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Plasma Characteristics under the Strong Magnetic Field in Small Helicon Device (SHD)

小口径ヘリコン源(SHD)における強磁場下のプラズマ特性

Kensuke Kishi, Shuhei Otsuka, Toshiki Nakagawa, Kohei Takizawa,
Daisuke Kuwahara and Shunjiro Shinohara
岸謙介，大塚修平，中川叔紀，瀧澤耕平，桑原大介，篠原俊二郎

Tokyo university of Agriculture and Technology
2-24-16, Naka-cho, Koganei, Tokyo 184-8588, Japan
東京農工大学　〒184-8588　小金井市中町2-24-16

Characteristics of radio-frequency (rf) plasma under the strong magnetic field (up to 2.8 kG) using the Small Helicon Device (SHD) have been studied to see the plasma performance such as an electron density and a flow velocity. Here, the plasma was generated at the frequency of 12 MHz with an rf power up to 1,250 W, where an rf antenna was wound around a quartz discharge tube, inner diameter of 20 mm and axial length of 400 mm. Experimental results showed that an electron density and ion velocity measured by an L-shaped Mach probe increased with the magnetic field strength at 50 mm downstream of the antenna.

1. Introduction

For a deep space exploration, electric propulsion systems are more suitable than chemical one because of its higher specific impulse defined as the ratio an exhaust velocity to the gravitational acceleration. Presently, a lifetime of electric propulsion systems (e.g., ion thrusters) are often limited due to electrode erosion by the collision with plasmas. In order to make the lifetime longer, we have been investigating new electrodeless plasma propulsion systems with a high-density (~10^{13} cm^{-3}) helicon plasma source, referred to as a Helicon Electrodeless Advanced Thruster (HEAT) project [1]. This acceleration principle uses the Lorentz force F_z, the product of the induced azimuthal current j_θ in the plasma and the external static radial magnetic field B_r.

When the magnetic field strength is increased, an electron density increases due to an improved confinement along with the stronger F_z by the effect of increased B_r. Therefore, the investigation of the plasma characteristics under the strong magnetic field is important to be applied to the electrodeless plasma propulsion system.

2. Experimental setup

Figure 1 shows a schematic diagram of Small Helicon Device (SHD) [2]. A vacuum chamber, made of SUS316, has an axial length of 865 mm and inner diameter (i.d.) of 165 mm. A quartz discharge tube, 400 mm in axial length and 20 mm in i.d., was connected to a gas feeding part (LHS in Fig. 1) and the vacuum chamber (RHS). The back pressure in the source region was ~1.3×10^{-3} Pa. The gas feeding part supplied argon gas with a flow rate of 20 sccm (~2 Pa in the source region) through a mass flow controller. Radio-frequency (rf) power was added to a single loop antenna made of a copper plate, 0.2 mm thick and 40 mm width. RF power was up to 1,250 W at the excitation frequency of 12 MHz. The magnetic field coil, an axial length of 100 mm and i.d. of 90 mm, was located at z = -150 mm in the axial direction. This

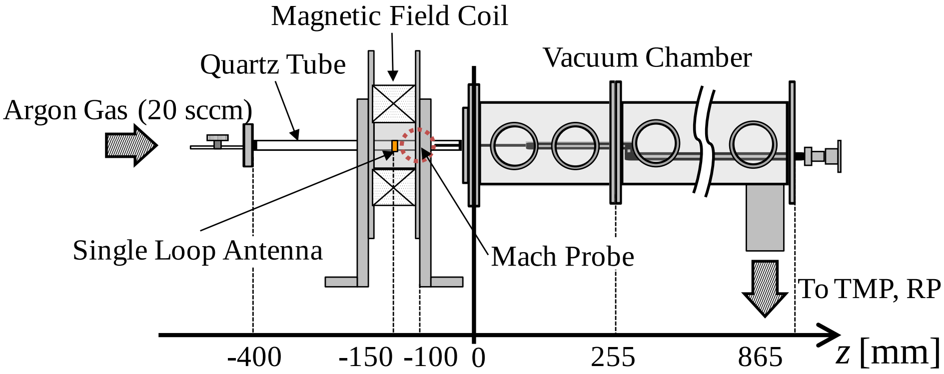

Fig. 1　Schematic drawing of SHD

coil can produce the maximum magnetic field of 28 G/A. Figure 2 shows the calculated magnetic field profile with the coil current of 50 A, where B_z on axis and B_r at 10 mm in the radial direction.

