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Numerical Analysis of the Gradient Drift Instability and its Control in Hall Thruster Plasmas

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Hall thruster is an electric propulsion system which has an E×B configuration with the axial electric field and radial magnetic field. Owing to the magnetic confinement of electrons, the Hall thrusters enable efficient ionization of propellant gas and ion extraction. Although the Hall thrusters have attained high thrust efficiency exceeding 60%, further improvement of the thruster efficiency is desired. One of the issues limiting the thruster efficiency is related to the anomalous electron transport. The anomalous electron transport is the well-known issue in the E×B discharge plasmas. Despite the long history of research, the physics behind the anomalous electron transport is not fully understood. According to recent findings, it is hypothesized that plasma oscillations that develop in the azimuthal (E×B) direction cause the electron transport enhancement.

The objective of this study is to numerically model the plasma instabilities that affect the cross-field electron transport, and to find an approach to mitigating the instabilities. The authors have reproduced 10 kHz-order rotating spoke (RS) [1] and 100 kHz-order gradient drift instability (GDI) [2]. The effects of these instabilities on the cross-field electron transport are discussed.

An axial-azimuthal two-dimensional model was built for the Hall thruster discharge. The hybrid particle-fluid model with the quasineutral assumption was used. In this study, the axial distributions of ionization source term and magnetic flux density were assumed. 100 μs simulation was performed to attain the converged discharge current and plasma states.

Figure 1(a) shows the axial-azimuthal distribution of the plasma density. At the upstream region of $x < 12$ mm, Coherent wave structure moving in the azimuthal direction (+E×B direction) was observed. This structure is the RS, and its characteristics are consistent with experimental data. Figure 1(b) shows the axial electron velocity distribution. At the downstream region of $x > 12$ mm, plasma instabilities with vortex like structures are induced. Through comparisons between the simulation results and the linear theory of the GDI, the simulated plasma instability is identified as the GDI.

The RS and GDI affects the cross-field electron transport in the Hall thruster discharge channel. The electron mobility under a magnetic field is described by the classical diffusion theory based on the electron-neutral atom collisions. Figure 2 presents the effective electron mobility distribution along the discharge channel. A significant enhancement of the cross-field electron transport is observed, especially in the downstream region of $x > 12$ mm. In this region, the electrons move across magnetic fields due to the GDI, rather than the electron-neutral collisions.

In the conference, the operating parameters affecting the GDI and the enhanced electron transport are discussed. We further propose controlling method for the plasma instabilities that use artificial disturbances, such as the inhomogeneous propellant gas injection [3] and azimuthally nonuniform magnetic field [4].

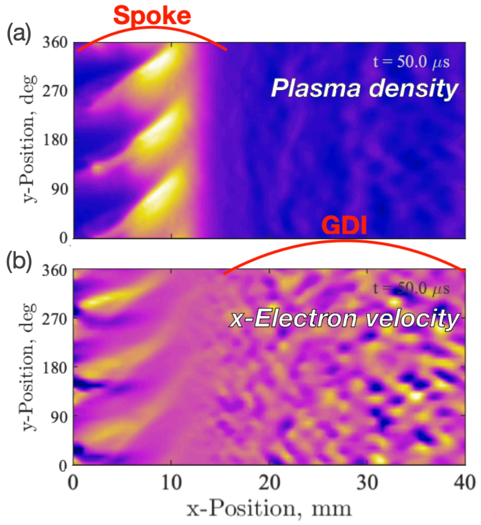

Figure 1 x-y (axial-azimuthal) distribution of (a) plasma density and (b) x- (axial) electron velocity.

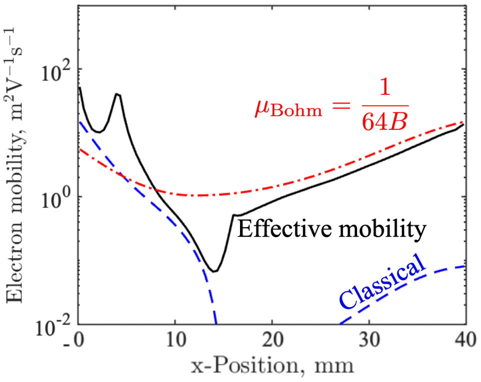

Figure 2 Effective electron mobility distribution compared with the classical (collisional) mobility.

References
[1] Kawashima and Komurasaki, *Phys. Plasmas* 28 (2021) 063502.
[2] Kawashima et al., *Plasma Sources Sci. Technol.* 27 (2018) 035010.
[3] Bak et al., *Phys. Plasmas* 26 (2019) 073505.
[4] Bak et al., *J. Appl. Phys.* 131 (2022) 0302.