SEGMENTED ELECTRODE HALL THRUSTER OPERATION IN SINGLE AND TWO STAGE REGIMES[1]

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Abstract

Variable thrust with low plume divergence over a range of mass flow rates can be achieved through segmented electrode operation. A cathode side electrode at the cathode potential by itself can decrease the plume divergence substantially, although at some cost in efficiency. However, the additional use of an anode side electrode retains the same reduced plume divergence, but at efficiencies comparable to the non-segmented operation. The high efficiency persists also when the anode side electrode is biased at an intermediate potential, thus producing two-stage Hall thruster operation.

1. Introduction

Decreased plume divergence was reported in parametric studies of a Hall thruster employing a single segmented electrode placed at the cathode side of the channel.[1] Although the plume divergence could be substantially improved over conventional operation, particularly at low mass flow rates, the single electrode configuration entails some decrease in efficiency. The present study shows that the low plume divergence operation is possible without the loss in efficiency if a second anode-side segmented electrode is employed in addition to the cathode side electrode.

That anode-side segment tends to increase the efficiency if it is biased at the anode potential or even if it is not biased. If the anode-side segment is biased at an intermediate potential, then two-stage operation, similarly at high efficiency and low plume divergence, can be achieved.

Thus, the use of these electrodes extends considerably the parameter regimes for favorable operating characteristics of Hall Thrusters. Through simple switching of electrode energizing, one may achieve such a variable mode operation.

The precise placement of these electrodes along the channel, as well as their precise shape and emissivity, is significant.

2. Segmented Electrode Placement

The vacuum system, diagnostics, and thruster have been described elsewhere.[1,2] Both the anode-side and cathode-side segmented electrodes have about 1 mm thickness of LaB_6, which was plated in a rhenium mesh to allow a strong structure of the emissive layer. This mesh was mounted on a molybdenum substrate ring of 3 mm for each electrode. In abbreviated notation, the anode-side or positive-side electrode is referred to as PS; similarly, the cathode-side or negative-side electrode is referred to as NS The length of the NS and PS electrodes was 4 mm and 10 mm, respectively. The same sizes were used in Ref. [2] for Tantalum segmented electrodes.

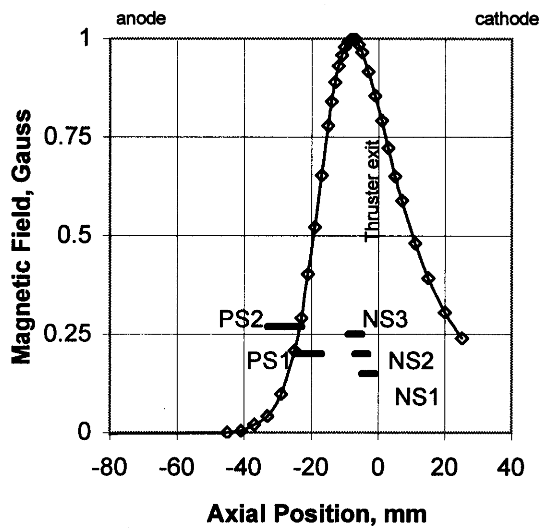


Fig. 1. Measured profile of the radial component of the magnetic field along the thruster axis near the channel median. Magnetic field is produced by a 2.1 A electromagnet current. NS1, NS2, NS3, OS1 and OS2 are locations of inner and outer segmented electrodes along thruster axis.

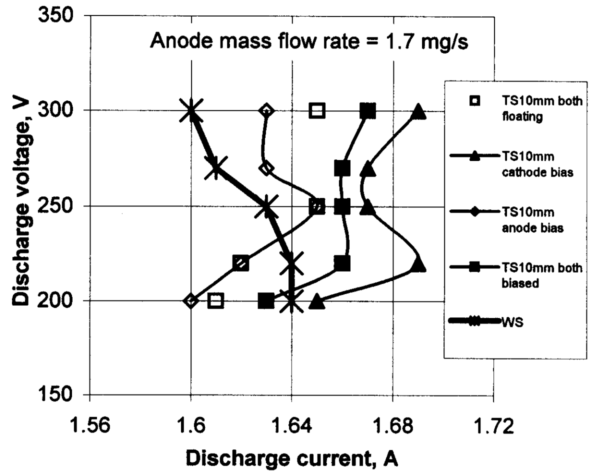
The various locations where the electrodes might be placed can be seen from Fig. 1. Electrodes are placed along the channel axis on low potential side (negative side or NS electrode), as well as on the positive side (PS). In the present work, the NS segmented electrode was attached to the inner wall, while PS electrode was inserted into the channel on its outer wall. This placement of the segmented electrodes made for easier implementation of operation with two segmented electrodes and prevented electrical breakdown along the channel wall.

