Prototype Photolithography for Multilayer Diffractive Lenses

CNF Project Number: 2472-16
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Primary Source(s) of Research Funding: National Cancer Institute (award number R21 CA251052), National Institute of General Medical Sciences (award number R21 GM138947) of the National Institutes of Health
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Primary CNF Tools Used: Heidelberg Mask Writer - DWL2000, SÜSS MicroTec Gamma Cluster Tool, ASML PAS 5500/300C DUV Stepper, Oxford PlasmaLab 100 ICP Etcher

Abstract:

We test a photolithography process to be used to fabricate large scale multilevel diffractive optics for use in thin optical systems.

Summary of Research:

Conventional optical systems, based on refractive lenses, must be of a certain thickness to perform their function. Optical requirements sometimes make such system impractically large and heavy. Solutions for some applications have included Fresnel lenses and gradient-index optics, and newer and intensively studied approaches include negative-index metamaterials, resonator-based metalenses and multilevel diffractive optics. The latter are ultrathin (few-wavelength) optical elements that use diffraction of radially symmetric elements, rings of various heights, to bend light. They can have the same imaging performance as metalenses while not being much thicker, and being faster and cheaper to fabricate [1]. Multilevel optics can be fabricated by repeated photolithography and etching steps with a sequence of patterns on the same wafer, whose superposition produces the final multilevel structure. After N steps, the MLD device has 2^N levels [2].

As a proof of concept, single-level samples to explore this process were fabricated at CNF on a silica wafer using the ASML DUV stepper with masks made with the Heidelberg Mask Writer - DWL2000. Each sample is about 1.5 mm across and contains circular features ranging from several dozen micrometers down to less than a micrometer. The wafer was coated in antireflective coating (ARC) and UV210 resist, exposed, processed

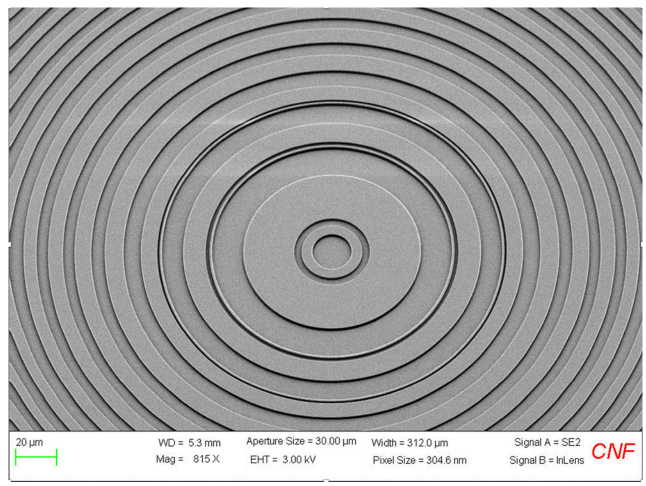

Figure 1: 35° SEM view of the center of one of the fabricated structures.

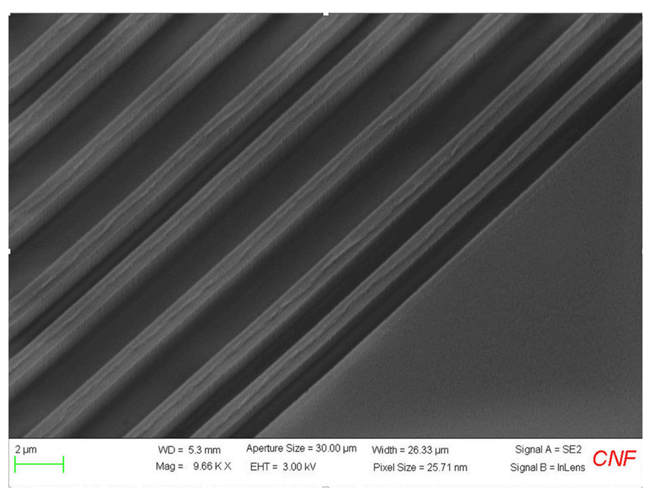

Figure 2: 35° SEM view of the edge of one of the fabricated structures.

in the Gamma tool and, after ARC removal, etched in the Oxford 100 etcher with a slow, consistent etching recipe. The resulting samples have well-defined edges both near the center, where features are largest (Figure 1), and near the edges, where they are finest (Figure 2), although the smallest (sub-micron) features are shallower than the design. By using a photolithographic process, the individual samples can be large (eventually, only limited by wafer size) and dozens can be made on a single wafer with little increase in overall fabrication time.

Conclusions and Future Steps:

The process has been proven suitable for the first step in the fabrication of a MLD system. Future tests would involve the fabrication of the remaining levels by repeating the process for 2-7 steps with a different exposed pattern each, using markers for alignment between layers. Tweaking the resist type and deposition method will be necessary to prevent pooling as the levels become deeper, and the etching method must be refined to achieve uniform depth even for the smallest features.

References:

[1] Banerji, S., Meem, M., Majumder, A., Vasquez, F. G., Sensale-Rodriguez, B., and Menon, R. (2019). Imaging with flat optics: metalenses or diffractive lenses? Optica, 6(6), 805. https://doi.org/10.1364/optica.6.000805.

[2] Saha, S. C., Li, C., Ma, Y., Grant, J. P., and Cumming, D. R. S. (2013). Fabrication of Multilevel Silicon Diffractive Lens at Terahertz Frequency. IEEE Transactions on Terahertz Science and Technology, 3(4), 479-485. https://doi.org/10.1109/TTHZ.2013.2251929.