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Polarization properties of linearly polarized parabolic scaling Bessel beams

Mengwen Guo, Daomu Zhao *

Department of Physics, Zhejiang University, Hangzhou 310027, China

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ABSTRACT

The intensity profiles for the dominant polarization, cross polarization, and longitudinal components of modified parabolic scaling Bessel beams with linear polarization are investigated theoretically. The transverse intensity distributions of the three electric components are intimately connected to the topological charge. In particular, the intensity patterns of the cross polarization and longitudinal components near the apodization plane reflect the sign of the topological charge.

1. Introduction

Diffraction free beams have been a subject of interest since the first generation of the Bessel beams reported by Durnin et al. in 1987 [1,2]. It is known that nondiffracting beams are exact solutions of the Helmholtz equation and have been reported in four coordinate systems, i.e., plane waves in Cartesian coordinate system, Bessel beams in circular cylindrical coordinate system [1,2], Mathieu beams in elliptic cylindrical coordinate system [3–5], and parabolic beams in parabolic cylindrical coordinate system [6]. Another important class of nondiffracting beams is the accelerating Airy beams [7–9] which can be regarded as exact solutions of the paraxial wave equation in translational shifted coordinate system. All these diffraction free beams share the property that under ideal conditions their transverse intensity distribution remains invariant during propagation in free space. Recently, the concept of nondiffracting beams was generalized to parabolic scaling beams (PSBs), and parabolic scaling Bessel beams (PSBBs) apodized by a Gaussian transmittance have been demonstrated theoretically and experimentally [10].

Laser beams are usually modeled within the framework of scalar and paraxial approximations, i.e., taking the electric field as a constant polarization vector (which can be complex) multiplied by a scalar function which agrees with the paraxial scalar wave equation. However, a scalar description fails to explain the polarization and focusing properties of laser beams correctly even for a linearly polarized beam. This is because that for a proper description of focusing, the longitudinal component must be considered and for a proper description of polarization, the cross polarization component must be considered [11]. In fact, a laser beam of finite transverse size must have three Cartesian components for consistency with Maxwell's equations [11–15]. The presence of cross polarization components for linearly polarized Hermite–Gauss and Laguerre–Gauss beams as well as Airy beams has been experimentally observed [11,15–19]. In addition, the polarization characteristics for cylindrically polarized Laguerre–Gauss and Bessel–Gauss beams have been investigated in detail [20].

In this paper, we investigate the evolution of the intensity profiles for the dominant polarization, cross polarization, and longitudinal components of linearly polarized PSBBs theoretically. We begin by deriving the analytic expressions for the three Cartesian components of the beams. We then present the numerical results for the evolution of their intensity distributions as the beams propagate away from the apodization plane. Finally, principal conclusions are made.

2. Theory

For a quasi-monochromatic beam of angular frequency ω and wavenumber $k = \omega/c$, propagating in the z direction in free space, the electric field of the beam has the form

* Corresponding author. Fax: +86 57187951328.
E-mail address: zhaodaomu@yahoo.com (D. Zhao).

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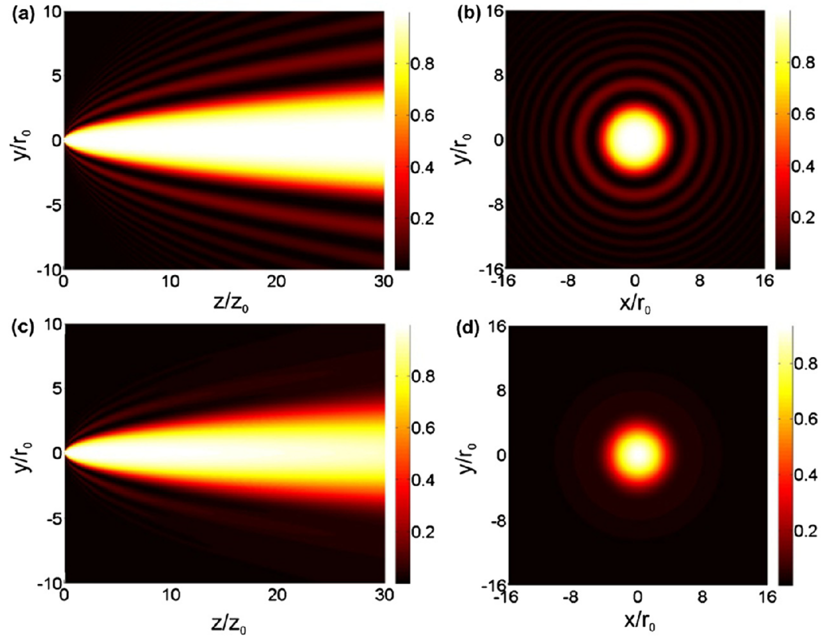

Fig. 1. (Color online.) Intensity profiles of (a)–(b) a diffraction-free PSBB and (c)–(d) a finite-energy PSBB with $m = 0$. (b) and (d) correspond to the transverse intensity profiles in the plane $z = 30z_0$. For convenience of exhibition, we neglect the $z^{-1/2}$ factor in Eqs. (7) and (9).

