Publ. Astron. Obs. Belgrade No. 89 (2010), 131-134 *Contributed Paper*

THE INFLUENCE OF THE ION INDUCED SECONDARY ELECTRON EMISSION ON THE CHARACTERISTICS OF RF PLASMAS

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Abstract. In this paper the effect of the secondary emission on the characteristics of rf plasmas has been studied. Calculations were performed for a dual-frequency capacitively coupled plasma reactor by using 1d3v PIC/MCC code. In the model, the energy dependence of the yields per ion, for differently treated metal surfaces have been implemented. The obtained simulation results indicate that the plasma characteristics are greatly affected by the secondary emission processes.

1. INTRODUCTION

One of the key processes that occur in a capacitively coupled plasma (CCP) sources represents the bombardment of the electrodes by the energetic ions from the plasma making them very useful for plasma processing devices (Makabe and Petrović 2006, Liberman and Lichtenberg 1994). This paper deals with the precise model of the ion induced secondary electron emission embedded in one-dimensional (1d3v) Particle-in-Cell/Monte Carlo collision (PIC/MCC) code for modeling an asymmetric plasma reactor (Verboncoeur 2005, Radmilović-Radjenović and Lee 2005). The results were obtained for argon discharge at 150mTorr driven by dual frequencies (2MHz/28MHz). Discharge is maintained between the electrodes of a cylindrical asymmetric reactor with a gap of 2.19cm and electrode area ratio of 1.73.

2. MODELING THE COEFFICIENT OF THE SECONDARY ELECTRON EMISSION

Secondary electron emission induced by an ion impact is described by the coefficient quantifying the number of secondary electrons produced at the cathode per ion, usually known as the electron yield per ion and denoted by γ_i. Although the secondary electron emission depends on the surface conditions and on the energy of the impacting ions, in practical applications, the coefficient γ_i is often considered as a constant leading to a serious disagreement between experimental and simulation results (Soji and Sato 1999).

In our model, we have implemented the energy dependence of the electron yield per ion in accordance with the expressions suggested by Phelps and Petrović (1999). The different coefficients corresponding to two different surface conditions: treated (clean surface, denoted by γ_i^c) and untreated (dirty surface, denoted by γ_i^d) are based on a large set of experimental data for discharges in argon and various electrode materials (Cu, Au, Pt, Ta):

$$\gamma_i^c = 0.7 + 1\cdot 10^{-5}\frac{(\varepsilon_i - 500)^{1.2}}{1+\left(\frac{\varepsilon_i}{7000}\right)^{0.7}}, \tag{1}$$

$$\gamma_i^d = \frac{0.006\varepsilon_i}{1+\left(\frac{\varepsilon_i}{10}\right)^{1.5}} + 1.05\cdot 10^{-4}\frac{(\varepsilon_i - 80)^{1.2}}{1+\left(\frac{\varepsilon_i}{8000}\right)^{1.5}}, \tag{2}$$

where ε_i represents the energy of the incident ion.

The second terms in (1) and (2) equal zero for energies below 500eV and 80eV, respectively.

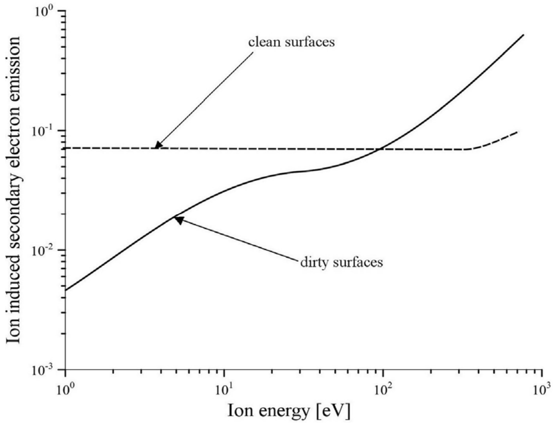

Figure 1: Electron yield per ion as a function of the ion energy (ε_i) impacting dirty or clean surface. The curves are plotted in accordance with eqs. (1) and (2).

Clean surface is assumed to be a metal surface that has been heated to 2000K in high vacuum (atomically clean). Untreated surface is chemically or mechanically cleaned metal surface. According to Phelps and Petrović (1999), for various metals the surface conditions have the main role in determining the secondary yields.

