Controlling Sheath and Plasma Properties due to Effects of Electron-Induced Secondary Electron Emission

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Plasma-surface interactions in the presence of strong secondary electron emission (SEE) have been theoretically studied in the context of numerous plasma applications such as diverters, surface discharges, dusty plasmas, plasma thrusters, and plasma processing. The electron flux to the wall is determined by the electron velocity distribution function (EVDF) and by the sheath potential, which are determined by ambipolar constraints consistent with the wall properties. A traditional fluid description of the plasma-surface interaction suggests that electron emission from an electrically floating wall greatly reduces the sheath potential drop and, thereby weakens thermal insulating properties of the near-wall sheath leading to the enhancement of electron energy losses on the wall. However, in a typical low-pressure gas discharge, the electron mean-free-path can be large compared with the characteristic size of the discharge, and therefore, the electron motion can be almost collisionless. Recent PPPL kinetic studies of a collisionless plasma slab bounded by dielectric walls with SEE predicted a strongly anisotropic, non-monotonic EVDF, which is depleted in the loss cone. This EVDF reduces the electron wall losses compared to Maxwellian plasmas, as shown in Fig. 1 [1-3]. Sheath oscillations occur due to coupling of the sheath potential and non-Maxwellian electron energy distribution function when there are intense electron beams emitted from the walls [2]. In a bounded plasma where the electrons impacting the walls produce more than one secondary electron on average no classical Debye sheath or space-charge limited sheath exists. Ions are not drawn to the walls and electrons are not repelled, as shown in Fig.1(c). Hence, the plasma electrons travel unobstructed to the walls, producing extreme particle and energy fluxes [1]. Strong dependence of the wall potential on SEE allows for active control of plasma properties by judicious choice of the wall material.

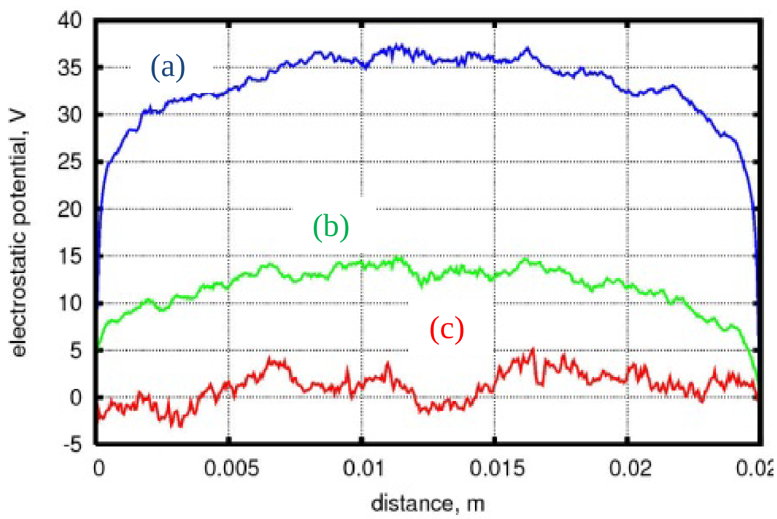


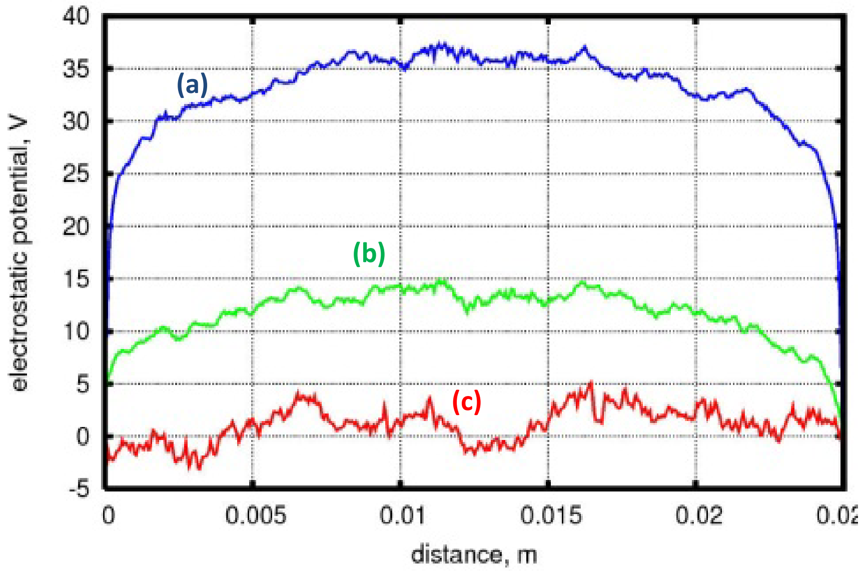
Fig. 1 – Potential profile in Hall thruster simulations for different values of electric field in the channel (a) E=200V/cm no emission (b) E=200V/cm with SEE, (c) E=250V/cm with SEE [1,3]

