Fabricating All-Glass, 1 cm Diameter Metalens Working at Visible Wavelength

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Primary CNF Tools Used: Heidelberg DWL2000, Hamatech mask chrome etch 1, ASML 300C DUV stepper, Gamma automatic coat-develop tool, CVC sputter, CHA Mark 50 e-beam evaporator, Trion Minilock III ICP etcher, Oxford 81, Oxford 82, Oxford 100, P10 profilometer, Zeiss Ultra SEM

Abstract:

Single-material, centimeter-scale metalens working in the visible wavelength is demonstrated in mass-manufacturing style. Using DUV stepper lithography, we show wafer-scale fabrication of a flat optical elements capable of diffraction-limited focusing at visible wavelength.

Summary of Research:

With the market growth of virtual reality (VR), augmented reality (AR), or mixed reality (MR) devices, aerial drone cameras, and on-board cameras for orbital satellites, the importance of payload for optical devices is evermore increasing. However, as such applications need large-aperture optics to meet its physical demands such as the size of the human eye's pupil, or to obtain better imaging in low-light conditions by increasing the amount of collected light. For conventional refractive optics, aperture size and the weight were in trade-off relations: The larger the aperture, the heavier the lens become at an undesirable rate. In addition, due to the nature of refractive optics where the optics relied on the refractive index of the lens material and its curvature at the material boundary, they were subject to spherical aberration (Figure 1). Such aberration was dealt with using expensive methods such as creating aspheric surfaces, cascading multiple lenses, choosing high-refractive materials, or using size-limiting variables such as using aplanatic point.

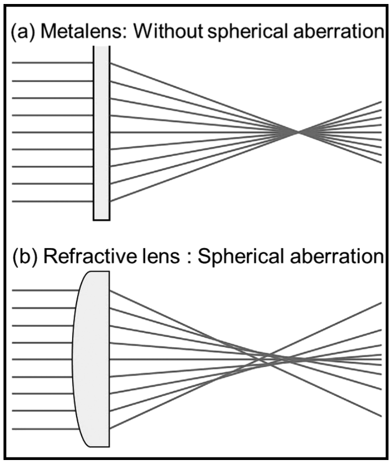

Figure 1: Effect of spherical aberration to focusing profiles. (a) Metalens, without spherical aberration. (b) Refractive lens, with spherical aberration.

In our previous reports [1,2], we have shown that metasurfaces, a new class of optics that rely on sub-wavelength structures capable of locally controlling the output phase, amplitude, and polarization, can pave way to an alternative solution for refractive optics. By placing sub-wavelength structures on a planar surface, one can design an optical component that resembles the functionality of a refractive optics counterpart. Many prior works presented in the field of metasurfaces used deposition of high-refractive index dielectrics, such as TiO_2, SiN, GaN, amorphous silicon, and such, to achieve such functionalities. In this research, we instead use fused silica (SiO_2) wafer, a low-refractive index material, and demonstrate a metasurface lens (metalens) capable of focusing and imaging as a lens in the visible wavelength.

To fabricate such lens, we choose DUV (248 nm, KrF) stepper lithography so that we can create features smaller than the incident wavelength. At CNF, we use Heidelberg DWL 2000 mask writer to create a reticle of the metalens. After writing the mask design by exposing the photoresist with UV laser scanner on a chrome-coated quartz reticle blank, we develop the photoresist using Hamatech mask chrome etch 1. After optical inspection of the developed pattern on the reticle, we wet-etch the chrome layer with the patterned photoresist as etch mask. The reticle substrate is chosen to fit the ASML 300C DUV stepper.

The substrate on which the metalens is fabricated is chosen to be a 4-inch fused silica wafer, as most of the tools in CNF are set to work with 4-inch wafers. On top, we deposit a thin-layer of chrome, with either CVC sputter (decommissioned) or CHA Mark 50 e-beam evaporator. After coating AR3 ARC layer and DUV resist using GAMMA automatic coat-develop tool (GAMMA), we expose the substrate with the metalens pattern written on the reticle, using ASML 300C DUV stepper. The exposed wafer is then put through post-exposure bake, develop, rinse, and dry process with the GAMMA tool. After ensuring the focus-dose conditions with the DUV stepper, we perform descum and ARC layer etch using Oxford 81 or 82 etcher. Then, we transfer the pattern to the chrome layer by plasma etching, using Trion Minilock III ICP-etcher. When the metalens pattern is transferred to the chrome layer, we remove the DUV resist and the ARC layer using Oxford 81 or 82 etcher, using oxygen plasma. The SiO_2 wafer is then plasma etched with the patterned chrome as etch mask, using Oxford 100 etcher until we reach the target etch depth. We inspect the fabrication results with P10 profilometer and Zeiss Ultra SEM. The fabrication of the metalens is completed when we then remove the chrome layer, leaving only SiO_2 pattern (Figure 2). From our measurements, we observe that the fabricated metalens show diffraction-limited focusing in the visible wavelength (Figure 3), and high-quality imaging properties.

The results of this research are being prepared for publication.

References:

[1] A. She, S. Zhang, S. Shian, D.R. Clarke, and F. Capasso, "Large area metalenses: design, characterization, and mass manufacturing," Opt. Express 26, 1573-1585 (2018).

[2] M. Khorasaninejad, W.T. Chen, R.C. Devlin, J. Oh, A.Y. Zhu, and F. Capasso, "Metalenses at visible wavelengths: Diffraction-limited focusing and subwavelength resolution imaging," Science 352, 1190 (2016).

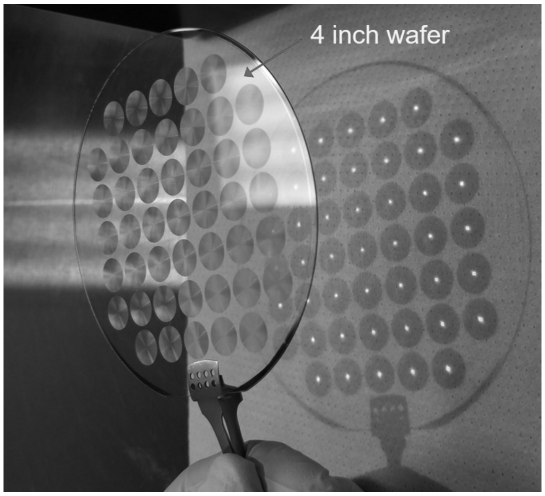

Figure 2: Photograph of fabricated metalens with diameter of 1 cm, on a 4-inch fused silica wafer.

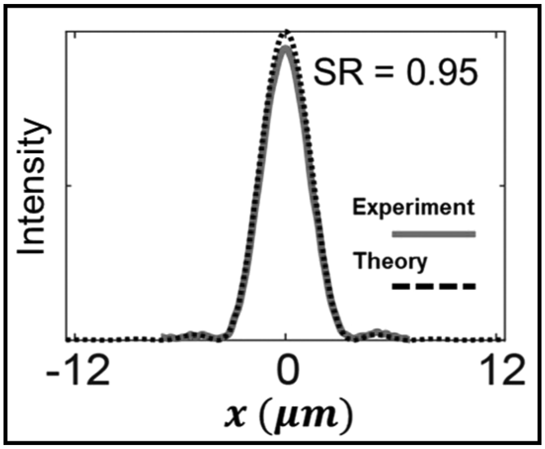

Figure 3: Focusing profile of the metalens.