

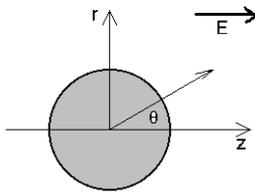
2D Simulation of Dust Particle Charging in Terms of Diffuse-Drift Approach

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At present self-sustained and non-self-sustained glow discharges are widely used in plasma-chemical devices and powerful gas lasers. During the operation of these systems the working medium becomes dusted with particles of micron and sub-micron sizes either due to electrode or wall erosion, or due to polymerization of the radicals forming in the discharge. Dust particles strongly, and in some cases, cardinally change the properties of the discharge, the rate and even the direction of plasma-chemical processes. One of the most important dust plasma parameters determining the unique properties of dust plasma is the charge collected by dust particles. In papers [1-4] there was one-dimensional simulation of the charging process of dust particles in atomic and molecular gases under high pressures in diffusion-drift approximation. But under the external field the problem of charging a dust particle becomes axially-symmetrical, therefore, at least two-dimensional simulation is required.

This work presents the results of two-dimensional numerical simulation of the charging



process of dust particles in argon under atmospheric pressure. The gas ionization was performed by an external ionization source. Equation system self-consistently describing the charging process of dust particles consists of the continuity equation for electrons and ions and the Poisson's equation. Let's introduce the

cylindrical coordinate system with the origin at the center of the dust particle and with the z-axis directed along the external field. The cylinder having the radius equal to the radius of the Zeits-Vigner cell of $R = \left(\frac{3}{4\pi} n_d\right)^{-1/3}$ and the height of $2R$ and containing a dust particle in the center is considered to be quasi-neutral. Here, n_d is the density of dust particles. In the cylindrical coordinates the self-consistent equation system for simulation of the dust particle charging in the external field is as follows:

$$\begin{aligned}
 \frac{\partial n_e}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r} \left(r \left[-D_e \frac{\partial n_e}{\partial r} - n_e k_e E_r \right] \right) + \frac{\partial}{\partial z} \left[-D_e \frac{\partial n_e}{\partial z} - n_e k_e E_z \right] &= R_e, \\
 \frac{\partial n_i}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r} \left(r \left[-D_i \frac{\partial n_i}{\partial r} + n_i k_i E_r \right] \right) + \frac{\partial}{\partial z} \left[-D_i \frac{\partial n_i}{\partial z} + n_i k_i E_z \right] &= R_i, \\
 \frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial \varphi}{\partial r} \right) + \frac{\partial^2 \varphi}{\partial z^2} &= -4\pi e (n_i - n_e),
 \end{aligned} \tag{1}$$

where $R_e = R_i = Q + k_{ion}n_eN - \beta_{ei}n_en_i$ are the source terms of electron and ion production and loss, E_r, E_z are the components of the self-consistent electrical field strength on the z -axis and r -axis, these components are calculated from the last equation of system (4) with the use of the following relationship

$$\mathbf{E} = -grad\phi, \quad (2)$$

which links the electrical field potential ϕ and strength \mathbf{E} , n_e, n_i are the densities of electrons and ions, respectively; N is the density of neutral particles; Q is the rate of the ionization by an external ionization source; k_{ion} is the gas ionization coefficient by plasma electrons; β_{ei} is the coefficient of dissociative electron-ion recombination; k_e, k_i and D_e, D_i are the mobilities and diffusion coefficients of electrons and ions, respectively (in the present work the transport coefficients were assumed to be constant, their values determined by the external electrical field).

At the ends of the cylinder the boundary conditions were assumed to be as follows:

$$n_e|_{z=R} = n_e|_{z=-R}, \quad n_i|_{z=R} = n_i|_{z=-R}, \quad E|_{z=R} = E|_{z=-R}, \quad (3)$$

at the cylinder axis and lateral faces there were second-kind boundary conditions:

$$\left. \frac{\partial n_e}{\partial r} \right|_{r=0} = 0, \quad \left. \frac{\partial n_i}{\partial r} \right|_{r=0} = 0, \quad \left. \frac{\partial \phi}{\partial r} \right|_{r=0} = 0, \quad \left. \frac{\partial n_e}{\partial r} \right|_{r=R} = 0, \quad \left. \frac{\partial n_i}{\partial r} \right|_{r=R} = 0, \quad \left. \frac{\partial E}{\partial r} \right|_{r=R} = 0. \quad (4)$$

It is usually assumed that when a dust particle touches the surface the charge of electrons and ions is absorbed with probability 1, therefore, zero boundary conditions were assumed to be within the dust surface:

$$n_e|_{\substack{r=r_{Dust} \\ z=z_{Dust}}} = 0, \quad n_i|_{\substack{r=r_{Dust} \\ z=z_{Dust}}} = 0, \quad \phi|_{\substack{r=r_{Dust} \\ z=z_{Dust}}} = 0. \quad (5)$$

It was assumed that a dust particle is of a conducting material. Polarization of the dust particle charge in the external field corresponded to the analytical solution of the problem about the conducting ball in the external uniform field [2].

