Plasma property measurement in a microwave discharge using laser Tomson scattering technique

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Abstract: For validity of the numerical simulation code evaluating the lifetime of the neutralizer. We investigated the quantity of wear of each part of the neutralizer and performed the element analyzing of the dielectric and back yoke and measured the space potential, the electron density, and the electron temperature. As a result of the experiment, we were able to acquire necessary data of the numerical simulation.

I. Introduction

In recent year, electric propulsions are used for artificial satellites, spacecraft, and so forth[1)]. The electron cyclotron resonance (ECR) microwave discharge ion thruster μ10 installed on the HAYABUSA[2)]. It was succeeded in gathering samples of an asteroid ITOKAWA and returning to the earth. Three neutralizers, however, showed the degradation of the performance[3)], therefore, improvement of the durability of the thruster is crucial challenge for microwave discharge ion engines. Kubota et al. have been developing a simulation code described the physical phenomenon in the neutralizers[2)]. For the validation of this code, a 100 mA class microwave discharge neutralizer, the erosion rate of each parts, and measurement of plasma properties, electron number density and electron energy distribution function (EEDF) in the discharge chamber of the neutralizer as well as plume region are essential.

Therefore, the aim of this study is to develop the 100 mA class microwave discharge neutralizer and to measure the erosion rate of each part and the plasma properties at plume region by means of electrostatic probe. In addition, plasma properties inside the discharge chamber is measured by laser Thomson scattering technique (LTS) [4)]. LTS is nonintrusive method for a measurement of plasma properties. In the incoherent regime, the scattered spectrum reflects the Doppler motion of individual electrons, and the scattered intensity is proportional to N_e [5)]. This method was developed to measure plasma properties in high temperature plasma having $N_e > 10^{19}$ m^{-3}. During the last decade, its applicability has been extended to lower density plasma, with densities of less than 10^{16} m^{-3}, by a signal accumulation technique [6)]. This technique allows us to apply LTS to the plasma produced in the discharge chamber of ion thrashers.

II. Experimental Setup

A. Microwave discharge neutralizer

Figure 1 shows the schematic diagram of the neutralizer used in the experiment. The inner diameter, length of the discharge chamber is 18 mm and 12 mm, respectively. The discharge chamber can be change to 21 mm. Four orifice plates, thickness of 2 mm and 8 mm and diameter of the orifice of 5 mm and 3mm are used. The samarium cobalt permanent magnet of 4 mm×4 mm×12 mm is put around the discharge chamber. Fig. 2 shows the internal magnetic field of the neutralizer at the number of magnets of 15. The magnetic circuit consist of a front yoke, a back yoke, a central yoke made by soft iron and the samarium cobalt magnets. The magnetic field strength inside the discharge chamber can be changed by changing the number of the permanent magnets.

Microwave power at 2.45 GHz is fed through a coaxial line and into the antenna. The incident microwave power is fixed at 8 W using PID controller. Three types of antennas—starfish, L-shape, and cross—are used, as shown in Fig. 3. All of the antenna are made of molybdenum.

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Electrons are collected by a collector 20 mm downstream of the neutralizer. The applied voltage on the collector against the neutralizer can be changed.

High-purity (99.9995%) xenon gas was used as the propellant. A thermal mass flow controller was used; flow rate error was less than 5% for most conditions. A 1.0 m diameter by 1.2 m long vacuum chamber was used in the electron extraction and wear test experiments. The pumping system comprised a turbo molecular pump with overall pumping speed of 4000 l/s for air. The temperature of the neutralizer is kept at 290-293K. The mass loss was measured by means of digital analytical balance with 1 mg readability.

The plasma parameters in the plume, that is, at 4 mm downstream of the orifice plate, was measured by means of electrostatic probe. The diameter and the length of the probe is 0.15 mm and 2 mm, respectively.

