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SIMULATION OF DUST PARTICLES INFLUENCE ON PLASMA OF DC DISCHARGE

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Abstract. Micron size dust particles influence on nonlocal properties of complex gas discharge plasma are simulated. Plasma is described within limits of diffusion approximation, combined with OML approximation for dust component. The current-voltage characteristics as the easy-to-observe measure of dust influence on the total amount of charged particles, as well as the radial distributions of plasma components in the DC discharge are calculated for different dust concentrations and discharge current.

1. INTRODUCTION

Under the presence of particles, the total number and the spatial distribution of free electrons and ions in plasma may change essentially. Under the appropriate conditions this leads to the formation of different types of electrostatic traps for the dust clouds (Vasilyak et al. 2003). The electrostatic space potential from particles imbedded in the DC or RF discharge can influence the micro and macroscopic properties of the plasma, changing current-voltage characteristics of the discharge (Balabanov et al. 2001, Vasilyak et al. 2002). That should be accounted for the adequate prediction of complex plasma behavior.

The local properties of such complex plasma around the dust particle, as well as the acquired charge and interaction between dust particles now may be described rather correctly using adequate assumptions on the plasma parameters. The complete review of studies on this subject is represented by Fortov and Morfill (2009). Less works are devoted to the solution of the nonlocal task of particle influence on the discharge or plasma properties. Change of measurable discharge characteristics resulting from the dust influence on complex plasma parameters was not simulated yet.

In this study, the influence of dust component on the properties of DC discharge plasma is described as the first step to solve the self-consistent problem of complex plasma description.

2. THEORETICAL BACKGROUND

The mechanism of gas discharge typical for the mentioned above experimental works is a collision, the DC discharge plasma can be described within the limits of diffusion approximation represented by Raizer (1991). Distributions of complex plasma components result from the conservation law for their flow densities. The radial flow densities of ions and electrons are given by the combination of drift and diffusion constituents and submit to the equation of continuity with the account of ionization by electron impact and recombination on the dust particles surface. The ion and electron distributions meet also the zero boundary condition at the tube wall coordinate R. Flows of charged components on the particle surface are given by the OML approximation following Allen (1992) and determine the equilibrium charge of the dust particle. The equation for plasma electro neutrality closes the system of equations.

The ODE system was solved by Runge-Kutta 4th order procedure simultaneously with the current normalizing condition. The boundary problem was solved using the “shooting” routine. The radial distribution of particles $n_d(r)$ was prescribed by the blurred step function with characteristic geometric size r_d=R/2 as:

$$n_\mathrm{d}(r) = n_{\mathrm{d},0}, r \le r_\mathrm{d}$$

$$n_\mathrm{d}(r) = n_{\mathrm{d},0} e^{(r_d - r)/0.1}, r > r_\mathrm{d}$$

with dust concentration $n_{\mathrm{d},0}$ at r=0, independent of discharge parameters.

3. RESULTS AND DISCUSSION

The stated problem was solved for 2 μm dust particles, embedded into the gomogenious glow discharge column with radius of R=8 mm at the air pressure of 0.5 Torr, current of 0.5 mA, $n_{\mathrm{d},0}$ up to 1.0×10^5 cm^{-3} at electron temperature 1.5 eV. Data for mobility and diffusion coefficients were given by Raizer (1991).

The radial distributions of plasma components and the radial electric field strength were calculated. In the absence of dust particles, the “undisturbed” distributions of ions and electrons are close to the theoretically predicted Bessel’s one. In the presence of dust particles with $n_{\mathrm{d},0} = 1.0\times10^5$ cm^{-3}, the equilibrium electron concentration n_e fall down from 1.7×10^8 cm^{-3} to 9×10^7 cm^{-3}, simultaneously the longitudinal electric field E_l increased by more then 2 V/cm (see Fig. 1). This correlates well with the results reported by Balabanov et al. (2001) and Vasilyak et al. (2002). The electron concentration loss rate increases with the rise of dust particle concentration in the central part of the discharge tube. This leads to the situation when the electron concentration on the outer face of the dust cloud becomes even higher then in the center of the tube.

Due to the fast diffusion of electrons towards the walls of the discharge tube, the central zone of gas discharge gains the positive potential, forming the electrostatic trap for negatively charged dust particles Due to the difference of more then 2 orders of magnitude between diffusion coefficients of ions and electrons**,** the radial distribution of n_i shows the abrupt increment at the boundary of dust cloud, while the electron distribution remains smooth in this region due to their high mobility.

