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Reducing Plasma Perturbations with Segmented Metal Shielding on Electrostatic Probes

by

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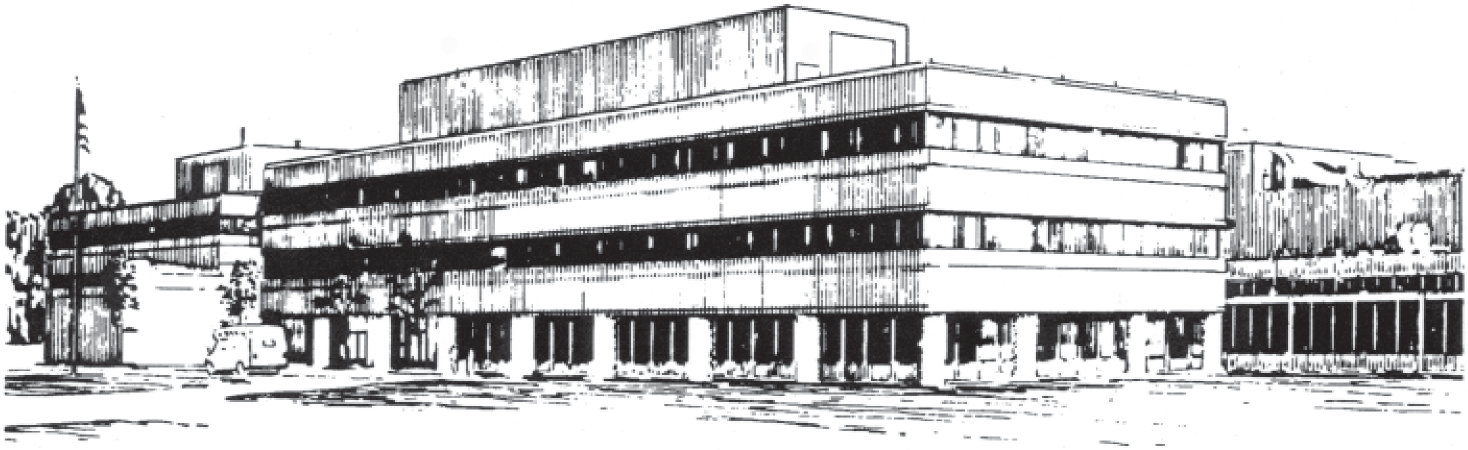

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TITLE

Reducing plasma perturbations with segmented metal shielding on electrostatic probes

ABSTRACT

Electrostatic probes are widely used to measure spatial plasma parameters in the quasi-neutral plasma created in Hall thrusters and similar E×B electric discharge devices. Significant perturbations of the plasma, induced by such probes, can mask the actual physics involved in operation of these devices. In an attempt to reduce these perturbations in Hall thrusters, the perturbations were examined by varying the component material, penetration distance and residence time of various probe designs. This study leads us to a conclusion that secondary electron emission from insulator ceramic tubes of the probe can affect local changes of the plasma parameters causing plasma perturbations. A probe design, which consists of a segmented metal shielding of the probe insulator, is suggested to reduce these perturbations. This new probe design can be useful for plasma applications in which the electron temperature is sufficient to produce secondary electron emission by interaction of plasma electrons with dielectric materials.

I. INTRODUCTION

A conventional Hall thruster is a crossed field electric discharge device with a radial magnetic field applied in a coaxial channel [1]. This magnetic field impedes electrons from their motion towards the anode leading to the establishment of a significant axial electric field in a quasi-neutral plasma. The ions, resulting from electron impact ionization of neutral gas atoms, are electrostatically accelerated through the azimuthally rotating cloud of magnetized electrons towards the channel exit. The thrust is produced as the reaction force to this acceleration. It is transferred through the magnetic field surfaces, which are essentially equipotential, to the magnetic circuit of the thruster. Probe measurements are one vital means to understanding the physical process involved in operation of Hall thrusters. However, introducing probes into the acceleration region causes significant perturbations to the Hall thruster discharge. For example, in references 2 and 3, the discharge current increased to as high as 50-100 % of its steady state value when the probe was introduced into the channel.

