DUSTY DISCHARGES WITH SECONDARY ELECTRON EMISSION

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INTRODUCTION

There are two main regimes of RF discharges [1,2] called the α – regime and γ - regime. They differ by the role of a secondary emission from electrodes or walls. RF discharges are supported mainly by a volume ionization in the α – regime unlike the γ - regime where the secondary emission is important for the discharge support. The α – regime is realized at a relatively high pressure, the γ - regime at a low pressure.

Although RF discharges with secondary emission were investigated earlier, the role of the secondary emission in the discharges is not yet clear. The main difficulty arises from the necessary to take into account (self-consistently with discharge parameters) all kinds of secondary electrons emitted from the electrodes (walls) by ion, electron, fast atom, or metastable impact as well as by ultraviolet radiation from the discharge. Recently, models of the effective secondary-emission yield γ per ion were developed for the breakdown [3] and DC glow discharges [4] in argon. The models take into account all kinds of secondary electrons and give the dependence of the effective yield γ on the cathode electric field reduced by the argon atom density. These models can be useful for RF discharges.

Dust particles can appear in RF discharges as the product of the plasma-wall interaction with their subsequent transport into an interelectrode space or can be created due to coagulation of various components in chemically active plasmas. It is known [5,6] that the dust particles can essentially influence the parameters of the RF discharges due to a continuous selective collection of background electrons and ions that can essentially influence their energy distribution functions. Dusty RF discharges with secondary electrons were not investigated earlier, although it is obvious that secondary emission has to influence the properties of dusty discharges especially at low pressures when the role of secondary electrons is growing. The computer simulation of dusty RF discharges with secondary electrons is the aim of the work.

MODEL

A one-dimensional RF discharge is considered between two plane electrodes separated by a gap of $d = 2.0$ *cm* which is filled with *Ar* at various pressures. Immobile dust particles of a given radius R_d are distributed uniformly in the interelectrode gap with a density N_d. The dust particles collect and scatter electrons and ions distributed in the discharge with density n_e and n_i, respectively. A harmonic external voltage $V_e(t)=V_o sin(wt)$ at a frequency $f=13{,}56$ *MHz* and various amplitudes V_o sustains the RF discharge. The discharge is grounded at $x=d$.

The PIC/MCC method described in detail earlier for discharges without dust particles is developed for computer simulations of the RF discharge with dust particles. The Monte Carlo technique is used to describe electron and ion collisions. The collisions include elastic collisions of electrons and ions with atoms, ionization and excitation of atoms by electrons, charge exchange between ions and atoms, Coulomb collisions of electrons and ions with dust particles, as well as the electron and ion collection and scattering by dust particles. In addition to a usual PIC/MCC scheme, the weighting procedure is used also for the determination of a superparticle charge part, which is interacting with a dust particle.

The electron-argon collision cross-sections used in the model are the same as those used in [7]. The Coulomb cross-section for electron and ion scattering by immobile dust particles is taken from [8]. The secondary emission is taken into account in the framework of the models of [3,4] or at given various constant yields γ of the effective secondary emission.

The simulation starts at an initial uniform distribution of electrons and ions with given densities and is prolonged by iterations up to a moment when a change of discharge parameters is less a given limit. Simulation shows that 400-1000 cycles are enough to obtain the periodically steady state of RF discharges.

RESULTS

Obtained spatial distributions of the electron n_e and ion n_i densities across the interelectrode gap are shown in Fig. 1 for various phases φ of the sustaining external voltage with an amplitude of $V=100$ *V*. The distributions are obtained at a dust particle density $N_d=3*10^{11}$ m^{-3}, a dust particle radius $R_d = 1$ μm, and an effective secondary electron emission yields $\gamma=G_1$ corresponding to the model [3]. Note, the distributions of the ion density shown here by solid lines are the same for various phases

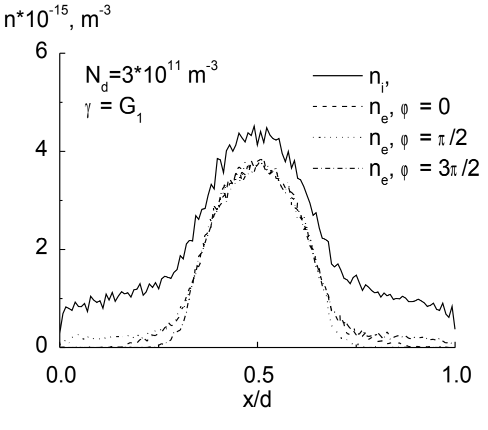

Fig. 1. Spatial distributions of the electron n_e and ion n_i density.

