Toward Artificial Magnetism Using Terahertz Split Ring Resonator Metamaterials

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Abstract: **Split Ring Resonator arrays have been fabricated to demonstrate magnetic resonance in the terahertz regime. Spectroscopic transmission measurements as a function of oblique angle enable quantitative values of the permeability to be calculated**

I. INTRODUCTION

Metamaterials are emerging as engineered material structures that can be fabricated toward specific magnetic and/or electrical characteristics. Research in the field of negative refractive index and metamaterials has produced demonstrations of artificial magnetic resonances based on split ring resonator (SRR) arrays spanning from the microwave regime [1] to wavelengths in the visible range [2]. In a mirror-symmetrized configuration of SRRs, a rigorous characterization of the magnetic resonance is possible, complete with retrieval of quantitative values for the permeability. In a non-symmetrized array, as demonstrated in the infrared [3], the additional complications of the SRR-light interaction discourages this retrieval. This paper describes the first measurements of the transmission of near-terahertz electromagnetic waves as a function of oblique angle, which will enable the first quantitative retrieval of the permeability. Initial spectroscopic results are presented, demonstrating the anticipated magnetic resonance behavior.

II. FABRICATION AND MEASUREMENT

First, the SRR samples were fabricated on Si. A n-doped, low resistivity, double side polished Si wafer was spin-coated with benzocyclobutene (BCB). BCB was chosen for its moderate dielectric constant ($\varepsilon = 2.4$) and low losses in the terahertz range, as well as ease of fabrication. The thickness of this BCB layer is uniform across the sample surface, and quite consistent between samples - ranging between 10.2µm to 11 µm. A split ring resonator array, in a mirror-symmetric arrangement, was patterned on top of this BCB layer via photolithography using AZ5214 negative photoresist.

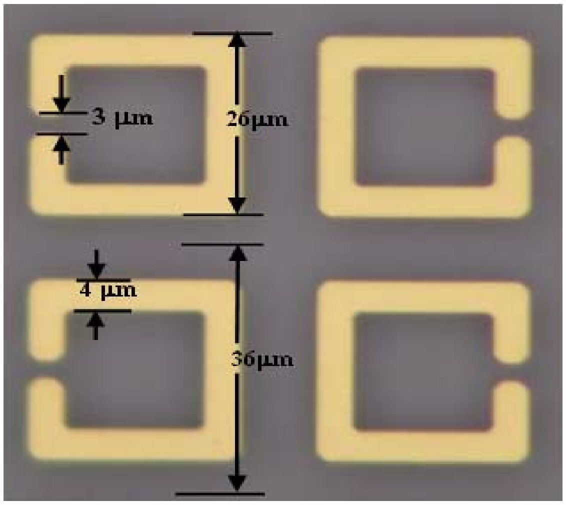

Figure 2. Mirror - symmetric split ring resonator array simulated to resonate at 1.29 THz.

Gold of thickness 100 nm was then deposited onto the sample by electron beam evaporation. This was followed by a lift-off process in acetone at 80 °C that left only metal SRRs on the BCB. A dimensioned photomicrograph of one of these samples is shown in Figure 1.

Finite element simulations indicated that this SRR array had a lowest order magnetic resonance at 1.29 THz, and so the spectroscopic investigation was

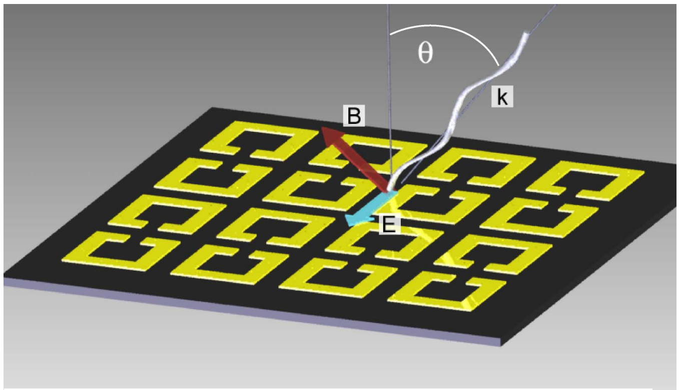

Figure 1. Rendered picture illustrating the polarization and orientation of the sample.

