. Chakraborty, S. Bepari, D. Kuila,* North Carolina A&T State University*; W. Goddard,* California Institute of Technology*; J. Foster,* University of Michigan, Ann Arbor*; S. Shannon,* North Carolina State University

In 2018 almost 36 million tons of plastic waste was produced in the US with only 9% recycled that year. One of the limiting factors for reusing or recycling plastic waste is the difficulty of conversion into usable products. One potential solution for this is a plasma pretreatment followed by a catalytic deconstruction into C2-C4 olefins. Catalytic deconstruction of plastics is a viable method for using plastic waste. Atmospheric plasma is investigated primarily for cost-effective pretreatment of the plastics. The oxidation of the plastics through the plasma treatment provides a potential avenue for the catalyst to more easily break down the material. The initial concept is shown with a pin-to-plate discharge within vials for analysis of the gas by-products as well as material analysis. The combination of VUV, UV, electron, and ion bombardment modifies the surface of the polymer for oxygen absorption both during and after treatment from the oxygen in normal air. This oxidation will be measured and quantified through XPS, contact angle measurements, FTIR spectroscopy, and RAMAN spectroscopy. The analysis of the gas products through mass spectroscopy is compared to molecular dynamics and reactive force-field simulations to understand the mechanism of the process. The plastics polypropylene and polyethylene are treated as powders, beads, and sheets of varying particle size/thickness, molecular weight, and density. The variation of the samples gives an indication of the material shape and characteristics for future processing and also allows for different analyses depending on the material's shape and thickness. These plastics are also treated in liquid plasma for comparison of the surface modifications. Analysis of the products of the catalytic deconstruction is done by GC/MS to characterize potential value-adding C2-C4 olefins and compare the process with and without plasma treatment.

Work supported by U.S. Department of Energy (DOE) no. DE-EE0009945 and National Science Foundation (NSF) GRFP.

12:00pm **PS2-MoM-16 Study of the Thermal Profile of an Atmospheric Pressure Argon Plasma Jet**, *J. Lalor,* Technological University Dublin, Ireland*;* ***Vladimir Milosavljevic,*** University of Belgrade, Serbia

Despite operating at room temperature, nonthermal plasmas generate energetic and reactive species capable of inducing surface modifications at the plasma/surface interface. This study explores the interaction between an Argon atmospheric pressure plasma jet (APPJ) and both insulating and conducting mesh surfaces. The dielectric barrier discharge APPJ operated at a voltage of 8 kV and a frequency of 21 kHz.

Previous studies have investigated the interaction between an atmospheric pressure plasma jet directed perpendicularly onto both dielectric and conductive flat surfaces, finding that the jet exhibits a laminar flow spreading radially from the impact point. In contrast, this study introduces a novel approach by treating a mesh substrate with 0.8 mm x 0.8 mm openings, allowing the gas plume to partially pass through the surface. This enables mapping the thermal interaction between the APPJ and the substrate, facilitating the study of the thermal cross-section of the jet plume. A series of experiments were conducted to investigate the responses of different materials, such as metals and polymers, to thermal energy from the APPJ, focusing on temperature rise, heat distribution, and cooling rates. The distance between the APPJ nozzle outlet and the mesh surface (standoff distance) was varied from 0 to 70 mm, and the corresponding thermal profile was recorded to determine the optimal standoff distance to prevent surface damage due to overheating. Additionally, treatment duration was examined by fixing the standoff distance and varying the treatment duration from 0 to 240 seconds, allowing the study of thermal data for various contact times.

For this research, a FLIR i7 thermal camera with a thermal resolution of 140 x 140 pixels was used. This camera captures detailed thermal images, enabling precise measurement of temperature distributions and thermal gradients across the treated surfaces. Its high sensitivity and accuracy are

essential for analyzing the thermal effects of the APPJ on different materials, ensuring reliable data collection and analysis throughout the experiments.

Therefore, this study investigates the thermal effects of atmospheric pressure plasma jet (APPJ) treatments on metal and plastic surfaces, focusing on varying treatment times and standoff distances. The results indicate that steel, with its high thermal conductivity, heats and cools rapidly, whereas polypropylene heats more slowly and retains heat longer. The research also demonstrated that closer standoff distances increased energy deposition, with material properties significantly influencing temperature dynamics.

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