Monolithic Bilayer Metasurface for Multicolor Phase-Amplitude Holography

Xiaoyan Huang[1] and Nanfang Yu[1*]
[1]*Department of Applied Physics & Applied Mathematics, Columbia University*
New York, NY, 10027 USA
**ny2214@columbia.edu*

Abstract: We propose a monolithic bilayer metasurface platform for phase-amplitude holograms operating at up to three colors, in both visible and infrared regimes.

I. Introduction

Phase-only (PO) holograms are fundamentally limited in their wavefront-shaping capability, rendering them unsuitable candidates to producing realistic holographic objects. Remedies such as Gerchberg-Saxton algorithms [1] have been widely used but they inevitably introduce a speckled texture, degrading the fidelity of holographic images. We have shown in a previous work [2] that a complete and independent control of phase and amplitude (i.e., an arbitrary modulation of amplitude from 0 to 1 and phase from 0 to 2π) is necessary for high-fidelity holography, and experimentally demonstrated a dielectric metasurface platform capable of artifact-free phase-amplitude (PA) holography at a single wavelength. In this approach, nanopillars of various cross-sectional shapes and rotation angles are used so that their degree of birefringence determines the amplitude response, when incident circularly polarized light is variably converted into re-radiation with the opposite handedness, and the phase response is a sum of the 'geometric phase', controlled by the orientation of the birefringence axis of the nanopillars, and the propagational phase within the nanopillars. In a follow-up work [3], we demonstrated experimentally that a metasurface doublet, consisting of single-color PA meta-holograms and an RGB meta-grating, can produce full-color, artifact-free holographic images.

II. Design of Monolithic Bilayer Metaunit Library

Here, we propose a monolithic bilayer metasurface capable of achieving high-quality phase-amplitude holography at multiple wavelengths. The metaunits consist of an amplitude modulation layer of an absorptive semiconductor or metal and a phase modulation layer of a transparent dielectric. The metasurface is etched monolithically so that the two layers share the same cross-sectional shape. Nanopillars of various geometries and orientation angles introduce a wide range of amplitude and phase modulation to incident light waves with different wavelengths and polarization states.

Depending on materials chosen for the two layers, the metasurface can operate either in the visible or in the near infrared. We use amorphous silicon (a-Si) as the amplitude modulation layer and titanium dioxide (TiO_2) as the phase modulation layer for visible metasurfaces. Nanopillars of various archetypes and sizes (**Fig. 1a**) are designed and their amplitude and phase responses are simulated at λ=600 nm, 615 nm and 630 nm. The phase-amplitude responses of the metaunit library at λ=600 nm with polarization along the x-axis and at λ=630 nm with polarization along the y-axis are shown in **Fig. 1b**. The library offers a good phase-amplitude coverage for most amplitude pairs. In the near-infrared, we use a top layer of aluminum (Al) for amplitude modulation and a bottom layer of a-Si layer for phase modulation. Phase-amplitude responses are recorded at λ=1.3 μm, 1.45 μm and 1.6 μm and good phase-amplitude coverage is observed at λ=1.3 μm and 1.6 μm (**Fig. 1c**).

III. Demonstration of Multicolor Phase-Amplitude Holography

The amplitude-phase control at different colors is encoded into different polarization channels. In the visible range, we use the 'x to x' channel for λ=600 nm (i.e., light at λ=600 nm is incident with horizontal polarization and horizontally polarized re-radiation is monitored). Similarly, amplitude-phase control at λ=615 nm (630 nm) is encoded in the 'y to y' channel ('x to y' channel). The same procedure is applied to the three wavelengths in the near infrared. In **Fig. 2**, we show simulated reconstructed holographic images at the three visible or near-infrared colors, comparing PA holograms and a Gerchberg-Saxton type PO hologram (PO-GS). All holograms have the same numerical aperture of 0.48. The PA holograms are superior to the PO-GS one in terms of producing holographic images with more concrete textures, sharper spatial features, and less amount of speckles, in both the visible and near-infrared cases.

