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Generation of multiple focal hole segment by tight focusing of azimuthally polarized double ring shaped beam

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Abstract

Based on the vector diffraction theory, the effect of phase modulation on the intensity distribution of TEM11 mode azimuthally polarized Laguerre-Gaussian beam in the focal region of high NA lens is investigated theoretically. It is observed that a properly designed complex phase filter can generate multiple focal hole segment and it is useful for the manipulation of optical traps.

Keywords : *polarized double ring shaped beam, radial electric field component*

1. INTRODUCTION

Growing interest in the generation of three-dimensional (3-D) optical beams that are dark regions in space surrounded by light are driven by wide ranging applications including dark optical traps for atoms (N. Friedman et.al. 2002), manipulation, guiding and binding of micro-particles and biological cells (T.Cizmar et.al 2012), erase beams for super-resolution fluorescence microscopy (T. Watanabe etal 2003), etc. Over the past years, a variety of techniques have been proposed for generating such optical bottle beams for applications in optical tweezers and atom traps (J. Arlt et.al. 2000, B. Ahluwalia et.al. 2004, P. Rudy et.al. 2001; D.Yelin et.al. 2004; J.X.Pu etal. 2005; L.Isenhower et.al.2009; P.Xu et.al. 2010;V.G.Shvedov et.al 2010). However, stable trapping of a single particle is expected if we can make the bottles small enough and comparable to the particlesize. Such “microbottles” were established recently with the volume speckle field (B. Tian, etal 2011). Recently, a sub wavelength focal hole (0.5λ) with a quite long depth of focus (48λ) is achieved near the focus by tight focusing of double ring shaped azimuthally polarized beam with high NA lens axicon (K. Lalithambigai et.al 2012). The objective of the study reported in this Letter is to investigate the effect of complex phase filter in the focal properties of the tightly focused azimuthally polarized double ring shaped beam. We observe that our proposed system generates a sub wavelength multiple focal holes. We also observed that by properly designing the complex phase filters one can achieve many novel focal patterns including splitting of focal rings and generation of multi ring structures.

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2. THEORY

A schematic diagram of the suggested method is shown in (Fig 1). The analysis was performed on the basis of Richards and Wolf’s vectorial diffraction method widely used for high-NA focusing systems at arbitrary incident polarization (B. Richards e.tal. 1959). Shown in (Fig. 1), if a complex pupil filter is placed at the pupil plane, where the polarized states of the incident beams in the area of inner and outer rings are reverse, so as to cause the destructive interference in the focal region. In the case of the

$$E(r,\varphi,z)=\begin{bmatrix}E_r\\E_\varphi\\E_z\end{bmatrix}=\begin{bmatrix}-Ae^{i\phi}(I_0+I_2)\\-iAe^{i\phi}(I_0-I_2)\\0\end{bmatrix}=\begin{bmatrix}A\int_0^\alpha \cos^{\frac{1}{2}}(\theta)\sin(2\cdot\theta)A(\theta)J_1(kr\sin\theta)e^{ikz\cos\theta}d\theta\\2A\int_0^\alpha \cos^{\frac{1}{2}}(\theta)\sin(\theta)A(\theta)J_1(kr\sin\theta)e^{ikz\cos\theta}d\theta\\0\end{bmatrix}\rightarrow(1)$$

