Generation of Twisted Photons in the mm Wavelength Region and Investigation of its Properties

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Introduction

- In 1992, L. Allen and his co-workers made the remarkable discovery that circularly polarized light, carries both a well-defined orbital angular momentum (OAM) and spin angular momentum (SAM).
- OAM of light arises as a consequence of field spatial distribution
- A light beam carrying orbital angular momentum has a characteristic helical structure and therefore, referred to as an 'Optical Vortex'.
- For the zeroth order of orbital angular momentum, the light beam is a plane wave, that is, the wavefront is a series of disconnected plane surfaces called as a Gaussian beam.
- To obtain higher orders of orbital angular momentum, means to generate a Laguerre-Gaussian beam. It is a beam of light which is twisted like a corkscrew about its axis of propagation

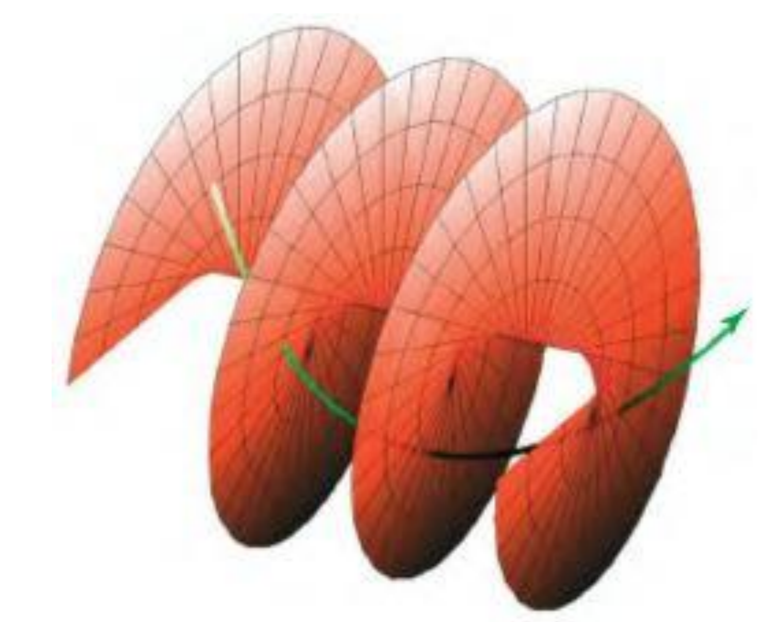

FIG 1. Schematic Diagram of a Laguerre-Gaussian Beam of the First Order [1]

Significance

- The unique feature of OAM is that it can be observed across a wide range on the electromagnetic spectrum, spanning across radio waves to X-rays.
- The most exciting aspect of photons that can carry OAM is that it enables it to trap and rotate colloid particles and even living cells, to act as a so-called 'optical spanner'.
- Orbital angular momentum of light has potential in various fields biophysics, micromechanics, communications, astrophysics, quantum information and several more [2].
- For instance, it provides an additional degree of freedom in communications. If information can be encoded in accordance with the orbital angular momentum of light, which theoretically has infinite number of probable states, it can transfer information at an extraordinary rate (about Tb/s).

Methodology

Several methods can be employed to generate OAM of light. The simplest method to generate OAM, is to use a spiral phase plate. A spiral phase plate has a constant radius but varies in thickness along its circumference. It converts the mode of the beam that transmits through it. It is made of a dielectric material like Teflon whose relative permittivity is 2.1. This allows it to impose a spiral phase shift on the beam passing through it. The specific geometry shown in figure (2) imprints the distinctive spiral staircase like structure of a Laguerre-Gaussian beam.

The spiral phase plate is built in such a way that the height between the thickest and the thinnest part of the phase plate is given by, $S = \left[\frac{l\lambda}{2\pi}\right]$

