National Aeronautics and Space Administration

Curved hybrid metalens

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Objectives:

The objective was to create a hybrid meta-optical lens with enhanced imaging properties by attaching a curved metasurface directly onto a commercial lens.

Background:

Hybrid meta-optics, in which optical metasurfaces are fabricated on the surface of conventional optical components, combine advantages of both technologies to achieve superior performance. Optical metasurfaces, over the last decade, are comprised of subwavelength nanostructures that control the phase, amplitude and polarization of incident light. The metasurface can precisely control light on very small scales. However, it is challenging to create highly efficient, large (few cm) metasurface components operating across a broad spectral range. In contrast, large conventional refractive lenses are routinely made, but suffer from a number of so-called aberrations which dramatically reduce the image quality**.** The standard method for reducing aberrations is to cascade several lenses together to reduce the total aberrations in the system. However, cascading of optical elements increases the size, weight and cost of optical systems. Moreover, these elements require precise alignment,increasing the complexity and cost. Fusion of conventional optics and metasurfaces into one hybrid meta-optical component, will combine the advantages of both approaches, nanoscale control of the phase front in large and efficient optical elements. In this project we have taken significant steps towards demonstration of a hybrid metalens.

Approach and Results:

We have designed a corrective metasurface which in simulation achieved diffraction-limited imaging performance, see Fig 1. This modelling was done by using a combination of the FDTD software Lumerical and the optical software CODE V.

One approach to create hybrid meta-optical devices is to fabricate the corrective metasurface directly on the lens itself. The advantage of this method is that the metasurface is created directly on the lens surface and the resulting device is a monolithic component. However, the microfabrication has to be done on a curved surface (lenses are curved) which is highly challenging. Here we have developed an alternative approach to create a hybrid meta-optical lens that is based on the curved CMOS sensor fabrication process developed at JPL. We have fabricated the metasurface on a flat substrate, thinned it down (from the back side) to few tens of microns such that it becomes flexible. This allows the membrane to be curved and attached to the lens surface. The benefit of this approach is that the lithography and etching are done on a flat substrate as is normally done for these processes.

In order to thin the silicon wafer from the back (after metasurface fabrication), we used a previously JPL-developed method for curved CMOS sensors. This method utilizes HNA (hydrofluoric, nitric, acetic) acid which has an etch rate that depends on the doping level of the silicon substrate. In order to have a stop layer for etching, we utilized “epi” silicon with a few tens of microns of low-doped silicon deposited on a more highly doped substrate. Unfortunately, we were unable to locate vendors carrying such wafers with appropriate size (1.5 - 2 inch diameter) and lead times for this short-term project. In order to make progress, we located 4 inch diameter wafers which we etched out suitably sized custom wafers from, see Fig. 2. On these custom epi wafers we have successfully fabricated metasurfaces, see Fig 3. The metasurface fabrication was done using electron-beam lithography and fluorine-based plasma etching. After metasurface fabrication, we have thinned down the wafers (from the back) to create malleable membranes using HNA etch, see Fig. 4 (left). We are currently working on applying the membrane on the curved surface, see Fig. 4 (right) for a photograph of a partially attached membrane.

Significance/Benefits to JPL and NASA:

Optical systems are pervasive in a vast number of JPL and NASA missions and instruments. Our hybrid lens approach developed in this work provides a highly general method for combining metasurface functionality with conventional optics to create high-performance devices. We developed processes such as thinning and curving that allows attachment of the fabricated metasurfaces to the conventional lens. We will test these hybrid lenses to demonstrate that they will enable compact high-performance optical imaging systems for future space instruments.

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Publications:

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