# TWO-DIMENSIONAL SIMULATION OF DYNAMIC DUST CLOUDS IN THE PLASMA BOUNDARY NEAR THE WALL

***O.Yu. Kravchenko, I.S. Maruschak, G.I. Levada***

***Taras Shevchenko National University of Kiev, Kiev, Ukraine***
***E-mail: maruschak@univ.kiev.ua***

It is carried a computer simulation of the dynamics of dust clouds near a conducting wall at microgravity conditions and its effect on the sheath. We used two-dimensional axially symmetric hydrodynamic model, which takes into account self-consistent variable charge of dust particles and the mutual influence of plasma and dust components. The simulation results show that the dust cloud modifies the potential profile of the plasma so that double layers are formed on its boundaries, which give rise to a flow of ions inside the cloud. In a number of regimes is formed a potential well for dust particles. It is shown that the dust cloud in the sheath under the influence of electrical forces and the ion drag force reciprocates in the direction perpendicular to the wall.

PACS: 52.27.Lw.

## INTRODUCTION

In many practical cases, including etching, deposition and sputter plasmas, dust particles have been observed at the plasma-sheath boundary [1]. Charged dust particles also appear at tokamak edges as natural contaminants arising from the plasma interaction with divertor plates, plasma limiters and blankets [2]. These microparticles result from sputtering of the electrode and wall surfaces, gas phase nucleation, and polymerization. The observation of the microparticles has shown that those particles are trapped inside the sheath region, close to the plasma-sheath boundary. Dust particles can strongly influence on sheaths [2,3] due to the selective adsorption of background electrons and ions (penetrating through sheaths) by dust particles. In the result, dust particles create the space electric charge influencing on the sheath structure.

Due to their heavy masses and tendency to form self-organized structures the dust particles affect waves, instabilities and transport processes. Recent laboratory experiments [4] have conclusively demonstrated the motions of charged dust clouds near negatively biased electrodes in low temperature dusty plasma discharges. In a dusty plasma sheath the dust grains execute bouncing motions, which are repeatedly away and towards the electrode

In this paper we use the two-dimensional fluid model to study the plasma sheath structure and the behavior of a dust cloud in the field of the plasma sheath in microgravity conditions.

## MODEL

We consider the wall region of two-dimensional dusty plasma model, wherein the plasma is contaminated by dust charged grains. Plasma consist of electrons, ions and dust particles with densities $n_e$, $n_i$, $n_d$. At initial time electron and ions are distributed uniformly in space, but dust particles form a cloud, which is located at the edge of the sheath. Dust particles are charged after their appearance in the plasma due to the selective collection of electrons and ions so that a change of plasma parameters starts inside the dust layer. This change propagates into plasma due to the self-consistent electric field.

An evolution of the sheath with the dust cloud can be considered in the hydrodynamic approach with the self-consistent electric potential $\varphi$ described by the following Poisson equation

$$\frac{\partial^2\varphi}{\partial x^2}+\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\varphi}{\partial r}\right)=-\frac{e}{\varepsilon_0}\cdot(n_i-n_e-z_d\cdot n_d)\ .$$

The change of the dust charge is described by equation

$$\frac{dq_d}{dt}=I_e+I_i\ ,$$

where electron and ion currents $I_e$ and $I_i$ flowing into dust particle are defined by relations:

$$I_e=-\pi a^2 e\left(\frac{8kT_e}{\pi m_e}\right)^{1/2} n_e\exp\left(\frac{eq_d}{akT_e}\right),$$

$$I_i=\pi a^2 e n_i\left(\frac{8kT_i}{\pi m_i}+v_i^2\right)^{1/2}\left(1-\frac{eq_d}{a(kT_i+m_i w^2/2)}\right).$$

The electrons are assumed to be in thermal equilibrium, therefore the density $n_e$ satisfies the Boltzmann relation.

The ions are described by the fluid equations

$$\frac{\partial n_i}{\partial t}+\nabla\cdot(n_i\cdot\overrightarrow{w_i})=\frac{I_i}{e}n_d\ ,$$

$$\frac{\partial n_i u_i}{dt}+div(n_i\cdot u_i\cdot\vec{w}_i)+\frac{e}{m_i}n_i\frac{\partial\varphi}{\partial r}=0\ ,$$

$$\frac{\partial n_i v_i}{dt}+div(n_i\cdot v_i\cdot\vec{w}_i)+\frac{e}{m_i}n_i\frac{\partial\varphi}{\partial z}=0\ ,$$

where $\vec{w}_i$, $e$, $m_i$ are the vector of drift velocity, charge, mass of the ions, $u_i, v_i$ are ion velocity components along axes $r$ and $z$.

