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Propulsive performance of a helicon plasma thruster operated for various rare gas species
ヘリコンプラズマスラスター推進性能の推進剤ガス種依存性

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A helicon plasma thruster is tested for various rare gas species and assessed by the thrust measurement. The rf power transfer efficiency for Argon, Krypton and Xenon are comparable, and then the thrust performances are also maintained at about 10 mN. However, significant difference in the loss of the axial momentum onto the radial physical boundary is discovered by individual measurements of the thrust components. It is found that the greater loss of the axial plasma momentum onto the source tube occurs for the heavier propellant gas.

1. Introduction

Electric propulsion devices are classified in terms of the plasma production and acceleration methods. The well-investigated propulsion devices, e.g., magnetoplasmadynamics (MPD) thruster [1], ion engine [2], and hall thruster [3], have a common problem of life time of electrodes exposed to the plasma. Therefore, the electrodeless propulsion devices, e.g., variable specific impulse magnetoplasma rocket (VASIMR) [4] and helicon plasma thruster [5] have been vigorously developed in recently. In these propulsion devices, the external magnetic field called magnetic nozzle is applied to improve the radiofrequency (rf) power coupling with the plasma and to accelerate the plasma plume via the magnetic plasma expansion.

In the helicon plasma thruster, the thrust is given by sum of three components of T_s, T_w and T_B [6]. Here T_s is static electron pressure force exerted on the axial upstream boundary, T_w is axial momentum delivered by the ions lost to the radial wall boundary, and T_B is Lorentz force onto the magnetic nozzle. The direct measurement of these thrust components has clearly demonstrated that the T_B term is increased by increasing the magnetic field strength and the thruster performance is improved as a result of inhibition of the cross-field diffusion in the nozzle [7]. However, T_B might be affected by not only magnetic field but also propellant gas species due to the change of the diffusion coefficient and/or the contribution of the ion motion terms, which has been neglected in the simple model being used so far. Similarly, T_s and T_w are affected by gas species, due to the change of the ionization potential, collisional cross-section, and ion mass. Here the effects of the propellant gas species are experimentally investigated to clarify the physics underlying on the magnetic plasma expansion and to improve the performance.

2. Experimental setup

The previously used helicon thruster head is used in the present experiment [7]. The rf antenna of the previously used helicon thruster head is powered by 13.56 MHz and 1 kW rf generator. Displacement of the thrust balance is be measured by a laser sensor and the displacement is converted into the thrust by using the coefficient relating the displacement to the thrust. T_s, T_w, and T_B can be measured by attaching either the back plate or the source tube or the solenoid coil to the balance. The total thrust T_{total} can also be measured by attaching all the thruster components to the balance.

3. Experimental Result

Figure 1 shows the measured T_{total} and a power transfer efficiency from the generator to the plasma itself as a function of the solenoid current I_B, where the mass flow rate of Ar, Kr and Xe is 0.75 mg/s, and that of Ne is 1.5 mg/s. No clear difference in T_{total} is detected when the propellant gases are chosen as Ar, Kr and Xe, but T_{total} for Ne is lower than that for the other cases. This seems to indicate that the helicon plasma thruster can provide a similar value of the thrust for any propellant species when the power transfer efficiency is similar.

Figure 2 shows the T_s, T_w and T_B components as a function of solenoid current, where the mass flow rate of various gases is same as in Fig. 1. It is found that the larger T_s can be obtained for heavier gas propellant. This is probably due to the lower ionization potential and larger ionization cross-section. T_w shows the larger negative value when heavier gas is chosen as propellant. This indicates that the loss of the plasma ions to the radial wall for heavier gas is greater than that for the lighter gas. This might occur due to a weakly magnetized situation of the ions and the resultant cross-field diffusion in the source tube. Hence, the inhibition of the cross-field loss to the radial wall will improve the thruster performance. On the other hand, T_B is similar value except for Ne. However it is obtained that the plasma density and the electron pressure for Xe are higher than those for the other gases. In the previous theoretical model, the azimuthal plasma current is simplified as only the electron diamagnetic current [8] by assuming fully magnetized ions. It is considered that such assumption causes the discrepancy between the thrusts measured directly and estimated from the plasma parameters. Hence further detailed model is required to understand the thrust generation mechanisms in the helicon plasma thruster.

4. Conclusion

The direct measurement of the thrust components for various propellant gases in the helicon plasma thruster indicates the following. First, the helicon plasma thruster is operational with any propellant species if the high power transfer efficiency is obtained in the source. Second, T_s is larger for the heavier gas propellant due to lower ionization potential and larger cross-section. Third, T_w which is the loss of the axial momentum is significant for heavier gas due to the radial plasma loss across the magnetic field. Finally, T_B is observed to be unchanged, which requires the further detailed thrust model.

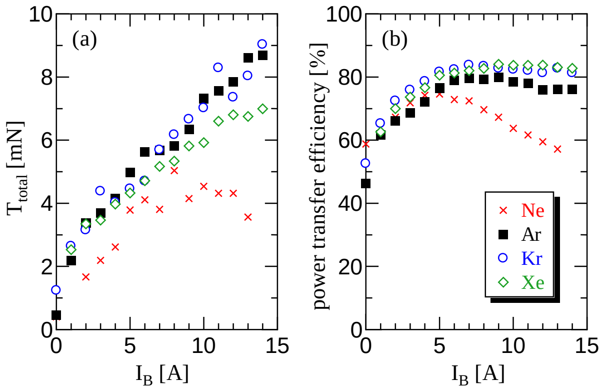

Fig. 1. (a) T_{total} and (b) power transfer efficiency as a function of solenoid current.

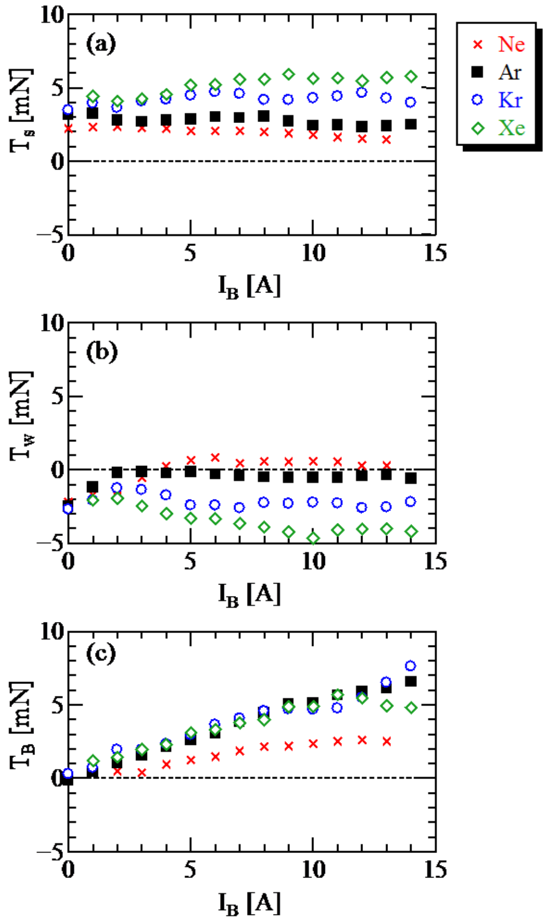

Fig. 2. (a) T_s, (b) T_w and (c) T_B as a function of solenoid current.

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