A COMPUTER SIMULATION OF THE EFFECT OF DUSTY PARTICLES ON THE CHARACTERISTIC OF RF DISCHARGES

O.Yu. Kravchenko, A.V. Vakulenko, T.E. Lisitchenko, G.I. Levada, Yu.A. Yastrub

Faculty of Radio Physics, Taras Shevchenko National Kyiv University, Kyiv, Ukraine,
e-mail: kay@univ.kiev.ua

We are carried out the computer simulation of the dust cloud dynamics in the radio frequency (RF) discharges at the microgravity conditions using PIC/MCC method for electrons and ions and hydrodynamics model for dust particles. The moving of dust particles is governed by the electrostatic force, ion and neutral drag forces, which are averaged over period of RF discharge. The obtained results show that dust particles form layer with sharp boundaries in the discharge chamber. Locations of the layer boundaries don't coincide with the edges of the rf-sheathes and depend on size of dust particles and ion density in discharge.
PACS: 52.27.Lw

1. INTRODUCTION

Physics of dusty plasma are considered now as one of the important branches of science and technology. First of all an active research on particle formation and behavior has been induced by contamination phenomena of industrial plasma reactors used for etching, sputtering, and plasma enhanced chemical-vapor deposition. Many experimental efforts have deal with the detection and dynamics dust particles in capacitive coupled radio frequency discharges, since they widely used as sources of reactive species for surface treatment. Such particles are trapped in the plasma bulk, forming dust clouds and voids [1], [2], and significantly affect the discharge behavior. In particular, dust particles change electron and ion velocity distribution functions and influence on ionization processes and flows of plasma particles toward the electrodes. The numerical simulations of the dust particles dynamics in RF discharges was carried out earlier in the frame of hydrodynamic model [3], which is not correct for discharges of the low pressure. However, many modern plasma reactors operate at low gas pressure and the mean free path of charged particles becomes comparable with or exceeds the thickness of electrode sheaths. The influence of dust particles on radio frequency discharge in the kinetic approach was investigated only for the case of static dust particles [4], [5]. In this paper we are carried out the computer simulation of the dust cloud dynamics in the radio frequency discharges at the microgravity conditions using PIC/MC method for electrons and ions and hydrodynamics model for dust particles.

2. MODEL

We use hydrodynamics approach to describe the dust particles motion

$$\frac{\partial n_d}{\partial t} + \frac{\partial (n_d v_d)}{\partial x} = 0, \qquad (1)$$

$$\frac{\partial v_d}{\partial t} + \frac{1}{2}\frac{\partial v_d^2}{\partial x} = \frac{1}{m_d} F_d. \qquad (2)$$

The potential of the electric field φ is described by Poisson equation

$$\frac{\partial^2 \varphi}{\partial x^2} = -\frac{e}{\varepsilon_0}\left[n_i - n_e + q_d n_d\right], \qquad (3)$$

where n_d, v_d, q_d are a density, drift velocity and charge of a dust particle, n_i, n_e are averaged for a discharge period an ion and electron densities correspondingly.

The change of the dust charge is described by equation

$$\frac{\partial q_d}{\partial t} + v_d \frac{\partial q_d}{\partial x} = I_e + I_i., \qquad (4)$$

where I_e is the electron and I_i is the ion current to the dust particle. The total force acting on the dust particles is a sum of the electrostatic $F_E = q_d E$, the ion drag F_i and the neutral drag F_n forces. The ion drag force is calculated using OLM approach [6] and consists of the collection F_i^c and orbit F_i^o components. The former is a result of momentum transfer from all ions collected by the grain

$$F_i^c = \pi b_c^2 n_i v_s m_i v_i, \qquad (5)$$

where $b_c = r_d\left(1 - 2eq_d / r_d m_i v_i^2\right)^{1/2}$. The orbit force is caused by the momentum transfer from the Coulomb scattering of ion-dust, then it be given by

$$F_i^o = n_i m_i v_i^2 4\pi b_0^2 \Gamma, \qquad (6)$$

where b_0 and Γ are impact parameters for deflection to $\pi/2$ angle and the Coulomb logarithm correspondingly. Ion and electron densities, the ion drift velocity; ion and electron currents to a dust particle are calculated using the PIC/MCC method.

The PIC/MCC method described in detail in [7] for discharges without dust particles is developed for computer simulations of the RF discharge with dust particles [5]. The Monte Carlo technique is used to describe electron and ion collisions. The collisions include elastic collisions of electrons and ions with atoms, an ionization and excitation of atoms by electrons, the charge exchange between ions and atoms, Coulomb collisions of electrons and ions with dust particles, as well as the electron and ion collection and scattering by dust particles. In addition to a usual PIC/MCC scheme, the weighting procedure is used also for the determination of a macroparticle charge part, which is interacting with a dust particle.

The Coulomb cross-section for electron and ion scattering by immobile dust particles is taken from [5].

The electron-argon collision cross-sections used in the model are the same as those used in [8]. Due to the significant difference in dust and ion (even more electron) mass dust particles move hardly at all at one electron time step. Thus in order to speed up simulation code the sub-cycling technique was used.