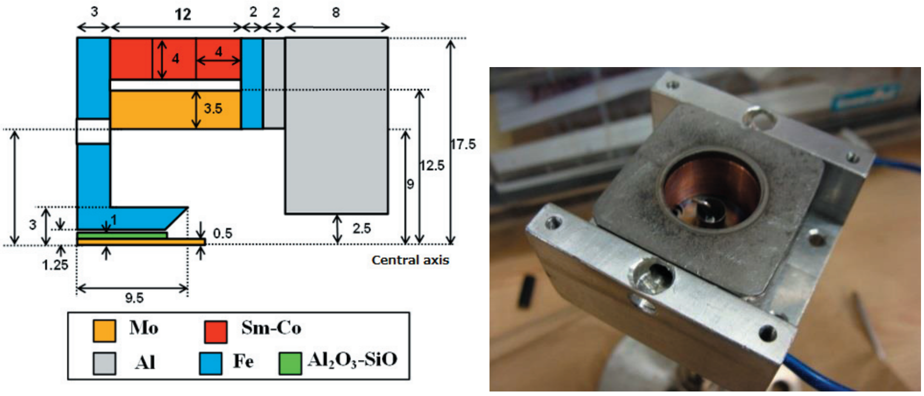

Figure 1. The schematic diagram of the neutralizer.

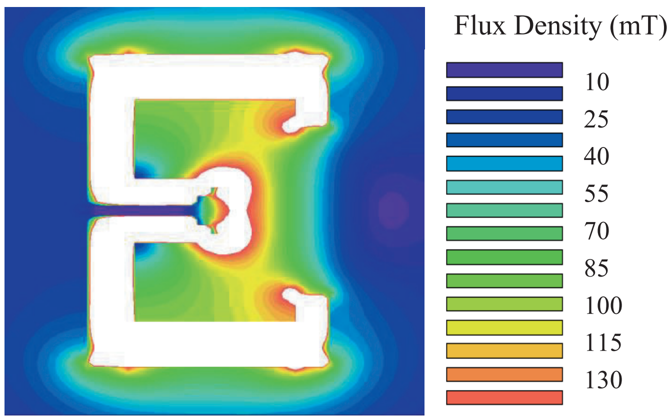

Figure 2. The internal magnetic field of the neutralizer.

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Figure 3. The photographs of each antenna (Left: cross, Middle: starfish, Right: L-shape)

III. Results and Discussion

A. Dependency of the electron extracted current on the neutralizer configurations

First, we investigated the dependency of orifice diameter on the extracted electron current. Fig.4 shows the extracted electron current for four orifice plate as shown in table 1. Diameters, 3 mm and 5 mm. In the case of diameter of 3 mm and thickness of 2 mm, the current jump at 39 V and, electron extracted current is 140 mA at collector voltage of 50 V. In the case of diameter of 3 mm and thickness of 8 mm, the current jump at 37 V and, electron extracted current is 75 mA at collector voltage of 50 V. In the case of diameter of 5 mm and thickness of 2 mm, the current jump at 35 V and, electron extracted current is 140 mA at collector voltage of 50 V. In the case of diameter of 5 mm and thickness of 8 mm, the current jump at 45 V and, electron extracted current is 150 mA at collector voltage of 50 V. When the diameter is 5 mm and the thickness is 8 mm, we found that the neutralizer could extract maximum current. Therefore, the optimum orifice thickness is 8 mm and the diameter is 5 mm.

Figure. 5 shows the extracted electron current for three magnet if field strength, the number of $4\times4\times12$ magnets of 14, that of 15, and ring magnets. In the case of magnets of 14, the current jump at 45 V and, electron extracted current is 120 mA at collector voltage of 50 V. In the case of magnets of 15, the current jump at 35 V and, electron extracted current is 140 mA at collector voltage of 50 V. In the case of ring magnet, the current jump at 40 V and, electron extracted current is 160 mA at collector voltage of 50 V. Therefore, the optimum magnets is ring.

