Development of 5cm Size Microwave Discharge Ion Thruster with Variable Magnetic Field

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Abstract: Utilization of outer space for commerce is developing and the space technology is being used for several essential services for the daily life of people recently. An electric propulsion system having a long life is effective to make this service certain. A microwave discharge ion thruster has advantages of its high specific impulse, high reliability and longer operating time. In this present work, a 5-cm-diam. microwave discharge ion thruster with variable magnetic field was fabricated with two types of electrostatic grids made of fine carbon and molybdenum, and ion beam extraction tests were carried out on the experimental condition of xenon gas flow rate of 1.5sccm, input microwave power from 8 to 20W, and acceleration voltage of 1500V. The performance test results and the design of an ion thruster with variable magnetic field are reported.

I. Introduction

Today, utilization of outer space for commerce is developing and the space technology is being used for several essential services for the daily life of people, such as a weather forecast, GPS (global positioning system) and satellite broadcasting. It is quite natural to think that space exploration is absolutely necessary for future generation of human beings because the solutions of today's problems, like population growth and a drain on natural resources, could be found by searching natural resources and monitoring environment from outer space. Furthermore, investigate and challenge spirit come from deep inside one's heart. Thus, those intellectual curiosity of researchers will be a motive force to move forward with the space exploration.

Almost 3 years have passed since the asteroid explorer Hayabusa returned from a small asteroid named Itokawa to Earth. The asteroid surface materials sampled by Hayabusa have been studied by researchers in the world to reveal the origin of the universe. Also, Hayabusa 2 lunched from Tanegasima space center on December 3, 2014. Both spacecraft equipped microwave discharged ion engines as a main propulsion system and the engines were one of the most significant parts to be successful the projects.

We have experiences in the development from 2cm to 10cm size microwave discharge ion thrusters[3,4]. In the previous works, to generate plasma in the discharge chamber of the microwave discharge ion thruster is sometimes difficult. The plasma ignition is affected with the magnetic and electric field configuration in the discharge chamber and needs strong magnetic field around the antenna for microwave emission.

In this study, a 5cm (in diameter) microwave discharge ion thruster with variable magnetic field was fabricated with electrostatic grids of fine carbon or molybdenum, and ion beam extraction tests were carried out on the experimental condition of xenon gas flow rate of 1.5sccm, input microwave power from 8 to 20W, and acceleration voltage of 1500V. The construction of the microwave discharged ion engine with variable magnetic field and ion beam extraction test results are reported.

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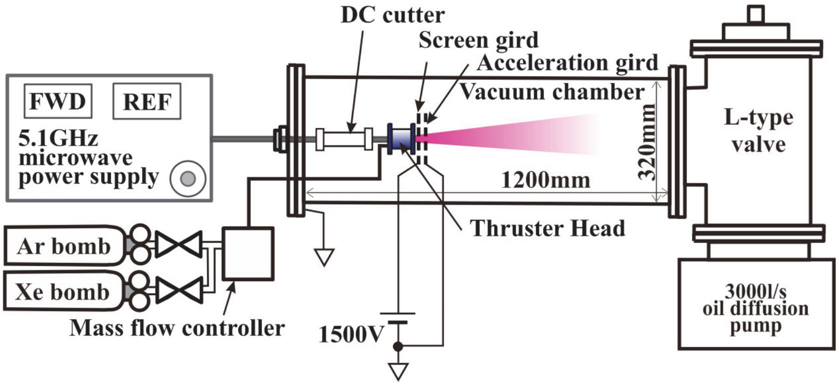

Figure 1. Schematic diagram of the experimental setup for the micro ion thruster.

II. Experiment

A. Experimental apparatus

Experimental apparatus for ion beam extraction is shown in figure 1. The apparatus is comprised of a cylindrical vacuum chamber (inner diameter of 32 cm and length of 120 cm), a 5.1GHz microwave power supply, a thruster head, and a vacuum pump of 3000 l/s oil diffusion pump. Microwave power is supplied from the power source through a coaxial cable to the thruster head from the 5.1GHz microwave power supply. The ultimate pressure and the pressure at xenon gas (as propellant) flow rate of 0.2 sccm in the vacuum chamber were 1.0×10^{-4} Pa and 1.6×10^{-3}Pa respectively.

