Controlling the Plasma Potential Distribution in Segmented-Electrode Hall Thruster

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***Abstract*—Segmented electrodes and ceramic spacers (CSs) placed along the Hall thruster channel are shown to produce strong modifications of axial and radial plasma potential distributions as compared to conventional nonsegmented thruster. These modifications are associated with differences in secondary-electron-emission properties of materials used for electrodes and CSs and correlate with plasma-plume divergence.**

***Index Terms*—Hall discharge, plasma propulsion.**

I. INTRODUCTION

THE HALL thruster (HT) [1] is an electromagnetic-propulsion device that uses a cross-field plasma discharge. A significant axial electric field with equipotentials along the magnetic-field lines $(E = -v_e \times B)$ accelerates ions and generates thrust. Ions are accelerated in a quasi-neutral plasma, so that no space-charge limitation is imposed on the achievable current and thrust densities. Fig. 1 shows the operation of a conventional annular HT with xenon gas.

In conventional HTs, the electric-field distribution is controlled mainly by the magnetic-field distribution in the ceramic channel [1], [2]. The placement of the acceleration region with a strong axial electric field relative to the axial magnetic-field distribution depends on the axial variation of the rate of the electron cross-field transport [3]. A strong secondary electron emission (SEE) from the channel walls can enhance the near-wall conductivity (due to electron-wall collisions) inside the channel [1]. As a result, a large voltage drop is established outside the thruster channel [4]. When the ion acceleration occurs outside the channel in the fringing magnetic field, the plasma flow is subjected to divergence because of defocusing equipotential surfaces in this region [5]. A large divergence of the plasma flow makes difficult the integration of the thruster with a satellite.

In segmented HT (Fig. 2) [4], [6], the use of nonemissive floating electrodes placed on one of the channel walls or both the inner and outer walls was shown to narrow the plasma plume as compared to the conventional nonsegmented thruster. The plume narrowing correlated with the reduction of the voltage potential drop outside the segmented channel [4]. Fig. 3 shows illustrative examples of electric potential distributions measured for floating segmented and conventional nonsegmented configurations of a 9-cm-diameter laboratory HT. The measurements were conducted using a fast movable floating emissive probe. There is a correlation between the plasma potential distribution and SEE properties of the channel-wall material. For a boron nitride channel [Fig. 3(a)], the outside voltage drop is larger than that for the segmented channel with lower SEE graphite electrodes [Fig. 3(b) and (c)] and smaller than that for the channel with a spacer made from a higher SEE glass ceramic [Fig. 3(d)].

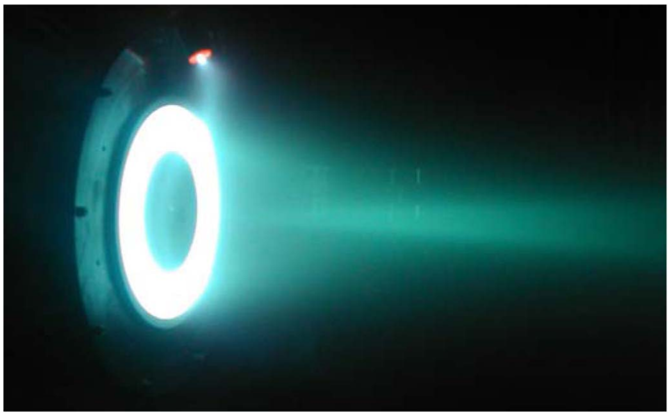

Fig. 1. Xenon plasma flow from a 2-kW PPPL HT with a 12-cm outer diameter annular channel. A plasma cathode neutralizer seen above the thruster channel operates also with xenon gas.

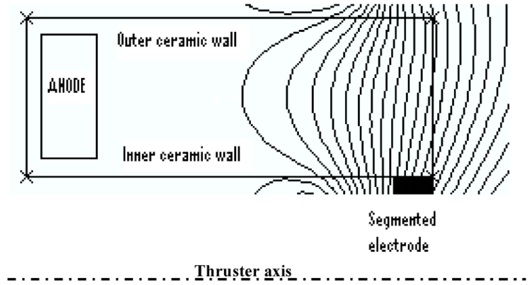

Fig. 2. Schematic of the 9-cm-diameter 1-kW HT with superimposed simulated magnetic field. The distance between the anode and the channel exit is 46 mm. The channel width is 17 mm.

