INFLUENCE OF DUST PARTICLES ON NON-LINEAR SHEATHS

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1. Introduction

Dust particles can play an important role in various plasma devices including future fusion reactors. These particles can be created close to cold wall surfaces where non-linear sheaths are existing practically always including cases of sheaths in magnetic fields. These sheaths determine an interaction of plasmas with wall surfaces including flows of charged particles from plasmas to these walls. Dust particles can essentially influence the properties of these sheaths without magnetic fields due to an influence on background electrons and ions [1].

The aim of this work is a computer modeling of non-linear sheaths with dust particles in magnetic fields.

2. Model

A one-dimensional slab of plasma without a magnetic field and dust particles consisting of equilibrium electrons and ions with densities $n_{eo} = n_{io} = n_o$ and temperatures T_e and T_i creates an equilibrium sheath in front of a plane electrode to which a large negative potential ϕ is applied. According to the Bohm sheath criterion, a drift ion velocity u_o close to a sheath boundary has to satisfy the well known boundary condition $u_o \geq (kT_e / M)^{1/2}$ where M is the ion mass. This criterion follows from a condition of a continuos change of plasma parameters on this boundary.

Dust particles with a density distribution $N_d = N_{do} \exp(-x^2 / x_o^2)$ and a radius R_d as well as a magnetic field B which is parallel to an electrode, appear in this sheath at some initial time instant and both a collection and scattering of electrons and ions by these dust particles starts here. These processes cause an evolution of the sheath to a new state in which new boundary conditions provide a continuous change of all plasma parameters. In some cases, dust particles or a magnetic field can appear separately at this initial time so that their influence can be investigated separately also.

The 2D PIC method is used for computer modeling of sheaths, taking into account the dynamics of dust particle charge in plasmas with self-consistent energy distribution functions of electrons and ions [2-4]. The Coulomb scattering of electrons and ions are taken into account in the framework of the Monte-Carlo method.

A case of a sheath without dust particles is used as a test of computer programs created according to these methods. In this case, spatial distributions of plasma parameters for a usual steady-state sheath are used as initial conditions for a computer simulation of their evolution. These simulations show that the initial equilibrium distributions are conserved during the simulation times. In case of some deviations of initial distributions from the equilibrium case, these non-equilibrium distributions evolve to equilibrium ones during several ion plasma cycles. These last results confirm the adequacy of the computer programs.

3. Results

The obtained results show that the influence of dust particles and magnetic fields on sheaths strongly depends on relations between some characteristic lengths and times which include the ion gyroradius R_b and the sheaths length L_s as well as a time τ_p of ion penetration through a sheath, an ion collection time τ_a, and an ion scattering time τ_s. Of course, this influence is very small in the case of $L_s << R_b$ and $\tau_p << \tau_a + \tau_s$. In the opposite case of $L_s >> R_b$ and $\tau_p << \tau_a + \tau_s$, dust particles and magnetic fields can create some barrier between a plasma and an electrode due to a strong collection and scattering of electrons and ions by dust particles as well as their reversal by a magnetic field so that electrons and ions cannot reach an electrode at all. In this last case, there is no space electric charge close to an electrode and the sheath is removed from the electrode.

Some obtained results are shown in Fig. 1-6 for $R_d = 0.1$, $N_{do} = 1$, $x_o = 16$, $\phi = -10$, $(R_b/L_s) = 1$, $(M/m) = 256$, and $(T_{eo} / T_{io}) = 10$ where spatial coordinates and all line sizes are normalized by the Debye length $\lambda_d = \left(kT_{eo} / 4\pi n_o e^2\right)^{1/2}$, a potential ϕ is normalized by the characteristic potential $\phi_o = kT_{eo}/e$, and time t is multiplied by the ion plasma frequency $\omega_{io} = \left(4\pi n_o / M\right)^{1/2}$. Top parts of these figures (a) were obtained without dust particles but with a magnetic field, bottom parts (b) were obtained with both dust particles and a magnetic field.

The obtained results show (Fig. 1a, were J_o is an electric current in the external circuit without a magnetic field) that a strong magnetic field causes strong oscillations of the total electric current $J = J_e + J_i$ in an external circuit in a case of a sheath without dust particles. These oscillations are caused by the electron component J_e at first, they have a frequency of about the ion plasma frequency and damp very quickly. Later these oscillations are caused by the ion component J_i , they have a frequency about 7 times less and damp slowly.

