RF DISCHARGE IN ARGON WITH CYLINDRICAL DUST PARTICLES

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Kinetic computer simulations of the low pressure RF discharge in argon with cylindrical and spherical dust particles are carried out using PIC/MCC method. The Monte Carlo technique is used to describe electron and ion collisions with neutral atoms, ions, and dust particles. Obtained results show the remarkable influence of the dust particle shape on spatial distributions of RF discharge parameters including the ion density and the dust particle charge. Possible reasons of the influence can be a difference of the collection effective cross-section between spherical and cylindrical dust particles with equal surfaces as well as the balance of charged particles in dusty RF discharges.

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1. INTRODUCTION

Dust particles created in RF discharges due to etching and sputtering of wall material or due to gas-phase nucleation, coagulation, and deposition in chemically active plasmas can have a complex form that is different from the spherical shape used in most theoretical investigations and numerical simulations of dusty RF discharges (see, for example [1]). The shape of dust particles can remarkably influence the behaviour of the dust particles in dusty plasmas and discharges. In particular, laboratory experiments [2,3] show that the levitation of cylindrical dust particles (microrods) in RF sheaths depends on their size. Microrods below a critical length settle parallel to the electric field, while longer microrods float perpendicular to the field. Therefore investigations of dusty RF discharges with non-spherical dust particles are relevant.

The aim of the work is the computer simulation of dusty RF discharges in argon with cylindrical and spherical dust particles at various given profiles of the dust particle density to investigate an influence of the shape of dust particles on dusty RF discharges.

2. MODEL

A one-dimensional RF discharge is considered between two plane electrodes separated by a gap of $d=2.0cm$ which is filled with Ar at the pressure 0.1 Torr. Immobile cylindrical dust particles of a given radius r_d and a length L are distributed according to a given distribution in the interelectrode gap with a maximum density N_{do} close to electrodes. The RF discharge is sustained by the external altering voltage with the frequency 13.56 MHz and the amplitude $V_o = 100\ V$. The discharge is grounded at $x=d$. The dust particles collect electrons and ions generated in the discharge with density n_e and n_i, respectively.

The effective cross-section σ for collection of electrons and ions by a cylindrical dust particle was obtained using the conservation of energy and momentum in a Debye cylinder around the cylindrical dust particles. At the condition of $L >> R_d$, the cross-section σ can be written as:

$$\sigma = 2 r_d L \sqrt{1 \pm \frac{Q_d}{2 E_n \pi L \varepsilon_0} \ln \frac{r_d}{r_d + \lambda_d}} ,$$

where E_n is the energy of electrons and ions (in eV) moving perpendicularly to the axis of the cylindrical dust particle on a boundary of the Debye cylinder, λ_d is the Debye length, Q_d is the total charge of the cylindrical dust particle in the electron charge, r_d and L is the radius and the length of the cylindrical dust particle, respectively. The sign "plus" and "minus" is valid for ions and electrons, respectively.

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, as well as the electron and ion collection 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 [4]. The Coulomb cross-section for electron and ion scattering by immobile dust particles is taken from [5].

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

3. RESULTS

Obtained typical spatial distributions of the ion n_i density across the interelectrode gap of the RF discharge are shown in Fig. 1 for spherical (solid line) and cylindrical (doted lime) dust particles distributed uniformly in the interelectrode gap with a dust particle density $N_d=5\times10^{11}\ m^{-3}$. The distributions are obtained at a spherical dust particle radius $R_d = 1\ \mu m$, and at a cylindrical dust particle with the length of $L=5\ \mu m$ and the radius $r_d = 0.1\ \mu m$ oriented parallel with the electric field of the RF discharge. Note that the surfaces of both particles are practically equal. As can be seen in Fig. 1, the ion n_i density is essentially larger in the case of cylindrical dust particles in the central part of the RF discharge unlike sheaths where the density is consisted with one for spherical dust particles. A possible reason of the difference can be a difference of the collection effective cross-section between spherical and cylindrical dust particles with equal surfaces.

There is a difference between spatial distributions of the dust particle charge Q_d for RF discharges with spherical and cylindrical dust particles shown in Fig. 2 for case of Fig. 1. It is seen cleanly in Fig. 2 that a non-monotony of spatial distributions of the dust particle charge Q_d is stronger in the quasi-neutral part of the RF discharge in the case of spherical dust particles. The possible reason of the difference can be averaging along the cylindrical dust particle, which is stretched in the direction more as the spherical dust particle.

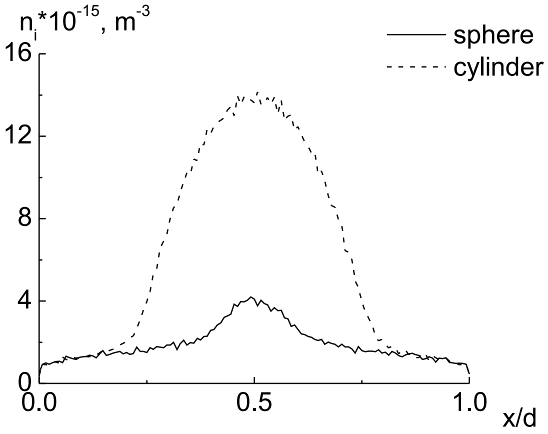

Fig. 1 Spatial distributions of the ion n_i density in the RF discharge with spherical and cylindrical dust particles