A possible mechanism behind these perturbations is the ablation of the insulator probe tube by energetic electrons and ions. In order to reduce the residence time of the probe inside a 140 mm diameter Hall thruster and thus to avoid tube ablation, a fast movable probe was used and helped to reduce the probe-induced perturbations down to 10% of the discharge current [4]. Nevertheless, the absolute amplitude of the discharge current perturbations in that thruster was comparable with those for a smaller 90 mm Hall thruster used in a different setup with a similar probe setup [2]. This might be explained by taking note that the plasma densities in the thrusters of Refs. 4 and 2 and the probe sizes were comparable. It can be speculated that for smaller thrusters, operating at smaller discharge currents, the relative fraction of probe-induced perturbations increases.

In the present work we consider the plasma—probe wall interaction and its dependence on the probe materials. We suggest a new probe design, which can substantially reduce the absolute amplitude of these perturbations and improve the probe durability.

II. EXPERIMENTAL SETUP AND PROCEDURE

The 90 mm laboratory Hall thruster and test facility used in this study (Fig. 1) has been described elsewhere [5]. Electrostatic probes in single, double, and emissive configurations were mounted on a high-speed axial positioning system, which inserts and removes the probe from the thruster at 10 m/s^2 acceleration and velocities up to 1.5 m/s. The probe consists of a high purity alumina tube that insulates the probe wire. Approximately 30 mm of the probe tube is exposed to the plasma and passes through a significant electric field while the probe is inserted into the thruster channel. In a different set of experiments, we found that the alumina insulating tube alone without the wire caused most of the perturbations induced by the probe [6]. Therefore in all the experiments described below, ceramic insulator tubes without wires were used. For Hall thrusters, the maximum electron temperature is typically 20-30 eV, near the first secondary electron emission (SEE) threshold for ceramic materials [1]. Hence, similar to interaction of the plasma with the ceramic channel walls of the thruster, the interaction of the plasma with the ceramic probe walls can have a significant effect on, for example, the electron transport across the magnetic field [1]. Therefore, in order to study the effect of the probe tube material, we used a tube made from quartz in addition to the alumina insulating probe tube. Moreover, a rod made from tungsten, which has a lower secondary electron emission than alumina and quartz, was used instead of the probe tube. The rod was connected to an external electric circuit, which allowed switching of the rod potential between floating and ground biased. The thruster and thruster power supplies were ground insulated.

The perturbations where characterized by changes in the measured discharge current during the insertion of the probe. The effect of these perturbations on the plasma within the thruster were studied by measuring the changes in the floating potentials of three fixed Langmuir probes at different azimuthal locations along the outer channel wall near the thruster exit (Fig. 1). The change in floating potential of the stationary Langmuir probes, $\Delta\phi_f$, is related to the change in plasma potential, $\Delta\phi_p$, and the change in electron temperature ΔT_e by: $\Delta\phi_f = \Delta\phi_p - (k\Delta T_e/e)\ln\left(\sqrt{M_i/2\pi m_e}\right)$, where k is the Boltzmann constant, e is the elementary charge, M_i is the ion mass, and m_e is the electron mass [7].

III. EXPERIMENTAL RESULTS AND DISCUSSION

A. Probe material effect

Fig. 2 shows the DC component of the discharge current as a function of the position of the end of the probe tube for the alumina, quartz, and tungsten. The disturbances were repeatable within 5% and functions of the position of the probe tip. As seen in Fig. 2, the increases in the discharge current caused by the presence of the quartz and alumina tubes are significantly greater than for the floating tungsten rod. In addition, in the case of the ceramic tubes, the perturbations are azimuthally localized in the vicinity of the probe immersion, whereas in the case of the tungsten rod, the perturbations are nearly azimuthally symmetric (Fig 3).

