Plasma Science and Technology
Room 302 - Session PS-WeA

Atmospheric Plasmas and Microdischarges

Moderator: L. Bardos, Uppsala University, Sweden

2:00pm **PS-WeA1 Limitations for Replacement of Low Pressure Plasma by Atmospheric Pressure Plasma*, D. Korzec,*** German University in Cairo - GUC, Egypt **INVITED**

A substantial research effort in recent years was focussed on the development of atmospheric pressure plasma (APP) for technological applications. For some applications such as surface treatment or rapid film removal the technological progress is fast and processes are available, being an alternative for the well established low pressure plasma approaches. For other applications, such as high quality film deposition or anisotropic structuring, the application of APP faces serious difficulties. These problems are discussed from the point of view of fundamental physical limitations. The different type of pressure scaling rules are critically reviewed, leading to the conclusion that APP works not because of scaling, but because of specific physical phenomena, which are significant in the pressure range over 100 Torr but can be disregarded for lower pressures. Special focus will be on the dynamics of the APP discharges and effective life times of species used for driving the APP processes. In this context, the frequency ranges for APP generation are investigated. It is shown, that only very narrow parameter windows and only selected gas mixtures allow the successful processing. Different types of APP discharges will be analyzed from the point of view of the basic physical limitations. Conclusion from this analysis will be the estimation of future trends in technological applications of APP and the definition of realistic process challenges.

2:40pm **PS-WeA3 Cold Atmospheric Plasma in Nitrogen and Air Generated by the Hybrid Plasma Source*, H. Barankova,*** *L. Bardos, D. Söderström,* Uppsala University, Sweden

Generation of long plumes of cold atmospheric plasma in nitrogen and air has been successfully performed by the Hybrid Hollow Electrode Activated Discharge (H-HEAD) source. The source with a simple cylindrical electrode terminated by a gas nozzle combines the microwave antenna plasma with the hollow cathode plasma generated inside the gas nozzle by pulsed DC power. The H-HEAD source is capable to generate up to 10 cm long plumes in air at the microwave power below 500 W and at air flow rate as low as 100 sccm. Corresponding flow rates in nitrogen plasma are even less than 80 sccm. The discharges in air and nitrogen have similar shapes and are comparable with corresponding plasma columns in argon. Comparison of optical emission spectra of the plasma in nitrogen and air are presented. Temperatures generated on steel substrates by interaction with nitrogen and air plasma columns at different microwave and DC powers are compared with corresponding effects in argon plasma.

3:00pm **PS-WeA4 Ultra Fast Surface Modification Processes Employing Compact Non-Equilibrium Atmospheric Pressure Plasmas*, N. Yoshida,*** Fuji, Machine Mfg. Co., Ltd., Japan*; H. Kano,* NU-EcoEngineering, Japan*; S. Den,* Katagiri Engineering Co., Ltd, Japan*; M. Hori,* Nagoya Univ., Japan

In the atmospheric pressure plasma processing, the vacuum facilities are basically not needed and the plasma chemistry with considerably large amount of radicals can be utilized. Consequently, the high-speed material processes such as etching, deposition and surface treatment will be potentially realized employing atmospheric pressure plasmas and the equipment cost can be drastically reduced compared with other plasmas. Up to now, many generation technologies of atmospheric pressure plasma have been proposed. We have developed the compact non-equilibrium atmospheric pressure plasma employing new type of micro-hollow cathodes. This device was constituted of the electrode with double micro-hollow structures, which is a very compact size of several ten micrometers and very light weight. Furthermore, it enables to generate the stable plasma in the atmospheric pressure condition. In this study, this plasma was generated with supplying voltage to two special hollow cathode electrodes, and throwing the argon gas of 500ml per minute into the both electrodes. The atmospheric pressure plasma generation can be realized not only in argon but also in air. When this plasma was irradiated on the glass surface for a short time, the considerable change was observed on the surface of the glass. XPS analysis indicated that the C-O bond on the glass surface was drastically decreased while a new peak of O=C-O bond appeared during the plasma irradiation. After only 0.08 seconds irradiation, the contact angle of 20 degree was obtained and after 0.4 seconds, that of 8 degree was easily realized. Therefore, the high hydrophilic processing was successfully achieved in a very short time by using this plasma. From these results, the compact non-equilibrium atmospheric pressure plasma developed in this study will be very promising for a lot of applications to various kinds of surface treatment fields.