References:

[1] M. D. Campanell, A.V. Khrabrov and I. D. Kaganovich, Phys. Rev. Lett. 1**08**, 255001 (2012).
[2] M. D. Campanell, A.V. Khrabrov and I. D. Kaganovich, Phys. Rev. Lett. **108**, 235001 (2012).
[3] M. D. Campanell, A.V. Khrabrov and I. D. Kaganovich, Phys. Plasmas **19**, 123513 (2012).

CONTROLLING PLASMA PROPERTIES: ELECTRON INDUCED SECONDARY ELECTRON EMISSION

- **Kinetic studies of bounded plasmas by walls having secondary electron emission (SEE) predict a strong dependence of wall potential on SEE [1-3].**
- **Sheath oscillations occur due to coupling of the sheath potential and non-Maxwellian electron energy distribution functions [2].**



Potential profiles:
(a) E=200V/cm no emission
(b) E=200V/cm with SEE,
(c) E =250V/cm with SEE [1,3]

- **When electrons impacting walls produce more than one secondary on average no classical sheath exists.**
- **Strong dependence of wall potential on SEE allows for active control of plasma properties by judicious choice of the wall material.**

[1] Phys. Rev. Lett. 108, 255001 (2012)
[2] Phys. Rev. Lett. 108, 235001 (2012)
[3] Phys. Plasmas 19, 123513 (2012)

HIGHLIGHT

Control of VUV Fluxes and Etch Profiles Through Control of Electron Energy Distributions in Pulsed Inductively Coupled Plasmas

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The use of plasmas for materials processing critically depends on controlling the flux of energetic particles, including photons, onto surfaces. This control is obtained by controlling the electron energy distribution, $f(\varepsilon)$, within the plasma. Pulsed power is an effective means of controlling $f(\varepsilon)$ in inductively coupled plasmas (ICPs) by allowing intense electric fields that would not otherwise be accessible with continuous excitation. Recent results by Economou and Donnelly [1] showed that VUV fluxes from ICPs are capable of etching Si in chlorine plasmas even in the absence of energetic ion bombardment. These findings motivated us to investigate methods to control the relative fluxes of ions and VUV photons by controlling $f(\varepsilon)$ through using different pulse power format in low pressure ICPs. These techniques were computationally demonstrated using the HPEM (Hybrid Plasma Equipment Model). With the HPEM, $f(\varepsilon)$ as a function of position and time during a series of pulsed periods was computed in a low pressure ICP sustained in a 20 mTorr, Ar/Cl_2 = 80/20 mixture while addressing radiation transport of VUV radiation from resonance lines of Ar and Cl and ion energy distributions to the surface using a Monte Carlo simulations. The Monte Carlo Feature Profile Model was used to asses the effects of the VUV flux on etch profiles in Si.

The ratio of VUV to ion flux incident onto the substrate is shown in Fig. 1 as a function of time during the pulse for different duty cycles (fraction of the cycle with power on). The intensity of the VUV flux relative to the ion flux can be controlled, through controlling $f(\varepsilon)$, by varying duty cycle with few other major effects. When averaged over the cycle, the photon/ion flux ratio decreases with duty cycle. This has a significant effect on etch profiles, also shown in Fig. 1. The isotropic nature of the VUV flux relative to the ion flux narrows the feature. The controllable increase in VUV flux also hardens the photoresist (PR).

