Wednesday Afternoon, November 5, 2003

Plasma Science and Technology
Room 315 - Session PS2-WeA

Atmospheric Plasmas & Micro Discharges

Moderator: G. Selwyn, Los Alamos National Laboratory

2:00pm **PS2-WeA1 Electrical Characterization and Time-resolved Emission Spectroscopic Studies of Dielectric-barrier Controlled Atmospheric-pressure Glow Discharges in Helium***, **J. Shin**, P.L. Varghese, L.L. Raja,* The University of Texas at Austin

We report experimental studies of a dielectric-barrier controlled atmospheric-pressure glow (APG) discharge. The study is aimed at providing fundamental understanding APG discharge phenomena in high-purity helium. Electrical characteristics and time-resolved emission spectroscopic diagnostics are used. Dielectric barrier controlled APG discharge phenomena is characterized by a single or multiple current pulse during each half cycle of voltage input to the discharge. We study discharge phenomena under a variety of conditions such as varying gap sizes, operating frequencies and dielectric placement. Significant and random scattering as well as random asymmetries in current pulse shape are observed. We correlate these discharge peculiarities with the time-resolved emission spectroscopic results. In particular, we report spectroscopic observations of discharge condition just prior to glow-to-arc transitions.

2:20pm **PS2-WeA2 Measurement of the Fluorine Atom Concentration in a Carbon Tetrafluoride and Helium Atmospheric-Pressure Plasma***, **X. Yang**, S.E. Babayan, G.R. Nowling, M. Moravej, R.F. Hicks,* University of California, Los Angeles

A titration technique has been developed to measure the fluorine atom concentration in the downstream region of a low-temperature, atmospheric pressure plasma fed with helium and carbon tetrafluoride. The fluorine atoms were titrated with H@sub 2@ molecules, and the HF reaction product was detected by infrared spectroscopy. The radio-frequency gas discharge produced 1.2x10@super 15@ cm@super -3@ of F atoms, which was about two orders of magnitude higher than that found in low-pressure plasmas. The average electron density and temperature in the plasma was estimated to be 6.1x10@super 11@ cm@super -3@ and 2.5 eV. A numerical model of the plasma indicated that most of the fluorine atoms were generated by the reaction of CF@sub 4@ with metastable helium atoms. The results of the experiments and the model will be presented at the meeting.

2:40pm **PS2-WeA3 Generation Mechanism of the Atmospheric Glow in a DBD Configuration***, **E. Aldea**,* Eindhoven University of Technology, The Netherlands*; C.P.G. Schrauwen,* TNO-TPD , The Netherlands*; M.C.M. van de Sanden,* Eindhoven University of Technology, The Netherlands

Conventional wisdom attributes the generation of atmospheric glow plasmas to gas pre-ionization, which is related to ions or to electron generation by metastable-metastable and metastable-surface collisions . However there is not yet unambiguous experimental evidence, which can prove the validity of either of the proposed mechanisms. Beside that this pre-ionization mechanisms can not explain either how the glow to arc transition a notorious instability of atmospheric plasmas is avoided. Therefore to our opinion the physical basis of the atmospheric glow remains an open and challenging issue. In this contribution we analyze the basic conditions needed for uniform glow plasma generation. A simple analysis of the glow generation indicates that it is extremely improbable that the metastables or ions can have a significant contribution to glow generation via a pre-ionization mechanism. The low diffusion rate of ions and metastables excludes any mechanism of streamers or electron avalanches superposition. The preionization mechanism based on ions or metastables cannot also explain why the standard breakdown mechanism of atmospheric plasma streamer breakdown does not occur. Besides these theoretical arguments no evidence was found in the experimental current-voltage characteristics, plasma emission or breakdown voltage suggesting a significant pre-ionization or even the presence of a large amount of metastables. We conclude that the major problem in generation of atmospheric glow plasma is glow to arc transition. In this respect metastables are rather the problem for a stable plasma generation because their presence enhance the probability of stepwise ionization and glow to arc transition. The experimental data suggests that the surface of the dielectrics plays a major role in uniform and stable atmospheric glow plasma generation. The surface effect is probably due to a high secondary emission at the surface.

3:00pm **PS2-WeA4 Ultraviolet Emission Spectroscopy and Absorption Spectroscopy of CF@sub 2@ Radical in Chemical Vaporization Machining (CVM) Plasma Generated with High Speed Rotating Cylindrical Electrode***, **Y. Oshikane**, S. Sato, A. Nagao, K. Yamamura, K. Endo, Y. Mori,* Osaka University, Japan

