Multi-Level Diffractive Lens (MDL) for extended-depth-of-focus over 50 mm fabricated by Grayscale Lithography

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Multi-level diffractive lenses (MDLs) have shown themselves to be useful tools in extended-depth-of-focus (EDOF) applications. MDLs are particularly sought because they are lighter-weight and thinner than conventional optics [1][2]. This project used an optimization-based inverse MDL design – with an EDOF of 50 mm, fabricated the design using grayscale lithography, and experimentally characterized the MDL.

During grayscale lithography, a photoresist coated wafer has a design written onto it by a pattern generator and is developed in a chemical bath to expose the three-dimensional structure. A glass wafer coated in positive photoresist (identical to the final MDL wafer) was fabricated to test the different grayscale values of the pattern generator. This information was used to determine the power setting of the generator and adjust the grayscale values to better match the desired heights of the MDL. The design consisted of 215 concentric rings of different heights (with a maximum of 1.7169 µm) and feature sizes of 7 µm, as shown in Fig. 1 (a) – (c).

Once fabricated, the MDL's outermost seventeen ring heights were measured with a confocal microscope and compared to expected height values to confirm the accuracy of the fabrication. The difference between expected and measured MDL ring heights was largely within 0.03 µm as shown in Fig. 1 (d) and (e). Its performance was experimentally characterized by illuminating the MDL with a 1064 nm, supercontinuum, collimated laser (shown in Fig. 2 (a)) and measuring the point-spread function (PSF) every 0.2 mm between 190 mm and 260 mm away from the MDL. The resulting normalized PSFs, shown in Fig. 2 (b) and (c), demonstrated an EDOF of 58.8 mm, which was longer than the expected 50 mm. The average efficiency of the lens was measured by finding the power through a 1 mm aperture in the focal region divided by the power through a 3 mm aperture approximately 38 mm away from the MDL. The resulting efficiency was 78.86%.

[1] Banerji, S. *et al.* (2020) "Extreme-depth-of-focus imaging with a flat lens," *Optica*, 7(3), pp. 214–217.
[2] Wang, P., Mohammad, N. and Menon, R. (2016) "Chromatic-aberration-corrected diffractive lenses for ultra-broadband focusing," *Scientific Reports*, 6(1).

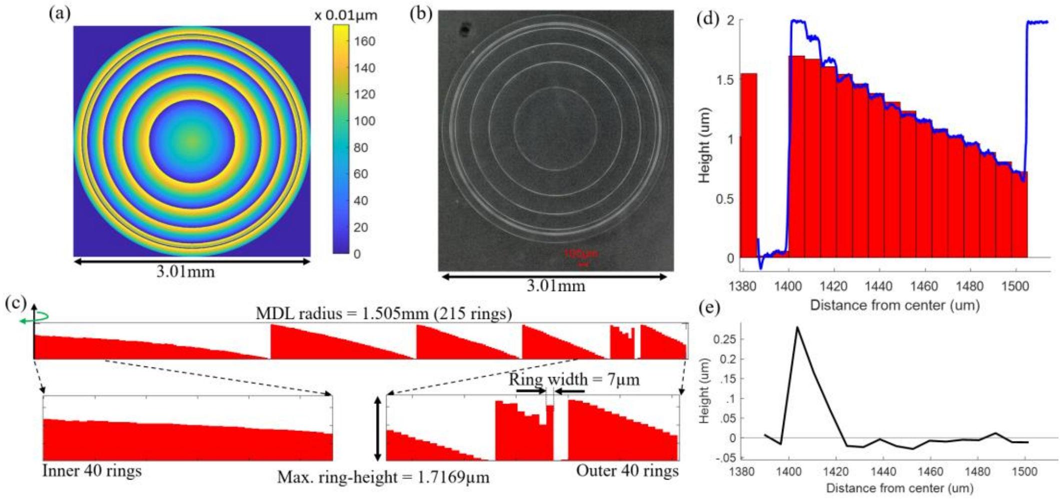

Figure 1: (a) Geometry of MDL with EDOF of 50 mm where the color scale represents ring height. *(b)* Image of a fabricated copy of the MDL designed for 50 mm EDOF. *(c)* Cross-section of MDL radius, including zoomed in portions of the inner and outer 40 rings. *(d)* Actual height profile of the 17 outermost rings of the MDL (blue) compared to the ideal design heights (red). *(e)* Graph of the difference between the measured and ideal height profiles. Note that everywhere except 1400 µm through 1420 µm has a difference of less than 0.03 µm.

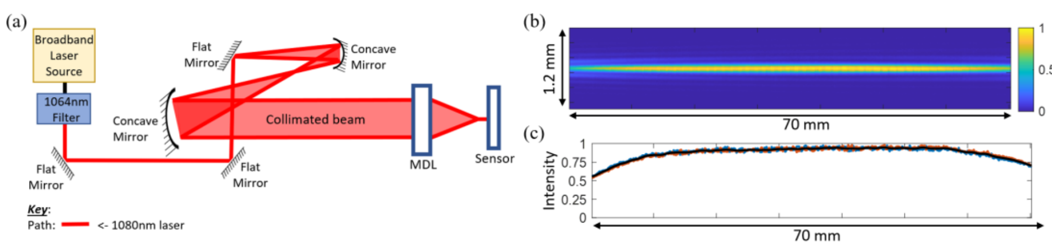

Figure 2: (a) Experimental setup, including laser source and beam collimation. *(b)* Combined PSF data, taken every 0.2mm from 190 mm to 260 mm from the MDL (a total distance of 70 mm), where the color scale is the normalized intensity of the beam. *(c)* Graph of the maximum intensity of the beam from 190 mm to 260 mm away from the MDL.