Plasma Luminescence Measurements in the ECR Ion Thruster µ10 Using an Optical Fiber Probe

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By the success of the Japanese asteroid explore "Hayabusa", the ECR ion thruster µ10 is to be installed with the successive explore "Hayabusa 2", and 1.0 – 1.5 tons geosynchronous satellites. To install with these spacecrafts, the thrust force of µ10 was enhanced from 8.0 mN to 10.1 mN by the improvement of the grids and the way of the propellant injection. And to investigate the change of plasma distribution in the thruster, a new optical fiber probe was introduced. By this probe, it turned out that there exist the plasma in the waveguide, which interferes with the transmittance of the microwave with high possibility.

Nomenclature

e	=	Electron
F	=	Thrust force
I_b	=	Beam current
I_s	=	Screen current
M	=	Mass of an ion
V	=	Electric Voltage
η_{div}	=	Efficiency of divergence of the ion beam
η_{multi}	=	Efficiency of multi charged ions

I. Introduction

The Japanese asteroid explorer "Hayabusa" was launched on May 9th 2003. It is going to return to earth in June 2010 powered by the ECR ion thruster µ10. Through the mission, the total established operation time has become 34,200 hours by July 2009. To apply the ion thruster µ10 to a wide variety of spacecrafts such as 1.0 - 1.5 tons geosynchronous satellites or the deep space explorer "Hayabusa 2", the thrust force of µ10 must be enhanced from 8.0 mN to 10.0 mN at least. To achieve the purpose, we have proposed two improvements.[1)] One was the introduction of a thinner screen grids and a small hole accelerator grid, and the other was the change of the way of the propellant injection. Conventionally there is a propellant inlet in the waveguide, this time eight new propellant inlets were added in the discharge chamber between magnets. And it turned out that a distribution of the propellant

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between the waveguide inlet and the discharge chamber inlets improved the beam current, and the best proportion of distribution was 1:2 to achieve 10.1 mN keeping Isp 3160 s.

Additionally we proposed a new plasma luminescence measurement using an optical fiber probe in order to reveal the effect of the propellant distribution. Until now it is confirmed that the luminescence of µ10 changes as the mass flow rate increases, which is shown in Figure 1.[2] This time, we have succeeded in measuring the difference of the luminescence for the first time.

This paper reports that the results of the enhancement of the beam current and that of the optical measurement inside the discharge chamber using an optical fiber probe.

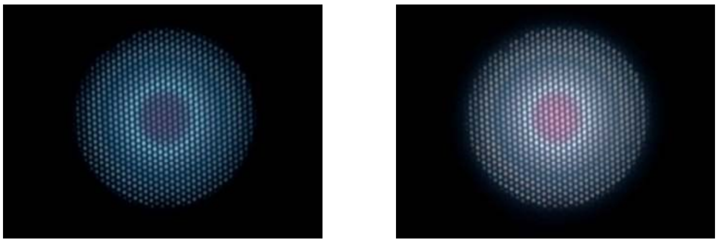

Figure 1. The difference of the plasma luminescence at the front view of µ10

II. Experimental Apparatus

A. The ECR ion thruster µ10

A schematic of the ECR ion thruster µ10 is shown in Figure 2. The µ10 consists of a waveguide, a discharge chamber, and three flat grids which are made of carbon composite. There a microwave antenna and a propellant inlet in the waveguide. The 4.25GHz microwave is transmitted from a waveguide to the discharge chamber. In the discharge chamber, there are two rings of samarium-cobalt magnets, and xenon plasma is produce by electron cyclotron resonance. Charged xenon ions are electrostatically accelerated by the grids. Equation (1) shows the relationship of the thrust force and an ion beam current. Since the thrust force is proportional to the ion beam current, the beam current must be enhanced from 135 mA to 169 mA at least to achieve 10.0 mN of thrust force.

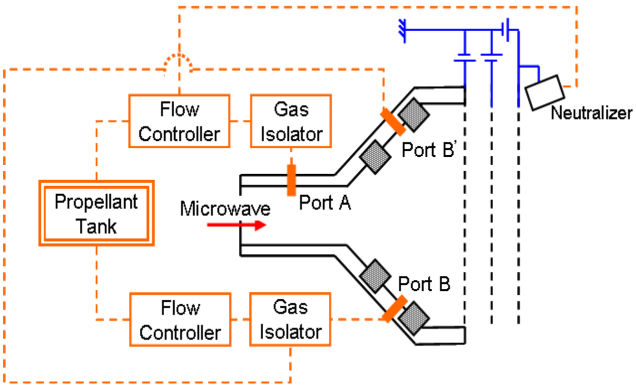

Figure 2. The schematic of the ECR ion thruster µ10

$$F = \eta_{div}\eta_{multi} I_b \sqrt{\frac{2MV_s}{e}} \qquad (2)$$

1. Propellant inlets

There is originally a propellant inlet in the waveguide, besides this, eight inlets are added between magnets rings. Though each of them can be selected open or close, it is certificated that the difference of a circumferential direction is quite little[1], and all inlet are open in this experiment. The mass flow rate of the waveguide inlet and the discharge chamber inlets is controlled independently.

