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by

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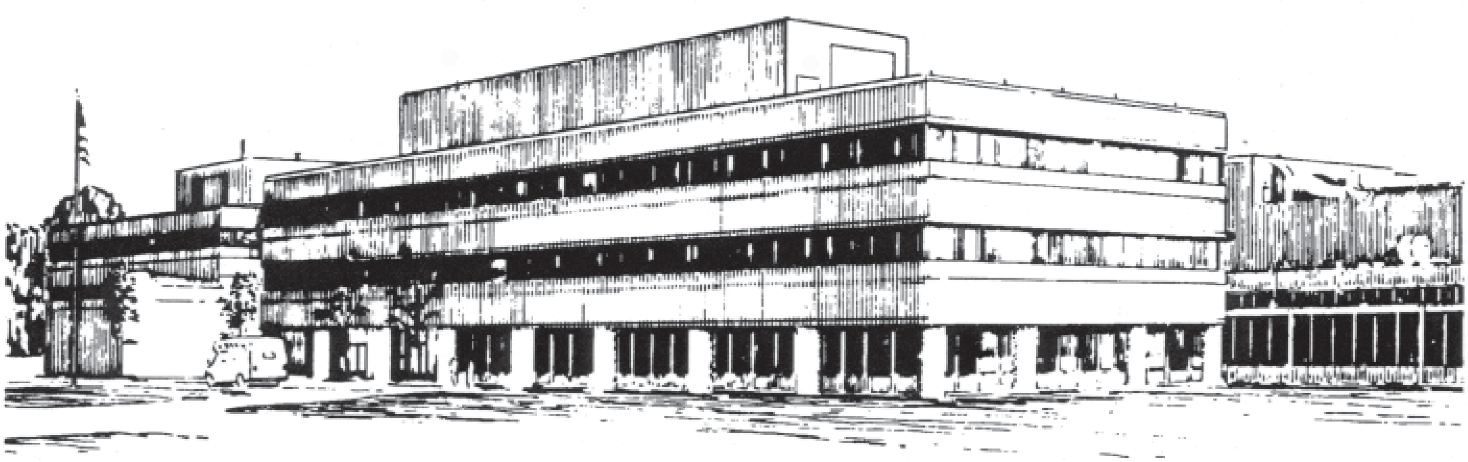

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DIAGNOSTIC SETUP FOR CHARACTERIZATION OF NEAR-ANODE PROCESSES IN HALL THRUSTERS

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ABSTRACT

A diagnostic setup for characterization of the near-anode processes in Hall thrusters was designed and assembled. Experimental results with a single floating probe show that radial probe insertion does not cause perturbations to the discharge and therefore can be used for near-anode measurements.

I. INTRODUCTION

Conventional Hall Thrusters can efficiently produce *Isp* in the range of 1000-2000 sec operating at moderate discharge voltages of several hundred volts. However, an increase of the discharge voltage to a thousand volts and above in order to reach higher *Isp* may be accompanied with a reduction of the thruster efficiency.[1] Physical mechanisms leading to this degradation of thruster performance are unknown, in part because *high Isp* operation of Hall thrusters is relatively less studied. Theory predicts the presence of a negative anode sheath and a back-ion flow in order to limit electron flux towards the anode at moderate discharge voltages.[2] An increase of the discharge voltage at the same magnetic field leads to the increase of the discharge current; however, the electron temperature is limited by the secondary electron emission from the channel walls. Therefore at large discharge voltages the electron drift velocity at the anode may become on the order of or larger than the electron thermal velocity, rendering the sheath unnecessary or making it positive. Existing experimental evidence indicate, although indirectly, some principal changes in the near-anode potential profile with the increase of the discharge voltage.[3] Analysis of boundary conditions for a quasi one-dimensional steady-state model of a Hall thruster shows that the discharge voltage determines the operating regime: for discharge voltages greater than a certain value, the negative anode sheath and the back-ion flow disappear.[4]

Near-anode processes may have an effect on the overall operation of a Hall Thruster. At the same discharge current electron energy flux towards the anode is higher in case of a positive sheath, because electrons gain kinetic energy in the positive voltage drop. As a result they can provide an additional ionization in this region,[5] which may be useful at low mass flow rates, and increase the anode heating. Taking into account that in Hall thrusters the anode is typically a gas-distributor, its damage by overheating may result in the irreversible failure of the thruster. In addition, a change of the voltage drop in the near-anode sheath causes changes in the electric field distribution along the entire channel, which may potentially affect the beam divergence inside and outside the thruster. Therefore it is important to investigate near-anode processes experimentally, and understand physical conditions for thruster operation in "no sheath" and "positive sheath" regimes.

The near-anode region in Hall thrusters is typically about 1-2 cm long. Plasma density, $n \sim 10^{10}$ - 10^{11} cm^{-3}, electron temperature, $T_e \sim 3$ - 5 eV, and their variations in the near-anode region are smaller than in the acceleration region. The magnetic field is also much smaller, so the electron flux towards the anode is mainly affected by the electron pressure gradients, $\frac{1}{en}\frac{dP}{dz}$ ~ 10 V/cm.

