1P019 光渦レーザーを用いたプラズマ流計測の現状と展望
Status and prospects of plasma flow measurement using optical vortex laser

吉村信次[1)], 寺坂健一郎[2)], 荒巻光利[3)]
YOSHIMURA Shinji[1)], TERASAKA Kenichiro[2)], ARAMAKI Mitsutoshi[3)]

[1)]核融合研, [2)]九大総理工, [3)]日大生産工
[1)]NIFS, [2)]Kyushu Univ., [3)]Nihon Univ.

Expanding the capability of laser diagnostics has a considerable impact not only on basic plasma research but also on plasma applications. We have been developing a novel plasma flow measurement method using Laguerre-Gaussian (LG) modes of laser beams, also known as optical vortices.

An optical vortex beam is characterized by the phase gradient in the azimuthal direction around the singularity point located at the beam center, which gives rise to an azimuthal Doppler shift [1], in addition to the routinely-used longitudinal Doppler shift, of the resonant absorption frequency of an atom moving vertically in the beam cross-section. The magnitude of the additional shift is proportional to the azimuthal component of the flow velocity. Therefore, detecting the azimuthal Doppler shift enables us to determine the flow velocity perpendicular to the wave vector of the laser beam, which is impossible in principle when using traditional laser spectroscopy.

One of the difficulties for experimentally detecting the azimuthal Doppler shift is its smallness. The ratio of the azimuthal shift to the longitudinal shift is approximately given by $l\lambda/2\pi r$, where l is the topological charge, λ is the wavelength of the laser beam, and r is the distance from the singularity point. The azimuthal Doppler shift is significant only in the vicinity of the singularity point, where the beam intensity vanishes.

There are two conceivable laser measurements where we can replace a plane-wave-like laser beam with an optical vortex beam: the laser absorption spectroscopy and laser-induced fluorescence method. In the following, we discuss these two methods.

In optical vortex laser absorption spectroscopy (OVLAS), the two-dimensional distribution of the transmitted beam intensity must be recorded while tuning the laser frequency across the absorption line. Since the resonant absorption condition depends on the position when considering uniform flow across the beam, the vertical flow velocity can be determined using the spatially resolved absorption spectra reconstructed from imaging data. A weak beam of which power is in μW order should be used to obtain pronounced absorption of the laser beam. Note that the asymmetric absorption modifies the intensity distribution of the beam, resulting in diffraction propagation. [2] To precisely determine the flow velocity, the error brought by the diffraction should be compensated.

In the optical vortex laser-induced fluorescence (OVLIF) method, the LIF signal is collected by a photo-multiplier tube that inevitably integrates the contributions from small segments on the whole beam cross-section. LG beams with high topological charge and small diameter are required for obtaining pronounced deformation of the LIF spectrum caused by the azimuthal Doppler shift. We have assessed the feasibility of OVLIF by numerical calculations. [3] A significant modification of the LIF spectrum has been obtained under the conditions that a high topological charge number of $l = 10$, a small spot size about 30 μm, and a fast beam-crossing flow of 10 km/s. A proof-of-principle experiment utilizing the high-velocity ion flow toward a negatively-biased electrode immersed in a plasma is now planning to perform using the HYPER-I device at NIFS.

References
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