Plasma Science and Technology
Room 2011 - Session PS2-WeA

Atmospheric and Microplasmas

Moderator: D.J. Economou, University of Houston

2:00pm **PS2-WeA1 Use of Hydrogen or Oxygen Atmospheric Pressure Plasmas for the Surface Treatment of Metals**, *E. Michel,* Unviersité Libre de Bruxelles, Belgium*; E. Silberberg,* ARL, Arcelor Group*;* ***F. Reniers,*** Unviersité Libre de Bruxelles, Belgium

Oxygen or hydrogen-based dielectric barrier discharges were used to remove organic contaminants from steel surfaces or to reduce surface oxides on various metals (copper, iron). Contaminated steel surfaces were treated using atmospheric pressure oxygen based plasmas in a DBD. In our configuration, the hot electrode only is covered with the dielectric, whereas the other electrode being the sample. Voltages between 1 to 4 kV were applied between the electrodes, at a frequency varying between 5 and 30 kHz. The plasma gas consisted in a mixture of He-O@sub2@, at atmospheric pressure, or pure oxygen at a reduced pressure. The plasma chemistry was characterized using optical emission spectrometry (OES). The electrical characteristic of the plasma were recorded as a function of the applied voltage, frequency and gas composition. The kinetics of decontamination was studied by Auger electron spectroscopy (AES) and infrared spectroscopy (IRRAS- FTIR). The effect of the frequency, the applied voltage, the discharge current, the initial amount of contamination and the gas composition on the kinetics of decontamination was studied. The resulting surface state of steel was investigated using AES and X-ray photoelectron spectroscopy. A macroscopic model for the kinetics of decontamination is proposed. Oxidised steel and copper surfaces were then exposed to low pressure hydrogen plasmas and high pressure hydrogen-helium plasmas. Although the DBD configuration was similar to the one developed for oxygen plasmas, the plasma reactor was attached to a XPS-UHV chamber to avoid post oxidation during transfer in air. Complete reduction of iron oxide and copper oxide could be achieved. The relationships between the plasma parameter (pressure, charge density, and frequency), the OES intensity of the hydrogen line, and the efficiency of surface oxide reduction were established for iron oxide.

2:20pm **PS2-WeA2 Fluoropolymer Deposition and Polymer Fluorination by Atmospheric Pressure Glow Dielectric Barrier Discharges**, ***F. Fanelli,*** *F. Fracassi, R. d'Agostino,* University of Bari, Italy

In this contribution we report our latest results on the PECVD of fluorocarbon thin films from glow dielectric barrier discharges (GDBDs) fed with He-C@sub 3@F@sub 6@ and He-C@sub 3@F@sub 8@-H@sub 2@ gas mixtures as well as on the fluorination of polymeric substrates by He-CF@sub 4@ GDBDs. The atmospheric plasma was generated in a parallel plate electrode configuration (5 mm gap) by applying an AC high voltage (< 4 kV@sub p-p@) in the frequency range 15 - 30 kHz. The effect of several process parameters (i.e. feed composition, frequency, voltage, etc.) was investigated inside the GDBD existence domain adequately evaluated by electrical measurements. Surface composition and structure were investigated through FTIR, X-ray Photoelectron Spectroscopy, Water Contact Angle measurements (WCA) and Scanning Electron Microscopy. He-C@sub 3@F@sub 6@ fed GDBDs allowed to deposit fluorocarbon films with F/C ratio of 1.5 at a deposition rate up to 35 nm/min. The investigation of He-C@sub 3@F@sub 8@-H@sub 2@ fed GDBDs showed that it is possible to tune the F/C ratio from 1.5 to 0.7 and to change the cross-linking degree of the coatings by varying the hydrogen concentration in the feed. H@sub 2@ admission promotes the increase of the deposition rate that is maximum when the fluorocarbon-to-hydrogen ratio is close to 1. Preliminary results from fluorination of polypropylene (PP) and polyethyleneterephtalate (PET) substrates with He-CF@sub 4@ mixtures allowed to observe the grafting of fluorinated functionalities which increased the WCA values up to 115° and 109° for PP and PET, respectively. Results of optical emission spectroscopy investigation of the plasma phase will be also presented.