2. New grids system

µ10's grid system consists of three carbon composite grids, a screen grid, an accelerator grid, and a decelerator grid. The original configuration of these grids is shown in Table 1. The nominal electric voltage of the screen grid is 1,500 V, that of the accelerator grid is -350 V, and the decelerator grid is grounded. Considering a limit of the electric isolation, the gap of the screen grid and the accelerator grid must be short as long as possible to increase the beam current. To increase the electric field between the screen grid and the accelerator grid, the thickness of a new screen grid has decreased from 0.95 mm to 0.50 mm.

And the aperture diameter of the accelerator grid is changed from 1.80 mm to 1.50 mm to improve the mass utilization efficiency. This new small holes accelerator grid (SHAG) prevents a leakage of neutral atoms from the discharge chamber. The open area fraction of the accelerator grid is down from 24 % to 17%.

Table 1. The configuration of grids

Grid	Diam.(mm)	Thickness (mm)	Gap(mm)
Screen	3	0.5	
			0.5
Accelerator	1.5	1	
			0.5
Decelerator	2.8	1	

Grid	Diam.(mm)	Thickness(mm)	Gap(mm)
Screen	3	0.95	
			0.5
Accelerator	1.8	1	
			0.5
Decelerator	2.8	1	

B. Optical fiber probes

In this experiment, a new method to investigate the luminescence in the discharge chamber is introduced using an optical fiber probe. The probe is made of a dielectric material silica glass. The diameter of its clad is 1.00 mm and that of its core is 0.90 mm. The probe's numerical aperture is 0.32, which is 35 degree. And the optical transmittance is optimized at the wavelength range 400nm - 1100nm. For it is composed of the dielectric material, its accessibility to microwave the electromagnetic field is very high comparing with conventional metal probes. The probes enable the nondestructive monitoring of the plasma luminescence inside µ10, while the ions are accelerated. And it has a local sensitivity.

Figure 3 shows the luminescence measurement setup. The probe is inserted from a center hole of the grids. At first one edge of the probe is set at the screen grid, then the probe is moved into µ10 by a stepping motor. It can detect the plasma luminescence with little interference.

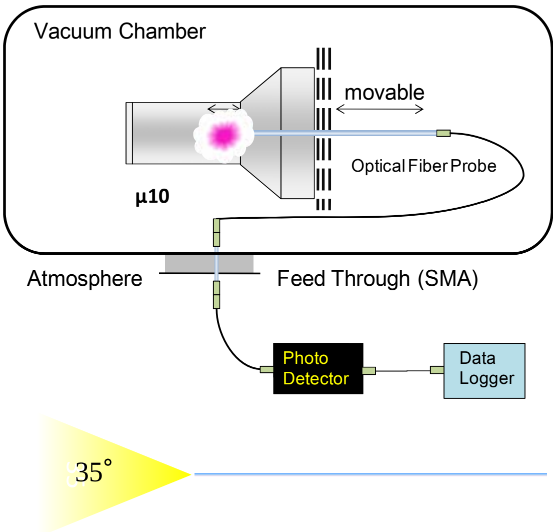

Figure 3. Plasma luminescence measurement set up

C. Vacuum facilities

Vacuum facility is shown in Figure 4. The diameter of a vacuum chamber is 2.0 m, and its length is 5.0 m. This chamber is installed with the four cryopumps, and the exhaust velocity of one cryopump is 28,000 l/s (Nitrogen). This chamber has two sub chambers, "sub A" and "sub B", which are separated from a main chamber by gate valves. Currently µ10 is set at the sub B chamber. In the sub A chamber, the endurance test of µ20 is underway. Each sub chamber has a turbo booster pump and it is connected to a common rotary pump to vacuum from the atmosphere pressure. The back ground pressure is 4.5Ø 10^{-5} Pa in the experiment.