The dust components of plasma are described by the following equations

$$\frac{\partial n_d}{\partial t}+\nabla\cdot(n_d\cdot\vec{w}_d)=0\,,$$

$$\frac{\partial n_d u_d}{dt}+div(n_d\cdot u_d\cdot\vec{w}_d)+\frac{Q_d}{m_d}n_d\frac{\partial\varphi}{\partial r}+F_{idr}=0\,,$$

$$\frac{\partial n_d v_d}{dt}+div(n_d\cdot v_d\cdot\vec{w}_d)+\frac{Q_d}{m_d}n_d\frac{\partial\varphi}{\partial z}+F_{idz}=0\,,$$

where $F_{idr}$ and $F_{idz}$ are components of the ion drag force [5], $w_d=(u_d,v_d)$ is the drift dust velocity vector.

## RESULTS AND DISCUSSION

The influence of dust particles on the sheath illustrates spatial distributions of the electric potential (Fig. 1). The potential profiles along a perpendicular direction to the wall are presented on the Fig.1,a for $n_d/n_0=0.01$ and $n_d=0$. Here spatial coordinates $r$ and $z$ are divided by the initial electron Debye length $\lambda$, the dust density $n_d$ is divided by the ion concentration in the undisturbed plasma $n_0$, the potential $\varphi$ is divided by the characteristic value $\phi_o=kT_e/e$. We can see that potential is decreased towards the wall monotonically if a dust cloud is absent. At the dust cloud boundaries potential jumps are formed that indicate about appearance of double layers. An electric force in these layers push dust particles if we took account of their movement. Note, the potential changes are different at boundaries of the dust cloud due to an ion flow towards the wall.

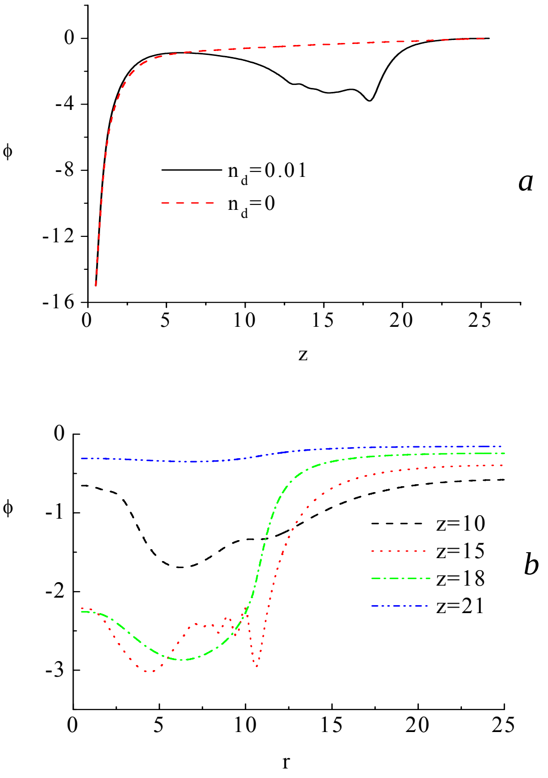

*Fig. 1. Potential distributions (a) along the perpendicular direction to the wall at $n_d=0.01\cdot n_0$, (b) along axe $r$ at different $z$ at $n_d=0.01\cdot n_0$*

Consider potential dependences of radius at different distance from the wall (Fig. 1, b). One can see that the electric potential is changed in area $0\le r\le 10$ before and after the dust cloud, as well as inside the one. It should be noted that potential distribution has oscillations in the dust cloud region in radial direction. This means that there are potential wells for dust particles, which may prevent from the expansion of particles in radial direction. Besides, oscillations of the electric potential indicate the possibility of a plasma-dust crystal formation.

Spatial distributions of the ion velocity are shown in Fig. 2. We can see that ions are accelerated on all the way to the wall in the case without a dust cloud. While the ion drift velocity is changed significantly at the boundaries of the dust cloud. It is observed an essential acceleration of ions to dust cloud boundaries which is associated with an electric field in double layers.

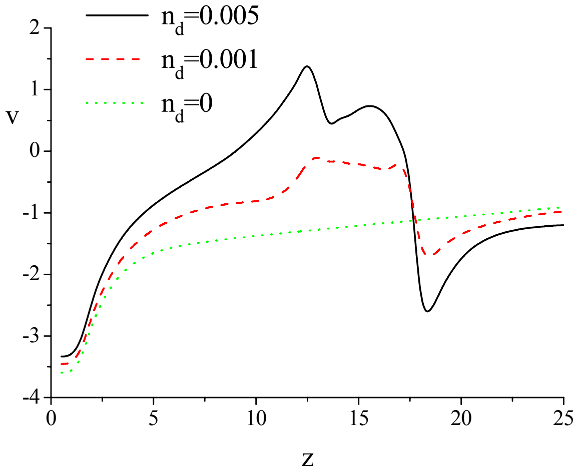

*Fig. 2. Spatial distributions of the ion velocity along axe $z$*

Note, that the ion flow is formed in radial direction to the dust cloud. At the cloud boundary an ion velocity depends of a dust density. The ion flow is subsonic at $n_d=0.001$ and the one is supersonic at $n_d=0.005$. In the latter case oscillations are appeared in distributions of plasma parameters. This may be due to the drift instability in plasma.

