1-A class Microwave Discharge Cathode Using Impregnated Tungsten

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Abstract: **The microwave discharge ion engine μ10 was the first time demonstrated in the space by the Japanese asteroid explorer "Hayabusa". The μ10 ion engine generates plasma by ECR discharge method. Since this plasma generation method is the electrodeless discharge, which does not require electrodes, it is possible to avoid electrode erosion. This is one of the typical failure mechanism in conventional DC ion engines, thus the microwave discharge ion thruster is potentially long life. In fact, the total accumulated operation time of μ10 ion thrusters equipped "Hayabusa" reached approximately 40,000 hours; therefore it is said that the μ10 ion engine is the most reliable thruster for spacecraft. However, compared to the DC discharge type ion engine, the beam current of the microwave discharge type is smaller, thus it is inferior in the point of thrust. The ultimate object of this study is to increase the emission current of microwave discharge neutralizer. To accomplish that object, in this paper we show the results of the fundamental research to increase emission current from neutralizer by composite method of the thermionic emission and the microwave discharge.**

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I. Introduction

THE ion engine is one of the electric propulsions for spacecraft. It generates plasma by heating and ionizing the propellant by an arc discharge or microwave, and gets thrust by accelerating the ions in the plasma by electrostatic acceleration. Although its thrust power ratio is low, it has a number of advantages, such as high specific impulse, high propulsion efficiency, 10,000 hours or more of long life, and abundant space achievements. And it is often used for long-term deep space exploration mission. The microwave discharge ion engine μ10 is equipped with the Japanese asteroid explorer "Hayabusa", and its accumulated total operation time reached approximately 40,000 hours. Since this type of ion engine has no electrodes, it can avoid some failure modes, such as electrode erosion, which is a major life limiting factor for the DC discharge type ion engines. Thus it is with excellent long life and high durability. However, its thrust is approximately 10mN, one order of magnitude lower than the DC discharge type ion thruster. Thus to increase the beam current is an important issue. This is also true both ion source and neutralizer. Several studies have been carried out with respect to thrust enhancement of microwave discharge ion engine. The thrust of ion thruster equipped with the Japanese asteroid explorer “Hayabusa2”, launched in December 2014, is raised to 10mN from 8mN, and it has met the mission requirements. There is also progressed development of large ion engine μ20. The United Arab Emirates satellite “DubaiSat2”, launched in November 2013, is equipped with the 500mA-class microwave discharge neutralizer, and it has been successfully demonstrated in 2014. However, considering the recent trend of development of high-power electric propulsion engines, it is sure that microwave discharge ion engine is required further thrust enhancement.

The object of this study is the development of the1-A class microwave discharge neutralizer. And this paper reports some experimental results of basic researches on electric emission characteristics of neutralizer by combining thermionic emission and microwave discharge.

II. Experimental Apparatus

To confirm the effectiveness of the increasing of emission current by combining thermionic emission and microwave discharge, we measure how the emission current changes due to insert a thermionic emissive probe into plasma column. Figure 1 shows the schematic diagram of the neutralizer used in this research, and Figure 2 shows the schematic diagram of the experimental apparatus. The neutralizer used in the experiments is the laboratory model of μ10. Each parameter of the neutralizer conforms to the nominal value of "Hayabusa 2"; input power of microwave is 8W, its frequency is 4.25GHz, and the xenon gas flow rate is 0.7sccm. The orifice diameter is 4mm. Figure 3 shows the nominal performance of the neutralizer. Table 1 lists the specifications of the vacuum chamber and vacuum pumps used in the experiments. For thermionic emission we use the 2% Th-W wire φ0.23mm in a circular shape. In order to measure the emission current changes due to thermionic emission, the contact voltage are set to 38V, constant voltage mode.