Figure 4. Vacuum facilities

III. Results and discussion

A. Beam current

μ10 was newly installed with the thinner screen grid and the small hale accelerator grid. Figure 5 shows the relationship between the beam current and xenon mass flow rate using the new grids system. The original μ10 is set at the microwave power of 34W. To confirm the response to the microwave power, it was set at the microwave power of 30 W, 37 W, and 44 W. When the propellant is injected from the waveguide inlet, the ion beam current saturates at 150 mA even if more microwave power increase. In contrast, when the propellant is injected only from the discharge chamber inlets, the microwave power increases the beam current. However this method needs more propellant to achieve 169 mA (10.0 mN) of the beam current. The best way of propellant injection is to use the both inlets. By distributing the propellant, the line is arbitrary changeable between two of them. The optimized proportion of the waveguide inlet to the discharge chamber inlets is 1 to 2. This proportion enables the 169 mA with the minimum of the xenon mass flow rate at the 34W of the microwave power.

The results of the introduction of the new grids system and the distribution of propellant between the discharge chamber inlets and the waveguide inlets are shown in Table 2.

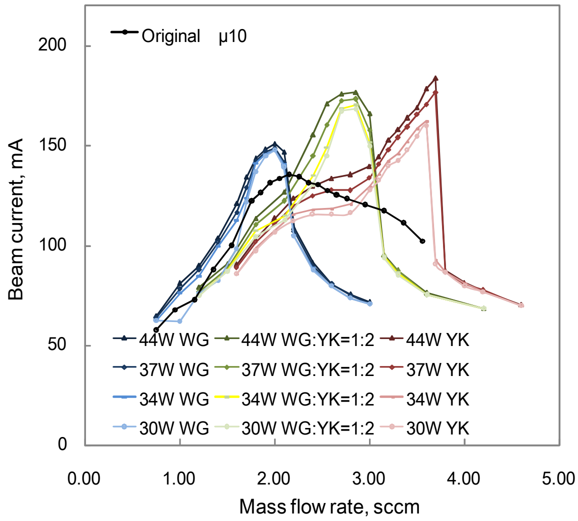

Figure 5. Improvement of beam current (WG : waveguide, YK : yoke)

Table 2. Specifications of µ10

	Original	New
Microwave Power (W)	32	34
Microwave frequency (GHz)	4.25	4.25
Beam diameter (cm)	10.5	10. 5
Thrust force (mN)	8.0	10.1
Beam current (mA)	135	172
Specific impulse (s)	3200	3160
Ion production cost (eV)	230	197
Xenon flow rate (sccm)	2.2	2.85 (WG:0.95, YK:1.90)
Screen voltage (V)	1500	1500
Accelerator voltage (V)	-350	-350

B. Luminescence measurement

Figure 6 shows the distribution of the plasma luminescence in µ10 which is installed with conventional grids. The distribution of the luminescence is apparently changed by the acceleration. And Figure 7 is the differential of plasma luminescence along with the optical probe axis, which expresses the local distribution of plasma in µ10. Without the ion beam acceleration, the luminescence can be detected around the boundary area of the waveguide and the discharge chamber. However once the ion beam is extracted, the intensity of the luminescence become little in the low mass flow rate. Then it suddenly vibrates at the 1.50 sccm xenon mass flow rate, and suddenly the plasma appears in the waveguide.

In the original configuration of µ10, the beam current rapidly increases around 1.50 – 1.75 sccm of the propellant mass flow rate. At that time, a reflectance of the microwave power suddenly decreases, then beam current saturates as the mass flow rate increases. Once the beam current saturates, the reflectance of the microwave power gradually increase, the beam current become lower, and the luminescence intensity become higher. The luminescence in the waveguide has close relationship with the beam current saturation. As one of interpretations, the presence of plasma in the waveguide cause the beam current saturation and increase of a microwave power reflectance.