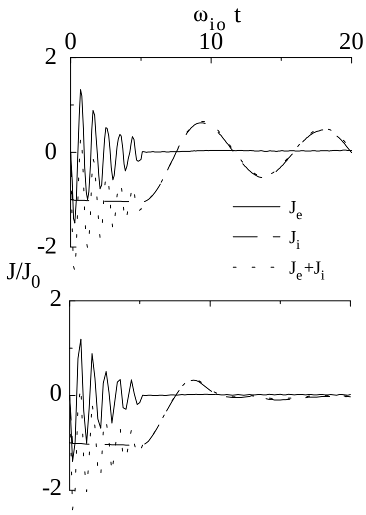

Fig. 1.

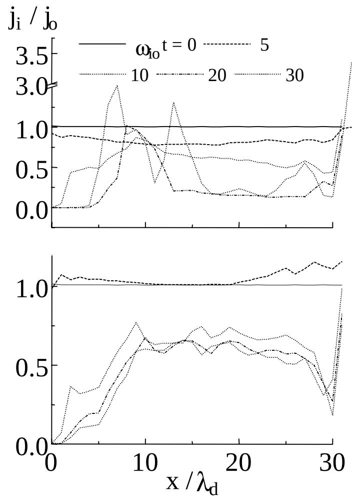

Fig. 2.

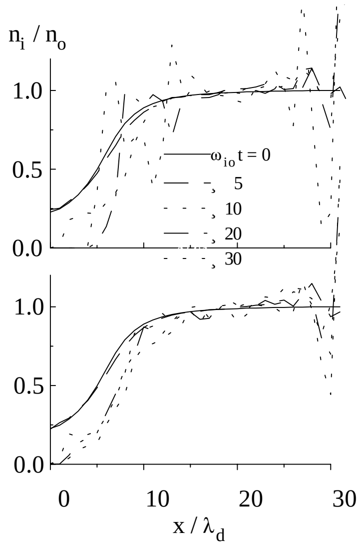

Fig. 3.

Spatial distributions of the drift electron current j_e (Fig. 2a), the ion density n_i (Fig. 3a), the electric potential ϕ (Fig. 4a) and field E (Fig. 5a) show some spatial structures causing oscillations of the electric current in the external circuit. These structures exist also close to the boundary between sheath and plasma with a continuous change of plasma parameters through this boundary.

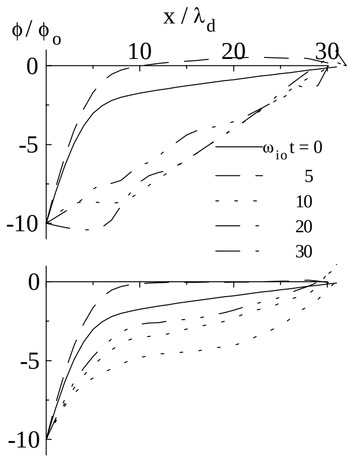

Fig. 4.

In the case of a sheath with a magnetic field, there are only the first oscillations of the total electric current J in an external circuit (Fig. 1b) with a frequency of about the ion plasma frequency. Slow oscillations do not develop at all due to an interaction of ions with dust particles. Spatial distributions of all parameters (Fig. 2b - 5b) show the existence in this case of a well developed sheath which is however not in a contact with an electrode and different from a usual sheath supported by the same voltage but without a magnetic field and dust particles. Spatial distributions of all parameters for the case of a usual sheath are shown by straight lines in these figures. In the case of a sheath with a magnetic field and dust particles, there are also non-uniform distributions of the dust

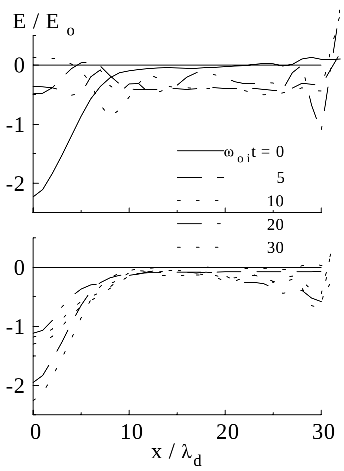

Fig. 5.

particle charge q_d shown in Fig. 6b contrary to the case of a sheath without dust particles (Fig. 6a).

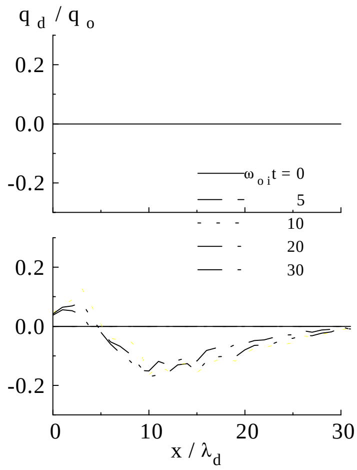

Fig. 6.

4. Conclusion

Computer modeling show a possibility of an essential influence of dust particles on non-linear sheaths with magnetic field. A spatial-temporal evolution of sheath parameters, due to appearance of dust particles in such sheaths, provide the existence of a well developed sheath which is not in contact with an electrode.

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