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# Measurement of electron density at extraction region in negative ion source by means of surface wave probe

# 表面波プローブを用いた負イオン源引き出し領域における電子密度計測


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Surface wave probe was adopted for measuring the electron density near a plasma grid in a large-scaled negative ion source and it was confirmed that the surface wave probe is highly available for diagnostic of magnetized plasmas. In addition, it was found that applying the bias voltage reduces the electron density while the $H^-$ ion density is almost constant and $H^-$ ions become the dominant negative particles at high bias voltage.


## 1. Introduction

Recently, a cavity-ring down method [1] and a millimeter-wave interferometer [2] have been utilized for measuring the $H^-$ density and the electron density near a plasma grid in $H^-$ ion sources, respectively. The $H^-$ density and the electron density have been successfully determined during the beam extraction. However, the obtained electron density with the interferometer is line-averaged and the local electron behavior, especially near the extraction hole, has not been clarified. One of the simplest methods to determine the local electron density is a Langmuir probe (LP), but it is quite difficult to determine the electron density precisely by the LP due to the magnetic field in $H^-$ ion sources.

A surface wave probe (SWP) is one of the most potential candidates for measuring the electron density at an extraction region. The SWP is widely used for diagnostic of reactive plasmas where the LP is covered with an insulator layer [3]. The SWP is relatively simple, consisting of a dielectric tube and a co-axial cable only. In addition, the electron density can be obtained with high spatial resolution. As can be seen, the SWP has many advantages for the electron density measurement. But, the SWP has not been adopted for studies of the magnetized plasmas.

To confirm the availability of the SWP for the study of $H^-$ ion sources, the SWP has been installed into a 1/3-size negative ion source for LHD-NBI and measurements of the electron density near the plasma grid were carried out.

## 2. Experimental setup

Fig. 1 shows a schematic illustration of the experimental setup. In $H^-$ ion sources, filter magnets are installed to form the transverse magnetic field which produces the low electron temperature region near the PG and electron deflection magnets are embedded in an extraction grid (EXG) to suppress the acceleration of the co-extracted electrons. As shown in Fig. 1(b), the magnetized direction of the electron deflection magnet changes alternately. The SWP is set over the aperture of a plasma grid (PG). Distance between the central axis of the SWP and the PG is 10 mm. Fig. 1(c) shows a cross-sectional view of the SWP. The SWP consists of an alumina tube with a diameter of 6 mm and a semi-rigid cable whose inner conductor with a length of 8 mm is exposed at the end. Radiofrequency power is applied to the semi-rigid cable at the frequency of 50 MHz to 1.5 GHz and the ratio of the reflected power $P_{\mathrm{ref}}$ to the applied power $P_{\mathrm{in}}$ is detected by a network analyzer. When the incident radiofrequency power satisfies the resonant condition, an electrostatic wave is excited at the interface between the alumina tube and the plasma at the region where the inner conductor of the co-axial cable is exposed and the incident power is strongly absorbed.

## 3. Experimental results

The Typical absorption spectra ($\log_{10}P_{\mathrm{ref}}/P_{\mathrm{in}}$) of the applied radiofrequency power are shown in figure 2. The absorption signals are observed and the resonant frequency increases with the discharge power. The electron density $n_e$ is obtained from the following equation.

$$n_e = 1.2 \times \left(\frac{\varpi}{F}\right)^2 \times 10^{10} \ \ [\mathrm{cm}^{-3}],$$

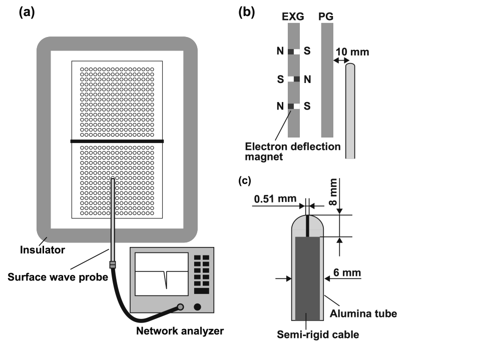

Fig. 1. (a) Schematic illustration of experimental setup, (b) positional relation of SWP with PG, (c) cross-sectional view of SWP.

where $\omega$ is the resonant frequency and $F$ is a constant derived from the dispersion relation and depends on the geometrical configuration of the probe.

To verify the validity of the SWP for $H^-$ ion sources, the electron density was determined by the SWP and the LP at the pure-volume production. The dependences of the electron density on the arc power with and without magnetic field are shown in Fig. 3(a), (b), respectively. In the case of no magnetic field, the electron density measurement was carried out using a small test chamber [4]. In Fig. 3(a), the obtained electron densities by the SWP and the LP increase monotonically as a function of the arc power and correspond to each other. On the other hand, applying the magnetic field the variation of the electron density observed with the SWP has the same tendency as that with the LP, but the obtained electron density by the LP is less than that by the SWP. This results from the strong magnetic field formed in the negative ion source. The electron cyclotron motion keeps the electrons from flowing into the probe tip and resulting in underestimation of the electron density. These results confirm that the SWP is highly available for the study of $H^-$ ion sources.

To investigate the effect of the bias voltage on the electrons near the PG, the electron density was measured at various bias voltages. Fig. 4 shows the

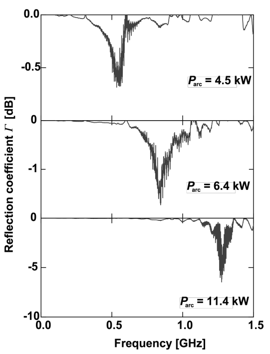

Fig. 2. Typical absorption spectra.

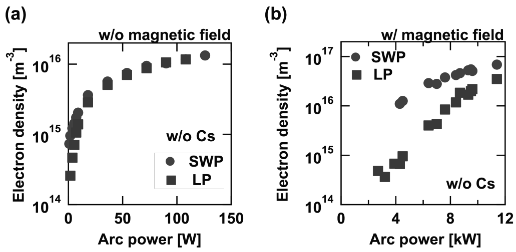

Fig. 3. Dependence of electron density measured by the SWP and the LP on arc power (a) with and (b) without magnetic field.

variation of the electron density and the $H^-$ ion density as a function of the bias voltage. Applying the bias voltage reduces the electron density while the $H^-$ ion density is almost constant with the bias voltage and $H^-$ ions become the dominant negative particles at the bias voltage of more than 6 V.

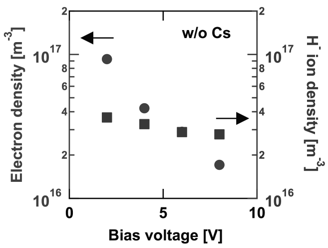

Fig. 4. Dependence of electron density and $H^-$ ion density on bias voltage.

## 4. Conclusion

In this study, it was confirmed that the surface wave probe is highly available for the study of the $H^-$ ion sources by comparison of the electron densities obtained with the surface wave probe and the Langmuir probe.

The electron density was measured with varying conditions for the plasma production. As a result, applying the bias voltage reduced the electron density while the $H^-$ ion density was almost constant with the bias voltage and the $H^-$ ions replace the electrons as dominant negative particles at high bias voltage.

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## References

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