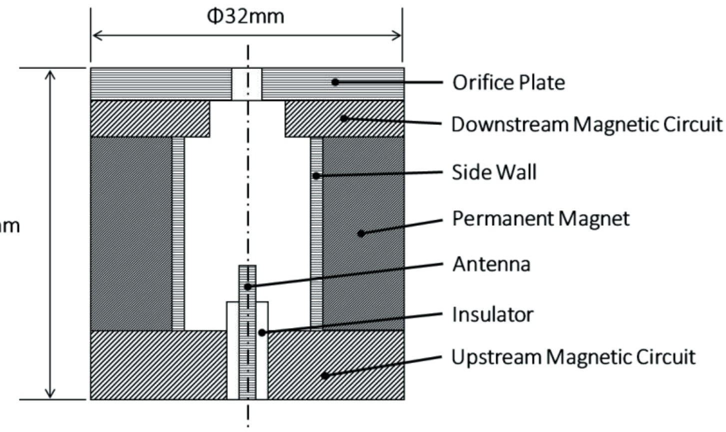

Figure 1. Schematic diagram of the neutralizer

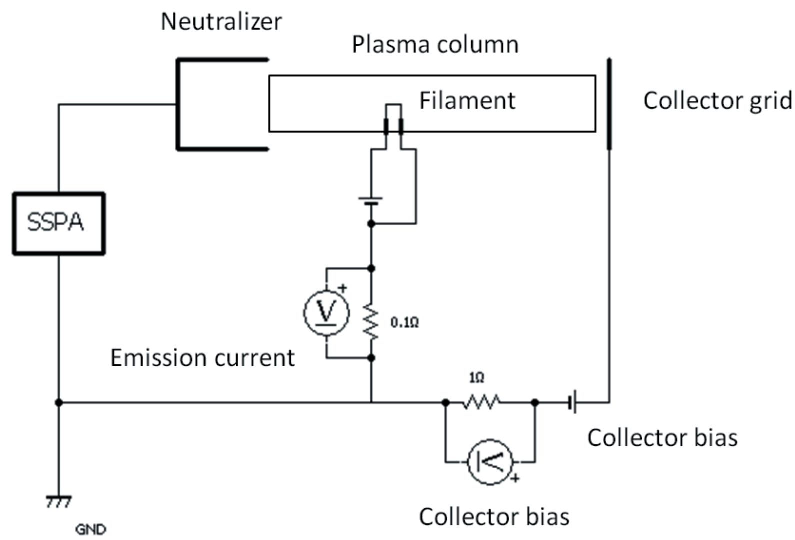

Figure 2. Schematic diagram of the experimental apparatus

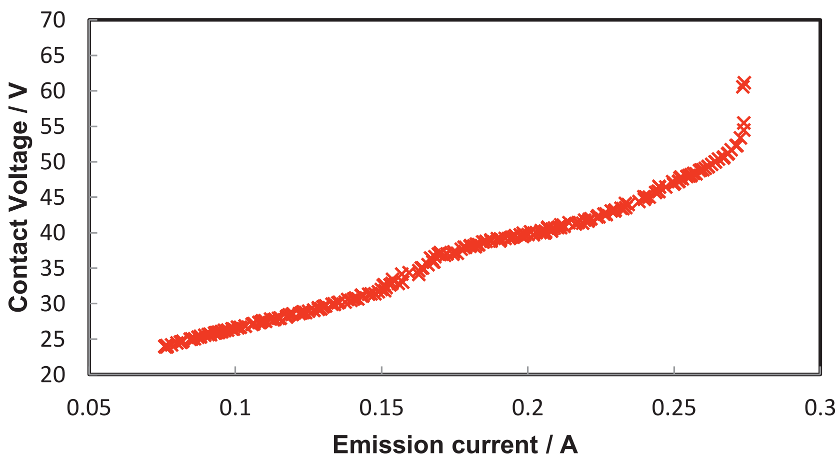

Figure 3. Neutralizer performance

A. Insertion position of probe

First, to investigate how the emission current changes depending on the insertion position of the probe, we measure the emission current in four cases shown in Figure 4. The probe is with the circular tungsten wire with 2mm diameter on the tip of it. The insertion position is changed only in the radial direction of the plasma column, and in the axial direction is fixed at 5mm downstream position from the orifice plate.