These locations correspond to those in the previously reported investigation of the one segmented case, where electrodes are placed at either the cathode side or the anode side.[1] In the two-segmented electrode cases described below, the cathode-side electrode is always at position NS2. When the anode-side electrode is in position PS2, exactly 16 mm separates the two electrodes. When the anode-side electrode is in position PS1, exactly 10 mm separates the two electrodes. Accordingly, those two cases are sometimes referred to respectively as the 16 mm and 10 mm cases.

3. Discharge Characteristics

One of the features of segmented electrode operation is an increase in the discharge current when a cathode-side electrode is biased at the cathode potential. Fig. 2 shows that this increase in the discharge current at gas flow rate of 1.7 mg/s persists when an anode-side electrode is inserted, whether that anode-side electrode is at floating potential or biased to the anode potential.

a)



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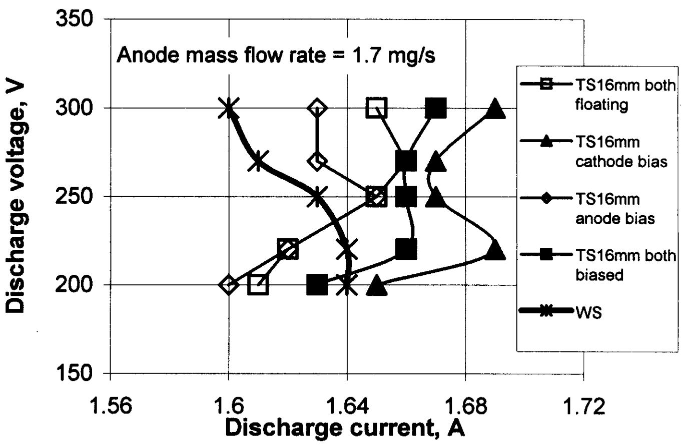
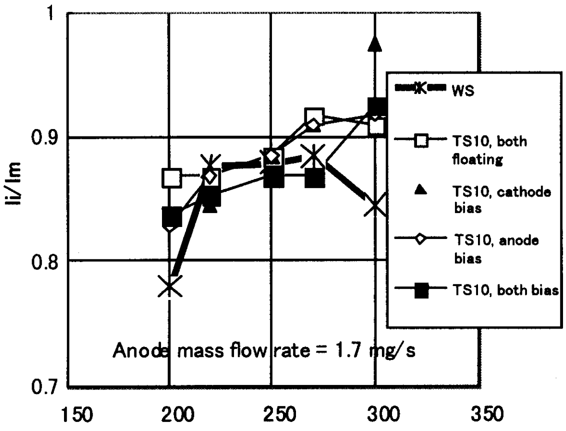


Fig. 2. Discharge voltage vs. discharge current at 1.7 mg/s for a) 10 mm and b) 16 mm spacing. TS is "two-segment" case, WS is "without segment" or conventional Hall thruster case.

Note that the mere presence of the segmented electrodes when the cathode-side electrode is not biased does not particularly produce an increase in the discharge current.

Figure 3 shows the propellant utilization. It is of interest that the propellant utilization is significantly increased over the conventional non-segmented case.

a)