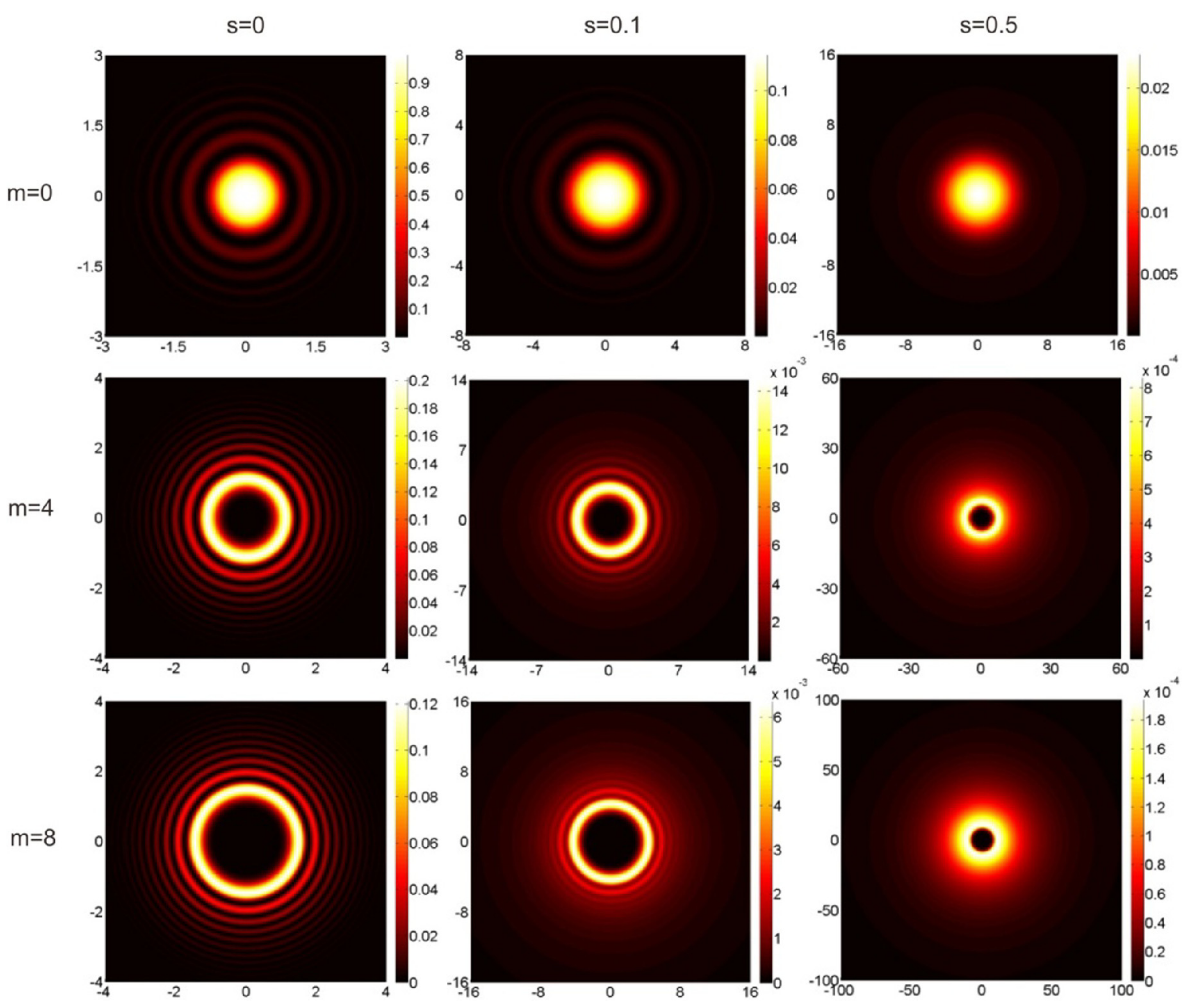

Fig. 2. (Color online.) Evolution of dominant polarization (x component) intensity profiles for a finite-energy PSBB with $m = 0, 4, 8$. For convenience, we omit the labels of the coordinates X and Y. The same treatment is made for Figs. 3–6.