§8. Development of High-Density Helicon Plasma Source for Negative Ion NBI

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In NIFS, the high power neutral beam injection (NBI) heating utilizing negative ions has been actively executing. Concerning the future plasma source in NBI, critical 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 constructed 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), whose main strong field region extends to ~ 30 cm in the axial direction. Here, iron yokes were added to increase the field. Two parallel copper plates with 3 cm each in the axial direction used as the rf antenna were 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 were 7 and 14 MHz with a fill pressure P_0 of 1-33 mTorr. In order to estimate the antenna loading, a directional coupler was used in addition to measure the antenna voltage and current. A Langmuir probe was scanned radially at the midplane.

Here, we present the results on the plasma performance using various gas species. In Ar discharges, we could obtain the electron density n_e more than 10^{13} cm^{-3} with the input rf power P_{rf} of less than 1 kW, as shown in Fig. 1: with the increase of B, n_e was higher in the high field region before the so-called density jump, due to the better radial confinement. However, this jump became weaker with the increase of B. For Xe discharges, less than 0.5 kW of P_{rf} was necessary to have the density jump on the order of 10^{13} cm^{-3} (e.g., P_0 = 10 mTorr, f_{rf} = 7 MHz and B = 1.36 kG). To the contrary, in the He discharges, a monotonic increase of n_e was found with P_{rf}, and n_e itself was much lower, e.g., ~ 10^{11} cm^{-3} with P_{rf} = 1kW, P_0 = 10 mTorr, f_{rf} = 7 MHz and B = 0.48 kG, than Ar and Xe discharges.

Figure 2 shows n_e as a function of B with Xe gas and P_{rf} = 0.8 kW (after the density jump). It can be seen that the maximum density is obtained near the field (B = 1.23 kG), which satisfied the relation that f_{rf} is equal to the lower hybrid frequency. Changing the gas species such as Ar and He and/or the rf frequency, this tendency to take the maximum density near the lower hybrid condition was also observed.

In conclusion, the high-density helicon plasma production (~ 10^{13} cm^{-3}) with less than 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.

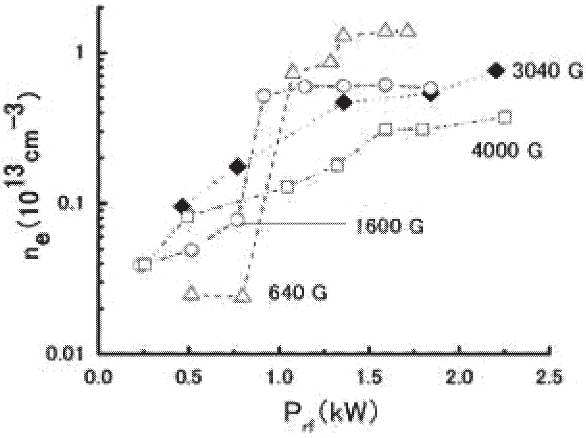

Fig. 1. Electron density n_e as a function of rf power P_{rf} (f_{rf} = 7 MHz and Ar pressure was 20 mTorr).

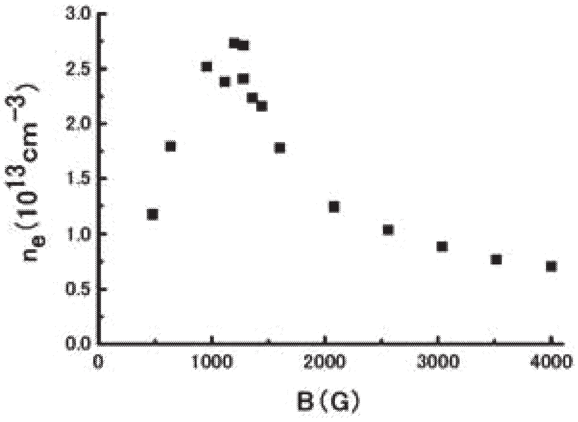

Fig. 2. Electron density n_e as a function of the magnetic field B (f_{rf} = 7 MHz and Xe pressure was 10 mTorr).

Reference

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