initiated near this region. The magnetic resonance of the sample was probed using s-polarized infrared light incident at an angle θ from the normal. It is important that the sample be oriented such that the electric field is aligned along the two symmetric legs of the SRR - to eliminate magneto-electric coupling which would complicate the analysis. Figure 2 illustrates the orientation of the sample structure and the polarization. The transmission through the entire sample was measured. The magnetic resonance is understood to result from out-of-plane **B**-field components coupling to the SRRs - which act as small Faraday loops. Thus for normal incidence light, magnetic coupling is not expected to be observed - as the **B**-field is entirely in-plane. As the incidence angle deviates from normal, the transmission spectra should begin to show the presence of magnetic oscillator interaction.

The expected gradual onset of the magnetic resonance at oblique angles is clearly visible in the transmission spectra shown in Figure 3. Figure 3 shows preliminary transmission data from 0.8 to 1.6 THz for three incidence angles: 0°, 30°, and 45°. The large oscillations in transmission amplitude are Fabry-Perot interference fringes from multiple internal reflections within the silicon substrate. Enveloped on top of these Fabry-Perot fringes, there are two noticeable trends with increasing angle. The first is a decrease in the overall level of transmission – expected for oblique incidence on any static dielectric such as the silicon substrate and BCB layer. The second is a sharp dip in transmission amplitude at 1.25 THz, which deepens as θ increases and is coupled to the magnetic mode.

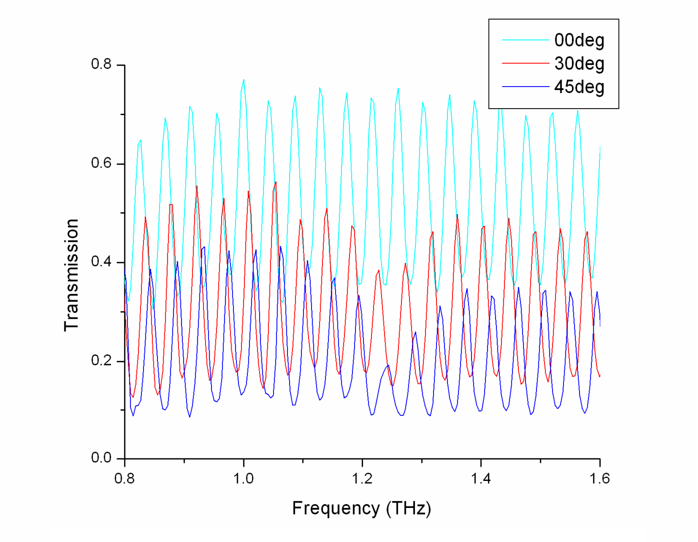

Figure 3. Experimental transmission spectra for three incidence angles: 0^0, 30^0, 45^0. The magnetic oscillator introduces an angle-dependent dip at 1.25 THz.

The shape of this transmission dip at multiple angles contains the entirety of the information about the magnetic oscillator, namely, the complex value of the permeability at each frequency. By treating the sample as a 3-layer boundary value problem (Silicon, BCB, SRRs) for which the continuity of the electric field and its derivative are enforced at each interface, the net transmission through the sample as a function of angle can be solved analytically. This will then enable the calculation of the complex permeability dispersion curve, using datasets from multiple angles to remove any ambiguity.

III. CONCLUSION

We have fabricated planar SRR metamaterials resonating at 1.25 THz. Oblique angle spectra taken for this sample exhibit the predicted transmission dip resulting from the magnetic resonance. This data is an important step towards obtaining the first quantitative measurement of metamaterial permeability.

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