Low Power Cylindrical Hall Thruster with Magnetic Field Tailoring

IEPC-2017-190

Presented at the 35th International Electric Propulsion Conference
Georgia Institute of Technology • Atlanta, Georgia • USA
October 8 – 12, 2017

Holak Kim[1], Seunghun Lee[2], Guentae Doh[3], and Wonho Choe[4]
Department of Physics, Korea Advanced Institute of Science and Technology (KAIST), Daejeon 34141, Republic of Korea

Abstract: Tailoring of magnetic field has been performed for a class of cylindrical Hall thrusters (CHTs) in the range of 200–500 W, which have retracted inner iron core in their discharge channel. The aim of the magnetic field tailoring is to reduce interaction between plasma and channel wall to minimize secondary electron emission, ion loss, surface erosion, etc. For CHTs with magnetic field tailoring, the overall operation range is 0.5–1.7 A of the discharge current and 150–350 V of the discharge voltage. At 300 V of the anode voltage, the propellant efficiency and the ion current are approximately 160% and 0.82 A, respectively. Multiply charged ions including Xe^{4+} and Xe^{5+} ions are observed, and the sum of the multi-charge ion fractions is larger than 50%. In comparison, for CHT without magnetic field tailoring, the propellant efficiency, ion current, and sum of the multiply charged ion fractions are 124%, 0.64 A, and 46%, respectively, which demonstrate better performance of the magnetic field tailored thruster.

I. Introduction

Hall thrusters have been widely studied and utilized as one of the most promising electric propulsion systems for various space missions.[1] Among the many parameters associated with the operation of Hall thrusters, magnetic field configuration is closely related to the thruster performance, plasma-wall interaction, plume divergence etc[2]. Our recent studies with cylindrical Hall thruster plasmas[3-5] showed a large fraction of multiply charged ions such as Xe^{2+} to Xe^{4+} and high energetic ions with energy higher than the anode voltage, and these phenomena turn out to be strongly related to the magnetic field configuration.[4] In addition, multiply charged ions have shown to enhance plasma performance, particularly resulting in high propellant efficiency. In this study, a low-power cylindrical Hall thruster with high propellant efficiency was developed by tailoring the magnetic field, having a large component parallel to the discharge channel wall. This type of tailored magnetic field can reduce the interaction between the plasma and the dielectric wall, which can result in improved thruster performance such as secondary electron emission, particle loss, surface erosion, etc.

[1] Postdoctoral researcher, KAIST, and holak_phys@kaist.ac.kr
[2] Senior researcher, Korea Institute of Materials Science, and seunghun@kims.re.kr
[3] Graduate student, KAIST, and kuntae21@kaist.ac.kr
[4] Professor, KAIST, and wchoe@kaist.ac.kr

II.Experimental Setup

The thruster used in the study is a cylindrical Hall thruster (CHT), which is almost identical to the conventional annular Hall thruster (AHT), and is made up of an anode with a gas distributor, two electromagnetic coils, and a boron nitride channel, as shown in Fig. 1.[2] Here, the most important difference in the CHT is the retraction of the inner iron core section in order to achieve a large plasma volume to surface ratio, which makes its magnetic field geometry significantly different from that of the AHT. The magnetic field is mostly radial in the channel of the AHT; however, the magnetic field has both strong radial and axial components in the CHT. As a result, the thruster performance and ion beam characteristics are generally different from each other. Depicted in Fig. 1(c) is the magnetic field lines in the untailored normal CHT. In comparison, the magnetic field is designed to have field lines more parallel to the dielectric wall near the wall surface in our developed CHT, as shown in Fig. 1(b). The aim of magnetic field tailoring is to reduce the interaction between plasma and channel wall to minimize secondary electron emission, ion loss, surface erosion, etc. The diameter and depth of the discharge channel in the developed CHT are 50 mm and 24 mm, respectively.

