Advanced Surface Engineering
Room: C4 - Session SE-MoA

Atmospheric Pressure Plasmas
Moderator: M.S. Wong, National Dong Hwa University, Taiwan

2:00pm **SE-MoA1 Production-scale Processing of Flexible Substrates using High Power, Low Temperature, Atmospheric Pressure Plasma Technology**, ***G.S. Selwyn***, APJeT, Inc. **INVITED**

The application of vacuum-based plasmas in semiconductor processing has helped lead the microelectronics revolution and today is a highly-developed and mature technology. However, the high cost of operation and maintenance for vacuum-based plasma, along with the limitation for treating vacuum-compatible substrates, greatly limits future applications using this technology. In contrast to the vast expansion of vacuum-based plasma over the last 30 years, non-equilibrium, atmospheric-pressure plasma has a 125 year history dating back to Siemen's original invention of the dielectric barrier discharge. Yet, the applications for atmospheric pressure plasma industry represent only a tiny fraction of today's use of vacuum-based plasma. Part of the reason for this is the low power density that Dr. Siemen's atmospheric pressure plasma was able to achieve and the faster processing rates and improved control vacuum-based plasma was able to provide. This talk will review and compare the various kinds of atmospheric pressure plasma sources and will illustrate the use of a high-power, stable, non-equilibrium atmospheric pressure plasma that operates with a gas temperature below 30C for low-cost processing of commodity materials, such as textiles, non-wovens and plastic films. A full-scale production machine that uses 72" electrodes and which operates at 10KW will be shown, along with the unique process this technology enables.

2:40pm **SE-MoA3 Effect of the Electrode Material in the Atmospheric Plasma Abatement of NO from Air Mixtures**, ***L. Bardos***, *H. Barankova*, Uppsala University, Sweden

Protection of the environment requires more stringent limits on engine exhausts, power plant emissions and all other sources of air pollution. Different air cleaning technologies are being developed and applied for removal of pollutant gases like NO, NO2, SO2 and CO2. A very promising treatment is based on non-thermal (cold) plasmas at atmospheric pressure where dominant energy carriers are electrons and the dominant chemistry is based on formation and interactions of gaseous radicals. A widely supported method of cleaning air mixtures in the exhausts of diesels and combustion plants from NO and NO2 utilizes the Plasma Assisted Catalytic Reduction where the cold plasma is combined with the solid-state catalyst. In this method the plasma acts as an oxidation catalyst where an atomic oxygen from air oxidizes NO to NO2 and the solid-state catalysts are then capable to convert all NO2 to N2 and O2. However, in most cases it is necessary to involve also auxiliary gases, typically hydrocarbons (propene, ammonia), to make the process efficient. The present work introduces an original cold plasma system based on atmospheric hollow cathodes working in a pulsed dc regime with variable pulse voltage and repetition frequency. The system design and parameters have been optimized for the best conversion performance. It has been found that the material of electrodes can affect the oxidation efficiency of the plasma substantially. The graphite electrodes allowed the 100% conversion of NO to NO2 without any auxiliary gas. Effects of several materials on the conversion efficiency are compared and discussed.

3:00pm **SE-MoA4 Mechanism for the Surface Activation of Polymers by Remote Atmospheric Pressure Plasma**, ***E. Gonzalez***, *M. Barankin*, University of California, Los Angeles, *P. Guschl*, Surfx Technologies, LLC, *R. Hicks*, University of California, Los Angeles

An atmospheric pressure oxygen and helium plasma was used to activate the surfaces of polyethylene (PE) and polymethyl methacrylate (PMMA). The plasma physics and chemistry was investigated by numerical modeling. It was shown that as the electron density of the plasma increased from $3x10^{10}$ to $1x10^{12}$ cm^{-3}, the concentration of O atoms and metastable oxygen ($^1\Delta_g O_2$) molecules in the afterglow increased from $6x10^{15}$ to $1x10^{17}$ cm^{-3}, while the concentration of ozone decreased from $5x10^{15}$ to $2x10^{15}$ cm^{-3}. The oxygen atoms, metastable oxygen ($^1\Delta_g$ O_2) molecules and ozone were the principle reactive species present in the afterglow. Exposing the polymers to the plasma afterglow for up to 30 seconds led to surface activation and an increase in bond strength of the polymers to adhesives by as much as 16 times. X-ray photoelectron spectroscopy of PMMA revealed an 8% increase in the C 1s peak area attributed to carboxylic acid groups (288.9 eV). In addition, the C 1s peak due to the methyl pendant groups (285.0 eV) decreased by 5%. The O:C ratio of PMMA increased from 0.4 to 0.7 after plasma treatment. Surface analysis of the polymers by internal reflection infrared spectroscopy confirmed the presence of carboxylic acid groups at 1710 cm^{-1} and hydroxyl groups at 3100 to 3500 cm^{-1} after activation. These results indicate that oxygen atoms and metastable O_2 molecules generated in the plasma rapidly oxidize the polymer chains. The experimental results as well as a detailed description of the reaction mechanism will be presented at the meeting.

