Effect of monoenergetic electrons on electronegative dusty plasma

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Abstract

There are several studies that consider the effect of monoenergetic electrons on the generalized Bohm velocity for electronegative dusty plasma in absence of the magnetic field. *Chekour and al* have shown that taking into account the monoenergetic electrons and dust grains increases the Bohm velocity. Indeed, the pulverisation of electrodes by charged particles such as ions, neutral atoms or molecules and photons, usually ejects these monoenergetic electrons. In this work, we have established a new formulation of the Bohm criterion taking into account the mono-energetic electrons. For this, we have established three dimensional and stationary theoretical models. The charge of dust particles is described by the Orbital Motion Limited model (OML). We have shown that the presence of negative ions reduces the attachment of these ions by the dust grains and the charges separation. As a result, the thickness of the electrostatic sheath is considerably reduced.

Introduction

The cathode (solid wall) is subjected to energetic particles bombardments such as ions, neutral atoms, or molecules, and photons, which lead to emission of fast monoenergetic electrons from a cathode. With energy range about $50eV - 100eV$. In the present work, we focus on the effect of monoenergetic electron on magnetized electronegative plasma sheaths contaminated by dust grains.

Theoretical Model

We consider a three dimensional collisionless, stationary and magnetized plasma sheath consisting of electrons (e), positive ions (i), negative ions (j), dust grains (d), and fast monoeneretic electrons coming from wall (f). We assume the sheath region lies between $z=0$ and the wall (the pre-sheath is neglected). At the edge $z=0$, we assume the electrostatic potential $\phi=0$, and the number density of species k $(k=e, j, i, d, f)$ is n_{k0}.

The electrons and the negative ions are assumed to be in thermal equilibrium, thus their number densities n_e and n_j satisfy the Boltzmann relation

$$n_{e,j} = n_{e_0, j_0} \exp\left(e\phi / T_{e,j}\right), \quad (1)$$

where T_k $(k=e, j)$ is the temperature of specie k.

The positive ions in the sheath of low-pressure plasmas are governed by the continuity and the momentum equations

$$\frac{\partial n_i}{\partial t} + \nabla.\left(n_i \vec{\mathrm{v}}_i\right) = 0, \quad (2)$$

$$\frac{\partial \vec{\mathrm{v}}_i}{\partial t} + \vec{\mathrm{v}}_i.\nabla \vec{\mathrm{v}}_i = \frac{\vec{F}_c}{m_i} + \frac{e}{m_i}\left(-\vec{\nabla}\phi + \vec{\mathrm{v}}_i \times \vec{B}\right) - \frac{\vec{\nabla} p_i}{n_i\, m_i}, \quad (3)$$

where p_i, m_i, $\vec{\mathrm{v}}_i$ and n_i are the pressure, the mass, the fluid velocity and the density of the positive ions respectively, and $\vec{B}$ is the magnetic field. The drag force $\vec{F}_c$ due to the elastic collisions of positive ions with neutral particles is given by the expression

$$\vec{F}_c = -m_i\, n_n\, \sigma_{in}\, \mathrm{v}_i\, \vec{\mathrm{v}}_i \;, \quad (4)$$

where σ_{in} is the ions-neutrals diffusion cross section and n_n is the neutral gas density. The tridimensional adiabatic fluid approximation for positive ions is used,

$$p_i = \frac{T_i}{n_i^{2/3}} n_i^{5/3}. \quad (5)$$

When the dust grains density is important, they can be described by a cold fluid model,

$$\frac{d\left(n_d \mathrm{v}_d\right)}{dz} = 0, \quad (6)$$

$$\mathrm{v}_d \frac{d\mathrm{v}_d}{dz} = -\frac{q_d}{m_d}\frac{d\phi}{dz} + g\,, \quad (7)$$

where q_d, m_d and v_d are the charge, the mass and the fluid velocity of dust grains respectively, g being the acceleration of gravity.