Solution of system (1) with boundary conditions (3)-(5) was performed by the alternating direction method with using the semi-implicit Crank-Nicholson scheme and the factorization method. Fig.1 shows the charge dependence of the dust particle with radius of $r_0=12 \mu\text{m}$ on the applied external field when the ionization rate by the external source is equal to $1.5 \cdot 10^{17} \text{ cm}^{-3} \text{ s}^{-1}$.

The external field has, as expected, a strong effect upon the dust charge. First of all, that occurs due to heat of electrons, which results in changing diffusion coefficients and mobility

of electrons. Field growth is accompanied by the growth in the electron characteristic energy, on which the electron charge is practically linearly dependent.

Fig.1 presents the result of calculating the dust particle charge according to one-dimension model [2-4]. Comparing the results of one-dimension and two-dimension models makes it possible to estimate the effect of dust particle and plasma polarization in the external field upon the charge of dust particles. This effect upon the charge of the dust particle is little due to the fact that the external field is little in comparison with the dust particle charge field. But the external field has a noticeable effect upon the spatial distribution of ions and electrons (fig.2). It should be noted that in the direction perpendicular to the external field the distributions of electrons and ions within the two-dimension model practically coincided to the distributions calculated according to the one-dimension model.

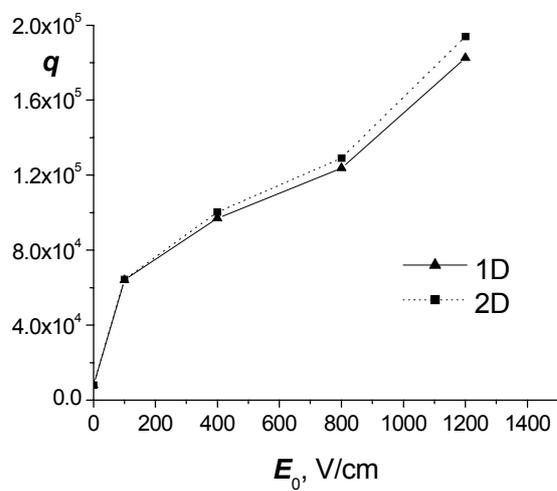


Fig.1. Charge dependence of the dust particle with the radius of $r_0=12 \mu\text{m}$ upon the external field for $Q=1.5 \times 10^{17} \text{cm}^{-3}\text{s}^{-1}$. (1D) is the calculation within the one-dimension spherically symmetrical model, and (2D) is the calculation within the two-dimension axially symmetrical model.

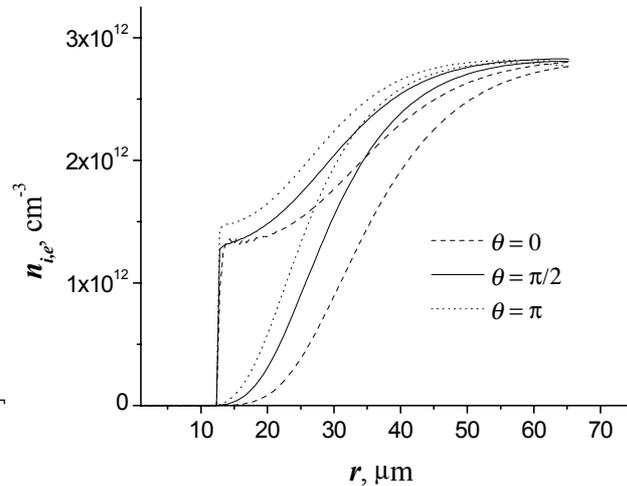


Fig.2. Distribution of electrons and ions in the vicinity of a dust particle along ($\theta=0$), against ($\theta=\pi$) and transverse ($\theta=\pi/2$) to the direction of the external field (the curves of the electron distribution are lower than those of the ion one). $r_0 = 12 \mu\text{m}$, $E_0 = 1200 \text{V/cm}$, $n_d = 10^6 \text{cm}^{-3}$, $Q=1.5 \times 10^{17} \text{cm}^{-3}\text{s}^{-1}$.

In fig.3 there are equipotential and force lines of the calculated electrical field in the vicinity of the dust particle with radius of $12 \mu\text{m}$ in the external field with strength of 1200V/cm for steady-state conditions. It is seen how strongly the charged dust particle disturbs the external electrical field. According to fig.3(b) the force lines only end on a dust particle. It means that the normal component of the field strength on the whole surface of the dust particle is negative (the tangential component is equal to zero, because it is assumed that the dust particle consists of the conducting material). That is clearly seen in fig.4 presenting an angular dependence of the field strength radial component on the dust surface. That figure

also presents a radial component on the surface of the conducting dust particle with the charge calculated above ($q = -1.8 \cdot 10^5$) in the external field with no plasma.