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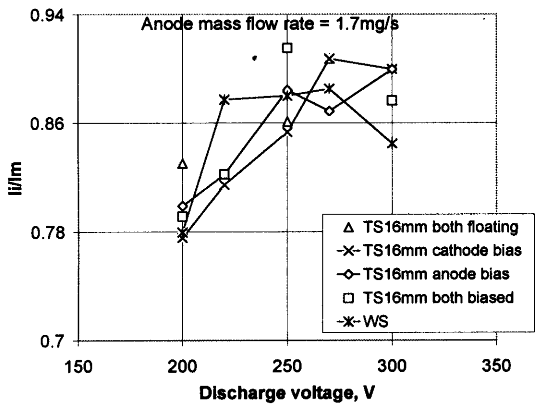
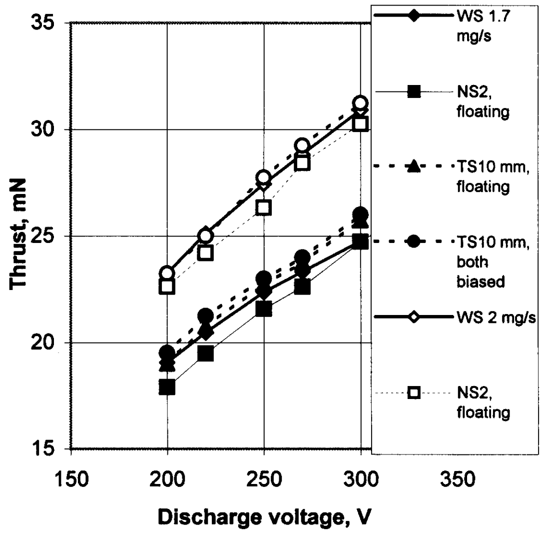


Fig. 3. Propellant utilization vs. discharge voltage measured at a mass flow rate of 1.7 mg/s a) 16 mm spacing. b) 10 mm spacing.

An interesting comparison can be made also to the previously reported results for one segment only, at NS2, where no anode side segmented electrode was present.[1] In the case of cathode side bias, the propellant utilization is increased by as much as 10% by the mere presence of the anode-side electrode, whether the anode-side electrode is biased or floating. The reason for this might be that the conic-shaped anode-side electrode increases the density or possibly increases the uniformity of the density. For whatever reason, the increased propellant utilization can lead to increased performance.

The increase in discharge current accompanied by increased propellant utilization, compared to conventional operation, leads to an overall performance for two-segmented operation not worse than conventional operation. Fig. 4 gives the thrust and the thruster efficiency as a function of discharge voltage. Note that the one-segmented electrode case gives less thrust and poorer efficiency than both the conventional operation and the two-segment operation.

a)



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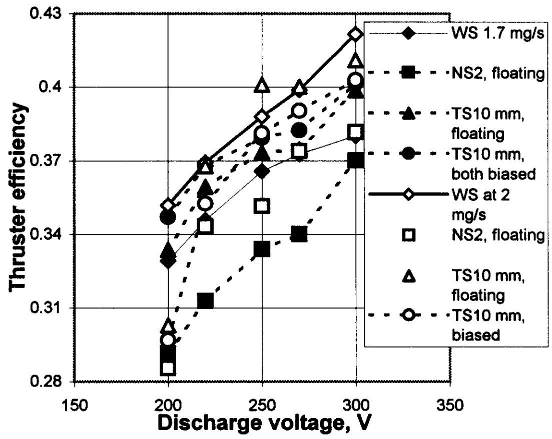


Fig. 4 Thrust (a), and the efficiency (b) versus discharge voltage at mass flow rate 1.7 mg/s.

4. Plume Characteristics

With the efficiency and thrust comparable to conventional operation, the two-segment approach is superior to the one-segment approach, so long as the favorable plume characteristics of the one-segment operation are retained. Figs. 4 and 5 show that the favorable plume characteristics are in fact largely unaffected by the presence of the second, anode-side electrode.

Fig. 5 shows the persistence of the reduction in half angle plume divergence by 10 degrees at low mass flow rate. This low mass flow rate regime is where the plume reduction tends to be greatest.[1] Interestingly, the plume divergence is largely dictated by the location of the cathode-side electrode, with the anode-side electrode playing a very minor role. Yet, the anode-side electrode plays a very telling role in increased propellant utilization. The combined effect thus creates the opportunity for variable thrust at no cost in efficiency but with favorable plume divergence.

4. Two Stage Operation

The opportunity for variable operation is much enhanced because the anode-side electrode can also be biased not necessarily at the anode potential, but at a potential intermediate between the anode and the cathode. Figures 5, 6 and 7 show this so-called "two-stage" operation, with the anode-side electrode biased 100 V negative with respect to the anode and 200V positive with respect to the cathode. Of course, this requires a separate power supply.

Note that the efficiencies are similar to conventional operation, whereas the cathode-side electrode segment can be used to control the plume divergence.

