EMISSION CHARACTERISTICS AND POTENTIAL OF MACROPARTICLE IN BEAM-PLASMA DISCHARGE

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Dust plasma now is one of most intensively developing directions of modern plasma physics. We will focus on the main task of the physical processes appearing in gas-discharge plasma with dust particles is definition of the value of electric potential of macroparticles, despite of the significant number of articles devoted to this problem. In the present work the behaviour of floating electric potential of a particle in beam-plasma systems over the average energies of electron beams taking into account a secondary electron emission and also an auto-electron emission is studied.

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1. INTRODUCTION

Investigation of the technological aspects of vacuum-plasma processes consider to be of great interest for the dust plasma applications. It is possible to cite vacuum-arc methods of deposition hardening and a decorative coating [1, 2] as an example, which based on generation of a stream of metal plasma with macroparticles (metal drops with the sizes from micrometers to hundreds micrometers) at burning of an arc discharge at low pressures. Presence of the drop phase at a plasma stream results to a deterioration of performances of coatings [3, 4].

In the present work interacting of an electron beam with a solitary dust particle being in plasma is observed, influence of emissive processes on the potential value is taken into consideration. Modeling of process of charging is fulfilled for a wide range of energies of an electron beam, and as consequence, for a wide range of potentials of a dust particle that results to usage of various approximations for description of ion collection and beam and plasma electrons.

2. A STEADY-STATE VALUE OF ELECTRIC POTENTIAL OF A DUST PARTICLE

The steady-state value of floating potential of dust particle in beam-plasma system is defined from a requirement of balance of currents:

$$I_i + I_e + I_b\left(1-\delta_e\left(\varepsilon_b-\varphi_s\right)\right) + I \ = 0 \qquad (1).$$

Here, I_i, I_e and I_b – currents of ions and electrons from plasma and a current of electrons of a beam on a surface of a dust particle accordingly, $I = A_a \cdot 1.4 \cdot 10^{-6}\dfrac{E^2}{\phi}\cdot 10^{(4.39\phi^{1/2}-2.82\cdot 10^7\phi^{3/2}/E)}$ – an autoelectronic emission current; E – an electric field strength which on estimates attains of values of $10^7 \div 10^8\ V/cm$, ϕ – potential of a work function of metal; $\delta_e\left(\varepsilon_b\right) = 7.4\cdot\delta_m\cdot\dfrac{\varepsilon_b}{\varepsilon_{bm}}Exp\left(-2\sqrt{\dfrac{\left(\varepsilon_b-\varphi_s\right)}{\varepsilon_{bm}}}\right)$ – a secondary electron emission coefficient representing an empirical-formula dependence from energy of primary electrons attaining surface of a material [5], φ – potential of a dust particle, ε_b – energy of electrons of a beam, ε_{bm} – energy of primary electrons at which the secondary emission ratio has the greatest value of δ_m. Depending on a relation of currents coming and leaving from a surface of a particle and the value of energy of electrons of a beam, its electric potential can be both negative, and positive.

In case of negatively charged particle ($\varphi_s < 0$) the electron current from plasma is defined by expression:

$$I_e = \sqrt{8\pi}a^2 n_0 v_{Te}\exp\left(\frac{e\varphi_s}{T_e}\right), \qquad (2)$$

where n_0 – a plasma density, T_e – temperature of electrons, $v_{Te} = \sqrt{\dfrac{T_e}{m_e}}$ – a thermal velocity of electrons.

The electron beam current on a surface of a dust particle is defined from model of restricted orbits by analogy to derivation of the formula of a current of electrons from plasma [5]. In expression (3) electron-electronic emission called by bombardment of a dust particle surface by electron beam is considered also:

$$I_b(a) = A_a\cdot n_b\cdot\sqrt{\frac{\varepsilon_b}{m_e}}\cdot\left(1-\frac{e\varphi}{\varepsilon_b}\right)\cdot(1-\delta), \qquad (3)$$

here A_a – area of surface of a dust particle with radius a; n_b – a density of electrons of a beam; e and m_e – a charge and electron mass accordingly; $v_{eb} = \sqrt{\dfrac{\varepsilon_b}{m_e}}$ – a velocity of electrons of a beam.