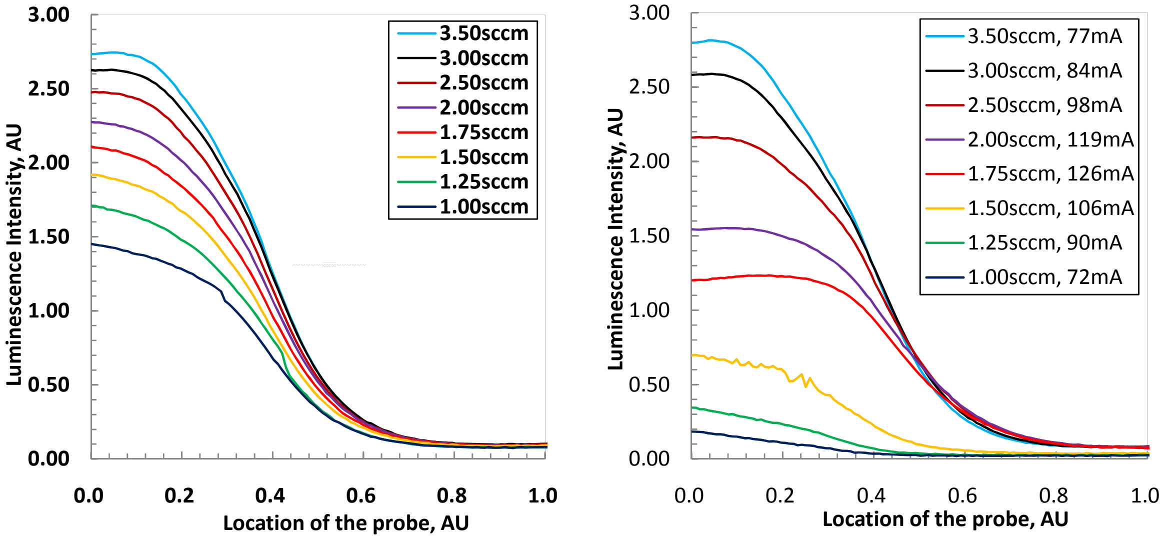

Figure 6. Distribution of plasma luminescence in the center of the ECR ion thruster µ10 (left : No acceleration, right : acceleration)

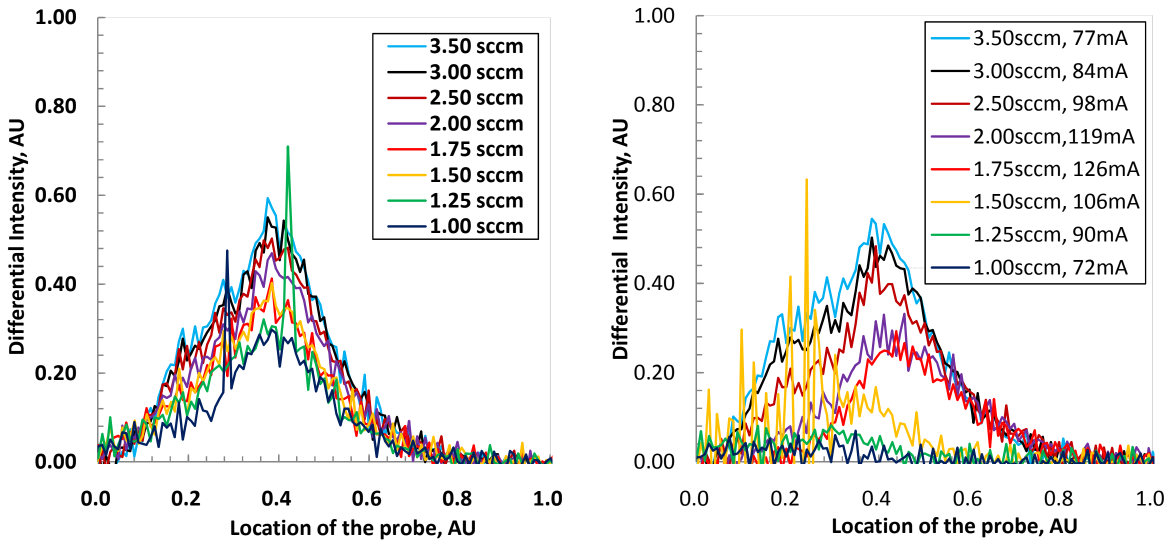

Figure 7. Differential plasma luminescence in the center of the ECR ion thruster μ10 (left : No acceleration, right : acceleration)

IV. Conclusion

The thrust force of μ10 is increased from 8.0 mN to 10.1 mN and at that time the specific impulse slightly decreased from 3200 s to 3160 s. Though the experiment, it is certificated that the thinner grid and small hole accelerator grid have the effectiveness on the enhancement of the beam current. The optimized distributional proportion of the waveguide inlet to the discharge inlets is 1:2.

And it also turned out that the new optical fiber enables the detection of the luminescence in the ECR thruster with little interference. The luminescence is detected in the boundary of the waveguide and the discharge chamber. Especially when the beam is accelerated, the luminescence is dramatically changed by the increase of the propellant. In the low mass flow rate, the little luminescence can be detected, however, as the mass flow rate increases, the luminescence oscillates and it can be detected in the waveguide. This shift is correlative with the beam current saturation. As one of interpretations, the propellant mass flow rate increases, the plasma density increase more and more in the boundary area. The plasma in this area prevents the microwave transmit to the discharge chamber and it makes the beam current saturation.

Acknowledgments

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