Abstract:

Plasma-Surface Interaction at Atmospheric Pressure: from Mechanisms with Model Polymers to Applications for Sterilization

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Cold atmospheric plasma (CAP) produces many types of chemically reactive species and is capable of modifying materials at atmospheric pressure. Studying plasma-surface interaction (PSI) at such pressure has been challenging due to the small mean-free-path (< 100 nm) which prohibits the method of using independently controlled beams of ions/neutrals. In the past few years, we developed an alternative approach of studying PSI at atmospheric pressure using well-controlled source-ambient-sample systems and comprehensive characterization techniques. First, we characterized and compared a few types of CAP sources such as atmospheric pressure plasma jet (APPJ) and surface micro-discharge (SMD). We found that the dominant reactive species generated by different CAP sources can be dramatically different. By tuning source operating parameters, we were able to manipulate the dominant reactants generated by these sources. Second, by controlling the gaseous environment wherein PSI took place, we could suppress certain unwanted interactions of plasma species with the ambient and regulate the delivery of reactive species to material surfaces. Lastly, we used polymers with representative functional groups to study the effect of reactive species on certain surface moieties. Due to the multi-phase nature of PSI, we integrated many characterization techniques in our study, including that of plasma/gas phases such as optical emission spectroscopy (OES), Fourier transform infrared spectroscopy (FTIR) and UV absorption, and that of material surfaces such as X-ray photoelectron spectroscopy (XPS), attenuated total reflection (ATR) FTIR and Ellipsometry. To our knowledge, the perpendicular electric field enhanced ATR-FTIR was used for the first time to study plasma processed polymer films less than 10 nm-thick. Combined with XPS, these techniques provide rich chemical information of both surface and subsurface modifications. By correlating plasma/gas phase with surface/subsurface measurements, we showed the dominant effect of a few types of reactive species such as O, OH and N_2O_5 on materials. We also provided evidence showing the competition between etching and surface modification during plasma treatment. Besides, we extended our investigation to studying the CAP-induced bacterial membrane damage, which might help understand the sterilization mechanism of CAP. We gratefully acknowledge funding from National Science Foundation (PHY-1415353) and US Department of Energy (DE-SC0001939). We thank Andrew J. Knoll, Elliot A. J. Bartis, V. S. S. K. Kondeti, Peter J. Bruggeman, Andrea Gilbert, Rohan Tikekar and David B. Graves for collaborations.