Structure of Velocity Distribution of Sheath-Accelerated Secondary Electrons in an Asymmetric RF-DC Discharge

Alexander V. Khrabrov[(a)], Igor D. Kaganovich[(a)], Peter L. G. Ventzek[(b)], Alok Ranjan[(c)] and Lee Chen[(b)]

(a) Princeton Plasma Physics Laboratory, Princeton NJ 08543
(b) Tokyo Electron America, Austin TX 78741
(c) TEL Technology Center America, Albany NY 12203

Low-pressure capacitively-coupled discharges with an additional DC bias applied to a separate electrode are important for plasma-assisted etching for semiconductor device manufacturing. Measurements of the electron velocity distribution function (EVDF) impinging on the wafer and in the plasma bulk show complex structure of EVDF with multiple peaks and steps. These features in the electron energy distribution functions are possibly caused by secondary electrons emitted from the electrodes and interacting with two high-voltage sheaths: a stationary sheath at the DC electrode and an oscillating, self-biased sheath at the powered electrode. We have performed test-particle simulations where the features in the EVDF of electrons impacting the RF electrode are fully resolved at all energies, and example appearing in Fig. 1. An analytical model has been developed to predict existence of peaked and step-like structures in the EVDF. These features can be explained by analyzing the kinematics of electron trajectories in the discharge gap. Step-like structures in the EVDF near the powered electrode appear to be due to accumulation of trapped electrons during part of the RF cycle and their subsequent release. Additional peaks, at lower energies, are formed by the electrons emitted from the RF electrode and eventually escaping to back to the same electrode. The latter electrons can be grouped by the number of bounces between the sheaths during their residence time in the discharge as shown in Fig. 1.

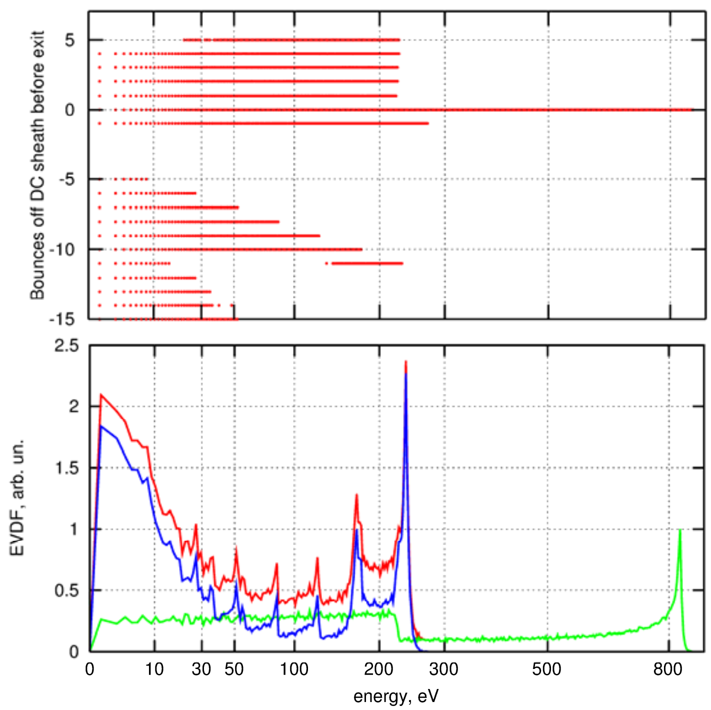


Figure 1 – (top) Numbers of bounces electrons perform in the gap before exiting to the RF electrode. (bottom) The EVDF of electrons at the RF electrode averaged over RF period as would be seen by an energy analyzer for V_{DC} =800V and V_{pp}=1500V. The green line shows contribution of electrons emitted from the DC electrode and blue line shows contribution of electrons emitted from the RF electrode. The red line is the sum of the two.

