*35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, P-4.157 (2008)*

Study of discharge oscillations in Hall thrusters

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1. Introduction

The electric propulsion has been used in spacecraft with a small and compact thruster. Recently, as spacecraft scales up, thrusters with higher thrust and efficiency are required. The Hall thruster is suitable for a long term mission in space because it has the features of higher thrust and longer specific impulse among electric thrusters. It is used to change the orbit and to control the attitude of spacecraft. Characteristics of the Hall thrusters have been investigated both experimentally [1,2] and theoretically [3]. However, we have to settle many problems such as the instability of the discharge current [4,5]. It is important to clarify the mechanism of the oscillation of the discharge current.

In the present paper, we study the discharge oscillation associated with the ionization by the electron-neutral collision. We consider the production of the neutrals by the recombination and production of the charged particles (electrons, ions) by the ionization. Spatiotemporal evolution of the discharge current is obtained by the equation of the continuity for the charged particles and the neutrals. We also investigate the effect of the ion density for the discharge current.

2. Discharge oscillation of electron current

We consider the models associated with the ionization by the electron-neutral collision and the neutral production process [4-8]. For the neutral production, we consider the plasma recombination and another process such as the neutral injection. Temporal evolution of the discharge current is obtained by the equations of the continuity for the electrons and neutrals. We use the constant value for the electron velocity and the neutral velocity. We assume that the ion density equal to the electron density (n_i=n_e). The ionization by the ion-neutral collision is neglected. The continue equations are

$$\frac{\partial n_e}{\partial t} + v_e \frac{\partial n_e}{\partial x} = \gamma_e n_e n_n - \alpha n_e^2 \ , \qquad (1)$$

$$\frac{\partial n_n}{\partial t} - v_n \frac{\partial n_n}{\partial x} = -\gamma_e n_e n_n + \alpha n_e^2 + \gamma_n n_n v_n \ , \qquad (2)$$

where n_e, n_n, v_e, v_n, γ_e and α denote the electron density, electron velocity, neutral velocity, the coefficient of the creative velocity for electrons and the recombination coefficient, respectively. In eq.(2), γ_n is the additional production rate of the neutrals. In the simulation, parameters used here are $\gamma_e = 5\times10^{-13}$[m^3/s], $\gamma_n = 5\times10^{2}$[1/m], $\alpha = 10^{-14}$, v_e=1000[m/s], v_n=300[m/s] and the channel length L=0.01[m]. Then, the initial and boundary conditions are taken as

$$n_e(x,0) = 10^{16}[m^{-3}], \quad n_n(x,0) = 10^{18}[m^{-3}],$$

$$\left.\frac{\partial n_e}{\partial x}\right|_{x=0} = \left.\frac{\partial n_e}{\partial x}\right|_{x=L} = 0 \ , \quad \left.\frac{\partial n_n}{\partial x}\right|_{x=0} = \left.\frac{\partial n_n}{\partial x}\right|_{x=L} = 0 \ ,$$

respectively. The discharge current is expressed as

$$J_e = -e n_e v_e S \qquad (3)$$

where S is the cross-section area of the channel. We use the inner radius is 48[mm] and the outer radius is 72[mm] for the channel. Fig.1 shows the temporal evolution of the neutral density. The discharge current is shown in Fig.2. It appears the discharge oscillation which the frequency is about 6×10^{14} Hz. It is shown that the oscillation of the discharge current has the large amplitude near the anode.

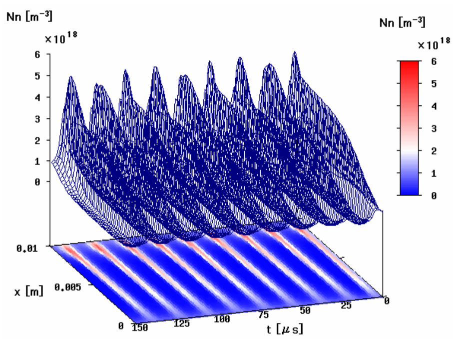

Fig.1 Temporal evolution of the neutral density

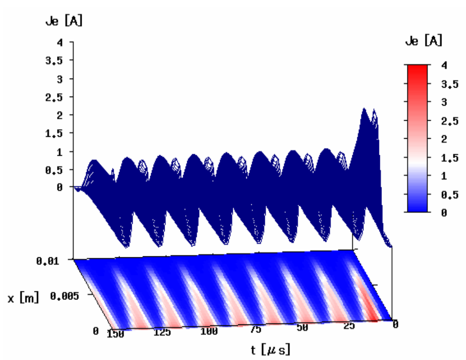

Fig.2 Temporal evolution of the discharge current

3. Effect of ion density

In order to investigate the effect of the temporal evolution of the ion density, we carry out the simulation include the continue equation of ions. The set of equations under consideration is