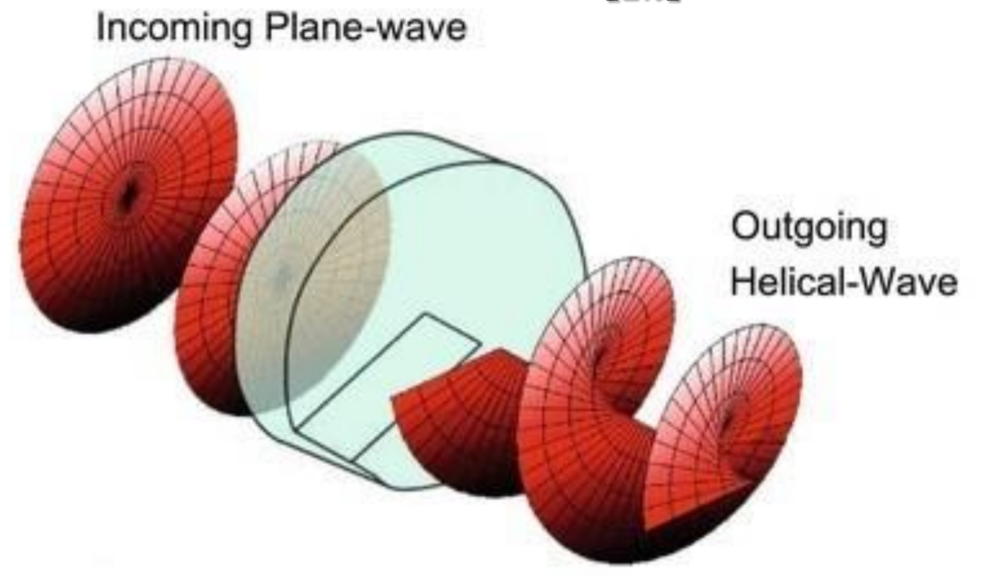

FIG 2. Artistic Representation of the Generation of OAM Using a Spiral Phase Plate [1]

Where, b is the thickness of the plate, l is the order of the Laguerre Gaussian Beam, is the wavelength of the light, n is the refractive index of the spiral phase plate (n = 1.41). The spiral phase plate delays the propagation of light differently at each point on the plate, thus causing a change in its phase. Different sizes of plates can be used to produce various orders of Laguerre Gaussian Beams.
To observe and investigate a Laguerre-Gaussian beam using an interferometer, it is superimposed with a Gaussian beam using Fourier-transform spectroscopy in a Michelson interferometer as shown in figure (3).

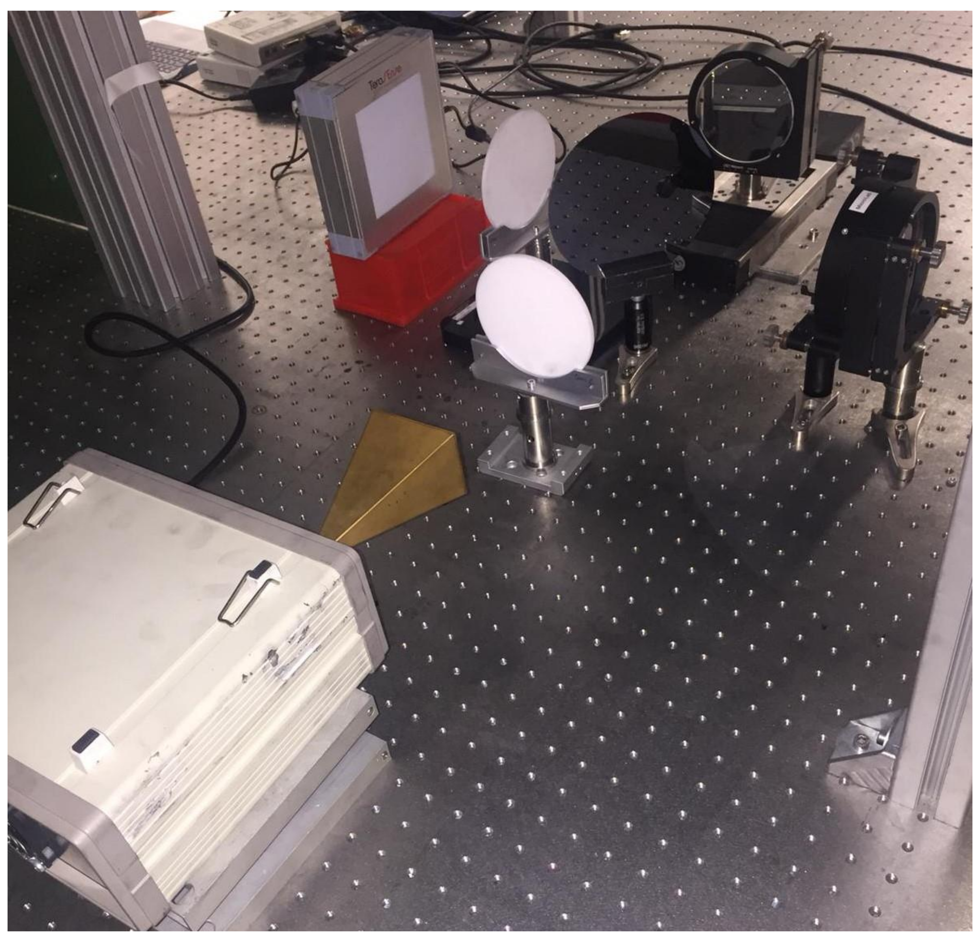

FIG 3. Experimental Setup – Michelson Interferometer

To produce a Laguerre-Gaussian beam of the first order (l=1), a spiral phase plate of radius 10 cm and thickness 10 cm was placed at close proximity in front of the stationary mirror 1 , which creates a phase shift in the Gaussian beam, the source was set to emit light with frequency 35.7 GHz and Attenuation at 0 dB. The notch on the translator was used to move the movable mirror 2, back and forth and therefore, used to change the path difference between the Gaussian and the Laguerre-Gaussian beams. This will allow the observer to see the rotational character of OAM.

