Reflective Plasmonic Metasurface and Metahologram

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***Abstract*—Holograms are the optical devices to reconstruct images by recovering amplitude and phase of light, which show many applications in our daily life. Recently, the metasurfaces, an array of sub-wavelength antenna, show the abilities to manipulate both the amplitude and phase of incident electromagnetic wave in a wide electromagnetic region from visible to microwave frequencies. Here, we realized a high-efficiency broadband plasmonic metasurface and metahologram by reflected metasurface made of subwavelength gold nanoantennas which is designed and fabricated in optical frequencies. The reconstructed images of our metahologram show polarization-controlled dual images with high contrast, functioning for both coherent and incoherent light sources within a broad spectral range and under a wide range of incidence angles. Aluminum plasmonics based metaholograms with multi-images, multi-channels, or multiplexing at different wavelengths, on the other hand, prefer narrower plasmonic resonances and less phase levels to realize multi-color metahologram. By combining with the techniques of tunable metasurfaces, metahologram can potentially be used to realize active hologram that works at arbitrary electromagnetic wave region.**

Keywords*—*metasurfaces; metaholograms; plasmonics; metamaterials; holography; nanoantennas.

I. INTRODUCTION (*HEADING 1*)

In the past decade, metamaterials/metasurfaces composed of sub-wavelength artificial structures show tailored optical properties within flat optics in electromagnetic regions [1, 2], such advances have led to demonstration of phase grating [3-5], lens [6], wave plates [7], Orbital angular detection [8], *et al*. Metamaterials with tunable effective refractive indices have been applied to holograms in which polarization-dependent dual images at different wavelengths were demonstrated in the near IR region [9, 10]. The spatial phase and amplitude modulation of metasurfaces exhibits a good candidate to achieve the spatial light modulators (SLM) and have been explored to realize the polarization-controlled dual images at arbitrary electromagnetic wave region in referred to as broadband metasurface hologram or metahologram [11-16]. What remains elusive is the demonstration of a full-color metahologram because of the inherent loss of gold in the visible range that had been commonly used in the above-mentioned literatures. Metasurfaces incorporating metal with higher plasma frequency like aluminum offer the unique opportunity to extend the working wavelength to cover the entire visible spectrum for the generation of full-color metahologram [16].

II. REFLECTIVE METASURFACE

We combine theory and experiment to demonstrate that a carefully designed gradient metasurface supports high-efficiency anomalous reflections for near-infrared light following the generalized Snell's law, and the reflected wave becomes a bounded surface wave as the incident angle exceeds a critical value. We carefully selected 5 different pairs of Au nanorods with different length and combine them to form a super cell for the metasurface. The reflection amplitude does not vary too much from one unit element to another, and the averaged value can be as high as 91%. Compared to previously fabricated gradient meta-surfaces in infrared regime, our samples work in a shorter wavelength regime with a broad bandwidth (750 − 900 nm), exhibit a much higher conversion efficiency (~80%) to the anomalous reflection mode at normal incidence, and keep light polarization unchanged after the anomalous reflection [5].

III. REFLECTIVE METAHOLOGRAMS

We realized a high-efficiency broadband 4-level phase plasmonic metahologram by reflected metasurface made of subwavelength 6×6 gold cross nanoantennas of 16 different shapes which is designed and fabricated in optical frequencies. As a result, the reconstructed images of metahologram exhibit far more efficient (reaches 18% for 780 nm illumination), polarization-controlled dual images with high contrast, functioning for both coherent and incoherent light sources within a broad spectral range (bandwidth ~880 nm) and under a wide range of incidence angles. The reflective hologram has

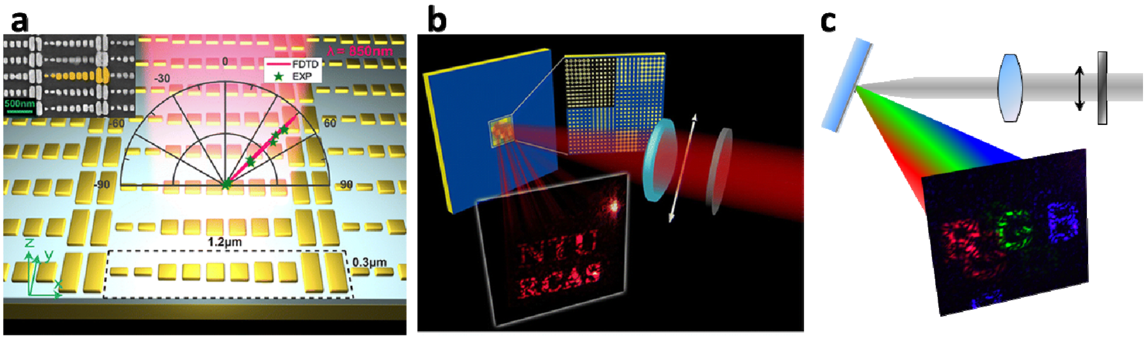

Fig. 1. (a) Gradient metasurface [5]. (b).Plasmonic metahologram [13]. (c) Multi-color metahologram [16].

a number of advantages such as simple fabrication process, low metal absorption, broad working spectral range, and greater tolerance to variation of incident angle and light incoherence [13].

Furthermore, we demonstrated a phase modulated multi-color metahologram based on aluminum plasmonics that is capable of producing images in three primary colors. The structure is made of aluminum nanorods that are arranged in a two-dimensional array of pixels with surface plasmon resonances in red, green, and blue. The multi-color metahologram consists of three sub-pixels operating at three primary colors and each sub-pixel is made of subwavelength 4×4 aluminum nanorod array. With proper design of the structure, we obtain resonances of narrow bandwidths and less phase levels to allow for implementation of the multi-color scheme. Taking into account of the wavelength dependence of the diffraction angle we can project images to specific locations with pre-determined size and order. With tuning of aluminum nanorod size, we demonstrate that the image color can be continuously varied across the visible spectrum [16]. By combining with the techniques of tunable metasurfaces, metahologram can potentially be used to realize active hologram that works at arbitrary electromagnetic wave region.

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