Review on the Formation of Laguerre Gaussian Modes

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Abstract: Laguerre Gaussian, or ring intensity modes, can be created or transformed from Hermite Gaussian modes using spiral phase plates, Mach-Zehnder interferometers, cylindrical lenses, or diffractive optics, for advanced optical imaging or lasing applications.

INTRODUCTION

Hermite Gaussian (HG) modes occur when light is modulated about the traditional cartesian coordinate system, creating various dots/blobs of intensity. In contrast, Laguerre Gaussian (LG) modes occur when light is modulated about the cylindrical coordinate system [1]. Its name comes from being utilized in Laguerre polynomial identities, that are often seen in quantum mechanics with Schrodinger's time independent wave equation for a harmonic oscillator potential [2, 3]. The LG polynomial takes the form of the radial term in the solution. Because of this azimuthal phase, LG modes are being further explored to see if they can result in additional orbital angular momentum. In quantum mechanics, with a potential wall scenario, its boundary conditions set the solutions as eigenfunctions that are circularly symmetric, resulting in LG modes. This then causes various discreet modes to occur, (indexed with integer multiples m, n, resulting in LG_{mn}) which look like various circular rings depending on the order of the mode. Research on how to create or convert various LG modes is being conducted.

METHODS

One approach to creating a LG_{01} mode is to use a Linac Coherent Light (LCLS) Gaussian mode and converting it to an LG mode using a spiral phase plate, causing a phase change of $\pi/2$ [1]. This mode can be determined by the superposition of traditional HG_{01} and HG_{10} modes, and then converted. This is done because of a screw phase dislocation on the axis, which causes destructive interference in the beams of light, and ultimately a ring-shaped intensity output. The usage of a spiral phase plate is a relatively new technology and has proven to be able to output high quality beams and far field intensity patterns that compare to theoretical models/simulations [4].

Before spiral phase plates were developed, Mach Zehnder interferometers were used to produce LG modes [3]. One of the main challenges with creating pure LG modes is that the azimuthal phase term can be either clockwise or counterclockwise. To surpass this, an extra cavity and mode converter of two cylindrical lenses can be used to transform an original HG mode [5]. This setup includes a Mach-Zehnder interferometer with the mode converter and lens input on one arm, and a beam expansion telescope in the other. The input lenses are used to form the second beams outside the interferometer so that the mode structure can sit side by side the beam waist. The beam expansion telescope utilizes two lenses to output a collimated beam. While this result may look like an HG mode, the large Rayleigh range for the mode acts as a phase reference for the LG modes. This ultimately means the LG mode is $\pi/2$ phase shifted [3].

Other ways LG modes have been created is through cylindrical lenses, diffractive optics, or computer holographic converters. In cylindrical lenses, the LG modes are converted from HG modes with varied focal lengths between the lenses, as seen in Figure 1. This method can produce pure LG modes [6]. In diffractive optics, photolithographic techniques are etched onto small scale structures of an optical element, and when a laser wave diffracts from these structures, arbitrary wave fronts or phase shifts can be created, allowing for an LG mode as well. In computer holographic converters, simulations are used to record the theoretical interference pattern between the electric field of the LG mode and the reference plane wave. Thus, there are various ways through both physical, experimental setups and computer simulations that can create LG modes [7].

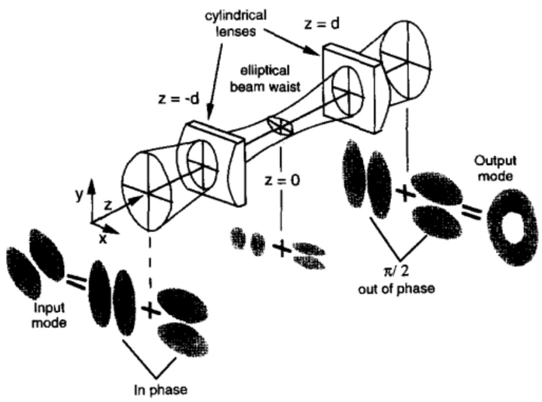

Fig. 1. Cylindrical Lens mode converter that can transform an HG_{10} mode at 45 degrees to an LG_{01} mode, resulting in a $\pi/2$ phase shift (Ref. [3], Fig 4).

CONCLUSIONS

The exploration of how to convert LG modes from HG modes takes place using spiral phase plates, or cylindrical lenses. In efforts to be able to produce a pure LG mode, computer holographic, diffractive optics, and Mach Zehnder interferometers have been used as well. LG modes are often used in applications of optical trapping and manipulation of particles, high resolution optical imaging and laser machining due to its ring-shaped intensity mode. In free electron lasers, it has been shown to greatly suppress microbunching instability in comparison to traditional Gaussian distributions [1]. Further examination and experimentation have been done to understand how effects of orbital angular momentum can impact LG modes. LG mode applications in solid state lasers, optical sorting, optical trapping, and resiliency to noise/turbulence is also underway. Continual research into how Laguerre Gaussian modes can be efficiently and accurately produced will greatly benefit more developments in higher efficiency optical lasers, optical filters, optical communication, high precision interferometry, quantum correlations and much more [4, 6, 7].

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