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Radio Frequency Plasma Cathode for High-Power Ion and Hall Thrusters
大電力イオンエンジンおよびホールスラスタ用高周波プラズマカソード

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Radio frequency (RF) plasma cathode has been developed as an electron source for ion and Hall thrusters in place of a hollow cathode. The electron emission characteristics of the RF plasma cathode were experimentally evaluated in the range of 10 to 400 W of RF power. It is confirmed that the electron emission current of 7 A was achieved at the RF power of 400 W with 13.56 MHz and the xenon mass flow rate of 0.2 mg/s. The effect of frequency of RF generator on the current is small whereas the inner diameter of the discharge vessel strongly affects the current. The efficiency of the 2-cm RF cathode is higher than that of the 4-cm RF cathode, because ion loss in the vessel wall decreases as the inner diameter decreases.

1. Introduction

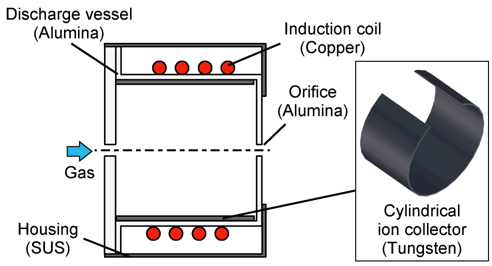
There is an interest in using high-power ion and Hall thrusters to reduce launch vehicle size and to facilitate in-space transportation of large masses in support of the human space exploration, because of their high specific impulse. The next generation thrusters are being developed for the in-space propulsion in the range 5 to 100 kW with lifetime in excess of 10,000 hours in U.S.A. and European countries [1]. An electron source called "cathode", which is used to ionize the propellant and to neutralize ion beam leaving the thrusters, is important component for the thrusters, because its performance militates against the thruster efficiency and the lifetime of thruster system. An electron current emitted from the cathode increases as the thruster's input power increases. Therefore, the development of high current cathode with lifetime in excess of 10,000 hours is necessary for the development of high-power ion and Hall thruster.

A hollow cathode is regularly employed as the electron source for ion and Hall thrusters. The hollow cathode uses a porous tungsten insert that is impregnated with an emissive mix of barium and calcium oxides, and alumina for thermionic emission. To prevent an insert poisoning, which can shorten the lifetime of the hollow cathode, contact between the insert and the active gas should be avoided, and the type of operation gas entering the cathode, which is commonly shared with the thruster propellant, is restricted. Additionally, the hollow cathode lifetime is considered to be restricted by oxide depletion from the insert. As a result, ion and Hall thrusters with the hollow cathodes have some difficulties in long-term operation, and they should be controlled strictly from a prelaunch to an end of life.

Thus, in order to liberate ion and Hall thrusters from the limitations of hollow cathode, a radio frequency (RF) plasma cathode was studied as the electron source for the thrusters. In previous study, the RF plasma cathode (RF/C) achieved an electron emission current of 2.6 A [2]. The current value is not enough for high-power ion and Hall thrusters. Therefore, the electron emission characteristics of the RF/C in high input RF power are evaluated.

2. Experimental Apparatus and Procedure

Figure 1 shows the schematic representation of the RF/C, which consists of a discharge vessel, an induction coil, an ion collector and housings. Two cathode sizes were fabricated and evaluated. One was the 2-cm RF/C, and the other was the 4-cm RF/C. The value shows an inner diameter of a cylindrical discharge vessel. There was an orifice at the center of end of the vessel for electron emission. When electrons are emitted from the orifice, ions that are equal to them have to be collected at the ion



Dimension	2-cm RF/C	4-cm RF/C
Vessel diameter	20 mm	40 mm
Vessel length	40 mm	
Orifice diameter	1.7 mm	
Orifice length	0.5 mm	
Total number of coils	11 turns	4 turns

Fig. 1. Schematic of RF plasma cathode.