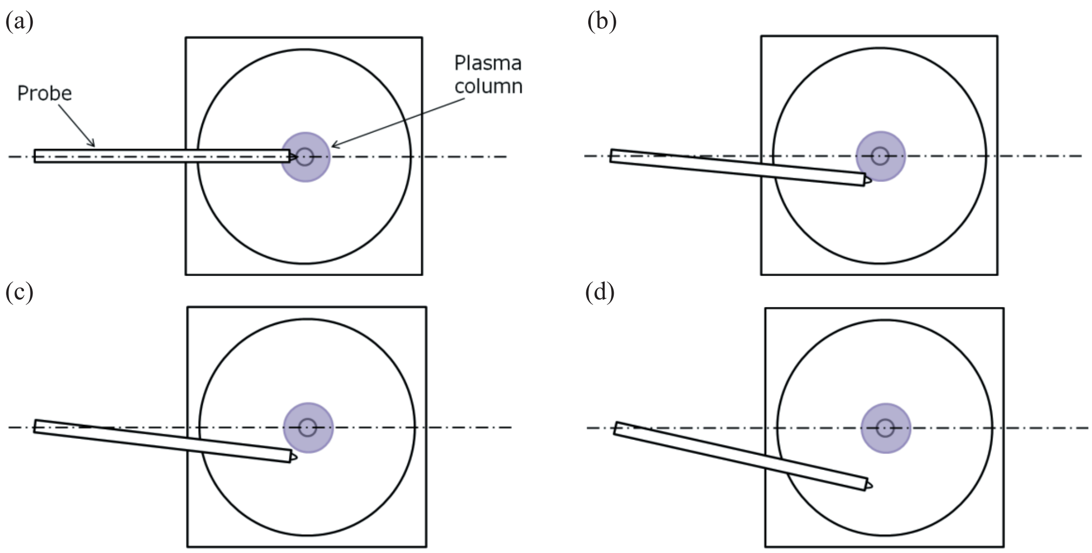

Figure 4. Probe insertion position

B. Wire diameter

Next, we change the diameter of the circular tungsten wire, and measure the emission current varying depending on wire input power. In this experiment we use wires of three kinds of diameter; 4mm, 7mm, and 10mm, and the insert position is also a fixed at 5mm downstream position from the orifice plate. Emission current is measured in the two cases of current flow in the wire shown in Figure 5.

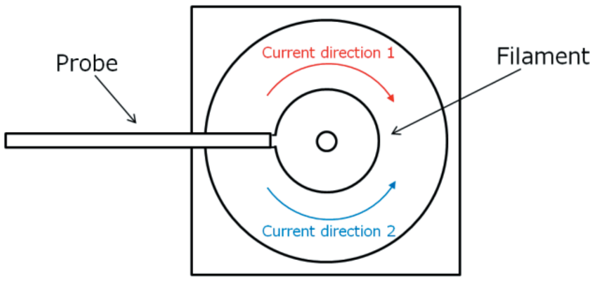

Figure 5. Current flow direction

C. Built-in orifice

Finally, we measure the performance of the neutralizer with a tungsten wire built-in orifice. Figure 6 shows the schematic diagram of built-in orifice. In this experiment, we measure the performance of the neutralizer without thermionic emission and the emission current varying depending on wire input power.

