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Effect of coherence and polarization on the polychromatic partially coherent dark hollow beam generated from axicon-lens system

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Abstract

An experimental study is carried out to investigate the effect of coherence and polarization on the polychromatic partially coherent dark hollow beam (PCDHB). The experimental results show that the spatial coherence and source polarization affect the dark region of the generated hollow beam. The study shows that by varying the source degree of polarization (DOP), we get a tunable dark region. We find that the longer the spatial coherence length of the input beam, the larger the central dark size of the resultant PCDHB. Further, it is shown that polychromatic PCDHB with low spatial coherence travel a longer distance without being distorted than a beam with a high spatial coherence. These kinds of polychromatic beams may find potential application in the field of polychromatic light based free-space optical (FSO) communications.

Keywords: coherence, polarization, hollow beam, free-space optics

(Some figures may appear in colour only in the online journal)

1. Introduction

Dark hollow beams (DHBs) having zero on axis intensity in space surrounded by light have attracted much interest in the past decade owing to their potential applications in atomic optics [1], free-space optical (FSO) communication [2, 3] and biological sciences [4]. Various techniques have been proposed to generate hollow beams [5–7], and different kinds of hollow beams have been studied so far [3, 8–10]. It has been shown that the coherent light is sensitive to phase distortions and other optical aberrations [11, 12]. In order to improve the quality of DHBs, partially coherent dark hollow beams (PCDHBs) have been introduced [6, 8]. These beams are less sensitive to speckles and less robust than coherent beams. In the last few years, a lot of attention has been paid to the study of PCDHBs because of their aforesaid advantages over completely coherent beams. Paraxial propagation properties of such beams have been studied in detail. It has been shown

that the PCDHBs are less sensitive to phase distortion and are less affected by atmospheric turbulence [13, 14]. Thus, these beams might find potential applications in FSO communications.

Most of the previous experimental studies were devoted to monochromatic DHBs. Limited experimental work on polychromatic DHB have been reported so far. A few year ago, the first experimental study of polychromatic PCDHB was reported [2], and it was demonstrated that spectral anomalies in such types of beams might be exploited for FSO communications. Subsequently, the polychromatic PCDHB was generated by coupling a polychromatic beam emitted from a light-emitting diode into a multimode fibre [15].

In this paper, we report the results of our recent experimental work carried out to study coherence and source polarization effects on PCDHBs. The experimental results show that as we change the spatial coherence of the input beam, the size of the dark region of the resultant PCDHB

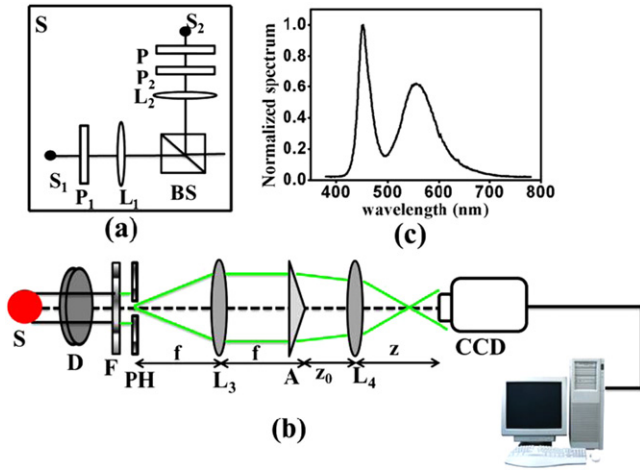


Figure 1. Schematic diagram of the experimental setup.

changes. Further, we get a tunable dark region for different values of the source polarization. Therefore, this study provides a flexible method for obtaining PCDHB with an adjustable and tunable dark region. Moreover, the observations show that the beam quality of the produced beam might be maintained by controlling the spatial coherence length of the partially coherent light.