3:20pm **PS-WeA5 Design, Diagnostics, and Applications of Microplasmas Operated at around Atmospheric Pressure*, K. Tachibana,*** Kyoto University, Japan **INVITED**

Recently, microplasmas of sub-millimeter to micrometer scales are of much interest for various applications such as displays, light sources, micro total analytic systems, micromachining tools, and so on. Microplasmas can be operated not only as a sole device but also in one or two dimensional arrays. In addition, those are operated at a higher pressure range, including atmospheric pressure, according to the shrinkage of the sizes. These features make their potential larger for wider applications. If we use gas discharges for the generation of microplasmas, the electrode configuration is categorized as counter, coplanar, and coaxial electrode types. The dielectric barrier discharge (DBD) scheme is also advantageous in their parallel operation in arrays, where electrodes are covered by dielectric materials for preventing the current concentration automatically thanks to the accumulated surface charge. As the first example, several types of microdischarges are introduced which are used in plasma display panels. Experimental results on spatiotemporal behaviors of microplasmas in unit discharge cell are explained, where the excited species have been diagnosed by using a laser absorption spectroscopy method and the electron density by a mm-wave transmission technique. Those results are discussed for the improvement of luminous efficiency. As the second example, a coaxial mesh-type DBD with a microplasma integrated structure is explained as a large area plasma source for the purpose of various surface treatment technologies. The superior performances are explained in a comparison with those of a conventional parallel plate DBD system for the wider parameter ranges of stable operations. As the third example, our new idea of microplasma devices for the control (switching, filtering, etc.) of microwaves will be explained by using the dielectric properties of plasmas. This idea can be expanded towards microplasma photonic crystals.

4:00pm **PS-WeA7 A Non-Equilibrium Atmospheric Pressure Plasma Operating at High Power Densities*, M. Moravej,*** University of California, Los Angeles*; X. Yang,* Researcher*; J. Penelon, S. Babayan,* Surfx Technologies*; R.F. Hicks,* University of California, Los Angeles

A new atmospheric pressure plasma source has been developed that shows exceedingly high processing rates. For example, kapton films have been etched at 5.0 mm/s using an argon and oxygen discharge with 6.0 vol.% O2 and a temperature of 280 Â°C. The plasma source consisted of a small quartz tube that was capacitively coupled to radio frequency power at 13.56 MHz. The input plasma power could be increased up to 150 W/cm3 without arcing, or forming a streamer like discharge. At this power density, the gas temperature was determined by spectroscopic methods to be 300Â±30 Â°C. The O atom concentration was measured in the plasma afterglow by nitric oxide titration, and was found to be 1.2Â±0.6 Â´1017 cm-3 at 150 W/cm3 and 6.0 vol.% O2 in Ar. This corresponds to 15% dissociation of the oxygen molecules fed to the source. The concentration of ozone in the downstream region equaled 4.3Â±0.5 Â´1014 cm-3, as determined by UV absorption spectroscopy. These results were found to be in good agreement with a numerical model of the plasma and afterglow that included the reaction mechanism and the plasma electron density and temperature as calculated from current-voltage measurements. At the meeting, we will discuss the physics and chemistry of this new atmospheric plasma in detail. We will also present results on materials processing with this device, such as silicon dioxide etching and/or thin film deposition.

4:20pm **PS-WeA8 Modeling of Pulsed Microdischarges for use as Thrusters@footnote 1@*, R.A. Arakoni,*** University of Illinois at Urbana-Champaign*; J.J. Ewing,* Ewing Technology Associates*; M.J. Kushner,* Iowa State University