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V. References

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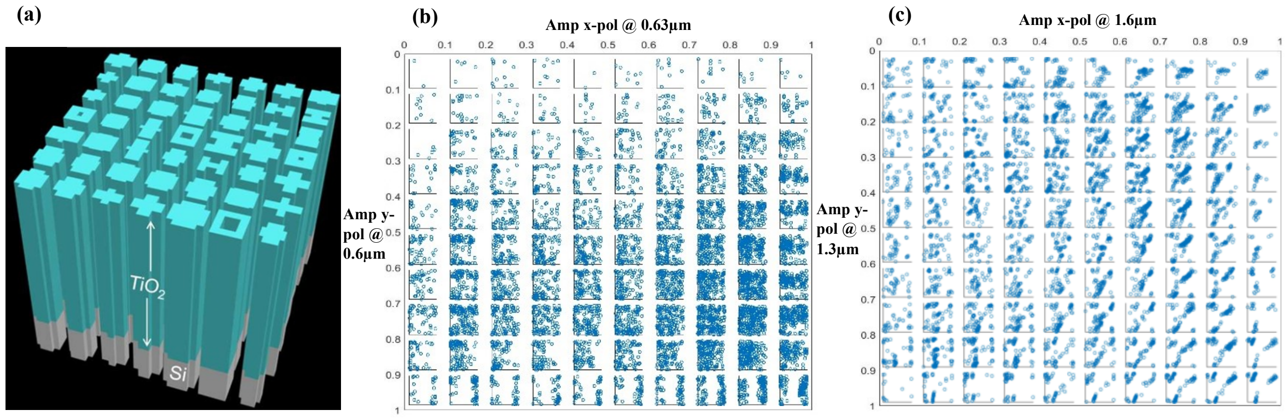

Fig. 1 (a) Schematic of a monolithic bilayer metasurface working in the visible range. In the infrared, similar metaunit cross-sectional shapes are used but with an amplitude modulation layer (Al) on the top and a phase modulation layer (a-Si) on the bottom. (b)-(c) Phase-amplitude coverage graphs of our visible and near-infrared metaunit libraries, respectively. Each dot represents the phase-amplitude response of one metaunit (amplitude response at two colors is divided into 100 bins and each bin represents phase response at the two colors).

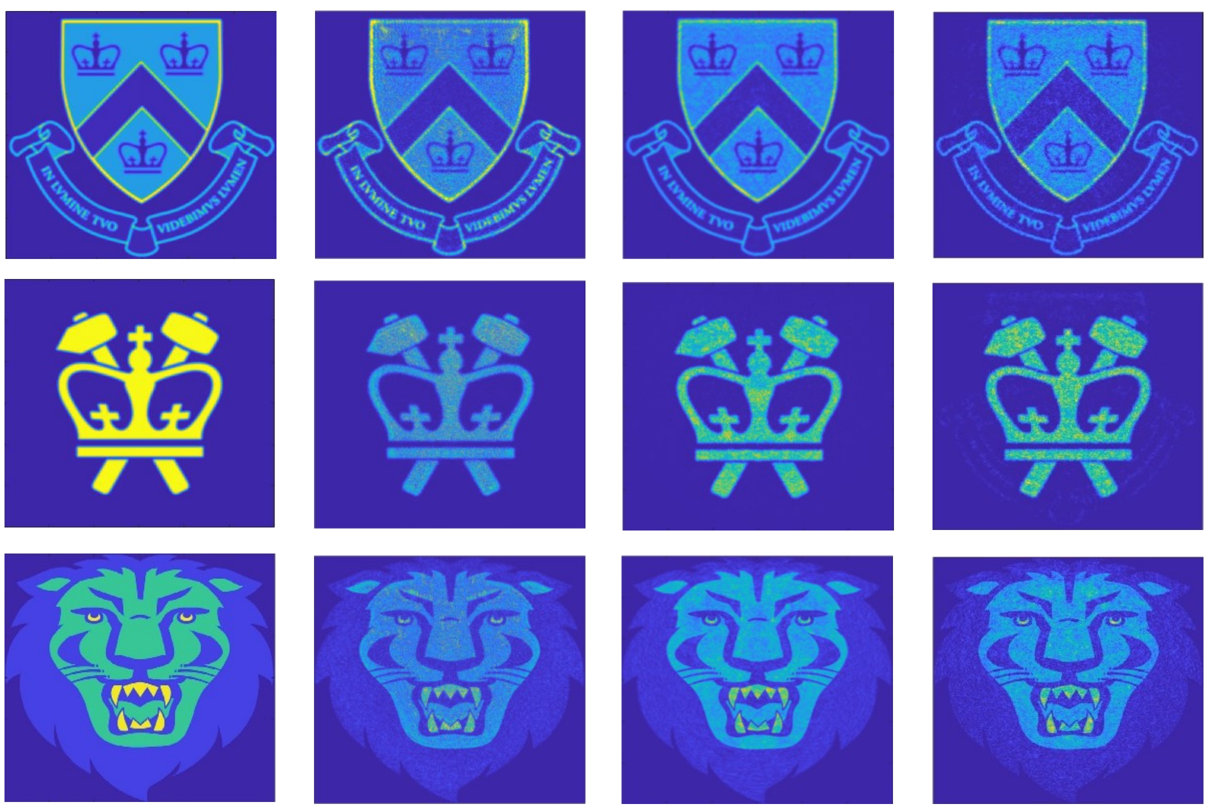

Fig. 2 Images showing target holographic objects (first column), holographic images created by PO-GS holography (second column), by PA holography in the visible (third column), and by PA holography in the infrared (fourth column). The three rows represent results obtained at the three visible or near-infrared wavelenths.