§5. Revisiting to the Plasma Hole Structure Using Advanced Diagnostics

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"Plasma hole" [1,2] is a vortex structure of which spontaneous formation has been studied in the HYPER-I device at the National Institute for Fusion Science. The dark part in the center of the plasma cross-section, which is shown in Fig. 1, corresponds to the low density region; i.e. a steep density gradient exists between the density hole and the surrounding plasma. An internal electric field due to the bell-shaped space potential distribution localized in the hole region drives the plasma into high-speed azimuthal rotation in the direction of $\boldsymbol{E}\times\boldsymbol{B}$. Moreover, the ion flow velocity has a radially inward component across the magnetic field, suggesting anomalous viscosity of the plasma hole. Directional Langmuir probes were mainly used to investigate the plasma hole structure so far. In this study, more quantitative ion flow velocity measurements have been conducted by using laser measurements recently applied to the HYPER-I plasma.

The experiments were performed in an argon plasma produced by electron cyclotron resonance absorption of microwaves at 2.45 GHz under the conditions that the argon gas pressure and the microwave power were 8.3×10^{-5} Torr and 3 kW, respectively. Laser-induced fluorescence (LIF) method was used to measure the azimuthal rotation velocity of argon ions. Two LIF schemes adopted in the present experiments are as follows: (a) the energy level terms used for laser-induced excitation ($3d^2G_{9/2} - 4p^2F_{7/2}$) and the fluorescence ($4p^2F_{7/2} - 4s^2D_{5/2}$) correspond to wavelengths of 611.5 nm and 461.0 nm, respectively. (b) the energy level terms used for excitation ($3d^4F_{7/2} - 4p^4D_{5/2}$) and fluorescence ($4p^4D_{5/2}$ – $4s^4P_{3/2}$) correspond to wavelengths of 668.6 nm and 442.7 nm, respectively. The wavelengths shown above are all in vacuum values and for ions at rest in the laboratory frame. A high-power pulsed dye laser was used for the scheme (a) and a narrow bandwidth external cavity diode laser (ECDL) for the scheme (b). A photomultiplier tube with an optical filter was used to detect the LIF emission in both cases.

Figure 2 shows the radial distributions of azimuthal ion flow velocity measured by two LIF schemes mentioned above. The open circle and the open square correspond to the schemes (a) and (b), respectively. In the case of scheme (a), i.e. the Dye laser scheme, solid-body-like $\boldsymbol{E}\times\boldsymbol{B}$ rotation, which characterizes the plasma hole, is clearly seen in the hole region. Although the LIF spectra were not obtained in low-density hole region with the scheme (b) due to the low output power, the absolute values of ion flow velocities obtained by both schemes are in good agreement outside the hole region. In addition, the diode laser can directly measure the ion velocity distribution functions (IVDFs) in relatively high density region; it is useful to study the shapes of IVDF in inhomogeneous plasmas as reported in the last fiscal year. On the other hand, the capability of measuring inside the hole region is an advantage of the pulsed dye laser. A precise wavelength calibration system, however, has not been developed for the pulsed dye laser system, yet. The development of such system utilizing a Fabry-Pérot resonator is now under consideration.

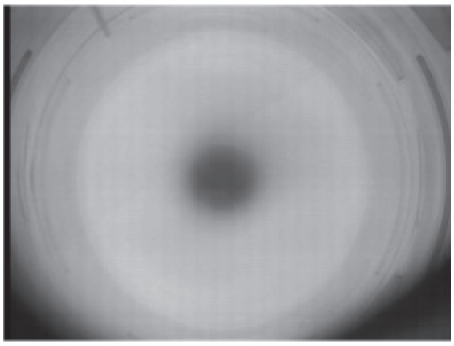

Fig. 1. A CCD image of the plasma hole taken through a quartz window at an open end of the HYPER-I device.

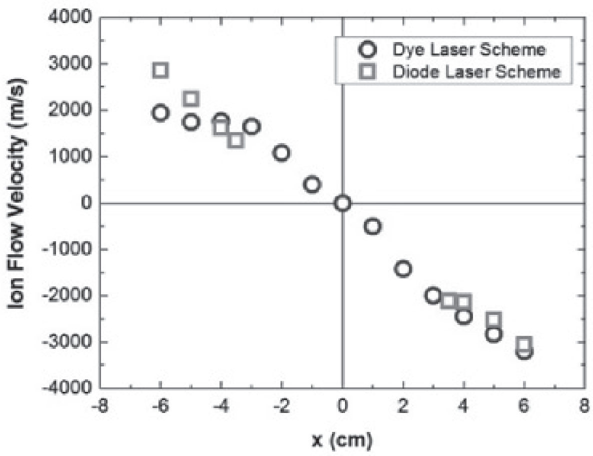

Fig. 2. Radial distributions of azimuthal velocity of argon ions measured with two different LIF schemes.

1) K. Nagaoka, A. Okamoto, S. Yoshimura, M. Kono, and M. Y. Tanaka, "Spontaneous Formation of a Plasma Hole in a Rotating Magnetized Plasma: A Giant Burgers Vortex in a Compressible Fluid", Phys. Rev. Lett. **89**, 075001-1-075001-4 (2002).
2) M. Y. Tanaka, K. Nagaoka, A. Okamoto, S. Yoshimura, and M. Kono, "Plasma Hole", IEEE Trans. Plasma Sci. **33**, 454-455 (2005).