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by

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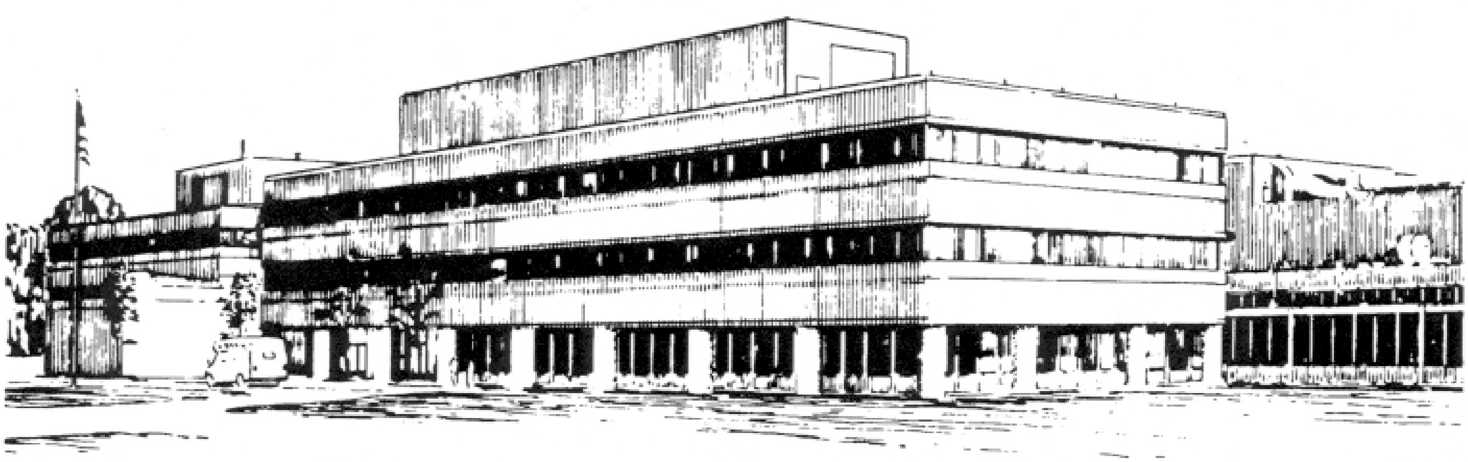

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Parametric Investigations of Miniaturized Cylindrical and Annular Hall Thrusters

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Abstract

A cylindrical geometry Hall thruster may overcome certain physical and technological limitations in scaling down of Hall thrusters to miniature sizes. The absence of the inner wall and use of the cusp magnetic field can potentially reduce heating of the thruster parts and erosion of the channel. A 2.6 cm miniaturized Hall thruster of a flexible design was built and successfully operated in the power range of 50-300 W. Comparison of preliminary results obtained for cylindrical and annular thruster configurations is presented.

Introduction

Scaling down the operating power of a Hall thruster requires a decrease in the discharge voltage or in the discharge current. While the first option is limited by the desire to keep *Isp* high, the second implies that the propellant flow rate should be decreased. In order to keep a high propellant utilization efficiency at low propellant flow rates, the thruster channel must be scaled down to preserve the ionization probability. Then, according to Ref [1], the length of the acceleration region, which is mainly determined by the magnetic field distribution, has to be decreased in proportion to the channel length, while the magnetic field has to increase inversely to the scaling factor. However, the implementation of the latter requirement faces difficulties due to magnetic saturation and enhanced heating of the miniaturized inner parts of the magnetic circuit.

The cylindrical Hall thruster suggested in ref. [2] has larger volume to surface ratio than conventional annular thruster and therefore, potentially smaller wall losses in the channel. As a result, it should suffer lower erosion and heating of the thruster parts, especially critical for the magnetic circuit. A relatively large 9 cm diameter version of this thruster already exhibited performance comparable with conventional annular Hall thrusters in the sub-kilowatt power range [2]. First experimental results on a miniaturized 2.6 cm diameter cylindrical Hall thruster were reported in ref. [3]. A relatively high background pressure in these experiments caused unstable operation of this thruster. In the present paper we describe recent experiments conducted in the upgraded vacuum facility with the same thruster.

Experimental setup

A 2.6 cm cylindrical Hall thruster shown in Fig. 1, was scaled down from a 9 cm cylindrical Hall thruster to operate at ~ 200 W power level [2,3].