Because relatively cold secondary electrons can lead to a decrease in the electron temperature in the plasma, it is suggested that the increase in the floating potential of the stationary probe for higher secondary electron emission ceramic tubes is caused by decreased electron temperature. On the other hand, in the case of the tungsten rod, the smaller increase of the floating potential is probably associated with an increase of the plasma potential. This is consistent with the measured azimuthal symmetries and the magnetic surfaces being equipotentials. The increase in floating potential for the tungsten rod may be attributed to the current flowing through the rod due to the presence of a voltage drop along it. In this case, the conducting rod acts as a resistor, which shorts the plasma, and, as a result, reduces the potential drop in the plasma. The current through the rod is limited by the presence of the sheath between the plasma and the rod. The increase in discharge current caused by the tungsten rod is related to the ions lost to the rod. When the rod was biased negatively with the respect to the plasma, the measured ion collection current was almost equal within 10% to the increase of the discharge current caused by the rod. The increase of the floating potential measured by the stationary probes and the increase in discharge current was almost the same for the floating and grounded rods.

B. Probe design to reduce perturbations

As it was shown above, a lower SEE tungsten rod causes significantly smaller disturbances of the discharge current than quartz and alumina tubes. The remaining smaller disturbances caused by tungsten can be attributed to its conductivity. The shorting caused by the conductivity is dependant on the potential drop along the shield and the collection area. Thus, ideally, the portion of the probe holder exposed to the plasma should have a high melting temperature, a high thermal conductivity, low SEE, and be electrically non-conducting. Since a dielectric with sufficiently high thermal properties and low SEE is not available, use of a low SEE metal shield on the insulating probe tube (Fig. 4) is preferable. Segmenting the metal shield limits the potential drop along each segment and so the current shorted through the shield and as a result, probe-induced perturbations. Such a shield can be made from commercially available molybdenum, graphite or tungsten tubes or by metal coating of the insulator tube.

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Figures List

Figure 1: PPPL 9cm Hall thruster with stationary and high-speed probes.

Figure 2: Discharge current perturbations caused by quartz, tungsten, and alumina probes.

Figure 3: Changes in stationary probe voltages azimuthally (a) near and (b) opposite the point of insertion for the quartz, tungsten, and alumina probes.

Figure 4: Probe schematic.

