Plasma Science and Technology
Room: 210A - Session PS+BI+SM-TuM

Plasmas for Medicine and Biological Applications
Moderator: Satoshi Hamaguchi, Osaka University, Japan

8:00am **PS+BI+SM-TuM1 Glow-Discharge Plasma Applications in the Biomedical Sciences: Frontiers and Horizons**, ***Buddy D. Ratner***, University of Washington **INVITED**

Plasma treatments for biomedical applications have been explored since the early 1960's, possibly earlier than that. Plasma treatments for medical devices and for materials used in biotechnology are now widely used and have improved he performance and safety of many devices. A few advanced technologies for biomedicine exploiting plasma deposition of organic thin films will be described. These include non-fouling surfaces, thermally responsive surfaces, biodegradable surfaces, rate-limiting barriers for controlled release and surfaces that permit the growth of precision polymeric brushes by atom transfer radical polymerization (ATRP). Frontiers for plasma deposition include better control of deposition chemistry, strategies to deposit unusual chemistries and depositions that integrate biological molecules and plasma-deposited chemistries.

8:40am **PS+BI+SM-TuM3 Non-Equilibrium Plasmas in Contact with Solutions: Biological Interactions and Material Synthesis**, ***Peter Bruggeman***, University of Minnesota **INVITED**

Non-equilibrium atmospheric pressure plasmas interacting with liquids offer a unique source of highly reactive chemistry beneficial for many applications in biology, medicine and advanced materials manufacturing. It has been shown that these plasma-liquid interactions can lead to inactivation of bacteria and virus and the synthesis of nanoparticles. Nonetheless the underpinning mechanisms are at least poorly understood. My group has been strongly involved in the study of the reactive chemistry of a well-characterized RF driven atmospheric pressure plasma jet and its interaction with liquids.

The presentation will highlight some examples of reaction pathways responsible for the inactivation of bacteria and virus in solution and the synthesis of silver nanoparticles from $AgNO_3$ solutions. I will illustrate the importance of reactive plasma chemistry induced by neutral gas phase reactive species such as OH, H_2O_2 NO, O, H, O_3 and singlet oxygen. In addition, we will show that UV emission, which is often neglected as a possible mechanism, can be important in some cases.

9:20am **PS+BI+SM-TuM5 Plasma Biomedicine and Reactive Species**, ***David Graves***, University of California at Berkeley **INVITED**

Low temperature plasma research directed towards biomedical applications such as sterilization, surgery, wound healing and anti-cancer therapy has seen remarkable growth in the last 3-5 years, but the mechanisms responsible for the biomedical effects have remained mysterious. It is known that CAP readily create reactive oxygen species (ROS) and reactive nitrogen species (RNS). Other potentially important plasma-generated species effects include charges, fields and photons. ROS and RNS (or RONS), in addition to a suite of other radical and non-radical reactive species, are essential actors in an important sub-field of aerobic biology termed 'redox' (or oxidation-reduction) biology. I will review the evidence suggesting that RONS generated by plasmas are responsible for their observed therapeutic effects. In addition, I will present several ideas about the most likely biological response mechanisms that are likely involved in therapeutic plasma biomedicine.

11:00am **PS+BI+SM-TuM10 Cold Atmospheric Plasma for the Treatment of Chronic Infected Wounds**, ***Jennifer Granick***, *V.S.S.K. Kondeti, A. Truong, R.C. Hunter, P.J. Bruggeman*, University of Minnesota

Two percent of the US population suffers from chronic non-healing wounds, often complicated by antibiotic-resistant bacterial infections, and the staggering cost of wound care exceeds $50 billion per year. Of increasing concern are multi-drug resistant bacteria, including methicillin-resistant *Staphylococcus aureus* and multi-drug resistant *Pseudomonas aeruginosa* infections. Within wounds, these bacteria adopt a biofilm-like state, and become notoriously recalcitrant to conventional antibiotic therapies. Currently approved products for the treatment of chronic wounds have not proven to be a panacea due to the complex nature of wound healing.