2. Experimental setup

Figure 1 shows the experimental setup used to study the effect of source polarization and spatial coherence of the input beam on the polychromatic PCDHBs. The beams were produced using a well known axicon-lens system [7]. The inset (figure 1(a)) illustrates the arrangement to vary the degree of polarization (DOP) of the beam incident on an axicon. S_1 and S_2 were white light LED sources (operated by a stabilized power supply) having almost the same spectral profiles. Light coming from S_1 and S_2 were made v-polarized and h-polarized by using polarizers P_1 and P_2 , respectively. Lenses L_1 and L_2 were used to collimate light coming from the polarizers P_1 and P_2 . The collimated light further combines at the beam splitter (BS). This source arrangement part (figure 1(a)) was marked as S in figure 1(b). Light coming from the BS was passed through a diffuser (D) to get uniform intensity of the light incident on the pinhole. To get a Gaussian profile of the beam, a broadband filter (F) with a peak wavelength at 560 nm was introduced before a pinhole (PH). This way, a spatially incoherent, polychromatic source of uniform brightness and a Gaussian spectral profile was produced by illuminating a PH. The diameter of the PH was 0.5 mm, and it was placed at the front focal plane of the lens L_3 . At the back focal plane of the lens L_3 we got the partially coherent light [16] that impinged on an axicon A (made of BK7 glass). As a result, Bessel beams were generated [17] that were further focused by a positive lens L_4 of focal length $f_2 = 120$ mm. This way, polychromatic PCDHBs were generated for $z_0 < f_2$, [7] where z_0 is the distance between axicon and lens L_4 . In this experiment, the distance between axicon and lens L_4 was

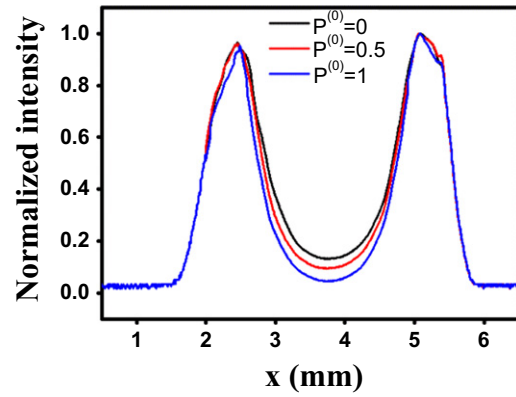


Figure 2. Variation in normalized intensity distributions of Polychromatic PCDHBs as function of x at $z = 150$ mm for different DOP of the source.

adjusted ($z_0 = 100$ mm) to get a clear far field intensity distribution of the ring shaped beams. The transverse spatial distribution of the light intensity for different propagation distances (z) (the distance between lens L_4 and CCD) was recorded by a computerized CCD camera (MicroPublisher 5.0 RTV, $3.4 \mu\text{m} \times 3.4 \mu\text{m}$ pixel size). Figure 2(c) is the spectrum of the white light (polychromatic) LED source.

3. Results and discussion

The DOP of the beam incident on the axicon lens was varied by putting a linear polarizer in front of the source S_2 (figure 1(a)) [18]. In these observations, the spatial coherence length of the beam incident on the axicon-lens was $L = 0.0342$ mm. Figure 2 depicts the normalized intensity distributions of the polychromatic PCDHBs as a function of x (radial direction) at $z = 150$ mm for different values of DOP, i.e., $P^{(0)}$. Figure 2 illustrates that maximum dip between two peaks of the intensity is obtained for completely polarized light, i.e., $P^{(0)} \approx 1$. The dip between two peaks of the intensity profile decreases as the DOP of the input beam decreases (or light becomes partially polarized). It is also observed that the width of the valley shrinks marginally as the DOP decreases, which confirms the theoretical prediction made in [19].

