Three-Color Phase-Amplitude Holography with a Metasurface Doublet

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Abstract: We report experimental demonstrations of a phase-amplitude metasurface doublet capable of producing 2D artifact-free, full-color holographic images. © 2020 The Authors

1. Introduction

Phase-only (PO) holograms have difficulty in generating concrete holographic images due to their limited capability to control the complex optical wavefronts; while iterative corrections such as the Gerchberg-Saxton algorithm [2] can be applied to compensate for the lack of amplitude control, they inevitably result in a grainy or speckled texture in the generated holographic images. To achieve artifact-free holography, complete and independent phase and amplitude control (i.e., amplitude continuously ranging from 0 to 1 and phase from 0 to 2π) is necessary [1]. We have previously devised a dielectric metasurface platform to achieve full phase-amplitude (PA) control and demonstrated high-fidelity holographic reconstruction with generated holographic images free from ringing and speckle artifacts [1]. In this approach, the degree of structural birefringence of meta-atoms is utilized to control the amplitude of converted light from circular polarization of one handedness to the opposite handedness, and the in-plane orientation of the birefringence axis is utilized to control the phase of the converted light via the “geometric phase” or Pancharatnam-Berry phase.

Here, we generalize that metasurface platform and demonstrate a metasurface doublet composed of Titanium Dioxide (TiO_2) nanopillars and operating in the visible that can produce full-color, artifact-free holographic images. The doublet consists of a metasurface layer containing three spatially separated PA holograms encoding the RGB components of a full-color image, and a second metasurface layer that acts as a wavelength-selective grating to fuse the RGB outputs from the first metasurface layer. Thus, the viewer observes a full-color holographic image as though it were produced by a single hologram.

2. Design of Three-Color Phase-Amplitude Metasurface Hologram Doublet

We design a three-color PA hologram doublet to generate a holographic image representing a full-color photo of butterfly specimens. We first construct, using full-wave simulations, three meta-atom libraries that provide full amplitude-phase control for red, green, and blue wavelengths at λ=620, 530, and 460 nm, respectively. The original photo is split into red, green, and blue channels, which are then encoded using the meta-atom libraries into three individual PA holograms placed contiguously on the metasurface hologram. We subsequently design a wavelength selective RGB grating based on the methods described in [3]. The metasurface grating is placed at a distance from the metasurface hologram to align and collimate the outputs from the three PA holograms to produce the complex, colorful scene (**Fig. 1(a)**).

3. Demonstration of Full-color, Artifact-free Holography

Holographic reconstruction is numerically simulated by propagation methods and the results are presented in **Fig. 1(b)**. The metasurface hologram alone projects a set of RGB holographic images along distinct oblique angles so that they become progressively displaced as the level of defocus increases (**Fig. 1(b)**, bottom row). With the RGB metasurface grating, the individual color channels are correctly mixed in the spatial and angular space, forming a sharp, artifact-free, colorful image on the designated image plane, and defocused images free from color displacement when the image plane is offset (**Fig. 1(b)**, top row).

Metasurface holograms and gratings are fabricated using a combination of electron beam evaporation, electron-beam lithography, and inductively coupled plasma etching. Each PA hologram has a dimension of 380 μm × 380 μm and the RGB metasurface grating has a dimension of 1 mm × 1 mm. TiO_2 meta-atoms have a height of 800 nm. Holographic images produced by individual PA holograms (**Figs. 2(b)-(d)**) are largely free of ringing and speckle artifacts. By computationally recombining the three images, a digitally reconstructed image of the butterfly photo is produced (**Fig. 2(e)**), which shows rich details and smooth textures as desired. Experimentally measured recombined image with the RGB metasurface grating shown in **Fig. 2(f)** has satisfactory quality in this proof-of-principle demonstration. We believe that the result can be refined by improving the design and fabrication of the metasurface grating.