Optical emission spectroscopy and broad-band absorption spectroscopy in UV region have been applied for determining CF@sub 2@ radical density in the chemical vaporization machining (CVM) plasma, which is generated in below 1 mm gap between the side of rotating cylindrical electrode (alumina) and flat substrate (silicon, quartz) by VHF at 150 MHz. By using a grating spectrograph consists of imaging aspheric mirrors coupled with cooled CCD camera, a spatially resolved UV spectrum has been recorded for CF and CF@sub 2@ radicals. Relative changes in CF@sub 2@ density in He/CF@sub 4@/O@sub 2@ plasma were monitored. The experiments cover a wide range of pressure, composition, rotation speed, and power deposition conditions (10@super 3@-10@super 5@ Pa, 0.01-1% CF@sub 2@, 0.01-1% O@sub 2@, 0-2000 rpm, 15-100 W). Increasing the pressure from 10@super 3@ to 10@super 5@ Pa showed large changes in CF@sub 2@ band spectrum. Both emission and absorption spectrum of a 10@super 3@ Pa He/CF@sub 4@/O@sub 2@ plasma showed the A(0,v,0)-X(0,0,0) (v=0 to 13) transition of the CF@sub 2@ molecule from 230 to 270 nm. But the spectrum shifts to longer wavelengths and showed the A(0,0,0)-X(0,v,0) (v=0 to 10) transition spectrum from 260 to 340 nm at atmospheric pressure. The spatially resolved absorption spectrum showed the absorption peaks near the side of electrode and substrate surface.

3:20pm **PS2-WeA5 A Simulation Study of the Role of Surface Phenomena in Dielectric-barrier Atmospheric-pressure Glow Discharges***, **X. Yuan**, L.L. Raja,* The University of Texas at Austin

Atmospheric-pressure glow (APG) discharges controlled by dielectric barriers can be used for a variety of new applications such as etching and deposition of thin films, surface modification, and plasma sterilization, without need for vacuum chambers. Dielectric-barrier controlled APG discharges exhibit a variety of interesting phenomena that are determined by plasma dynamics, volumetric chemistry, and dielectric surface effects. A clear understanding of these interactions is often difficult to unravel through purely experimental means and first principles simulation approaches can play an important role. In this talk, we will present detailed one-dimensional simulation results for a dielectric-barrier APG discharges in high-purity helium. Simulation results will be used to explain several experimentally observed dielectric-barrier APG characteristics such as large scatter in peak current values, asymmetry in current pulses, and parametric dependence of peak current pulse values on different discharge operating conditions. Our modeling results present convincing evidence that run-to-run variations in surface conditions (such as secondary electron emission coefficients) control the experimental observations such as scattered and asymmetric current pulses.

3:40pm **PS2-WeA6 Miniature Microwave Plasma Torch Applicators and Characteristics***, **T.A. Grotjohn**,* Michigan State University and Fraunhofer Center for Coatings and Laser Applications*; K. Hemawan, S. Zuo,* Michigan State University*; J. Asmussen,* Michigan State University and Fraunhofer Center for Coatings and Laser Applications

The experimental evaluation of two miniature microwave plasma torch applicators that have potential use in materials synthesis and surface treatment are described. The first applicator employs an open ended coaxial structure with the discharge located at the tip of the center conductor. The discharge is formed at atmospheric or slightly below atmospheric pressure where the feed gas flows through the center conductor of the applicator. The second applicator is similar to a microstripline coupling structure described earlier.@footnote 1@ This applicator couples microwave energy to a surface wave discharge formed in an open ended tube placed between and perpendicular to the strip transmission lines. The feed gases are fed directly through the surface wave discharge and flow out to a pressure controlled environment ranging from approximately 10 Torr to atmospheric pressure. Both microwave plasma torches are experimentally evaluated over a range of input power and a variety of feed gas mixtures including argon, mixtures of argon with hydrogen and selected hydrocarbon gases, nitrogen, and air. These torches operate from 10's to 100's of watts of input power and are able to maintain discharges over a wide range of flows from diffusional flow of radicals for gentle surface processing to high velocity flows approaching supersonic velocities. Objectives of this work are to create compact microwave plasma torch designs that operate from below atmospheric pressure to one atmosphere pressure with processing spot sizes ranging from several mm down to less than 0.25 mm. The numerous applications of these microplasma torches include cutting, welding, cleaning and other surface treatments. @FootnoteText@ @footnote 1@ T. A. Grotjohn, et.al., "Characteristics of Miniature Microwave Excited Plasma Discharges," AVS Symposium, Denver, 2002.

