Insight into Performance Improvement of ECR Neutralizer

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W. Ohmichi[1]
The University of Tokyo, Bunkyo, Tokyo, 113-8656, Japan

and

H. Kuninaka.[2]
The Institute of Space and Astronautical Science, Sagamihara, Kanagawa, 252-5210, Japan

Abstract: The electron cyclotron resonance microwave discharge ion thruster μ10, which was installed in Hayabusa, has experienced an autonomous stop in the final phase of Hayabusa project by the degradation of the neutralizer. It was shown that the neutralizer is a critical element that limits the thruster lifetime. From the previous studies, it was shown that to increase sputtering resistance of surface of discharge chamber against divalent xenon ions bombardment is effective to enhance endurance. To suppress the sputtering, suppressing the neutralizer voltage is effective. To achieve it, first we found out which area are mainly sputtered using split electrodes. Then we suppressed the voltage by improving the area which is mainly sputtered.

I. Introduction

THE Japanese asteroid explorer Hayabusa is the first spacecraft that uses an electron cyclotron resonance (ECR) microwave discharge ion thruster[1)] as its primary propulsion system. The accumulated operating time of Hayabusa's four "μ10" thrusters is nearly 40,000 hours[2)] in space. This achievement depends to a large extent on plasma generation by ECR heating. Discharge electrodes, whose erosion is a typical cause of failure for conventional ion thrusters,[3)] are eliminated in microwave plasma generation. However, the μ10 thruster experienced a degradation of its neutralizer. The neutralizer is a critical component limiting the thruster lifetime. It is necessary to increase the endurance of the neutralizer to make the spacecraft lifetime longer. The objective of the present study is to discover methods to extend its life. From the previous study[4)] it was shown that to increase sputtering resistance of surface of discharge chamber against divalent xenon ions bombardment is effective to enhance endurance. To suppress the sputtering, suppressing the neutralizer voltage is effective. To achieve it, first we found out which area are mainly sputtered by using split electrodes.

II. Experimental Setups

To find out the method to suppressing the contact voltage, first we find out where we should improve in the neutralizer by separated electrodes.

A. Separated Electrodes

When ECR neutralizer emits electrons, the same charge of xenon ions bombard inside of the neutralizer as a counterpart. This charge flows to the earth ground. We measured this net ion current by insulating each part of the neutralizer and investigated net ion current distribution when running the neutralizer. Figure 1 shows the example of

[1] Graduate student, Department of Aeronautics and Astronautics, wataru@ep.isas.jaxa.jp
[2] Professor, Department of Space Flight Systems, kuninaka@isas.jaxa.jp

net ion current measuring of the orifice plate. We can measure net ion current of each part by this method except net ion current of antenna. Figure 2 diagrams the measurement system of the neutralizer in its so-called diode mode. It is evacuated by a turbo molecular pump to 3 mPa and operated at the parameters given in Table 1. The length of the matching circuit is adjusted to minimize the reflected power at a nominal electron emission current of 135 mA. In the present experiments, the electron emission current is between 85 and 170 mA. The contact voltage is the potential difference between the anode and the neutralizer in diode mode, for which electrons emitted by the neutralizer are collected by the anode located 1.6 cm away from the exit of the neutralizer orifice. In operational mode, the neutralizer emits electrons into a plasma beam. To measure net ion current of antenna we used a microwave connector called "bias-tee" which was a high pass filter of the microwave and the core of the coaxial cable could be electrostatically separated from the upstream circuits. With the use of bias-tee, we could regard the antenna as a cylindrical probe and measure the ion saturation current and the floating potential. Figure 3 shows the experimental setup of measuring the net ion current, ion saturation current and the floating potential.

