MODELLING OF RADIO FREQUENCY CAPACITIVELY COUPLED PLASMA AT INTERMEDIATE PRESSURES

S. BEREZHNOI, I. KAGANOVICH*, A. BOGAERTS*, R. GIJBELS*.
Physical Technical Department, St. Petersburg State Technical University, 195251, Russia
** Department of Chemistry, University of Antwerp, Belgium*

The interest in radio-frequency (RF) capacitively coupled plasmas (CCP) is stipulated by the wide use of this discharge in plasma aided materials processing industry and analytical chemistry. In this paper the results of modelling of CCP in planar geometry at pressures of several torrs are reported. The steep increase of plasma density in the discharge centre with current density is investigated numerically at $\alpha-\gamma$ transition. It has been shown that the main reason for this is the non-locality of γ-electron ionization.

For numerical modelling we use the fast modeling procedure described in [1], based on the separation of different temporal and spatial scales. We consider the full current equal to $j = j_0 \sin(\omega t)$. In the plasma and in the plasma phase of the sheath region: $n_e(x) \approx n_i(x)$, and RF electric field is given by $E(x,t) = j(t)/[eb_e n(x)]$. In the sheath region in the space charge phase ($n_e(x) \approx 0$) Poisson equation is to be solved. The field of ionic space charge is $E(x,t) = [4\pi j_0/\omega](\cos(\omega t) - \cos(Z))$, where Z=Z(x) is the inverse function of x(Z) which describes the position of plasma-sheath boundary at the RF field phase Z=ωt. In the plasma Z=0. The Poisson equation results in the equation for Z: $\sin(Z)\frac{dZ}{dx} = e\frac{\omega}{j_0}n(x)$. Ion displacement during the RF period is small in comparison with the sheath thickness. And averaged over the RF period the ion continuity equation can be used $\frac{d}{dx}(Vn) = \langle I_\alpha \rangle + \langle I_\gamma \rangle$, where $V, \langle I_\alpha \rangle, \langle I_\gamma \rangle$ are averaged over RF period ion velocity, ionization rates by α and γ electrons respectively. For calculation of the ionization rate we use the Townsend approximation: $I_\alpha(x,t) = n_e b_e |E(x,t)| \alpha(|E(x,t)|/N_a)$, where α is Townsend coefficient. For γ-ionization we have $I_\gamma(x,t) = \alpha\gamma\Gamma_i(L)(1+\cos(\omega t))\exp\left[\int_x^L \alpha(x',t)dx'\right]$ [1], where γ is the coefficient of secondary ion-electron emission, $\Gamma_i(L)$ is the ion flux at the electrode. We have taken into account the neutral gas heating that results in dependence of neutral gas density on neutral gas temperature T(x). $kN_a(x)T(x) = p = \mathrm{const}$, where p is gas

H. Schlüter and A. Shivarova (eds.),
***Advanced Technologies Based on Wave and Beam Generated Plasmas*, 525–526.**

pressure. The neutral gas temperature was found from the heat conductivity equation [3]. The fast modelling procedure was validated for different gases in [2].

We compare results of modelling with experimental data from [3]. The background gas is argon, $\omega = 13.56 * 2\pi \, \mathrm{MHz}$, the discharge gap is 6.7cm, p=3torr.

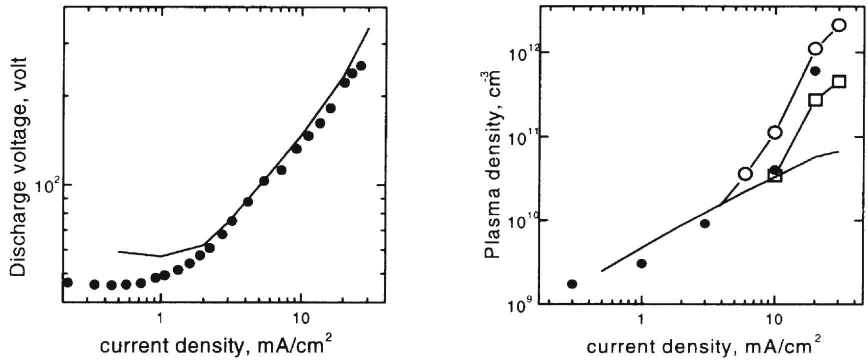

Figure 1. Comparison of calculated discharge voltage and plasma density (solid line) with experimental data (filled circles).

The calculated discharge voltage agrees well with experimental data. However, the steep variation of the rate of plasma density increase at large current densities is absent in contrast to experimental results. The reason for such increase is non-locality of ionization produced by γ-electrons [4]. When ionization by γ-electrons is spreaded into plasma region it leads to steep increase of plasma density at the plasma-sheath boundary. And plasma density at the discharge center increases too. To check this surmise the calculations were performed with spreaded γ-ionization. Spreading was performed according to $I_{non-local}(x) = \int_x^L I_{gamma}(t)\exp(-(t-x)/k\lambda_\gamma)dt/k\lambda_\gamma$, where λ_γ is the mean free path of γ-electrons for ionization at energy 40eV, k - is some constant determining depth of spreading. Calculations were performed for k=1 and k=3. The resulting plasma density at the discharge center versus current density is shown in figure 1. The solid line represents data calculated without spreading. Open squares and circles represent data calculated with spreading for k=1 and k=3, respectively. The solid circles represent experimental data.

This work was supported in part by IAEA (contract no. 9238/ R0/ Regular Budget Fund), INTAS (grant no. 68171-97-M-5379), RFBR (project no. 98-02-16000 and 4391501) and by the University of Antwerp, Belgium (New Research Initiative "Mathematical Simulation of Pulsed, Radio-Frequency and Magnetron Discharges").

References.

1. Smirnov A.S., Tsendin L.D., (1991) IEEE *Trans. Plasma Sci*, **19**, 130.
2. Kaganovich I.D., Tsendin L.D., Yatsenko N.A., (1994) Sov.Phys.-Tech. Phys., **39**, 1215.
3. Godyak V, Piejak R 1992 *Plasma Sources Sci. and Techn.* **1**, 36, and personal communication.
4. V.A. Godyak and A.S. Khanneh, (1986) *IEEE Trans. Plasma Sci*, **14**, 2, 112.