Arbitrary Vector Beam Generation with a Single SLM in Double-Pass Configuration

N. TOLEDO-GARCÍA,[1,2] C. AGAZZI,[1] A. CARNICER,[1] E. MARTÍN-BADOSA,[1,2] M. MONTES-USATEGUI,[1,2] D. MALUENDA,[1,2] AND J. TIANA-ALSINA[1,2,*]

[1] *Department de Física Aplicada, Facultat de Física, Universitat de Barcelona, Carrer de Martí i Franquès 1, 08028 Barcelona, Spain*

[2] *Institut de Nanociència i Nanotecnologia (IN2UB), Universitat de Barcelona, 08028 Barcelona, Spain*

[*] *jordi.tiana@ub.edu*

Abstract: We present a versatile methodology for the generation of three-dimensional vector beams using a single spatial light modulator (SLM) in a non-interferometric double-pass configuration, specifically designed to overcome the intrinsic polarization selectivity of conventional single-pass schemes. By sequentially modulating both orthogonal polarization components, our approach enables the creation of circularly polarized Laguerre–Gaussian LG_0^1 beams as well as vector beams with spatially varying polarization, including azimuthal polarized modes. We experimentally characterize their intensity profiles, polarization distributions, and robustness against optical aberrations under both low- and high-numerical-aperture conditions. While directly motivated by the requirements of depletion-based super-resolution microscopy techniques such as STED, RESOLFT, and subtraction microscopy, the proposed strategy provides a general and reconfigurable route to vector beam generation, with potential impact in other areas of photonics including optical trapping, quantum information, and high-capacity optical communications.

1. Introduction

The concept of vector beams emerged from a succession of experimental observations and theoretical insights accumulated over nearly two centuries. Their earliest manifestations appeared with conical diffraction in biaxial crystals, where light propagating along special crystal axes naturally formed hollow conical beams with azimuthally varying polarization, revealing the inherently vectorial nature of electromagnetic waves [1]. Later, systematic studies of light propagation in anisotropic media demonstrated that spatially varying birefringence could generate complex polarization patterns across a beam profile. The rise of singular optics [2] reframed these phenomena in terms of polarization singularities (i.e. points or lines where the polarization is undefined) leading to the classification of beams with structured polarization such as radial, azimuthal, and Poincaré beams [3], as well as their association with optical angular momentum (OAM) [4].

The discovery that Laguerre–Gaussian modes, whose helical phase increases uniformly with the azimuthal angle and forms a screw-like wavefront with a characteristic ring-shaped intensity distribution, carry a well-defined OAM per photon [4, 5] marked the modern starting point for structured-light research [6, 7]. Although a single Laguerre–Gaussian mode is a scalar field with uniform polarization, the coherent superposition of two orthogonally polarized LG_{01} modes with opposite topological charges (+1 and -1) produces a vector beam whose polarization varies azimuthally around the propagation axis—an azimuthally polarized beam [8]. Since then, the study of vector and vortex beams has become a central theme in modern optics [9–11]. A vortex beam is a coherent light field whose transverse phase structure contains one or more phase singularities, around which the phase winds by an integer multiple of 2π, corresponding to its topological charge or vortex strength.

Vector beams, in contrast to scalar beams with uniform polarization, exhibit spatially inho-