To study the coherence effects, the arrangement at the source was slightly changed. The experimental setup, as shown in figure 1(b), was used to study the effect of spatial coherence variation on the polychromatic PCDHB. For convenience; the DOP of the source was set at $P^{(0)} \approx 1$. It has been shown that to get $P^{(0)} \approx 1$, light coming from either source (S_1 or S_2) should be zero [18]. Intensity of the beam coming from the polarizer P_2 is nearly zero when the polarizer P and P_2 are orthogonal. Now S was working as an incoherent light source. Light was made partially coherent at the back focal plane of the lens L_3 by putting the source S in the front focal plane of the lens L_3 [16]. The coherence length is estimated by the formula $L = \frac{3.832\lambda f}{2\pi d}$, [16] where λ is the peak

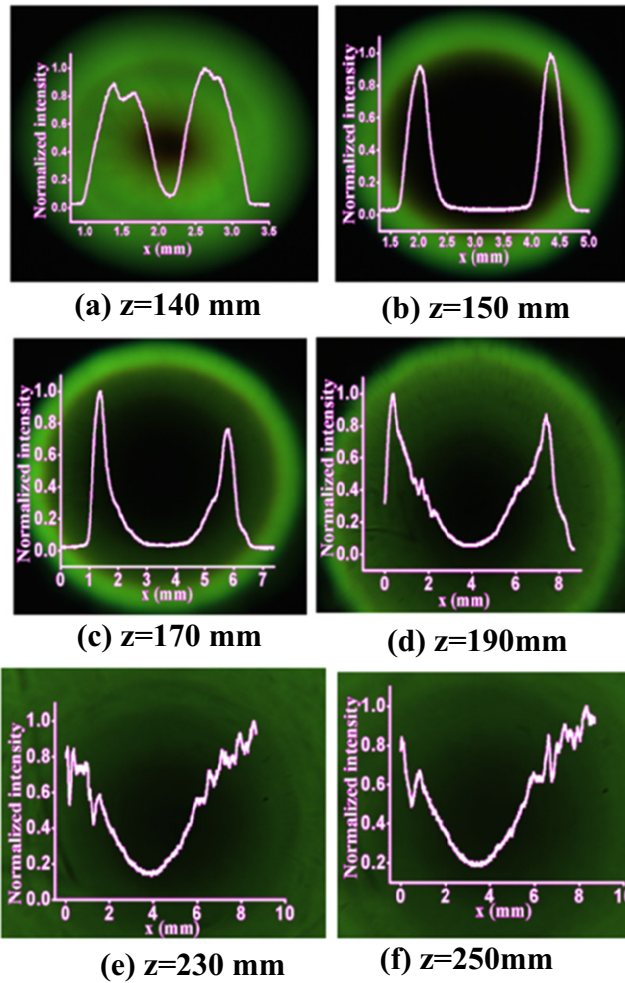


Figure 3. Experimental results of the radial intensity distribution of polychromatic PCDHBs with propagation distance and the corresponding intensity profile for spatial coherence length $L = 0.1025$ mm.

wavelength, f is the focal length of lens L_3 and d is the diameter of the pinhole. (The FWHM of the source spectrum is 75 nm (525 nm–600 nm). The value of L (for $f = 50$ mm) in the extreme values vary from 0.0321 mm to 0.0366 mm. These values are comparable to the value of L (0.0342 mm) calculated for the peak wavelength 560 nm. So the value of L at the peak wavelength vary $\pm 7\%$ of the extreme values). This indicates that coherence length is directly proportional to the focal length. We used lenses (L_3) of different focal lengths to change the spatial coherence in order to achieve adjustable dark focus of the PCDHBs.

Figure 3 illustrates our experimental results of the transverse intensity distribution with corresponding intensity line profile of the polychromatic PCDHBs produced at different propagation distances (z) for initial spatial coherence length $L = 0.1025$ mm. Figure 4 shows the results for the case of $L = 0.0342$ mm. The study indicates that the DHBs having a smooth beam profile are said to be high quality DHB [6]. When the distance between lens L_4 and CCD is less than 170 mm, we get a smooth beam profile of the PCDHBs for both the value of initial coherence lengths $L = 0.1025$ mm and