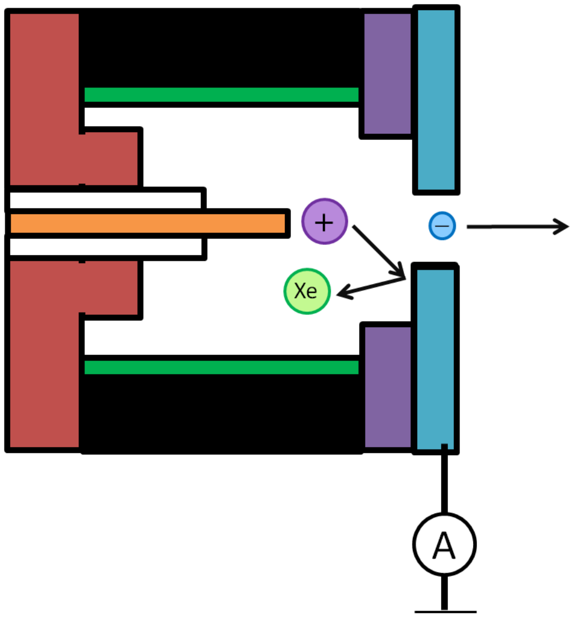

Figure 1. Schematic of the net ion current measuring of the orifice plate. *Red and purple parts are magnetic circuits which are steel. Green part is sidewall of discharge chamber which is molybdenum. Blue part is orifice plate which is also molybdenum. Orange part is antenna which is brass. Black parts are magnets and white parts are dielectric.*

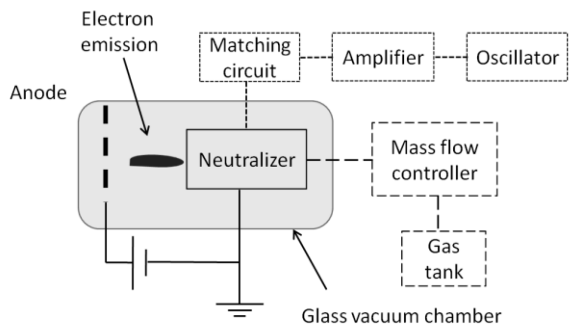

Figure 2. Schematic of the neutralizer performance measurement system.

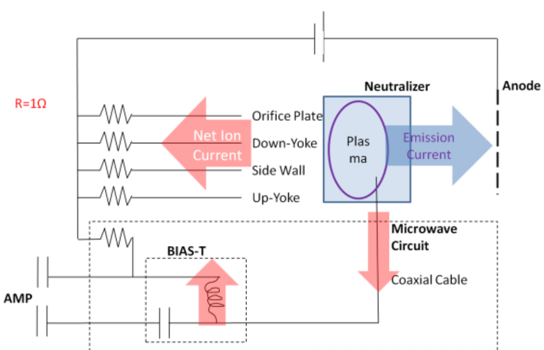

Figure 3. Schemtaic of the net ion current measuring circuit. *Summary of the emission current and summary of the net ion current is the same. Power source supplies the contanct voltage.*

Table 1. Nominal specifications of the µ10 neutralizer.

Microwave power	8 W
Microwave frequency	4.25 GHz
Xenon flow rate	0.5 sccm (0.49 µg/s)
Electron emission current	135 mA at 8 mN
Contact voltage between neutralizer and beam plasma	22 V

III. Experimental Results

A. Separated Electrodes

Figure 4 shows the results of net ion current distribution of neutralizer. The colors in figure are corresponding with Fig. 1. In Fig. 4, it is shown that

1) side wall is collecting most net ion currents than other parts.
2) antenna is collecting many electrons.

In addition to 1), density of net ion current mA/cm2 is almost the same in side wall, upstream yoke, and downstream yoke. In addition to 2), neutralizer is the component which emits electrons, so it indicates that antenna work against the neutralizer performance.

From these facts, floating the antenna is effective to suppress the neutralizer voltage that is shown by Fig. 6. Figure 5 shows the results of net ion current distribution when antenna is floated. The antenna is not collecting electrons much more than ions anymore and all the parts of neutralizer are collecting ions than electrons.

