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Analysis of polarisation states at sharp focusing

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ABSTRACT

We investigate the inter-relation of the phase and polarisation singularities in systems with high numerical aperture. We consider sharp focusing by means of three types of systems: a micro-objective, a diffractive axicon and a micro-objective combined with an axicon-type multichannel diffractive optical element. The complex transmission function of the element is matched to optical vortices. We analyse numerical results of Gaussian laser beam focusing with various polarisations and phase distributions in detail.

1. Introduction

Signal processing often involves the expansion of the signal in some way to reduce the number of features. One of the remarkable methods is optical vortices carrying orbital angular momentum (OAM). It finds applications in diverse areas including fibre-optic communications, free-space optical communications and RF communications [1].

It is convenient to use multichannel optical systems [2–9] for simultaneous signal expansion into several basic functions. Telecommunications is a field of especially important application of multichannel optical systems. Owing to the stable volume increment of global traffic in telecommunications systems, interest in telecommunications systems with spatial division multiplexing (SDM) is increasing. The SDM technology in the optical fibre can be implemented using mode division multiplexing (MDM) [6]. However, when an MDM system is used, the problem of mode coupling should be solved [7]. One method of solving this problem is to use the "multiple-input, multiple-output" (MIMO) technology based on an electronic correction of inter-mode interference [7–9]. Polarisation multiplexing is also used [10–12]. The polarisation is exploited both in optical fibres and for antennas. Polarisation state affects the diffraction picture [13], so it can be used to analyse and detect the type of input beam [14,15].

Investigations of the mutual influence of the optical phase vortices and polarisation singularities, transformation one to another or enhancement of the angular momentum have a long history [16–28]. The vortex phase is used for the analysis of polarising properties of laser fields [29–31]. Overwhelmingly, visual observation of the interrelation of the vector (polarisation) and scalar (phase) optical vortices is possible only in a high numerical aperture mode, for example, at sharp focusing [30–34].

We have investigated the possibility of detecting the polarisation state of the focused incident beam using singular phase elements [35]. The complex transmission function of such elements can be described as a superposition of optical vortices. These elements can be realised by means of diffractive optics [36] and be used as additions to focusing systems [30–35]. Moreover, a singularity can be inserted in the structure of a focusing element [37].

Sharp focusing can be implemented by means of a micro-objective [38], a parabolic mirror [39,40], a diffractive lens [40–42] or an axicon [43–46]. It was suggested [40] that sharper focusing (comparing with a micro-objective) can be achieved using a parabolic mirror or a diffractive lens. For the parabolic mirror, this suggestion was confirmed experimentally [39]. For a diffractive lens, it was shown numerically [41,42]. In addition, an improvement of focusing properties of an aplanatic lens by addition of an axicon structures was shown [42,47].

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2. Theoretical models

2.1. Focusing by a micro-objective

To simulate an aplanatic focusing optical system, we can use the Debye approximation [48]:

Table 1
Gaussian laser beam Focusing by the micro-objective and the diffractive axicon with NA = 0.95 (picture size is 2λ × 2λ).