The ideal therapy for chronic, infected wounds would be non-painful, bactericidal without risk of resistance, able to break-up biofilms and enhance wound healing. Recently, there has been interest in the use of cold atmospheric plasma (CAP) technology for the treatment of infections and non-healing wounds. The technology could potentially fulfill the requirements of an ideal wound healing therapy. CAP devices producing ionized gas have been developed that can operate in ambient air and that are safe to touch without any pain sensation. CAP generates a complex mixture of reactive oxygen and nitrogen species (RONS) that are able to kill bacteria, while stimulating host cell growth. CAP has the potential to combine antiseptic and wound healing capabilities in a single treatment procedure and could eliminate the risk of cytotoxicity present in many current treatment methodologies for infected wounds.

The effects of CAP on bacteria and mammalian keratinocytes and fibroblast cells have been evaluated *in vitro*. Our prototype argon CAP device produces antibacterial effects on planktonic bacterial cultures of *S. aureus* and *P. aeruginosa* at a maximal treatment duration of 20 ml/min at conditions that do not impact cell viability of fibroblasts and keratinocytes *in vitro.* We have also recently demonstrated that CAP is effective in reducing the viability of *P. aeruginosa* biofilms grown *in vitro*. When grown on the surfaces of PVC microtitre plates for 48 h, argon-air derived CAP treatment of established biofilms showed a 95% reduction in cell viability, as determined by resazurin fluorescence, relative to untreated controls, when treated at a dose of 30min/ml, which is similar to the treatment time equivalent of mammalian cell treatment.

As part of the early investigations of the use of CAP treatment as a viable therapy for chronic-infected wounds, the presentation will focus on bacterial biofilm reduction by CAP treatment *in vitro* as well as in a mouse skin wound model. The effects on mouse host cells will be examined.

11:20am **PS+BI+SM-TuM11 Humidity Effect on the Surface Modification and Bio-Deactivation of Lipopolysaccharide (LPS) by Surface Micro-Discharge (SMD)**, ***Pingshan Luan***, *E.A.J. Bartis, A.J. Knoll,* University of Maryland, College Park, *C. Anderson, D.B. Graves,* University of California at Berkeley, *J. Seog, G.S. Oehrlein*, University of Maryland, College Park

The surface micro-discharge (SMD), due to its scalable large area and flexibility of working gases, has great potential for many applications such as material processing and plasma medicine. The SMD normally works under ambient air conditions that contain not only N_2 and O_2 but also water vapor which can have a large impact on both the discharge behavior and plasma gas chemistry. In this study, we evaluate the effect of ambient humidity on SMD in various N_2/O_2 mixtures and the subsequent effect on the surface modification and bio-deactivation of lipopolysaccharide (LPS). Electrical behavior and optical emission spectrum (OES) of the SMD source were studied. We found that while the additional moisture did not help create strong OH (A-X) emission from SMD, it resulted in lower plasma density and extra power dissipation. We used X-ray photoelectron spectroscopy (XPS) to characterize the surface modification of LPS after treatment. We found that all SMD-treated LPS surfaces show oxygen uptake and formation of surface-bound NO_3, while the amount of these modifications was strongly dependent on the ambient gas composition. By comparing the XPS of wet-treated (50% relative humidity at 20 °C) surfaces with their dry counterparts, we find that the water vapor reduces both the oxygen uptake and surface NO_3 formation, and that the difference between wet- and dry-treated surfaces decreases with the increasing fraction of ambient N_2. When the N_2 fraction is up to 80% (synthetic air), the LPS surface shows comparable amount of modification with or without humidity. Among all the dry- and wet-N_2/O_2 mixtures, the dry 5% of N_2 ambient shows the greatest modification rate. We also evaluated the bio-deactivation efficiency of the SMD on LPS using enzyme-linked immunosorbent assay. Similar to surface modification, we found that the bio-deactivation rate of SMD in dry ambient is much higher than that of SMD in their wet counterparts, except the synthetic air condition which shows similar amount. The authors gratefully acknowledge financial support by the US Department of Energy (DE-SC0001939) and National Science Foundation (PHY-1004256 and PHY-1415353).

