Topic number: 6.

Modeling the effects of the secondary electron emission in a dual-frequency capacitively coupled plasma reactor

Aleksandar Bojarov[(*)], Marija Radmilović-Radjenović, Zoran Lj. Petrović

Institute of Physics, Pregrevica 118, Belgrade, Serbia
[(*)] **bojarov@ipb.ac.rs**

Energetic ion bombardment of the substrate surface is a basic physical phenomenon that occurs in capacitively couples plasma (CCP) sources, making them very useful as plasma processing devices. In this paper the effects of the electrode conditions (clean and contaminated electrodes) on the characteristics of an asymmetric discharge have been studied. The simulation results were obtained by a Particle-in-cell Monte Carlo collision modeling (PIC/MCC) of a dual frequency (2MHz/28MHz) capacitively coupled plasma source (DF-CCPs) [1] - [3]. The argon discharge is maintained between the two electrodes separated by a gap of 2.19cm, with an electrode area ratio 1.73.

The main feature of the code represents the inclusion of a realistic model for the ion induced secondary electron emission from the electrode surfaces. The secondary electron emission from a surface under the action of an ion 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 [4]. Although, this coefficient depends on the cathode material and the gas it was often assumed that γ_i is a constant causing differences between the simulation and experimental results [5],[6]. The energy dependence of the yield, based on a large set of experimental data for DC discharges in argon and various electrode materials (Cu, Pt, Au, Ta, Mo) has been suggested by Phleps and Petrović [4]:

$$\gamma_i^c = 0.07 + 1 \cdot 10^{-5} \frac{(\varepsilon_i - 500)^{1.2}}{1 + \left(\frac{\varepsilon_i}{7000}\right)^{0.7}} \tag{1}$$

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

According to authors, in literature there are two general surface conditions: treated-clean surface (1) and untreated-dirty surface (only labeled as such but surface cleaned mechanically and even chemically)(2) and γ_i as a function of the ion energy ε_i, changes drastically when the surface condition is changed (Fig.1.a). After the point where these two functions intersect, for ion energies above $100eV$, the dirty surface is more effective in production of secondary electrons than the clean surface.

The γ_i-coefficient which depends on the surface conditions and on ion energy hitting the electrode, describes the processes of creation and sustaining the discharge more realistically than the widely used method of modeling γ_i by a constant value from binary collision experiments. This is observable through the particle concentrations in the discharge area (see Fig.1.b).

The ion flux on the electrodes is nearly equal on all surfaces (Fig.2.a), giving us a possibility to observe the effect of ion energies on the creation of secondaries [7]. The difference in the secondary electron fluxes, shown on Fig.2.b, depends on the energy of incoming ions. Analysis of the results for the inner surface, leads us to the conclusion that the majority of ions arrive at this electrode with energies above $100eV$, which results in overall greater production of secondaries if the inner surface is dirty than if it's clean. A smaller potential drop in the sheath region of the outer electrode, results in less energetic ions hitting the surface, thus producing similar fluxes of secondaries for clean and dirty outer electrodes. As expected, the artificial $\gamma_i = 0.2$ overestimates the

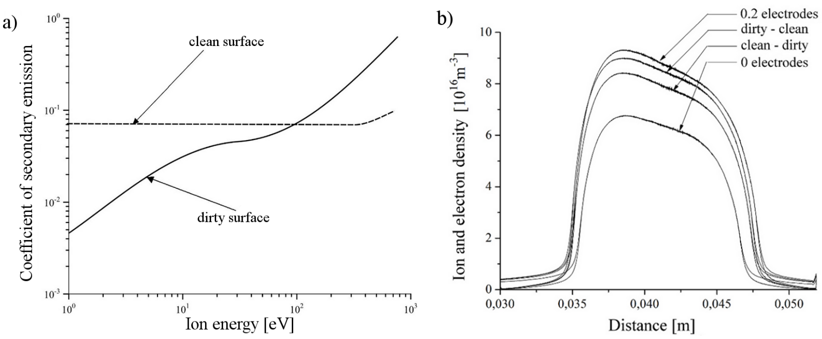

Fig. 1: a) Coefficient of secondary electron emission (γ_i) as a function of the energy (ε_i) of ion bombarding clean or dirty surface, in accordance with the relations (1) and (2). b) The spatial profile of the plasma density for different surface conditions.

real secondary emission for all surface conditions, since the assumed average of the yield in argon is 0.07. According to this analysis, the dirty-clean reactor will produce more secondary electrons than the clean-dirty reactor, thus resulting in overall greater plasma density Fig.1.b. Realistically however, one would expect both electrodes to be "dirty" according to [4] but it is not impossible to expect that due to high energy ion bombardment the powered inner electrode could have surface conditions more akin to the "clean" conditions [4].

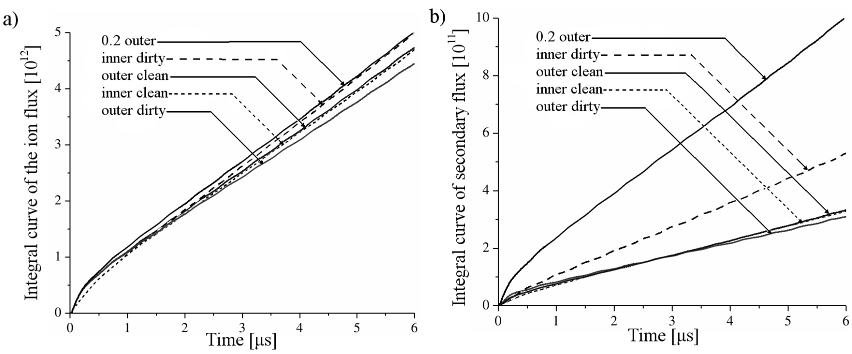

Fig. 2: a) Number of ions hitting the electrodes with different surface conditions. b) Number of secondaries that have been emitted from the surfaces corresponding to the picture a).

Results presented here indicate that the ion induced secondary emission of electrons may be a significant parameter of the discharges. For a good PIC/MCC code a secondary emission must be included in manner that it will realistically describe the processes of creation of secondary electrons, as it has been shown by implementing the equations (1) and (2).

Reference

[1] J. P. Verboncoeur, 2005, Plasma Phys. Control. Fusion 47, A231.
[2] M. Radmilović-Radjenović and J. K. Lee, 2005, Phys. Plasmas 12, 063501.
[3] A. Bojarov, M. Radmilović-Radjenović and Z. Lj. Petrović, 2009, Hemijska industrija 63.
[4] A. V. Phelps and Z. Lj. Petrović, 1999, Plasma Sources Sci. Technol 8, R21.
[5] M. Soji and M. Sato, 1999, J. Phys. D:A ppl.Phys. 32, 1640.
[6] H.B. Smith et al.,2003, Phys. Plasmas. 10, 875.
[7] M. Radmilović-Radjenović and Z. Lj. Petrović, 2009, Europ. Phys. J. D 54, 445.