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

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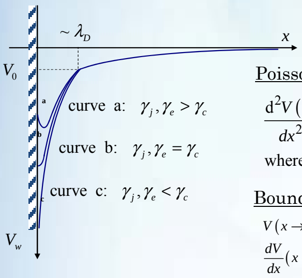
1. Introduction

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 γ_j by ion bombardment is almost linearly proportional to the charge state j, so that the ratio γ_j/j reaches around unity for Ar^{8+} ion, and secondary electron yield γ_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



Poisson's equation

$$\frac{d^2V(x)}{dx^2} = -\frac{1}{\varepsilon_0}\left[\sum_j e_j n_j(x) - e n_e(x)\right],$$

where $n_e(x) = n_{ec}(x) + n_{eh}(x) + n_{em}(x)$.

Boundary Condition

$$V(x\to\infty)=0$$

$$\frac{dV}{dx}(x\to\infty)=0$$

2. Multiply charged ions (MCI)

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

$$\frac{dn_j}{dV} = \frac{n_j e_j}{m_j v_j^2}.$$

3. Bi-Maxwellian electrons (two-temperature)

$$n_{ec}(x) = n_{ec0}\exp(\psi),\quad n_{eh}(x) = n_{eh0}\exp\left(\frac{\psi}{\theta}\right),$$

where $\psi = -e(V_0 - V(x))/kT_{ec}$, $\theta = T_{eh}/T_{ec}$.

4. The emitted electrons from the wall

$$n_{em}(x) = n_{ems}\Big/\left[1-\psi\Big/\left(\psi_w - \frac{N^2\mu}{2}\right)\right]^{1/2}$$ where

$$\psi_w = -e(V_0 - V_p)/kT_{ec},\quad \mu = m_e/m_j,\quad v_{em} = N\sqrt{kT_{ec}/m_j}.$$

1. Modified Bohm criterion

$$M = \sqrt{\sum_j \frac{j^2 n_{js}}{n_{es}} \frac{1+\beta+G_e}{(1-G_i)\left(1+\frac{\beta}{\theta}\right)\left(\frac{G_e+G_i(1+\beta)}{2(\psi_w - N^2\mu/2)}\right)}},$$

where

$$\beta = \frac{n_{ehs}}{n_{ecs}},\quad G_j = \frac{\gamma_j M}{\sqrt{N^2 - 2\psi_w/\mu}},$$

$$G_e = \frac{\gamma_e\left(\exp(\psi_w) + \beta\sqrt{\theta}\exp(\psi_w/\theta)\right)}{\sqrt{2\pi\mu(N^2 - 2\psi_w/\mu)}}.$$

2. Total current & Floating condition (J_{tot}=0)

$$J_{tot} = J_i + J_{ec} + J_{eh} + J_{em} = 0,$$ floating condition

where

$$J_{ec} = \frac{j_{ec}}{j_0} = \frac{1-G_i}{1+\beta+G_e}\sqrt{\frac{1}{2\pi\mu}}\exp(\psi_w),$$ cold electron current

$$J_{eh} = \frac{j_{eh}}{j_0} = \frac{\beta(1-G_i)}{1+\beta+G_e}\sqrt{\frac{1}{2\pi\mu}}\exp\left(\frac{\psi_w}{\theta}\right),$$ hot electron current

$$J_{em} = \frac{j_{em}}{j_0} = \frac{G_e + G_i(1+\beta)}{1+\beta+G_e}\sqrt{N^2 - \frac{2\psi_w}{\mu}},$$ emitted electron current

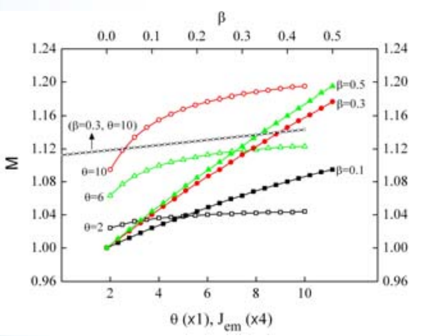
$$J_i = \frac{j_i}{j_0} = M.$$ multicharged ion current

3. Critical emission condition

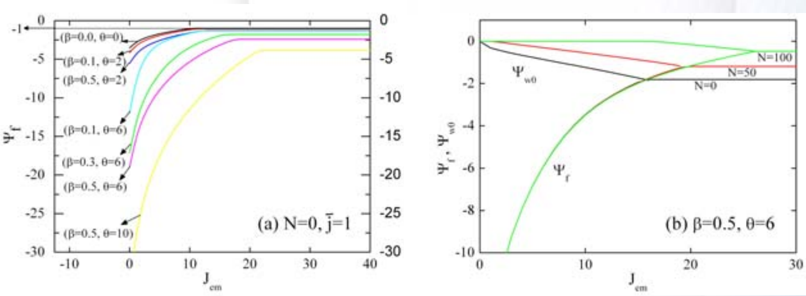
$$\left.\frac{d\psi}{d\xi}\right|_{\psi=\psi_p} = 0,\quad \text{where } \xi = x/\lambda_D.$$

Electric field =0 at the probe surface

4. Results



The dependence of Bohm velocity as functions of β (for θ=2, 4, and 6) and θ (for β=0.1, 0.3, and 0.5), and the emission current J_{em}



Floating potentials (ψ_f) andd critical emission potentials (ψ_{w0}) dependent on the emission current (j_{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_{em}). However the reduction of the sheath potential becomes independent of the emission current J_{em} when $J_{em} > J_{emc}$ (or γ_e and $\gamma_j > \gamma_c$).

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