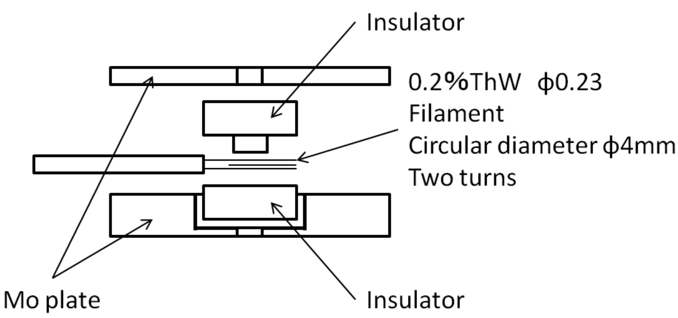

Figure 6. Schematic diagram of built-in orifice

III. Experimental Results and Discussions

A. Insertion position of probe

Figure 7 to 10 show the change of emission current due to differences of the probe-insertion position. Comparing the insertion position (a) and (b), twice larger emission current is obtained with the same input power in the case of position (a). In addition, the emission current does not increase in the case of position (c) and position (d). From these results, it is said that the emission current more increases when the probe position is closer to the center of plasma column. Further, in the insertion position (a) and (b), the electron current contributed by the neutralizer is also increasing. The mechanism of this result is thought as follows; ionization of neutral particles that are in non-ionized state is promoted by thermionic emission, further plasma is generated in the plasma column, and the plasma density in the discharge chamber is increased. The neutralizer collects the same ions on its surface as emitted electrons. Thus emission current is limited by the ion saturation current. In this case, the increase of plasma density causes the increase of ion saturation current, and the emission current is increased. However, in the insertion position (a), the plasma column often disappears. Since this wire diameter is small, the plasma stream is inhibited by the probe insertion.

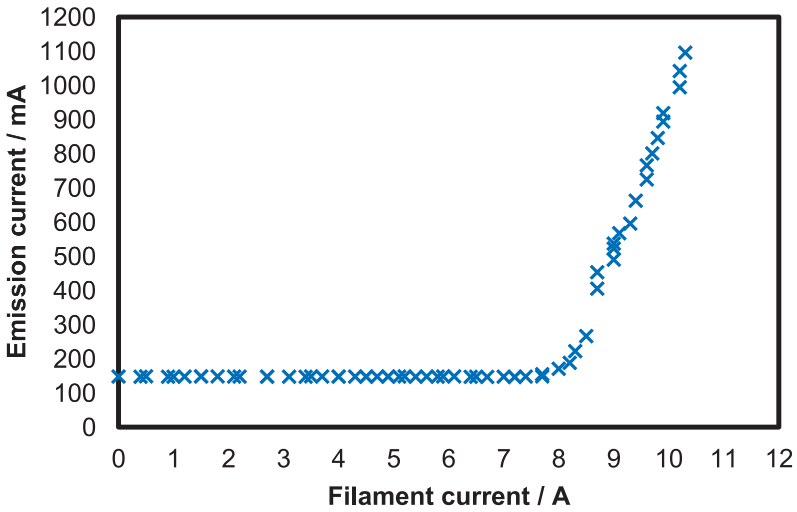

Figure 7. Filament current dependence of emission current (position(a))

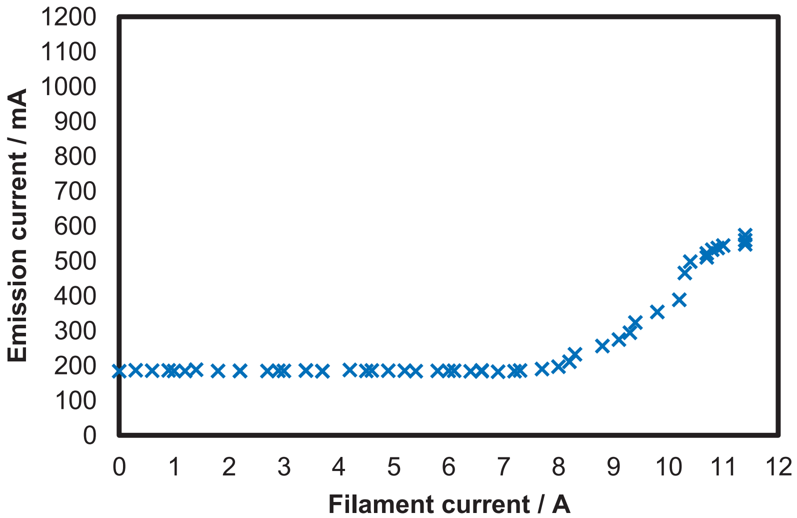

Figure 8. Filament current dependence of emission current (position(b))