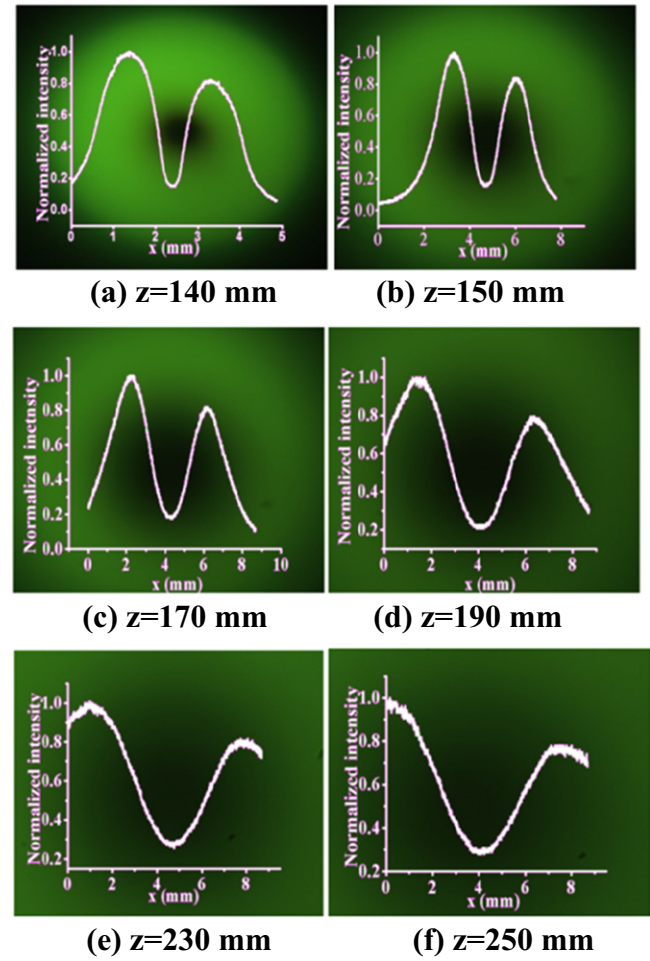


Figure 4. Experimental results of the radial intensity distribution of a polychromatic PCDHBs with propagation distance and the corresponding intensity profile for spatial coherence length $L = 0.0342$ mm.

$L = 0.0347$ mm, respectively. However, for $z = 175$ mm or $z > 175$ mm, smooth beam profiles are obtained for only those PCDHBs for which the value of initial coherence is low. In other words, as the propagation distance (z) increases, the beam with low spatial coherence might travel a longer distance without being distorted than the beams with high spatial coherence. In this way, the beam quality (or beam profile) would be maintained for a longer propagation distance. Smooth beam profile is the essence of low coherence as speckles in the generated hollow beam also decrease. Our results agree with that reported earlier [6, 8].

The effect of spatial coherence on the dark region of the generated polychromatic PCDHB for $P^{(0)} \approx 1$ is shown in figure 5. Figure 5(a) represents the intensity distribution of the PCDHB in the x - y plane for different spatial coherence length at $z = 150$ mm. Figure 5(b) depicts the corresponding normalized intensity line profiles. One can notice from figure 5 that the size of the dark region increases as the spatial coherence length of the input beam increases. The size of the dark region for coherence lengths 0.0683 mm, 0.1025 mm, 0.1367 mm and 0.1708 mm, respectively, were calculated to