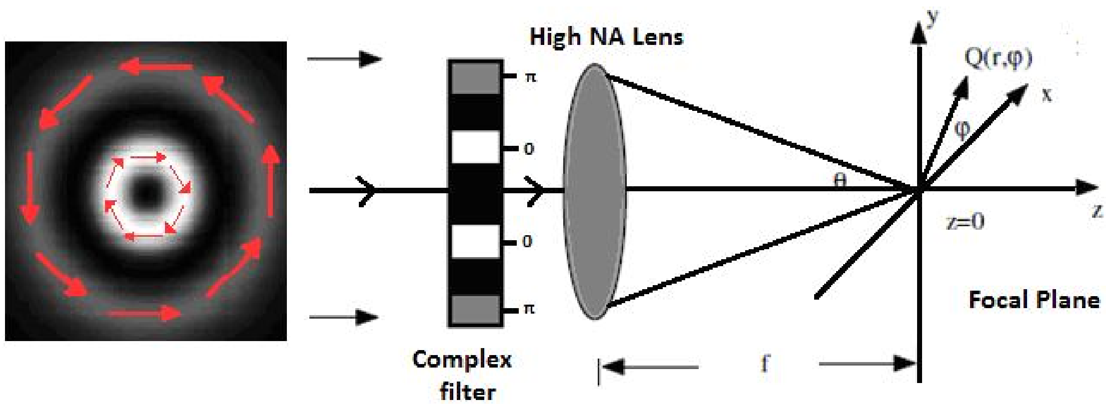

Fig. 1. (black and gray line) Schmatic Diagram of the proposed system. Azimuthally polarized double ring shaped beam passes through a multibelt spiral complex filter and is subsequently focused by a high-NA lens.

azimuthally incident polarization, adopting the cylindrical coordinates r, z, ö and the notations.

Where NA is the numerical aperture for $\alpha = arc\sin(NA/n)$ and n is the index of refraction between the lens and the sample. $J_0(x)$ and $J_1(x)$ denote the Bessel functions of the first kind of orders 0 and 1, respectively. The function $A(\theta)$ describes the amplitude modulation.

$$A(\theta)=\beta^2\frac{\sin\theta}{\sin^2\theta}\exp\left[-\left(\beta\frac{\sin\theta}{\sin\alpha}\right)^2\right]L_p^1\left[2\left(\beta\frac{\sin\theta}{\sin\alpha}\right)^2\right] \quad (2)$$

For illumination by a double ring-shaped R-TEM11* beam with its waist in the pupil, this function is given by (K. B. Rajesh et.all 2008). Where β is the parameter that denoted the ratio of pupil diameter to the beam diameter and L_p is the generalized Laguerre polynomial. If p=1, the incident azimuthally polarized beam is a double-ring azimuthally polarized. It is seen from Eq. (1) that an additional radial electric field component is produced after introducing the phase filter (G. H. Yuan, et.al 2011). Owing to this radial component, the polarization near the focal plane is rather complicated and space variant.

3. RESULTS

We perform the integration of Eq. (1) numerically using parameters λ =1, β =1.4 and NA of the objective is 0.9. Here, for simplicity, we assume

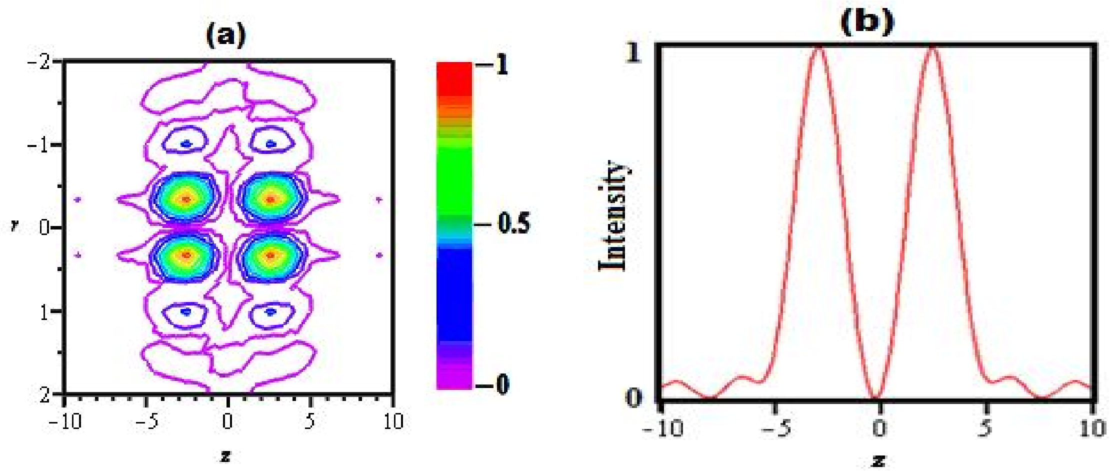

Fig 2. (a) Shows the contour plot of the total intensity distribution in the yz plane near the focus for the focusing system with complex phase filters. (b) Shows on axial intensity distribution ($E_r + E_\varphi$) at r=0.3λ.

