

Towards high efficiency, dynamically tunable metaholograms

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Abstract: We propose a method for determination of nanoantenna transmitted phase for coupled, resonant nanoantennas in a heterogeneous array, necessary for design of metaholograms with ~90% optical efficiency. Progress toward fabrication of VO₂ nanoantennas is demonstrated.

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1. Introduction

Metasurfaces have emerged as revolutionary media for achieving light manipulation at the nanoscale level. This has resulted in the design and fabrication of flat optical devices useful for holography and beam-shaping applications. All-dielectric Huygens' metasurfaces have the potential to produce highly efficient holograms due to their strong coupling to incident light and low loss. Furthermore, their sensitivity to changes in material properties makes them good candidates for dynamic, reconfigurable holograms. However, the near-field antenna coupling between nearest-neighbor antenna elements makes the design of this type of metasurface challenging [1]. Here, we present efforts towards design and fabrication of tunable metaholograms, taking into account near-field coupling between nearest-neighbor antenna elements. To achieve tunability, we work towards fabrication of tunable vanadium dioxide (VO₂) metasurfaces to match computational designs.

2. Nanoantenna Hologram Design

As an initial step, we demonstrate a successful intensity-to-phase map using the Gerchberg-Saxton (G-S) algorithm [2]. This algorithm uses an iterative process, starting with the known intensity profile of the incident illumination field, to produce the phase map required for the generation of the desired holographic image. It begins with assigning a random phase to the input field at the hologram plane. The wavefront is then propagated back to the image plane through a Fourier transform. The phase in the image plane is extracted and then propagated back to the hologram plane through an inverse Fourier transform. In the hologram plane, the amplitude is set to unity. These steps are repeated to give a convergent phase map which we use to generate the greyscale image as shown in Fig. 1a.

In order to choose the geometry of each element in the metasurface hologram to provide the appropriate phase map, we must know the phase of that element while taking into account the effects of nearest neighbor coupling. To extract this phase for different metasurface geometries, we propose a simple triangulation method. As illustrated in Fig. 1b, in the simple case of a 1 x 3 antenna array, this method is used to obtain the phase of the center antenna using the principle of superposition. The process begins by computing the scattered electric field due to these nanoantennas using a finite element software (COMSOL). Three points are then selected beneath the antenna plane and the electric field at these points is observed. This electric field represents the superposition of the electric fields of the three nanoantennas. Three non-linear equations are generated due to these points, approximating the antennas as isotropic point sources, and simultaneously solved using a numerical method to obtain the phase of each of the nanoantenna elements. Once the phase of each antenna is known as a function of its nearest neighbors, a holographic phase map may be transformed into a nanoantenna array design.

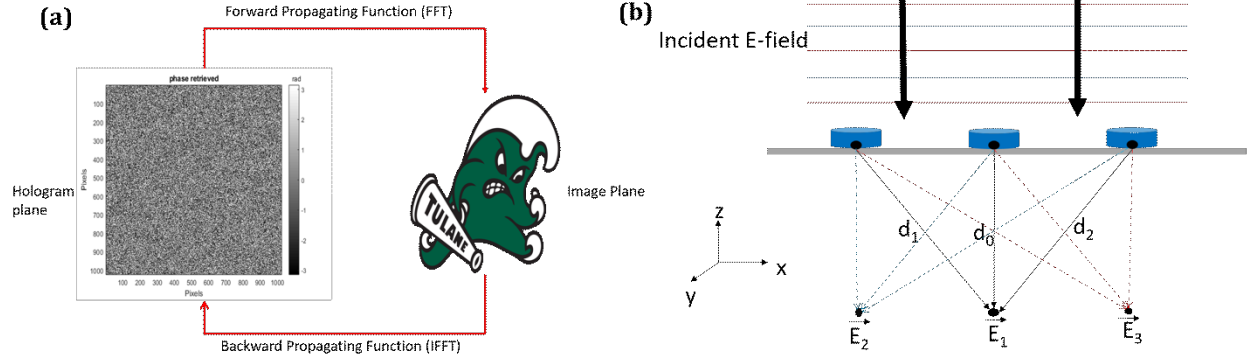


Fig. 1 (a) Schematic showing iterative steps of the G-S algorithm to map image intensity to hologram phase (b) Schematic showing the triangulation method used to extract phase from coupled antennas.

3. Tunable Metaholograms: Growth and Device Fabrication

In order to generate dynamically tunable metaholograms, a tunable constituent material must be utilized. VO_2 is well-known for its metal-insulator transition that occurs around 67°C due to the presence of an external stimulus such as an electric field, pressure, or temperature change [3]. This transition is accompanied by changes in resistivity, refractive index, and absorption coefficient. This property has been exploited for thermochromic and optical sensing applications. We here present efforts towards dynamic control of light using sub-wavelength VO_2 antenna arrays. The VO_2 films were grown using pulsed-laser deposition, after which nanoantennas are patterned on the surface using electron beam lithography. Fig. 2a shows the measured phase transition of our VO_2 thin films by plotting the normalized optical transmittance versus temperature. Fig. 2b shows a scanning electron micrograph of fabricated VO_2 metasurfaces. In order to increase our VO_2 synthesis capabilities, Fig. 2c shows progress towards solution-processed thin films of VO_2 made by photonic curing of thermally aged vanadyl acetylacetonate ($\text{VO}(\text{acac})_2$) in methanol. Experimental work is in progress to better replicate designed nanoantennas and characterize their tunable performance.

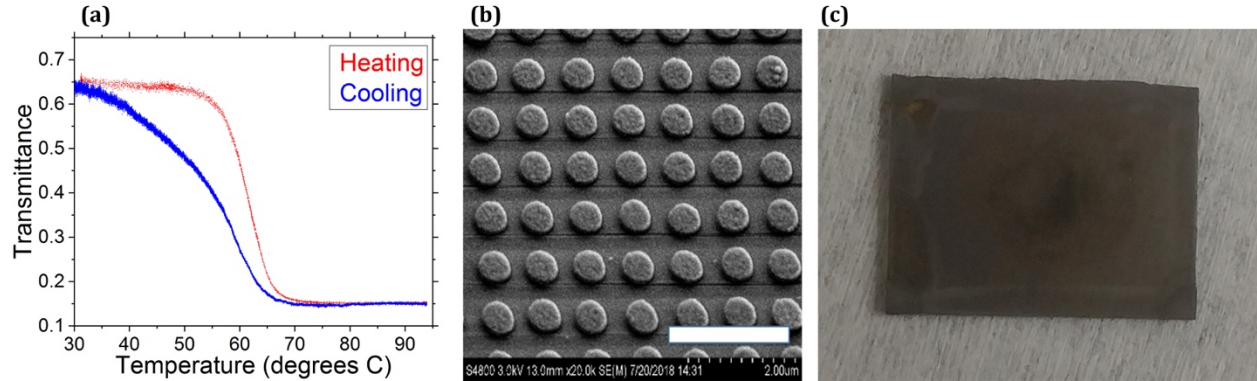


Fig. 2. (a) Optical measurements of VO_2 thin films showing phase transition from metal to insulator phase around 68°C . (b) SEM image of VO_2 metasurfaces (scale bar is 2 microns) (c) Solution-processed VO_2 thin film fabricated through photonic curing.

4. Conclusion

Intensity-to-phase mapping is achieved using the Gerchberg-Saxton algorithm. Elemental nanoantenna phase is extracted in the presence of coupled nearest neighbors from finite element calculations using a triangulation method. VO_2 metasurface fabrication improvements are being made towards matching designed nanoantenna geometries.

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