The fast monoenergetic electrons are also described by a cold fluid equations

$$\frac{d\left(n_f \mathrm{v}_f\right)}{dz}=0, \tag{8}$$

$$\mathrm{v}_f \frac{d\mathrm{v}_f}{dz}=\frac{e}{m_e}\frac{d\phi}{dz}. \tag{9}$$

In order to relate the self-consistent potential to electron, negative and positive ions, fast monoenergetic electrons as well as dust densities in the sheath, we use Poisson's equation

$$\frac{d^2\phi}{dz^2}=-\frac{1}{\varepsilon_0}\left(n_i\,e-n_e\,e-n_j\,e-n_f\,e+n_d\,q_d\right) \tag{10}$$

Finally, the dust charge is mainly determined by the currents collected by the dust grains

$$\mathrm{v}_d \frac{dq_d}{dz}=I_e+I_i+I_j+I_f \tag{11}$$

where, $I_k\left(k=e,i,j,f\right)$ is the current of specie "k".

According to the orbit motion limited model (OML), the expressions of the electrons, the negative and positive ions and the fast monoenergetic currents for spherical dust grains with radius r_d are given by

$$I_{e,j}=\left(8\pi\right)^{1/2} r_d^2\, q_{e,j}\, n_{e,j}\, \mathrm{v}_{te,tj}\, K_{e,j}\left(q_d\right), \tag{12}$$

$$I_{i,f}=\pi\, r_d^2\, q_{i,f}\, n_{i,f}\, \mathrm{v}_{i,f}\, K_{i,f}\left(q_d\right), \tag{13}$$

where,

$$\begin{cases} K_{e,j}\left(q_d\right)=\exp\left(\dfrac{e\,q_d}{r_d\,T_{e,j}}\right) \\ K_i\left(q_d\right)=1-\dfrac{2\,e\,q_d}{r_d\,m_i\,\mathrm{v}_i^2} \end{cases} \quad \text{for } q_d<0, \tag{14}$$

$$\begin{cases} K_{e,j}\left(q_d\right)=1+\dfrac{e\,q_d}{r_d\,T_{e,j}} \\ K_i\left(q_d\right)=\exp\left(\dfrac{2\,e\,q_d}{r_d\,m_i\,\mathrm{v}_i^2}\right) \end{cases} \quad \text{for } q_d>0, \tag{15}$$

$$\begin{cases} K_f\left(q_d\right)=1-\dfrac{q_d}{r_d\left(\phi_0-\phi\right)} & \text{for} \quad q_d\ge -r_d\left(\phi-\phi_0\right) \\ K_f\left(q_d\right)=0 & \text{for} \quad q_d< -r_d\left(\phi-\phi_0\right) \end{cases}. \tag{16}$$

Numerical results

For a numerical solution of the model equations, we have considered the plasma oxygen containing the graphite dust grains $\left(\rho_d=2g/cm^3\right)$. The positive and negative ions are O_2^+ and

O_2^- respectively. The physical parameters used are: $T_e = 2\,eV$, $T_i = T_j = 0.01\,eV$, $n_{i_0} = 10^9\,cm^{-3}$, $u_{i_0} = 1.5$, $u_{d_0} = 3$, $\theta = 20°$, $\delta_d = 10^{-4}$, $r_d = 2\,\mu m$, $\phi_0 = 4V$ $\alpha_c = 0.008$, $u_{i_0} = \mathrm{v}_{i0} / c_{is} = 1.5$, $u_{d_0} = \mathrm{v}_{d0} / c_{ds} = 3$, $c_{is} = \left(T_e / m_i\right)^{1/2}$, $c_{ds} = \left(z_c T_e / m_d\right)^{1/2}$, $z_c = r_d T_e / e^2$, $\theta = \left(\hat{z}, \vec{B}\right) = 20°$, $\delta_d = n_{d0} / n_{i0} = 10^{-4}$, $r_d = 2\,\mu m$, $\phi_0 = 4V$, $\alpha_c = \lambda_{Di}\, \sigma_{in}\, n_n = 0.008$ and $\lambda_{Di} = \left(\varepsilon_0 T_i / n_{i0} e^2\right)^{1/2}$, ε_0 being the vacuum permittivity.