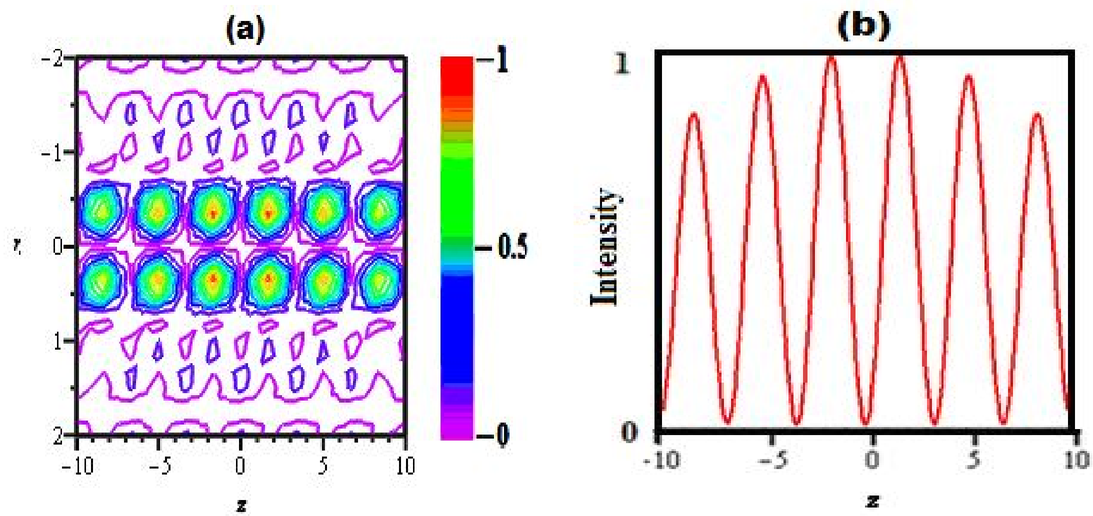

Fig. 3. (a) The contour plot of total intensity distribution for the focusing system. (b)Shows an on axial intensity distribution($E_r + E_\varphi$) at r=0.3λ.

that the refractive index n=1 andA=1.The effect of complex filter on the input azimuthally polarized double ring beam is evaluated by replacing the function $A(\theta)$ by $A(\theta)\ CF(\theta)$ where $CF(\theta)$ is given by

$$CF(\theta) = \begin{cases} 0, \ for 0 < \theta < \theta_1, \theta_2 < \theta < \theta_3, \\ 1, \ for \theta_1 < \theta < \theta_2, \\ -1 \ for \theta_3 < \theta < \alpha \end{cases} \tag{3}$$

Fig (2-a) shows the total intensity distribution of the focal hole segment generated by the proposed high NA lens in combination with dedicated complex phase filter (CPF). Such a sub wavelength super long dark channel may find applications in optical, biological, and atmospheric sciences. Fig (2-a) shows the splitting of focal hole segment generated by the high NA lens for the complex filter with θ_1= 35.82°, è$_2$= 54.83° and è$_3$=61.91°. It is observed from the figure that the FWHM of each ring is 0.374ë.

The axial distance between two ring structures is 5.2λ and is shown in Fig. (2-b). Fig (3-a) shows the array of focal hole segment generated by the high NA lens for the complex filter with θ_1=40.82°,θ_2=42.83°and θ_3=61.91°. From the figure we measure the FWHM of each ring is 0.372λ and are separated by the axial distance of 3.8λ between them.