Figure. 6 shows the extracted electron current for three antenna shape, L shape, cross, and starfish. In the case of L shape, the current jump at 40 V and, electron extracted current is 120 mA at collector voltage of 50 V. In the case of cross, the current jump at 50 V and, electron extracted current is 80 mA at collector voltage of 50 V. In the case of starfish, the current jump at 50 V and, electron extracted current is 60 mA at collector voltage of 50 V. Therefore, L shape performance was the best in these antennas[9)]. It is thought that the loss was suppressed because the surface area of the antenna is small[10)]. Therefore, we adopted the L shape antenna.

Figure. 7 shows the electron extracted current for two discharge chamber diameter, 18 mm and 21 mm. In the case of 18 mm, the current jump at 40 V and, electron extracted current is 120 mA at collector voltage of 50 V. In the case of 21 mm, the current jump at 45 V and, electron extracted current is 55 mA at collector voltage of 50 V. Therefore, we adopted the discharge chamber whose inner diameter is 18 mm.

Table 1. Orifice plate parameters.

Orifice plate	Diameter, mm	Thickness, mm
1	3	2
2	3	8
3	5	2
4	5	8

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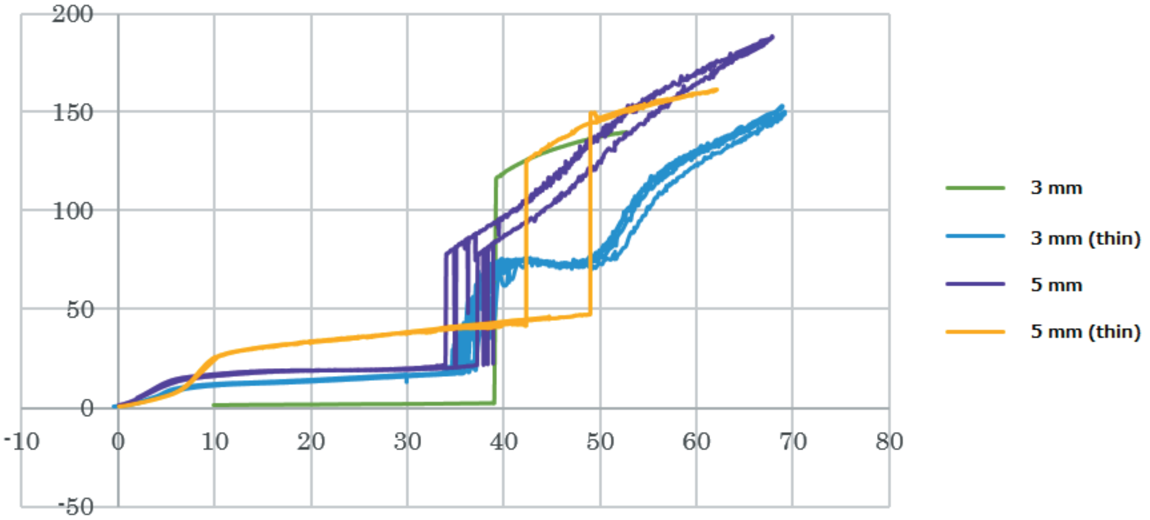

Figure 4. The comparison at the diameter and the thickness.

