Effect of Presheath Current Density on the Sheath Structure of Plasma

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Abstract

A Kinetic Trajectory Simulation (KTS) model is used to study the effect of presheath current density on the sheath region. It has been observed that the plasma parameters in the sheath region and at the material wall are highly influenced by the presheath current density. Electron density at the wall is found to increase linearly and sharply, whereas ion density at the wall is found to be increasing nonlinearly and monotonically with respect to the presheath current density. Starting with the same density at the sheath entrance, i.e. $10^{18}\ m^{-3}$, *the ion and electron densities at the wall change from* $3.761 \times 10^{17}\ m^{-3}$ *to* $4.436 \times 10^{17}\ m^{-3}$ *and* $1.250 \times 10^{16}\ m^{-3}$ *to* $5.156 \times 10^{16}\ m^{-3}$ *when the presheath current density increases from* $-3.507 \times 10^{3}\ Am^{-2}$ *to* $3.507 \times 10^{3}\ Am^{-2}$ *respectively. The result obtained is expected to be useful in controlling the flow of particles at the wall.*

Keywords: *plasma, shecth, presheath, Bohm criteria.*

Introduction

For all practical purposes, plasma has to come in contact with material wall. Due to high mobility of electrons compared with that of the ions, the wall is bombarded by electrons and is negatively charged with respect to the surrounding plasma [1]. The negative potential then attracts the ions and repels part of electrons, forming a positive-space charge region in front of the wall. This positive space charge region is known as the "sheath". Within the sheath region the plasma is significantly non-neutral; however, it becomes practically quasineutral at the sheath edge. As we move towards the wall, the potential falls off rapidly so the electric field is strong and the motion of the particles is dominated by electric force rather than magnetic force. The sheath structure is responsible for the flow of the particles and the energy towards the wall and may also affect the bulk-plasma behavior [2].

A residual electric field penetrates sheath edge deep into the bulk plasma. This electric field is responsible for acceleration of the ions and helps to satisfy a condition which is necessary for the formation of the sheath [3]. The condition (or criterion) is called "Bohm criterion". This condition demands that ions enter the sheath region with a high velocity, which cannot be generated by the thermal motion of the ions. Consequently, the ions must be accelerated by an electric field penetrating the presheath region.

The plasma flowing towards the wall passes through these two regions: "sheath" and "presheath". The scale length of the sheath and presheath is different. So usually they are studied separately using different models and methods. For our case, we have applied the coupling scheme in [4], which gives the plasma parameters at the sheath side of the sheath entrance for parameters given at the presheath side. This coupling scheme satisfies the most crucial requirement of the presheath-sheath transition, i.e. quasi-neutrality, sheath edge singularity and kinetic "Bohm criterion".

Model

A. Principle of KTS

KTS is an iterative method for numerically calculating the self consistent, time independent kinetic plasma states in some given bounded spatial regions. The distribution functions of the particle species involved are calculated directly by solving the related kinetic equations along the respective collisionless particle trajectories. The KTS model is used to study plasma sheath formed in front of an absorbing material wall for different presheath current densities [5].

B. Plasma Sheath Model

In this model, a simplest case of "1d1v" is taken, where the velocity space as well as the confirgurational space is one dimensional. An infinitely strong magnetic field is considered to be perpendicular to the wall so that the "1d1v" approximation is fulfilled.

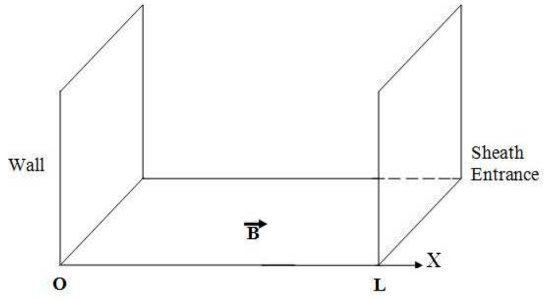

Fig.1. Plasma sheath model

At first a potential profile is guessed in between the wall and the sheath edge and using this, the electron and ion densities are calculated. Now these densities are used to solve Poisson equation, which in turn gives new potential profile. The method is iterated to obtain the final self-consistent result. We have used MATLAB-program for our simulation.

Results and discussion

In Fig.2 the self consistent potential is shown from the plasma edge to the wall for different presheath current densities. For all values of presheath current density the corresponding potential shows a sharp gradient close to the wall but is almost constant near the sheath entrance, where the potential is fixed to zero. This is obvious because the potential at the wall cannot be distributed over the entire plasma, since Debye shielding will confine the potential variation within the order of few Debye lengths.

For the presheath current densities, $J_{ps} = 7.014 \times 10^3$ Am^{-2}, 3.507×10^3 Am^{-2}, 0, -3.507×10^3 Am^{-2}, the values of wall potential are, $\varphi_W = -22.43$ V, -25.14 V, -29.27 V, -37.96 V respectively. On increasing the value of presheath current density, negativity of the wall potential decreases, i.e. the magnitude moves towards zero. This is because as the presheath current density is increased, the flux of ion entering the sheath region increases. These ions are accelerated towards the wall and absorbed by the wall, making the wall potential less negative.