φ unlike the electron density distributions which are different close to electrodes. As can be seen in Fig. 1, the electron density distributions are the same in the central part of the interelectrode gap for various phases φ however there is a difference between electron and ion densities due to the space charge of the dust particles, similar to [5,6]. The distributions show the existence of the central quasi-neutral region (with taking into account the total dust particles charge) and non-neutral RF sheaths close to both electrodes like in the case of the RF discharge without the secondary emission [5,6].

The influence of the secondary emission on the dusty RF discharge can be seen in Fig.2 where spatial distributions of the ion density, n_i are plotted for various combinations of the effective secondary-emission yield γ and the amplitude V_o of the harmonic external voltage. Fig. 2 shows that the increase of γ causes an essential increase of the ion density in the central part of the discharge at $V_o = const$ whereas the ion density is practically unchanged in sheaths. The density increase is caused by an additional ionization in the central discharge part by secondary electrons whereas the ion shielding of the given applied voltage causes the invariability of the ion density distributions in sheaths. As can be seen in Fig.2, the remarkable influence of the secondary emission on the discharge parameters takes place only at $\gamma > 0.2$. Note, the discharge parameters obtained in the framework of the model [4] ($\gamma = G_2$) does not differ from the parameters in the discharge without the secondary emission because the effective secondary-emission yields γ in the model [4] is less than $\gamma = 0.2$. The model [3] provides a very strong increase of the ion density in the central discharge part because the model gives an effective secondary-emission yield γ that can amount to high values.

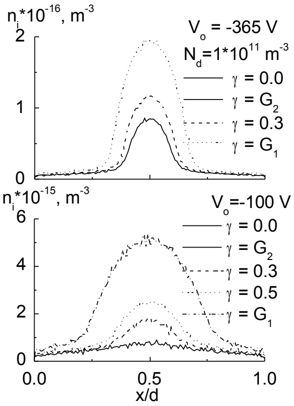

Fig. 2. Spatial distributions of the ion n_i density for various γ and V.

Spatial distributions of the dust particle charge q_d are shown in Fig. 3 for the conditions of Fig. 2. As can be seen in Fig. 3, the charge q_d depends very weakly on the yield γ at $V_o = 365$ V unlike the ion n_i density shown in Fig. 2. It is a typical result for intensive RF discharges and is caused by the dust particle charging in low-pressure RF discharges considered earlier in [5,6]. There it was shown that non-monotonic profiles of the dust particle charge in RF discharges are caused by the change of the ion current into a dust particle in non-uniform quasi-neutral plasma with omnipresent fast electrons due to their fast penetration in regions wit low electric fields.

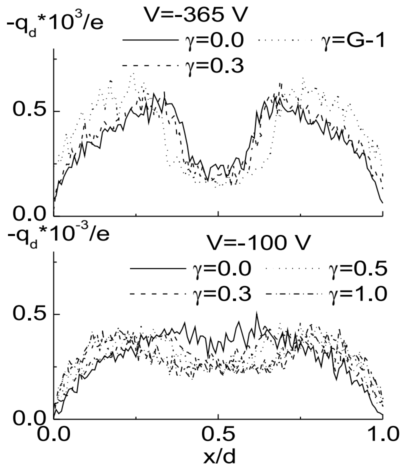

Fig. 3. Spatial distributions of the dust particle charge q_d.

The simulations of RF discharges with secondary emission show that the ratio of the electron and ion currents into a dust particle is approximately conserved while changing the effective secondary-emission yields γ in intensive RF discharges. This causes the invariability of dust charge distributions. Typical examples of spatial distributions of the dust particle charge q_d for low-power RF discharges are shown in Fig. 3 in the case of $V_o = 100$ V. As can be seen in this case, the secondary emission changes the negative charge of a dust particle in the quasi-neutral central part of the discharge compared to the high-power RF discharge. However, like in the high-power RF discharges, the change of the yield γ does not result in a change of the spatial distributions.

CONCLUSION

In conclusion, dusty RF discharges are simulated by using the PIC/MCC method. Secondary electron emission is taken into account in the framework of the of the effective yields developed earlier. It is shown that the secondary emission essentially influence the electron and ion densities in the discharges due to more intensive ionization caused by secondary electrons. However the dust particle charge is conserved at the change of the secondary emission due to a specific charging of dust particles.

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