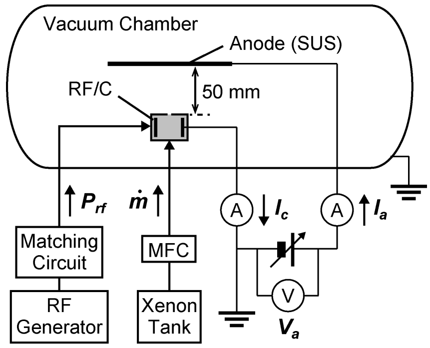


Fig. 2. Experimental Setup

collector to maintain quasi-neutrality at the plasma. Thus, the collector, which is inserted into the vessel, is necessary for the RF/C during steady operation. The cylindrical tungsten collector shown in Fig. 1 was inserted into the vessel along its wall to fill the roles of ion collection, and the collector had an axial slit for propagation of electromagnetic field.

Figure 2 shows the experimental setup. The RF/C and an anode were set in a vacuum chamber. The anode was located at 50 mm downstream of the cathode, and it was biased positively by a DC power supply to extract electrons from the cathode. On the other hand, the collector was connected to ground potential. When electrons are emitted from the cathode by the potential difference, an electron current is carried to the anode and an ion current is carried to the collector: the electron current to the anode was called "anode current" in this paper. The anode current of each RF/C was measured as a function of the RF power and frequency.

3. Results and Discussion

Figure 3 shows the anode current at the xenon mass flow rate of 0.2 mg/s as a function of the RF power, cathode size and frequency of RF generator. The anode current is proportional to the RF power regardless of the cathode size and the frequency as show in Fig. 3. In 4-cm RF/C, this proportional relationship was confirmed from 10 to 400 W. The anode current of 7 A was achieved at RF power of 400 W with 13.56 MHz, the xenon mass flow rate of 0.2 mg/s. At same RF power, the anode current of the 2-cm RF/C is higher than that of 4-cm RF/C, and the effect of frequency on the anode current was small. In space applications, it is desirable for electron sources to emit a higher electron current at a lower input power. Therefore, the 2-cm RF/C is higher performance than the 4-cm RF/C.

When electrons are emitted from the orifice, ions that are equal to them have to be collected at the ion collector. Thus, the amount of electrons emitted from the RF/C is limited by the amount of ions collected in the ion collector. In the RF/C, the

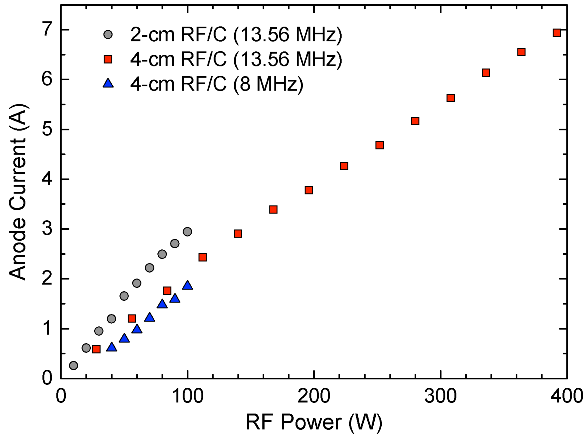


Fig. 3. Anode current at xenon mass flow rate of 0.2 mg/s as a function of RF power, cathode size and frequency of RF generator.

internal wall of the discharge vessel is not completely covered by the ion collector as shown in Fig. 1, because of propagation of electromagnetic field. Thus, ions produced within the cathode is not only collected onto the ion collector surface, but also lost in the vessel wall. The ion loss in the vessel wall is not preferable for electron emission from the cathode. Since the ratio of the ion collection area to the surface area of the vessel internal wall at the 2-cm RF/C is 1.2 times as high as that at the 4-cm RF/C. Therefore, the ion loss in the vessel wall decreased at the 2-cm RF/C. The reduction of ion loss in the vessel wall is one of the reasons for the high performance of the 2-cm RF/C.

4. Conclusion

The electron emission characteristics of the RF/C were evaluated in the range of 10 to 400 W of RF power. It is confirmed that the electron emission current of 7 A was achieved at the RF power of 400 W with 13.56 MHz and the xenon mass flow rate of 0.2 mg/s. The effect of frequency of RF generator on the emission current is small whereas the vessel inner diameter strongly affects the emission current. The efficiency of the 2-cm RF/C is higher than that of the 4-cm RF/C, because ion loss in the vessel wall decreases as the inner diameter decreases. This result shows that the electron emission performance of the RF/C is still not enough for the cathode of high-power ion and Hall thrusters. Thus, more efforts require improving the performance of the RF/C as future work.

References

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