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A fork grating with controllable vortex diffraction order

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Abstract. It is well known that optical vortices have great potential in optical communications, quantum computations, micro-manipulation, and many other applications. Controlling the diffraction order of the beam vortices is still a challenge. Our system consists of a planar dye-doped liquid crystal(DDLC) cell that has a fork-grating lithography mask printed on it. Changing the diffraction order of fork grating diffractions can be accomplished by applying an electric field to the cell. Therefore, a fork-shaped phase profile can be obtained characterized by the alternation of ordinary and extraordinary refractive indices. The devices allow for the control of vortex diffraction order, as well as excellent polarization independence and high efficiency.

Keywords: diffraction order, fork grating, optical vortex beam, refractive index

Introduction

In the past two decades, optical vortices have attracted considerable attention and have been extensively studied. An optical vortex is a beam of light characterized by a helical phase front. Thus, the wavefront is twisted like a corkscrew around its propagation axis [1]. There are a number of phase windings in one wavelength known as the topological charge, which represents the phase rotation velocity around the axis. Phase windings are(or topological charge, m) a key property of these vortices. In order for an optical vortex to maintain continuity, m must be an integer[2,3]. Thus, orbital angular momentum (OAM) is quantized. Phase singularity at the axis causes no intensity, which results in a donut-shaped distribution of intensity. Depending on the topological charge, the shape of the ring is determined. Topological charge and its corresponding OAM provide a new level of freedom in characterizing the properties of a light beam, thereby opening up new applications and even uncharted terrain.[4] According to theory, optical vortices contain an infinite number of states as a result of their unlimited topological charge.[3]

In addition to characterizing the light properties by determining their orbital angular momentum (OAM), it opens the doors to widespread applications in informatics, micromanipulation, and astronomy [5]. In quantum computing, OAM multiplexing can be used to encode and store information based on the multiple states of light[1], which are created by the vortices in light. Optical vortex coronagraphs increase the contrast of astronomical observations by blocking the strong background light, which is useful for searching for extrasolar planets. Optical vortices have a wide range of applications in fields such as informatics, micro-manipulation, and astronomy[2]. In order to generate optical vortices, several techniques have been developed. A cylindrical lens mode converter was used in the initial research to realize Laguerre-Gaussian mode vortices[6]. Consequently, spiral phase plates have been used to produce optical vortex by directly rephasing plane waves [1,7]. The electro-optical (EO) properties of liquid crystals (LCs) have led to the development of tunable vortex generators [8,9]. LC spiral phase plates or fork gratings for controlling diffraction order of optical vortices are typically made with liquid crystal cells [10].

In this work, a controllable diffraction order optical vortex generator is demonstrated via a dye-doped E7 liquid crystal cell driven by an electric field. Based on the printed fork grating lithography mask on DDLC, it can control the diffracted order of vortex beams. Furthermore, it switches the diffracted order of the fork grating vortex beams independent of incident polarization.

Generation of optical vortex

In order to generate optical vortices, several techniques have been developed. However, it has a bulky and complex optical setup, which makes it difficult to generate beam vortices with large m numbers. One of the ways for generating an optical vortex beam is fork grating. Fork gratings are diffraction gratings with dislocations in the center, which offer an efficient method of generating beam vortices [8,9,10]. A fork grating can convert a Gaussian beam into a series of helical phases, each with its own twist direction. Currently, this is a very convenient way to generate beam vortices. The phase function of an optical vortex can be described by $\Psi 1 = \mathrm{exp}(im\theta)$ (Figure 1 a), where θ is the azimuthal angle of a cylindrical coordinate system (r, θ, z) around the z-axis, which indicates the beam propagation direction, m is the topological charge and can be positive or negative, depending on the direction of the twist (positive for counterclockwise rotation and negative for clockwise rotation)[2].

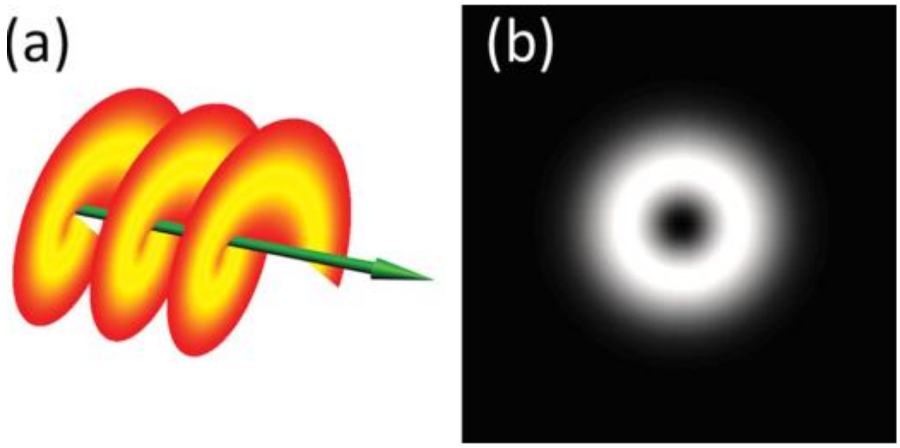

Figure 1: a) The helical wave fronts of a vortex beam with m=1 calculated according to $\psi_1 = exp(im\theta)$ *b) normalized intensity distribution when the beam is viewed against the propagation axis[2].*

The interference between plane wave $\psi_2(x) = exp(ikx)$ (where k is the spatial frequency, which indicates the wavenumber) and an object wave $\psi_1 = exp(im\theta)$. The interference pattern could be described by the function[1-3]:

$$H = |\psi_1 + \psi_2| = |exp(im\theta) + exp(ikx)|^2 = 2[1 + cos(kx - m\theta)]$$

Where $\theta = tan^{-1}({}^{y}/_{x})$ is the polar coordinate. Figure 2 shows the fork grating si,ulation for m=1.