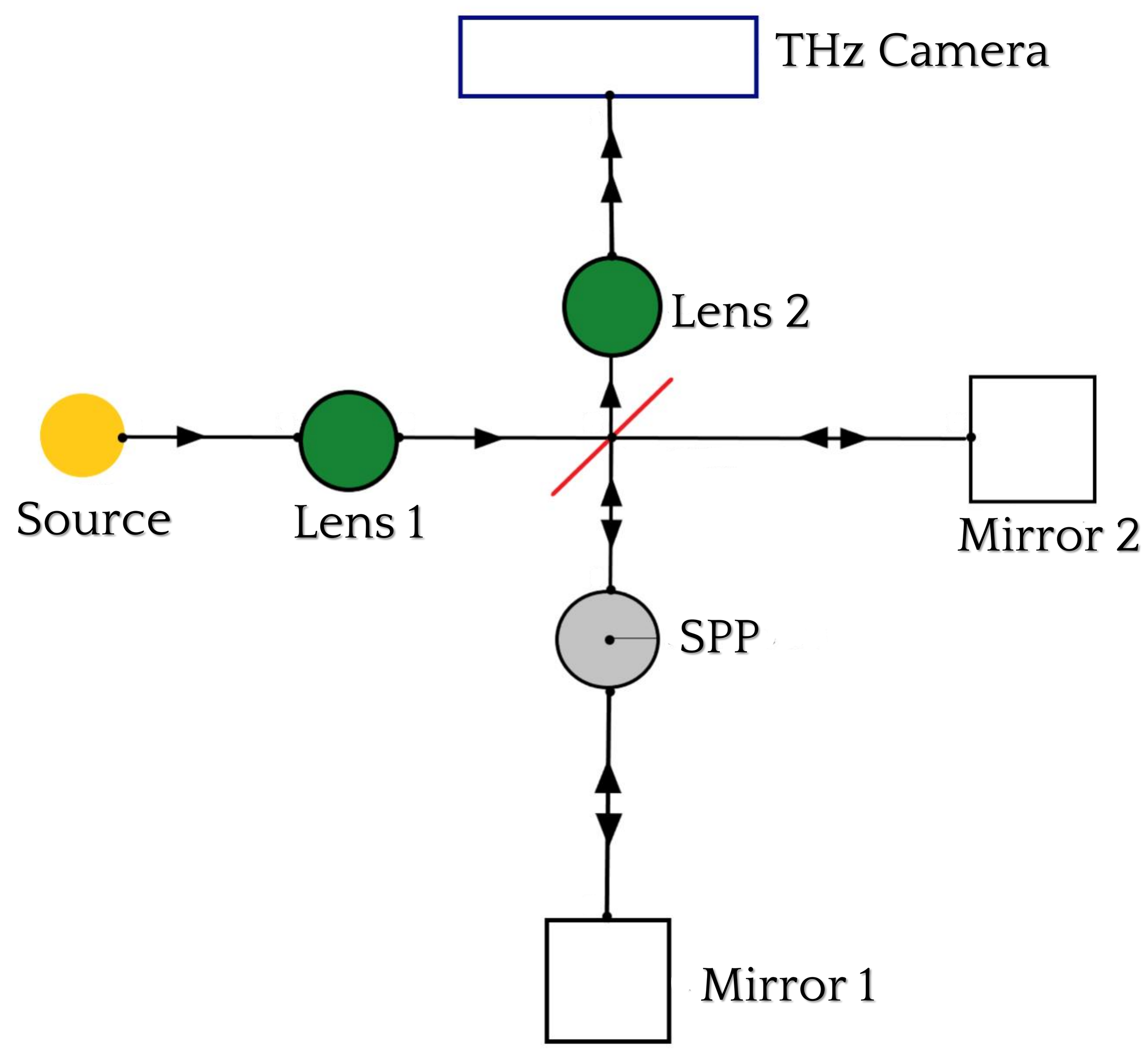

FIG 4. Schematic Diagram of the Experimental Setup

Results

The images are captured using a Terahertz imaging sensor whose sensitivity band range is approximately 50 – 700 GHz. The experimental images captured using the interferometer are compared to the images generated from the wave equations coded in a python environment.