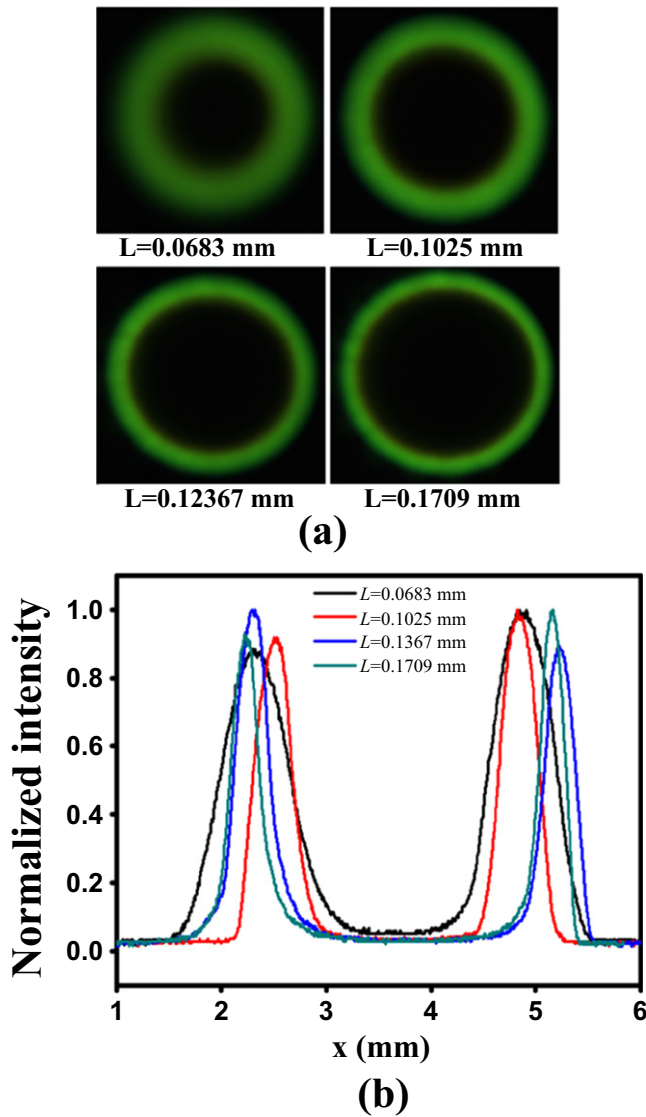


Figure 5. Intensity distribution of polychromatic PCDHBs at $z = 150$ mm for different spatial coherence length (b) Curves for normalized intensity distributions as a function of transverse distance x .

be 1.3151 mm, 1.6438 mm, 2.2117 mm and 2.72 mm. In this way, one may control the size of the dark region of the beams.

The visibility of PCDHB describes the spatial structure (formations of internal patterns) of the dark region of the polychromatic PCDHB. The values of visibility in the dark region of PCDHB were determined from the experimental data using the same procedure as described in [20]. The visibility of the dark region as a function of propagation distance z for different spatial coherence length is shown in figure 6. It was observed that the visibility first increases and attains a maximum value; subsequently, it starts decreasing with the propagation distance z . For low value of the spatial coherence length, the visibility drops to a particular value; and further, it maintained that value for long propagation distances. On the other hand, there was a sharp decrease in the visibility for large values of spatial coherence length. The

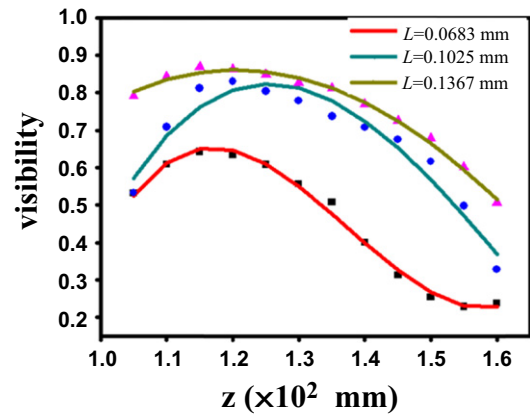


Figure 6. Experimentally measured visibility of the Polychromatic PCDHBs as a function of propagation distance (z) for different spatial coherence length.

decay in the visibility was due to the occurrence of speckles in the beam with high spatial coherence length.

4. Conclusion

In this experimental investigation, we observed that the beams with low spatial coherence travel a longer distance in free-space without being distorted. It is also noticed that the dark region of the polychromatic PCDHBs depends on the spatial coherence of the incident beam as well as on the source polarization. We illustrated these properties by showing intensity distributions and corresponding intensity profiles, which indicate the change in the dark region. We have shown that the height of the valley between two intensity peaks and the width of the valley increases as the DOP increases. Further, it is shown that the width of the dark region also get influenced by the spatial coherence. These kinds of hollow beams are less sensitive to speckles and show advantages over a completely spatially coherent hollow beam. Therefore, such types of beams might find potential applications in short range and indoor FSO communications.

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