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Particle modelling of a miniature neutralizer-free radio-frequency ion thruster for small satellite applications: revealing the mechanism of plasma generation, ion acceleration and plume neutralization

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Microsatellites have triggered a worldwide research upsurge in recent years and due to its need for very small and accurate thrust to achieve orbit control, the demand for micro electric propulsion system is urgent. Radio Frequency (RF) ion thrusters using a low pressure inductively coupled plasma source have the advantages of high specific impulse, easy to scale and long lifetime, which are gradually applied to microsatellites as the low-power electric propulsion system. Considering that the lifetime of neutralizer is a restriction for long time operation of ion thrusters, a new technology for neutralizing the plume without external neutralizers has been developed which simultaneously extracts positive ions and electrons, using RF biasing instead of DC biasing to the grid system of thruster. Regardless of widespread attention to miniature neutralizer-free gridded ion thruster, little is known about its underlying operating mechanisms.

Therefore, we established particle-in-cell Monte Carlo collision (PIC/MCC) models to investigate the physics of inductively coupled plasma generation, ion acceleration and plume neutralization respectively in a real-size miniature neutralizer-free RF ion thruster which has been benchmarked by comparing with the experiments. The energy relaxation characteristics of electrons in the discharge chamber in response to the change of operating parameters, i.e. RF coil current, gas pressure and applied frequency were widely investigated. The fundamental physics of RF biasing including electron and ion spatial and temporal dynamics during the ions acceleration and plume expansion were described and the influence of the misalignments of apertures on the grid system performance was identified. This study lays a solid foundation for further development of miniature neutralizer-free RF ion thrusters for small satellite applications. Figure 1 illustrates the distribution of electron and ion density in the real-size thruster (I_{coil} = 14.55 A, f = 2.0 MHz, P = 1 mTorr) as well as the particle number density in the DC and RF grid systems with misalignments of apertures, respectively. This work is supported by the National Natural Science Foundation of China (Grant Nos. 51977003 and 52277133).

References

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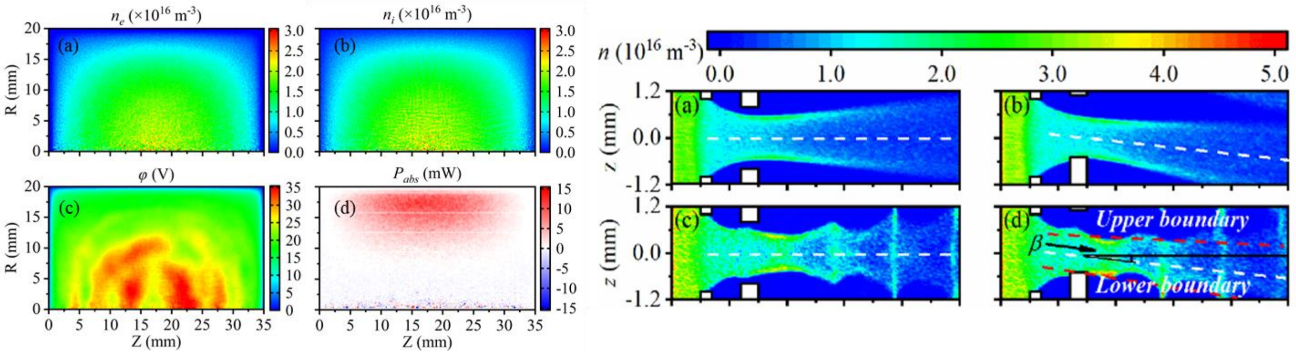

Figure 1 Spatial distributions of low-pressure inductively coupled plasma properties (a) Electron density. (b) Ion density. (c) Potential. (d) Absorbed power per cell in the discharge chamber (left figure) as well as the ion number density distribution in the grid system (right figure) (a) Hole shift = 0 mm, DC, (b) Hole shift = 0.3 mm, DC, (c) Hole shift = 0 mm, 13.56 MHz at ωt/2π = 0.75, (d) Hole shift = 0.3 mm, 13.56 MHz at ωt/2π = 0.75. The white dashed line in the right figure (a)–(d) represents the centerline of the ion beam. The black angle in the right figure (d) represents the deflection angle of the beam centerline about the positive x direction. The red dashed lines in the right figure (d) represents the upper boundary and lower boundary of the ion beam, in which 95% of ions are contained. The rectangles appearing in the figures show the position of grids.