8th Asia-Pacific Conference on Plasma Physics, 3-8 Nov, 2024 at Malacca

Experimental and numerical investigation on the dynamic mechanism of discharge instabilities in the wall-less Hall thruster

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The wall-less Hall thruster eliminates the channel wall of the traditional Hall thruster to avoid the plasma erosion-induced decrease in thruster performance and operation lifetime, which has promising application prospects for future complex space missions such as low-orbit satellite constellations, etc. The operation of the wall-less Hall thruster is accompanied by ubiquitous discharge instabilities manifested by oscillations in the discharge current, voltage, and plasma parameters with very complex wave characteristics over a wide spectrum from a few kHz to more than a dozen MHz. Discharge instabilities will significantly affect the operation mode, beam divergence and discharge channel sputtering erosion, which are unavoidable technical issues in the development and application of the wall-less Hall thruster.

Therefore, we develop an advanced plasma diagnostic system consisting of advanced optical diagnosis and a kinetic model based on the particle method to capture the plasma characteristics in the discharge instabilities. Optical diagnosis includes optical probe pairs and synchronized high-speed imaging system, which capture the optical signal of the thruster plasma to study the transient characteristics of instabilities[1]. A high-efficacy particle-in-cell/Monte Carlo collision-direct simulation Monte Carlo (PIC/MCC-DSMC) code was developed with acceleration techniques and verified by hierarchical verification[2]. Each sub-module and the whole code were verified respectively by comparing the results with the analytical solutions and benchmarks. The results show that the acceleration techniques significantly improve the calculation speed of both solving potential field and moving particles with high calculation accuracy. It is found that the breathing mode, electron cyclotron drift instability, ion transition time instability and spoke instability coexist in wall-less Hall thruster discharges. Plasma oscillations play a key role in the anomalous cross-field transport of electrons, which dominate the establishment and maintenance of plasma discharge[3]. The azimuthal plasma oscillation exhibits high-frequency electron cyclotron drift instability in the ignition stage of the discharge, then the periodic low-frequency spokes will be developed in coupling with the axial breathing mode as the discharge gradually stabilizes. These findings will provide new insights into the optimal design and reliable operation of a wall-less Hall propulsion system. This work is supported by the National Natural Science Foundation of China (Grant Nos. 523B2078).

References

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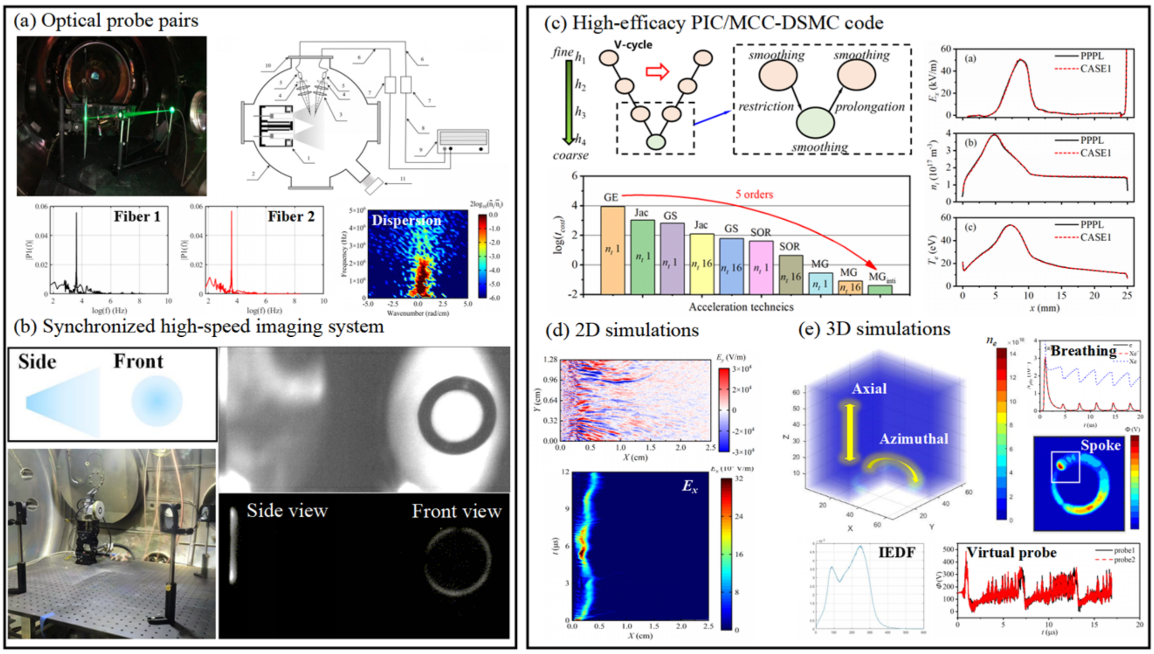

Figure 1. (a) Optical probe pairs, (b) Synchronized high-speed imaging system[1], (c) High-efficacy PIC/MCC-DSMC code[2], (d), (e) 2D and 3D simulations for plasma instabilities in wall-less Hall thrusters[3].