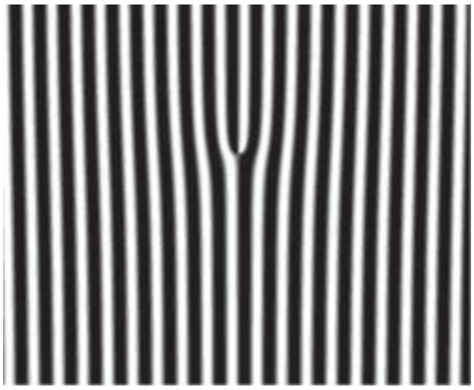

Figure 2: simulated holograms according to equation(1) for m=1 [1].

Experimental

For generating and controlling diffraction order of vortex beam, was used the nematic homogeneous liquid crystal E7 dopped by methyl red(MR) in $20\mu m$ cell, and a fork grating lithography mask. It was written by 532nm laser which is beam lighting a sample about normal incidence for writing the fork-grating might on DDLC, it was shown in FIG. 2. By appling electric field on cell the diffraction of the He-Ne probe beam showed that the grating originates from a reorientation of the director in the plane of incidence. This reorientation was first attributed to a photorefractive-like effect. Experimental schematic of setup for the generation vortex beam was shown in (Figure. 3).

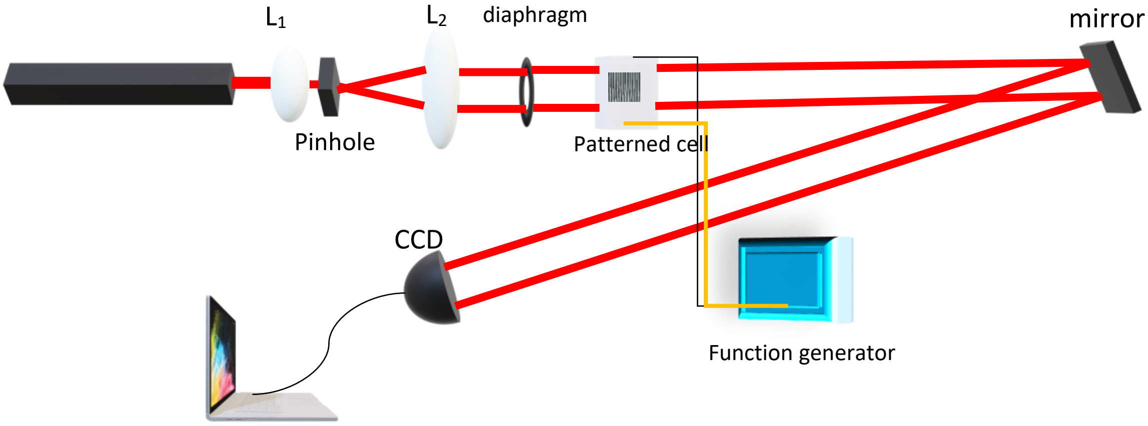

Figure 3: schematic diagram of generation vortex beam and controlling diffraction order

Figure 3 shows the experimental setup for characterizing the phase grating. A He-Ne laser ($\lambda = 632nm$) was used as probing beam. The incidence beam is collimated and unplorized which illuminated cell. After the cell is put a mirror for reflecting light onto CCD. In addition, the intensity of each order was detected by a CCD in the far-field located at a distance of

~194cm. Figure 4 shows the recorded diffractions orders of forkgrating which is printed onto DDLC by applying voltage it can be shown the diffraction order of the generation vortex beam can be changed.

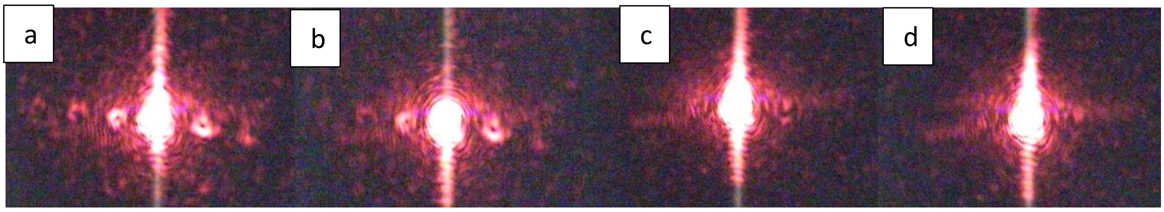

Figure 4:diffraction order of DDLC by applying electric field a)v=1.72v b) v=2.59v c)14.1v d)22.1v

Conclusion

In the described system a fork-grating lithography mask is printed on DDLC planar cell. Changing the diffraction order of fork grating diffractions can be accomplished by applying an electric field to the cell which is shown in Figure 4. When the applied voltage is increased the diffraction order of generated vortex beam is being to disappears. Therefore, it can be obtained the alternation of ordinary and extraordinary refractive indices varying by changing the applied voltage. The devices allow for the control of vortex diffraction order, as well as excellent polarization independence.

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