Silver and Carbon Ink-Jet Printing to Create an Amplitude and Phase Controlled THz Metasurface

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Abstract— **Controlling the amplitude and phase response of an optical device was once thought to be constrained by the bulk material properties of that device. Demonstrations of metamaterials and metasurfaces have shifted this paradigm. We show that the amplitude and phase of a transmitted THz signal through an array of V-shaped antennas can be controlled by varying the conductivity and geometry of the V-shaped structures. These structures are created using conductive silver and resistive carbon ink deposited by a consumer ink-jet printer.**

I. INTRODUCTION

WHILE discussing the background for this work, it is important to note the impressive applications of phase controlled v-shaped structures that have already been demonstrated to exhibit extraordinary refraction and vortex beams, flat lenses, phase filters and waveplates[1]. We build upon these results by providing an additional functionality in controlling the amplitude of transmitted radiation by carefully varying the conductivity of the V-shaped structures. This control over the spatial conductivity of the antennas is achieved by simultaneously ink-jet printing varying amounts of conductive silver ink and lossy carbon ink.

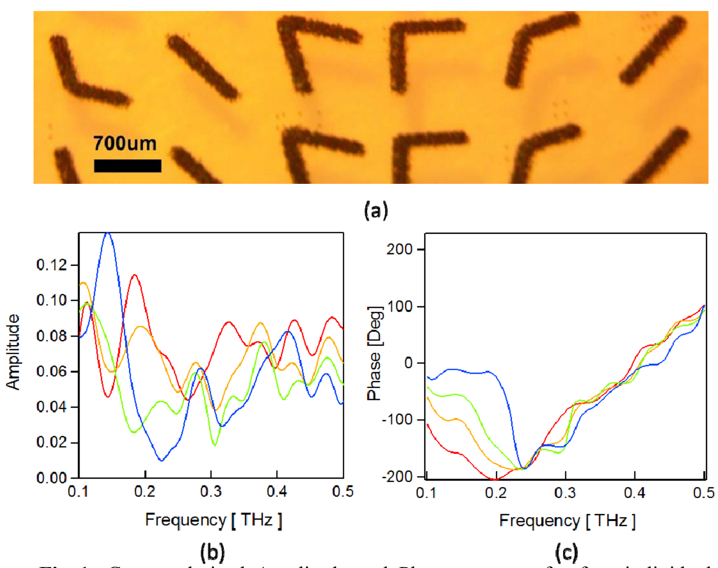

Fig 1: Cross polarized Amplitude and Phase response for four individual printed arrays of V-shaped plasmonic antennas with various interior angles for the V-shaped antenna. **(a)** Micrograph of an array of printed V-shaped antennas with varying interior angles. **(b)** Amplitude of absolute cross polarized transmittance for four different printed V-Shaped antennas with interior angles of 60°,90°,120° and 180°. At a frequency of .12THz all four antennas have the same cross polarized transmittance of 9%. **(c)** Phase of cross polarized radiation for the same four printed V-Shaped antennas. At a frequency of .12THz the phase separates between the four antennas with a maximum phase shift of 125°.

This ink-jet printing technique allows for rapid and cheap production of structures with resolution appropriate for the THz and millimeter wave regime.

II. RESULTS

Fig. 1a shows an example of a printed array of V-shaped antennas using conductive silver ink. The individual cross-polarized amplitude and phase response of each of the 4 structures is shown in Fig. 1b and 1c. At a frequency of .12THz the transmittance of all 4 structures is equal to 9%, while the phase response for the 4 geometries is spread evenly across 125°. Thus, by controlling the geometry of the V-shaped structures, a point of constant amplitude but varying phase can be created.

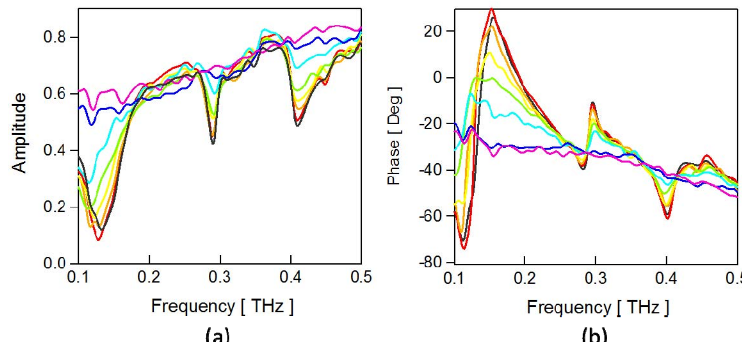

Fig 2: Co-Polarized Amplitude and Phase response of an array of 180° V-shaped plasmonic antennas, or simple dipole antennas, where the conductivity of the structures are varied by changing the ratio of silver and carbon ink. The ratio of silver and carbon ink is varied from 100% silver ink to 100% carbon ink over 8 steps. **(a)** Measured amplitude or absolute transmission through the array of dipoles as a function of frequency. Clear resonant feature are visible at the designed frequencies of 150 and 300 GHz for the 100% silver structures which washes out as the ratio of carbon ink is increased. **(b)** Measured phase response for the array of plasmonic dipoles. At the amplitude resonance peak locations of 150 and 300 GHz the phase remains relatively unchanged for the samples of varying conductivity.

Fig. 2a and 2b show the co-polarized amplitude and phase response for an array of printed dipole antennas, where the conductivity of the dipoles is varied by changing the ratio of silver and carbon ink. Here at the design frequencies of .15THz and .3THz, the resonance amplitude of the dipole changes significantly with changes in conductivity. However, the phase response right at the resonance frequency remains unchanged with varying conductivity. Thus we show we can simultaneously control both amplitude and phase of v-shaped antennas by changing geometry and conductivity respectively.

REFERENCES

[1] N. Yu and F. Capasso, "Flat optics with designer metasurfaces," Nat. Mater. 13, 139–150 (2014).