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Study on plasma instabilities in Hall thrusters: mechanisms and mitigation strategies

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Hall thrusters, as typical E×B discharge devices, are inherently susceptible to various plasma instabilities that significantly influence discharge performance and long-term operational stability. Among them, low-frequency oscillations (5–100 kHz) and electron drift instabilities (EDI, ~MHz) are two major phenomena contributing to discharge current fluctuations, enhanced anomalous electron transport, and reduced propulsion efficiency.

This study employs both fluid and kinetic simulation methods to investigate the mechanisms and mitigation strategies for these two types of instabilities. For low-frequency oscillations, a one-dimensional fluid model encompassing both the discharge channel and plume region is developed. In this model, the influence of wall energy loss on electron temperature is considered by incorporating secondary electron emission effects, which enables a more accurate analysis of how channel width affects oscillation behavior (Figure 1a, 1b). Results show that optimizing the channel length-to-width ratio, accounting for wall erosion, and adjusting magnetic field gradients can effectively suppress low-frequency oscillations and enhance thruster stability.

To further understand EDI near the channel exit, a 1.5D and 2.5D PIC model is constructed in the axial-azimuthal and radial-azimuthal direction. The evolution of EDI from its linear growth to nonlinear saturation is captured, highlighting its role in enhancing axial electron mobility through azimuthal ion heating and electron-ion interactions (Figure 1c, 1d). Parametric studies reveal that using lighter propellants increases the linear growth rate and frequency of EDI, but can help reduce the amplitude of the oscillations. Additionally, adjusting electromagnetic field configurations and considering electron-neutral collisions are found to be effective in mitigating EDI-induced anomalous transport.

These findings contribute to a deeper understanding of instability mechanisms in Hall thrusters and provide practical guidance for structural and operational optimization to improve performance and extend device lifetime.

References

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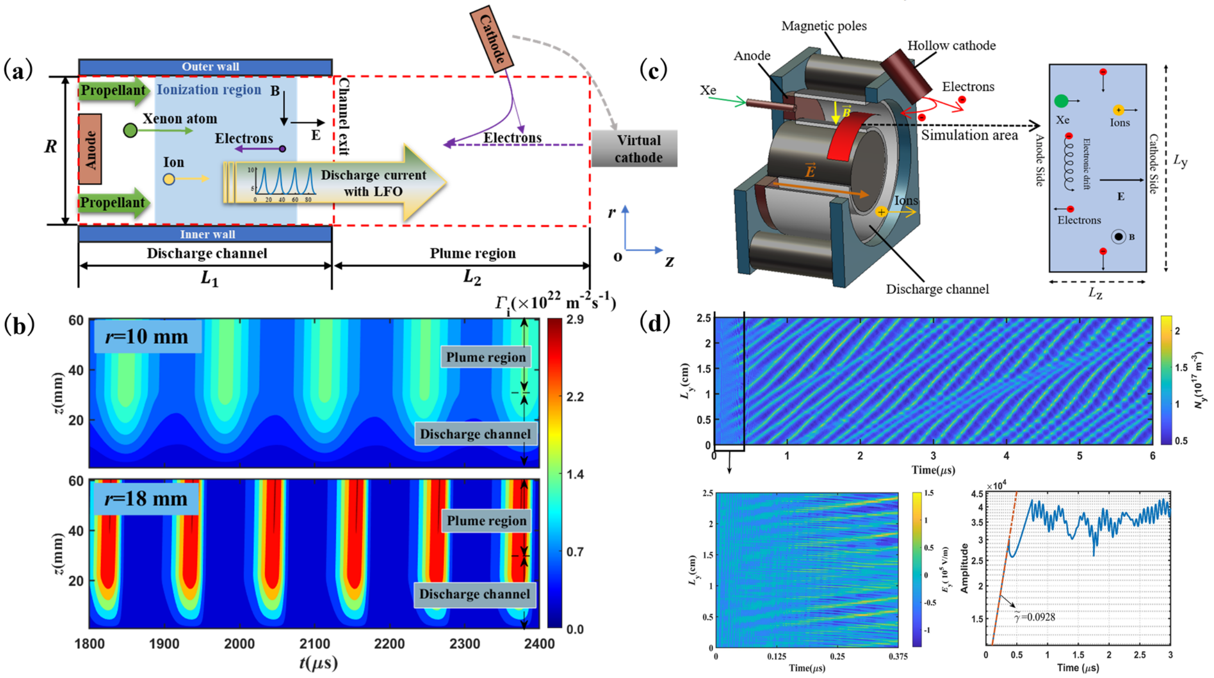

Figure (a) Schematic diagram of the mechanism of low-frequency oscillations in a Hall thruster (b) Spatiotemporal evolution of ion flux at different channel widths under low-frequency oscillations (c) Typical 3D structure of a Hall thruster and schematic of the EDI simulation region. (d) The temporal evolution of electron density, and the temporal evolution of the amplitude of azimuthal electric field oscillations.