§3. Evaluation of Laser Line Width for 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 an advantage in absolute velocity measurement. On the other hand, in some theoretical considerations Mach number is a better measure. When the plasma has a finite ion temperature, the ion sound velocity is a function of both electron and ion temperatures. Therefore ion temperature measurement is important as well as that of the electron temperature. 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. Therefore evaluation of the laser line width is necessary for the ion temperature measurement.

In our previous work, a LIF Doppler spectroscopy system has been developed for the HYPER-I device[3)]. 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. Then, flow velocity of argon ion was determined from the Doppler shift of the spectrum. While Fabry-Perot interferometers are usually used for evaluation of laser line width of diode lasers, optimization of the free spectrum range and finesse is also important to utilize the interferometers in advance of optical alignment. Because the line width of the pulsed laser system is expected to be broader than that of the diode lasers, utilizing grating monochromator can be a solution for the line width measurement in the pulsed laser system. In this report, evaluation of the laser line width using a grating monochromator is described.

The first step is to evaluate the instrumental width of monochromator. In the experiment, a Czerny-Turner mount monochromator was used. The focal length was 1m. The full width at half maximum (FWHM) of line spectra as a function of slit width is shown in Fig. 1, where a hollow cathode lamp and an electron cyclotron resonance plasma were used for the light source. The instrumental width of the monochromator is less than 6 pm for slit width smaller than 5 μm.

In the next step, the laser spectrum was observed using the monochromator as shown in Fig. 2. Broadening of the spectrum results from both the instrumental width and the laser line width. The former is represented by Gaussian and the latter by Lorentzian. Considering the instrumental width determined above, we can determine the laser line width from the spectrum by Voigt function fitting. Then the line width is about 1.9 pm at 611.5 nm.

Finally, lower limit of measurable ion temperature of LIF Doppler spectroscopy is discussed. Since broadening of LIF spectrum contains both the Doppler broadening and the laser line width, deconvolution is needed for experimental analysis. In order estimation, a significant Doppler broadening is comparable to the laser line width, ~ 2 pm. The width, then, corresponds to an ion temperature of 0.08 eV. On the other hand, an instrumental width determines lower limit for passive spectroscopy: When the instrumental width is 6 pm, the lower limit is 0.7 eV. Therefore about one order improvement is expected for ion temperature measurement using the LIF Doppler spectroscopy instead of the passive spectroscopy.

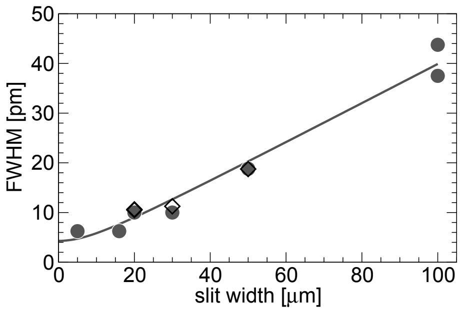

Fig. 1: Instrumental width of a $f = 1$m monochromator measured by neutral line emissions ($\bullet$) and by ion ones ($\diamond$).

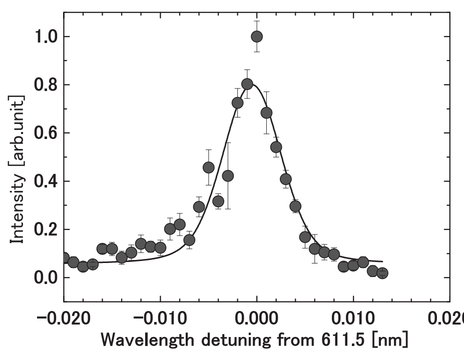

Fig. 2: Line spectrum of a pulsed dye laser measured by a monochromator.

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.