3. RESULTS AND DISCUSSION

Simulations have been carried out at several different radii of dust particles and pressure values, whereas the other plasma parameters are kept constant. The rf frequency and the amplitude of rf power are set $\nu_{rf} = 10\,MHz$ and $V_{rf} = 150\,V$, the distance between the electrodes is set to 0.05 *m*, the initial dust density is set $n_{d0} = 10^{10}\,m^{-3}$.

Results of calculations were shown that dust particles are pushed out from sheaths into the plasma and are distributed in the central part of discharged gap. The stationary spatial distribution of dust particles is settled after a time. Discussed below spatial profiles correspond to time *t* = 0.02 *s* when steady state of the dust layer is achieved in the rough.

Fig. 1a shows the dust density at three radii r_d and the neutral gas pressure *p = 0.1 Torr*. Values of radii have indicated in micrometers. As shown in this figure, in all cases dusty layers with sharp boundaries are formed and the dust density is at maximums at these boundaries. Width of the dust layer is decreasing with increasing dust particle radius. This fact is caused by the increasing of the dust particle charge and electrostatic force with the increasing r_d . The dust density distribution is uniform in the central part of the layer in all cases depictured in the figure.

Dust layers are modified plasma parameters. Fig. 1b shows spatial profiles of the ion current averaged over period of the rf discharge. We can see that it is happened a strong perturbation of the ion current near dust densities peaks. Namely, ion flows are directed to dust density peaks at $r_d = 6\,\mu m$.

The time-averaged ion density is pictured in Fig. 2. It is seen the decreasing of the ion density with increasing of the dust particle radius, that is a consequence of a bigger ion deposition on dust particles. In case with $r_d = 6\,\mu m$ peaks of the ion density are formed in locations of dust density peaks. Double layers are appeared in locations of these peaks and stimulate the ion acceleration in the direction to peaks.

Fig. 3 shows dust density spatial distributions at three values of a neutral gas pressure and $r_d = 3\,\mu m$. Values of gas pressure in figure are indicated in torrs. Note, that the width of dust layer is a monotonically increasing function of the pressure. This result is a consequence of more thin sheaths at a big pressure and the balance of forces acting on a dust particle is reached closer to electrodes. At the gas pressure *p = 0.1 Torr* the biggest dust density peaks is formed at dust layer boundaries. As a result the big potential jumps are appeared at these locations which accelerate ions toward electrodes.

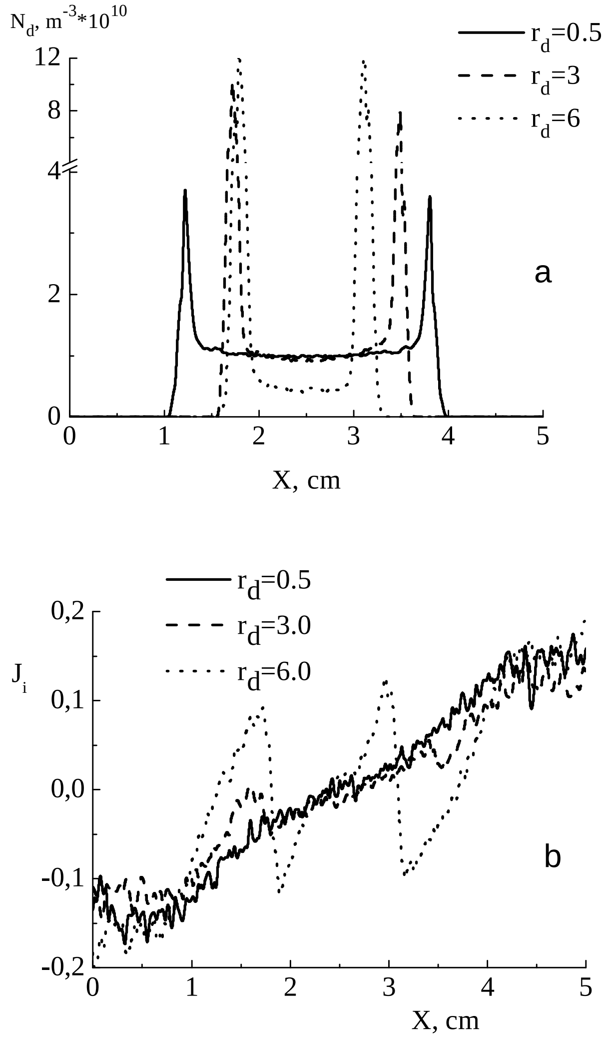

Fig.1. Dust density profiles (a) and time-averaged ion current profiles (b) at different dust particle radii

