Achromatic and Varifocal Metalens Doublet Fabrication by Two-photon Lithography

Fatih Balli[1], Mansoor A. Sultan[2,] and J. Todd Hastings[2]

[1] *Physics and Astronomy, Univ. of Kentucky, Lexington, KY 40506*
fatih.balli@uky.edu

[2] *Electrical and Computer Engineering, Univ. of Kentucky, Lexington, KY 40506*
m.sultan@uky.edu and *todd.hastings@uky.edu*

Metasurfaces are 2D engineered artificial interfaces achieved by using quasi-periodic, sub-wavelength unit cell structures. They have received a great deal of attention due to their compact size, light weight, efficient wavefront shaping, and polarization conversion properties. Metasurfaces offer a platform for miniaturization of optical devices. Some examples are color routers[1], optical trapping[2] and biomedical devices [3]

In this work, we discuss the fabrication process for two types of low-index metalenses composed of air-spaced metasurfaces. First, we discuss the fabrication of our recently demonstrated two element hybrid achromatic metalens (HAML). This device combines a phase plate and nanopillars, as shown in Fig. 1, and offers achromatic performance across the near-infrared and short-wave infrared spectral regions.[4] Second, we discuss a novel air-spaced, varifocal, metalens, shown in Fig. 2, that employees nanoholes instead of nanopillars. Phase control of light, and thus focal length, is obtained through mutual rotation of the singlet structures. In both cases, the metalens elements are separated by an air gap, and the upper element is supported by printed pillars at the edge of the structure. Thus, careful control of exposure and development parameters is required to achieve the required dimensions and prevent collapse of both pillars and entire elements.

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[1] B. H. Chen et al., "Gan metalens for pixel-level full-color routing at visible light," *Nano letters*, vol. 17, no. 10, pp. 6345–6352, 2017.

[2] Y. Ma et al., "Trapping and manipulation of nanoparticles using multifocal optical vortex metalens," *Scientific Reports*, vol. 7, no. 1, pp. 1–9, 2017.

[3] S. Zhang et al, "Meta- surfaces for biomedical applications: imaging and sensing from a nanophotonics perspective," *Nanophotonics*, vol. 10, no. 1, pp. 259–293, 2020.

[4] Balli, F., Sultan, M., Lami, S.K. et al. A hybrid achromatic metalens. *Nat Commun* 11, 3892 (2020). https://doi.org/10.1038/s41467-020-17646-y

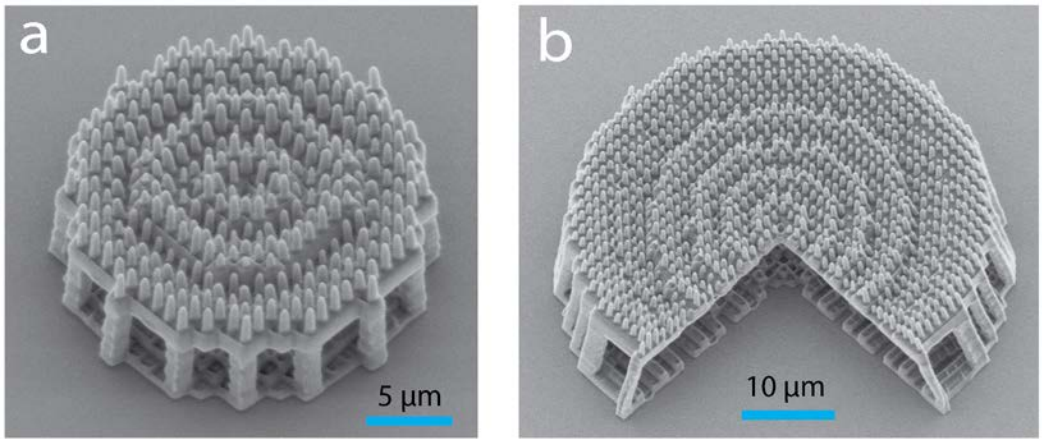

Figure 1: Scanning electron microscope (SEM) images of an air-spaced, hybrid achromatic metalens. **a**, Complete air-spaced metalens doublet with a 20 µm aperture. **b**, Sectioned structure showing the lower phase plate, and the upper hybrid (phase plate + nanopillars) optical elements, of a 40 µm aperture lens.

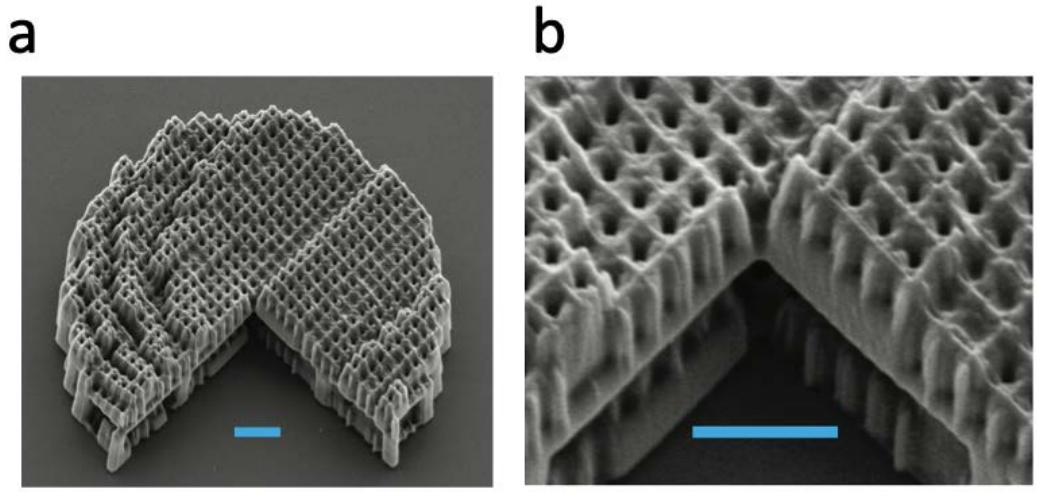

Figure 2: SEM images of 30 µm aperture size varifocal doublet metalens. Scale bar is 4 µm. **a**, Isometric view of fabricated zoom lens. **b**, Zoomed-in image of the center of the lens showing the phase pate + nanohole structure.