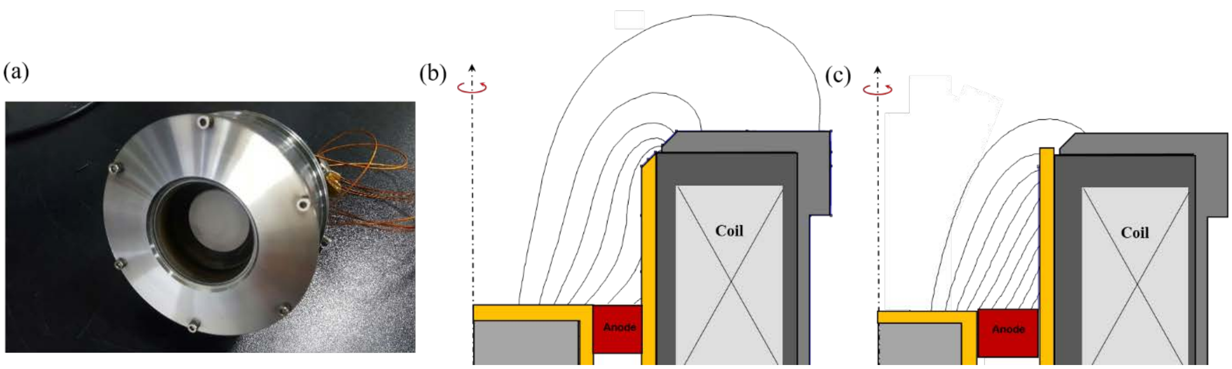

Fig. 1. (a) A picture of the developed magnetic field tailored CHT and (b) its magnetic field lines. (c) Field lines of the untailored CHT for comparison.

The experiment was performed in a 3 m long and 1.5 m diameter vacuum vessel. The operating pressure was kept below 33 μTorr at a Xe mass flow rate of 8 sccm. The thruster was mounted on a thruster stand, which is a simple pendulum type with two pivots for thrust measurements, and a commercial hollow cathode was used as an external neutralizer operated with 1 sccm during operation. Plume characteristics were measured by using a Faraday probe, a retarding potential analyzer (RPA), and an E×B probe.[3]

III.Results and discussion

The discharge current was measured as the magnetic field strength, and the Xe mass flow rate were varied. The coil currents of the two electromagnets and the Xe mass flow rates were varied in the range of 1.5–2.5 A/turn and 4–7 sccm, respectively. The discharge current versus the anode voltage at 1.5 A/turn of the coil current is plotted in Fig. 2.[2] The discharge current and power consumption under the above operation conditions were 0.55–1.75 A and 83–612 W, respectively. As shown in the figure, the discharge current increases linearly as the anode voltage was increased under the given operation conditions. The overall discharge currents of the magnetic field tailored CHT are higher than those of the untailored CHTs.

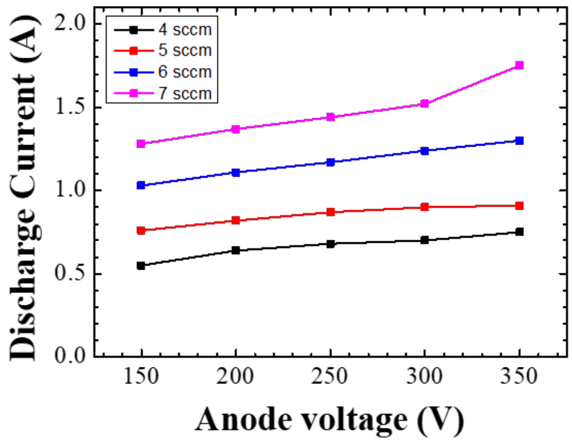

Fig. 2. Discharge current versus anode voltage

The angular distribution of the current density and the energy distribution function (IEDF) of the emitted ions at 5 sccm Xe mass flow rate are depicted in Fig. 3. The ion current density is approximately 1.10–1.45 A/m^2 at the thruster axis, which increased and saturated with the anode voltage. The peak of the IEDF is approximately 282 eV at 300 V of the anode voltage. It is noted that its shape is asymmetric with respect to the peak energy, and also shows a large population of high energy ions.[6] In addition, at 300 V anode voltage and 7 sccm Xe mass flow, the propellant efficiency ($\eta_p = M_i I_i / e\dot{m}$, where M_i is the ion mass, I_i is the total ion current, and $\dot{m}$ is the Xe mass flow rate) and the ion current are approximately 160% and 0.82 A, respectively. Abundant multiply charged ions up to Xe^{5+} were observed, and the total fraction of the multiply charged ions was larger than 50%. In comparison, for the untailored, i.e., normal CHT,[4] the propellant efficiency, ion current, and total fraction of the multiply charged ions at the same operation conditions were 124%, 0.64 A, and 46%, respectively. This high propellant efficiency may be due to the presence of a large population of multiply charged ions. This high propellant efficiency is also related to the measured high thrust (> 15 mN), which may be brought about by the reduced plasma-wall interaction in the discharge channel.

