ION ENERGY DISTRIBUTIONS IN RF SHEATHS WITH DUST PARTICLES

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We study ion energy distributions functions (IEDFs) within an rf sheath with dust particles in SiH_4 radio-frequency discharges and compare results with ones in Ar rf discharges. The simulations are carried by PIC/MCC method over a wide range of pressure, dust density and dust radius. Our model includes electron-neutral collisions, various kinds of collisions of ions with neutrals, positive-negative ion collisions. Results of calculations show that IEDFs for positive ions SiH_3^+ in silane rf-discharge essentially differ from IEDFS for positive ions in Ar discharges. Ions near electrodes get greater energy in electronegative discharge in consequence of inessential charge exchange processes in the rf-sheath. Peaks of high energy ions are appeared in IEDFs, which are caused by significant decreasing of the radio-frequency sheath width and the ratio of ion penetrating time through sheath to the radio-frequency discharge period. Results of calculations show that big dust particles slow down ions in rf-sheaths, but the presence small dust particles can increase energy of ions. It is explained by the increasing of the potential drop near electrode.
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1. INTRODUCTION

High density plasma sources are widely studied due to their growing use in semiconductor manufacturing and fabrication. In processing plasmas, it is well known that the ion energy arriving at the substrate is crucial in etching and deposition rates of the film. In general, the motion of the ions as well as the ion distribution functions are determined by the spatiotemporal variations of the sheath electric field and the collisions the ions undergo while traversing the sheath. Dust particles can appear in sheaths of rf discharges as the product of the plasma-wall interaction or can be created due to coagulation of various components in chemically active plasmas. It is known [1,2] that the dust particles can essentially influence the parameters of the rf discharges due to a continuous selective collection of background electrons and ions that can essentially influence their energy distribution functions.

Analytical models assume limiting approximations such as constant sheath width, sinusoidal sheath potential drop, and therefore give only qualitative features of the IEDF. Because of the complexity of rf sheath dynamics, most calculations of IEDFs rely on numerical methods.

In the present paper we discuss IEDFs within an rf sheath both in Ar discharges and in SiH_4 discharges with dust particles. The simulations are carried out over a wide range of pressure, dust density and dust radius.

2. MODEL

A one-dimensional RF discharge is considered between two plane electrodes separated by a gap of d = 5.0 cm which is filled with Ar or SiH_4 at various pressures. Immobile dust particles of a given radius Rd are distributed uniformly in the interelectrode gap with a density N_d. The dust particles collect and scatter electrons and ions distributed in the discharge with density ne and ni, respectively. A harmonic external voltage $V_e(t) = V_0 \sin(\omega t)$ at a frequency f=13,56 MHz and various amplitudes V_0 sustains the RF discharge. The discharge is grounded at x=d.

The PIC/MC method is based on a kinetic description of the particle motion in velocity position space. Positive and negative 'superparticles' move in the self-consistent electric field they generate. The electric field is obtained by solving the Poisson equation. The Monte Carlo formalism is used to describe the effect of collisions. The displacement between collisions is ruled by Newton's law.

The PIC/MCC method described in detail earlier for discharges without dust particles [3] is developed for computer simulations of the RF discharge with dust particles [4]. 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, 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 superparticle charge part, which is interacting with a dust particle [5].

There are three kinds of charged particle in our model of SiH_4 discharge (electrons, positive ions SiH_3^+ and negative ions SiH_3^-) and two kinds of charged particle in the model of Ar discharge (electrons and ions Ar^+).

3. SIMULATION RESULTS

In this paper we present results for argon and silane discharges with dust particles, as well as without ones. Calculations are performed at some values of the dust density, dust particle radius, the neutral gas pressure and the interelectrode distance. The frequency and amplitude of the radio-frequency voltagy were $\omega = 13{,}56\ MHz$, $V_0 = 150\,V$.

Fig. 1 shows ion energy distribution functions for Ar^+ in rf-sheaths at pressure p=0.1 Torr. Various curves correspond to various dust densities and dust radii. It is seen that big dust particles slow down ions in rf-sheaths, but the presence small dust particles can increase energy of ions (case with dust radius $r_d = 50\ nm$ and dust density $n_d = 5\cdot 10^{13}\ m^{-3}$). It is explained by increasing of the potential drop near electrode. Furthemore, some peaks are appeared in IEDFs for case with dust radius $r_d = 50\ nm$ and dust density $n_d = 5\cdot 10^{13}\ m^{-3}$. The reason of these peaks is the decreasing of the sheath width and, therefore, the decreasing of ion penetrating time through sheath τ_i.