11:40am **PS+BI+SM-TuM12 Plasma Diagnostics of Dielectric Barrier Discharge within a Sealed Meat Package**, ***Vladimir Milosavljevic***, Dublin Institute of Technology, Ireland, *J. Lalor, P. Bourke, P.J. Cullen*, Dublin Institute of Technology

Atmospheric pressure, non-thermal plasma DBD is increasingly used in many processing applications. Despite their widespread usage, it remains largely unknown whether cold atmospheric plasma DBD maintains similar characteristics, such as gas temperatures and particle flux, when they breakdown while arcing or whether they possess different operating modes. It is essential for laboratory/industrial adoption of such plasmas that plasma diagnostics of the process are provided. Optical emission and absorption spectroscopy have been used as diagnostics techniques with an added avantage of their non-intrusive nature.

The type of operating gas influences the stability of atmospheric plasma discharges. In this study is used a sealed meat package filled with one of two gas mixtures: O_2-CO_2 and N_2-CO_2 . Different concentrations of nitrogen or oxygen and carbon-dioxide could cause the transition from a stable homogeneous discharge into a filamentary discharge. Atmospheric plasma discharges are affected by the surrounding ambient air, and for sealed packages from transfer between the package gas and the surrounding ambient atmosphere. In the vast majority of atmospheric plasma discharges, reactive nitrogen species dominates the ionic composition of atmospheric discharge and has an impact on the breakdown voltage. When N_2 is added/mixed with CO_2 plasma discharges, the CO_2 emission lines are significantly quenched. In the case of O_2-CO_2 chemistry, nitrogen is not a carrier gas but it still present in the package due to contaminant transfer with the surrounding ambient air, modifying the plasma chemistry in the package. The plasma's optical spectrum in O_2-CO_2 chemistry shows molecular oxygen, nitrogen and OH peaks. Oxygen could come from the ambient air, the O_2-CO_2 gas mixture or from humidity in the package. Electron impact excitation of molecular oxygen, at low collision energies, is of particular importance because of its role in atmospheric physics and has been objective of this study. In our study we have also recorded the O_3 band-head that belongs to the Hartley Band. Ozone plays very important role for the biological aspect of this study and shows the highest change in a concentration with the processing time. Combining the results from spectral radiation in the package provides an electron energy distribution function. The study includes a detailed experimental investigation of the spatial and temporal spectroscopic data and links them with plasma kinetics.

The research leading to these results has received funding from the European Union´s Seventh Framework Programme managed by REA Research Executive Agency (FP7/2007-2013) under Grant Agreement number 605125.

12:00pm **PS+BI+SM-TuM13 Low-Temperature Plasma Surface Modification of Porous Polymeric Materials for Environmental and Medical Applications**, ***Michelle Mann***, *A. Pegalajar-Jurado, E.R. Fisher*, Colorado State University

Three-dimensional (3D) porous polymeric materials are widely used in biomedical and environmental applications, such as wound healing and water filtration. Polymers used for these applications are chosen for their mechanical properties and porosity, yet the surface properties, such as hydrophobicity, limit their use in aqueous environments. For example, polymeric ultrafiltration membranes typically require pretreatment before use and tend to foul due to adsorption of biomolecules in the watercourse. Bioresorbable polymeric scaffolds used for wound healing are prone to attachment of bacteria, leading to prolonged infection at the wound site. These issues can be addressed with two simultaneous approaches. To prevent bacterial attachment and proliferation, antibacterial properties can be introduced into the materials via incorporation of biocidal agents or antibacterial coatings. Moreover, surface modification can be used to create more compatible polymeric materials by increasing wettability. Through plasma processing, tailored surface modification can be achieved while retaining the morphology and bulk properties of the material. Here, we will describe the modification of ultrafiltration polysulfone (UPS) membranes and poly(ε-caprolactone) (PCL) scaffolds to create low-fouling materials with enhanced wettability. $H_2O_{(g)}$ plasma treatment of UPS membranes and PCL scaffolds results in materials with significantly enhanced wettability while scanning electron microscopy (SEM) images demonstrate porous morphology is maintained. X-ray photoelectron spectroscopy (XPS) data show an increase in surface oxygen content throughout the membrane cross-section after plasma treatment, and modified UPS membranes demonstrate a significant increase in initial water flux. In addition, the performance of modified UPS membranes in the filtration of biological solutions will also be discussed. Furthermore, the biological performance of PCL scaffolds incorporated with various biocidal agents will be presented along with biocidal agent leaching studies.

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