Note that, in a quasi-neutral plasma, the effective ratio of secondary to primary electron fluxes cannot exceed a critical value of about one, which corresponds to the space-charge-saturated wall sheath [7]. For different materials, this critical value is reached at different energies of primary electrons [8]. Differences in the SEE on the opposite channel walls made

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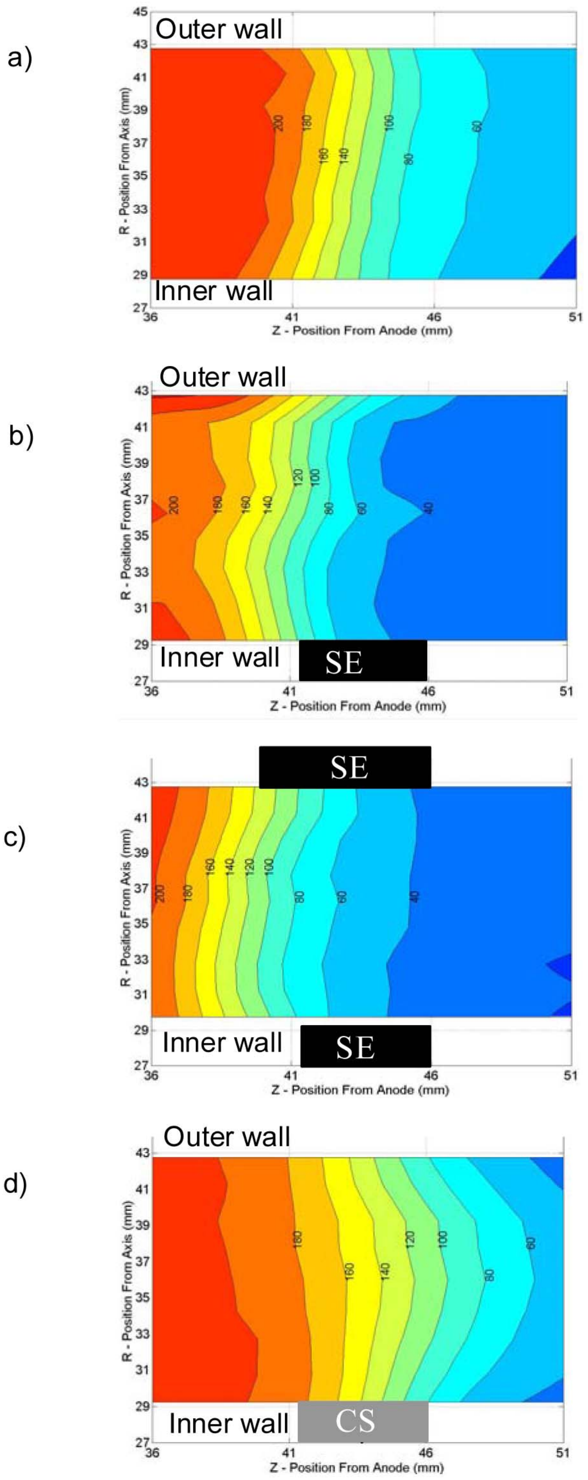

Fig. 3. Electric potential distribution measured with a floating emissive probe for different segmented configurations of a 9-cm-diameter HT operated at the discharge voltage of 250 V, xenon gas flow rate of 17 sccm, and the same magnetic field (Fig. 2). (a) Conventional nonsegmented channel made from a boron nitride ceramic. (b) Single segmented floating electrode (SE) made from a low SEE graphite material placed on the inner channel wall. (c) Two segmented floating graphite electrodes placed on the inner and outer walls. (d) Ceramic spacer (CS) made from a high SEE machinable glass ceramic. The thruster channel exit is at 46 mm from the anode.

from different materials may cause nonuniform plasma structures across the thruster channel [4], [9].

According to the model [9], the radial change of the electron cross-field mobility due to the magnetic-field gradient and due to the electron current along the magnetic field may explain nonuniform potential distributions shown in Fig. 3(b) and (d). This electron current may be driven by the radial temperature gradient [9]. Moreover, recent theoretical and numerical studies [10]–[12] suggested that SEE electrons from the opposite channel walls form counter-streaming beams. These beams may carry a considerable portion of the cross-field electron current (near-wall conductivity) due to their cycloid trajectory in the $E \times B$ field [11], [12]. They should depend on SEE properties of the wall material and can be affected by asymmetrical conditions [13], including differences in the SEE on the opposite walls and the radial distribution of the magnetic field. In a typical HT, the electron temperature can be large enough (20–50 eV, [12]) to induce a strong SEE from boron nitride and glass ceramics [8] but not from a graphite electrode. This difference might explain a smoother shape of equipotentials obtained for the high SEE spacer [Fig. 3(d)] than that for the low SEE electrode [Fig. 3(b)]. Future studies should be focused on validation of these predictions.

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