§6. Characterization of High-Density Helicon Plasma Source for Negative Ion NBI

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High power neutral beam injection (NBI) heating utilizing negative ions has been actively executing in NIFS. As to the future plasma source in NBI, key issues are easier plasma production with a good stability, higher plasma density and higher ionization, and developments of large or compact plasma sources. Developing a neutral beam source with the high particle flux is also important in the charge-exchange recombination spectroscopy. The present objective is, first, characterizing a compact, high-density, high-field plasma source, using a helicon wave scheme [1] in the range of radio frequency. Then, developing a negative ion source with, e.g., hydrogen gas, will be investigated to apply to the advanced NBI in NIFS.

The main device parameters of the compact helicon plasma source with the strong magnetic field [2] are as follows: the discharge chamber uses a quartz tube, which has an outer (inner) diameter of 10 (9.5) cm and 90 cm axial length. The magnetic field B can be applied up to 10 kG (the highest field among the world's helicon sources), and main strong field region extends to ~ 30 cm in the axial direction. Here, iron yokes are added to increase the field. Two parallel copper plates with 3 cm each in the axial direction used as the rf antenna are wound around the quartz tube at the midplane. By changing the electrical connection, the excitation of the axial wavenumber spectrum can be changed [3,4]. The rf frequencies f_{rf} in this experiment are 7 and 14 MHz with a fill pressure P_0 of 1-33 mTorr. In order to estimate the antenna loading, a directional coupler is used in addition to measure the antenna voltage and current. A Langmuir probe is scanned radially at the midplane.

Here, we present the results on the plasma performance using various gas species. In Ar discharges, we can obtain the electron density n_e ~ 10^{13} cm^{-3} with the input rf power P ~ 1 kW, as shown in Fig. 1: with the increase of B, n_e is higher in the high field case before the so-called density jump, due to the better radial confinement. However, this jump becomes weaker with the increase of B. For Xe (He) discharges, n_e is higher (lower) with the same rf power.

Figure 2 shows n_e as a function of B with Ar gas (after the density jump). In the case of P_0 = 10 mTorr and P = 0.8 kW, it can be seen that the maximum density is obtained near the field (B = 1.36 kG), which satisfies the relation that f_{rf} is equal to the lower hybrid frequency. On the contrary, in the case of P_0 = 4 mTorr and P = 1 kW, this field dependence is not clear. Changing the gas species such as Xe and He and/or the rf frequency, this tendency to take the maximum density near the lower hybrid condition is also observed.

In conclusion, the high-density helicon plasma production (~ 10^{13} cm^{-3}) with ~ 1 kW rf power was successfully established using a compact, very strong magnetic field device (up to 10 kG), changing gas species, rf frequency and the magnetic field. The more detailed characterization in a wide range of operating parameters will be done, whose results are expected to contribute to the advanced NBI system in NIFS.

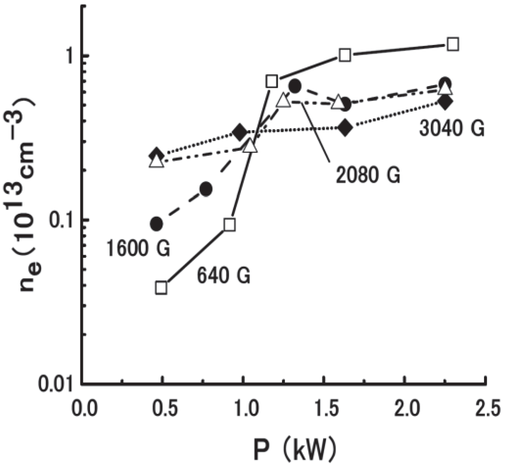

Fig. 1. Electron density n_e as a function of the input rf power P field B (f_{rf} = 7 MHz and Ar pressure is 4 mTorr).

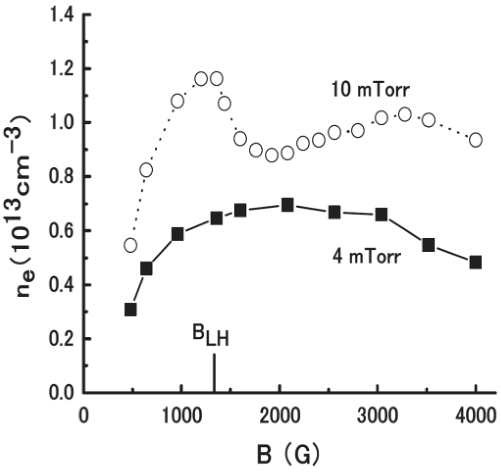

Fig. 2. Electron density n_e as a function of the magnetic field B (f_{rf} = 14 MHz and Ar pressure is 4 and 10 mTorr).

1) S. Shinohara: J. Plasma Fusion Res. **78** (2002) 5.
2) S. Shinohara and H. Mizokoshi: Rev. Sci. Instrum. **77** (2006) 036108.
3) S. Shinohara *et al.*: Plasma Phys. Control. Fusion **42** (2000) 41 and **42** (2000) 865.
4) S. Shinohara *et al.*: Phys. Plasma **8** (2001) 3018.