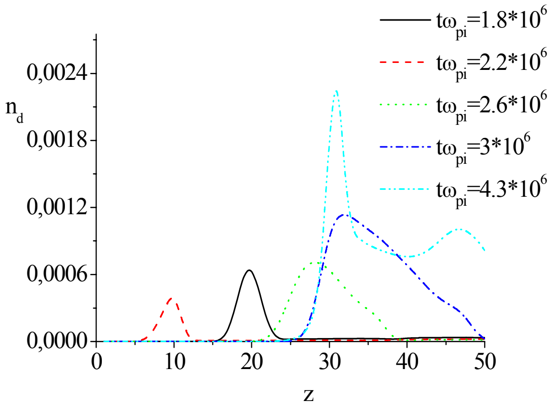

*Fig.3. Spatial distributions of the dust density along the perpendicular direction to the wall at different times*

We obtained also spatial distributions of dust density at different times. Results show that peaks of the dust density are formed in space of the dust cloud and dust particles perform the oscillations along axial direction (Fig.3). Moreover, dust cloud is compressed along axial and radial axes. It is shown that ion density is increased in the dust cloud and has peaks on the boundaries of dust cloud.

## CONCLUSIONS

The simulation results show that the dust cloud modifies the potential profile of the plasma so that double layers are formed on its boundaries, which give rise to a flow of ions inside the cloud. In a number of regimes is formed a potential well for dust particles. It is shown that the dust cloud in the sheath under the influence of electrical forces and the ion drag force reciprocates in the direction perpendicular to the wall.

This work was supported by joint NASU-RFFR grant.

## REFERENCES

1. G.M. Jellum, D.B. Graves. Particulates in aluminum sputtering discharges// *J. Appl. Phys.* 1990, v. 67, p. 6490.
2. J. Winter. A new challenge in nuclear fusion research // *Physics of Plasmas.* 2000, v. 7, N 10, p. 3862–3866.
3. G.S. Selwyn, J. Singh, R.S. Bennett. In situ laser diagnostic studies of plasma-generated particulate contamination//*J. Vac. Sci. Technol. A.* 1989, v. 7, p. 2758.
4. S. Takamura, T. Misawa, N. Ohno, S. Nunomura, M. Sawai, K. Asano, K. Kaw. Dynamic behaviour of dust particles in the plasma-sheath boundary // *Phys. Plasmas*. 2001, v. 8, p. 1886-1892.
5. Jin-Xiu Ma, M. Y.Yu. Electrostatic sheath at the boundary of a dusty plasma // *Phys. Plasmas.* 1995, v. 2, p. 1343-1348.

*Article received 16.09.10*

---

## ДВУХМЕРНОЕ МОДЕЛИРОВАНИЕ ДИНАМИКИ ПЫЛЕВЫХ СГУСТКОВ НА ГРАНИЦЕ ПЛАЗМЫ ВОЗЛЕ СТЕНКИ

***А.Ю. Кравченко, И.С. Марущак, Г.И. Левада***

Проведено компьютерное моделирование динамики пылевых сгустков возле проводящей стенки в условиях микрогравитации и ее влияния на приэлектродный слой. Использовалась двухмерная аксиально-симметричная гидродинамическая модель, которая учитывает самосогласованный переменный заряд пылевых частиц и взаимное влияние плазмы и пылевой компоненты. Результаты моделирования показывают, что пылевой сгусток изменяет профиль потенциала плазмы так, что на его границах образуются двойные слои, которые приводят к появлению потоков ионов внутрь сгустка. В ряде режимов формируется потенциальная яма для пылевых частиц. Показано, что в приэлектродном слое пылевой сгусток под действием электрической силы и силы ионного трения совершает возвратно-поступательное движение в направлении, перпендикулярном к стенке.

---

## ДВОВИМІРНЕ МОДЕЛЮВАННЯ ДИНАМІКИ ПИЛОВИХ ЗГУСТКІВ НА ГРАНИЦІ ПЛАЗМИ БІЛЯ СТІНКИ

***О.Ю. Кравченко, І.С. Марущак, Г.І. Левада***

Проведено комп'ютерне моделювання динаміки пилових згустків поблизу провідної стінки в умовах мікрогравітації та її впливу на приелектродний шар. Використовувалась двохвимірна аксіально-симетрична гідродинамічна модель, яка враховує самоузгоджений змінний заряд пилових частинок та взаємний вплив плазми і пилової компоненти. Результати моделювання показують, що пиловий згусток змінює профіль потенціалу плазми так, що на його границях утворюються подвійні шари, які приводять до появи потоків іонів всередину згустка. В ряді режимів формується потенціальна яма для пилових частинок. Показано, що в приелектродному шарі пиловий згусток під дією електричної сили та сили іонного тертя здійснює зворотньо-поступальний рух в напрямку, перпендикулярному до стінки.