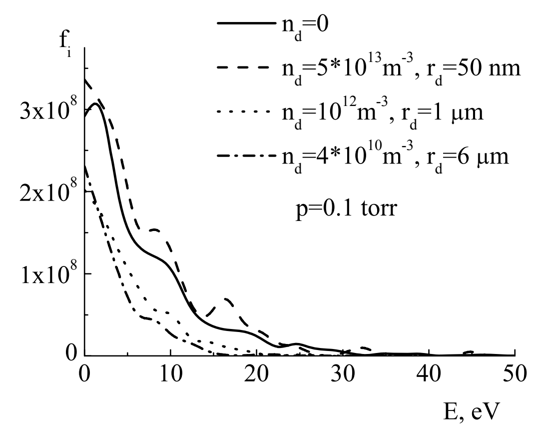

Fig.1. Computed IEDFs for Ar discharges at pressure p=0.1 Torr

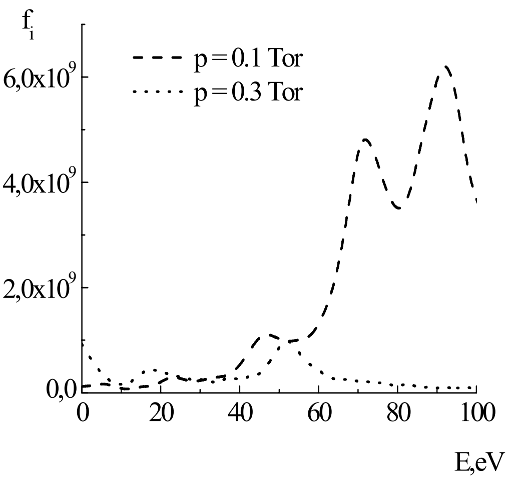

Fig.2. Computed IEDFs for SiH_3^+ ions in silane discharges at pressure p=0.1 Torr and p=0.3 Torr

In Fig. 2 IEDFs for positive ions SiH_3^+ in silane rf-discharge at various pressures are pictured. It is seen the appearance of peaks of high energy ions, which are caused by significant increasing plasma potential in the electronegative discharge. The increasing of a gas pressure is caused the shift peaks towards to an energy decreasing. In Fig.3a and Fig3b are presented phase portraits of ions Ar^+ and SiH_3^+ correspondingly. It is significant, that ions near electrodes get greater energy in electronegative discharge, than in electropositive one.

This result is due to the inessential role of charge exchange processes in the rf-sheath in electronegative discharges. Peaks of high energy ions are appeared in IEDFs, which are caused by significant decreasing of the radio-frequency sheath width and the ratio of ion penetrating time through sheath to the radio-frequency discharge period.

Results of calculations show that big dust particles slow down ions in rf-sheaths, but the presence small dust particles can increase energy of ions. It is explained by the increasing of the potential drop near electrode. Comparison of simulation results with analytical calculations in a collisionless rf sheath is discussed.

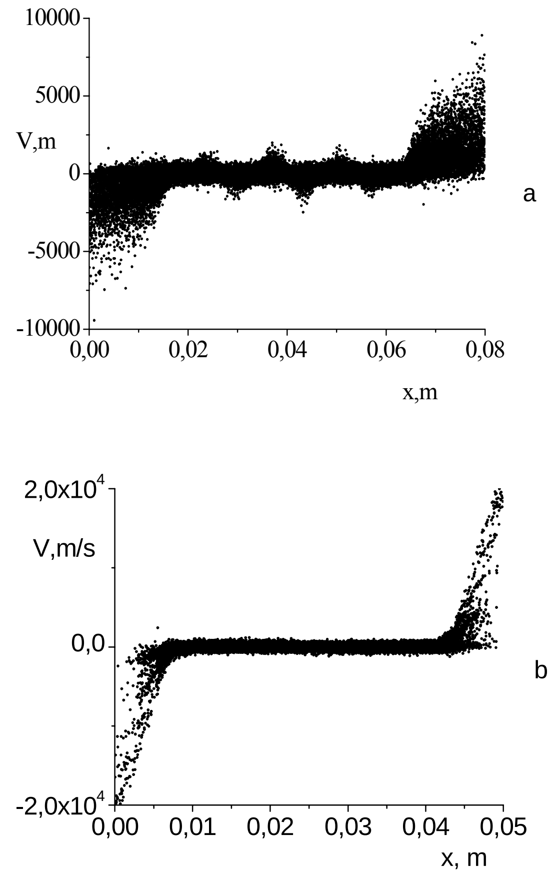

Fig.3. Phase portrait of ions

(a) - Ar^+ at $n_d = 4\cdot 10^{10}\ m^{-3}, r_d = 6\,mkm$;

(b) - SiH_3^+ at $n_d = 4\cdot 10^{10}\ m^{-3}, r_d = 6\,mkm$

4. CONCLUSIONS

The evolution of the IEDF at various combinations of pressure, dust density and dust radius has been studied by means of a 1D PIC/MCC model and compared between an electropositive rare gas (argon) discharge and an electronegative molecular gas (silane) discharge.

