Designing and 3D Printing Customised Phase Plates based on Modified Gerchberg-Saxton Algorithm

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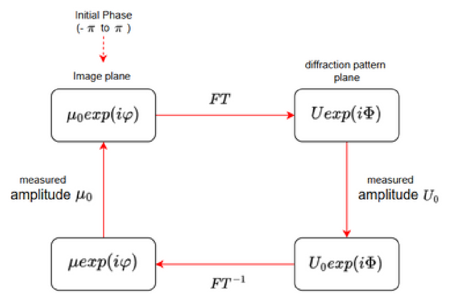
Abstract

This research presents a method for designing phase plates using the Gerchberg-Saxton algorithm, adapted with the Huygens principle to optimize terahertz wave modulation. The design process involved iterative simulations in Python to refine phase distributions, and the resulting phase plates were fabricated using polymer materials with commercial 3D printers, selected for their optical properties at terahertz frequencies. Simulations and experiments showed that the 3D-printed phase plates closely matched the desired wavefront transformation, validating the approach's adaptability and potential for practical optoelectronic applications, though further refinements are needed for perfection.

Research Method

To design and fabricate the phase plate, the Gerchberg-Saxton algorithm is used with some modifications. The GS algorithm may provide a robust method for designing phase plates. However, its common application in THz waves can be limited. Thus, the GS algorithm was modified to integrate the Huygens principle, ensuring the algorithm would handle the propagation characteristics of THz waves. The calculations are modified using the formulas below:



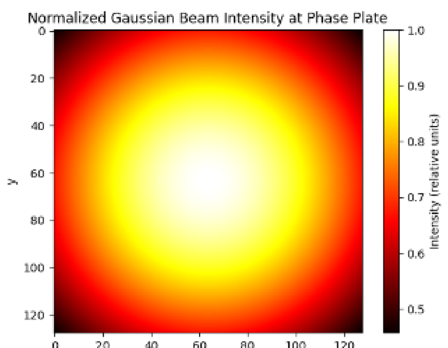
$$E^d_{(x,y)}(x',y') = \frac{A_{(x,y)}}{r_{(x,y),(x',y')}} exp[-ikr_{(x,y),(x',y')} + i\phi].$$

$$E^i_{(x',y')} \propto \sum_{(x,y)} E^d_{(x,y)}(x',y')(1+cos\Omega)$$

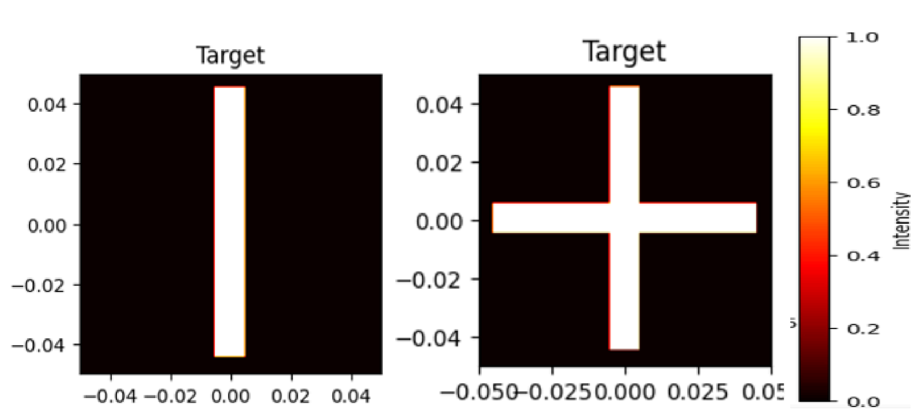
Each point (x, y) in the diffraction plane acts as a source of a spherical wave contributing to the electric field at (x', y') in the image plane, with the distance r(x,y)(x′,y′), wave number kk, amplitude A(x,y), and phase ϕ(x,y) determining the contribution. The total field is calculated by summing these contributions, including the term (1+cosΩ), where Ω is the angle between the optical axis and the line connecting (x, y) to (x', y').

$$E(x,y) \propto \frac{1}{2\pi\omega^2} exp[-\frac{x^2+y^2}{4\omega^2} + \frac{2i\pi}{\lambda}(\sqrt{l^2+x^2+y^2} - l)]$$

The above formulas are also used to represent an accurate initial beam input intensity. l is the distance between the output beam and the phase plate; it is set to *75 mm*. A beam width of *80 mm* and *200 GHz* was also set following the equipment spec in the lab.



