Fabrication Strategy for Large-Area Meta-Optic Elements Exceeding the Exposure Size Limits of Lithography Tools

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Primary CNF Tools Used: Heidelberg Mask Writer - DWL2000, HamaTech Mask Chrome Etch 1, ASML 300C DUV Stepper, Gamma Automatic Coat-Develop Tool, CHA Mark 50 E-beam Evaporator, Plasma-Therm Dual Chamber 770, Oxford 81, Oxford 82, Oxford 100, P10 Profilometer, Disco Dicing Saw, Zeiss Ultra SEM

Abstract:

We show a fabrication path for creating a mass-producible metalens that works at visible wavelength, exceeding the inherent exposure size limit of the currently available lithography tools. We use the rotational symmetry of the metalens to save the number of required photomasks (reticles) for cost-efficiency, and therefore create a 10 cm diameter metalens from seven reticles with 2 cm × 2 cm exposure areas at wafer-scale, respectively.

Summary of Research:

For imaging at low-light conditions, one needs to increase the imaging optic's diameter to take in more light. However, simply increasing the diameter of an imaging lens faces two important tradeoffs in their application: the increase in aberration and the weight of the optic itself.

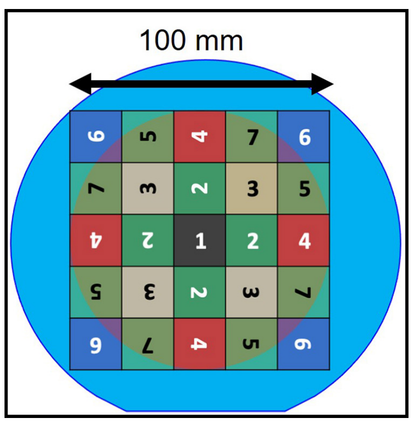

Figure 1: 10 cm diameter metalens fabrication strategy: The metalens is divided into 25 sections of 20 mm × 20 mm area, respectively. Only seven reticles are needed to expose the whole metalens by exploiting the rotational symmetry of the metalens.

For applications in aerial drones or satellite imaging systems, where the payload is one of the primary concerns, simply increasing the lens diameter is therefore not a desirable option.

Here, we show our process development in creating a 10 cm diameter, ultrathin metasurface lens (metalens) consisting of 18.7 billion nanostructures with DUV projection lithography, which is more than 40 times thinner and 16.5 times lighter than a refractive lens with similar optical power.

A metasurface optical element consists of sub-wavelength spaced structures on a two-dimensional surface that alters the incoming light and produce a designed outgoing wavefront. Each subwavelength structure in the metasurface locally change the transmitted light's amplitude, phase, polarization, or wavenumber in a way that one can design the combined wavefront to create optical functions, such as metasurface lenses (metalenses) [1], orbital angular momentum beam generators [2], polarization-dependent holograms [3], or Jones-matrix holograms [4].

For a metasurface optical element to function at a visible wavelength, the constituent sub-wavelength structures are required be in the order of few tens to hundreds of nanometers to avoid efficiency losses by high-order diffraction. Fabrication of such a metasurface therefore requires high-resolution lithography process such as electron-beam lithography or DUV lithography to be able to resolve such features. In the recent years, we have shown that a mass-production of metalenses with 1 cm in diameter and diffraction-limited performing at visible wavelength is possible with DUV lithography [5].

