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Wide spectroscopic measurement of plasma using Small Helicon Device (SHD)
小ヘリコン装置(SHD)を用いたプラズマの広域分光計測

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In order to study an electrodeless plasma propulsion system using a high-density (~10^{13} $\mathrm{cm^{-3}}$) helicon plasma for a long-term space mission, we have developed a Small Helicon Device (SHD) to investigate characteristics of a small-diameter helicon plasma. Because of difficulties of measuring parameters such as an electron density and its temperature in a small-diameter plasma, we have been developing spectroscopic methods from a view point of no perturbation to plasma compared to probe method. We have measured light emissions from the plasma by using a wide-range spectrometer Ocean Optics HR2000+. In this study, preliminary results of the spectroscopic measurement will be presented.

1. Introduction

An electric propulsion is a better system for a long term space mission than a chemical one because of its higher specific impulse. However, an operation lifetime of a conventional electric propulsion system is limited by a damage of electrodes contacting directly with a plasma. To solve this problem, we have been studying an electrodeless plasma propulsion system [1], using a developed Small Helicon Device (SHD) [2] to decrease weight and space of the thruster system. This small-diameter source will also contribute to industrial applications such as a coating of inner wall of a thin tube.

Plasma diagnostics is very important to characterize plasma performance. Although an electrostatic probe is a common method to measure plasma parameters, it disturbs a plasma flow in SHD because an inner diameter (i.d.) of a discharge tube is less than 20 mm. Not to disturb the plasma performance, here, spectroscopic methods are adopted. We have measured light emissions from plasmas by using a wide-range spectrometer, Ocean Optics HR2000+, to investigate plasma parameters such as an electron density.

2. Theory

If an electron temperature (written as T_e) is uniform for a non-saturated phase of the ionizing plasma, which satisfies in our plasma conditions, the intensities of Ar I (as $I_{\mathrm{Ar\,I}}$) and Ar II (as $I_{\mathrm{Ar\,II}}$) are expressed [3] as below,

$$I_{\mathrm{Ar\,I}} \propto n_e n_0, \tag{1}$$

$$I_{\mathrm{Ar\,II}} \propto n_e^2. \tag{2}$$

From Eq. (2), we can derive Eq. (3) as follows,

$$\sqrt{I_{\mathrm{Ar\,II}}}/n_e = \mathrm{const.} \tag{3}$$

(n_e: electron density, n_0: neural particle density)

Our final goal is to obtain n_e and T_e in an argon discharge by an intensity ratio method [4] between emission lines from neutral particle. As the first step, we have tried to estimate n_e by using Eq. (3).

3. Experimental Devices

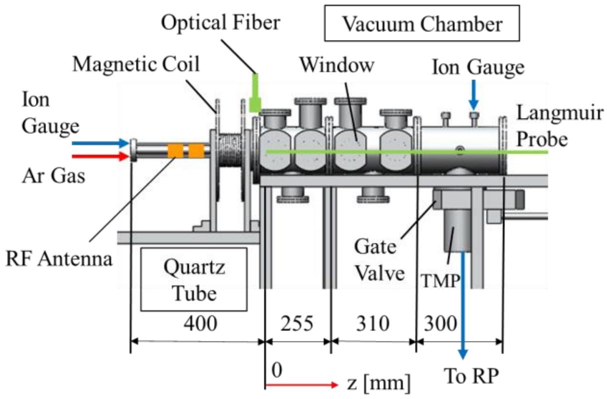

Fig.1. SHD

Experiments have been carried out in SHD, as shown in Fig. 1. SHD consists of two parts; a quartz discharge tube and a vacuum chamber. Here, the inner diameter (i.d.) of the tube was changed: 20, 10 and 3 mm. A radio frequency (RF) antenna is a double-loop antenna, and the RF power is < 1,100 W with a frequency of 12 MHz. The pulsed discharge duration time is 100 ms with a duty of 1/10. Ar gas is fed with a flow rate from 0.7 sccm to 30 sccm (< 2 Pa in the source region). In the case of the electron density measurement using a Langmuir probe, we assumed T_e of 3 eV.

Spectroscopic measurements were conducted, using a wide-range spectrometer of Ocean Optics HR2000+, whose specification is shown in Table I.