DOE Center for Control of Plasma Kinetics

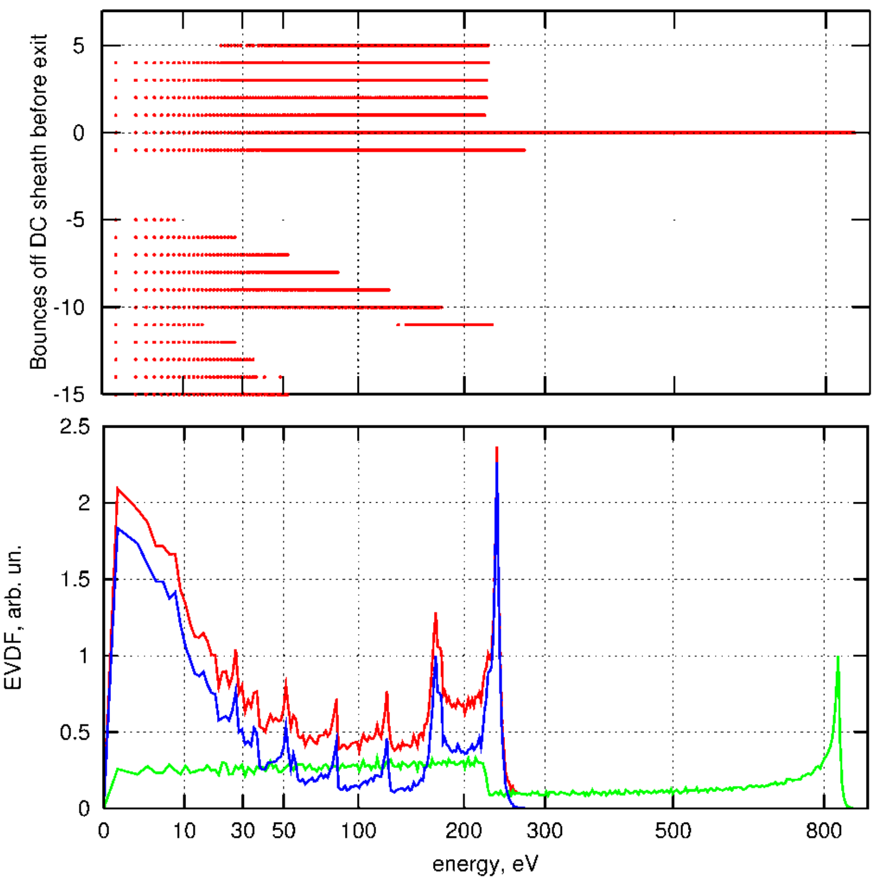
Highlight

Center for Predictive Control of Plasma Kinetics: Multi-Phase and Bounded Systems

Department of Energy Plasma Science Center

COMPLEX ELECTRON ENERGY DISTRIBUTIONS IN ASYMMETRIC RF-DC DISCHARGES

- **Low-pressure capacitively-coupled discharges with a DC bias applied to a separate electrode are important for plasma-assisted etching for semiconductor device manufacturing.**
- **Measurements of the electron energy distribution function (EEDF) impinging on the wafer and in the plasma bulk show complex structure and multiple peaks and steps.**
- **An analytical model has been developed to predict peaked and step-like structures in the EEDF. T**
- **These features are explained by analyzing the kinematics of electron trajectories in the discharge gap.**



- **EEDF showing correlation between number of bounces between electrodes and energy peaks**

PLSC_0215

HIGHLIGHT

PRINCETON PLASMA PHYSICS LABORATORY

Center for Predictive Control of Plasma Kinetics: Multi-Phase and Bounded Systems

Department of Energy Plasma Science Center

DOE Plasma Science Center
Control of Plasma Kinetics

Experiments and Simulations of Atmospheric Pressure Plasma Jets Interacting with Surfaces

Demetre J. Economou, Vincent M. Donnelly, Shyam Sridhar, Lei Liu, Eduardo Hernandez and Wen Yan

University of Houston, Houston, TX 77204-4004, economou@uh.edu

Interest continues to increase in low-temperature atmospheric-pressure plasmas, fueled mainly by realized and potential biomedical applications. For selected area exposure, atmospheric pressure plasma jets (APPJ) are most common. The plasma generated by this source extends up to several cm from the end of the tube where it mixes with open air, making it ideal for treating specimens, including bacteria-covered surfaces, or living tissue. Although the jet appears to be continuous, it consists of periodic streamers or "bullets" that propagate at speeds of 10 km/s or more.

Many optical emission spectroscopy (OES) and laser induced fluorescence (LIF) studies of APPJ have been conducted to measure species concentrations as a function of distance from an electrode, jet tip, or substrate, with a spatial resolution of at best a few µm. While this dimension may be commensurate with the sheath width, it is much larger than the mean free path (mfp) at atmospheric pressure (~100 nm in air). If species are lost and/or formed substantially at a surface immersed in the plasma, then a considerable gradient will exist over a distance of as little as 100 nm.

A combined experimental-simulation study of APPJs interacting with surfaces is under way. A schematic of the experimental setup is shown in Fig. 1. An APPJ is sustained in helium in a quartz tube with controlled environment of the surrounding gas (e.g., oxygen, dry air, humid air). The jet interacts with a surface which can be insulating (e.g., quartz) or conducting (e.g., quartz with a thin layer of ITO). Optical emission spectroscopy, in a wide range of wavelengths (UV to near IR) is the main plasma diagnostic. We are developing a new OES technique to be able to probe the last 100 nm of gas near a surface. This technique is based on measuring spectra as a function of angle using a semi-cylindrical prism. (See Fig. 1).

At the same time, we are employing a plasma transport and reaction fluid model to predict the spatiotemporal profiles of plasma species and electric field. An electron energy equation is solved with the rate coefficients calculated based on a Boltzmann solver. The ionization profiles and plasma "bullet" propagation along the jet axis, as well as bullet breakup upon striking the surface are also under investigation. Finally, the fluxes of important species (e.g., O atoms in the case of He plasma gas in an O_2 ambient) on the surface are predicted for both insulating and conducting surfaces, and compared to data.