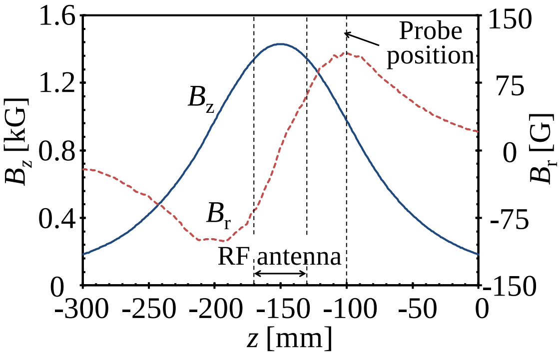

Fig. 2 The calculated magnetic field, B_z [kG](on the axis) and B_r [G] (on r = 10 mm) distribution for 50 A solenoid current.

Electron densities n_e and ion velocities v_i were measured by an L-shaped Mach probe, under the three conditions of the magnetic field (B_z =0, 1.4, and 2.8 kG). Here, an electron temperature was assumed to be 3 eV (typical value) and the ion flow velocity was derived, using the magnetized model (model constant $\kappa = 1.26$) [3, 4].

3. Experimental results

Figure 3 shows n_e as a function of rf input power P_{input}. The measurement position was downstream of the rf antenna, r = 0 mm and z = -100 mm. Comparing three magnetic field cases, n_e with B_z = 2.8 kG was the highest at any rf power. The maximum n_e was higher than other cases by more than three times. Since the strong magnetic field can generate higher n_e, we can expect the higher n_e with the stronger magnetic field larger than 3 kG. In this case of B_z = 2.8 kG, there was a clear density jump, from 8.7×10^{11} to 6.1×10^{12} cm^{-3}, between P_{input} of 500 W and 750 W. But n_e did not increase above P_{input} of 1,000 W.

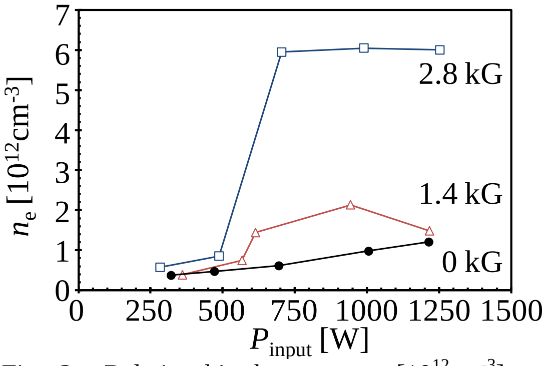

Fig. 3 Relationship between n_e [10^{12}cm^{-3}] and P_{input} [W] for B_z = 0, 1.4, and 2.8 kG.

Figure 4 shows v_i as a function of P_{input}. Comparing three magnetic field cases, v_i with B_z = 2.8 kG is the highest at any rf power. In the cases of B_z = 0, 1.4, and 2.8 kG, the highest value of v_i is 3.4, 1.0, and 5.6 km/s, respectively. For further measurements, we need to calibrate the flow velocity measured by an L-shaped Mach probe.

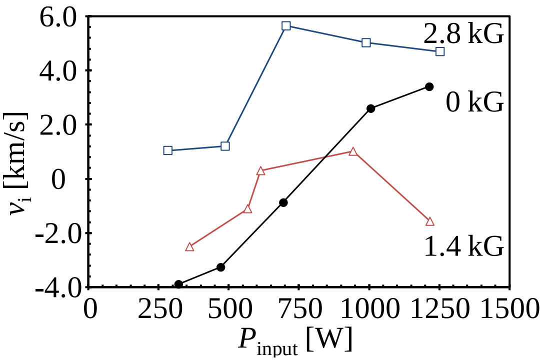

Fig. 4 Relationship between v_i [km/s] and P_{input} [W] for B_z = 0, 1.4, and 2.8 kG.

4. Conclusion

To investigate the ion acceleration under the strong magnetic field up to B_z = 2.8 kG in i.d. of 20 mm, we have tested three cases of the magnetic field under f = 12 MHz and P_{input} up to 1,250 W, using Ar gas (20 sccm). The maximum n_e and v_i were 6.2×10^{12} cm^{-3} and 5.6 km/s, respectively.

In the conference, more details of the experimental setup and results will be presented.

References

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