Wide spectroscopic measurement of plasma using Small Helicon Device (SHD)

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In order to study an electrodeless plasma propulsion system using a high-density (~10^{13} \text{ 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 viewpoint 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 $I_{Ar\text{ I}}$) and Ar II (as $I_{Ar\text{ II}}$) are expressed [3] as below,

$$I_{Ar\text{ I}} \propto n_e n_0,$$

and

$$I_{Ar\text{ II}} \propto n_e^2.$$

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

$$\sqrt{I_{Ar\text{II}} / n_e} = \text{const}.$$

($n_e$: 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](image)

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**

<table>
<thead>
<tr>
<th>Detector</th>
<th>CCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength range [nm]</td>
<td>360–792</td>
</tr>
<tr>
<td>Blaze wavelength [nm]</td>
<td>500</td>
</tr>
<tr>
<td>Wavelength resolution [nm]</td>
<td>0.45</td>
</tr>
<tr>
<td>Integration time [s]</td>
<td>0.001–65</td>
</tr>
</tbody>
</table>

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

\[ \sqrt{I_{\text{Ar II}}/n_e} \] vs. RF power with 10 mm i.d.

\[ \sqrt{I_{\text{Ar II}}/n_e} \] vs. RF power with 20 mm i.d.

$I_{\text{Ar II}}$ 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, $\sqrt{I_{\text{Ar II}}/n_e}$ 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 $\sqrt{I_{\text{Ar II}}/n_e}$ 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.

$\sqrt{I_{\text{Ar II}}/n_e}$ 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 3 mm 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 $I_{\text{Ar II}}$ 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.

References