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Laser-induced fluorescence spectroscopy with optical vortex beam in a partially ionized plasma

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Laser-induced fluorescence Doppler spectroscopy (LIF) using a narrow-band tunable laser has become a standard diagnostic method for low-temperature laboratory plasmas because it can measure the local velocity distribution function of ions and neutral particles. We have developed a high-accuracy LIF system using a tunable laser to measure the flow velocity of ions/neutrals in partially ionized plasmas and clarified some phenomena using the LIF system, such as ion acceleration and streamline detachment from the magnetic field [1], axial neutral flow reversal [2], and formation of asymmetric velocity distribution function due to neutral depletion [3].

In most cases, the LIF method has been performed using a plane wave as an injection laser beam [See Fig. 1(a)], and the flow velocity parallel to the wavenumber of the laser is measured. In other words, in the conventional LIF method, the measurable flow direction is limited by the injection direction of the laser beam. This limitation relates to the difficulty of LIF measurement in the actual experimental circumstances, for example, measurement of flow toward a wall.

Recently, we have proposed a new LIF spectroscopy using optical vortex beams (OVLIF) to determine the flow velocity perpendicular to the wavenumber vector. The optical vortex is a propagating mode (Laguerre-Gauss modes) with a donut-shaped intensity profile shown in Fig. 1(b) and has a spiral phase structure to the beam axis. The Doppler shift of resonant absorption for a particle crossing the cross-section of the optical vortex beam is approximately given by $\delta = -\boldsymbol{k}\cdot\boldsymbol{v} - (\ell/r)v_\theta$ [4], where $\boldsymbol{k}$ is the wavenumber vector, $\boldsymbol{v}$ the velocity of the particle (v_θ means the perpendicular component), ℓ the topological charge, r the distance from the beam center. The second term changes its magnitude depending on its position in the beam cross-section when the flow across the beam vertically is considered. The resultant spatial dependence of the resonant absorption condition deforms the LIF spectrum.

To verify the usefulness of the OVLIF method, we have numerically evaluated the shapes of LIF spectra obtained by optical vortex beams [5]. Figure 1 shows the calculated spectra of OVLIF and the conventional LIF methods. Using an optical vortex beam results in a modification of the LIF spectrum from the Maxwell distribution (flattening and broadening) when there is flow across the beam. Hence, by quantifying the modification of the LIF spectrum, we can determine the flow velocity of the particles crossing the beam. Recently, we have been starting experiments to demonstrate the principle of the OVLIF method with the HYPER-I device at National Institute for Fusion Science (Japan) [6]. A plane wave beam emitted from a tunable diode laser is converted to an optical vortex beam by using a spatial light modulator (SLM), which can generate an optical vortex beam with an arbitrary topological charge by changing the hologram pattern. In this study, the OVLIF measurements have been carried out for metastable argon ions in an ECR plasma.

In this conference, we will introduce our previous results obtained by LIF measurements and discuss the details of OVLIF spectroscopy.

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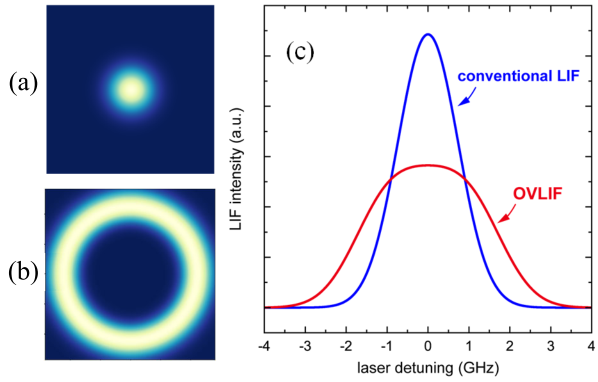

Fig. 1. 2D beam intensity profiles: (a) Gaussian beam (plane wave); (b) LG beam ($\ell = 10$). (c): Calculated LIF spectra obtained from the conventional LIF and the OVLIF methods.

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