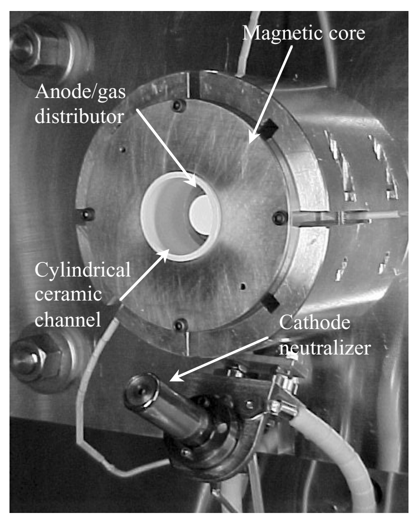

Fig. 1 A 2.6 cm cylindrical Hall thruster.

Similar to the large thruster, this miniaturized cylindrical thruster consists of a Boron Nitride ceramic channel, an annular anode, which is also a gas distributor, two electromagnetic coils, and a magnetic core. The overall diameter and length of the thruster are both, 7 cm. A flexible design of this thruster allows variations of the thruster geometry.

In this study we investigated two different thruster configurations, namely, conventional with an annular channel of 2.6 cm length, 2.6 mm OD diameter and 1.4 cm ID diameter, and cylindrical with the same OD and the channel length. The channel of the cylindrical thruster features a short annular region, approximately 1 cm long, and longer cylindrical region. Following ref [2], the length of the annular region is selected in order to provide a high ionization of the working gas at the boundary of annular and cylindrical regions.

Two electromagnetic coils are connected to separate power supplies. The currents in the coils are co-directed in conventional configuration and counter-directed in cylindrical configuration to produce cusp magnetic field with a strong radial component in the channel [2]. Fig. 2 shows simulated results of the magnetic field distribution for the annular and cylindrical thrusters.

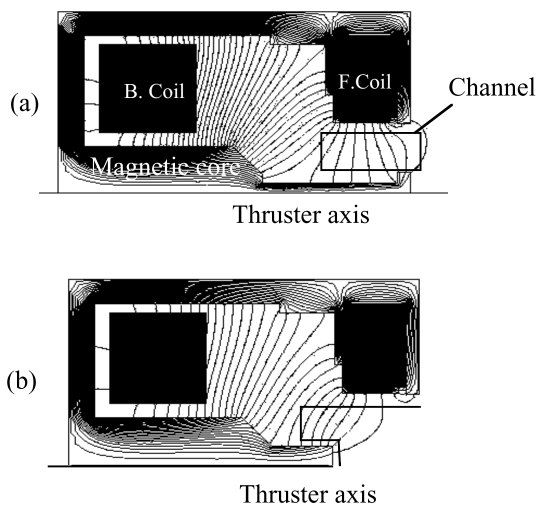

Fig. 2 Magnetic circuit of the annular thruster (a) and cylindrical (b) thruster. The channel OD diameter is 2.6 cm.

The magnetic field was measured inside both these thrusters using a miniature Hall probe. The results of these measurements and simulations are in a good agreement.

For example, for the operating currents of 1.4 A in the back coil and 0.9 ampere in the front coil, the maximum radial magnetic field is 300 Gauss at the inner wall near the exit of the annular channel. In the cylindrical configuration, the radial magnetic field reaches the maximum, ~ 450 Gauss, a few millimeters from the anode near the inner wall of the short annular part and then reduces towards the thruster exit.

A commercial HeatWave plasma source was used as a cathode-neutralizer. This cathode was able to operate at xenon flow rate of 1.5-2 sccm and sustain the thruster discharge current of 0.2 A with external heating and keeper.

The vacuum test facility has been recently upgraded with an Osaka corrosion resistance turbo pump. The measured pumping speed reached ~1700±300 l/s for xenon that is roughly 5-6 times larger than it was before the upgrade. Uncertainties in the determination of the pumping speed are caused by deviations of the background pressure measured by two Bayard-Alpert tabulated ion gauges. Two commercial flow controllers, 0-10 sccm and 0-15 sccm, volumetrically calibrated in the flow rate range of 1-10 sccm, supplied a research grade xenon gas to the anode and the cathode, respectively.

In addition to ac and dc electrical and mass flow measurements, the total ion flux coming from the thruster and the plume angle were measured by a movable electrostatic probe with a guarding sleeve. The probe can be rotated from ±90 deg relative to the thruster exit. The distance between the probe and the thruster center is 14 cm.

Thruster operation and V-I characteristics

The 2.6 cm Hall thruster was operated at the discharge voltages of 150 - 300 V and xenon mass flow rates of 0.4 — 0.8 mg/s. The cathode was placed near the thruster exit at the 60 degrees angle to the thruster axis (See Fig. 1). The operation of the thruster in the cylindrical and annular configurations is shown in Fig. 3

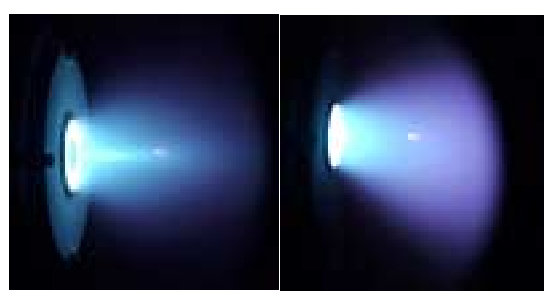

Fig. 3 Thruster operation in the annular (a) and cylindrical (b) configurations.

