자기확산 매질에서 비등방성 광보텍스의 진행특성
Propagation properties of anisotropic optical vortex through a self-defocusing medium

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Optical vortices have been of interest because of helical wavefront structure, unlike planar wavefront [1]. They are characterized by a dark core in the beam pattern and by accumulated phase change of $2m\pi$ around the vortex core, where m is referred to be a topological charge. These topological defects show particle-like properties like electronic charges when they interact with background beam or other vortices, such as the conservation of topological charges, attractive/repulsive interactions between same/opposite charges, creation and annihilation of charge pairs, and so on. A particular characteristic of topological charges is that they tend to rotate each other.

Linear propagation properties was well studied analytically [2]. In the case of nonlinear propagation, they attracted much interest since they develop into optical vortex solitons that can guide signal beam through the self-induced spatial fiber [3]. Most of these studies by experimental and theoretical/numerical approaches were focused on optical vortices with isotropic phase profiles, that is, with constant phase gradient along a circular path of wavefront ramp. In this paper, our interest is extended to include optical vortices with anisotropic phase profiles [4]. The propagation properties of anisotropic optical vortices through a self-defocusing nonlinear medium is studied numerically.

Well-known analytical form of a single vortex is $A(x,y)=A_0(x,y)\exp(im\phi)$, where A_0 is the complex amplitude which goes to zero near the vortex, $\phi=\tan^{-1}(y/x)$ is an azimuthal angle in the cylindrical coordinates. In this case, the phase gradient along a circular path with unit radius is constant, $\nabla\phi=m$ around the point defect. Here we can introduce the anisotropy as follows:

$$E(x,y)=E_0(x,y)(x+i\sigma y)^m=A_0(x,y)\exp(im\Phi), \qquad (1)$$

where $\Phi=\tan^{-1}(\sigma y/x)$, and σ is the anisotropy parameter which is one of fundamental parameters that determine the internal structure of the vortex. For $|\sigma|>1$, equi-phase lines are pushed to the x-axis whereas they are pulled to the y-axis for $|\sigma|<1$. Of course, $|\sigma|=1$ for isotropic vortices.

Nonlinear propagation of a beam in a self-defocusing Kerr-like medium is described by

(1+2)-dimensional nonlinear Schrödinger equation as follows:

$$2ik\frac{\partial A}{\partial z} = \left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right)A + 2\frac{n_2}{n_0}k^2|A|^2 A, \tag{2}$$

where $k = n_0 k_0$ is the wave number in the medium. The intensity-dependent refractive index change is $\Delta n = n_2|A|^2$ ($\ll 1$), where n_2 is referred to be the nonlinear refractive index coefficient. Here it is assumed that the response of material is instantaneous and the loss is zero.

In numerical simulations, it is assumed that the background intensity profile is Gaussian. Initial field can be expressed as follows:

$$A(x,y) = A_0 \tanh(r/w_v)\exp(im\Phi)\exp(-r^2/w_0^2). \tag{3}$$

The nonlinear refractive index change of $\Delta n = 2\times10^{-5}$ supports the vortex soliton with the core radius of $w_v = 22.6\,\mu m$ where $\lambda = 500\,nm$ and $n_0 = 1$ are assumed. The transverse numerical grid was 1200×1200 with element size of $1.1\,\mu m$. In this paper, the background beam radius is fixed to be $w_0 = 10\,w_v$.

Figure shows contoured gray-scale beam pattern after the vortex beam of (a) propagates the distance of (b) 0.3*cm*, (c) 1.6*cm*, and (d) 6.4*cm* when m = 1 and σ = 5. It shows that the dark core of vortex soliton is established stably even though the diffraction affects the background beam severely at the initial stage. The phase distributions (not shown here) also shows that the anisotropic vortex changes into an isotropic vortex during the propagation through a self-defocusing medium while it doses not change into an isotropic one during the propagation through a linear (free-space) medium.

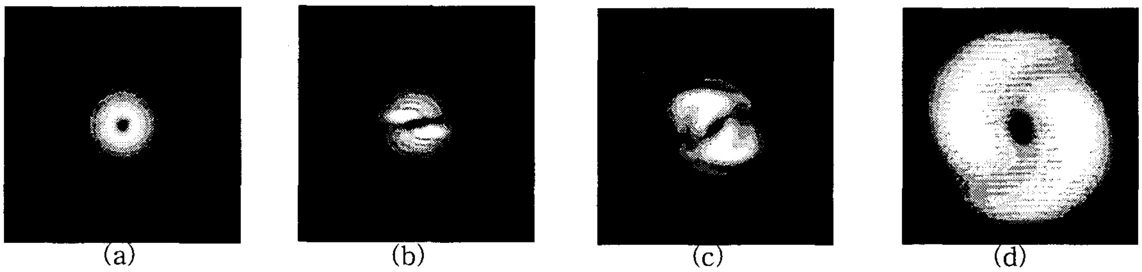

Fig. Contoured gray-scale beam pattern after the vortex beam of (a) propagates the distance of (b) 0.3*cm*, (c) 1.6*cm*, and (d) 6.4*cm* when m = 1 and σ = 5.

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