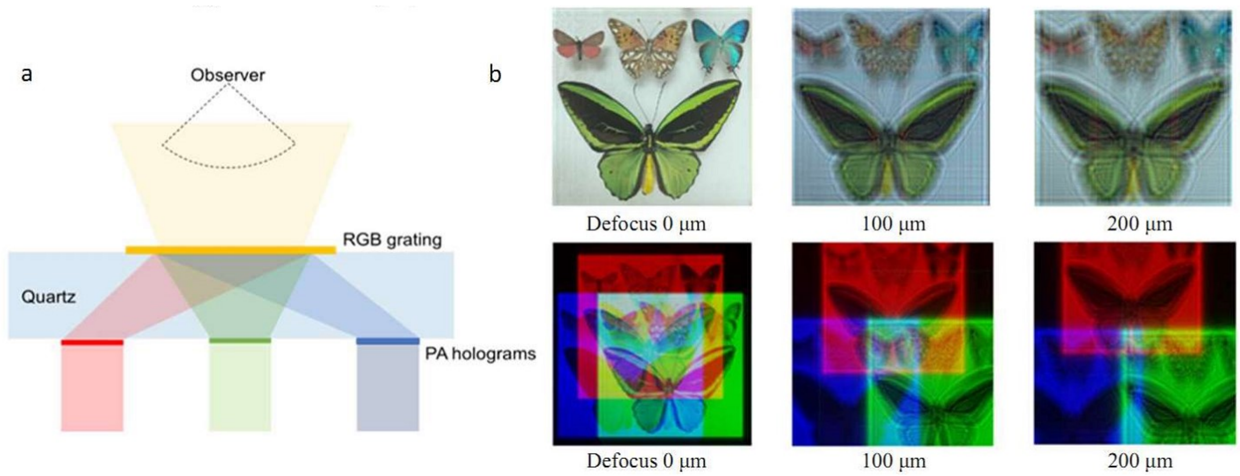

Fig. 1 (a) Schematic of a three-color metasurface hologram doublet. Individual PA holograms lie close to each other and are designed to project their outputs towards the center of a wavelength-selective metasurface grating; the latter deflects the RGB signals so that a recombined full-color holographic image is produced in the forward direction. (b) Simulated reconstruction results with (top row) and without (bottom row) the metasurface grating at different defocus levels.

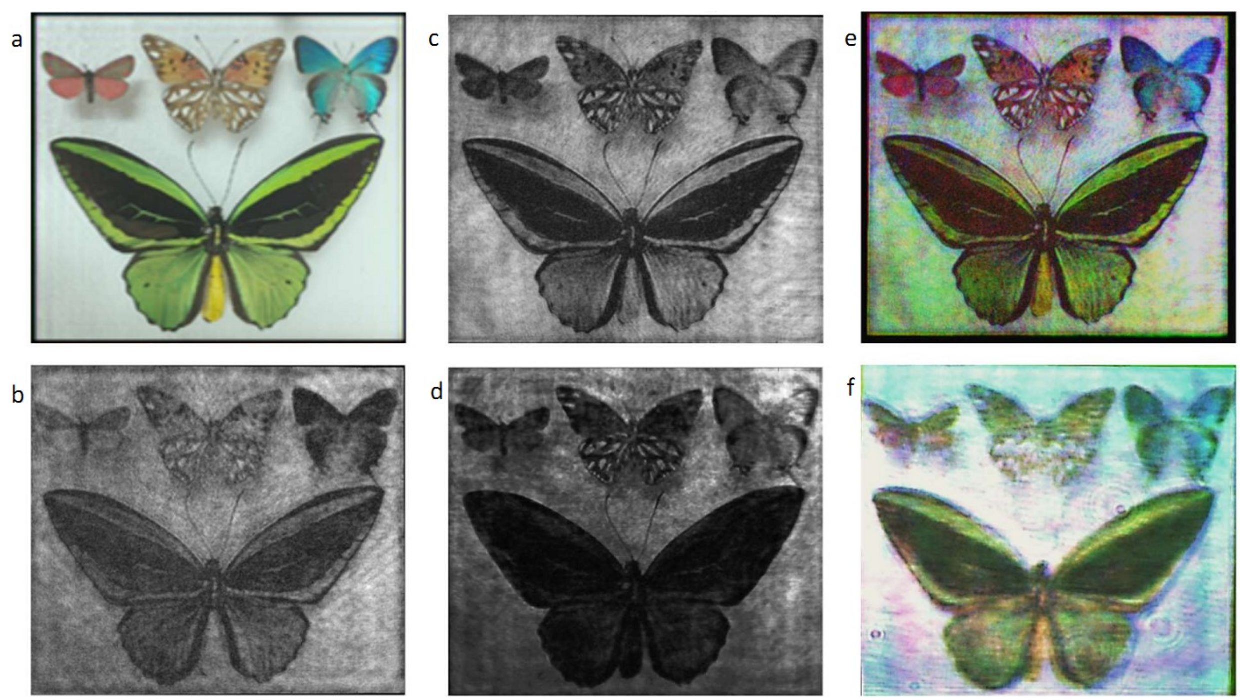

Fig. 2 (a) Simulated reconstruction result with the wavelength-selective metasurface grating. (b)-(d) Holographic images generated experimentally by the three PA holograms at the red, green, and blue wavelengths. (e) Direct digital reconstruction using the results in (b), (c), and (d). (f) Experimental reconstruction with the wavelength-selective metasurface grating.

4. Conclusion

In conclusion, we have demonstrated a phase-amplitude metasurface doublet to reconstruct complex and colorful holographic images free of artifacts commonly present in phase-only holographic approaches. We believe that this technique will be of great interest to display and AR/VR applications. We acknowledge funding supports from DARPA (D15AP00111, HR00111720034), AFOSR (FA9550-14-1-0389, FA9550-16-1-0322) and NSF (QII-TAQS-1936359, ECCS-2004685).

5. References

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