At low values of potential $\dfrac{e\varphi_s}{T_e} \sim 1$ of a dust particle the path of ions are well enough described by model of restricted orbits. In this case the ion current on a particle very close to the expression derived in [5]:

$$I_i = A_a j_r\left(\frac{s^2}{a^2}\left(1-e^{-\Phi}\right)+e^{-\Phi}\right), \qquad (4)$$

where, $j_r = \dfrac{1}{2}n_0\left(\dfrac{2kT_i}{\pi m_i}\right)^{1/2}$, $\Phi = \dfrac{a^2}{s^2-a^2}\dfrac{e\varphi_s}{kT_i}$, $A_a = 4\pi a^2$, T_i and m_i – temperature and an ion mass, accordingly.

Let us $z=\frac{e\varphi}{T_e}$, $\mu=\frac{m_e}{m_i}$, $\tau=\frac{T_e}{T_i}, \tau_b=\frac{T_e}{\varepsilon_b}$, $\widetilde{n}=\frac{n_b}{n_0}$, $\xi=a/\lambda_d$. The balance equation of currents (1) will become:

$$\exp(-z)=\sqrt{2\pi}\sqrt{\frac{\mu}{\tau}}\left(\frac{(\xi+1)^2}{\xi^2}\left(1-\exp\left(\frac{\xi^2}{2\xi+1}\cdot z\tau\right)\right)+\right. \quad (5)$$

$$\left.+\exp\left(\frac{\xi^2}{2\xi+1}\cdot z\tau\right)\right)-\frac{\tilde{n}}{2\sqrt{\tau_b}}(1-z\tau_b)\cdot\left(1-\delta_e(\tau_b,z)\right)$$

In a extreme case $\xi\sqrt{\tau}<<1$ that corresponds to a low densities of plasma, exponential expansion in the formula (4) result into the well-known formula of an ion current [3, 6].

$$I_i^{OML}=\sqrt{8\pi}a^2 n_0 v_{Ti}\left(1-\frac{e\varphi_s}{T_i}\right) \quad (6)$$

In this case the balance equation (5) assumes the simplified form:

$$\exp(-z)=\sqrt{\frac{\mu}{\tau}}(1+z\tau)-\frac{\widetilde{n}}{2\sqrt{\tau_b}}(1-z\tau_b)\cdot(1-\delta_e(\tau_b,z)) \quad (7)$$

In a case is positively charged particle $\varphi_s>0$, an electron current from plasma and a current of a beam look like:

$$I_b=\pi a^2 n_b v_{eb}\left(1+\frac{e\varphi_s}{\varepsilon_b}\right), \quad (8)$$

$$I_e=\sqrt{8\pi}a^2 n_0 v_{Te}\left(1+\frac{e\varphi_s}{T_e}\right). \quad (9)$$

Such regime of charging is possible in some range of energies of an electron beam. Energies ε_1 and ε_2 also define an energy ranges of primary electrons, at which secondary electron emission coefficient $\delta_e(\tau_b,z)>1$.

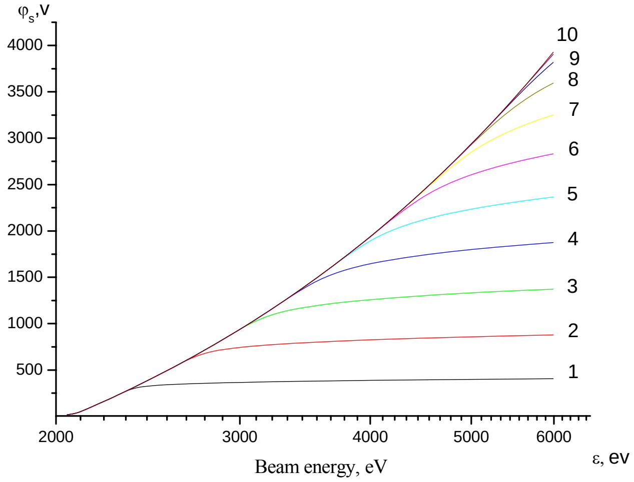
In beam-plasma discharge the temperature of ions is close to zero, having guessed, that as a result of a secondary electron emission the potential of a dust particle can to take value over more 1 V, the ion current on a particle surface can be neglected. The equation for potential determination of positively charged dust particle looks like:

$$1+z+\frac{1}{2\sqrt{\tau_b}}(1+z\tau_b)\cdot(1-\delta_e(\tau_b,z))=0\,. \quad (10)$$

