New FTIR-Based Characterization Facility for Study of Plasma-Surface Interactions

P. Luan, A. Knoll, S. Zhang and G. S. Oehrlein
University of Maryland, College Park (oehrlein@umd.edu)

Cold atmospheric plasma (CAP) sources produce chemically reactive species capable of modifying material surfaces. Numerous applications of CAP are based on this principle yet the plasma-surface interaction (PSI) mechanisms between reactive species and material surfaces are still unclear [1]. The multi-phase nature of PSI requires the comprehensive characterization of both plasma and gas phases, along with the surface/subsurface properties of materials being contacted by the plasma [2].

Recently, the award of a supplementary DOE equipment grant made it possible to develop a generic Fourier transform infrared spectrometer (FTIR)-based characterization facility for studying the interaction of CAP sources with materials at University of Maryland. Equipped with a liquid N₂ cooled HgCdTe (MCT) detector, 1-16 m variable path length gas detection cell, specular reflectance, diffuse reflectance (DRIFTS) and attenuated total reflection (ATR) accessories, this new setup is capable of quantitatively measuring the type and density of reactive gas molecules (sub-ppm to a few percent) and the chemical composition of thin films (a few monolayers to μm), powders and others. PSI mechanisms can be studied by correlating changes in material composition to the quantified densities of gas phase reactive species, both measured by FTIR. Initial examples are shown in Fig. 1. In Fig. 1(a), we observed CH₄ conversion by O₂ and production of gas phase CO, CO₂ and H₂O in an atmospheric pressure plasma jet (APPJ)-nickel catalyst system. In Fig 1(b) we found that reactive species generated by a surface micro-discharge (SMD) CAP source damaged the benzene rings of polystyrene (PS) and converted them into various ether (C-O) and carbonyl (C=O) groups. Along with other characterization tools such as ellipsometry, X-ray photoelectron spectroscopy (XPS) and atomic force microscopy (AFM), this FTIR system will contribute significantly to the understanding of plasma-polymer interactions, plasma catalysis and bacterial sanitation through various PSC collaborations in the near future.

References

Figure 1 – Results from new FTIR facility: (a) Methane conversion into CO, CO₂ and H₂O in an APPJ-Ni plasma catalysis system. (b) the chemical composition change of 10 nm PS films under the treatment of a SMD source. MCT detector was used in both (a) and (b). ATR accessory was used in (b).
FTIR-BASED CHARACTERIZATION FACILITY FOR PLASMA-SURFACE INTERACTIONS

- A Fourier transform infrared spectrometer (FTIR) system equipped with liquid N₂ cooled HgCdTe (MCT) detector, 1-16 m gas detection cell, specular reflectance, diffuse reflectance (DRIFTS) and attenuated total reflection (ATR).

- Capable of measuring the type and density of reactive gas molecules (sub-ppm to a few percent) and the chemical composition of thin films (a few monolayers to μm), powders and others. Plasma-surface interaction can be studied by correlating results of the gas phase and surface/near-surface measurements.

- IR absorption spectrum showing methane conversion into CO, CO₂ and H₂O in an APPJ-Ni plasma catalyst system

- IR absorption spectrum showing the chemical composition changes of 10 nm PS films under the treatment of a surface micro-discharge (SMD)
Gas Breakdown in Microgaps with Surface Protrusion on the Cathode

Yangyang Fu, Peng Zhang, and John P. Verboncoeur
Michigan State University (fuyangyang@egr.msu.edu, pz@egr.msu.edu, johnv@egr.msu.edu)

Gas breakdown phenomenon in macroscopic gaps has been widely studied and is well understood by Paschen’s law [1,2]. The breakdown mechanisms can be more complex in microdischarges at atmospheric pressure. Since at high pressure the dimensions are sharply reduced with pd scaling, the presence of surface protrusions on the electrode surfaces become important [3].

In this work, using a two-dimensional fluid model, Townsend breakdown voltages in microgaps were predicted based on the resulting voltage-current (V-I) characteristics. The predicted V-I curve, which includes the dark discharge, the Townsend discharge and the subnormal glow regions, identifies the breakdown voltage when the discharge current enters the subnormal region. As shown in Fig. 1, an increase in the size of the protrusion’s size leads to a decrease in breakdown voltage while changing the aspect ratio only has a small influence on the breakdown voltage. In Fig. 2, the normalized current density distributions on the cathode surface are presented. Surface protrusions appear to enhance the relative current density at the tip of the protrusion but reduce the current density elsewhere on the cathode. Due to this characteristic, it was found that when the effective distance (from the cathode protrusion tip to the anode) is fixed, the breakdown voltage versus the aspect ratio will show a minimum value if the aspect ratio varies in a wider range.

Controlling the surface finish of electrodes is difficult in micro-systems. Absolutely smooth surfaces would maximize voltage hold-off. Even if this finish could be achieved during fabrication, there is roughening of surfaces during handling and assembly that introduce “scratch-and-dig”; and during use due to sputtering, micro-arcs and deposition. Our predictions for breakdown voltage on surface roughness provide insights to system variability due to inherent or usage induced roughness. For example, it might be strategic to pre-roughen surfaces to values expected during use to reduce system variability. This would be at the cost of maximum hold-off voltage but provides stability.

References

Figure 1 – Breakdown voltage versus protrusion size and aspect ratio.

Figure 2 – Normalized cathode current distributions with different protrusions and R=500 µm.
GAS BREAKDOWN IN MICROGAPS WITH SURFACE PROTRUSIONS ON THE CATHODE

- Breakdown mechanisms are more complex in microdischarges at atmospheric pressure since with pd scaling the presence of surface protrusions on the electrode surface becomes important.

- The effects of protrusion size and aspect ratio on breakdown voltage ($U_b$) were quantified using a 2D fluid model. $U_b$ is more sensitive to protrusion size than the aspect ratio – an effect important to assessing system variability.

- Breakdown voltage with protrusions

- Normalized cathode current densities