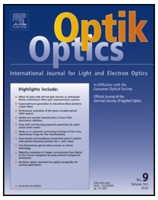
Optik 126 (2015) 5263–5268

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo



Measuring the fractional and integral topological charges of the optical vortex beams using a diffraction grating

Man Liu [a,b,*]

[a] *School of Science, Qilu University of Technology, Jinan 250353, China*
[b] *College of Physics and Electronics, Shandong Normal University, Jinan 250014, China*

ARTICLE INFO

Article history:
Received 24 September 2014
Accepted 6 September 2015

Keywords:
Vortex beams
Diffraction grating
Intensity distribution
Phase distribution

ABSTRACT

The diffraction properties of intensity and phase of the optical vortex beam through the diffraction gratings are studied. It is found that the profiles of the zero-order light spot in the center is similar to the +1 and −1 diffraction orders, and the distributions of light spots is related to the topological charges of vortex beam. For the fractional topological changes, the profiles of light spots is become long in the *y* direction, which parallel to the direction of slits of grating, and the patterns for positive and negative of topological charges are mirrored in the *x* axis. For the integral topological changes there is no difference between the patterns for positive and negative of topological charges, in this case, we can easily determined the topological charges from the patterns of phase. The results may be used to detect the fractional and integral topological charges of vortex beams.

1. Introduction

As we all know, all beams with an Azimuthal phase term, $\exp(il\theta)$ of which Laguerre–Gaussian beams are an example, have an orbital angular momentum of $l\hbar$ per photon, where θ is the Azimuthal angle and l (positive or negative) is the topological charge [1]. If the phase around the center of vortex beam increases in clockwise direction, the sign of topological charge is negative; if the phase around the center of vortex beam is increases in the counterclockwise direction, the sign of topological charge is positive. The optical vortex beam carrying orbital angular momentum not only can be transferred to the micro particle, to drive the particles rotation, but also can realize the capture of micron, sub micron particles [2], quantum information processing [3–8], atomic operation [9–12], micro operation [13–15] and biological sciences [16,17]. In recent years, it has attracted more attention in astronomical applications [18,19]. The topological charges of vortex beams can be applied to the optical information coding and transmission, especially the fractional topological charges, this new coding method has the advantages of high capacity, high security and so on, so the measurement of the topological charge of vortex beam is very important. Detection the topological charge of vortex beam is hot research topic in recent years [19–21].

In this paper, the characteristics of the intensity and phase distributions of Laguerre–Gaussian (LG) beam passing through a diffraction grating in the Fraunhofer diffraction region are simulated. It is found that the light spot of zero order in each center is similar to the +1 and −1 orders. For fractional topological charges, the light spots are all parallel to the direction of slit of grating and the intensity distribution patterns are symmetric in the *x* axis with the fractional topological charges of vortex beams are opposite; for integral topological charges, the intensity distribution patterns are also related to the topological charges of incident optical vortex beams, while in this case there is no difference between the intensity distribution patterns for positive and negative topological charges, making it impossible to differentiate between positive and negative topological charges, in this case, it can be distinguished from the phase distribution patterns. So this method can easily to probe the topological charges of optical vortex beams directly by observing the bright spots in intensity distribution patterns or the number of phase vortices in the central region in phase distribution patterns.

2. Theoretical study the intensity and phase distributions in the Fraunhofer diffraction region

First, we study the distribution characteristic of intensity and phase in the far field produced by optical vortex beams through a