Remarkably, the 1 kHz - range relaxation type oscillations of the discharge, observed in [3], disappeared once the vacuum conditions were improved.

Illustrative curves of voltage versus current characteristics measured for both thruster configurations are shown in Fig. 4. Although the discharge current for the cylindrical thruster configuration is larger than for the annular thruster, the current utilization efficiency, which is the ration of the total ion flux at the exit to the discharge current, differs by about 10% only at voltages of 250-300V (See Fig. 5). This result is because the propellant utilization in the cylindrical thruster is larger than for the annular thruster and increases with the discharge voltage.

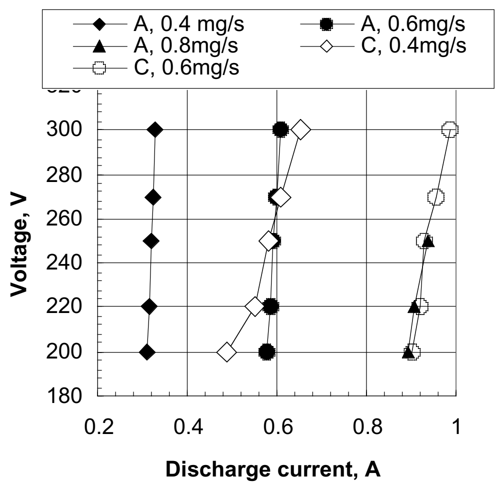

Fig. 4 Discharge voltage versus current characteristics for the 2.6 cm cylindrical (C) and annular (A) thrusters. The cathode flow rate is 0.2 mg/s.

The typical spectra of the discharge current oscillations are shown in Fig. 6. Although the amplitude of oscillations is relatively lower for the cylindrical configuration, the discharge at low propellant flows is not as quiet as it was found to be in the large 9 cm cylindrical thruster [2]. The characteristic peak at frequencies ~ 50-60 kHz may be attributed to ionization instabilities, which appear because of depletion of neutral atoms in the ionization and acceleration regions [4]. We may suggest that when the thruster is scaled down, the frequency of these oscillations, which was typically ~ 20 kHz for a 9 cm annular Hall thruster [2], almost triples as the thruster sizes are reduced by about factor of 3.

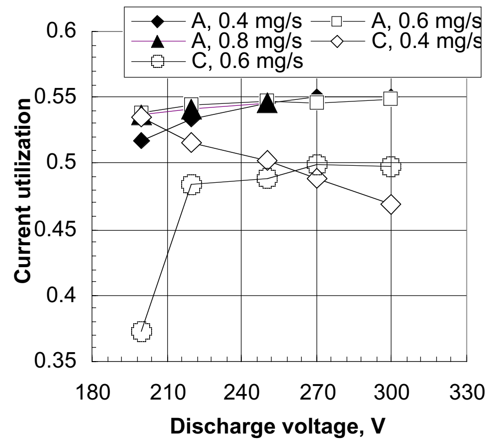

Fig. 5. Ion current at the exit to discharge current ratio versus discharge voltage for the 2.6 cm cylindrical (C) and annular (A) thrusters.

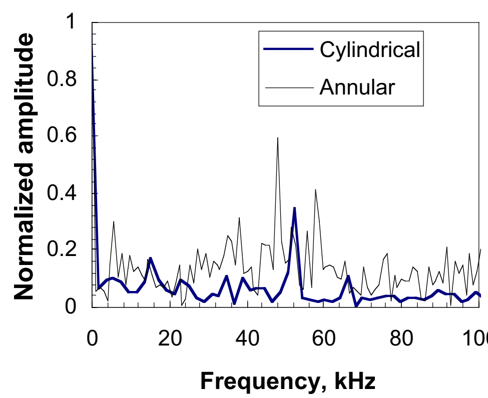

Fig. 6. Spectra of discharge current oscillations for annular and cylindrical thrusters at V_d=300V, and anode flow rate of 0.4 mg/s.

Summary

A 2.6 cm miniaturized cylindrical thruster was developed and operated in a broad range of the operating parameters. Discharge characteristics of this thruster were comparable to those measured for the annular thruster of the same overall dimensions. Several interesting effects such as an increase in the propellant utilization and relatively quieter operation of the cylindrical thruster were observed. The physics behind these effects is not yet clear.

Acknowledgment

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