At enough high potentials $\frac{e\varphi_s}{T_e}>>1$, an ion current transfers in a regime of limitation by volume charge and can be presented by Chield-Lagmuire law. The requirement of balance of currents is described by system of two equations where along with the unknown variable φ_s an unknown variable s – the size of a volume charge layer occurs:

$$\begin{cases} I_e(a)+I_b(a)+I_i^{3/2}(a)+I(a)=0 \\ I_i(a)-I_i(s)=0 \end{cases} \quad (11)$$

Here $I_i^{3/2}(a)=A_a\cdot\frac{4\sqrt{2}}{9}\cdot\sqrt{\frac{e}{m_i}}\cdot\frac{\varphi^{3/2}}{\alpha^2(s/a)}$ – a current of ions on a surface of the dust particle, expressed by the law of «3/2» in a spherical case; $\alpha^2(s/a)$ – a transcendental function; $I_i^b(s)=A_s\cdot n\cdot 0.61\cdot\sqrt{\frac{T_e}{m_i}}$ – an ion current going from a layer surface A_s .



Dependence of potential (φ_s) of a dust particle on energy of a beam (ε_b) for the various sizes of dust particles
1 – $a=0.1\mu m$ *,2 –* $a=0.2\mu m$ *,3 –* $a=0.3\mu m$ *,*
4 – $a=0.4\mu m$ *, 5 –* $a=0.5\mu m$ *,6 –* $a=0.6\mu m$ *,*
7 – $a=0.7\mu m$ *,8 –* $a=0.8\mu m$ *, 9 –* $a=0.9\mu m$ *,*
10 – $a=1\mu m$

First equation represents balance of currents on a surface of a dust particle; second one is a continuity equation.

Numerical solution of the equation (11) were made for plasma with a density of $n_0=10^9 cm^{-3}$, particle sizes $a=10^{-3}\div10^{-5} cm$, and $n_b=10^9 cm^{-3}$ of a density of an electron beam over the range beam energies.

On the Figure the value of potentials of a dust particles in beam-plasma discharge are shown. One can see, that at high potentials, with magnification of energy of a beam charging of a dust particle is practically stopped, this effect on small dust particles becomes much stronger. Presence of this effect is stipulated by rise of electric field strength near to a surface of a dust particle and appearance of autoelectronic emission which hinders the further charging of a dust particle.

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ЭЛЕКТРИЧЕСКИЙ ПОТЕНЦИАЛ МАКРОЧАСТИЦЫ В ПУЧКОВО-ПЛАЗМЕННЫХ СИСТЕМАХ

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Пылевая плазма в настоящее время является одним из наиболее интенсивно развивающихся направлений современной физики плазмы. Несмотря на множество работ посвященных этому вопросу, при изучении физических процессов, происходящих в газоразрядной плазме с пылевыми частицами, актуальной задачей является определение величины электрического потенциала микрочастиц. В настоящей работе изучается поведение плавающего электрического потенциала макрочастицы в пучково-плазменных системах в диапазоне средних энергий электронных пучков с учетом вторичной электронной эмиссии, а также авто-электронной эмиссии.

ЕЛЕКТРИЧНИЙ ПОТЕНЦІАЛ МАКРОЧАСТИНКИ У ПУЧКОВО-ПЛАЗМОВИХ СИСТЕМАХ

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За теперішнього часу пилова плазма є одним з напрямків сучасної фізики плазми, які найбільш інтенсивно розвиваються. Незважаючи на велику кількість робіт, що присвячені цьому питанню, при вивченні фізичних процесів, що відбуваються у газорозрядній плазмі з пиловими частинками, актуальною проблемою є визначення величини електричного потенціалу макрочастинки. В даній роботі вивчається поведінка плаваючого електричного потенціалу макрочастинки у плазмово-пучкових системах у діапазоні середніх енергій електронних пучків з урахуванням вторинної електронної емісії та автоелектронної емісії.