INTRODUCTION

The current interest in interaction of plasma with dust particles is stimulated by numerous applications of dusty plasmas in technology and in fundamental science. Plasma with condensed dispersed phase is applied in synthesis of nanoparicles, surface modification and plasma coating. The dust particles change both local and integral plasma parameters [1]. In presentation we analyze the influence of dust structures on the electric field of a discharge considering the heat release, and the reverse influence of discharge electric field on the radial balance of dust structures in plasma.

NUMERICAL MODEL

In this study we follow the basic points of driftdiffusion model of the positive column of glow discharge which proved the reliability for simulations in neon plasma with micron size dust particles [2]. We consider neon plasma consisting of neutrals, electrons, ions and metastable neon atoms of 1-s configuration with the energy of 16.62 eV. The ionization by single electron collision with neon atom in the ground state, and the step-wise ionization through the metastable state are considered. Molecular ions and negative ions are neglected. In addition to the specific ion and electron losses in dusty plasma, we have also considered the quenching of metastable atoms on dust particle surface. The ion and metastable atom temperatures were supposed to be equal gas temperature, the mean electron energy and transport coefficients were obtained using the SIGLO Database and the electron Boltzmann equation solver BOLSIG+. Using this approach, we have found the radial distributions of ions, metastable atoms and electrons and the electric field for the given dust particle distribution \(n_d\), the total discharge current \(I\) and pressure \(P\) in the plasma. To find the radial gas temperature profile in a discharge tube, we have neglected the convective heat conduction equation (1/4 \(\partial^2 T/\partial r^2\)) – \(\nu^2 n_e\mu eE\) with the appropriate boundary conditions: (\(\partial^2 T/\partial r^2\))\(\left|_{r=R_d}\right. = \partial T/\partial r\left|_{r=R_t}\right. = 0\), \(r=0\) here \(\nu, n_e, \mu, E\) is the rate of Joule heat release, \(\mu\) is the electron mobility, \(r\) is the thermal conductivity of neon, \(T_e\) is the temperature of electrons, \(T\) is the temperature of the neutral gas phase, \(E\) is the electric field strength and \(\mu_e\) is the electron mobility. Simulations were carried out for the discharge tube radius \(R=25\) mm, dust particle size \(a=2.5\) mm, the temperature of the wall of the discharge tube \(T_w=295\) K. The dust particle distribution \(n_d(r)\) was given by an axially symmetrical flat profile of size \(a/R>2\) with dust particle concentration on the axis of the discharge tube \(n_d(r=0)\), and exponential and ended blurring \(n_d(r)/n_d(r=0)\)\(e^{-|r|/R}\). The forces acting on the dust particle were considered as in [3]. The resulting forces \(F=\int dF\) is a sum of three constants: electric field force \(F_e(r)=z_eQ_eE/r,\) where \(z_e\) is the charge of dust particle, momentum force \(F_m(r)=\mu_e\mu_eE/r^2\) where \(\mu_e\) is the atomic free path; ion drag force \(F_{drag}\) where \(m_d\) is a mass of dust particle, \(u_i\) the ion flow velocity, and \(v_i=\mu_\text{i}\text{dust} n_i\text{dust}/\mu_\text{e}\text{dust} n_e\text{dust}\) the ion to dust particle momentum exchange rate. Simulations were carried out for single test dust particle in a discharge with \(Z_d=510^9\) m/s. The charge of test dust particle in pure neon was supposed to be independent of its radial coordinate. In other cases the dust particle charge depended on the radial coordinate, being determined by the flows of ions and electrons to its surface accordingly to CEC model [4].

RESULTS

Numerical results are represented for \(h=3\) mm and \(P=0.9\) Torr. In free discharge the undisturbed radial concentration profiles of plasma particles are close to Bessel distribution. Dust particle produces an additional electric losses in the plasma bulk, changing plasma ionization balance. For the maintenance of the discharge current, the ionization frequency should increase through the increase of \(E\) and electron temperature. For constant \(E\), increases from \(7.4\) V/cm in dust free discharge to \(11.4\) V/cm in discharge with dust particles \((d=4\times10^{-4}\text{cm}^{3}\text{cm}^{-3})\). The increase of \(n_d\) leads to the case when \(n_d\) on the outer face of dust cloud becomes higher than in the center of the tube. I.e. the maximum of electron profile shifts towards the wall tube, forming a local minimum in the center of discharge tube. At high \(n_d\), the strong depletion of \(n_d\) within the dust cloud causes the reverse flow of electrons from free discharge towards the tube axis and results in the inversion of \(E\) and \(T\). Following from this point, there appears the change of the electric force acting on the dust particles. The increased electric field strength leads to the increase of Joule heat release \(Q_e\), while the redistribution of \(n_d\) on the cross section of discharge tube causes the shift of its maximum towards the tube walls. The simulated temperature profiles are represented in Fig.1.

With increase of current, there appears the formation of zones free from dust particles (voids), which localize in the center of the dust structure on the discharge axis. The picture of the void development is determined by the Joule heating in the discharge. The zone without dust particles formed with increasing discharge current, is nonuniform along the length of the structure. The formation of zones without dust particles qualitatively is observed, for example, on the radial profile of the potential energy of dust particles, where the dust particles tend to occupy the position of equilibrium in a potential well with a minimum value of the potential energy (Fig. 3b). One can see that the arising additional force represented in Fig.3a, leads to the shift of the minimum of potential energy towards the wall of the discharge tube with the increase of the dust particle concentration. This should result in the formation of dust voids (voids) observed earlier in [5] and in the increase of the concentration of dust particles near the outer border of the dust structure [5].

CONCLUSION

- It was shown that the mechanism of radial sustenance of dust particles in the discharge realizes through the self-consistent influence of dust particles on the discharge electric field configuration.
- The introduction of dust particles in the positive column of glow discharge in neon lead to the noticeable increase of the longitudinal electric field strength that caused the increase of the Joule heat release in the discharge.
- The arising additional temperature and concentration gradients changed the net force acting on the dust particles and lead to the shift of the equilibrium position and shape of dust structure. The arising additional force leads to the shift of the minimum of potential energy towards the wall of the discharge tube.
- The self-consistent electric field and thermophoretic force are shown to play the major role in the formation of voids in dense dust structures.

REFERENCES