In each simulation, 128 grid sizes are used to ensure the high quality and accuracy of the calculation and dimension of 100x100 mm for both the phase plate and the target image plane. The set distance between the diffraction plane and the image plane is set to 50 cm.



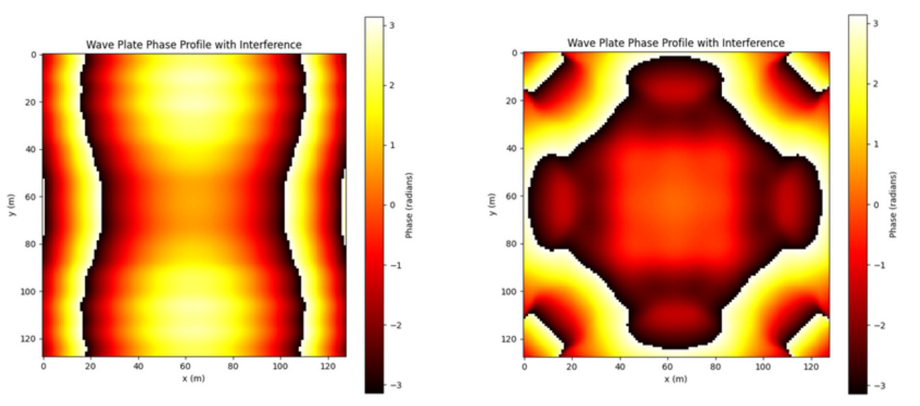
For simulation, the algorithm runs for 100 iterations for each target desired output intensity (the above image). After getting the phase profile, another formula is introduced to calculate the thickness of the phase plate.

$$z(x,y) = \frac{\phi(x,y)\lambda}{2\pi(n-1)}$$

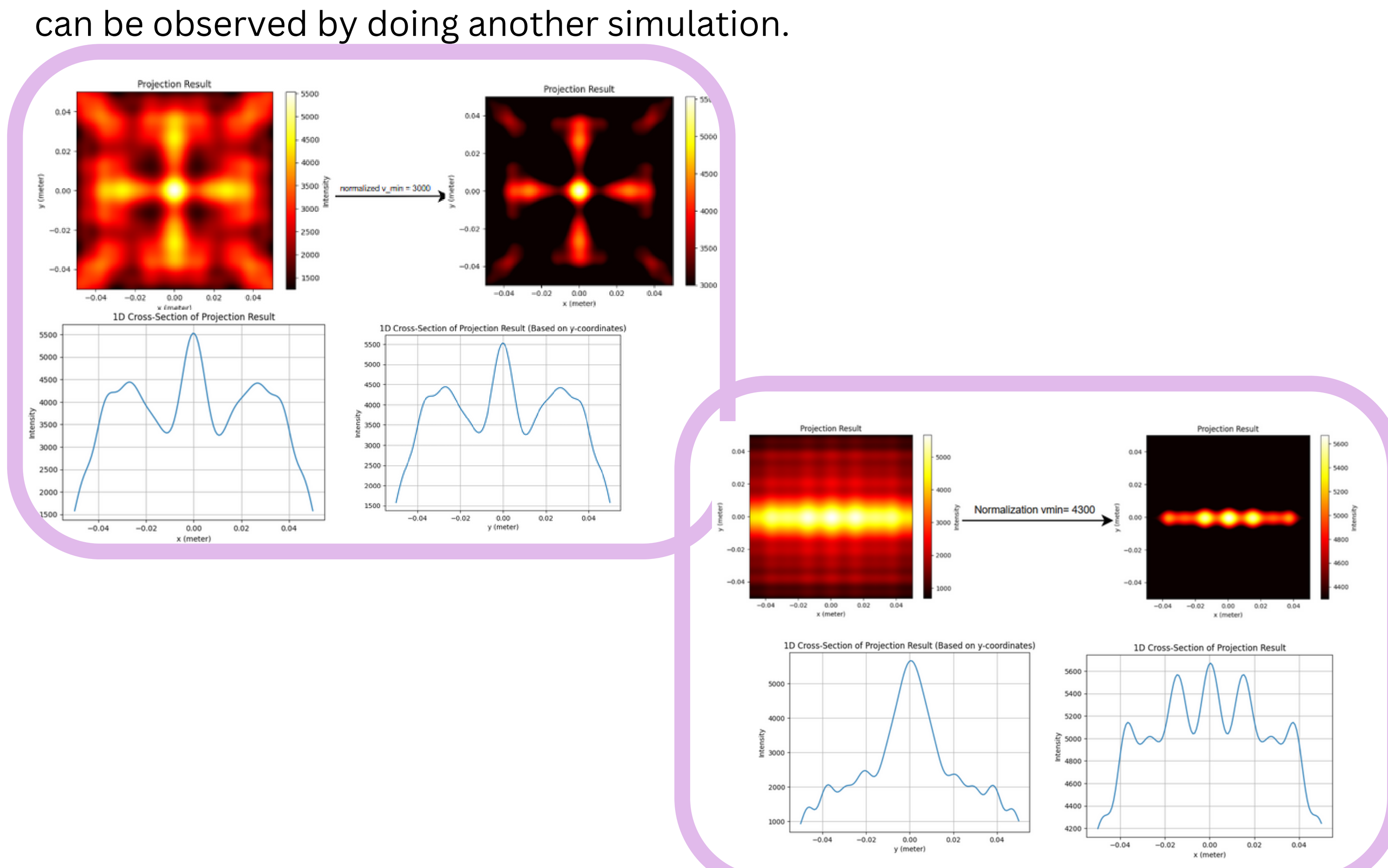
n is the refractive index of the polymer materials that are used for the fabrication; n = 1.7. After acquiring the thickness, then the phase plate can be fabricated.

