S2-3

高周波プラズマカソードの研究開発
Research and Development of Radio Frequency Plasma Cathodes

渡邊裕樹，竹ヶ原春貴
Hiroki Watanabe and Haruki Takegahara

首都大学東京
Tokyo Metropolitan University

1. Introduction

Hall thrusters are frequently used worldwide to realize the orbit control of geostationary satellites, as well as for the orbital transfer of space probes[1]. Hollow cathodes (H/Cs) are regularly employed as electron sources in Hall thrusters to ionize the propellant using electric discharges and to neutralize the ion beam leaving the thrusters. Conventional hollow cathodes use a porous tungsten insert that is impregnated with an emissive mix of barium and calcium oxides, and alumina for thermionic emission. To prevent poisoning the thermionic emitter, which can shorten the lifetime of the hollow cathode, contact between the insert and the active gas should be avoided, and the type of the operation gas entering the cathode, which is commonly shared with the thruster propellant, is restricted. In addition, the lifetime of the hollow cathode is considered to be restricted by oxide depletion from the insert. As a result, it is difficult for Hall thrusters with hollow cathodes to realize long-term operation, and they should be controlled strictly from prelaunch to end-of-life.

We focused on a plasma cathode employing a radio frequency (RF) discharge as a simple and robust electron source to liberate Hall thrusters from the experiencing the shortcomings of the hollow cathode. The RF plasma cathode (RF/C) is an electrical discharge device producing RF plasma that emits electrons from its boundary. Although the plasma cathode requires additional discharge power to produce electrons, it does not have the drawbacks associated with the thermionic emitter. In this study, we evaluated the discharge characteristics and the thrust performance together with the combination of a Hall thruster and the RF plasma cathode.

2. Experimental Apparatus and Procedure

Figure 1 shows a schematic representation of the RF plasma cathode, which consists of a discharge vessel, an orifice plate, an induction coil, and an ion collector. The cylindrical vessel is made of alumina, and its inner diameter and length are 40 mm and 80 mm, respectively. Copper wire whose diameter is 5 mm is wrapped around the vessel as the induction coil. The orifice plate is made of graphite, and there is a 2-mm diameter orifice at the center of the plate for electron emission. Then electrons are emitted from the orifice, an equivalent quantity of ions then has to be collected at the ion collector in the cathode to maintain quasi-neutrality in the RF plasma. Thus, the graphite collector is necessary during the steady operation of the cathode.

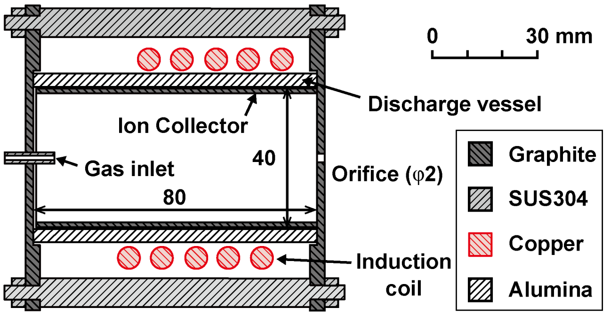

Fig. 1 Schematic of the RF plasma cathode.

All of the experiments were conducted in a vacuum chamber, whose diameter and length were 1.6 m and 3.2 m, respectively. Xenon was employed as the operation gas for the cathode and the propellant for the thruster. The induction coil in the RF plasma cathode was energized at 13.56 MHz by a RF generator via a matching circuit. For an experiment to evaluate the electron-emission characteristics of the RF plasma cathode, a plate anode was located downstream of the cathode. The anode was biased positively by the DC power supply to extract electron from the cathode. The anode current was measured as a function of the RF power and cathode mass flow rate. A 1-kW class anode-layer-type Hall thruster developed at Tokyo Metropolitan University was employed to evaluate the thrust performance together with the combination of the Hall thruster and the RF plasma cathode. The thrust and discharge current were measured as a function of the discharge voltage and anode mass flow rate. To compare the RF plasma cathode and the hollow cathode, thrust performance of the combination of the Hall thruster and the hollow cathode was also evaluated.

3. Results and Discussion

Figure 2 shows the anode current of the RF plasma cathode as a function of the RF power at various cathode mass flow rates. The anode current is the electron current emitted from the cathode. The data

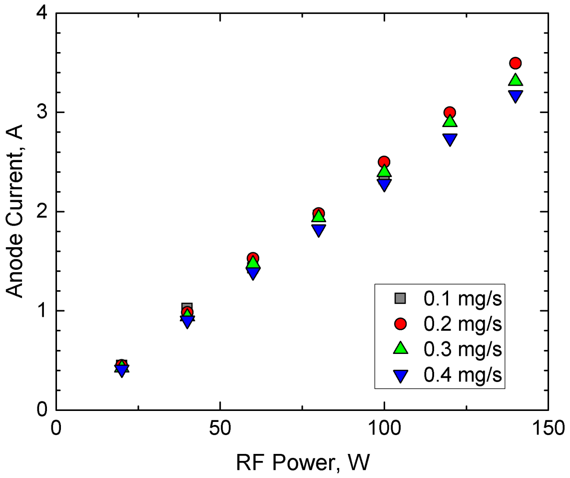

Fig. 2 Anode current of the RF plasma cathode as a function of RF power at various cathode mass flow rates.

presented in Fig. 2 show that the anode current proportionally increased as the RF power increased. On the other hand, the effect of the cathode mass flow rate on the anode current at a constant RF power is small. An anode current of 3.3 A was obtained at an RF power of 140 W, a cathode mass flow rate of 0.3 mg/s, and an anode voltage of 58 V. The anode current is sufficiently high to operate the 1-kW class Hall thruster.