In this paper we have performed PIC/MCC simulations considering different reactor constructions: inner electrode is dirty, while the outer electrode is clean (dirty-clean); inner electrode clean and the outer dirty (clean-dirty); when γ_i is a constant and equal to 0.2 (0.2 electrodes) and in the fourth case not taking into account secondary electron emission assuming that γ_i is equal to 0 (0 electrodes).

3. THE INFLUENCE OF THE SECONDARY ELECTON EMISSION ON THE PLASMA POTENTIAL AND PLASMA DENSITY

One of the important characteristics of CCP RF discharges is the plasma density because of its direct relation to the ion flux on the cathode. Different secondary emission coefficients lead to different plasma densities as depicted in Fig. 2. The influence of the secondary yield on the plasma density can be explained by the different rates of secondary production on different electrode surfaces. The different ion energy distributions (see Fig. 3) on inner and outer electrode, determine which reactor construction is more efficient in supporting production of secondary electrons. In the case of IEDFs, the real reactor which most effectively sustains the discharge is the dirty-clean reactor. Unrealistic models with a constant γ_i (0.2 and 0 electrodes) lead to results different to that obtained with the realistic secondary emission models (dirty-clean and clean-dirty).

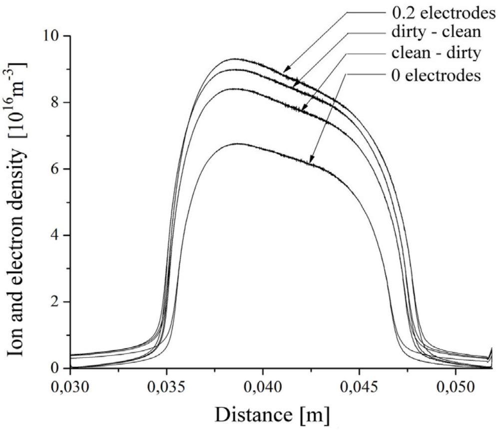

Figure 2: Plasma density averaged over period of 2MHz.

The IEDF on the inner electrode, as shown in Fig 3, is a parameter that greatly affects the profile of CCP etched surfaces. As can be observed from Fig. 4, plasma potential, however, does not show significant differences for the realistic dirty-clean and clean-dirty reactors. On the other hand, results obtained with a constant γ_i are considerably different from the standard secondary emission model (Radmilović-Radjenović and Petrović 2009).

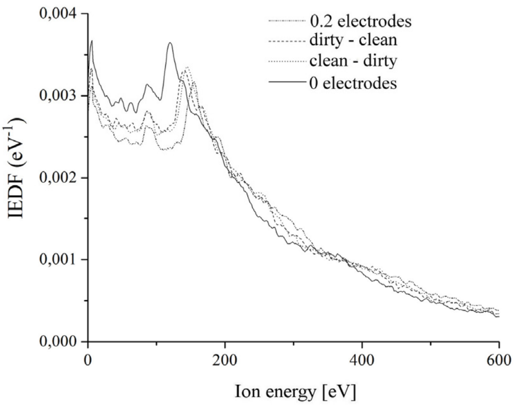

Figure 3: The Ion Energy Distribution Function (IEDF) on the inner electrode averaged over period of 2MHz.

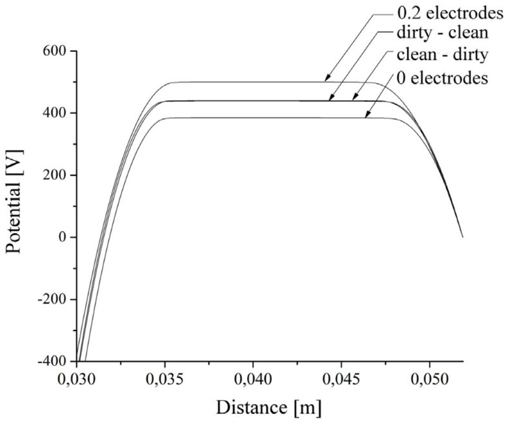

Figure 4: Plasma potential averaged over period of 2MHz.

Overall conclusion may be that in modeling CCP discharges an exact model of the secondary electron emission should be included. The need to include secondary emission that is properly accounted for is of interest for industrial applications, in microelectronic industry where high power plasma etching is used for producing high aspect ratio etch profiles.

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