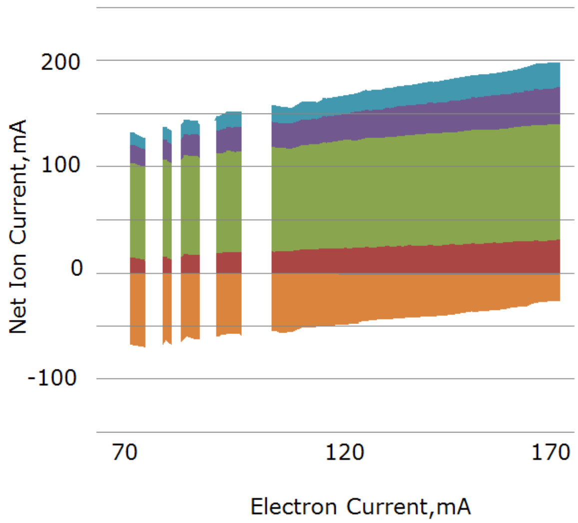

Figure 4. The net ion current distribution of nominal neutralizer. *Each color is corresponding with Fig. 1.*

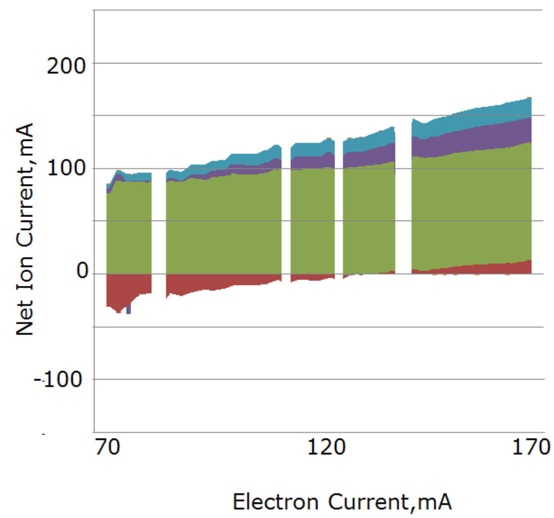

Figure 5. The net ion current distribution of floated antenna neutralizer. *Each colors are corresponding with Fig. 1. The antenna is not collecting net electrons any more.*

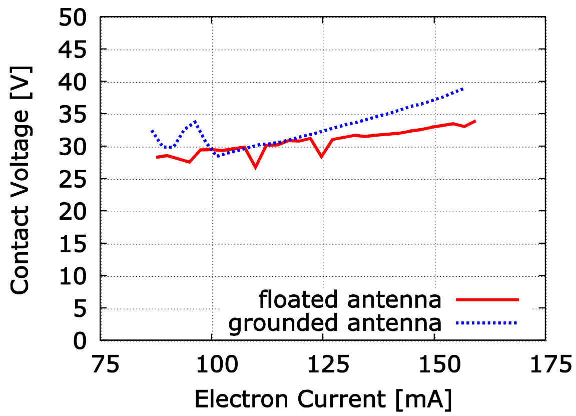

Figure 6. Performance of neutralizers with grounded antenna and floated antenna.

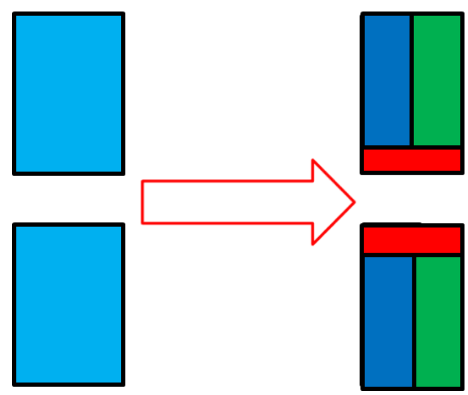

Figure 7. The schematic of new-designed orifice plate.

B. Improving point

As we mentioned before, components of the neutralizer except the antenna are collecting ions more than electrons, so when we floated them performance got worse. However, when we floated an orifice plate, performance got better. We newly made orifice plate shown as Fig. 7. This orifice plate suggests us the difference of ion collecting with the inner surface of the discharge chamber (blue), surface of the orifice (red) and the surface of outside the neutralizer (green). We call them as “outer”, “inner” and “downstream” in here.