Similar to the experimental studies of the sheath and presheath in low-pressure gas discharges,[6] measurements of the plasma parameters in the near-anode region can also be implemented by various electrostatic probe techniques including single, double and emissive probes. However, implementation of conventional plasma diagnostics for measurements inside the Hall thruster channel is complicated by its relatively small size and obstacles imposed by thruster structures, in particular by the magnetic circuit. Besides, introducing probes axially into the acceleration region with T_e ~ 20 eV has caused significant perturbations to the Hall thruster discharge, namely increases up to and greater than 50% and fluctuations of the discharge current.[7,8,9] This may cause inaccuracy of up to tens of volts in measured plasma potential, which is unacceptable for characterization of a near-anode region where the overall expected potential change is of order of several volts.

In this paper we describe the diagnostic setup for near-anode measurements and experimental results for characterization of the effect of probe insertion and axial motion on thruster operation. The probe is introduced radialy into the near-anode region and does not pass through the acceleration region. It is not expected to cause significant perturbations to the discharge or get severely damaged because the electron temperature and plasma density in the near-anode region are low. For the same reason probe residence time should not be an issue and therefore radial probe insertion does not require high-speed motion.

II. DIAGNOSTIC SETUP

The new 2 kW Hall thruster and test facility used in this study are described in Ref. 10. Fig. 1 shows a diagnostic setup for near-anode measurements and the probe location relative to the thruster channel. The probes holder, which can accommodate up to three plain electrostatic or hot emissive probes simultaneously, is mounted on a CVI precision rotary stage and a Newport linear stage for fine pitch and height adjustment of the probe relative to the thruster channel. These manually controlled stages are assembled on a Velmex motor-driven X-Y linear positioning stage, equipped with two 400-steps/rev step-motors, two 40-rev/inch high precision lead screws and two 5 μm-resolution Renishaw optical encoders. This motor-driven stage is mounted on an additional CVI rotary stage for a fine yaw adjustment, which is fixed on an aluminum breadboard near the thruster mounting table. Probes can be introduced into the thruster through a 2mm wide and 10 mm long axial slot starting at 2 mm from the anode, made in the outer ceramic wall of the thruster channel. The motor-driven positioning stage allows probe motion along the slot between the inner and the outer channel walls. Control of the positioning system and the signal measurements are performed by a National Instruments, PC-based, data acquisition system.

For the present study we introduced a single floating electrostatic probe into the plasma near the anode in order to measure probe induced perturbations in a discharge current. The probe consists of a high purity alumina single bore tube 1.5 mm in diameter covering 0.25 mm diameter thoriated tungsten wire (Fig. 1). The uncovered tip length was 3 mm and the overall probe length was 165 mm.

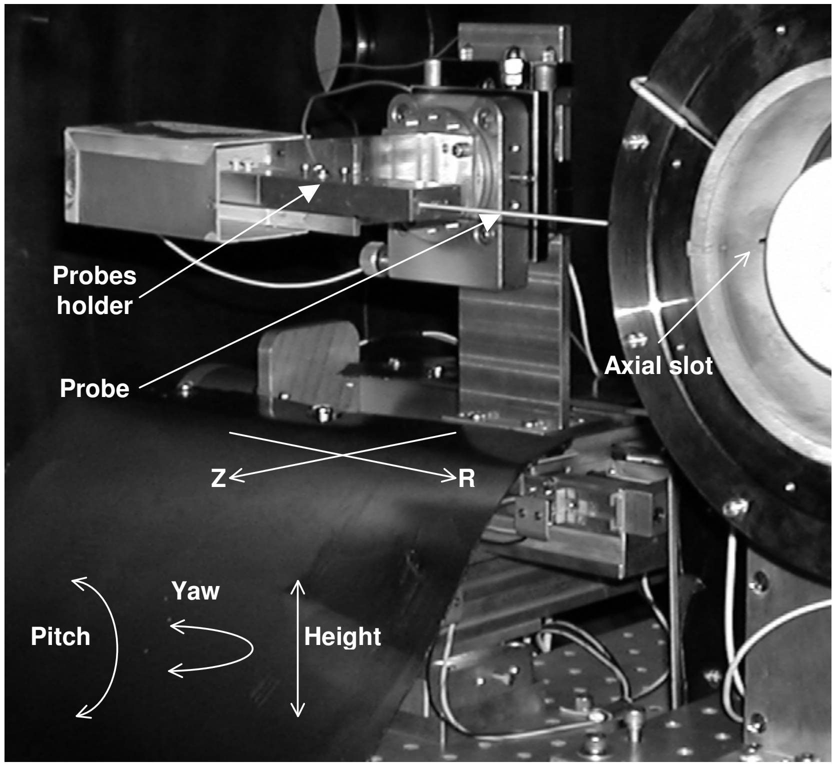
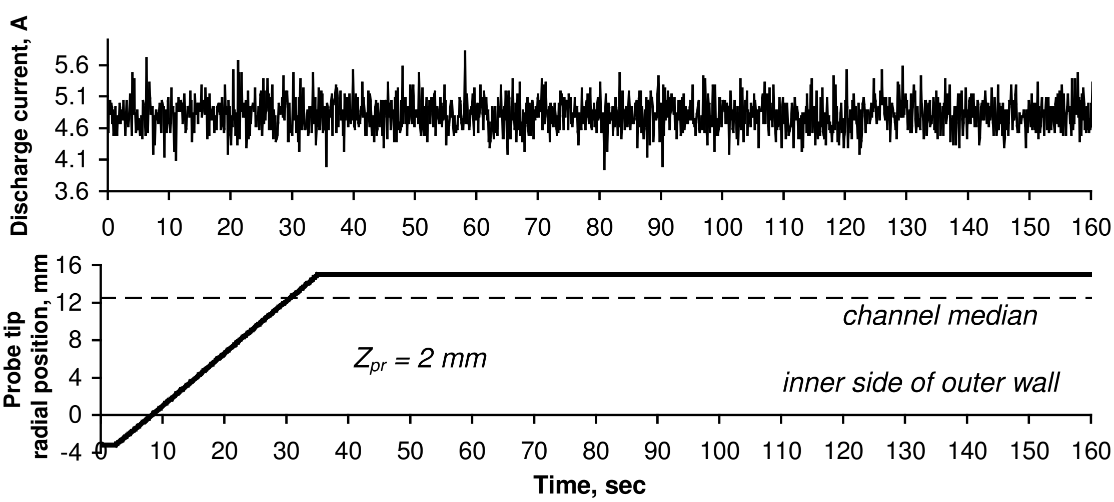


