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Micro Ion Thrusters using RF/Microwave-excited plasma sources
高周波／マイクロ波プラズマ源を用いた超小型イオンスラスタ

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Two types of micro ion thrusters are numerically investigated by using a particle-in-cell simulation with a Monte Carlo collision algorithm: the one is an RF discharge and the other is a microwave discharge ion thruster. A finite-difference time-domain algorithm for the electromagnetic fields of microwaves and a finite element analysis for the magnetostatic fields of permanent magnets are also conducted for the microwave ion thruster. Simulation results have shown that ions in the plasma source are accelerated through a grid hole, gaining the energy from the potential difference between two grids, and high energy ion beams of about 1 kV are obtained with an interaction with electrons injected in space for the RF ion thruster. For the microwave discharge ion thruster, the electrons are well confined owing to the mirror magnetic fields and can be effectively heated in the ECR layer downstream of the ring antenna.

1. Introduction

In recent years, the worldwide interest in microspacecraft has grown to such an extent that even universities are currently able to launch and operate microspacecraft because of their low costs and short development periods. However, most microspacecraft do not have any propulsion systems, which is why they rely on passive controls. If a microspacecraft had microthrusters mounted on it, we could control the microspacecraft more effectively to create a specific flight path. Owing to the limited power generation and propellant storage, high specific impulses, high-thrust efficiencies and low-power consumptions are required for microthrusters, in addition to small size and light weight. Although several types of microthrusters are proposed and some of them are already developed, ion thrusters are one of the most promising propulsion systems for microspacecraft among them.

In this paper, two types of micro ion thrusters are described: the one is an RF discharge and the other is a microwave discharge ion thruster, which are shown in Fig. 1. In order to clarify the mechanism of plasma discharges in a small space and ion beam extraction for optimum designs, numerical simulations could represent a powerful tool to compensate for lack of information obtained from experiments because of the difficulty to investigate the plasma characteristics in a small discharge chamber by experiment.

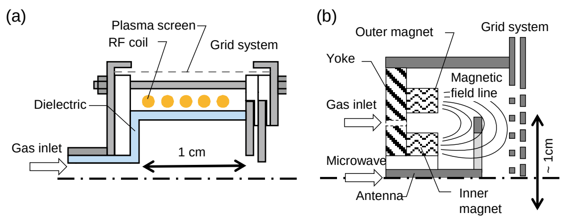

Fig.1. Schematics of (a) an RF and (b) a microwave discharge ion thrusters.

2. Numerical Model

To investigate the characteristics of the plasma source and ion beam profiles, we have conducted particle-in-cell simulations with a Monte Carlo collision algorithm (PIC-MCC), assuming the following conditions. (i) The propellant gas is Xe. (ii) Only Xe ions and electrons are treated as particles, and neutral particles are time independent and uniform in space. (iii) The reactions taken into account are elastic scattering, excitation, and ionization for electrons, and elastic scattering and charge exchange for ions. (iv) The coulomb collision is not taken into account. Cross section data for electrons and ions are the same as the ones used in Refs. [1,2]. The postcollision velocities of electrons and ions are determined by the use of the conservation equations for momentum and energy. The coordinate system is axisymmetric for the RF ion thruster whereas the three-dimensional Cartesian coordinate system is employed for the microwave ion thruster. A finite-difference time-domain (FDTD) algorithm for the electromagnetic fields of microwaves and a finite element analysis for the magnetostatic fields of permanent magnets are also conducted for the microwave ion thruster. The methodology is described in details in our previous papers [1,2].

3. Results and Discussion

3.1 *RF discharge ion thruster*

Figure 2 shows a typical example of the calculation for the RF plasma discharge and ion beam extraction with electron injection for neutralization, where the RF frequency is 100 MHz, the power absorbed by the plasma is 0.1 W, the discharge chamber pressure is 3.8 mTorr, the screen grid voltage is 1000 V, and the accelerator grid voltage is −100 V. The ions in the plasma source are accelerated through a grid hole, gaining the energy from the potential difference between two grids, and high energy ion beams of about 1 kV are obtained with an interaction with electrons injected in space. While most ions are seemed to be extracted through the grid hole without any loss due to collisions with the accelerator grid, some ions are found to collide with the downstream side of the accelerator grid probably owing to the existence of slow ions generated through charge-exchange collisions. The electrons injected in space are repelled because of the negative potential of the accelerator voltage, and some electrons are found to be heated at the edge of the electron distribution in space.

3.2 *Microwave discharge ion thruster*

A typical example of the simulation results is shown in Fig 3, where the microwave frequency is 4.2 GHz, the power absorbed by the plasma is 0.3 W, and the background Xe gas pressure is 1 mTorr. The figure indicates the peak electric field near the circumference of the microwave antenna, especially between the antenna and the permanent magnets. Similarly, the peak electron density is located on the ECR layer in front of the antenna. The distribution of the electron density spreads along the magnetic field lines, which indicates that the electrons are well confined because of the mirror magnetic fields. The peak electron density, electron temperature, and plasma potential obtained are 1.6×10^{17} m^{-3}, 18 eV, and 20 V, respectively. The asymmetry of the distribution displayed around the center at *x*-*y* plane is probably due to the statistical fluctuation caused by a small number of superparticles, where the plasma density is less than a quarter of the peak density.

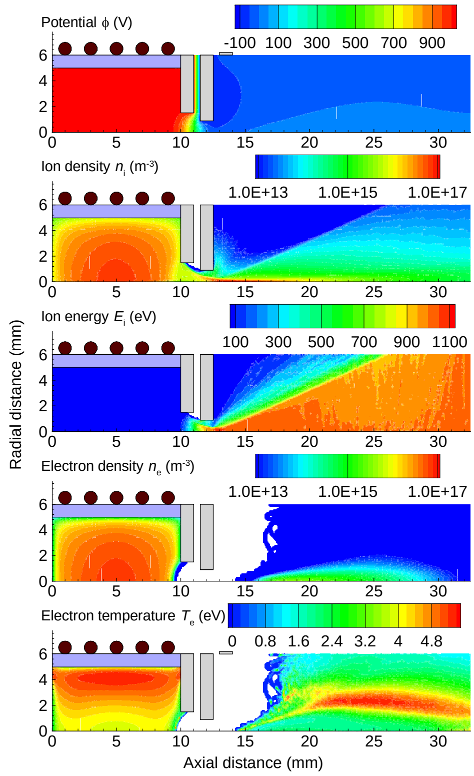

Fig.2. Two-dimensional distributions of the ion beam extraction for the RF ion thruster.

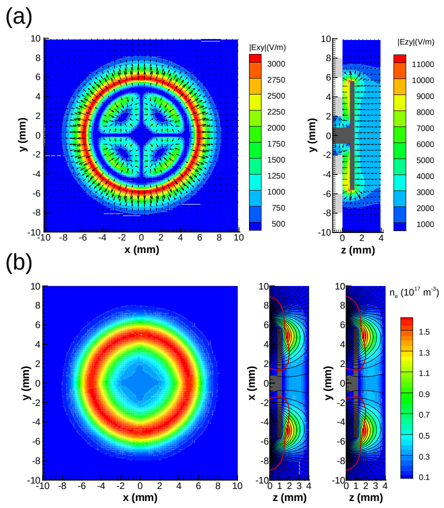

Fig.3. Three-dimensional distributions of (a) snapshots of the electromagnetic fields of microwaves and (b) the time-averaged electron density with magnetic field lines.

Acknowledgments

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