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Numerical Study of an Electrodeless Plasma Thruster Using an *m* = 0 Coil

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1. Introduction

An electric propulsion system is suitable for space exploration missions because of its high specific impulse. However, conventional electric propulsion has a limitation of the operation time owing to electrodes erosion. Therefore, electrodeless plasma thrusters using a helicon plasma were proposed to remove the time limitation for the thrust generation. The higher thrust performance can be obtained by combining an acceleration scheme using an $m = 0$ coil (m is the azimuthal mode) with the helicon plasma thruster. In this acceleration scheme, the helicon plasma is surrounded by a glass tube and the coil. An alternating current (AC) is applied to the coil, which generates a rotating electron motion while inducing an azimuthal current j_θ. The Lorentz force between j_θ and a radial component of a magnetic nozzle accelerates the plasma to the axial direction. However, a detailed dynamics for the plasma acceleration is not observed from the previous experiment for the $m = 0$ scheme [1]. Therefore, in this study, the plasma transport is numerically solved to reproduce the process of the particle acceleration using the $m = 0$ coil.

2. Numerical Methods

It is assumed that the acceleration process can be described in the Cartesian coordinate. Coordinates x, r, and θ are the axial, radial, and azimuthal components in the axial coordinate corresponding to x, y and z in the Cartesian coordinate, respectively. A one-dimensional (1D) equation of continuity, equation of motion for the electrons and ions, and Poisson's equation are numerically solved to reproduce the plasma transport in the x-direction. In addition, the 1D equation of motion for the electrons and Maxwell's equation are integrated along the y-axis to obtain the z component of the electron velocity v_{ez} driven by the $m = 0$ coil.

3. Simulation Condition

An AC of 254 A is applied at $y = -18$ and 18 mm to model the $m = 0$ coil. The AC frequency f is changed in a range from 5 to 40 kHz. A uniform plasma with the electron and ion densities of $n_{e,i} = 10^{19}\ \mathrm{m}^{-3}$ is set in the simulation domain. v_{ez} is evaluated at $y = 7$ mm. When the plasma transport in the x-direction is calculated, the plasma is assumed to have the z-direction velocity v_{ez} in a region from $x = 25$ to 40 mm by assuming that the $m = 0$ coil is set from $x = 25$ to 40 mm. $B_y = 0.01$ T is uniformly applied as the radial component of the magnetic nozzle. The electron and ion temperatures are set as $T_e = 2$ eV and $T_i = 0.5$ eV, respsctively. The degree of ionization is assumed to be 0.5 %. The elastic collision frequency ν_m is calculated using Bolsig+ [2], which becomes $5.4 \times 10^6\ \mathrm{s}^{-1}$.

4. Results

v_{ez} is generated due to an electromagnetic (EM) induction when the AC is applied to the $m = 0$ coil. Figure 1 shows the density difference $n_e - n_i$ and the electric field E at 1/4 period of 25 kHz. n_e increases at right end of the coil because the electrons are accelerated by the Lorentz force $v_{ez} \times B_y$. After the electron acceleration, the ions are driven to the right end of the coil because of the electric field induced by a charge separation. Our simulation result indicates that a main mechanism of the $m = 0$ acceleration scheme is valid.

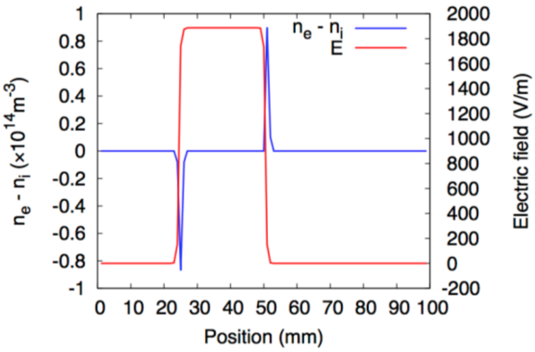

Figure 1. Spatial distribution of $n_e - n_i$ and E.

A specific impulse, which is evaluated from the ion velocity, has the maximum value of 2.8 s when f is 25 kHz. The ions catch up with the electrons accumulated at the right end of the coil when f is low because the time duration for the particle acceleration is sufficiently large. The ion velocity decreases because the charge separation becomes weaker. On the other hand, the electron cannot arrive the right end of the coil and the strong charge separation is not induced when f is high because the time duration of the electron acceleration is too short. Therefore, the ion velocity becomes small for the case of the high f.

5. Conclusion

A 1D plasma model is numerically solved to reproduce an acceleration process of charged particles using an $m = 0$ coil system. The AC applied to the coil generates the z-direction velocity, which induces the Lorentz force for the electron acceleration. The ions are pulled by an electric field due to a charge separation after the electron acceleration. The specific impulse has the maximum value at $f = 25$ kHz. We will examine a detailed mechanism for the plasma acceleration using a 2D plasma model, and it will be discussed in the full paper.

Refernces

[1] S. Shinohara, J. Plasma Fusion Res., Vol. 91, No. 6, pp. 412-428, 2015.

[2] https://fr.lxcat.net/solvers/BolsigPlus/