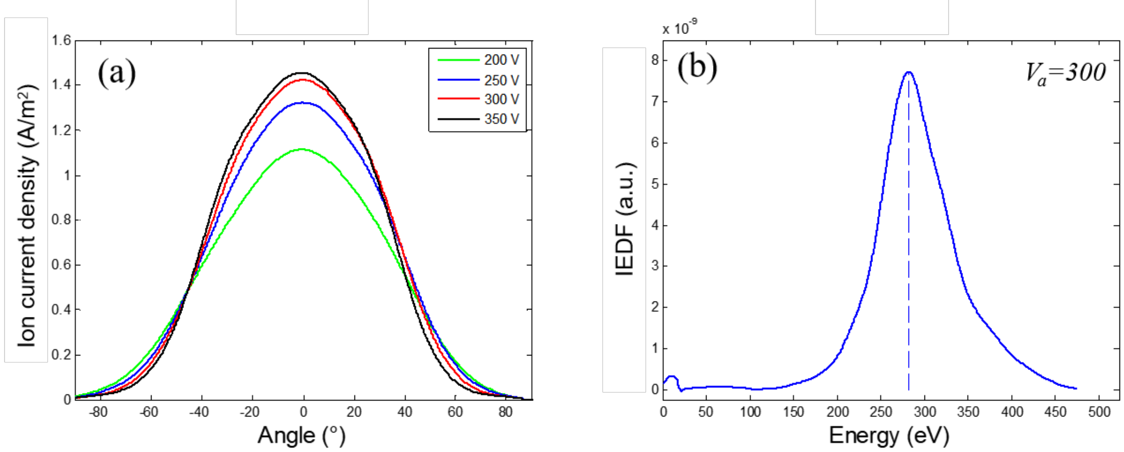

Fig. 3. (a) Angular distribution of the ion current density, and (b) IEDF at 300 V anode voltage and 5 sccm Xe mass flow rate

IV. Summary

A cylindrical Hall thruster with a tailored magnetic field configuration has been developed and studied by aiming at reducing plasma-wall interaction. At 4–7 sccm Xe mass flow rate, the power consumption was 83–612 W and the discharge current was 0.55–1.75 A. At 7 sccm and 300 V anode voltage, the propellant efficiency and the ion current were 160% and 0.82 A, respectively, and the total fraction of the multiply charged ions was larger than 50%. The propellant efficiency of the tailored CHT was higher by 30% than that of the untailored CHT under similar operation conditions. This high propellant efficiency may be due to the large population of the multiply charged ions and is related to the high thruster performance.

Acknowledgments

Technology Program (Grant No. 2014M1A3A3A02034510) through the National Research Foundation of Korea, funded by the Ministry of Science, ICT and Future Planning. This work was also partly supported by the Korea Aerospace Research Institute (Grant No. 2017M1A3A4A03025130) funded by the Ministry of Trade, Industry and Energy of Korea.

References

[1]Goebel, D. M. and Katz I. Fundamentals of Electric Propulsion: Ion and Hall thrusters. John Wiley & Sons, 2008.

[2]Kim, H., Lee, S., Doh, K., Choe, W. Development of a low power magnetic-field-tailored Hall thruster. *Joint Conference: 13st ISTS, 26th ISSFD & 8th NSAT* (2017).

[3]Kim, H., Lim, Y., Choe, W., Seon, J. Effect of multiply charged ions on the performance and beam characteristics in annular and cylindrical type Hall thruster plasmas. *Appl. Phys. Lett.* **105**, 144104 (2014).

[4]Kim, H., Lim, Y., Choe, W., Park, S., Seon, J. Effect of magnetic field configuration on the multiply charged ion and plume characteristics in Hall thruster plasmas. *Appl. Phys. Lett.* **106**, 154103 (2015).

[5]Kim, H., Choe, W., Lim, Y., Lee, S., Park, S. Magnetic field configurations on thruster performance in accordance with ion beam characteristics in cylindrical Hall thruster plasmas. *Appl. Phys. Lett.* **110**, 114101 (2017).

[6]Lim, Y., Choe, W., Mazouffre, S., Park, J., Kim, H., Seon, J., Garrigues, L., Nonlinear ion dynamics in hall thruster plasma source by ion transit-time instability. *Plasma Sources Sci. Technol.* **26**, 03LT01 (2017).