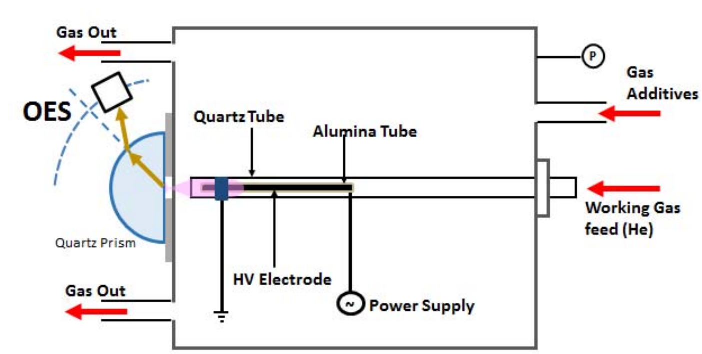


Figure 1 – Schematic of experimental apparatus for making spectcrosopic measurements within 100s nm of the surface.

DOE Center for Control of Plasma Kinetics

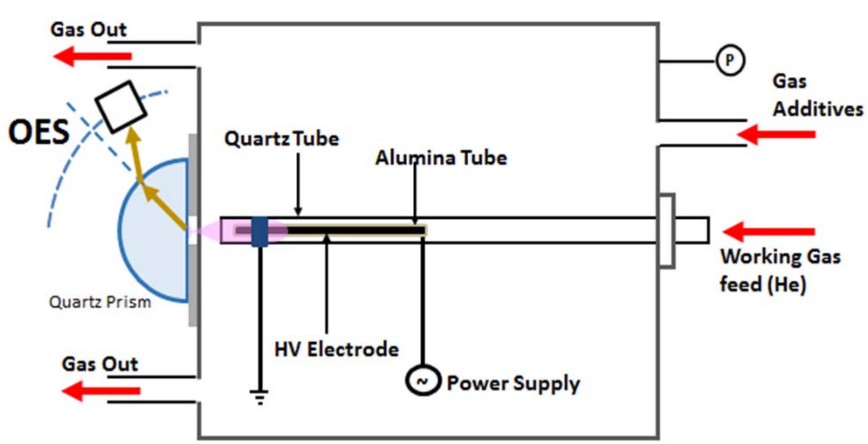
Highlight

Center for Predictive Control of Plasma Kinetics: Multi-Phase and Bounded Systems

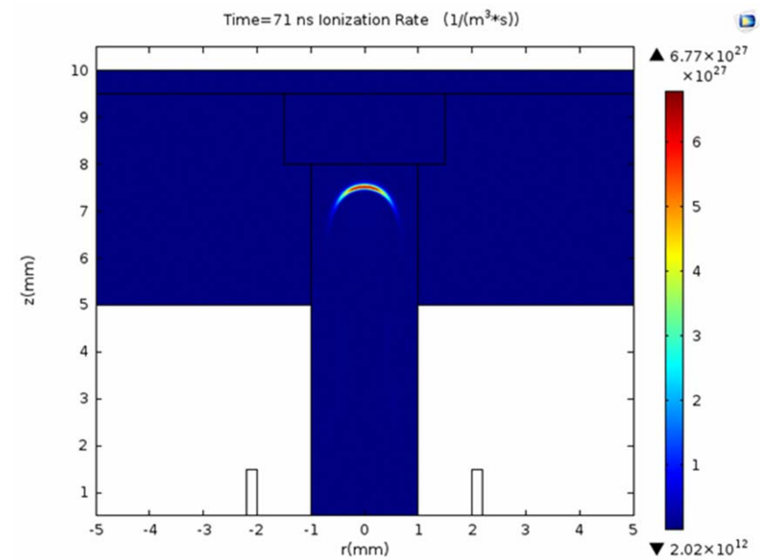
Department of Energy Plasma Science Center

EXPERIMENTS AND SIMULATIONS OF ATMOSPHERIC PRESSURE PLASMA JET INTERACTING WITH SURFACES

- **Experiment consists of an He atmospheric pressure plasma jet in a controlled gas environment and impinging on a surface.**
- **Optical emission spectra are collected as a function of angular position to probe the last 100 nm of gas phase species near the solid surface.**
- **Experiments focus on the effect of additive gas (O_2, H_2O, etc.) and organic or water ultra-thin films adsorbed on the surface.**
- **Simulations use fluid transport focusing on the effect of ambient gas, adsorbed layers, and the nature of the surface (conductive vs. insulating).**



- **Experimental setup**



- **Plasma bullet prediction from model.**

PLSC_02_2015

HIGHLIGHT

UNIVERSITY of HOUSTON

Center for Predictive Control of Plasma Kinetics: Multi-Phase and Bounded Systems

Department of Energy Plasma Science Center

DOE Plasma Science Center
Control of Plasma Kinetics