Fabricating Fresnel Zone Plate with Extended Depth of Focus Through $Ge_2Sb_2Te_5$ (GST) Photothermal Lithography

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Fresnel zone plates (FZPs) have always been considered a versatile alternative to conventional focusing lenses, particularly in two-dimensional planar optical circuits for micro- and nano-photonics.[1] They can function across a broad spectrum, from X-ray to infrared, making them good prototype for various lithography techniques and resolutions.

To fabricate FZPs, we employ photothermal lithography, a technique that utilizes optical power as a heat source to modify a photoresist. In our work, this method is used to directly pattern the opaque regions of the FZP onto a $Ge_2Sb_2Te_5$ (GST) thin film, a phase-change material (PCM) known for its robustness and non-photosensitivity. Since PCMs undergo a phase transition when exposed to thermal stimuli, we utilize the optical power from a 532 nm laser source to heat the GST above its phase transition temperature (175 °C), thereby forming the desired FZP structure.

In this work, we introduce a novel approach by segmenting the FZP into multiple sub-areas with varying focal lengths, allowing precise control over their arrangement and focal properties. This method effectively extends the depth of focus (DOF) of FZPs, making them promising components for optical systems that require a large DOF, such as those used in laser ablation, microscopy, and machine vision.[2]

As shown in Figure 1, the designed FZP has a radius of 39.78 μm and consists of 31 concentric rings with focal lengths starting at f = 32 μm, increasing incrementally by 0.2f per ring. For a wavelength of λ = 532 nm, the resulting focal length reaches f = 103 μm, while the DOF is extended to 16 μm, significantly larger than the 4 μm DOF of a conventional FZP with the same parameters.

The direct laser writing (DLW) optical setup and the fabrication process are illustrated in Figure 2. A computer-driven algorithm generates the laser writing pattern, followed by a wet etching process, which selectively removes the un-patterned amorphous GST, leaving behind the crystallized GST that constitutes the final FZP. To evaluate the effectiveness of the fabricated FZPs, we develop an optical verification system to ensure that the designed structures meet their intended performance.

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[1] Geints, Yu E., et al. "Study of focusing parameters of wavelength-scale binary phase Fresnel zone plate." *Journal of Optics* 23.6 (2021): 065101.

[2] Trung, Hieu Tran Doan, et al. "Design and fabrication of a Fresnel zone plate with an enhanced depth of focus." *Applied Optics* 63.24 (2024): 6384-6392.

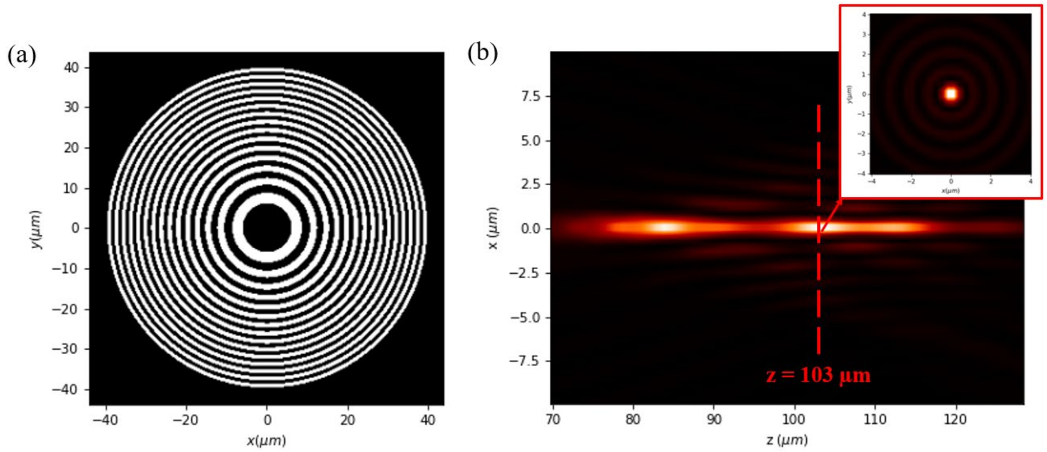

Figure 1: (a) The designed FZP with an extended DOF for λ = 532 nm. (b) The intensity distribution at the *xz* plane at y = 0. Inserted: the intensity distribution at the *xy* plane at z = 103 μm.

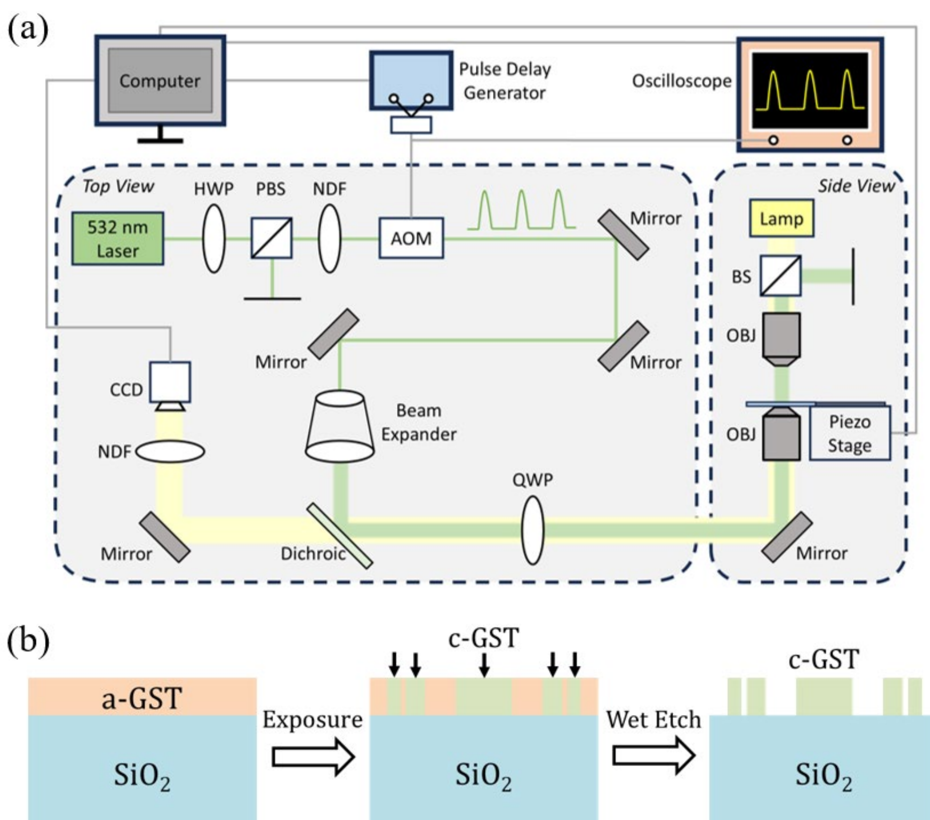

Figure 2: (a) Schematic of the DLW system based on GST photothermal lithography. (b) Schematic of the FZP fabrication process.