B. Thruster head

Figure 2 and 3 show a schematic diagram and a photograph of a microwave discharge ion thruster head with variable magnetic field. The thruster consists of a discharge chamber surrounded by neodymium magnets (surface magnetic flux density of 0.4T), an antenna, two electrostatic grids of a screen grid and an acceleration grid to accelerate ions in the plasma for thrust production, and six Sm-Co movable magnets (surface magnetic flux density of 0.35T) to change magnetic field configuration in the discharge chamber. A star type antenna is used for microwave emission into the discharge chamber. A background magnetic field is generated with the cylindrical Nd magnets in the thruster head. The magnetic field strength and configuration are determined by choosing the number of the magnets and location of the movable magnets which

Table 1 Dimensions of Mo electrostatic grids.

	Fine carbon		molybdenum	
material	Screen	Accel.	Screen	Accel.
Open ratio (%)	67	24	50	35
Hole diameter (mm)	3	1.8	1.2	1.0
Hole number	163		851	
Potential (V)	1500	0	1500	0
Grid gap (mm)	0.5		0.34	

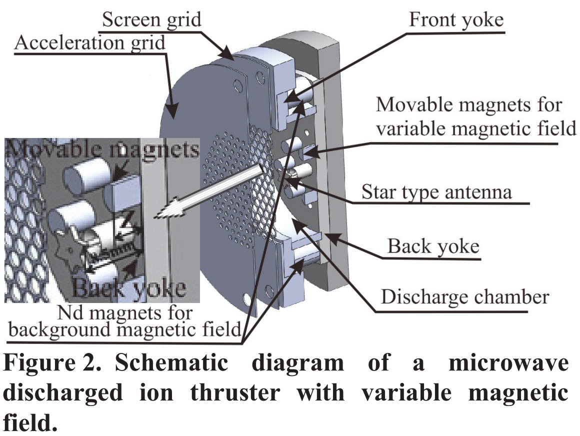

Figure 2. Schematic diagram of a microwave discharged ion thruster with variable magnetic field.

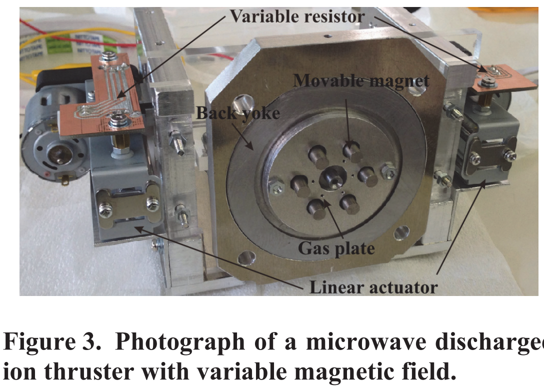

Figure 3. Photograph of a microwave discharged ion thruster with variable magnetic field.

move in the direction of axis. Microwave discharge plasma is generated by strong magnetic field produced with movable magnets and spread out by the change of the magnets position. The movable magnets are moved by two linear actuators and their position is determined with sliding variable resistors (Figure.3). The propellant gas is let into the thruster head through the gas plate to spread it out.

C. Ion beam extraction test

Ion beam extraction tests of the 5cm size microwave discharged ion thruster with variable magnetic field were conducted with fine carbon grids or Mo grids to determine its performance. A star type antenna was used for the tests as this type antenna has good performance for plasma generation[3]. These tests are under experimental conditions of the Xe gas flow rate of 1.5sccm and input microwave power from 8 to 20W.