Figures 6 and 7 demonstrate the use of the anode-side electrode for the two-stage operation. The voltage versus current is shown in Fig. 6. The thrust versus discharge voltage and the efficiency versus discharge voltage are shown in Fig. 7.

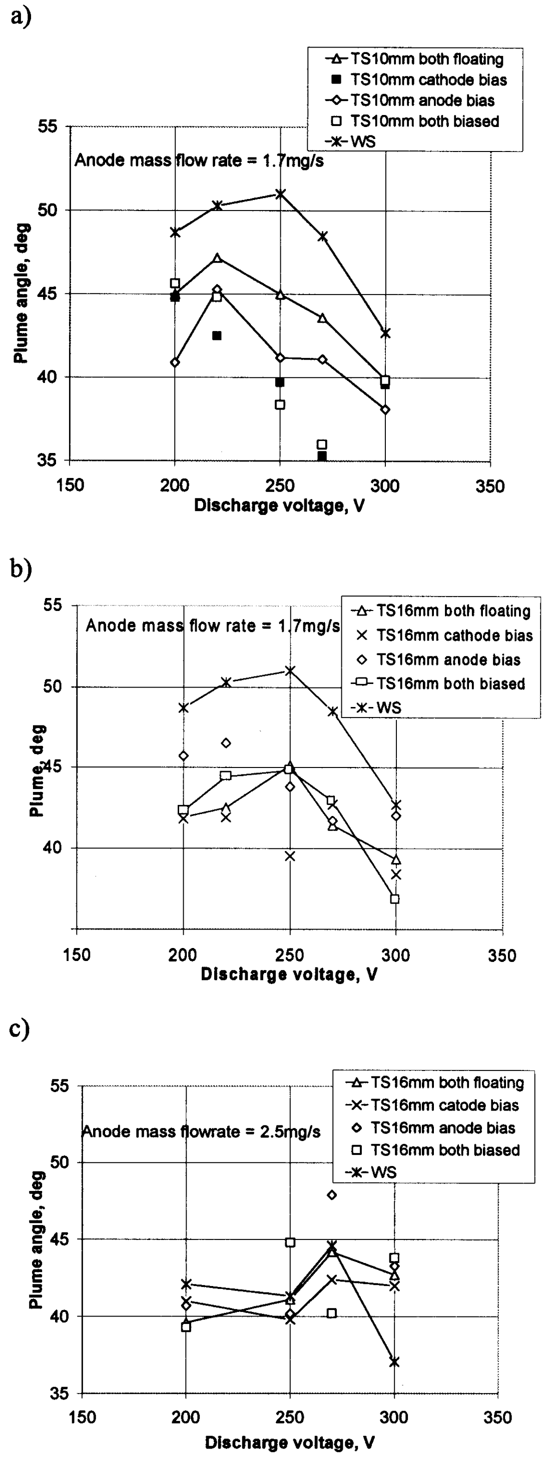


Figure 5. Plume angle vs. discharge voltage.
a)10 mm spacing and mass flow rate of 1.7mg/s.
b)16 mm spacing and mass flow rate of 1.7mg/s.
c) 16 mm spacing and mass flow rate of 2.5 mg/s.

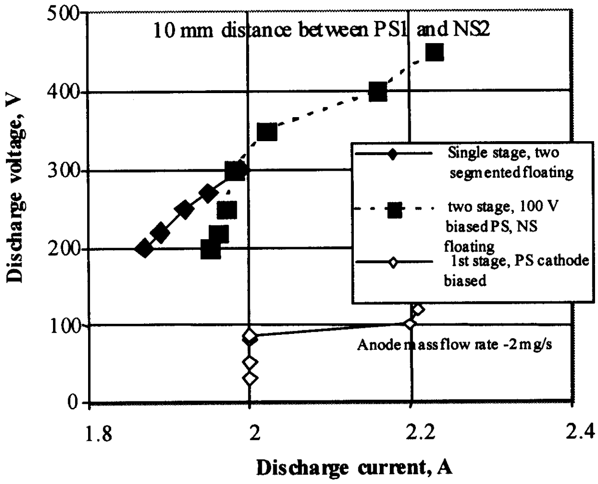
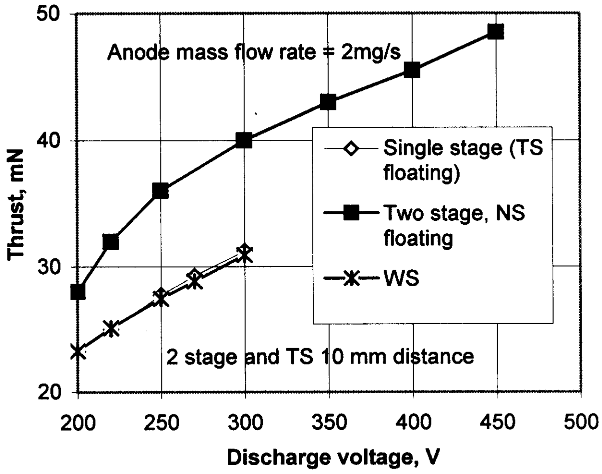


