§2. Ion Temperature Measurement by Pulsed Laser induced Fluorescence

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Experimental understanding of flow structure requires measurement of flow velocity field. While the directional Langmuir probe method is applied to various vortices in cylindrical plasmas[1)], Doppler spectroscopy using the laser induced fluorescence (LIF) is developed as a less perturbative measurement method[2)]. The latter also has advantages in absolute velocity measurement and ion temperature measurement. Since the LIF spectrum includes Doppler broadening, ion temperature can be obtained by the LIF measurement of the ion. On the other hand, the spectrum is also broadened by the line width of the laser. We have evaluated the laser line width in our previous works. In this report, ion temperature measured by the LIF is described.

The experiments were performed at a diverging magnetic field region in HYPER-I device[3)]. A LIF Doppler spectroscopy system was developed for the HYPER-I device. A pulsed Nd:YAG laser and a dye laser were used for the experiments. LIF spectrum of argon ion (611.5 nm for excitation, 461.0 nm for fluorescence) was obtained. The laser line width, which was determined using a grating monochromator, was about 1.9 pm at 611.5 nm. The laser was injected from downstream end of the device with slightly tilted incident angle against the z-axis to obtain parallel velocity distribution[4)]. Fluorescent light was collected in a y-direction port using a lens and a fiber optic. Typical LIF spectra measured at the same position with incident and reflecting laser beams are shown in Fig. 1. Because a red shifted spectrum is obtained with the incident beam and a blue shifted spectrum vice versa, downstream flow is indicated. The flow velocity obtained from the difference of peaks is $v_z = 4\,\mathrm{km/s}$. Broadening of the spectra is convolution of Doppler broadening and laser line width. Using the laser line width described above, a Doppler broadening width $\Delta\lambda_{\mathrm{Dop}} \simeq 0.015\,\mathrm{nm}$ is obtained corresponding to the ion temperature $T_\mathrm{i} \simeq 3.2 - 3.5\,\mathrm{eV}$.

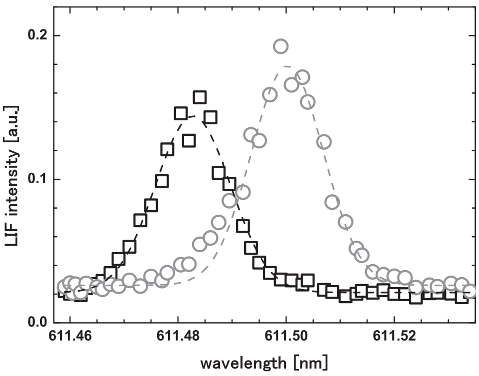

Fig. 1: Typical LIF spectra measured by quasi-parallel laser injection. Circle represents LIF spectrum obtained from incident beam, square from reflecting beam.

By changing the observation volume shot by shot in y-direction, radial profiles of ion temperature and ion flow velocity are obtained as shown in Fig. 2. Almost uniform temperature ($T_\mathrm{i} \simeq 3\,\mathrm{eV}$) and flow velocity ($v_z \simeq 4\,\mathrm{km/s}$) profiles are obtained in a free space. On the other hand, when a cylindrical obstacle is installed at $y = -6\,\mathrm{mm}$, those profiles show disturbance. About 10 % decrease is observed in flow velocity profile at $y = 10\,\mathrm{mm}$. Increase in temperature up to 4.6 eV also observed at the same position. Near the surface of obstacle ($y = 3\,\mathrm{mm}$), no such a significant variation are observed, as well as those measured at far from the obstacle ($y = 30\,\mathrm{mm}$). The Larmor radius is also experimentally determined. It is note that those distance are smaller than the Larmor radius (50 mm at 0.03 T).

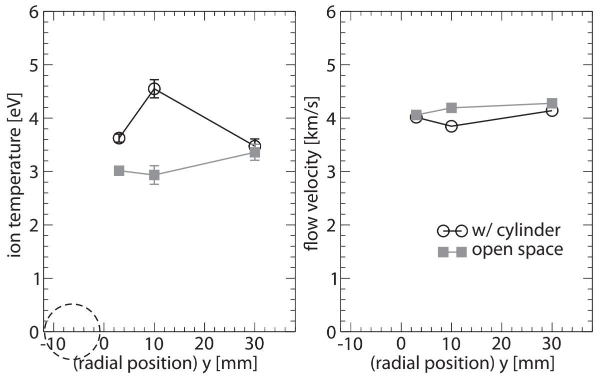

Fig. 2: Ion temperature (left) and flow velocity (right) profile measured by laser induced fluorescence in Argon plasma. Open circle represents those measured with a cylindrical obstacle at y = -6 mm, while filled symbol represents those measured without the obstacle. A broken circle on the horizontal axis indicates the position and diameter of the obstacle.

1) Nagaoka, K. et al.: Phys. Rev. Lett. **89** (2002) 075001, Okamoto, A. et al.: Phys. Plasmas **10** (2003) 2211.

2) Okamoto, A. et al.: J. Plasma Fusion Res. **80** (2004) 1003.

3) Yoshimura, S. et al.: J. Plasma Phys. **81** (2015) 345810204.

4) Yoshimura, S. et al.: Plasma Fusion Res. **5** (2010) S2052.