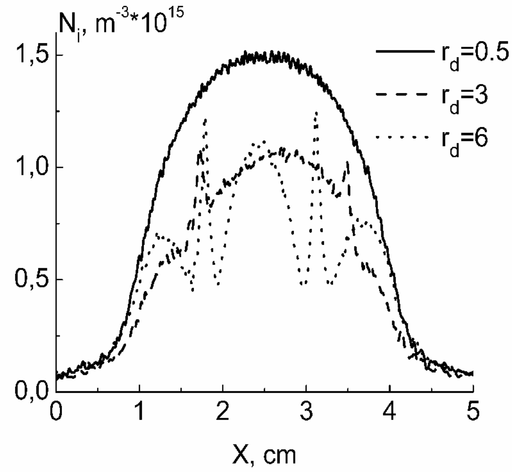

Fig.2. Ion density profiles at different dust particle radii

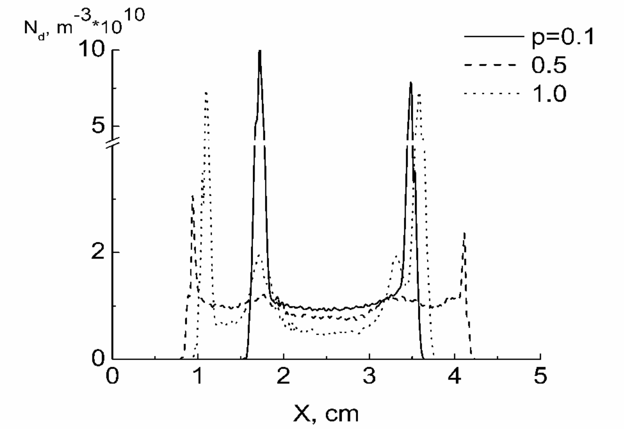

Fig. 3. Dust density profiles at different pressure values of the neutral gas

To conclude, the dust cloud forming have been numerically studied in radio frequency discharge under microgravity. It was shown that the dust particles compression is happen in some locations of the discharge chamber due to join action of an electrostatic, an ion drag and a neutral drag forces. It was studied the influence of a dust particle radius and a neutral gas pressure on plasma parameters distributions.

REFERENCES

1. M. Mikikian, L. Boufendi, H.M. Thomas, G.E. Morfill, A.P. Nefedov, V.E. Fortov et al. //*New Journal of Physics*. 2003, p.19.1-19.12.
2. G.E.Morfill, H.M.Thomas, U.Konopka, H.Rothermel, M.Zuzic, A.Ivlev, J.Goree //*Phys. Rev. Letters*. 1999, v.83, p. 1598-1601.
3. M.R. Akdim, W.J. Goedheer //*Physical Review E*. 2002, v.65, p. 015401.
4. Y. Chutov, W. Goedheer, O. Kravchenko, V. Zuz, Yan Min // *Journal Plasma and Fusion Research*. 2001, v.4, p.340-348.
5. Y.I. Chutov, W.J. Goedheer // *IEEE Trans. Plasma Phys.* 2003, v.31, p.606-613.
6. P.K. Shukla, A.A. Mamun. *Introduction to Dusty Plasma Physics*. Bristol and Philadelphia: "IoP Publishing Ltd.", 2001.
7. C. K. Birdsall // *IEEE Trans. Plasma Sci*. 1991, v.19, p.65-85.
8. V. Vahedi, G. DiPeso, C.K. Birdsall, M.A. Liberman, T.D. Roghlien // *Plasma Sources Sci. Technol.* 1993, v.2, p.261-272.

КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ ВЛИЯНИЯ ПЫЛЕВЫХ ЧАСТИЦ НА ХАРАКТЕРИСТИКИ РАДИОЧАСТОТНОГО РАЗРЯДА

А.Ю. Кравченко, А.В. Вакуленко, Т.Е. Лиситченко, Г.И. Левада, Ю.А. Яструб

Проводится компьютерное моделирование динамики пылевого сгустка в радиочастотных разрядах в условиях микрогравитации. Используется PIC/MCC метод моделирования для электронов и ионов, а также гидродинамическая модель для пылевых частиц. Движение пылевых частиц определяется электростатической силой, силами трения с ионами и нейтралами, которые усредняются по периоду радиочастотного разряда. Полученные результаты показывают, что пылевые частицы формируют слои с резкими границами в разрядной камере. Положения границ пылевых слоев не совпадают с границами приэлектродных слоев и зависят от размера пылевых частиц и плотности ионов в разряде.

КОМП'ЮТЕРНЕ МОДЕЛЮВАННЯ ВПЛИВУ ПИЛОВИХ ЧАСТИНОК НА ХАРАКТЕРИСТИКИ РАДІОЧАСТОТНОГО РОЗРЯДУ

О.Ю. Кравченко, А.В. Вакуленко, Т.Є. Лиситченко, Г.І. Левада, Ю.А. Яструб

Проводиться комп'ютерне моделювання динаміки пилового згустку в радіочастотних розрядах в умовах мікрогравітації. Використовується PIC/MCC метод моделювання для електронів та іонів, а також гідродинамічна модель для пилових частинок. Рух пилових частинок визначається електростатичною силою, силами тертя з іонами та нейтралами, які усереднюються по періоду радіочастотного розряду. Одержані результати показують, що пилові частинки формують шари з різкими границями в розрядній камері. Положення границь пилових шарів не співпадають з границями приелектродних шарів і залежать від розміру пилових частинок та іонної густини в розряді.