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

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

Recently, the optical vortex is intensively studied in the area of the optical science. Figure 1 shows phase planes of a plane wave and optical vortex beam. The phase plane of the optical vortex beam has a spiral shape; therefore a singularity of phase exists at the center of the phase plane. The optical vortex has been applied for a high resolution microscope, optical tweezers, etc. using the singularity. On the other hand the optical vortex has orbital angular momentum, and it might be useful feature for the spectroscopy in plasma. We aim to apply it for a novel plasma spectroscopy. This year, we have tentatively designed a tunable optical vortex laser and started development. Equation (1) shows the Hermte-gaussian (HG) solutions of the Helmholtz wave equation in rectangular coordinates.

$$u_{nm}^{\mathrm{HG}}(x,y,z)=C_{nm}^{\mathrm{HG}}H_n(x\sqrt{2}/\omega)H_m(y\sqrt{2}/\omega)/\omega\exp\left[-i(n+m+1)\psi\right] \times\exp\left[-ik(x^2+y^2)/2R_{\mathrm{C}}\right]\exp\left[-(x^2+y^2)/2R_{\mathrm{C}}\right], \tag{1}$$

where $C_{nm}^{\mathrm{HG}}=(2/\pi n!m!)^{1/2}2^{-N/2}$ and $H_n(\xi)$ is the Hermite polynomial of order n. On the other side, Equation (2) shows the Laguerre-gaussian (LG) solutions of the Helmholtz wave equation in cylindrical coordinates.

$$\begin{aligned}u_{nm}^{\mathrm{LG}}(r,\phi,z)&=(-1)^{\min(n,m)}C_{nm}^{\mathrm{LG}}\left(\sqrt{2}r/\omega\right)^{|n-m|}\\&\times L_{\min(n,m)}^{|n-m|}(2r^2/\omega^2)\exp\left[-i(n+m+1)\psi\right]\\&\times\exp\left[-ikr^2/2R_{\mathrm{C}}\right]\exp\left[-r^2/\omega^2\right]\exp\left[-i(n-m)\phi\right],\end{aligned} \tag{2}$$

where $C_{nm}^{\mathrm{LG}}=(2/\pi n!m!)^{1/2}\min(n,m)!$ and $L_p^l(\zeta)$ is the generalized Laguerre polynomials. The LG mode beams are called as optical vortex. Since the HG modes and the LG modes are commutative each other, a LG mode can be expressed by a set of HG mode solutions.

$$u_{nm}^{\mathrm{LG}}(x,y,z)=\sum_{k=0}^{N}i^k b(n,m,k)u_{N-k,k}^{\mathrm{HG}}(x,y,z), \tag{3}$$

$$b(n,m,k)=\left((N-k)!k!/2^N n!m!\right)^{1/2}1/k\frac{d^k}{dt^k}\left[(1-t)^n(1+t)^m\right]\Big|_{t=0}. \tag{4}$$

By using the relation, LG mode beam is composed of the relevant HG mode beams [1].

We have started development of a tunable optical vortex laser. Figure 2 shows the schematic diagram of the optics system. An extended cavity diode laser (ECDL) is used as a light source. The ECDL is tuned at 696 nm in order to excite Ar metastable. In order to prevent strong optical feedback from the Fabry-Perot interferometer (FPI), an optical isolator is placed in front of the ECDL. The shape and phase of the output of the ECDL are tuned using a mode matching lens and a mirror mounted on a piezoelectric transducer, respectively. The HG00 mode beam is converted into HG01 mode beam using the FPI. Figure 3(a) shows a calculated intensity profile of HG01 mode. HG01 mode beam is converted into LG01 mode beam (Fig. 3(b)) by shifting Gouy phase of the diagonal component of HG01 mode using a cylindrical lens pair. We are now constructing the FPI aiming at efficient HG mode beam conversion.

[1] M. W. Beijersbergen, et al., Optics Comm. **96** (1993) 123-132.

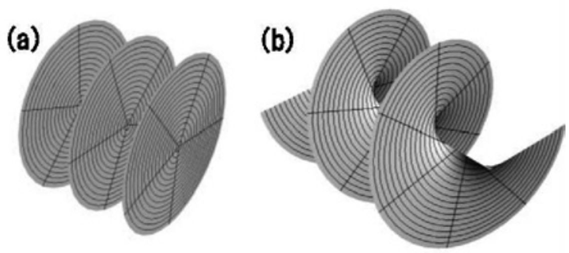

Fig. 1 Phase planes of (a) plane wave, and (b) LG_{10} mode beam.

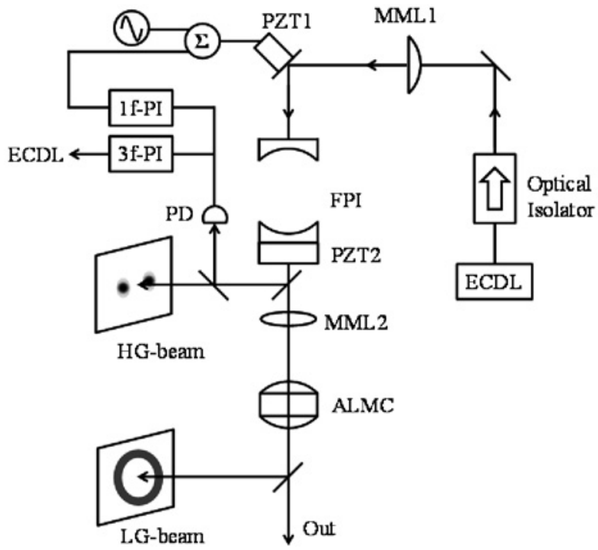

Fig. 2 Setup of optical vortex laser

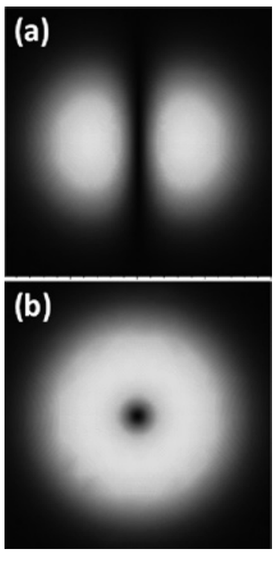

Fig. 3 Calculated intensity profile of (a)HG_{10} mode beam, and (b)LG_{10} mode beam