The on axial intensity of the generated focal hole segment at r = 0.3λ is shown in fig (3-b). It is observed from the figure that the focal hole near focus and the one at the extreme end (z =10λ) is only 0.90% . Hence it is possible to generate multiple focal hole segment with almost uniform intensity.

4. CONCLUSION

In conclusion the generation of sub wavelength super long focal hole segment is demonstrated for the proposed high NA lens and a dedicated complex phase filter. We have also showed the possibility of generated multiple sub wavelength focal hole segment trough properly designed complex phase filter. The authors expect the proposed work to find its application in manipulation of optical traps.

5. REFERENCE

Ahluwalia, B., Yuan, X., and Tao, S., "Transfer of 'pure' on-axis spin angular momentum to the absorptive particle using selfimaged bottle beam optical tweezers system", Opt. Express.12, 5172, -5177 (2004).

Arlt, J and Padgett, M., "Generation of a beam with a dark focus surrounded by regions of higher intensity: the optical bottle beam" Opt. Lett. 25, 191-193 (2000).

Cizmar, T., Romero.L.C.D, K., Dholakia, K. and Andrews, D. L., Multiple optical trapping and binding: new routes to self-assembly" J. Phys. B 43, 102001 (2010).

Friedman, N., Kaplan, A. and Davidson, N., "Dark optical trap",Opt. Lett.35, 2164-2166 (2010).

Isenhower, L., Williams, W., Dally, A. and Saffman, M., "Atom trapping in an interferometrically generated optical bottle beam", Opt. Lett. 34, 1159-1162 (2009).

Lalithambigai, K., Suresh, P. V., Ravi, R, K., Prabakaran, K., Jaroszewicz, Z., Rajesh, K. B., Anbarasan, P. M. and Pillai, T. V. S., "Generation of sub wavelength super- long dark channel using high NA lens axicon," Opt.Lett 37, 999 -1002(2012).

Rajesh, K. B. and Anbarasan, P. M., "Generation of sub- wavelength and super-resolution longitudinally polarized non-diffraction beam using lens axicon," Chin. Opt.Lett. 6(10), 785-787 (2008).

Richards, B. and Wolf, E., Proc. R. Soc. Lond. A..Math.Phys., "Electromagnetic diffraction in optical systems,II. Structure of the image field in an aplanatic system," Sci.253 (1274), 358 (1959).

Rudy, P., Ejnisman, .R., Rahman, A., Lee, S. and N. Bifgelow, P., "An all optical dynamical dark trap for neutral atoms", Opt. Express 8, 159 (2001).

Sakai, M. and Fuji. M., Two point separation in super- resolution fluorescence microscope based on up-conversion fluorescence depletion technique,"Opt. Express 11, 3271 (2003).

Tian, B and Pu. J., "Tight focusing of a double-ring-shaped, azimuthally polarized beam",Opt. Lett. 36, 2014-2016 (2011).

Watanabe, T., Iketaki, S.Y., Omatsu.T,. Yamamoto.K. Shvedov.V.G,A. Rode.A.V, Izdebskaya.Y.V,A. Desyatnikov.S, Krolikowski.W and Y. S. Kivshar, "Selective trapping of multiple particles by volume speckle field", Opt. Express 18, 3137 -3481(2010).

Xu, P., He, X., Wang, J. and Zhan, M., "Trapping in a single atom blue-detuned optical bottle beam Opt. Lett. **35**(2010) 2164-2166.

Yelins, D., Bouma, B. E. and Tearney, G. J., “Generating an adjustable three-dimensional dark focus”, Opt. Lett. 29, 661-663 (2004).

Yuan, G. H., Wei, S. B. and Yuan, X. C., Non-diffracting transversally polarized beam”,Opt. lett.36,3479-3481(2011).

Youngworth, K. S. and Brown, T. G., “Focusing of high numerical aperture cylindrical-vector beams,” Opt. Express 7(2), 77 (2000).