---

[*] Correspondence to: School of Science, Qilu University of Technology, Jinan 250353, China.
E-mail address: lium@qlu.edu.cn

http://dx.doi.org/10.1016/j.ijleo.2015.09.004

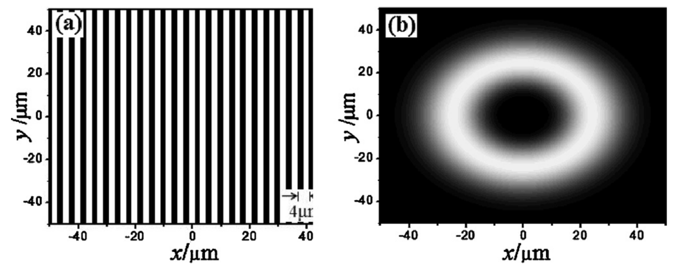
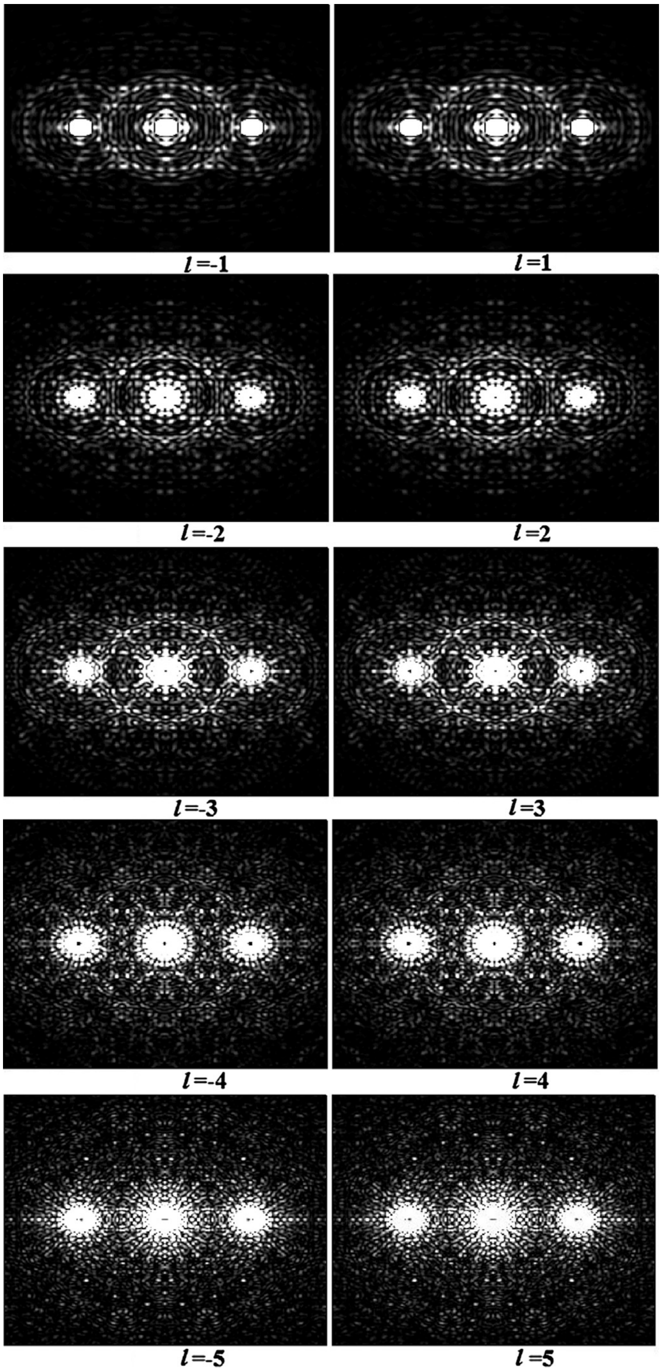


Fig. 1. The left patter is the diffraction grating; the right pattern is the intensity distribution of LG beams with l = +3.0 on plane z = 0.