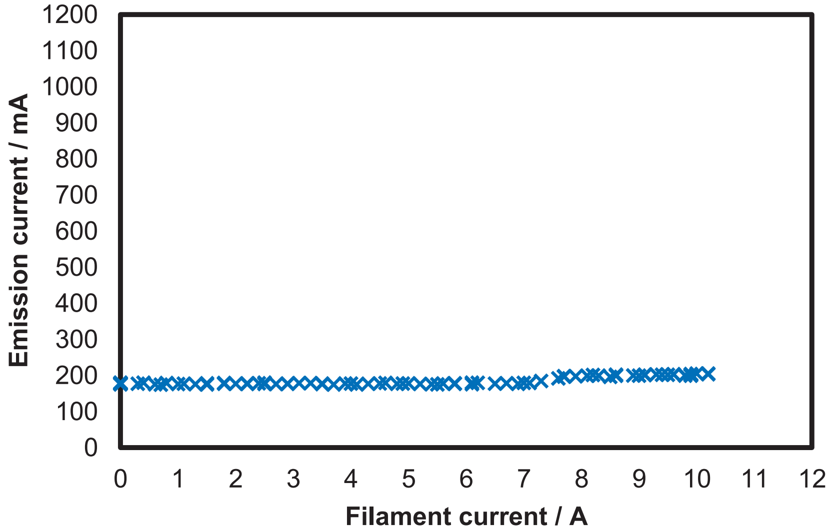

Figure 9. Filament current dependence of emission current (position(c))

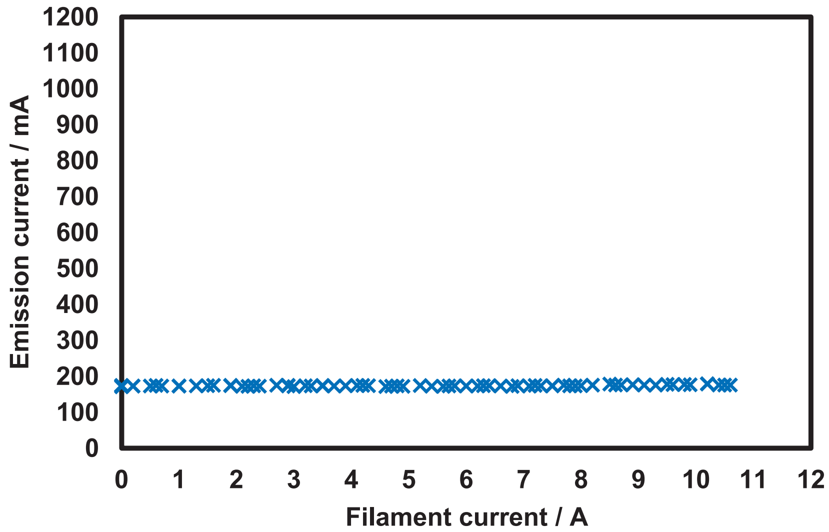

Figure 10. Filament current dependence of emission current (position(d))

B. Wire diameter

Figure 11 and Figure 12 shows the change of the emission current due to the difference of the wire diameter. In the cases of φ7 and φ4, emission current reaches 1A at 70W power input, and in the cases of φ7 and φ10, emission current changes depending on the current flow direction in the wire. With respect to φ4 wire, emission current is not limited by the current flow direction in the wire and stable after filament ignition. Taken together with the results described in section A, it is effective for emission current increase that insertion position is close to the central plasma column, and the wire is large diameter enough not to inhibit the plasma stream. From the above, the φ4 thermionic emission wire is optimal.