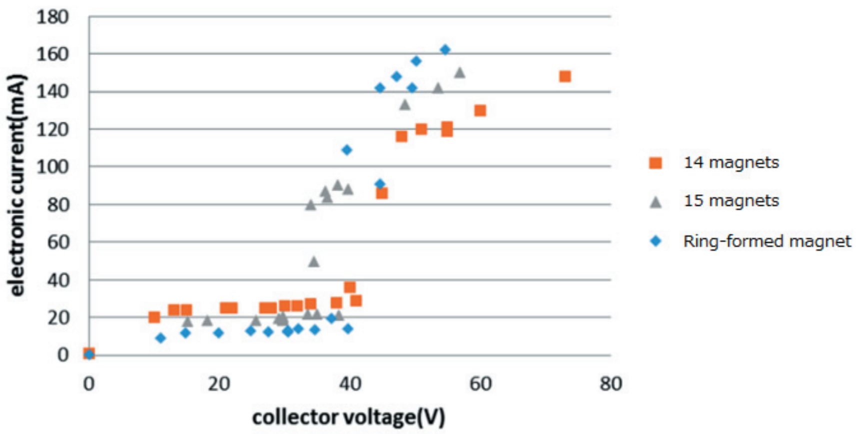

Figure 5. The comparison at the magnetic field.

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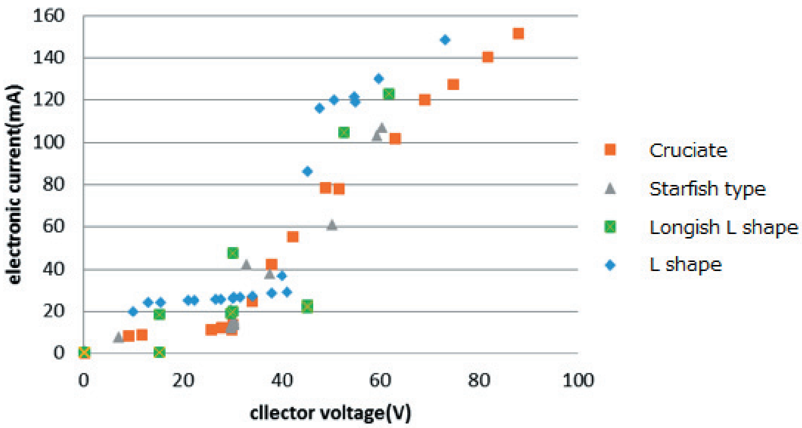

Figure 6. The comparison at the shape of the antenna.

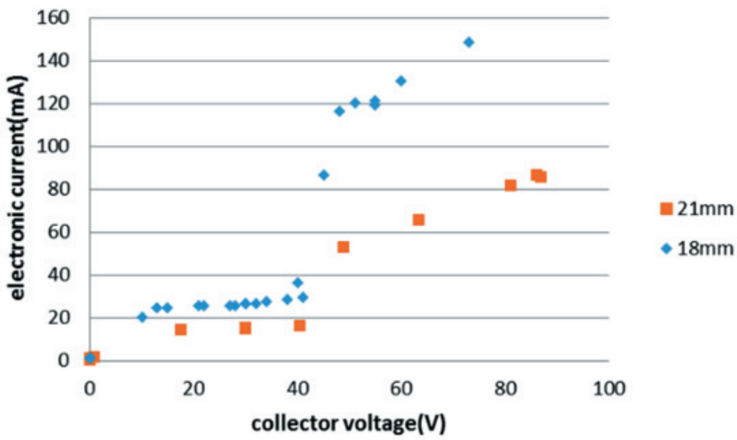

Figure 7. The comparison at the inner diameter of the discharge chamber.

C. The results of 100 hours durability test

We performed 100 hours durability test using the optimized neutralizers. The shape of the optimized neutralizers is as follows, the orifice thickness is 8 mm, the orifice inner diameter is 5 mm, the antenna shape is L, and the discharge chamber inner diameter is 18 mm. The ignition probability using ring magnet is small, therefore, we used fifteen 4×4×12 magnets. The material of each part is different for easy detection, that is, the antenna, chamber wall, front and back yokes, orifice plate are made of molybdenum, copper, sort iron and aluminum, respectively. Fig. 8 shows the history of the electron extracted current and the microwave reflection power. As time goes by, the electron extracted current decreases 150 mA and the reflection power increases 0.4 W.

