Optik 158 (2018) 762–766

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Ellipticity of polarized ellipses in vector beams with orthogonal circularly polarized bases

Dong Ye[a], Xinyu Peng[a], Muchun Zhou[a,*], Yu Xin[a], Minmin Song[b]

[a] Department of Optical Engineering, School of Electronic and Optical Engineering, Nanjing University of Science and Technology, Nanjing 210094, China
[b] Shanghai Aerospace Control Technology Research Institute, Shanghai 200233, China

ARTICLE INFO

Article history:
Received 14 November 2017
Accepted 19 December 2017

Keywords:
Polarization
Optical vortices

ABSTRACT

Vector beams with spatially inhomogeneous polarization have been under researched for years, and a common analysis method is to decompose the vectorial field to two orthogonal circularly polarized components. While the former work concentrated on the azimuth variation of the polarized ellipses and had generated the relationship between the azimuths and the phase difference of the components, we analyzed the ellipticity and sense of the ellipses, which are related to the amplitude distributions of the components. This will play an important role in constructing the topological structures in reverse.

1. Introduction

Vector beams with spatially inhomogeneous polarization distributions have received significant interest in recent years. The most conspicuous one is cylindrical vector beams, with cylindrical symmetry in polarization, have been researched theoretically and experimentally due to their sharper focus and strong enhancement of longitudinal components [1–4]. And the beam has been found in applications such as nanoparticle manipulation [5–7], microscopy [8–9], plasmonic focusing [10], nonlinear optics [11], quantum optics [12], and optical communication [13–14]. In cylindrical vector beams, the ellipticity of the polarized ellipses are 0 (linearly polarized), and the azimuths of the ellipses vary helically.

Recently another vector beams containing all the polarization states on the surface of Poincaré sphere have been proposed, the so-called full Poincaré beams [15]. Some nondiffracting Poincaré beams are also raised, such as Bessel-Poincaré beams [16] and Mathieu-Poincaré beams [17]. The azimuths of the polarized ellipses in such beams also helically change, while the ellipticity of the ellipses is no longer always 0. It varies from 0 to 1, and the line of linearly polarized states is the boundary of opposite handedness. Hence in such beams containing polarization singularities, whose azimuth or handedness can't be defined [18–20].

When analyzing or experimentally generating vector beams, the common method is decomposing the field into two orthogonal components with linearly or circularly polarized bases [21–23]. In fact, the circular bases will be more convenient than the linear ones, which will be analyzed in next section, and this method has been applied in generating cylindrical vector beams and Poincaré beams. The former works concentrated on the azimuths variation of the polarization ellipses, which is related to the phase difference of the two components, and didn't discuss the ellipticity of the ellipses too much. In this

* Corresponding author.
E-mail address: zhoumuchun@njust.edu.cn (M. Zhou).

https://doi.org/10.1016/j.ijleo.2017.12.098
0030-4026/

article, we analyzed the relationship of the parameter with the two components, and used two examples to illustrate the role ellipticity played in constructing topological structures.

2. Theoretical analysis

When we want to calculate the polarization states of the vectorial field, we will need the help of Stokes parameter. But if we decompose the field with different bases, linear or circular, the expression of the Stokes parameters are also different. We assume the components with linearly polarized bases are expressed as

$$\begin{cases} E_x = A_x e^{i\delta_x}, \\ E_y = A_y e^{i\delta_y}. \end{cases} \tag{1}$$

Where the subscript x, y denote the direction of the components, A_x, A_y are the amplitudes of the components, and δ_x, δ_y are the corresponding phases. The Stokes parameters in this system is calculated as:

$$\begin{cases} S_0 = \left|E_x\right|^2 + \left|E_y\right|^2 = A_x^2 + A_y^2, \\ S_1 = \left|E_x\right|^2 - \left|E_y\right|^2 = A_x^2 - A_y^2, \\ S_2 = 2Re\left(E_x^* E_y\right) = 2A_x A_y \cos\left(\delta_y - \delta_x\right), \\ S_3 = 2Im\left(E_x^* E_y\right) = 2A_x A_y \sin\left(\delta_y - \delta_x\right). \end{cases} \tag{2}$$

Where Re(·) means taking the real part of the item, Im(·) means taking the imaginary part, and the superscript * denotes conjugate. With these items, we can calculate the azimuth angle ψ ($0 \le \psi < \pi$) and the angle χ ($-\pi/4 \le \chi \le \pi/4$) which specifies the ellipticity and the sense as:

$$\begin{cases} \tan 2\psi = \dfrac{S_2}{S_1} = \dfrac{2A_x A_y \cos\left(\delta_y - \delta_x\right)}{A_x^2 - A_y^2}, \\ \sin 2\chi = \dfrac{S_3}{S_0} = \dfrac{2A_x A_y \sin\left(\delta_y - \delta_x\right)}{A_x^2 + A_y^2}. \end{cases} \tag{3}$$

And the ellipticity e is defined as $\tan\chi$. With the linearly polarized bases, the parameters of the polarized ellipses are not presented intuitively. This can be solved by decomposing the vectorial field into components with circularly polarized bases. Similarly, we can define the components with circularly polarized bases:

$$\begin{cases} E_R = A_R e^{i\delta_R}, \\ E_L = A_L e^{i\delta_L}. \end{cases} \tag{4}$$

The subscript R and L denote right-handed and left-handed. And we should define the unit vector $\mathbf{e_R}$ and $\mathbf{e_L}$ in Cartesian coordinate as:

$$\begin{cases} \mathbf{e_R} = \dfrac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ \mathrm{i} \end{pmatrix}, \\ \mathbf{e_L} = \dfrac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ -\mathrm{i} \end{pmatrix}. \end{cases} \tag{5}$$

The Stokes parameters in this system can be calculated as:

$$\begin{cases} S_0 = \left|E_R\right|^2 + \left|E_L\right|^2 = A_R^2 + A_L^2, \\ S_1 = 2Re\left(E_R^* E_L\right) = 2A_R A_L \cos\left(\delta_L - \delta_R\right), \\ S_2 = 2Im\left(E_R^* E_L\right) = 2A_R A_L \sin\left(\delta_L - \delta_R\right), \\ S_3 = \left|E_R\right|^2 - \left|E_L\right|^2 = A_R^2 - A_L^2. \end{cases} \tag{6}$$

This time the angles ψ and χ are calculated as:

$$\tan 2\psi = \frac{S_2}{S_1} = \tan\left(\delta_L - \delta_R\right), \tag{7.a}$$