2:40pm **PS2-WeA3 Numerical and Experimental Study of Microhollow Cathode Sustained Discharges in Ar and O2 at Relative High Pressure**, ***E. Muñoz-Serrano,*** *T. Callegari, G. Hagelaar, L. Pitchford, J.P. Boeuf,* CPAT - CNRS, France **INVITED**

Many research groups around the world are now actively investigating ways of generating and maintaining a stable, non-thermal, high-pressure plasma in electric discharges. Since the initial work of Schoenbach and his colleagues, it is now well established that such plasmas can be generated and maintained in discharges in small - 100's of micron-sized - geometries. The simplest such system consists of a cathode/dielectric/anode sandwich through which a cylindrical hole of some 200 microns is drilled. This is refered to as a MicroHollow Cathode Discharges or MHCD. Our work is focused on the study of the parameters that characterize the behaviour of a Micro Cathode Sustained (MCS) discharge@Footnote 1@ in which a third planar electrode (anode A2) is placed parallel at some distance (1 cm) from the anode (A1) of the MHCD sandwich. Thus, the MHCD is used as an electron source to form a higher plasma volume between the MHCD and the anode A2. Our experimental results to date suggest that the plasma in the MCS region can be treated like a positive column where the plasma is sustained by a local balance of charged particle losses and production processes. Our 2D model of the radially expanding positive column plasma in the MCS region is qualitatively consistent with experimental results in argon and in oxygen discharges. Results from these experimental and numerical results will be presented to illustrate the plasma properties that can be achieved in microdischarges in this MCS configuration. We would like to acknowledge the contribution of collaborative the experiments of V Puech (LPGP, Orsay) and A Rousseau (LPTP, Palaiseau) conducted in microcell geometries.@FootnoteText@@footnote 1@R.H. Stark and K.H. Schoenbach, J. Appl. Phys. 85 (1999) 2075.

3:20pm **PS2-WeA5 Spatially Resolved Gas Temperature Measurements in an Atmospheric Pressure DC Glow Microdischarge with Raman Scattering**, ***S.G. Belostotskiy***[1]*, Q. Wang, V.M. Donnelly, D.J. Economou,* University of Houston*; N. Sadeghi,* Universite J. Fourier de Grenoble, France

Spatially resolved rotational Raman spectroscopy of ground state nitrogen N@sub 2@(X@super 1@@SIGMA@@sub g@@super +@) was used to measure the gas temperature (T@sub g@) in a nitrogen dc glow microdischarge (gap between electrodes d ~ 500 μm). An original backscattering, confocal optical system was developed for collecting Raman spectra. Stray laser light and Raleigh scattering were blocked by using a triple grating monochromator and spatial filters, designed specifically for these experiments. The optical system provided a spatial resolution of <100 μm. Gas temperatures were determined by matching experimental spectra to model spectra obtained by convolution of theoretical line intensities with the apparatus spectral resolution, with Tg as the adjustable parameter. T@sub g@ was determined as a function of pressure and discharge current density (P = 400 - 760 Torr, j@sub d@ = 200 - 1000 mA/cm@super 2@). Midway between the electrodes, T@sub g@ increased linearly with j@sub d@, reaching 420 K at 1000 mA/cm@super 2@ j@sub d@ for a pressure of 720 Torr. Spatially resolved gas temperature measurements will also be presented and discussed in combination with a mathematical model for gas heating in the microplasma.

3:40pm **PS2-WeA6 Experimental and Theoretical Studies of Atmospheric Pressure Direct Current Microplasma Argon Discharges**, ***Q. Wang,*** University of Houston*; I. Koleva,* Sofia University, Bulgaria*; D.J. Economou, V.M. Donnelly,* University of Houston*; N. Sadeghi,* University Joseph Fourier-Grenoble & CNRS, France

A combination of plasma diagnostics and modeling were performed on a slot-type DC microplasma discharge in argon at atmospheric pressures. The gas temperature was measured by N@sub 2@ emission spectroscopy (C -> B transition) by adding small quantities of nitrogen (B rotational spectra, and the gas temperature was determined from the lower of the two temperature values. At 760 Torr and 18 kW/cm@super 3@ power density, the gas temperature was between 500 K and 1100 K, depending on position between the electrodes. Electron densities were determined from the spectral line broadening of H-@beta@ emission. The electron density in the bulk plasma was the 10@super 14@ cm@super -3@ range. A model of a DC argon microplasma discharge was in agreement with experimental data. Spatially resolved gas temperature measurements as a function of gas flow through the microplasma also agreed with the model. The gas temperature decreased with increasing gas flow due to convective removal of heat. The gas temperature peaked off axis near the cathode as ions accelerated in the cathode sheath and deposited part of their energy in frequent collisions with the neutral gas.

