Simulation and Fabrication of a Spiral Phase Plate for Generation of Optical Vortices

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Introduction

An optical vortex is any radially-symmetric configuration of an electromagnetic field with an value of zero in the center, that carries orbital angular momentum. In this study, it is generated as a Gaussian beam is incident on a spiral phase plate (SPP), resulting in a linear phase gradient from 0 to 2π around the azimuthal coordinate of the beam; the output beam then has a helical wavefront, as it twists about its axis of propagation. The point of zero intensity at the center is created by the destructive interference of infinitely many phases coinciding at the center, known as a phase singularity.

This study explores the simulation of the intensity distribution of an optical vortex as it is generated by a SPP, for use in STED (Stimulated Emission-Depletion) Microscopy. In addition, the fabrication of a preliminary SPP is outlined, along with a comparison of its generated intensity distribution to the simulation.

Methods - Simulation

The simulation was computed in Matlab, by first defining the input Gaussian beam and the phase profile of a SPP. The thickness of the SPP was calculated as a function of the azimuthal coordinate, and the differences between the indices of refraction of the SPP and the surrounding medium. Finally, a fast Fourier transform (FFT) was computed on the combined Gaussian profile with the azimuthal phase term, to calculate the approximate far field intensity distribution of the beam.

Methods - Fabrication

Since smooth, continuous SPPs are difficult to fabricate, they are usually fabricated in layers; the higher the number of layers, the better it approximates the ideal phase plate. Transparent SPPs are usually fabricated from polymeric materials, and the one used in this study is AZ nLOF 2070

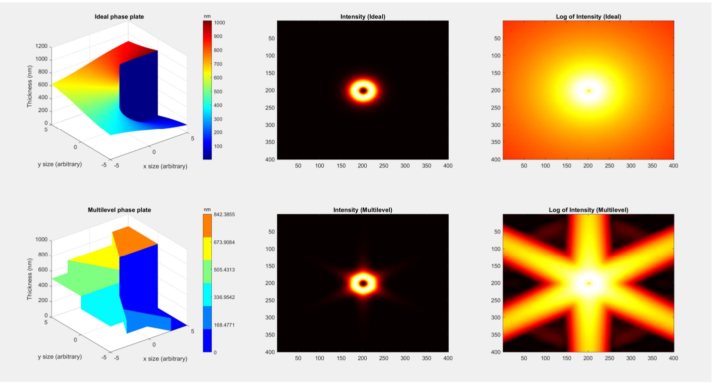

Figure 1: An example figure generated by the Matlab script, displaying 3D models of an ideal SPP (top left), a 6-level phase plate (bottom left), the intensity distribution generated (middle), and the log of the intensity distribution (right).

photoresist, with a refractive index of 1.626 for a wavelength of 632.8 nm. It was diluted in a ratio of 1:4 with AZ EBR Solvent to achieve film thicknesses on the order of 100-500 nm after spin coating. The photoresist solution was applied on a small glass substrate, and spin coated with parameters designed to achieve the calculated thicknesses. The coated substrate with then exposed with UV light from a micro-pattern generator, in a technique known as direct photolithography. The resulting two-step phase plate is shown in the next column.

Results and Conclusion

The optical vortex generated by this two-step phase plate is shown to the right, along with the simulated intensity distribution. As can bee seen from figure 5, the experimental intensity profile closely matches the expected parabolic distribution near the zero point, but deviates with increasing distance from that point, as long streaks originating from the center can be seen in figure 3 that do not decrease in intensity as quickly as predicted. The cause of this is still unknown, whether it is due to the optical setup or the fabrication, as this was just the beginning of experimentation with the fabrication process.

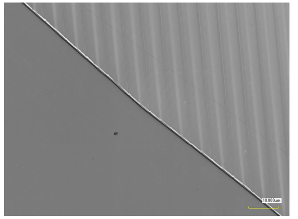

Figure 2: A view from a 150x microscope objective showing the edge of the phase plate. Note that the striations from the UV-laser scanning exposure are clearly visible.

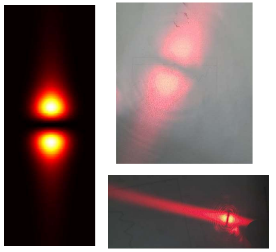

Figure 3: Simulated intensity distribution (left), experimental intensify distribution at a distance of 0.84 m to image plane (top right), and at a distance of 0.1 m (bottom right).

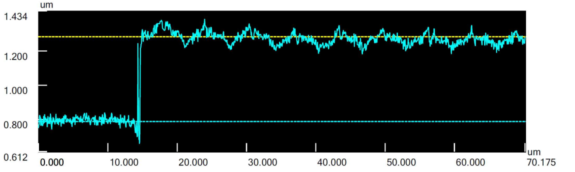

Figure 4: A cross section of the height profile from the substrate to the phase plate. The striations can be seen as a wave-like pattern, but the overall average height difference was measured to be approximately 500 nm.

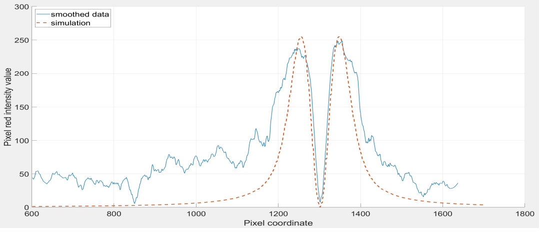

Figure 5: Cross-section of the simulated intensity profile superimposed on the experimental intensity profile