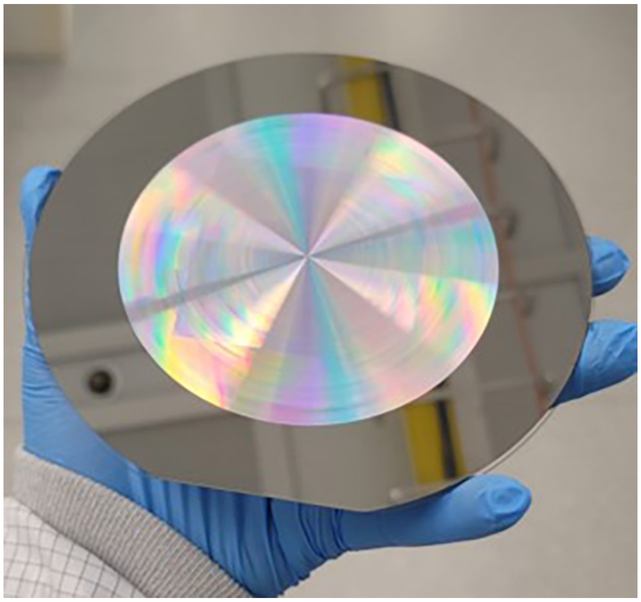

Figure 2: Photograph of the 10 cm diameter metalens' photoresist pattern on an aluminum coated 150 mm fused silica wafer.

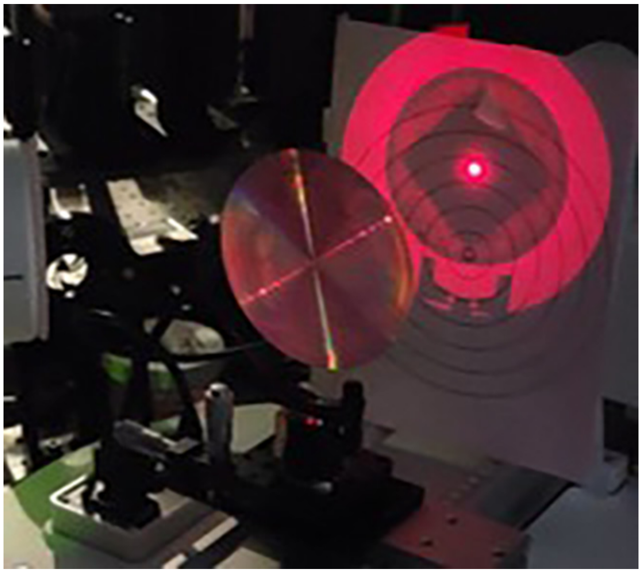

Figure 3: Photograph of the 10 cm diameter metalens focusing collimated He-Ne laser (633 nm).

To create a 10 cm diameter metalens, however, one faces size limitations restricted by the fabrication methods. With the conventional stepper lithography tools having maximum exposure area of 32 mm × 22 mm on a wafer per die, the stepper restricts the maximum diameter of a circular aperture metalens to 22 mm. To overcome such limitations, we divide the metalens into 25 sections, each consisting of 20 mm × 20 mm area.

For cost-effective fabrication, we use the rotation symmetry of the metalens to reduce the number of required reticles (Figure 1). As the metalens is rotationally symmetric, we can expose the whole 10 cm metalens with only seven reticles, instead of 25, if we rotate the wafer 90, 180, 270 degrees to expose each section, respectively, with global alignment process that has alignment error less than an order of magnitude smaller than the metalens' target wavelength. Figure 2 shows the result of DUV (248 nm, KrF) projection lithography of 10 cm diameter metalens on an aluminum coated 150 mm fused silica wafer. DUV lithography was performed with DUV-24P ARC layer and UVN2300 negative DUV resist.

Figure 3 shows the fabricated 10 cm diameter, all-glass metalens, focusing a collimated visible (λ = 633 nm) beam. The reticles for the central section (sections 1, 2, and 3 in Figure 1) were fabricated by an industry-grade photomask company, and outer sections 4-7 were fabricated with CNF tools (Heidelberg Mask Writer - DWL2000). As the reticles are of different quality, one can see the diffraction efficiency difference between the fields visible in the transmitted collimated beam at the focal plane of the metalens. Such difference can be resolved if all reticles are fabricated from the same source.

As the whole lens is fabricated with CMOS foundry compatible process, the shown metalens is mass-producible by IC chip companies. Detailed results and analysis are being prepared for peer-reviewed publication.

Conclusions and Future Steps:

We demonstrated a proof-of-concept fabrication of mass-manufacturable, all-glass 10 cm diameter metalens, capable of focusing monochromatic visible wavelength. We are further investigating on finding a path toward a broadband, achromatic, and large diameter metalens.

References:

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