Experimental Results

After running the algorithm, the phase profile for both target output intensity is acquired and the thickness to design the phaes plate can be calculated.

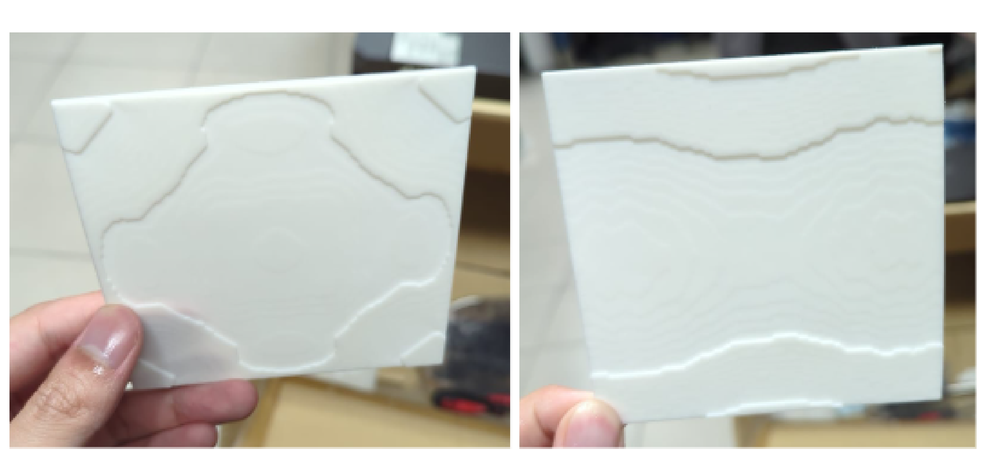


With the acquired phase profile and the thickness calculation, then the phase plate can be fabricated. Moreover, the accuracy of the generated phase plate can be observed by doing another simulation.



From the above results, both generated phases are able to generate an output intensity that is close to our initial target output intensity. Meaning that our algorithm is converging. However, some adjustment can still be made since the generated output intensity is still not perfect.

An obvious adjustment that can be made is that how to plot the image, from the generated output intensity of the vertical line, it failed to converge into a vertical line instead it is generating a horizontal line, giving a sign that there is some mistake on how to handle the image plotting.



Conclusion

This research successfully applies a modified Gerchberg-Saxton algorithm, integrated with the Huygens principle, to design phase plates for shaping terahertz (THz) wave beam profiles. Using computational simulation and 3D printing, the study achieved results closely matching target intensities in simulations, validating the algorithm's effectiveness under simulated conditions. However, some discrepancies, such as mismatched output patterns, highlight areas for improvement in plotting and parameter optimization. Based on the computational calculation, the methodology provides a robust framework for designing and fabricating THz optical components, demonstrating significant potential for advancing optoelectronic applications.

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