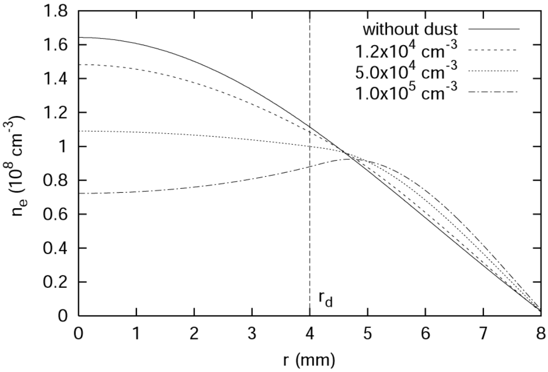

Figure 1: Radial distribution of electron concentration n_e at various values of dust particles concentrations $n_{d,0}$ in discharge at I=0.5 mA, P=0.5 Torr.

The current-voltage characteristics at P=0.5 Torr and different dust particle concentration, are given in Fig. 2, representing the experimentally observed fall down with the increase of the discharge current. One can see again the increasing discharge stability with the increase of discharge current.

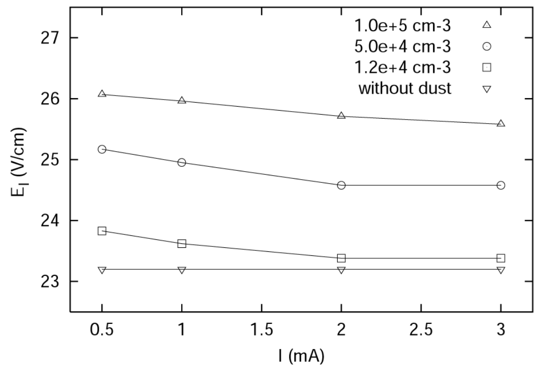

Figure 2: The current-voltage characteristics for the discharge in air at P=0.5 Torr and dust concentrations up to 1.0×10^5 cm^{-3}.

Fig. 3 demonstrates the influence of dust cloud on the configuration of electric field. The vertical dashed line with the abscissa R-λ, marks the region of applicability of the diffusion approximation for the description of nonlocal discharge characteristics. The higher is the dust concentration, the lower is the radial electric field, especially inside the dust cloud. When the dust concentration attains some critical value, the radial electric field E_r changes the direction in some region inside the dust cloud. In that region, the corresponding force acts on the dust particles, tending to change their positions. This force has not been taken into account in this work, and will be included in the model as the next step.

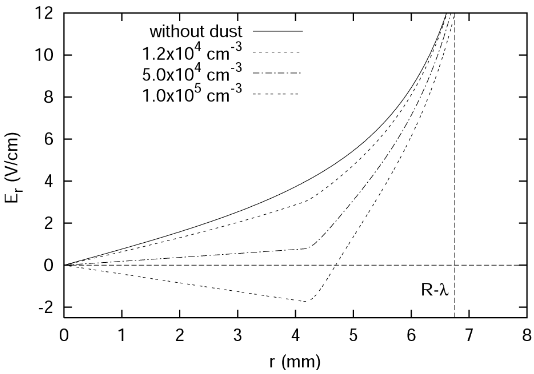

Figure 3: Distributions of radial electric field at various values of dust concentration. Lines represent results calculated for various values of $n_{d,0}$. The corresponding values of the longitudinal component E_l of the electric field were: E_l = 23.2 V/cm, without dust; E_l = 23.8 V/cm, at $n_{d,0}$= $1.2\times2\ 10^4$ cm^{-3}; E_l = 24.9 V/cm, at $n_{d,0}$= $5.0\ \times10^4$ cm^{-3}; E_l = 25.7 V/cm, at $n_{d,0}$= $1.0\ \times10^5$ cm^{-3}.

4. CONCLUSIONS

Simulation of measurable plasma parameters of glow discharge under the presence of dust particles was the subject of the study. The radial distributions of plasma components, as well as electric field and particle charges were calculated. The increase of dust concentration and corresponding electron losses, should be compensated by the increase of E_l and consequently of the ionization rate for the maintenance of the discharge existence, that mean, of the total discharge current. It was shown that the higher is the current, the higher is stability of the discharge against the disturbing action of dust. The current-voltage characteristics represent the experimentally observed falling down with the increase of the discharge current. The higher was the dust concentration, the lower was the radial electric field within the dust cloud. When the dust concentration attained some critical value, the radial electric field reversed its direction in some regions inside the dust cloud.

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