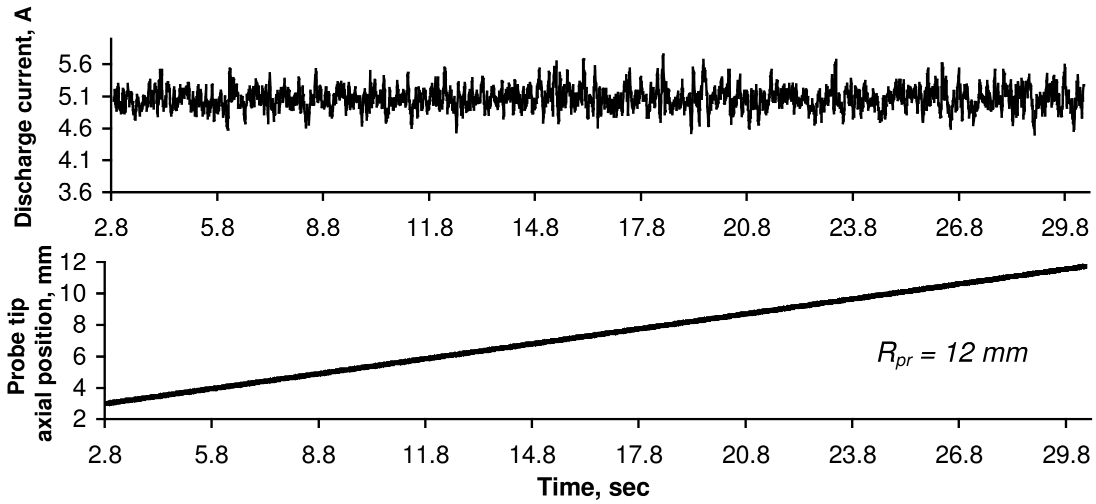
FIG. 1. Radial probes diagnostic setup for near-anode measurements.

III. EXPERIMENTAL RESULTS

A floating electrostatic probe was introduced radialy into the near-anode plasma at various thruster operating parameters, namely discharge voltages, V_d, from 200 to 700 volts and mass flow rates, dm/dt, from 20 to 50 SCCM. During the first experimental session probe was inserted radialy as deep as 20 mm into the channel at various axial positions, Z = 2.5 – 12 mm from the anode, and left in plasma for up to 5 min. During the second experimental session probe moved from the anode side, Z = 2.5 mm, to the cathode side, Z = 12 mm, of the slot at several radial locations from near the outer wall, R = 0, to near the inner wall, R = 25 mm. Measured discharge current vs. time characteristics are shown on Fig. 2.



a.)



b.)

FIG. 2. Discharge current vs. time characteristics for V_d = 500 V and dm/dt = 50 SCCM.

a.) Nov 8, 2002 – Radial insertion. Sampling rate = 10 samples/sec.

b.) Dec 23, 2002 – Axial motion. Sampling rate = 200 samples/sec. Averaged over 10 data points.

We found that in all delivered experiments probe motion did not disturb the plasma of the discharge. This leads to the conclusion that radial probe insertion can be used for plasma measurements in the near-anode region of a Hall thruster.

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