3:40pm **SE-MoA6 Coating Growth Behavior during the Plasma Electrolytic Oxidation Process**, ***R.O. Hussein***, *D.O. Northwood, X. Nie*, University of Windsor, Canada

In this study, aluminum oxide was deposited on an Al-alloy substrate to produce hard ceramic coatings using a Plasma Electrolytic Oxidation (PEO) process working at atmospheric pressure. Two different operation modes were used, namely a DC power mode and pulsed DC power mode with different frequencies. Optical Emission Spectroscopy (OES) was employed to study the species, electron temperature and densities of the plasma. The morphology, composition, and microstructure of the coatings on the Al substrate were investigated using Scanning Electron Microscopy (SEM) with energy dispersive X-ray (EDX) analysis, and X-ray diffraction. At the early stage of the PEO process the plasma electron temperature increased which shows the same trend as the output voltage. Aluminum emission line intensities (which are related to the spark behavior during the discharge) were higher for the pulsed DC mode than that from DC mode, causing different surface morphologies. It was also found that pulsed DC mode enhanced the coating growth during the early discharge stage, due to the strong ejection of aluminum from the substrate-oxide interface during the plasma discharges. The coating characteristics and OES analysis thus led to a better understanding of the ceramic coating growth behavior as influenced by the power operation modes.

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4:00pm **SE-MoA7 Saddle-like ICP Antenna for RF Atmospheric Plasma Processes**, ***Y. Glukhoy***, American Advanced Ion Beam Inc.

A saddle-like ICP antenna with the several spiral coils distributed with an angular uniformity and enveloping a quartz tube of a plasma reactor was developed. It generates a transversal RF field directed normally to axis of this reactor. Due to such a design property of this antenna can be tuned between an initial capacitively coupled and a following inductively coupled state to facilitate a plasma ignition especialy at atmospheric pressure. Unlike a conventional coil generating a filament-like ICP atmospheric discharge this antenna provides a larger high temperature area for evaporation of precursor as well as for a plasma-chemical reaction. This antenna was successfully tested for nanocoating by silicon dioxide of the different surfaces including the inner walls of the hollow articles.

1. Y.Glukhoy, I. Ivanov RF Atmospheric Plasma Systems for Nanopowder Production and Deposition of Nanocrystallines. AVS 53rd International Symposium, San Francisco, California, November , 2006 CA, USA.

4:20pm **SE-MoA8 Diagnostic Study of an Arc Plasma Jet Under Atmospheric Pressure and Its Applications to Materials Processing**, ***C.C. Hsu***, *C.Y. Wu, Y.W. Hsu, Y. Lin, Y.J. Yang*, National Taiwan University

An atmospheric-pressure arc plasma jet was studied, and its use for material processing will be presented. This plasma jet was sustained by a DC pulsed power source of 20 kHz ~ 40 kHz using nitrogen. A voltage probe and a current probe were used to monitor the voltage and current (I-V) waveforms. The optical emission at the plasma jet downstream was monitored by an optical emission spectrometer. Multiple thermocouples were used to measure the downstream jet temperature. The I-V waveforms reveal that the jet undergoes abnormal glow to arc transition within each pulse power period. This transition is shown to be critical for sustaining a stable plasma jet and is primarily controlled by the power input to the plasma in the abnormal glow regime. Temperature and optical emission measurements show that the jet temperature decreases and the excited-state species densities increase with the increase of the gas flow rate, while both quantities increase with the increase of the applied voltage. These allow for the independent control of the temperature and the excited-state species densities by using these two operating parameters. The use of this plasma jet for materials processing, namely zinc oxide thin-film deposition and niobium oxide nanowire fabrication, will be presented. The correlation between the plasma behavior and the fabricated materials characteristics will be discussed.

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