Table I. specification of spectrometer

Detector	CCD
Wavelength range [nm]	360~ 792
Blaze wavelength [nm]	500
wavelength resolution [nm]	0.45
Integration time [s]	0.001~ 65

Intensities of spectra can be detected by a CCD. An optical fiber, P600-2-UV-VIS (core diameter: 600 μm, total length: 2 m), is connected to this spectrometer. A collimate lens 74-UV is connected to the edge of the optical fiber to adjust parallel sight.

Measurement points of the spectrometer and a Langmuir probe are located at z = – 60 mm. Integration time of the spectrometer is 80 ms.

4. Experimental Results

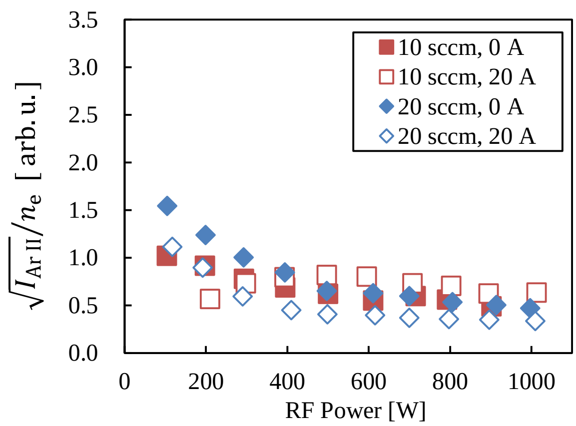

Fig.2. $\sqrt{I_{\mathrm{Ar\,II}}}/n_e$ vs. RF power with 10 mm i.d.

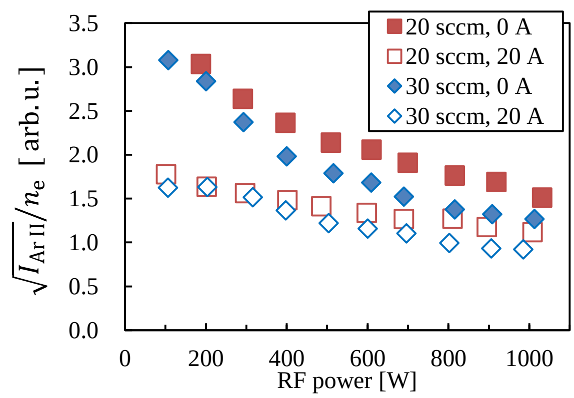

Fig.3. $\sqrt{I_{\mathrm{Ar\,II}}}/n_e$ vs. RF power with 20 mm i.d.

$I_{\mathrm{Ar\,II}}$ at a wavelength of 434.8 nm was measured by the spectrometer, and n_e was by a Langmuir probe. In Figs. 2 and 3, $\sqrt{I_{\mathrm{Ar\,II}}}/n_e$ vs. RF power is plotted with 10 and 20 mm i.d. tubes, respectively. Here, the mass flow rate and the current of magnetic field coil (28 G/A) are shown.

Both $\sqrt{I_{\mathrm{Ar\,II}}}/n_e$ in Figs. 2 and 3 tend to decrease as RF power increases. Considering that the cross section of Ar II line is a sensitive function of T_e, while the probe current is proportional to $\sqrt{T_e}$, in the region of < 400 W of RF power T_e was considered to be higher than the region above 400 W.

$\sqrt{I_{\mathrm{Ar\,II}}}/n_e$ with 0 A tends to be lower than with 20 A, which indicates the higher T_e without the magnetic field than with the field. Therefore, T_e should be measured to be examined.

As to the data taken in 3mm i.d. discharges, we are estimating n_e considering a solid angle of a view line and T_e.

5. Conclusion

We have measured light emissions from plasmas by using a wide-range spectrometer, where inner diameters of discharge tubes were 3, 10 and 20 mm.

In the case of a thin tube such as 3 mm i.d., it is difficult to use Langmuir probe. Therefore, we plan to determine the electron density by the use of $I_{\mathrm{Ar\,II}}$ relation [Eq. (3)] obtained from 10 and 20 mm cases. Note that we need to calibrate the constant value of RHS of Eq. (3), since a solid angle with a line integral must be considered along with measurements of the electron temperature.

In the presentation, details of these results will be shown.

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