$$\frac{\partial n_e}{\partial t} + v_e \frac{\partial n_e}{\partial x} = \gamma_e n_e n_n - \alpha n_e n_i \ , \tag{4}$$

$$\frac{\partial n_i}{\partial t} + v_i \frac{\partial n_i}{\partial x} = \gamma_e n_e n_n - \alpha n_i n_e \ , \tag{5}$$

$$\frac{\partial n_n}{\partial t} + v_n \frac{\partial n_n}{\partial x} = -\gamma_e n_e n_n + \alpha n_e n_i + \gamma_n v_n n_n \ , \tag{6}$$

where n_{i} and v_{i} denote the ion density and ion velocity, respectively. We use v_{i}=500[m/s] for the ion velocity and the other parameters are used same value in eq.(1) ~(3). The initial and boundary conditions are taken as

$$n_e(x,0) = n_i(x,0) = 10^{16}[m^{-3}], \quad n_n(x,0) = 10^{18}[m^{-3}],$$

$$\left.\frac{\partial n_e}{\partial x}\right|_{x=0} = \left.\frac{\partial n_e}{\partial x}\right|_{x=L} = 0 \quad , \quad \left.\frac{\partial n_i}{\partial x}\right|_{x=0} = \left.\frac{\partial n_i}{\partial x}\right|_{x=L} = 0 \quad , \quad \left.\frac{\partial n_n}{\partial x}\right|_{x=0} = \left.\frac{\partial n_n}{\partial x}\right|_{x=L} = 0 \quad ,$$

respectively. The discharge current is expressed as

$$J = J_e + J_i = e(n_i v_i - n_e v_e)S \ , \tag{7}$$

The electron current and the ion current are shown in Fig.3 and Fig.4, respectively. Fig.5 shows the temporal evolution of the neutral density. The total discharge current is shown in Fig.6. It is shown that the oscillation of the electron current is large amplitude near the anode, while the ion current has large amplitude near the cathode.

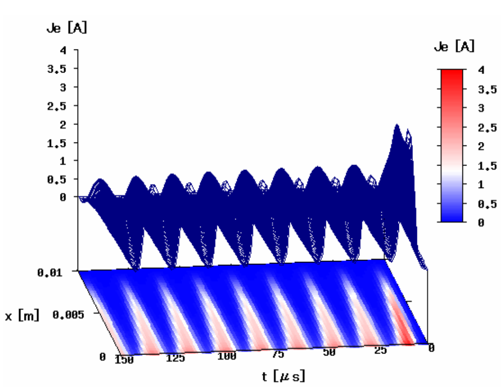

Fig.3 Temporal evolution of the electron current

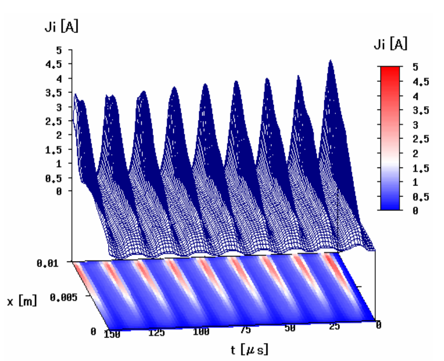

Fig.4 Temporal evolution of the ion current

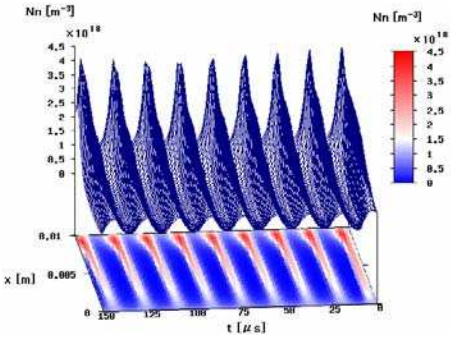

Fig.3 Temporal evolution of the neutral density

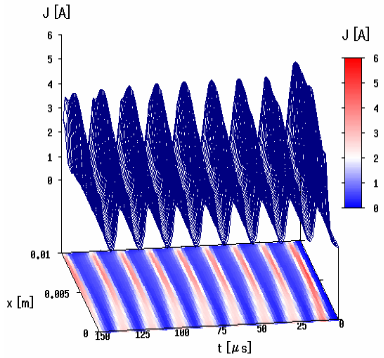

Fig.4 Temporal evolution of the discharge current

4. Conclusions

We have investigated the discharge oscillation associate with the ionization by the electron-neutral collision and the plasma recombination for the Hall thruster. In the simulation, we consider the additional production of the neutrals. We obtained the temporal evolution of the axial profile of the the discharge current. It is shown that the frequency of the discharge current is about 6×10^4 [Hz]. It is found that the ion current intense the discharge current because the axial velocity of the ions opposite direction with the velocity of the electrons.

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