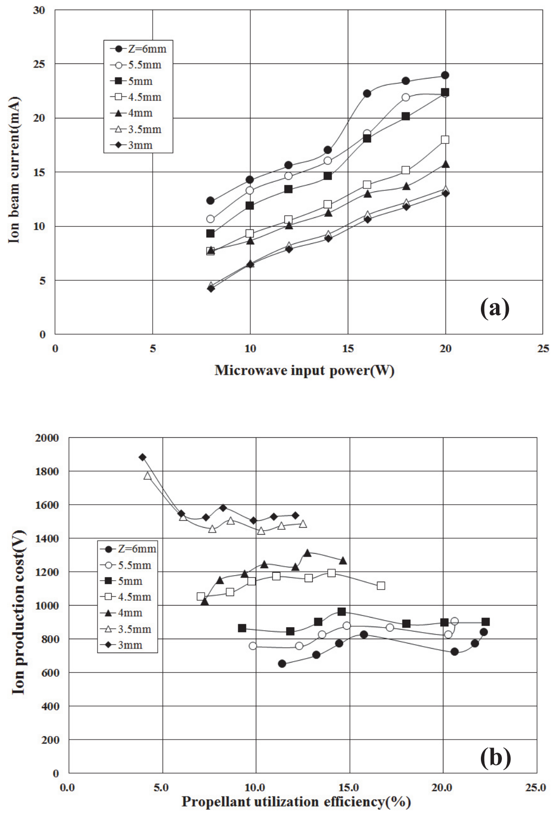

Figure 4. (a)Extracted ion beam current of 5cm microwave discharge ion engine with variable magnetic field (Xe gas flow rate of 1.5sccm). Z is the position of the movable magnets, (b) the performance of it.

III. Results and discussion

Results of ion beam extraction tests of the 5cm size microwave discharge ion thruster with fine carbon grids (Xe gas flow rate: 1.5sccm) are shown in Figure 4. The value of Z is the height of the movable magnets from the back yoke (Fig.2). In figure 4(a), extracted ion beam current is proportional to input microwave power. Maximum ion beam current of 24mA is extracted at input microwave power of 20W and Z=6mm. Figure 4(b) shows the thruster performance designated by using propellant utilization efficiency and ion production cost. Propellant utilization efficiency of 22% and ion production cost of 837V were obtained at the maximum ion beam current of 24mA. Plasma in the thruster was easily ignited at Z=7mm and Xe gas flow rate of 1.5sccm. Plasma ignitability is improved by using the movable magnets, however plasma spreading in the thruster head for performance improvement is not observed. Optimization of the background magnetic field is needed to spread dense plasma.

Figurer 5 shows the ion beam measurement results of the ion engine with Mo grids. The tendency of the results is very similar to that with fine carbon grids but the measured values were a little bit smaller than those with fine carbon grids due to the difference of electrostatic optics.

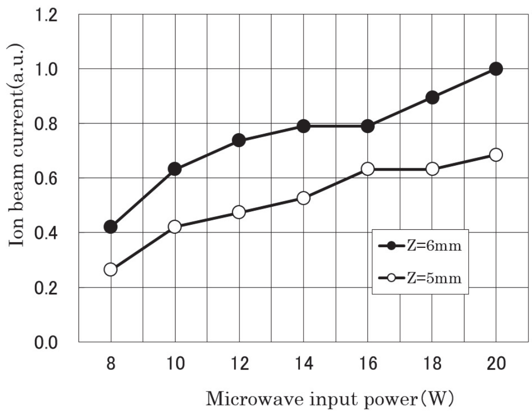

Figure .5 Extracted ion beam current of the 5cm microwave discharge ion engine with Mo grids (Xe gas flow rate of 1.5sccm).

IV. Conclusion

A 5 cm size microwave discharge ion thruster with variable magnetic field was fabricated and ion beam extraction tests were carried out with two types of electrostatic grids. The obtained results are as follows.

1) Maximum ion beam current of 24mA, propellant utilization efficiency of 22%, and ion production cost of 837V were obtained by using fine carbon grids at input microwave power of 20W and Xe gas flow rate of 1.5sccm.

2) Plasma in the thruster was easily ignited at Z=7mm and Xe gas flow rate of 1.5sccm. Plasma ignitability is improved by using the movable magnets.

3) Optimization of the background magnetic field is needed to spread dense plasma.

4) The tendency of the results with Mo grids is very similar to that with fine carbon grids.

Acknowledgments

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