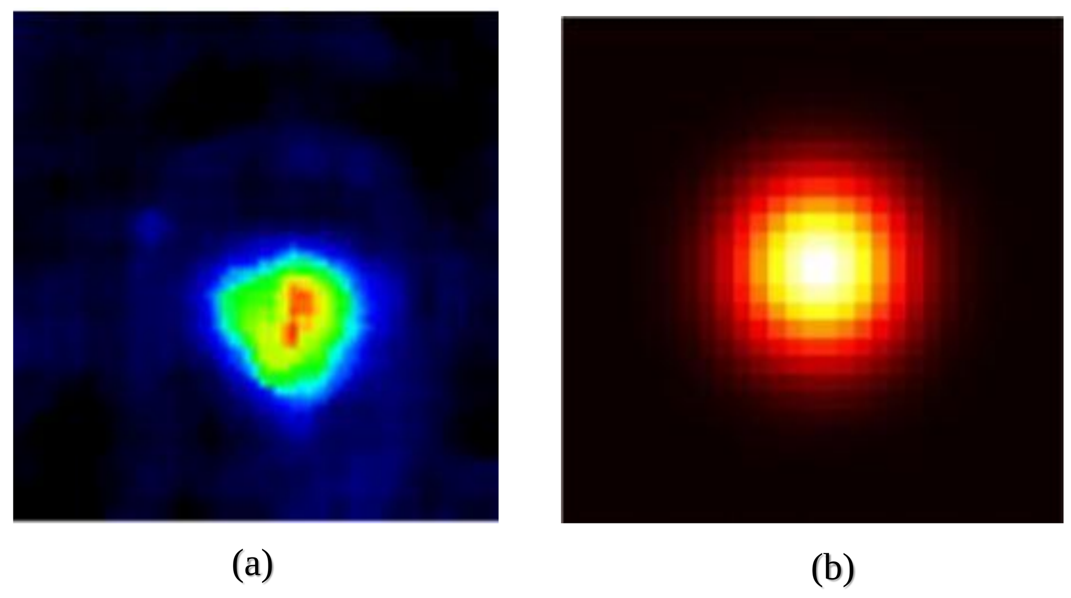

FIG 5. (a) Direct Image of a Gaussian Beam from Experimental Method (b) Direct Image of a Gaussian Beam Generated in a Python Environment

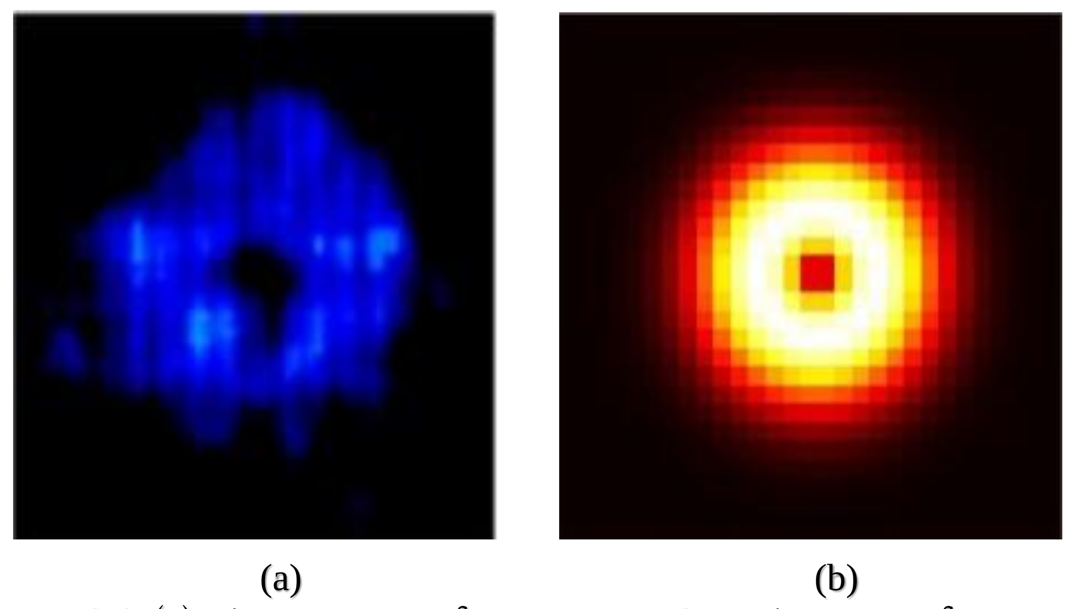

FIG 6. (a) Direct Image of a Laguerre-Gaussian Beam from Experimental Method (b) Direct Image of a Laguerre-Gaussian Beam Generated in a Python Environment

