DUST PARTICLE CHARGING IN SHEATH

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The charging and the screening of spherical dust particles in sheaths near the wall were studied using computer simulation. The three-dimensional PIC/MCC method and molecular dynamics method were applied to describe plasma particles motion and interaction with macroscopic dust grain. Calculations were carried out at different neutral gas pressures and wall potentials. Values of the charge of the dust particles and spatial distributions of plasma parameters are obtained by modelling. The results have shown that the charge of the dust particles in the sheath, as well as the spatial distribution of the ions and electrons near the dust particles, depend strongly on the wall potential. It is shown that for large negative values of the wall potential the negative charge of a dust particle decreases due to the decline of the electron density in its vicinity. In addition, the flow of energy of the ions on the surface of dust particles is increased due to better focusing effect of the dust particle field on ions.

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INTRODUCTION

The problem of the charging and screening of dust particles immersed in plasma is one of the basic problems of dusty-plasma physics. The grain charge, together with the electric potential distribution around the grain, determines electric interactions between dust particles. These grain-grain interactions are responsible for a number of collective phenomena, such as formation of ordered (crystal-like) structures and phase transitions. Various approximate models and PIC/MCC computer simulations have been used previously to calculate the particle charge [1-4]. These studies were carried out for spherical dust particles immersed in uniform equilibrium plasma. However, most of the dusty plasma experiments were done in the sheath region close to the wall in a gas discharge plasma. The presence of the electric field and ion flow in the sheath plays an important role in the dust particle charging. Hereupon, the investigation of dust particle charging and screening in sheath is an actual problem.

MODEL AND SIMULATION METHOD

We consider a spherical dust particle in the sheath, which occurs at the plasma boundary with a flat conductive wall. Wall potential φ_w is given and does not change over time. It is assumed that at the initial time the dust particle is uncharged, the plasma consists of electrons and ions and is homogeneous. Over time, the sheath is formed near the wall, and the dust particle acquires a certain charge q_d. In our calculations the dust particle radius was $R_d=5\ \mu m$, the distance of the dust particles from the wall was $L = 10^{-4}\ m$, the pressure of the neutral gas was varied from $0\ldots5$ *Torr*. At the sheath edge densities of plasma particles (electrons and ions) were $n_0=10^{17}\ m^{-3}$. Electron flow in this point is assumed to be thermal, but the ion flow velocity is assumed to have ion sound velocity. The mass of the neutral gas atoms and ions was equal to hydrogen to reduce computational time, but the elementary cross-sections were equal to argon. The electron and ion temperatures were assumed to be $T_e=1\ eV$ and $T_i=0.03\ eV$ respectively. The length of the computational area cube is $L= 2\cdot10^{-4}\ m$, that is much greater than electron Debye length. The simulation time is $\tau=5\cdot10^{-8}\ s$ that exceeds the time at which the ion flies the length L.

The three-dimensional PIC/MCC method is applied for solving this task [5]. In order to accurately resolve close-range interactions between dust grains and plasma particles, the PIC model has been combined with a molecular dynamic MD algorithm. In the resulting particle-particle particle-mesh (P3M) model, the long-range interaction of the dust grains with charged particles of the background plasma is treated according to the PIC formalism. For particles which are closer to the dust grain than a Debye length their interaction force is computed according to a direct particle-particle MD scheme using the exact electrostatic potential [6]. The interaction between plasma particles and neutral gas was simulated using Monte-Carlo method for describing of elementary processes, such as elastic, excitation, ionization, charge exchange processes. If an electron or ion in its motion crossed the particle surface, it was thought that it recombines and its charge is transferred to the dust particle.

RESULTS

Simulations results were obtained for various wall potentials φ_w and neutral gas pressures p. Typical results of the computer simulations are shown in Figs. 1-4. Temporal dependences of a dust particle charge are presented in Fig. 1. Fig. 1,a corresponds to the wall potential $\varphi_w=-9\ V$, and Fig. 1,b corresponds to $\varphi_w= -16\ V$. Different curves in the figures correspond to different values of the gas pressure, indicated in the figure. As can be seen in Fig. 1,a, charge of a dust particle increases monotonically with time for all values of the gas pressure and tends to some constant values. The charge of dust particle is increased in magnitude with increasing gas pressure.

In the case of $\varphi_w= -16\ V$, after the initial increase of dust particle charge, there is a further reduction of it. In addition, there is a non-monotonic dependence of the charge on the gas pressure. Note, that the charge of a dust particle in this case is much smaller in absolute value than in the case of $\varphi_w=-9\ V$.