Figure 8 shows the net ion current distribution of this orifice plate neutralizer. In this figure, the colors in figure are corresponding with Fig. 7. Figure 8 shows that the downstream side of orifice plate which colored by green are 0 mA in all electron currents. It results in no change in performance shown in Fig. 9.

Figure 9 shows the performance difference between nominal neutralizer and orifice floated neutralizers. In Fig. 9, it is shown that floating inner orifice is effective to performance improvement, but floating outer orifice have a bad effect to performance improvement. From this fact, it shows outer side of orifice is dominant in collecting ions but inner side of orifice is not.

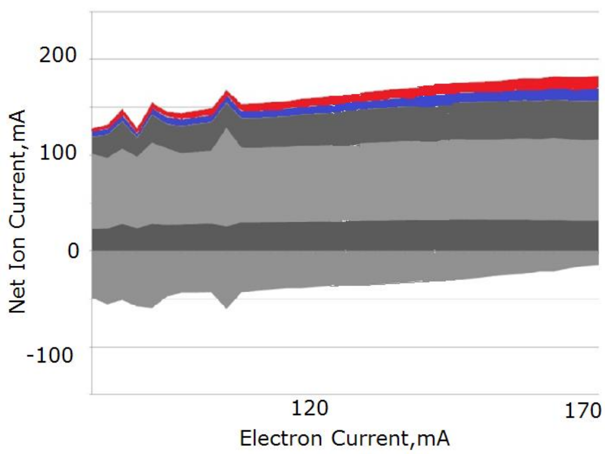

Figure 8. The net ion current distribution of new designed orifice plate neutralizer. *Each colors are corresponding with Fig. 7. Gray areas are almost the same asFig. 4.*

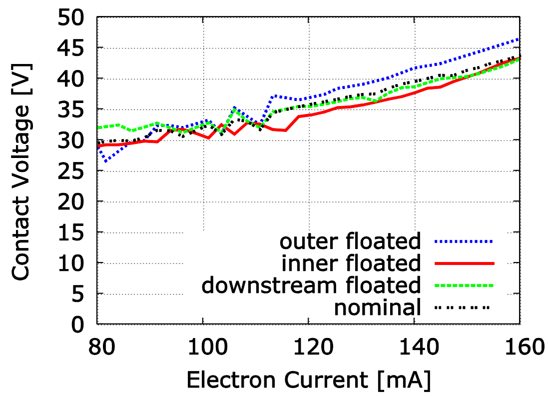

Figure 9. Performance of nominal neutralizer and new designed orifice plate neutralizer in some conditions.

C. Dielectric Orifice

We replaced inner orifice which is shown in Fig. 7 as dielectric. Figure 10 shows the performance difference between nominal orifice and dielectric orifice. It is clear that replacing the molybdenum inner orifice to dielectric is effective to performance improvement at high electron current.

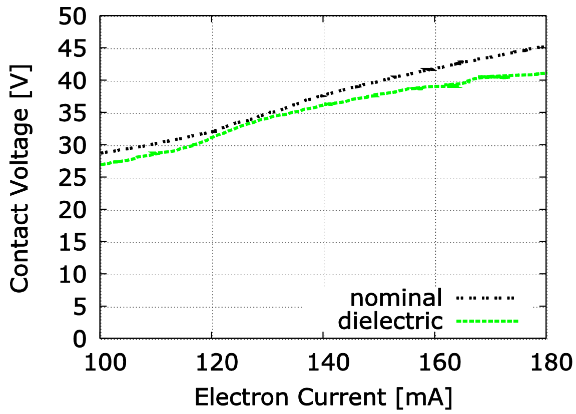

Figure 10. Performance of nominal neutralizer and dielectric inner orifice neutralizer.

IV. Conclusion

Neutralizer voltage can be suppressed by floating antenna. This is because antenna is collecting electrons much more than ions. The voltage also can be suppressed by floating inner orifice.

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