Normal ion beam extraction and neutralization were experimentally confirmed for the combination of the Hall thruster and the RF plasma cathode. Figure 3 and 4 show the discharge current and thrust for the two cathodes as a function of the discharge voltage at various anode mass flow rate, respectively. The discharge current is not affected by the difference of the cathode type. The result indicates that the plasma produced in the acceleration channel and the quantity of ions leaving the thruster is same for the hollow cathode and the RF plasma cathode. In contrast to the relationship between the discharge current and the cathode type, the thrust for the hollow cathode is slightly lower than that for the RF plasma cathode for an anode mass flow rate of 1.0 mg/s, as shown in Fig. 4. For an anode mass flow rate of 2.0 mg/s, the thrust for the hollow cathode is approximately the same to that for the RF plasma cathode. For an the anode mass flow rate of 2.9 mg/s, the thrust for the hollow cathode is 1 mN higher than that for the RF plasma cathode. We consider that the changes in the cathode-to-ground voltage that are due to the differences in the cathode type are the reasons for which the thrust slightly depends on the differences in the cathode type.

4. Conclusion

To prevent the Hall thrusters from experiencing the drawbacks of the hollow cathode, we focused on the plasma cathode employing the RF discharge as a simple and robust electron source and evaluated the

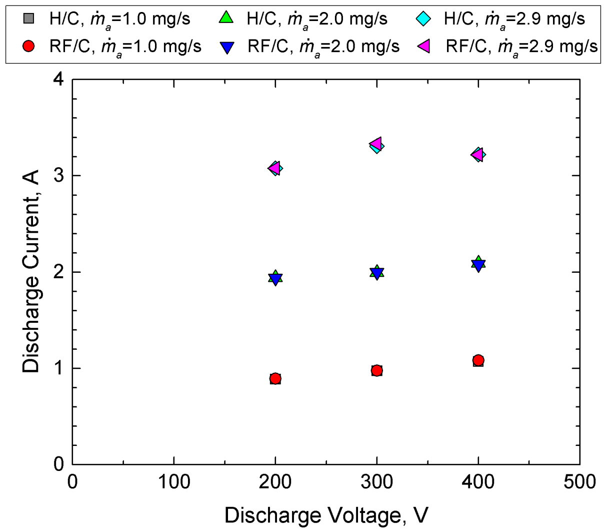

Fig. 3 Discharge current for the two cathodes as a function of discharge voltage at various anode mass flow rates.

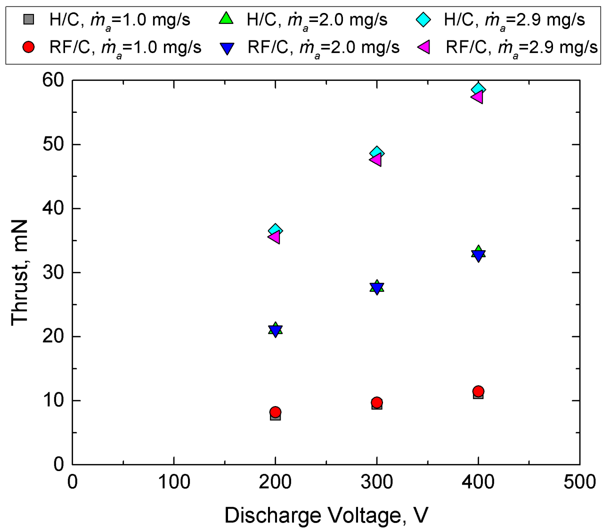

Fig. 4 Thrust for the two cathodes as a function of discharge voltage at various anode mass flow rates.

discharge characteristics and thrust performance together with the combination of the Hall thruster and RF plasma cathode. The results can be summarized as follows:

(1) An anode current of 3.3 A was obtained at an RF power of 140 W, a cathode mass flow rate of 0.3 mg/s, and an anode voltage of 58 V. The anode current is sufficiently high to operate a 1-kW class Hall thruster.

(2) Normal ion beam extraction and neutralization were confirmed for the combination of the Hall thruster and the RF plasma cathode. Based on this result, the feasibility of the RF plasma cathode as an electron source for Hall thrusters in ground tests was confirmed.

References

1) D. M. Goebel, I. Katz, *Fundamentals of Electric Propulsion Ion and Hall Thrusters*, JPL Space Science and Technology series, Wiley & Sons, 2008.