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Characteristics of Electric Propulsion using High-Density Helicon Plasma
高密度ヘリコンプラズマを用いた電気推進特性

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In order to establish a completely electrodeless electric thruster, we have been studying electromagnetic acceleration methods for a high-density plasma, and estimating the plasma performance using various diagnostics. Plasma thrust is the most important feature of the thruster; therefore estimation of this is needed. We have developed and utilized a pendulum-target-type thrust stand and a laser-induced fluorescence system to analyze the thrust. The target-type thrust stand measures a direct thrust of thruster, and laser-induced fluorescence measurement shows a spatial distribution of particle flow velocities. By the use of these, we could evaluate the thrust complementary. In this paper, experimental results using Ar and Xe are presented.

1. Introduction

An electric thruster is an promising propulsion method for a long-term mission such as a deep-space exploration owing to their high specific impulse. However, electric thrusters, e.g., ion engines, Hall thrusters and magnetoplasmadynamic (MPD) thrusters, have a problem with erosion of electrodes due to direct contact with plasmas. Therefore, to extend the life-time of a thruster, it is essential to eliminate direct contact between electrodes and plasmas. To solve this problem, we have been studying a completely electrodeless helicon plasma thruster [1].

To verify our acceleration schemes, plasma diagnostics to estimate such as a plasma thrust and an ion flow velocity are needed. The thrust is the most important parameters of a thruster, as well as a specific impulse and a thrust efficiency. On the other hand, the ion flow velocity distribution measurement is a powerful tool to observe an effect of the electromagnetic acceleration in our scheme [1]. In this study, we have developed and used a target-type thrust stand [2] and a laser induced fluorescence (LIF) system [3] as the thrust and the ion flow velocity measurements, respectively.

2. Electromagnetic Acceleration

The objective of the proposed helicon plasma thruster is outlined as follows; 1) Generation of a dense source plasma using a helicon wave with an excitation frequency between an ion and an electron cyclotron frequencies applied from the outside of a discharge tube (non-contact with plasma) using a radio frequency (RF) antenna. 2) Acceleration of the dense plasma by the Lorentz force F_z using the product of the induced azimuthal current j_θ and the static radial magnetic field B_r. There are several methods proposed for exciting j_θ in the plasma, and our laboratory is promoting schemes that use two types of coils: rotating magnetic field (RMF) coils [4] and an m (azimuthal mode number) = 0 coil [5]. Here, B_r is generated using a combination of electromagnets and permanent magnets surrounding a discharge tube, which have a relatively larger B_r component than electromagnets. Using either the combined magnetic field configuration or the permanent magnets only, we have succeeded in generating high-density ($>3 \times 10^{12}$ cm^{-3}) Ar and Xe plasmas on the Large Mirror Device (LMD, Fig. 1), and have observed increases of the ion flow velocity and the electron density than these by using only electromagnets.

3. Thrust stand

The thrust stand [6] is installed in a vacuum chamber, at the downstream of the quartz tube. The thrust stand measures the plasma thrust by a displacement of the target structure using a displacement sensor. The target consists of a cone-shape end plate with a 60° angle from the thruster axis with an outer diameter (o.d.) of 320 mm, and a series of 14 thin discs, 240 mm inner diameter (i.d.) and 320 mm o.d. with a thickness of 0.3 mm. The distance between neighboring discs is 9.5 mm. Produced ions and neutral particles ejected from a quartz discharge tube enter the target, then they are reflected by the cone-shape end plate, to enter gaps of discs. Since particles collide with

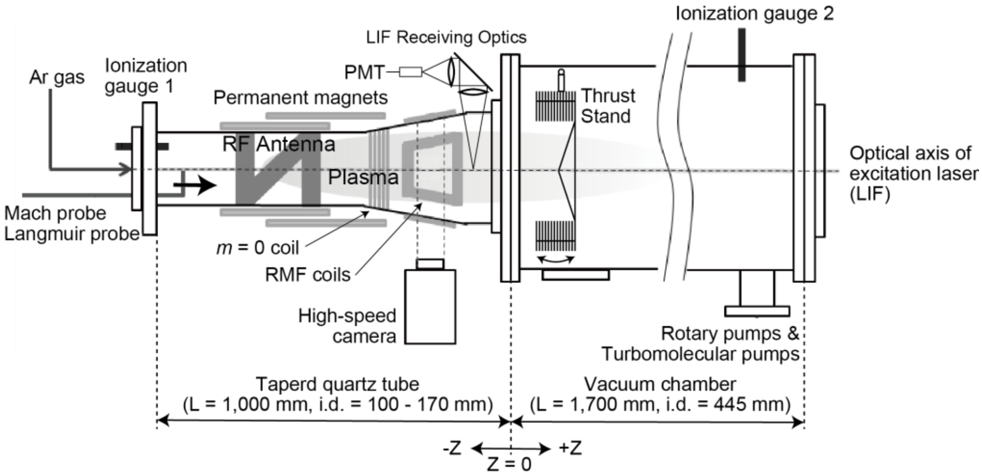

Fig. 1 Schematic diagram of large mirror device (LMD)

disks many times, they transfer their axial momentum to the target (inelastic condition). The measurement range of the thrust stand is about 1 ~ 100 mN for a 75 ms discharge.

4. Laser-induced fluorescence

Since LIF is a powerful tool for plasma diagnostics because of a non-invasive method with a high spatial resolution, it can deduce velocity distributions of any particles (ions, atoms and molecules). For an argon ion, we use a classical LIF scheme, in which Ar II $3d^4F_{7/2}$ metastable state is optically pumped by 668.16 nm (in vacuum) laser light to $4p^4D_{5/2}$ state, which decays to $4s^4P_{3/2}$ state by an emission at 442.60 nm [3,7]. For an excitation laser, a tunable laser diode system has been utilized. The laser light is electrically demodulated at a frequency of 455 kHz by the use of electro-optic modulators (EOM). The fluorescent emission is collected by a fiber optical cable, and then it passes through a 4 nm bandwidth interference filter to reach a multi-pixel photon counter. In order to separate LIF signal from a background radiation, a fluorescence radiation and electric noises, we have used a narrow band-pass filter and detector circuit.

5. Experimental results

We have measured direct thrusts using the thrust stand, and indirect one from the ion flow velocity using the LIF system in Ar gas discharges. In addition, direct thrusts in Xe gas discharge have been measured by the thrust stand. The maximum values of the thrust, the power efficiency, thrust efficiency, and specific impulse are ~41 mN, ~15 mN/kW, ~4.0 %, and ~1,500 s, respectively.

Details of devices and experimental results will be reported in presentation.

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