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Electron transport and plasma instability in ECR plasma discharges for a miniature ion thruster

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Micro thrusters are one of the indispensable components for microspacecraft in order to carry out advanced missions, such as mega-constellations and deep-space exploration. For such purposes, ion thrusters are a promising propulsion system to achieve high delta-v and total impulse, and a miniature ion propulsion system for a 50-kg class satellite was developed and operated in space for the first time in the world in 2014.[1]

The ion thruster employs ECR plasma sources for both its ion source and neutralizer, which consist of a ring-shaped microwave antenna and permanent magnets (Fig. 1). In order to clarify the mechanism of ECR discharges in a small space and to provide clear guidelines for its optimum designs, a three-dimensional particle-in-cell simulation with a Monte Carlo collision algorithm has been conducted.[2-8] The configuration of the plasma source produces the ECR layer in front of the antenna and the magnetic mirror field in the radial direction. The magnetic field confines electrons for an efficient plasma generation but inhibits the electron extraction through the orifices at the same time.

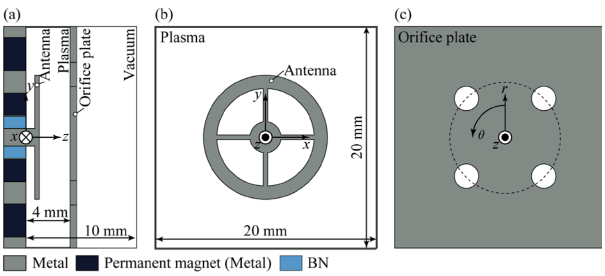

Fig. 1. Schematic of the calculation model: (a) the z–x/y plane, (b) x–y plane at the antenna, and (c) x–y plane at the orifice plate. Figure is reproduced from Ref. [7].

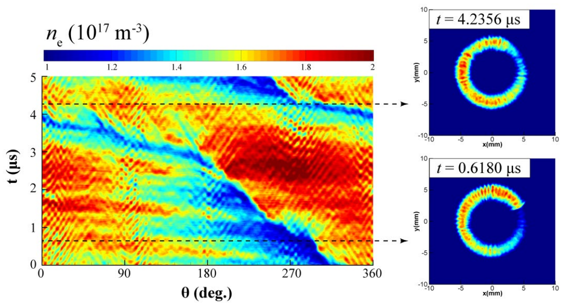

Fig. 2. Time evolution of the electron density in the high-density region on the θ-axis together with typical electron density distributions at the x–y plane. The θ -axis is drawn at r = 5.0 mm and z = 2.2 mm. Figure is reproduced from Ref. [7].

In the plasma source, the characteristic radial striped patterns rotating in the azimuthal direction have been observed (Fig. 2).[4,7] This structure induces the potential difference in the azimuthal direction, which in turn causes the azimuthal electric fields. The resultant $\boldsymbol{E} \times \boldsymbol{B}$ drift velocity seems to contribute to the electron transport across the magnetic field and electron extraction through the orifices.

This phenomenon is confirmed in both xenon and water plasma discharges; an enhanced instability is observed in the water discharge, probably owing to its negative ions (Fig. 3).[6] The magnetic field configurations have also affected the instability and electron extraction efficiency.[7,8] The results obtained in these studies seem to be related to those observed in various $\boldsymbol{E} \times \boldsymbol{B}$ devices.[9]

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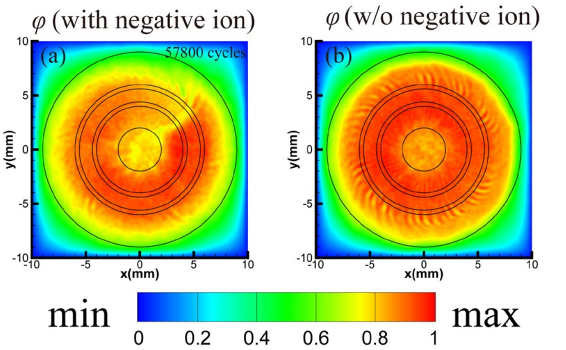

Fig. 3. Distributions of (a) the normalized potential on the x–y plane with negative ions and (b) without negative ions. Figure is reproduced from Ref. [6].

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