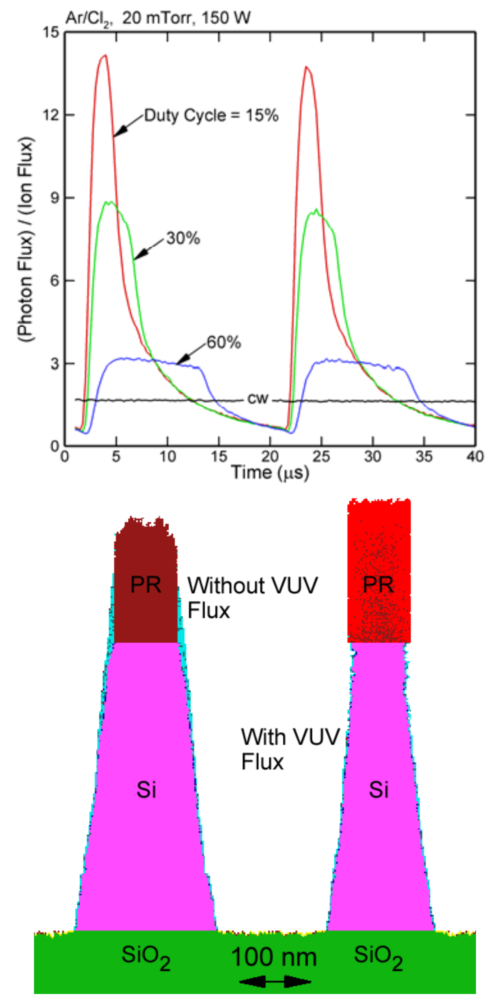


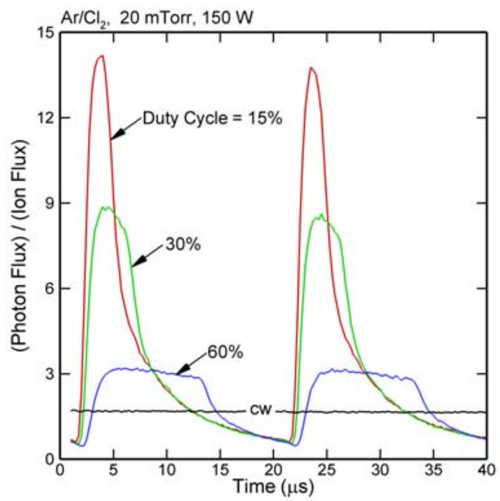
Fig. 1 – (top) Ratio of photon flux to ion flux in a pulsed ICP plasma (20 mTorr, Ar/Cl_2 = 80/20) for different duty cycles. (bottom) Changes in etch profiles in silicon due to influence of VUV fluxes.

References

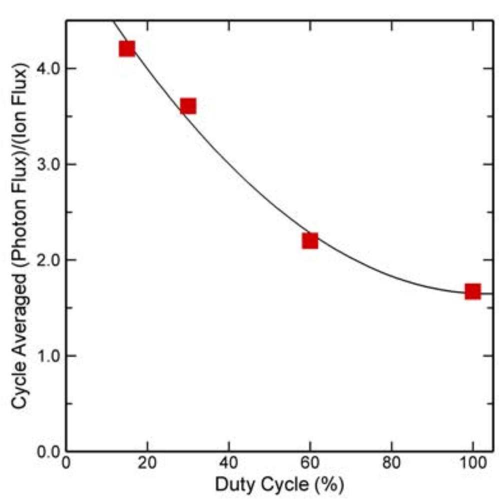
[1] H. Shin, W. Zhu, V. M. Donnelly and D. J. Economou J. Vac. Sci. Technol A **30**, 021306 (2012).

CONTROL OF VUV FLUXES THROUGH CONTROL OF *f(ε)* USING PULSED POWER

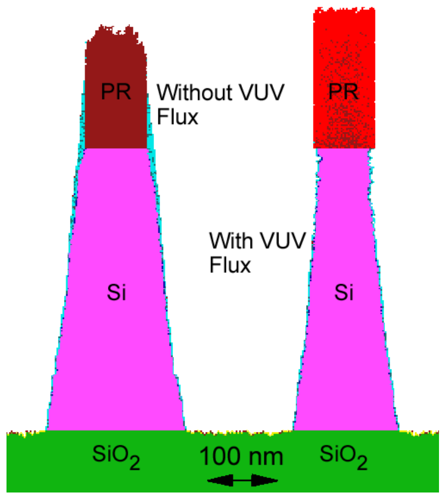
- **Pulsed plasmas can be used to shape electron energy distributions *f(ε)* in ways not possible using continuous power. One feature of such shaping of *f(ε)* is being able to control the ratio of VUV photon to ion fluxes.**
- **The HPEM was used to computationally investigate the control of VUV fluxes in pulsed inductively coupled plasmas in Ar/Cl_2 mixtures by shaping *f(ε)*. The VUV/ion flux ratio decreases with increasing duty cycle. This control can be used to tune the shape of etch profiles.**



- **VUV/ion flux for different duty cycles (Ar/Cl_2 = 80/20, 20 mTorr)**



- **Cycle averaged VUV/ion flux vs duty cycle.**



- **Effect on Si etch profile by controlling VUV flux.**

 HIGHLIGHT

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