Fig. 6 Discharge voltage versus current measured at a mass flow rate of 2 mg/s for a two stage configuration of the thruster. The 1st stage was biased 100 V negative to the anode. In addition, two curves are for a two segmented, floating, configuration and for the 1st stage of a two stage configuration, when the PS electrode was biased 200 V positive to the cathode.

6. Discharge Current Oscillations

For each thruster operating point, measurements of oscillations in the thruster power circuit were performed. The signals from a low-inductance shunt were recorded by two National Instruments digital oscilloscope boards. Strong oscillations of discharge current were detected. The amplitude of those oscillations reached 80% of the discharge current even at the optimum value of magnetic field. The introduction of segmented electrodes into the thruster channel tends to reduce both the amplitude and the frequency of the oscillations (see Fig. 8). Since the frequency of discharge oscillations might scale as the electron axial speed over the ionization layer width[3] it stands to reason that a decrease in that frequency could inform on the position or width of the ionization layer.

a)



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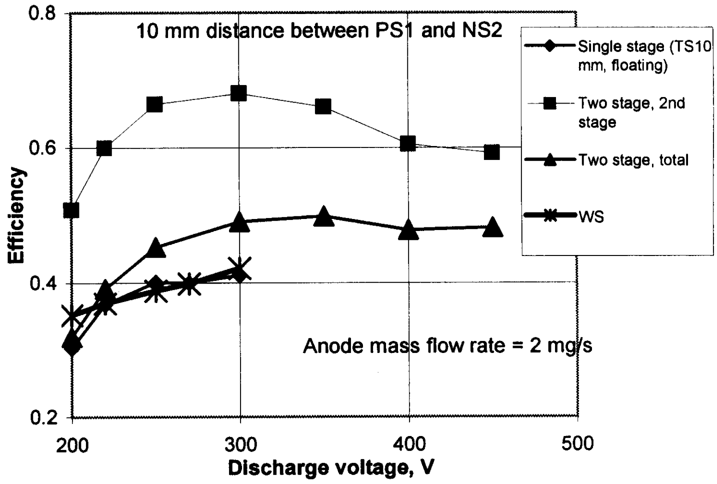

Fig. 7 Thrust (a) and the efficiency (b) versus discharge voltage measured for a two stage thruster configuration at mass flow rate 2 mg/s.

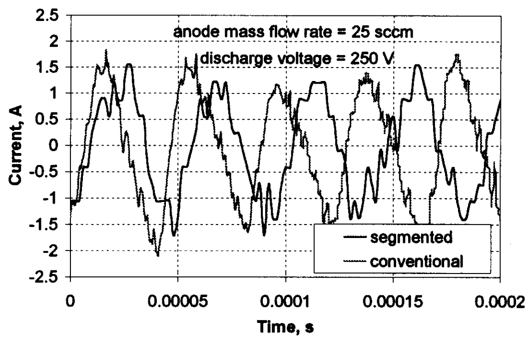

Fig. 8. Discharge current oscillations. The conventional operation (WS) gives approximately 24.5 kHz and the segmented operation with 16 mm spacing gives 21.5 kHz. The mass flow rate is 2.5 mg/s and the discharge voltage is 250 V.

7. Conclusions

The use of a second segmented electrode on the anode-side of the Hall thruster combines the favorable plume divergence characteristic of single-segmented operation with the high efficiency of conventional operation. The decrease in plume divergence is particularly significant at low mass flow rates. It appears that the added flexibility through the use of these electrodes can extend the parameter regimes for favorable operating characteristics of Hall Thrusters. Through simple switching of electrode energizing, one may achieve such a variable mode operation.

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