Sheath Formation of a Plasma Containing Multiply Charged Ions, Cold and Hot electrons, and Emitted Electrons

H.J. You #
National Fusion Research Institute

1. Introduction

It is quite well known that ion confinement is an important factor in an electron cyclotron resonance ion source (ECRIS). Particularly, it has been pointed out that the ion confinement is closely related to the plasma potential, since many empirical techniques (wall coatings, secondary electron materials, electron injection and biased disks, and gas mixing) were found to lower plasma potential. In this sense, the detailed sheath formation is very important in understanding how multiply charged ions (MCIs), bulk (cold and hot) electrons, and secondary electrons (either by MCIs and bulk electrons) are contributing to the plasma potential (sheath potential drop). The present study was motivated by the fact that the secondary electron yields are strongly dependent on the charge state of the ions and on the incident energy of electrons: secondary electron yield \( \gamma \) by ion bombardment is almost linearly proportional to the charge state \( j \), so that the ratio \( \gamma_j/\gamma_c \) reaches around unity for \( Ar^{+}\text{ }8+ \) ion, and secondary electron yield \( \gamma_e \) by electron bombardment is typically larger than 0.5 for the incident energy larger than 100 eV. Therefore, the contributions of the secondary electron emissions on the sheath formation would be severe if the charge state of ions is high and there are highly energetic electrons in the plasma. In the model, modification of the “Bohm criterion” was given: thereby the sheath potential drop and the critical emission condition were also analyzed.

2. Sheath Model

1. Sheath model & Poisson’s equation

\[
\frac{d\psi}{dx} = \frac{\rho_n}{\varepsilon_0}
\]

Poisson’s equation

\[
\frac{d^2\psi}{dx^2} = \frac{1}{\varepsilon_0} \left[ J_{\text{in}} \right] - \psi \left( \frac{\partial\psi}{\partial x} \right) + \psi \left( \frac{\partial\psi}{\partial x} \right)
\]

where \( \psi(x) = \psi_0 + \sum \psi_n \left( x \right) \), where \( \psi_n \left( x \right) = \psi_0 + \psi_1 + \psi_2 + \ldots + \psi_n \).

2. Multiply charged ions (MCI)

The \( j \)-charged ions can be described by continuity and momentum equation, thereby yielding following equation

\[
\frac{dN_j}{dt} = 0
\]

3. Bi-Maxwellian electrons (two-temperature)

\[
N_e(x) = n_\text{exe} \exp \left( \frac{\psi(x)}{T_e} \right)
\]

\[
N_{\text{eh}}(x) = n_{\text{eh0}} \exp \left( \frac{\psi(x)}{T_{\text{eh}}} \right)
\]

where \( \psi = \frac{\sqrt{V_0 - T_e(x)}}{T_e} \), where \( \theta = T_{\text{eh}}/T_e \).

4. The emitted electrons from the wall

\[
N_{\text{em}}(x) = n_{\text{em0}} \left[ \left( V_0 - \psi(x) \right) / T_{\text{em}} \right]^{1/2}
\]

where \( \psi_{\text{em}} = \frac{\sqrt{V_0 - V_{\text{em}}}}{T_{\text{em}}}, \quad \psi_{\text{em0}} = n_{\text{em0}} / T_{\text{em}}, \quad \psi_{\text{em0}} = N_{\text{em0}} / T_{\text{em0}}.\)

4. Results

The dependence of Bohm velocity as functions of \( \beta \) for (a) \( \psi \) (for \( \theta = 0, 0.2, 0.4, \) and \( 0.6 \)) and \( \psi \) (for \( \beta = 0.1, 0.3, \) and \( 0.5 \)), and the emission current \( J_{\text{em}} \) and floating potentials (\( \psi_{\text{f}} \)) and critical emission potentials (\( \psi_{\text{em}} \)) depend on the emission current (\( J_{\text{em}} \)) and the hot electron density and the temperature.

5. Conclusions

The presence of hot electrons and emitted electrons are found to strongly affects the sheath formation. Particularly, it is important that larger emission current can result in reduced sheath potential (or floating potential). Also, the sheath potential can be even more decreased if secondary electrons are emitted with higher initial velocity (\( V_{\text{em}} \)). However the reduction of the sheath potential becomes independent of the emission current \( J_{\text{em}} \) when \( J_{\text{em}} > J_{\text{em0}} \) (or \( \psi_{\text{em}} > \psi_{\text{em0}} \)).