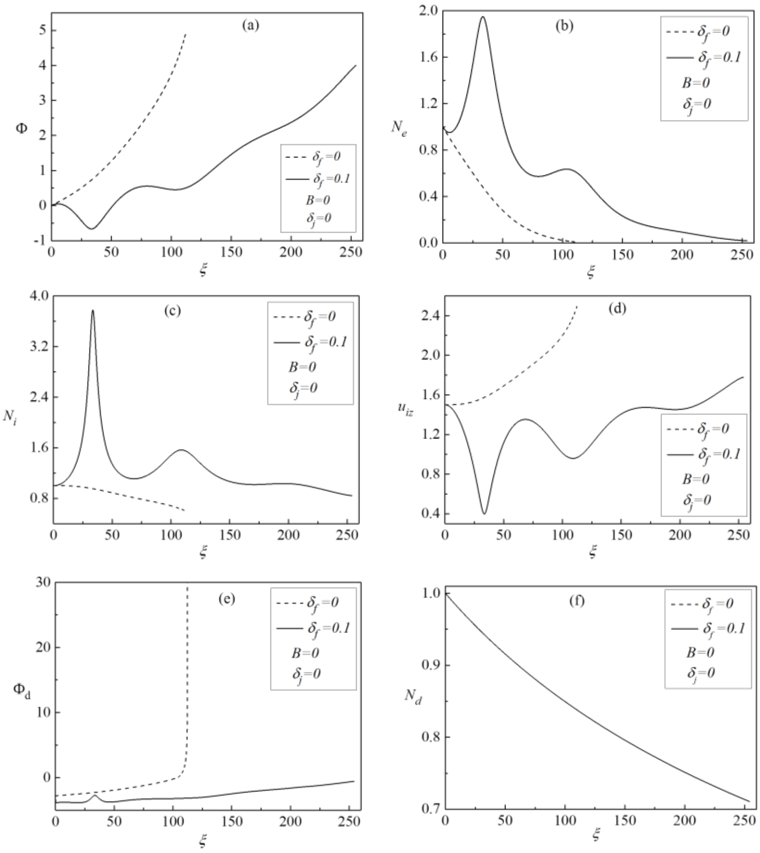

FIGURE 1. Normalized electrostatic potential Φ (a), normalized electron density N_e (b), normalized ion density N_i (c), normalized positive ions velocity u_{iz} (d), normalized dust grains surface potential Φ_d (e) and normalized dust grains density N_d (f) as function of ξ for two values of the density ratio of the monoenergetic electrons δ_f.

In Fig (1), we have shown the effect of the monoenergetic electrons on the physical proprieties of the magnetized electrostatic sheath. For this, we have studied two cases: the first case without the monoenergetic electrons $\left(\delta_f = 0\right)$ and in the second case $\delta_f = 0.1$. First, we observe that the presence of the monoenergetic electrons makes the sheath structure oscillatory. The numerical results show that the presence of monoenergetic electrons increases the positive ion density and so producing the decrease of positive ions fluid velocity. Furthermore, the presence of monoenergetic electrons increases the charge number on the dust grains (Fig (1.e)) and the sheath thickness. Finally, for the physical parameters used, the magnetized field effect is negligible.

In conclusion, the interaction of plasma with a solid wall (electrode) and the formation of electrostatic sheath have been studied in the presence of dust grains and monoenergetic electrons. In particular, we have shown that the presence of monoenergetic electrons increases the charge separation and consequently the sheath thickness. Moreover, the sheath structure becomes oscillatory.