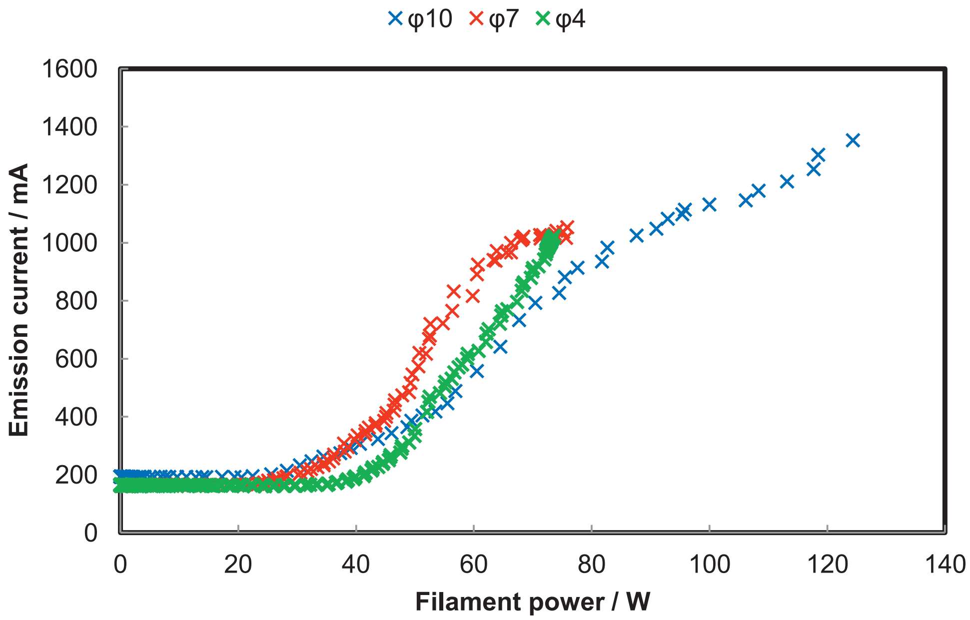

Figure 11. Wire diameter dependence of emission current (direction 1)

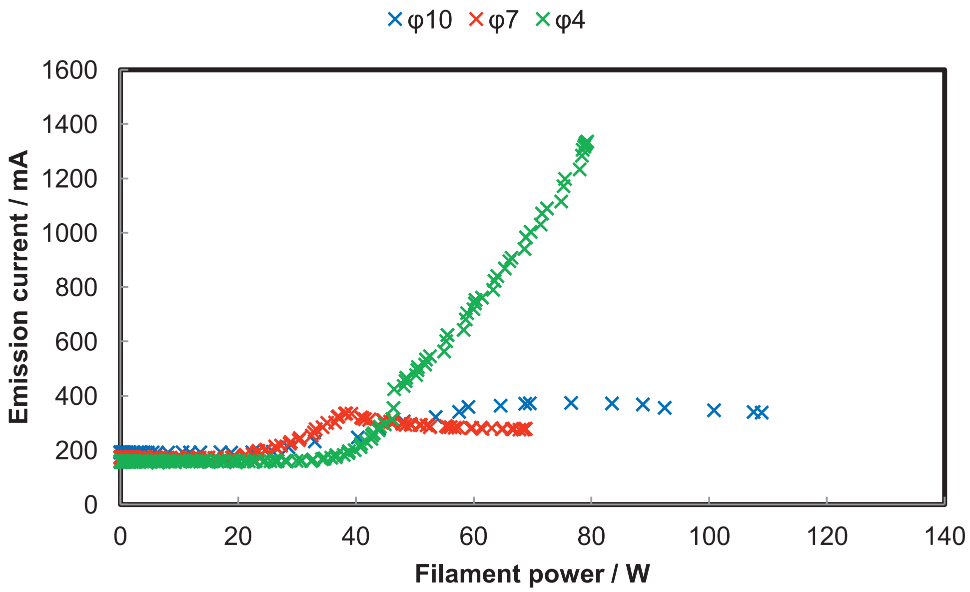

Figure 12. Wire diameter dependence of emission current (direction 2)

C. Built-in orifice

Figure 13 shows the built-in neutralizer performance, and Figure 14 shows the emission current varying depending on wire input power. Comparing with Figure 2, the neutralizer performs at relatively low contact voltage. However, when the bias voltage of the collector grid is turned off, emission current is instable and plasma column disappears. This is because that the orifice length is extended nearly three times, the conductance increases, and it disturbs the electrons drawing. Furthermore, as Figure 14 shows, the emission current is instable and the increase of emission current from neutralizer is not caused. This is also caused by the extension of orifice length, that is, the plasma generated in the plasma column is difficult to affect the plasma density in the discharge chamber. Anyway, it is considered necessary to reduce the orifice length.