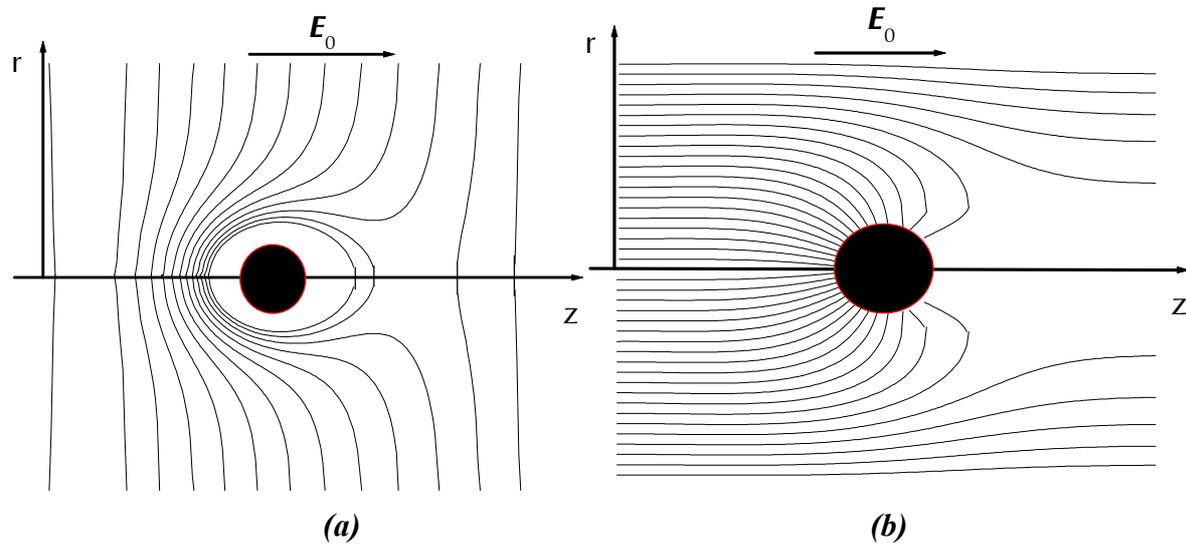


Fig.3. Equipotential and force lines of the calculated electrical field in the vicinity of the dust particle for steady-state conditions.

$$r_0 = 12 \mu\text{m}, E_0 = 1200 \text{ V/cm}, n_d = 10^6 \text{ cm}^{-3}, Q = 1.5 \times 10^{17} \text{ cm}^{-3} \text{ s}^{-1}.$$

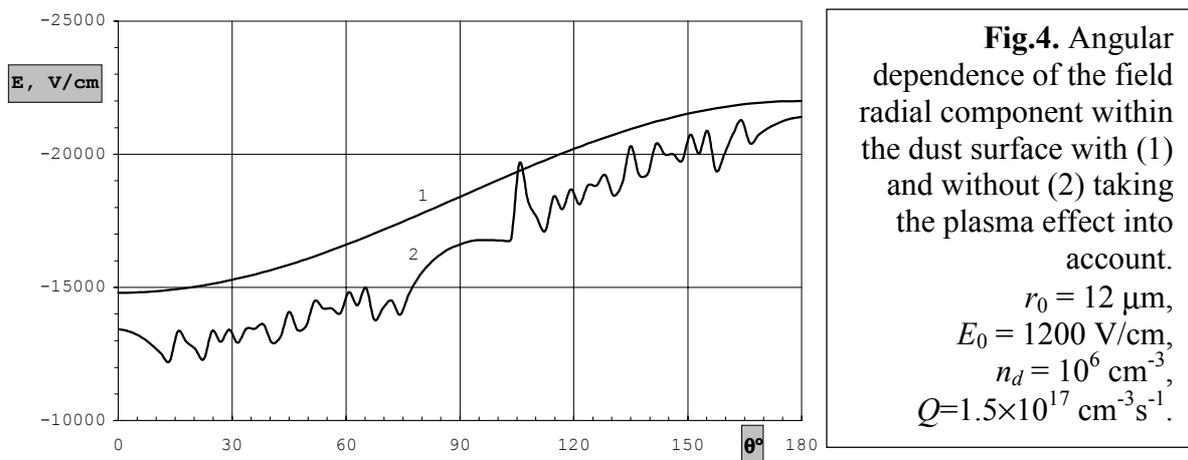


Fig.4. Angular dependence of the field radial component within the dust surface with (1) and without (2) taking the plasma effect into account.

$$r_0 = 12 \mu\text{m},$$

$$E_0 = 1200 \text{ V/cm},$$

$$n_d = 10^6 \text{ cm}^{-3},$$

$$Q = 1.5 \times 10^{17} \text{ cm}^{-3} \text{ s}^{-1}.$$

Conclusion

Calculating the charge of dust particles in the external field, which is considerably weaker than the field of the dust particle, can be performed with a good accuracy according to the one-dimension model.

References.

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