J. Environ. Nanotechnol.
Volume 3 (2014) pp. 43-45
ISSN (Print): 2279-0748
ISSN (Online): 2319-5541
doi: 10.13074/jent.2014.12.144130

Effect of Coma on Tightly Focused Radially Polarized Vortex Beams

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Received: 03.07.2014 Accepted: 04.10.2014

Abstract

In this paper attention is given to the effects of primary coma on the radially polarized vortex beam based on the vector diffraction theory. It is observed that by properly choosing the polarization angle and topological charge one can obtain many novel focal patterns suitable for optical tweezers, laser printing and material process. However, it is observed that the focusing objective with coma generates structural modification and positional shift of the generated focal structure.

Keywords: *Vector diffraction theory; Radially Polarized Vortex beam; Polarization; Coma.*

1. INTRODUCTION

In modern optics study and applications of the optical vortex beam have recently generated great research (Nye *et al.* 1994, Soskin *et al.* 2001 and Kotlyar *et al.* 2005, Saraswathi *et al.* 2013). Recently the focusing properties of a circularly, radially, azimuthally or linearly polarized vortex beam by a high numerical-aperture lens have been discussed Quabis *et al.* 2001 and Helseth *et al.* 2004, Veerabagu *et al.* 2013). The size and shape of the focused structure of the vortex beam play an important role in many applications such as in microscopy, lithography, data storage, particle trapping, etc. A deformed focused structure may cause serious problems in optical trapping and microscopy.

Deformation in the focused structure can be due to aberrations. Under realistic experimental conditions, it's inevitable to suffer wave front aberrations even for the well corrected objectives (Biss *et al.* 2004, and Braat *et al.* 2003). An important investigation was initiated by Braat et al who used extended Nijboer-Zernike representation of the vector field in the focal region of an aberrated high NA optical beam. In this paper we present the results of intensity distribution of radially vortex beam with and without coma. Our results have been compared with those others in the absence of coma, and found to be in reasonably good agreement.

2. THEORY

The analysis was performed on the basis of Richards and Wolf's vectorial diffraction method (B. Richards *et al.* 1959) Widely used for high-NA focusing systems at arbitrary incident polarization. We adapted the same analysis method as that in Refs. (Youngworth *et al.* 2005).The focal field of a radially polarized vortex beam can be written as

$$\vec{E}\left(r,z,\varphi\right)=E_r\vec{e}_r+E_z\vec{e}_z\rightarrow(1)$$

Where E_r, E_z are the amplitudes of the three orthogonal components and $\vec{e}_r$, $\vec{e}_z$ are their corresponding unit vectors. The two orthogonal components of the electric field is given as

$$Er=-iA/2\pi\times\int_0^{\alpha}\int_0^{2\pi}\sqrt{\cos(\theta)}\times\sin(2\theta)\times A1\times\cos(\phi-\varphi)\exp(in\phi)$$

$$\times\exp[ik(z\cos(\theta)+r\sin(\theta)\cos(\phi-\varphi)]d\phi d\varphi\rightarrow(2)$$

$$Ez=iA/\pi\times\int_0^{\alpha}\int_0^{2\pi}\sqrt{\cos(\theta)}\times\sin^2(\theta)\times A1\times\exp(in\phi)$$

$$\times\exp[ik(z\cos(\theta)+r\sin(\theta)\cos(\phi-\varphi)]d\phi d\varphi\rightarrow(3)$$

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Where r,φ and z are the radial, azimuthal and longitudinal coordinates of the observation point in the focal region respectively. $2\pi/\lambda$ is wave number, and $\propto = \sin^{-1}(NA)$ is the maximal angle determined by the numerical aperture of the lens. A_1 denotes the wave front aberration function in the beam which can be expressed as (Kant 1995).

$$Al = \exp\left[I.k.Ac\left(\frac{\sin(\theta)}{\sin(\alpha)}\right)^3 \cos\phi \right] \rightarrow (4)$$

Where the coma coefficient Ac is in units of the wave length of the beam.

3. RESULTS

Fig 1(a) shows the intensity distribution in the focal plane for $NA = \sin(80^\circ)$ and topological charge n=1, which corresponds to radially polarized vortex incident beam without coma. The generated focal structure agrees well with the fig.(1.d) of (Rao *et al.* 2009). The total intensity is the sum of the radial intensity and longitudinal intensity. In this case, the azimuthal component disappears and only the radial and longitudinal components are present. It is observed that the total intensity has a bumpy structure which is in contrast to the n=0 case, where the longitudinal component distribution has an on-axial maximum and results in a highly confined focal spot. Fig.1(b-d) shows the intensity distribution at the focus for different Ac values. It is observed from the figure, that the intensity distribution in the focal plane undergoes significant changes in the presence of coma. It is noted, that the coma not only changes the focal structure and intensity distribution of the generated focal segment but also shifted it in the radial direction. It is clearly observed, that as the value of coma coefficient increases, the shifting of generated focal segment along radial axis is also increased.

Fig.1.(b) shows the position of maximum intensity of the generated focal spot at r= -0.75λ when Ac=0.5 λ .However further increasing of Ac to 1.5 λ shifted the focal segment axially to r= -1.5 λ and is shown in Fig.1(d). It is also observed when the value of Ac increases, the generated focal segment undergoes structural modification such that the size of the generated focal segment squeezing in the radial direction and broadens near the focus (z=0).

The modification of the structure is visible when the value of Ac increases to 1.5 λ and a new residual intensity spot begins to appear in the radial direction. Figure.1(e-h) shows the corresponding two dimensional intensity distribution calculated at the position of maximum intensity. It is observed from the figure, that the increase of Ac value decreases the radial component intensity.

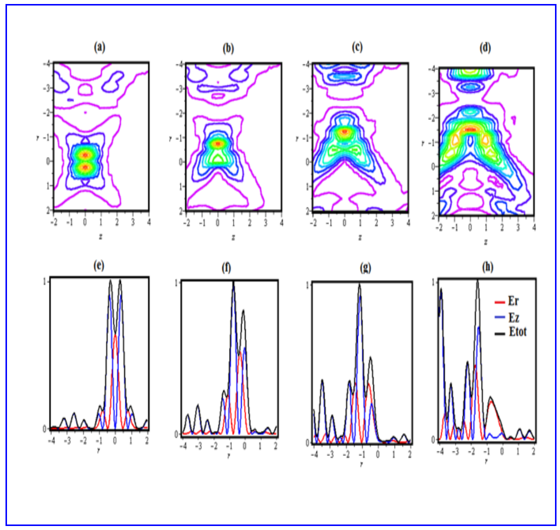

Fig. 1: Total intensity distribution of radially polarized vortex beam (a) Ac=0.0 ,(b)Ac=0.5, (c) Ac=1.0, (d) Ac=1.5 & Two dimensional intensity distribution at the focal plane (e)Ac=0.0, (f) Ac=0.5, (g) Ac=1.0, (h) Ac=1.5

4. CONCLUSION

To summarize, the effects of the coma on tightly focused radially polarized vortex beam have been investigated using vector diffraction theory. The results show that the presence of coma generates positional shift, structural modifications and spreading of intensity distribution. The author expect such a study is important in practical applications such as optical tweezers, laser printing and material processing.

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