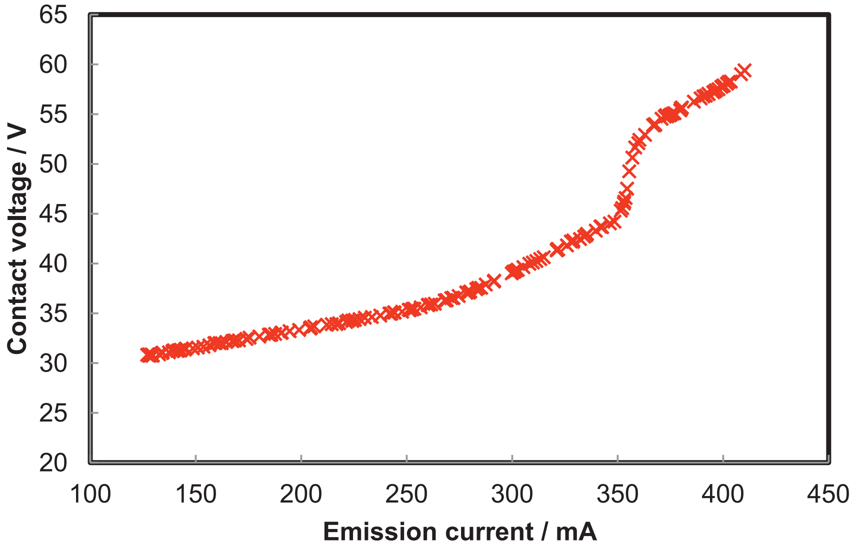

Figure 13. Neutralizer performance (built-in orifice)

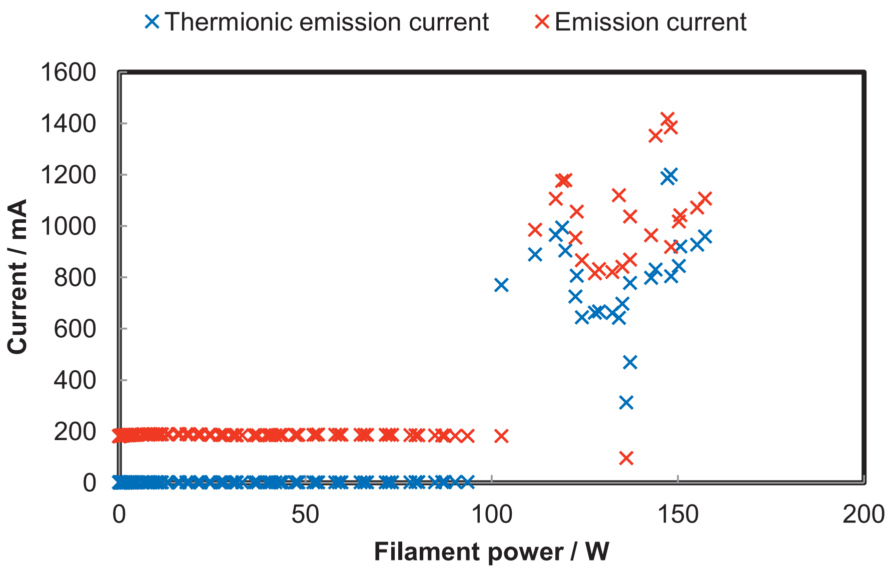

Figure 14. Filament power dependence of emission current and thermionic emission current

IV. Conclusion

In this experiment, we measure the contribution of thermionic emission probe to the emission current by changing the wire insertion positions and wire diameters. From these results, the following conclusion is derived.

1) The probe insertion position should be closer to the center of the plasma column.
2) The wire diameter should be enough small not to inhibit the plasma flow, and φ4 wire is optimum.
3) The wire built-in orifice is effective for increase of emission current, but cause the instability of plasma flow. Orifice length of optimization is necessary.

From the above, we believed that enhancement of the emission current is possible by combining thermionic emission and microwave discharge. In addition, it was also found that the performance of the neutralizer itself is improved by about 60% by thermionic emission. Based on these, and future challenges to optimize the orifice shape.

References

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