§2. High Accuracy Measurement of Neutral-Gas Flow in HYPER-I

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The phenomena which are driven by the interaction among neutral particles and plasma have been found in several types of plasmas. The formation of anti-$\boldsymbol{E}\times\boldsymbol{B}$ type vortices in a high density ECR plasma generated with the HYPER-I device is also regarded as the phenomenon in which the neutral-ion interaction plays an important role. The anti-$\boldsymbol{E}\times\boldsymbol{B}$ type vortex is generated in the area where the plasma density increases and the neutral density decreases. To clarify the dynamics in such a non-uniform system, the total pressure balance among particles should be studied. The total pressure p_T is defined as the summation of static pressure p_S and dynamic pressure p_D:

$$p_T = p_S + p_D,$$
$$p_S = kTn,$$
$$p_D = \tfrac{1}{2}\rho v^2,$$

where T, n, ρ and v are the temperature, the number density, the mass density and the flow velocity of the neutral gas, respectively. The purpose of our study is to clarify the effect of the dynamic pressure (neutral flow) on the formation of the anti-$\boldsymbol{E}\times\boldsymbol{B}$ type vortex. The neutral flow velocity is determined by Doppler shift of the laser-induced-fluorescence (LIF) spectrum obtained by sweeping an excitation laser frequency around the resonant wavelength of argon metastable atoms. Improvement of wavelength calibration of the excitation laser is one of the most important issues for the neutral flow measurement, since the expected Doppler shift is very small. Here, we briefly report the ability of the newly developed LIF spectroscopy system for the measurements of neutral flow velocity. The detailed description of the HYPER-I device and the LIF spectroscopy system have been reported elsewhere.[1,2)]

LIF Doppler measurement of argon metastable atoms was performed in an ECR plasma generated by 2.45 GHz microwave with the input power of 250 W. The wave length of an extended cavity diode laser (ECDL) is tuned to 696.735 nm, which excites the $4s'[3/2]^o_2$ state of argon atom to the $4p'[1/2]_1$ state. The polarization direction of the laser light parallels magnetic field. The maximum laser power was 17 mW. A Fabry–Pérot interferometer (FPI) is used to confirm single-mode oscillation of the ECDL. The fringes of FPI are also used as a scale of frequency of the ECDL. The newly developed LIF system utilizes argon saturated absorption spectroscopy, in which the laser frequency is calibrated by the frequency of Lamb dip and fringes of FPI. The use of Lamb dip as the frequency standard is particularly appropriate for the flow velocity measurement, because the spectrum is Doppler-shift free and Doppler broadening free. By utilizing the Lamb dip as the frequency standard, the reliability and stability of laser frequency calibration are improved. Figure 1 shows a saturated absorption spectrum and fringes of FPI simultaneously recorded during the same discharge period. The linewidth of the Lamb dip which appears in the saturated absorption spectrum (Fig. 1(a)) is significantly narrower than the Doppler broadening of neutral particles, which assures the improvement of accuracy in determining the standard frequency. The splitting of Lamb dips is attributed to the Zeeman splitting of magnetic sublevels of the transition. The center dip is used for the calibration of the absolute value of the laser frequency. Figure 1(b) shows the fringes of the FPI. The frequency interval of each fringe is 294 MHz, and is utilized as the frequency scale. By combining the position of Lamb dip and the fringes, we have determined the center frequency of LIF spectrum. Figure 2 shows the Doppler-shifted LIF spectra observed at $x=\pm 2$ cm. The profiles of two spectra are almost identical except the peak shift, which can be clearly seen by magnifying the spectra. In this case, the frequency shift is approximately 40 MHz, corresponding to the relative speed of 28 m/s. Carrying out successive measurements at different positions, we have obtained the radial flow velocity profile of neutral particles.

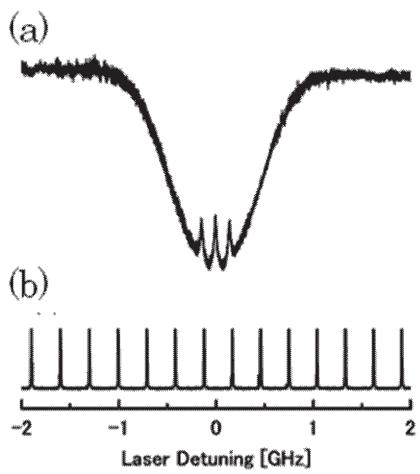

Fig. 1. (a) saturated absorption spectrum, (b)fringes of Fabry-Perot interferometer.

1) Tanaka, M. et al.: Rev. Sci. Instrum. **69** (1998) 980
2) Aramaki, M. et al.: Rev. Sci. Instrum. **80** (2009) 053505

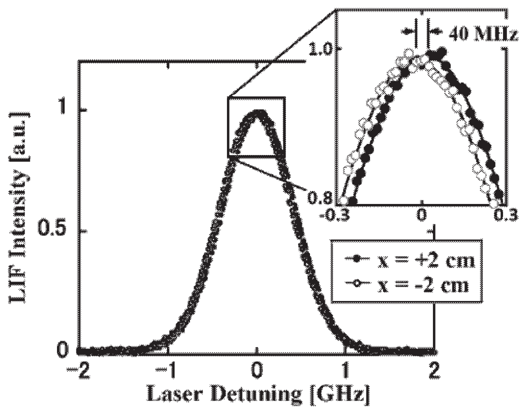

Fig. 2. LIF Doppler spectra observed at the vicinity of the plasma centre.