Microdischarges having characteristic dimensions of 100s of µm with back pressures of 10s to 100s of Torr are being investigated for use as sources of thrust for small satellites. These devices are capable of generating up to mN of thrust using noncontaminating propellants such as rare gases. The class of device of interest is a cylindrical discharge operated in dc or pulsed modes. The bore of the discharge is fabricated in a heat-resistant ceramic with micro-fabricated ring electrodes. The dominant mode of propulsion is thermal heating of the neutral gas by the discharge, primarily by charge exchange. In this talk, this class of microdischarge will be computationally investigated using a 2-dimensional plasma hydrodynamics model having an unstructured mesh to resolve non-equilibrium electron, ion and neutral transport using fluid equations.@footnote 2@ Sheath accelerated, beam-like electrons are resolved using a Monte Carlo simulation. A compressible Navier-Stokes module provides the bulk fluid velocities and temperatures. Changes in surface properties are addressed with a surface site-balance model. Results from a parametric investigation of back pressure (a few 10s to 100s of Torr), power, and pulse length will be discussed for rare gas mixtures with the goal of maximizing the velocity of the exhaust at the exit plane. Velocities of up to 100s m/s have been predicted in the throats of the devices with plasma densities of 10@super 13@ - 10@super 14@ cm@super -3@ with back pressures of 50 Torr in a cw operation mode. Since the source of propulsion is plasma heated gas, the siting of the plasma within the bore of the microdischarge, and subsequent heat transfer to the walls, is an important design consideration. @FootnoteText@ @footnote 1@ Work supported by Ewing Technology Associates, NSF (CTS03-15353) and AFOSR. @footnote 2@ A. N. Bhoj and M. J. Kushner, J. Phys. D, 37, 2910 (2004).

4:40pm **PS-WeA9 Atmospheric Microplasma-on-a-Chip Operating in Air***, **J. Hopwood**,* Northeastern University*; F. Iza,* Pohang University of Science & Technology, Korea

In this paper, an atmospheric pressure plasma-on-a-chip operating in air is described. The microplasma is ignited and sustained by microwave power (900 MHz, 3 watts) from a common cell phone power amplifier. The discharge is sustained within a 25µm gap formed in a microstripline split-ring resonator. The microstrip transmission lines are surface micromachined on a 22 mm diameter aluminum oxide wafer using electroplated copper and gold. The high quality factor (Q) and narrow discharge gap of the split-ring resonator result in electric field strengths in excess of 10 MV/m prior to plasma ignition. The discharge appears as an intense filament, but is not in thermal equilibrium as the measured rotational temperatures for the second positive system of nitrogen are 500-700 K in atmospheric pressure air. The impedance of the microplasma is found by measuring the microwave reflection coefficient of the resonator as a function of frequency. From the plasma impedance, the electron density is found to be on the order of 10@super 14@ cm@super -3@ in atmospheric pressure argon. Lifetime testing shows that the micro-electrodes are not eroded by ion bombardment after 100 hours operating in air at 3 watts. Applications for this microplasma include portable chemical analysis by optical emission spectrometry and ion mobility spectrometry. This work is supported by the NSF under Grant No. DMI-0078406.

5:00pm **PS-WeA10 Diagnostics and Simulations of a Helium Micro-Discharge at Atmospheric Pressure***, **Q. Wang**, D.J. Economou, V.M. Donnelly,* University of Houston*; I. Koleva,* University of Sofia

Spatially resolved measurements (resolution ~ 6 µm) were taken across an L=200 µm slot-type discharge in an atmospheric pressure direct current helium microplasma. Gas temperature profiles were determined from N@sub 2@ emission rotational spectroscopy. Stark splitting of the hydrogen Balmer-@beta@ line was used to investigate the electric field distribution in the cathode sheath region. Electron densities were evaluated from the analysis of the spectral line broadenings of H-@beta@ emission. The gas temperature was between 350 and 550 K, peaking nearer the cathode and increasing with power. The electron density in the bulk plasma was in the range 4-7 x 10@super 13@ cm@super-3@. The electric field peaked at the cathode (~60 kV cm@super -1@) and decayed to small values over a distance of ~ 50 µm (sheath edge) from the cathode. These experimental data are in generally good agreement with a self-consistent one-dimensional model of the discharge. The influence of gas heating on the discharge properties (such as current-voltage characteristic, cathode and anode sheath profiles), was also investigated. As the discharge current increased, the simulations indicate that the anode sheath turned from a positive ion sheath to an electron sheath, with concomitant changes in the sheath electric field profile and direction. This can be explained, based on the balance of charged particle gain and loss. Gas flow does not have a significant effect on gas temperature because of the high thermal conductivity of helium.

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