Fig. 2 demonstrates spatial distributions of ion (a) and electron (b) density along a line that passes through the center of the dust particle parallel to the axis *y* in the case of the wall potential $\varphi_w=-9\ V$. Note, that dust particle is located at the point $y=10^{-4}\ m$. The forming of peaks is observed for the ion density behind the dust particle towards the wall. Moreover, the peaks decrease with increasing gas pressure. The formation of these peaks occurs due to ion focusing by the field of the dust particle and the formation of an ion cloud behind the dust particle. In addition, the ion density minimum is formed in the vicinity of the dust particle in all variants of calculations.

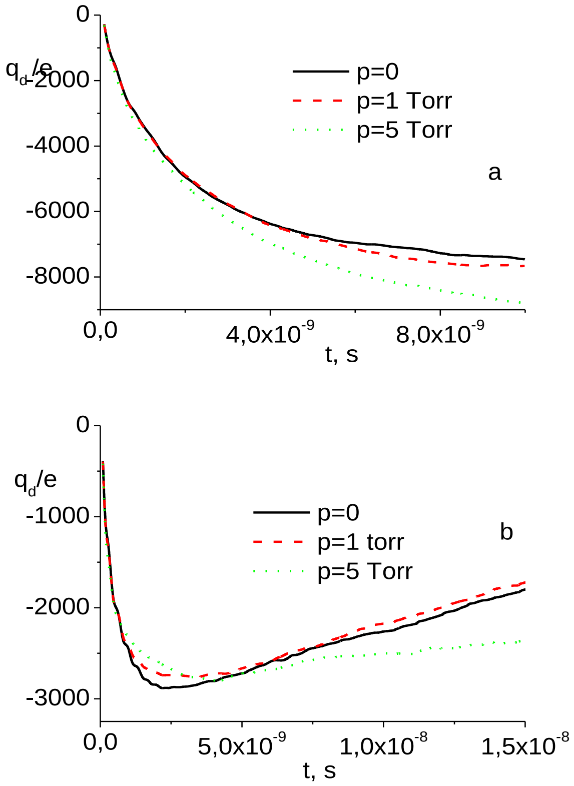

Fig. 1. Temporal dependences of the dust particle charge for case of $\varphi_w=-9\ V$ (a) and $\varphi_w=-16\ V$ (b) and different gas pressures, represented on the figure

Fig. 2,b shows corresponding spatial distributions of electron density along the specified direction. It can be seen that near the wall (at $y=2\cdot10^{-4}\ m$) the electrons are practically absent. Additionally, maxima of the electron density are much smaller than maxima of ion density behind the dust particle. Therefore, a region of large positive charge is formed behind the dust particle towards the wall.

Fig. 3 shows the spatial distributions of the ion (a) and the electron (b) densities in the case of the wall potential $\varphi_w=-16\ V$. In these cases, the focusing of ions is not observed behind the dust particle. The reasons for this is that at the increasing negative wall potential ions gain greater velocity and are less deflected when they move in the field of the dust particle.

Feature of spatial electron distributions in these cases is that between the dust particle and the wall electrons are practically absent. This leads to a substantial reduction of the electron current on the dust particle, whereby negative charge of the dust particle reduces greatly (see Fig. 1,b).

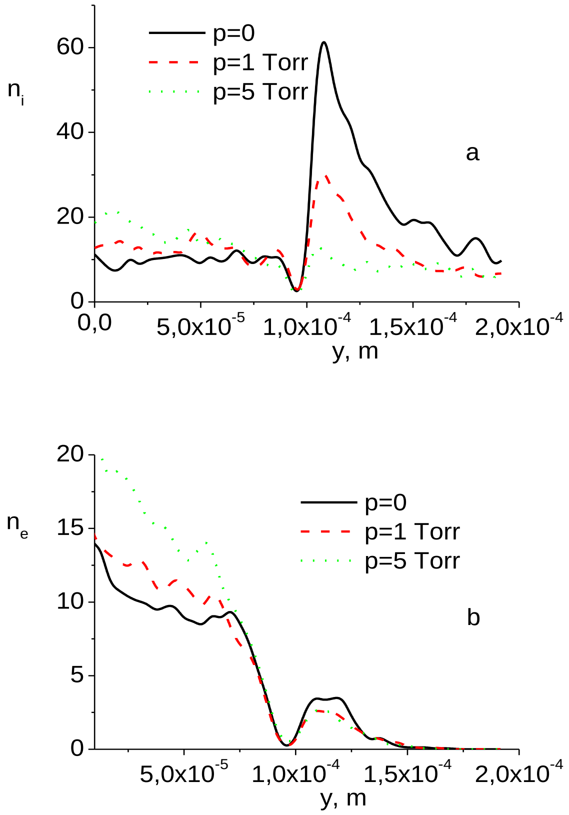

Fig. 2. Spatial distributions of ion density (a) and electron density (b) along y-axis for $\varphi_w=-9\ V$ and different values of neutral gas pressures

Fig. 4 shows the spatial distributions of the electric field potential along axes *y* for specified previously cases. In the presented calculations for $\varphi_w=-9\ V$ (see Fig. 4,a) distributions of electric potential are almost identical at different gas pressures. Near the dust particle potential well is formed, due to a high negative charge of the dust particle. In the case of $\varphi_w=-16\ V$ potential well is small in the vicinity of the dust particles, since the charge of dust particles in these cases is much smaller. However, in this case, the gas pressure stronger influences on the spatial distributions of electric potential. With increasing gas pressure the thickness of the sheath (region of sharp change of the potential) decreases and the electron density increases near the dust particle. This leads to an increase of the electron current on the surface of dust and to an increase of its charge in magnitude.