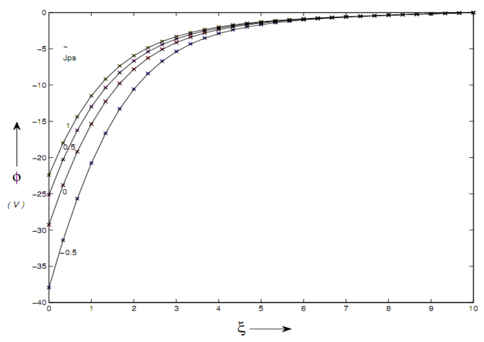

Fig.2. Self consistent potential versus normalized distance for different presheath current density

Fig.4 shows the variation of electron and ion densities at the wall for different values presheath current densities. For the presheath current densities, $J_{ps} = 7.014 \times 10^3$ Am^{-2}, 3.507×10^3 Am^{-2},0, -3.507×10^3 Am^{-2}, the values of electron at the wall are $n_{ew} = 7.030 \times 10^{16}$ m^{-3}, 5.156×10^{16} m^{-3}, 3.232×10^{16} m^{-3}, 1.250×10^{16} m^{-3} and the values of ion density at the wall are, $n_{iw} = 4.639 \times 10^{17}$ m^{-3}, 4.436×10^{17} m^{-3}, 4.719×10^{17} m^{-3}, 3.761×10^{17} m^{-3} respectively. It has been observed that while increasing the value of current density, the electron density at the wall increases linearly and sharply whereas the ion density at the wall increases non linearly and monotonically. This is because as the presheath current density is increased, the flux of ion entering the sheath region increases, increasing the ion density in the sheath. These ions are accelerated towards the wall and some of them are absorbed by the wall, making the wall potential less negative but increasing the ion density at the wall. Consequently, those electrons which were repelled earlier near the wall can now reach the wall, increasing the electron density at the wall.

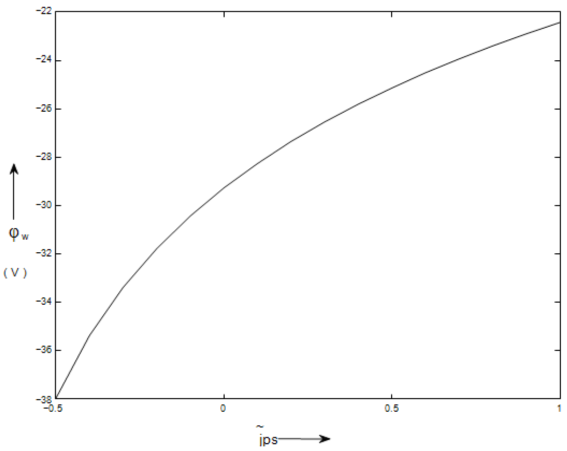

Fig. 3. Self consistent wall potential versus presheath current density

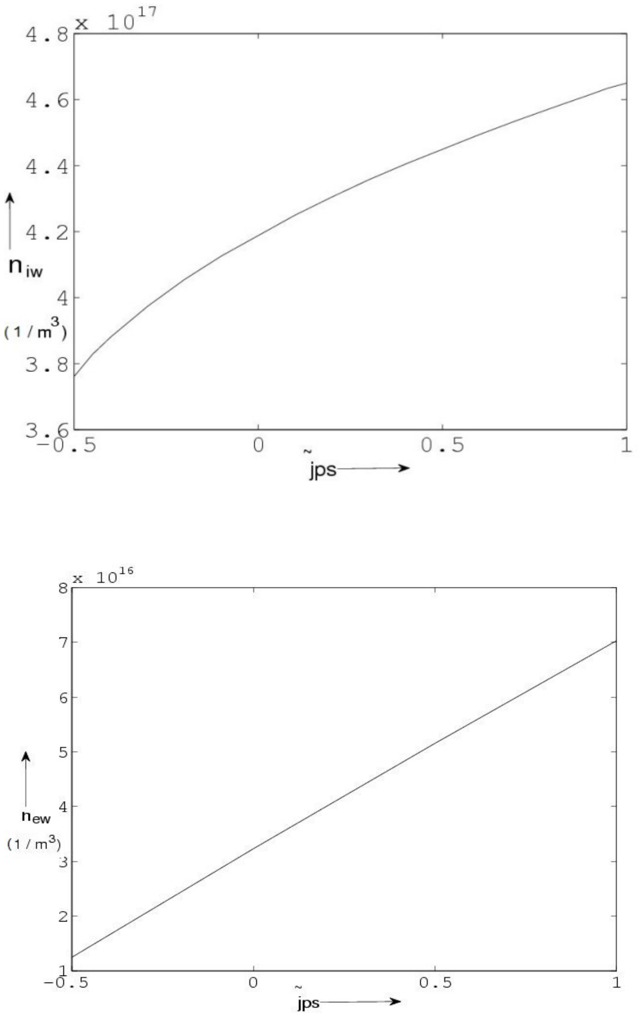

Fig. 4. Electron and Ion density at the wall versus presheath current density

Conclusion

The self consistent potential has been seen to have a sharp gradient close to the wall but is constant near the sheath entrance. The decrease in potential is less spectacular as the value of presheath current density is increased.

The electron and ion densities increase as we increase the value of presheath current density. Starting with the same density at the sheath entrance, the ion and electron densities at the wall change from 3.761×10^{17} m^{-3} to 4.436×10^{17} m^{-3} and 1.250×10^{16} m^{-3} to 5.156×10^{16} m^{-3} when the presheath current density increases from -3.507×10^{3} Am^{-2} to 3.507×10^{3} Am^{-2} respectively.

The result obtained is expected to be useful in controlling the flow of particles at the wall.

Reference

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