All-glass, 100 mm Diameter Metalens Operating in the Visible Wavelength

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One of the key challenges in remote sensing, low-light imaging, and high-power laser applications is creating precision large-aperture optics. A larger aperture enables better photon collection, resulting in improved signal-to-noise ratios at the imaging plane when used for imaging applications.[1] Additionally, a larger aperture provides room for reducing the energy density incident on the optic to minimize damage caused by high-power sources. However, creating a large optic with low wavefront error using conventional machining and polishing methods used in lens manufacturing poses a significant engineering challenge, which in turn leads to lower manufacturing yields and higher costs.

Metasurface optics, which allows wavefront shaping by placing designed sub-wavelength scale structures that impart phase or polarization shift, has been shown to be able to create various optical functionalities with low-wavefront error.[2] Majority of the metasurfaces in the previous studies were experimentally demonstrated using electron-beam lithography followed by CMOS technology compatible processes, demonstrating the potential of mass-manufacturing the optical devices at existing semiconductor foundries.[3] We have shown through our previous work [4] that the metasurfaces can be mass-produced for the impact at scale outside the laboratory, by demonstrating all-glass, diffraction-limited focusing, 1 cm diameter metalens operating in the visible wavelength using conventional deep-ultraviolet (DUV) projection lithography. Other studies have shown that nano-imprint lithography (NIL), and roll-to-roll (R2R) processing are also viable candidates for impacting the consumer market.[5] However, when attempting to produce a large-diameter metalens using these processes, one is faced with a size limitation imposed by the manufacturing tool. This is due to the fact that a typical production-level lithography tool has a maximum exposure area limit of 22 mm x 32 mm, which restricts the maximum size of the metasurface optics that can be created with a single photomask.

In this presentation, we showcase the experimental demonstration of a monolithic, hyperbolic phase profile, 100 mm diameter metalens (NA=0.32, f/1.5) designed for collimated incidence, operating in the visible wavelength (λ=632.8 nm). The metalens is designed to consist of approximately 18.7 billion 1.5 μm tall fused silica nanopillars. In order to comply with the DUV lithography tool limits, we divide the metalens into 25 sections of 20 mm x 20 mm areas. By utilizing rotational symmetry, we manufacture the entire metalens using only 7 photomasks, which helps to reduce costs. We evaluate the imaging performance of the metalens by measuring various parameters such as point-spread-function, Strehl ratio, modulation transfer function (MTF), full-lens interferogram, and focusing efficiency. We showcase the low-light imaging performance of the metalens by capturing images of celestial objects such as the Sun (sunspots), the Moon, and stars (North America Nebula). Additionally, we analyze the impact of different fabrication errors on the imaging quality, providing insights into the factors contributing to the degradation of lens performance. We also present experimental results on the optical performance of the glass metalens against thermal stress, indicating its feasibility for use in space applications or high-intensity laser collimations.

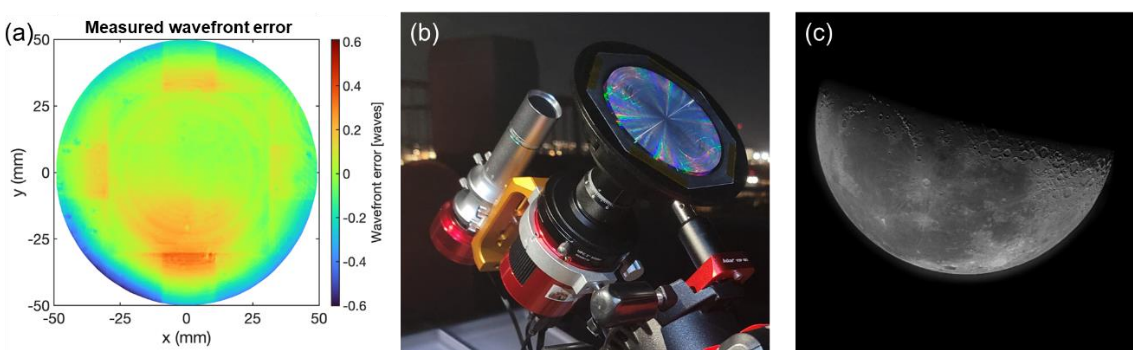

Fig. 1 (a) Measured wavefront error of the 100 mm diameter metalens. (b) Astro-imaging apparatus using the 100 mm metalens as the sole imaging optic. (c) Image of the Moon taken with the metalens astro-imager shown in (b).

References

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