We measured the mass loss of each parts of the neutralizers before and after the examination one hundred hour's operation, as shown Table. 2. The mass of the front yoke, the back yoke, and the orifice increased. And the mass of the discharge chamber, the antenna, the dielectric decreased. The contamination with the metallic luster attached to the back yoke. In addition, the antenna was worn out by sputtering. Furthermore, the color of the dielectric near the antenna becomes black.

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XRF analysis shows that the contamination of the dielectric consists of Aluminum (45%), Silica (23%), Copper (10%), Molybdenum (6%), Potassium (4%), iron (45) and other materials, as shown in Fig. 9 and the contamination of the back yoke consists of Copper (81%), Aluminum (16%), Iron (2%), Magnesium (1%) and other materials, as shown in Fig. 10.

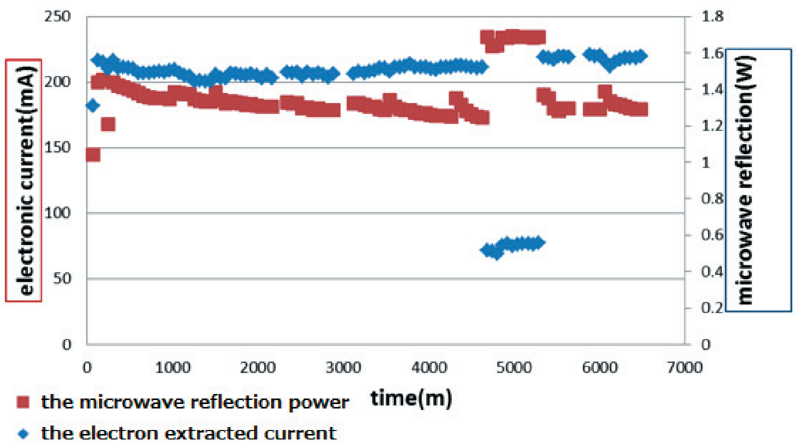

Figure 8. The transition of the electron extracted current and the microwave reflection electricity.

Table 2. The mass transition in around 100 hours of each part of the neutralizers.

Kind	Material	Weight(Before)[g]	Weight(After)[g]	Difference[g]
Orifice	Aluminum	51.0751	51.0808	0.0057
Back yoke	Soft iron (S45C)	28.5077	28.5206	0.0129
Front yoke	Soft iron (S45C)	15.9682	15.9708	0.0026
Discharge chamber	Copper	25.0356	25.0168	-0.0188
Antenna	Molybdenum	0.1673	0.166	-0.0013
Insulator	Ceramic	0.0617	0.0616	0.0001
	Total	120.8156	120.8166	0.001

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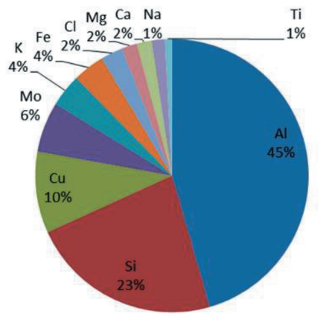

Figure 19. The result of the element analyzing of the dielectric.

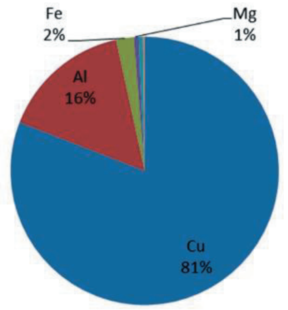

Figure 20. The result of the element analyzing of the back yoke.