Results of our simulations show that negative ions are distributed in the central part of the discharge chamber and their mean energy much more than one of positive ions in this place. Dust particles increase the mean energy of negative ions in the discharge. In rf-sheaths of electronegative discharges positive ions are accelerated to bigger energies than in the case of argon discharge. It caused by essential role charge exchange processes in electropositive (argon) discharges. Results of calculations show that big dust particles slow down ions in rf-sheaths, but the presence small dust particles can increase energy of ions. It is explained by the increasing of the potential drop near electrode.

REFERENCES

1. L. Boufendi, A. Bouchole. Particle nucleation and growth in a low-pressure argon-silane discharge // *Plasma Sources Sci. Technol.* 1994, N 3, p.262-267.
2. M. Surendra, D.B. Graves, G.M. Jellum. Self-consistent model of a direct-current glow discharge: Treatment of fast electrons // *Phys. Rev. A.* 1990, v. 41, N 2, p. 1112-1126.
3. C.K.Birdsall. Particle-in-cell charged –particle simulations, plus Monte Carlo Collisions with neutral atoms, PIC-MCC// *IEEE Trans. Plasma Sci.* 1991, N 19, p.65-85.
4. V. Vahedi, G. DiPeso, C.K. Birdsall, M.A. Lieberman, T.D. Rognlien //*Plasma Sources Sci. Technol.* 1993, N 2, p. 261-272.
5. Y. Chutov, W. Goedheer, O. Kravchenko, V. Zuz, Yan Min // *J. Plasma and Fusion Research,* 2001, N 4, p. 340-348.

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РАСПРЕДЕЛЕНИЯ ИОНОВ ПО ЭНЕРГИИ В РЧ- ПРИЭЛЕКТРОДНЫХ СЛОЯХ С ПЫЛЕВЫМИ ЧАСТИЦАМИ

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Исследуются функции распределения ионов по энергии в приэлектродном слое с пылевыми частицами в емкостном РЧ-разряде в силане и результаты сравниваются с результатами, полученными в аргоновом разряде. Моделирование выполнялось при помощи PIC/MCC метода в широком диапазоне давлений, концентраций и радиусов пылевых частиц. Наша модель включает столкновения электронов с нейтралами, различные виды столкновений ионов с нейтралами, столкновения позитивных и негативных ионов. Результаты вычислений показали, что функции распределения ионов по энергии для позитивных ионов SiH_3^+ в силановом РЧ-разряде отличаются от функций распределения ионов в аргоновом разряде. Ионы вблизи электрода имеют большую энергию в электроотрицательном газе вследствие несущественной роли процессов перезарядки в этих разрядах. В ионных функциях распределения появляются пики, которые связаны со значительным уменьшением ширины РЧ-приэлектродного слоя и отношения времени пересечения ионами приэлектродного слоя к периоду разряда.

РОЗПОДІЛИ ІОНІВ ЗА ЕНЕРГІЄЮ В РЧ- ПРИЕЛЕКТРОДНИХ ШАРАХ З ПИЛОВИМИ ЧАСТИНКАМИ

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Досліджуються функції розподілу іонів за енергією в приелектродному шарі з пиловими частинками в ємнісному РЧ-розряді в силані та результати порівнюються з результатами, одержаними в аргоновому розряді. Моделювання виконувалось за допомогою PIC/MCC методу для широкого діапазону тиску, концентрації та радіусу пилових частинок. Наша модель включає зіткнення електронів з нейтралами, різні види зіткнень іонів з нейтралами, зіткнення позитивних та негативних іонів. Результати обчислень показали, що функції розподілу іонів за енергією для позитивних іонів SiH_3^+ в силановому РЧ-розряді відрізняються від функцій розподілу іонів в аргоновому розряді. Іони біля електроду одержують більшу енергію в електронегативному розряді внаслідок несуттєвої ролі процесів обміну зарядом в цих розрядах. В іонних функціях розподілу з’являються піки, які пов’язані зі значним зменшенням ширини РЧ- приелектродного шару і відношення часу прольоту іонів через приелектродний шар до періоду розряду.