4:00pm **PS2-WeA7 Microplasma Surface Modification of the Inner Surface of Small Diameter Polyethylene Tubing for Improved Hematocompatibility*, J.L. Lauer*, *J.L. Shohet, C. Pratoomtong, R.D. Bathke, R.M. Albrecht, S. Esnault, J.S. Malter,* University of Wisconsin, Madison*; S.B. Shohet,* University of California, San Francisco*; U. von Andrian,* Harvard Medical School

Microplasma surface modification was used to modify the inner surface of small diameter (280 and 800 µm and up to 1 meter in length) polyethylene (PE) tubing. Polyethylene glycol was grafted to the lumenal surface using an oxygen plasma and then cross-linked with an argon plasma. The plasma was created by placing hollow cathodes electrodes, in vacuum, at the ends of the PE tubing. The electrodes were powered by a 15 kV pulsed a.c. supply. Since feedstock gases and reaction products must pass along the length of the tubing, the resulting pressure drop has the potential to cause nonuniform plasma chemistry and thus a nonuniform treatment along the tubing. Emitted light from the plasma was analyzed with a monochromator, that was moved along the length of the tubing, giving insight on plasma uniformity. Treatment effectiveness on the lumenal surface was evaluated using a capillary rise method, which can be directly related to the contact angle. Uniformity of the atomic surface composition along the length of the inner surface of the PE tubing was analyzed by XPS. To test for hematocompatibility, a loop, powered by a peristaltic pump, circulated heparinized human blood for times up to one hour at flow rates of the order of 1 ml/minute at 37 C. After the flow test, the tubing was rinsed with phosphate buffer solution (PBS) for 10 minutes (with the same flow rate as the blood). The cells were fixed for 30 minutes with 1.25% by volume glutaraldehyde and 0.5% by weight tannic acid dissolved in PBS. After the fixation, the tubing was rinsed with PBS for another 10 minutes. It was then dehydrated with two-minute exposures to ethanol of increasing concentration from 50% to 95%. Plasma-treated and untreated tubing were then evaluated by studying the morphology of adhering platelets along the tubing with SEM. By suitably modifying the plasma parameters, the degree of uniformity as a function of distance along the tubing and proximity to the peristaltic pump can be optimized.

4:20pm **PS2-WeA8 Microdischarge Plasma in Supercritical Fluid*, K. Terashima,*** The University of Tokyo, Japan **INVITED**

We have performed the study of microscale/nanoscale plasma science and technology.@footnote 1@ In this talk, our recent work on microdischarge plasma in supercritical fluid (SCF), particularly near the critical point (CP), for CO@sub 2@ (CP:7.38MPa,304K)and H@sub 2@O (CP:22.1MPa,674K), are presented. SCF,which is an intermediate state of matter between liquid and gas, has attracted much interest in scientific and enginering fields due to abnormal characteristics, such as high solubility. In particular, near CP, large density fluctuation results in drastic change of the properties. From a microscopic viewpoint, the SCF consistes of various sized clusters. Therefore, it is highly anticipated that the ionized state, such as the plasma state, in SCF may exhibit unique characteristics and reactions, that are distimct from those of the normal plasma state in gas. In addition to the first generation@footnote 2@ of plasma in SCF, abnormal features of breakdown voltages (V@sub B@) as a function of environmental pressure are demonstrated. For CO@sub 2@, measurements of V@sub B@as a function of pressure for high-pressure CO@sub 2@ up to SCF conditions of various temperatures have been performed using a 1-µm-gap coplanar film electrode. The curve of the V@sub B@ exhibits an inflection at around 3 MPa and a drastic decrease near CP. The V@sub B@ in pressure environments higher than the inflection at around 3 MPa can be analyzed using the Townsend theory and density fluctuations, which typical indicates clustering, and the drastic decrease of V@sub B@ near CP was shown by a scaling function. The same features were also observed for H@sub 2@O. Finally, as an example of an application, the preparation of carbon-cluster systems, such as nanopolyhedra and nanotubes, using SCF-CO@sub 2@ plasma is also presented. @FootnoteText@ @footnote 1@ K.Terashima, L.Howald, H.Haefke and H.J.Güntherodt, Thin Solid Films 282(1996)634. @footnote 2@ T.Ito and K.Terashima, Appl.Phys.Lett.80(2002)2854.

5:00pm **PS2-WeA10 Two-dimensional Simulation of dc Microdischarge Phenomena*, P.S. Kothnur*,** *L.L. Raja,* The University of Texas at Austin

Microdischarges have gained much attention in the plasma process community for a variety of applications. Proposed applications range from generation of intense UV radiation to maskless etching of thin films. Recently, arrays of microhollow cathode discharges are being investigated for applications such as sources of flat panel light sources or electron sources. While some estimates of properties of micro hollow cathode discharges are available, a detailed understanding of the plasma dynamics and chemistry is lacking. Further, it is not fully clear as to what conditions influence the existence of the hollow cathode effect in microdischarge geometries. This talk presents results from a self-consistent, two-dimensional computational study of the glow-like phenomena in microdischarges. The model includes a description of multi-species transport and chemistry, electric field, electron and heavy species energy distributions in the microdischarge. The talk explores conditions under which the hollow cathode effect occurs in microdischarge geometries, and presents a fundamental understanding of the overall microdischarge phenomena. Further, we explore thermal heating effects in dc microdischarges in the presence of bulk flow inside the discharge. This aspect of the study is motivated by our proposed use of microdischarges in space thruster applications.

Author Index

Bold page numbers indicate presenter