l=-1 l=1

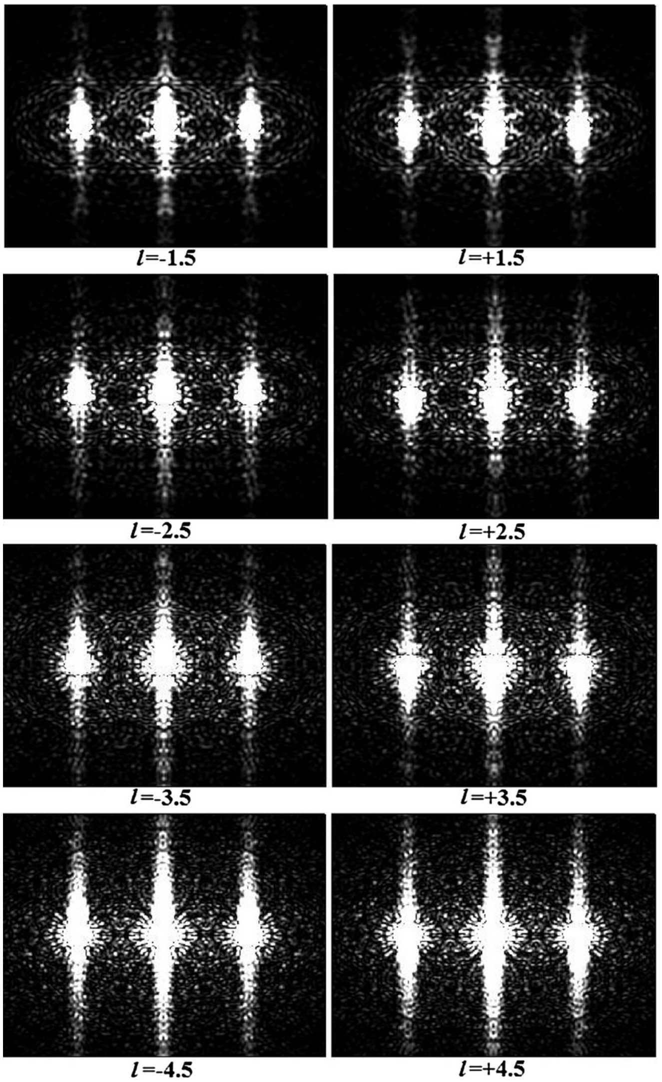
l=-2 l=2

l=-3 l=3

l=-4 l=4

l=-5 l=5

Fig. 2. The intensity distribution patterns in far field behind the grating illuminated by the LG beams with l = −1, l = +1, l = −2, l = +2, l = −3, l = +3, l = −4, l = +4.0, l = −5 and l = +5.0, respectively.



l=-1.5 l=+1.5

l=-2.5 l=+2.5

l=-3.5 l=+3.5

l=-4.5 l=+4.5

Fig. 3. The intensity distribution patterns in far field behind the grating illuminated by the LG beams with l = −1.5, l = +1.5, l = −2.5, l = +2.5, l = −3.5, l = +3.5, l = −4.5 and l = +4.5, respectively.

diffraction grating. Laguerre–Gauss beam is the most typical optical vortex beam, in the z = 0 incident plane, which have the complex amplitude can be written as

$$E_i(x_0, y_0) \propto \left(\frac{\sqrt{x_0^2+y_0^2}}{\omega}\right)^{|l|} \exp\left(-\frac{x_0^2+y_0^2}{\omega^2}\right) \exp(il\theta) \tag{1}$$

where ω is the radius of the beam waist, l is the topological charge of vortex beam, and (x_0, y_0) is coordinate. The complex amplitude of LG beams passed through a grating at a point in the observation plane can be expressed as

$$E_0(x_0, y_0) = E_i(x_0, y_0)t(x_0, y_0) \tag{2}$$

where $E_i(x_0, y_0)$ is the light field before the diffraction grating, $t(x_0, y_0)$ is amplitude transmittance function, which can be given by

$$\begin{aligned} t(x_0, y_0) &= rect\left(\frac{x_0}{a}\right) + rect\left(\frac{x_0-d}{a}\right) rect\left(\frac{x_0-2d}{a}\right) \\ &\quad + \cdots rect\left(\frac{x_0-(N-1)d}{a}\right) \\ &= \sum_{m=0}^{N-1} rect\left(\frac{x_0-md}{a}\right) \end{aligned} \tag{3}$$