Spatial distributions of the ion density n_i across the interelectrode gap of the RF discharge are shown in Fig. 3 at various spatial distributions of dust particles. The distributions are obtained at two distributions of dust particles, namely: at parabolic distributions of the dust particle density with the ratio $\alpha = N_d / N_{do} = 0.1$ of the density N_d in the centre of the interelectrode gap to the density N_{do} close to electrode and at uniform distributions of the dust particles at $\alpha = 1$. As can be seen in Fig. 3, the ion density n_i is smaller in the central quasi-neutral part of the RF discharge at uniform distributions of both shape of dust particles. In sheaths, the ion densities n_i are coincided in the case of uniform and parabolic distributions of cylindrical dust particles unlike the case of spherical dust particles where the ion n_i density is larger at the uniform

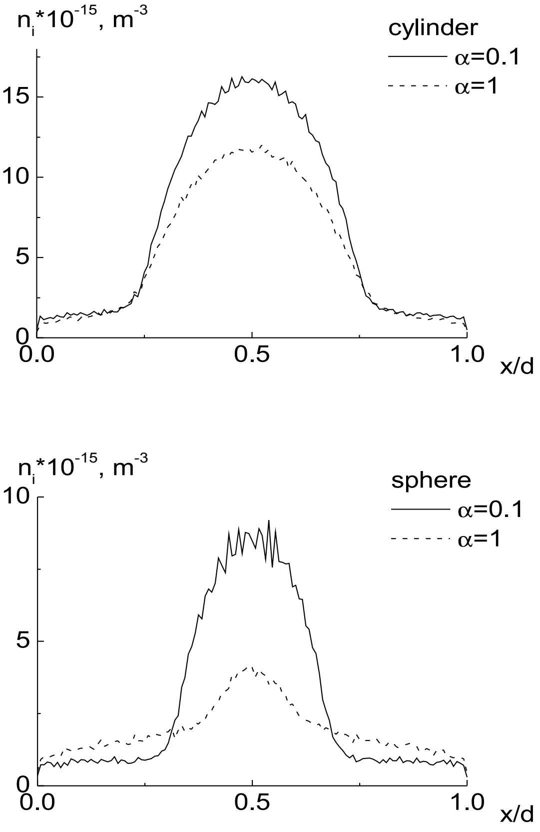

Fig. 1. Spatial distributions of the ion density n_i at uniform (α = 1) and parabolic (α = 0.1) distributions of spherical and cylindrical dust particles

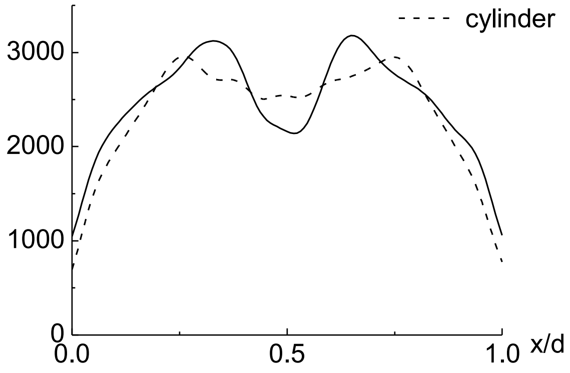

Fig. 2. Spatial distributions of the dust particle charde Q_d for spherical and cylindrical dust particles

distribution of the dust particles. The differences of spatial distributions of the ion n_i density indicated above can be explained by a difference of the collection effective cross-section between spherical and cylindrical dust particles with equal surfaces and the balance of charged particles in dusty RF discharges discussed in detail in [1].

CONCLUSION

Kinetic computer simulations of the low pressure RF discharge in argon with cylindrical and spherical dust particles are carried out using PIC/MCC method. The Monte Carlo technique is used to describe electron and ion collisions with neutral atoms, ions, and dust particles. Obtained results show the remarkable influence of the dust particle shape on spatial distributions of RF discharge parameters including the ion density and the dust particle charge. Possible reasons of the influence can be a difference of the collection effective cross-section between spherical and cylindrical dust particles with equal surfaces as well as the balance of charged particles in dusty RF discharges.

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РАДИОЧАСТОТНЫЙ РАЗРЯД В АРГОНЕ С ЦИЛИНДРИЧЕСКИМИ ПЫЛЕВЫМИ ЧАСТИЦАМИ

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Кинетическое компьютерное моделирование радиочастотного разряда в аргоне с цилиндрическими и сферическими пылевыми частицами проводился с использованием PIC/MCC метода. Техника Монте-Карло использовалась для описания электронных и ионных соударений с нейтральными атомами и пылевыми частицами. Полученные результаты показывают, что форма пылевых частиц заметно влияет на пространственные распределения параметров радиочастотного разряда, в том числе на распределения концентрации ионов и заряда пылевых частиц. Возможными причинами этого влияния может быть разница эффективных сечений сферических и цилиндрических пылевых частиц с одинаковой поверхностью, а также баланс заряженных частиц в запыленных радиочастотных разрядах.

РАДІОЧАСТОТНИЙ РОЗРЯД В АРГОНІ З ЦИЛІНДРИЧНИМИ ПИЛОВИМИ ЧАСТИНКАМИ

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Кінетичне комп’ютерне моделювання радіочастотного розряду в аргоні з циліндричними і сферичними пиловими частинками проводилося з використанням PIC/MCC методу. Техніка Монте-Карло використовувалася для опису електронних і іонних зіткнень з нейтральними атомами і пиловими частинками. Отримані результати показують, що форма пилових частинок помітно впливає на просторові розподіли параметрів радіочастотного розряду, в тому числі на розподіли густини іонів і заряду пилових частинок. Можливими причинами цього впливу може бути різниця ефективних перетинів сферичних і циліндричних пилових частинок однакової поверхні, а також баланс заряджених частинок в запорошених радіочастотних розрядах.