D. The results of the plasma potential measurement experiment

We measured the plasma properties at 4 mm downstream from the neutralizers using the single probe[11)]. Fig. 11 shows plasma potential 4 mm downstream of the orifice plate vs. collector voltage at mass flow rate of 0.05 mg/s and incident microwave power of 8 W. Fig.12 shows electron temperature 4 mm downstream of the orifice plate vs. collector voltage at mass flow rate of 0.05 mg/s and incident microwave power of 8 W. Fig. 13 shows electron density 4 mm downstream of the orifice plate vs. collector voltage at mass flow rate of 0.05 mg/s and incident microwave power of 8 W. Fig. 14 shows electronic extracted current 4 mm downstream of the orifice plate vs. collector voltage at mass flow rate of 0.05 mg/s and incident microwave power of 8 W. We were able to obtain the data in order to evaluate the numerical simulation.

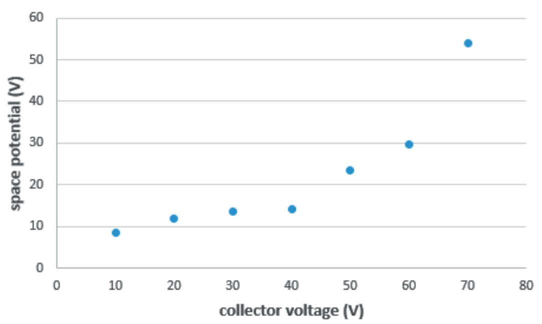

Figure 11. Plasma potential 4 mm downstream of the orifice plate vs. collector voltage at mass flow rate of 0.05 mg/s and incident microwave power of 8 W.

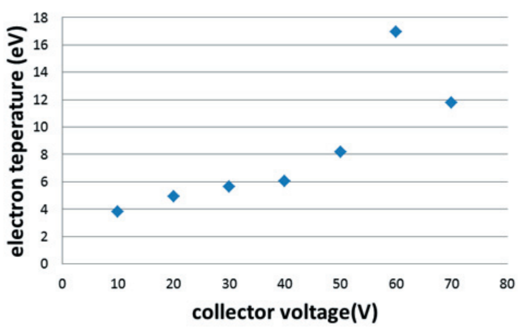

Figure 12. Electron temperature 4 mm downstream of the orifice plate vs. collector voltage at mass flow rate of 0.05 mg/s and incident microwave power of 8 W.

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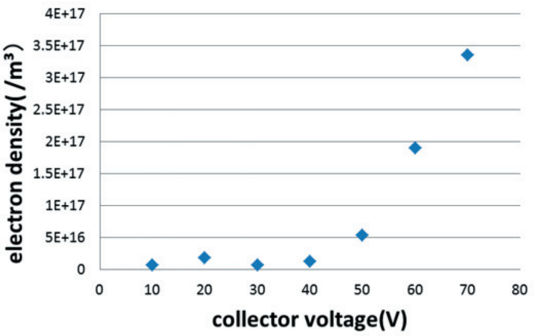

Figure 13. Electron density 4 mm downstream of the orifice plate vs. collector voltage at mass flow rate of 0.05 mg/s and incident microwave power of 8 W.

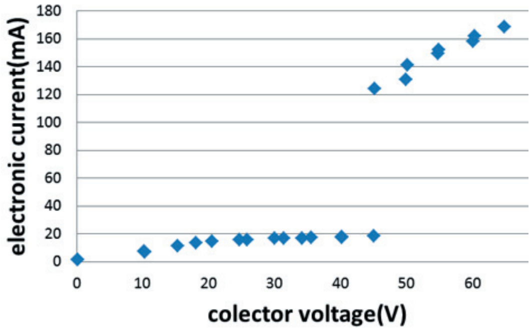

Figure 14. Electronic extracted current 4 mm downstream of the orifice plate vs. collector voltage at mass flow rate of 0.05 mg/s and incident microwave power of 8 W.

IV. Conclusion

In this study, we performed 100 hours durability test and investigated the mass transition and element analyzing of the dielectric and the back yoke. We obtained the data of the mass loss, the contamination and the element analyzing of the dielectric which are needed to inspection of the validity of the numerical simulation by 100 hours durability test. We will perform the experiment with LTS in order to investigate the plasma parameter such as the electron temperature and the density.

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