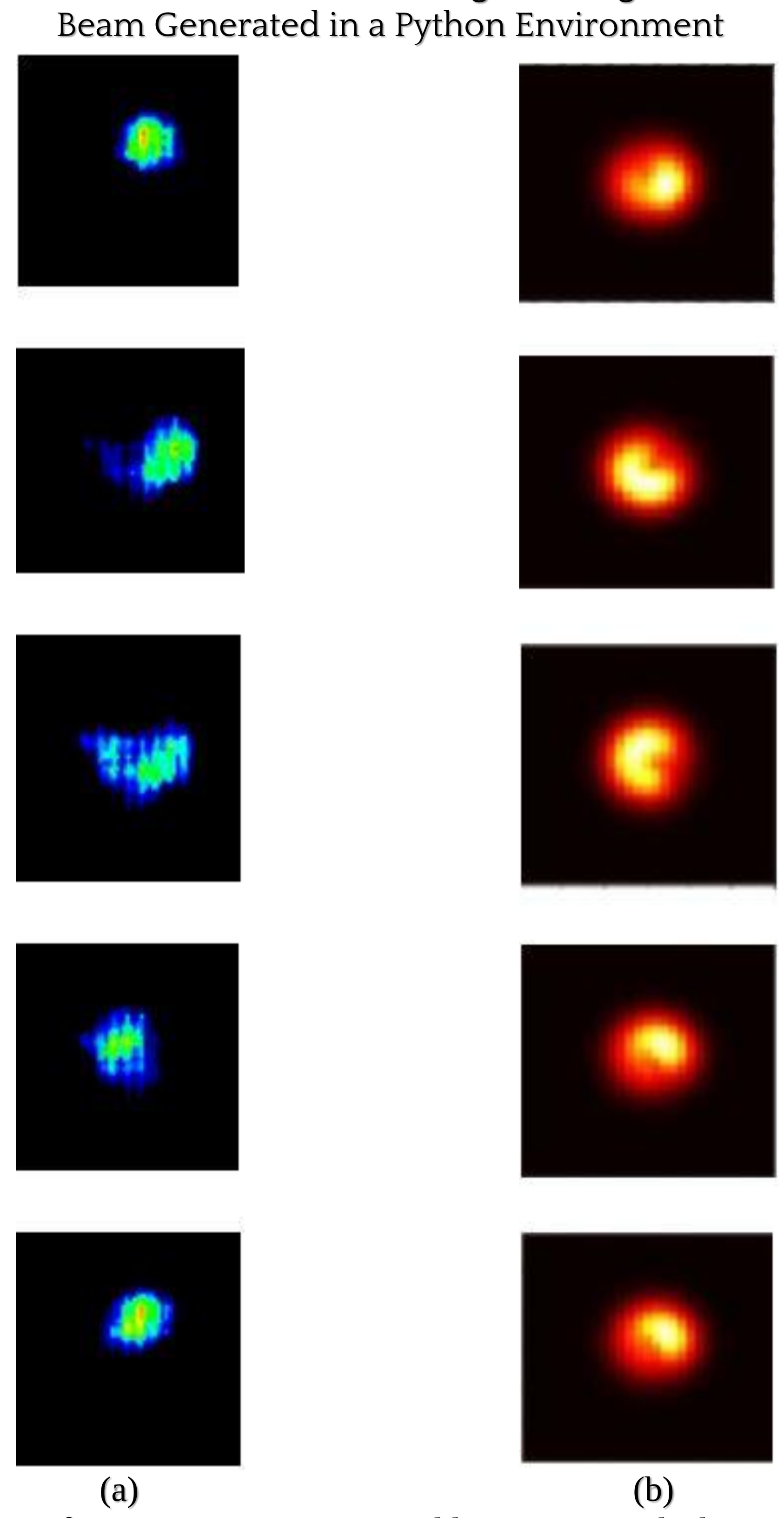

FIG 7. Interference Image Captured by Sequential Change of Path Difference Between the Gaussian and the Laguerre-Gaussian Beams in (A) a Python Environment (B) through Experimental Procedure

References

[1] Juan P. Torres and Lluis Torner. Twisted Photons: Applications of Light with Orbital Angular Momentum. 2011.
[2] Enrique J. Galvez. Gaussian beams in the optics course. Am. J. Phys., 74(4):355–361, 2006

Advisory

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