Plasmonic Metasurface Based Ultra-thin Phase Holograms and Planar Micro-lenses

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Abstract: We experimentally demonstrate a phase hologram generated at a visible wavelength by a plasmonic metasurface consisting of Babinet-inverted nano-antennas perforated on a 30-nm-thick gold film. Micrometer-sized planar lenses are made with the same technique.
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1. Introduction

Plasmonic metasurfaces – artificial ultra-thin plasmonic structures for optical components with improved or completely new functionalities – open a viable way of manipulating the propagation of light on a subwavelength scale. Plasmonic metasurfaces consisting of nano-antennas have been used to achieve many unparalleled applications such as bending the light abnormally [1] in a fairly broad range of wavelengths, [2] generating an optical vortex beam, [1, 3] coupling between propagating waves and surface waves, [4] creating a macroscopic near-infrared lens. [5]

We experimentally demonstrate a phase hologram generated by a plasmonic metasurface consisting of Babinet-inverted nano-antennas, which create discrete phase shifts and form a desired wavefront of cross-polarized light, perforated on a 30-nm-thick gold film. This ultra-thin, compact hologram works at a visible wavelength produces a high-resolution, low-noise holographic image. We also demonstrate micrometer-sized planar lenses created by such metasurfaces. Those lenses work at entire visible spectral range and have very strong focusing abilitiy and extra-large chromatic aberration in comparison with conventional lenses.

2. Experiment and results

To design the metasurface which generates the hologram, we considered a virtual object, the word 'PURDUE', to emit 676-nm, linearly polarized, coherent light and we mapped the phase and amplitude of the co-polarized electric field onto the plane where the metasurface to be located, which is 10 µm below and parallel to the image plane. Subwavelength-sized (150×150 nm^2) pixels are introduced on the metasurface in order to discretize the area. The phase modulation is accomplished by approximating the phase map with 8 discrete phase levels, which are then reproduced by 8 distinct antenna shapes inside each pixel. The amplitude modulation is done by two states (on and off states) with a chosen threshold, which can be implemented by putting a pixel either with or without an antenna.

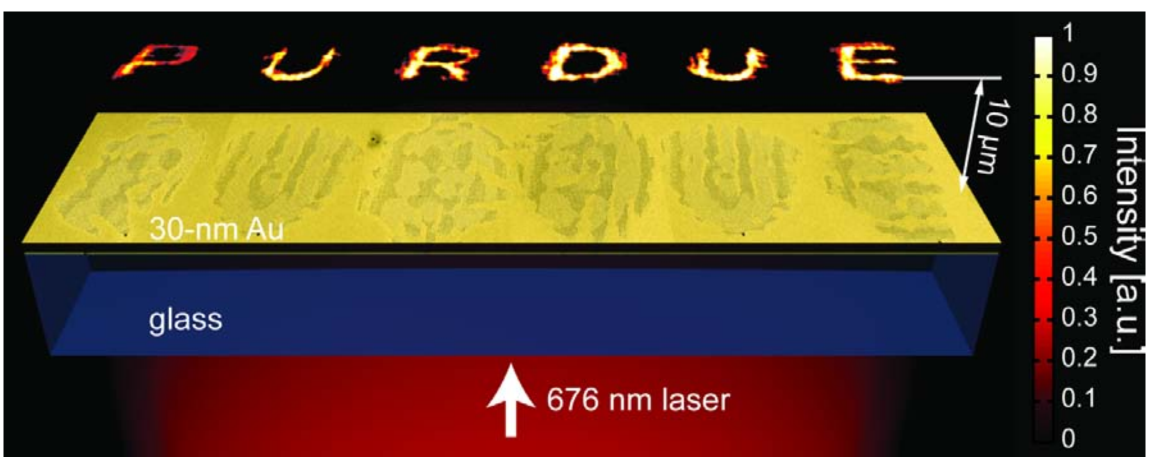

Fig 1. An illustrative view of the holographic image generated by a nanofabricated plasmonic metasurface. The sample is illuminated by a Kr/Ar laser at 676 nm from the glass substrate side. The images are obtained experimentally at a plane 10 µm above the metasurface. The pattern on the gold film are the field emission SEM image of the fabricated sample.