[1] **PSTD Coburn-Winters Student Award Finalist**

4:00pm **PS2-WeA7 Use of Dual Atmospheric Microdischarges for Manipulating the Growth of Silicon Nanoparticles**, ***N.A. Brunelli***, *K.P. Gipias, R.C. Flagan,* California Institute of Technology

Atmospheric microdicharges have been shown@footnote 1@ to produce Silicon nanoparticles between 1-2 nm in diameter, which exhibit intense photoluminescence emission at 420 nm with a quantum efficiency of 30%. It is desirable to obtain emission at longer wavelengths for imaging applcations, by increasing the diameter of the nanoparticles. However, it has been exceedingly difficult to manipulate the nanoparticle size in a single microdischarge, where perturbations to the growth conditions seem to only influence the number of particles produced while the size remains invariant. We demonstrate here that by using two microdischarges in series that silicon nanoparticles generated in the first microdischarge can be overgrown to larger sizes in the second microdischarge. The addition of precursor in the second microdischarge and adjustment of other operating parameters allows the particle size to be tuned. We quantify this claim by using a new ultrafine radial differential mobility analyzer (UF-rDMA) immediately after the second microdischarge to monitor in real time the particle size. The particles are then deposited on solid substrates for independent size verification by atomic force microscopy (AFM). Finally, we characterize the nanoparticles by photoluminescence and transmission electron microscopy. @FootnoteText@ @footnote 1@ R.M. Sankaran, et al. Nano Lett. 5 (3) 2005.

4:20pm **PS2-WeA8 Development of Multi-Micro Hollow Cathode Lamp with Metallic-Element-Emission Allay**, ***T. Ohta***, *S. Taneda, M. Ito,* Wakayama University, Japan*; S. Takashima,* Nagoya University, Japan*; H. Kano,* NU EcoEngineering CO., LTD., Japan*; S. Den,* Katagiri Engineering CO., LTD., Japan*; M. Hori,* Nagoya University, Japan

For quantitative analysis of metallic elements, the atomic absorption spectrometry has been widely used. The development of the compact light source, which emits simultaneous multi-atomic lines for the analysis, is required, since the analysis should be performed quickly on-site in the environmental field. Therefore, we developed the multi-light source using micro hollow cathode discharge. Micro hollow cathode discharge can be stably generated in high-pressure without an arc discharge, which destroys the devices. The four Cu pipes attached with metallic wires, which are Fe, Mo, and Brass respectively, were used as a cathode. The inside diameter of Cu pipe was 0.7 mm. The Cu mesh as an anode was set at the distance of 160?m from the cathode. The discharge was generated by using helium as a working gas at the pressure of 0.02 MPa, the current of 71 mA, and the discharge voltage of 320 V. The emissions of four metallic elements from the each pipe were simultaneously obtained. The analysis line of Cu (324.74 nm), Zn (213.86 nm), and Fe (344.06 nm), and resonance line of Mo (379.83 nm) were observed. The emission intensities of metallic elements increase with a decrease in the pressure. The pD, where p is a pressure and D is a cathode hole diameter, was 1.1 Torr cm and the discharge was stably generated with hollow cathode effect. The multi-light source using micro hollow cathode discharge was successfully developed. The multi-micro hollow cathode discharge would open the window to analyze the various metallic elements simultaneously by changing the wire elements.

4:40pm **PS2-WeA9 Finite Element Analysis of Atmospheric Pressure RF-excited Plasma Needle**, ***Y. Sakiyama***, University of Tokyo, Japan*; D.B. Graves,* University of California, Berkeley

The atmospheric pressure RF-excited plasma needle is a non-thermal discharge powered at 13.56 MHz with a localized plasma sustained at the sharp tip of a thin cylindrical conducting electrode. Using a finite element solution to the governing fluid equations, we identify two discharge modes of the plasma needle as well as the transition mechanism. The gas used is helium with 0.1% nitrogen addition. The needle has a point-to-plane geometry with a radius of 3 μm at the tip, 150 μm at the base and an inter-electrode gap of 1 mm. The plasma needle operates as a corona discharge at low power and a glow discharge above a critical power. The discharge power increases but the discharge voltage drops abruptly by a factor of about 2 in the corona-glow transition. In corona-mode, the peak plasma density and ionization is confined near the needle tip. Penning ionization of the trace nitrogen gas is the dominant ionization reaction and displacement current dominates over the conduction current. On the other hand, the plasma spreads back along the needle surface in glow-mode. Direct ionization of helium prevails over Penning ionization and conduction current accounts for 80% of the total current in glow mode. The corona-glow transition is also characterized by a dramatic decrease in sheath thickness and an order of magnitude increase in plasma density and volume-averaged ionization. The transition is observed whether or not secondary electron emission is included in the model. The influence of species such as oxygen and water vapor, and the role of forced convection towards a surface to be treated, will be also presented. Experimental validation of the model predictions is discussed.

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