We now analyse the energy flow to the dust particle due to electron and ion fluxes to the surface. It is assumed in our model that the kinetic energy of plasma particles is transferred to dust particle entirely in collisions.

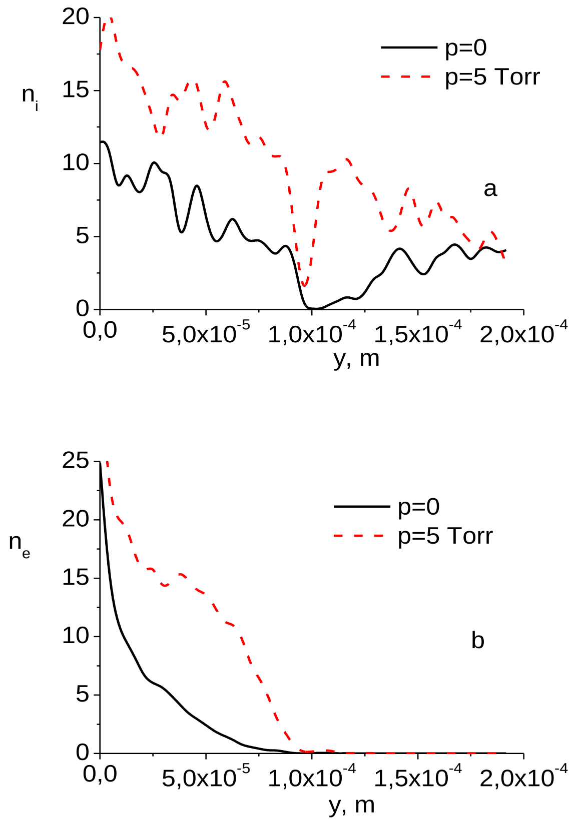

Fig. 3. Spatial distributions of ion density (a) and electron density (b) along y-axis for φ_w= -16 V and different values of neutral gas pressures

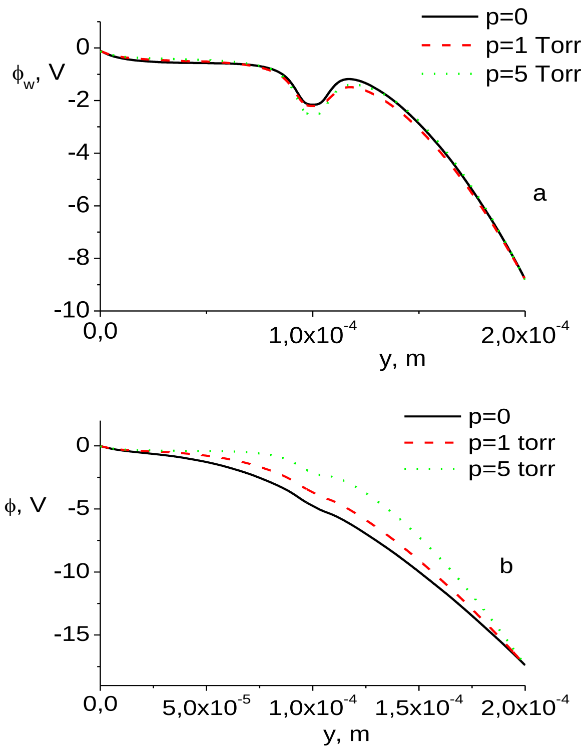

Fig. 4. Spatial distributions of electric potential along y-axis for $\phi_w = -9\,V$ *(a) and for* $\phi_w = -16\,V$ *(b)*

Fig. 5,a shows time dependences of the energy flux of ions to the surface of the dust particles in the absence of neutral particles in the sheath (p=0) for two values of the wall potential. It can be seen that with the increasing of the negative wall potential, the energy flux of ions on the dust particle is reduced. Similar dependences of ion energy fluxes are shown in Fig. 5,b for the neutral gas pressure *p=5 Torr*. The increasing of the ion energy flow with a decrease of the negative potential of the wall is observed in this case also. This result is explained by the more effective focusing action of the dust particle field on ions in the case of φ_w*=-9 V*