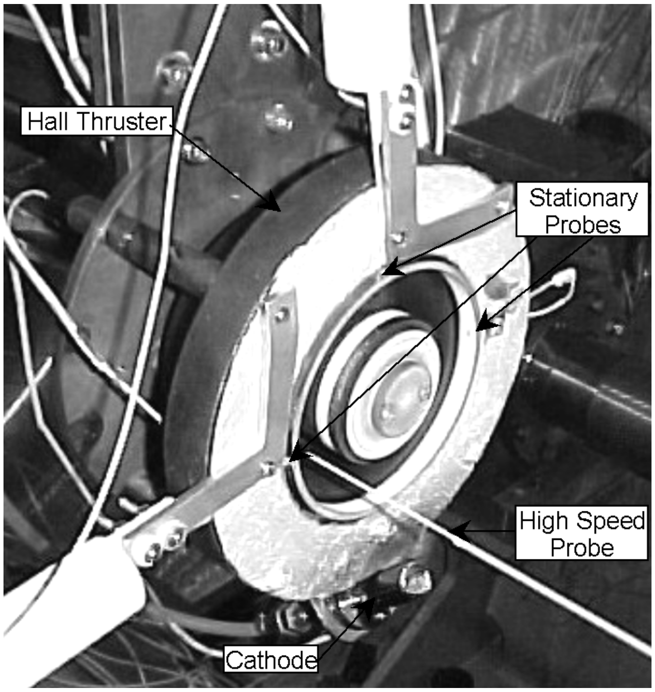

Figure 1

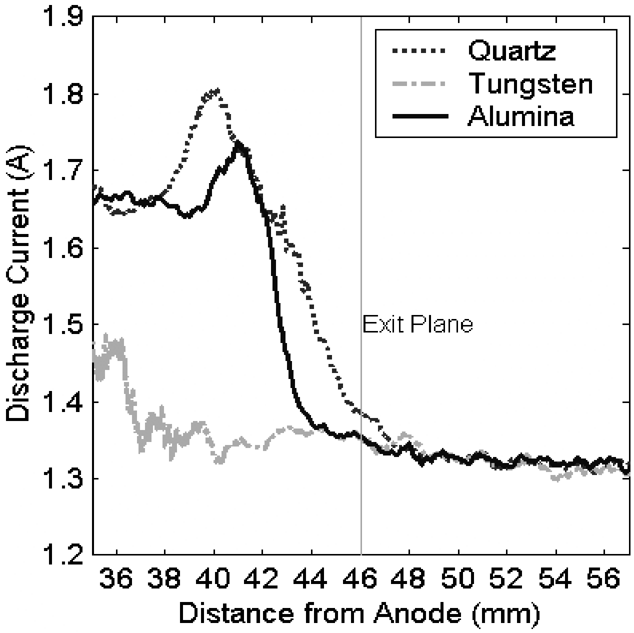
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
Discharge Current (A)
36
38
40
42
44
46
48
50
52
54
56
Distance from Anode (mm)
Quartz
Tungsten
Alumina
Exit Plane

Figure 2

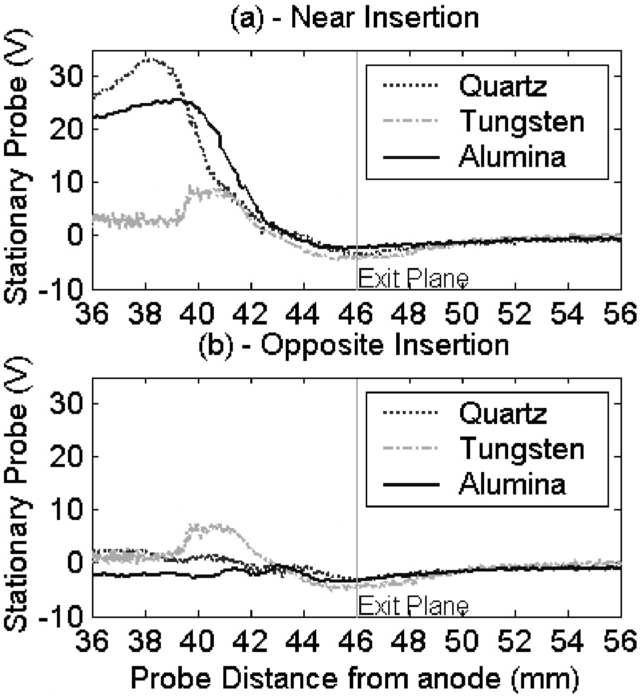
(a) - Near Insertion
Stationary Probe (V)
30
20
10
0
-10
36 38 40 42 44 46 48 50 52 54 56
Quartz
Tungsten
Alumina
Exit Plane
(b) - Opposite Insertion
Stationary Probe (V)
30
20
10
0
-10
36 38 40 42 44 46 48 50 52 54 56
Quartz
Tungsten
Alumina
Exit Plane
Probe Distance from anode (mm)

Figure 3

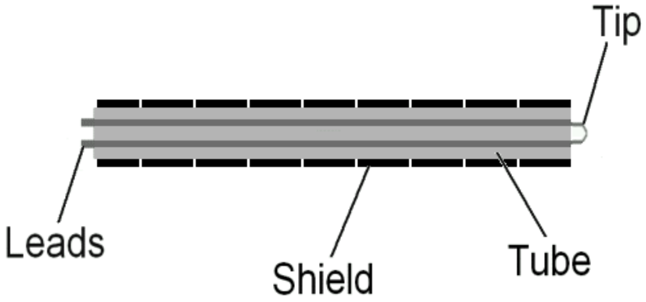

Figure 4

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