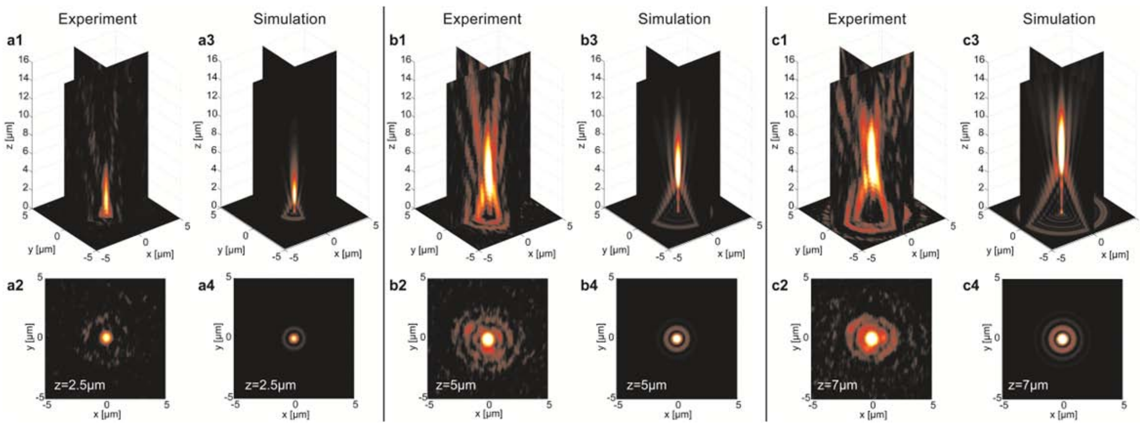

Fig. 2. Comparison between the measured and simulated results for three different metasurface lens designed at a wavelength of 676 nm. (a) Results for the lens designed for a focal length of 2.5 µm, (b) 5 µm, and (c) 7 µm. (a1), (a2), (b1), (b2), (c1), and (c2) Reconstructed cross-polarized light intensity distribution on the transmission side of the metalenses as derived from measurements; (a3), (a4), (b3), (b4), (c3), and (c4) Simulated results for the same designs. (a1), (a3), (b1), (b3), (c1), and (c3) Intensity distributions for two cross-sectional planes cutting through the center of the metalens; (a2), (a4), (b2), (b4), (c2), and (c4) Intensity distribution at the respective focal planes (z coordinates are shown on the plots). The x-y planes in (a1), (b1), and (c1) are at z = 0 µm. The x-y planes in (a3), (b3), and (c3) are at z = 0.1 µm (avoiding the singularity at z = 0 µm in the simulations). The effect of the depth of focus of the objective lens has been taken into account in the simulations by averaging the intensity data in the z-direction within a 0.5-µm window.

The cross-polarized light intensity is measured using a conventional optical microscope [6]. The transmission images from the sample were recorded by a CCD camera. By changing the distance between the objective lens and the sample stage, intensity images at different distances from the metasurface are obtained. An illustrative view of the holographic image generated by the metasurface is shown in Fig. 1.

Similarly, if the virtual object is chosen to be a point source in the design, the metasurface behaves as an optical lens. Fig. 2 shows the measured and simulated results for such metasurfaces lenses designed with different focal lengths at 616 nm. We observed experimentally that the lenses also work at 531 nm and 476 nm.

3. Conclusion

Our results experimentally prove a viable route for producing complex phase holograms from nanostructured plasmonic metasurfaces. We fabricate the proof-of-concept samples built on a Babinet-inverted nanoantenna design and generated high-resolution, low-noise holograms at a visible wavelength. We applied similar technique to build micrometer-sized metasurface lenses which work at entire visible spectral range and have very strong focusing ability and extra-large chromatic aberration in comparison with conventional lenses.

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