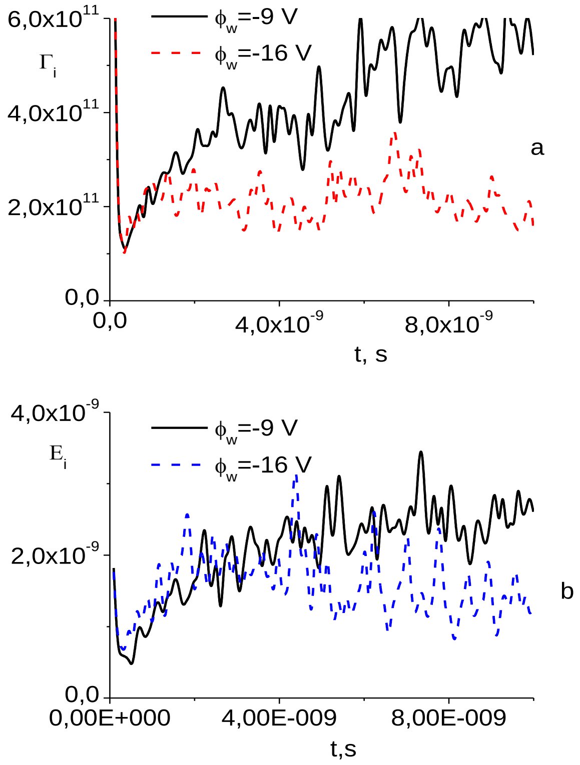

Fig. 5. Temporal dependences of the ion energy flow to dust particle for case p=0 (a) and p=5 Torr (b) and different wall potentials, represented in figure

Comparison of energy fluxes of ions at the same potential wall, but different pressures, shows a decrease of this flows with increasing pressure. The reason for this is the influence of collisions between ions and neutral atoms (elastic collisions and charge exchange processes) on ion fluxes on the dust particle.

CONCLUSIONS

This paper covers the charging and screening of dust particles in the sheath. The charges of dust grains and spatial distributions of plasma particles around them were obtained at different neutral gas pressures and wall potentials. The formation of the ion clouds behind dust particles owing to focusing of ion flows was observed at low wall potentials. The dust particle charge decreases in magnitude with increasing of negative wall potential. Simulation results also showed the formation of the potential minimum near the dust particle in case of low wall potential.

The ion energy flows on dust particles in sheaths were calculated. They increase with decreasing of gas pressure due to the influence of ion - atom collisions on the ion flux onto dust particles. It is also shown that the ion energy flow increases with decreasing of the wall negative potential, which is a consequence of improving of the focusing action of the dust particle field.

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ЗАРЯДКА ПЫЛЕВОЙ ЧАСТИЦЫ В ПРИЭЛЕКТРОДНОМ ШАРЕ

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Зарядка и экранирование сферических пылевых частиц в приэлектродных слоях вблизи стенки были изучены с помощью компьютерного моделирования. Трехмерный PIC/MCC-метод и метод молекулярной динамики были применены для описания движения частиц плазмы и взаимодействия их с макроскопической пылинкой. Расчеты проводились при различных значениях давления нейтрального газа и потенциала стенки. Значения заряда пылевых частиц и пространственные распределения параметров плазмы получены при помощи моделирования. Результаты показали, что заряд пылевых частиц в приэлектродном слое, а также пространственные распределения ионов и электронов вблизи пылевых частиц сильно зависят от потенциала стенки. Показано, что при больших значениях потенциала стенки отрицательный заряд пылевой частицы уменьшается в связи с уменьшением плотности электронов в ее окрестности. Кроме того, поток энергии ионов на поверхность пылевой частицы увеличивается за счет лучшего фокусирующего действия поля пылевых частиц на ионы.

ЗАРЯДКА ПИЛОВОЇ ЧАСТИНКИ В ПРИЕЛЕКТРОДНОМУ ШАРІ

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Зарядка і екранування сферичних пилових частинок у приелектродних шарах поблизу стінки були вивчені за допомогою комп'ютерного моделювання. Тривимірний PIC/MCC-метод і метод молекулярної динаміки були застосовані для опису руху частинок плазми та взаємодії їх з макроскопічною пилинкою. Розрахунки проводились при різних значеннях тиску нейтрального газу і потенціалу стінки. Значення заряду пилових частинок і просторові розподіли параметрів плазми отримані за допомогою моделювання. Результати показали, що заряд пилових частинок у приелектродному шарі, а також просторові розподіли іонів і електронів поблизу пилових частинок сильно залежать від потенціалу стінки. Показано, що при великих значеннях потенціалу стінки негативний заряд пилової частинки зменшується в зв'язку зі зменшенням концентрації електронів поблизу неї. Крім того, потік енергії іонів на поверхню пилової частинки збільшується за рахунок кращої фокусуючої дії поля пилових частинок на іони.