§6. Development of a Tunable Optical Vortex Laser for a Novel Plasma Spectroscopy

Aramaki, M. (Nagoya Univ.),
Terasaka, K., Tanaka, M.Y. (Kyushu Univ.),
Yoshimura, S., Morisaki, T.

Recently, the optical vortex is intensively studied in the field of a high resolution microscopy, optical tweezers, etc. However, its potential for plasma diagnostics has not been studied yet. Figure 1 shows the phase plane of an optical vortex beam. The three dimensional phase structure of the phase plane is valuable characteristics for the Doppler spectroscopy. An atom moving in a plane wave does not feel the Doppler effect in the direction parallel to the phase plane, on the other side, the motion in an optical vortex induces the Doppler effect in all the three dimensional directions. We aim to develop a three dimensional Doppler spectroscopy method using the optical vortex. In this study, we have developed an optical vortex light source for the new spectroscopic method.

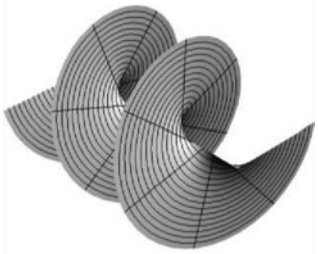

Fig. 1 Phase plane of optical vortex beam.

In rectangular coordinates, the Helmholtz wave equation has the series of the mutually-orthogonal solutions called as Hermite-Gaussian (HG) modes. Alternatively, the mutually-orthogonal solutions in cylindrical coordinates are called as Laguerre-Gaussian (LG) modes. The LG mode beams are called as optical vortex. The LG mode is expressed as the superposition of HG mode solutions [1].

$$u_{nm}^{\mathrm{LG}}(x,y,z)=\sum_{k=0}^{N} i^{k} b(n,m,k)\, u_{N-k,k}^{\mathrm{HG}}(x,y,z), \qquad (1)$$

$$b(n,m,k)=((N-k)!k!/2^{N}n!m!)^{1/2}1/k!\frac{d^{k}}{dt^{k}}\left[(1-t)^{n}(1+t)^{m}\right]_{|t=0}. \qquad (2)$$

We adopt a method which generates a LG mode beam by superimposing HG mode beams, because the method does not require expensive optical components.

Figure 2 shows the schematic diagram of the optical vortex generator that we have developed this year. A HG00 mode beam is obtained from an extended cavity diode laser (ECDL) tuned at 696 nm. The beam shape of the ECDL is elliptical, and it is circularized using an anamorphic prism pair. The spectrum of the ECDL is monitored using a Fabry-Pérot interferometer (FPI). In order to prevent strong optical feedback from the FPI, a double stage optical isolator (60dB) is placed in front of the FPI. The HG00 mode beam is mode-matched to a higher order HG mode in a ring cavity, therefore, the ring cavity outputs a higher order HG mode beam. The reflectivity of the input and output mirror of the

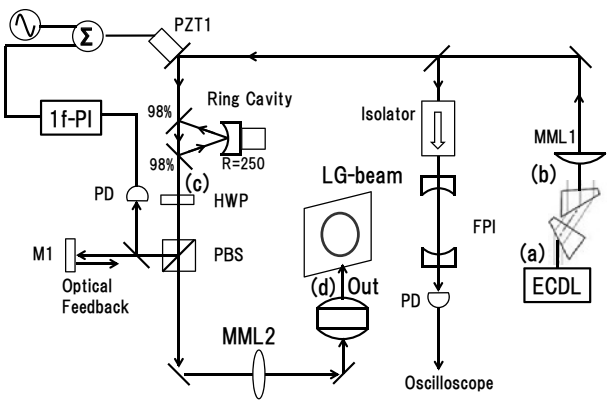

Fig. 2 Setup of optical vortex generator

ring cavity is 98%. A part of the output of the ring cavity is returned to the ECDL to lock it to the resonance wavelength of the ring cavity. The phase of the feedback light is controlled by a mirror mounted on a piezoelectric transducer to stabilize the optical feedback. Finally, the higher order HG mode beam is converted into the LG mode beam by shifting Gouy phase of the diagonal component using a cylindrical lens pair.

Figure 3 shows the beam shapes observed at (a) to (d) positions indicated in Fig. 2. Figure 3 (a) shows the original beam profile of the ECDL. The output power was 9 mW. The elliptical beam profile is circulalized by the anamorphic prism pair (Fig. 3 (b)). The HG00 mode beam is mode-matched to the HG02 mode in the ring cavity. Figure 3 (c) shows the output beam of the ring cavity. The power of the HG02 mode beam was 4 mW. The HG02 mode beam is mode-matched into the cylindrical lens pair. Figure 3 (d) shows the optical vortex (LG02) beam generated from the HG02 mode beam.

Although we have successfully developed an optical vortex generator, we need to develop additional techniques for stabilization of the mode locking of the higher order resonance in the ring cavity.

1) M. W. Beijersbergen, et al., Opt. Commun. **96** (1993) 123-132.

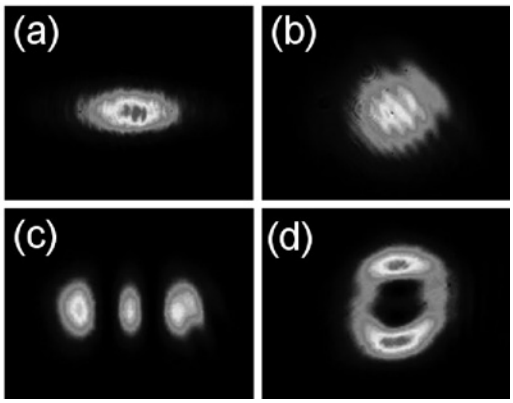

Fig. 3 The beam profiles of (a)ECDL output, (b)circulalized HG00 mode beam, (c) output of the ring cavity, and (d) obtained optical vortex beam.