Metamaterials for the Terahertz Gap

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***Abstract*—Metamaterials are engineered materials which offer superb electromagnetic performance over naturally occurring materials, and offer great potential to construct novel devices operating in the terahertz frequency regime. Here we experimentally demonstrate metamaterial narrow band filters, perfect absorbing elements for THz imaging, and ultra-fast THz switches. Experiments are supplanted with simulation and theory, thus verifying high performance.**

I. Introduction And Background

RECENTLY, there has been considerable effort to construct engineered electromagnetic (EM) materials for operation specifically within the terahertz gap[1]. Artificial systems, called metamaterials, are composites whose EM properties originate from oscillating electrons in unit cells comprised of highly conductive and shaped metals such as gold or copper. The sub-wavelength unit cell is replicated to form a material, which allows for a designed resonant response of the metamaterial's electrical and magnetic properties. Metamaterials can be regarded as effective media and characterized by a complex electric permittivity $\varepsilon(\omega) = \varepsilon_1(\omega)+i\varepsilon_2(\omega)$ and complex magnetic permeability $\mu(\omega) = \mu_1(\omega)+i\mu_2(\omega)$.

For many potential THz applications it would be desirable to have low loss materials, but with significant EM response, such that basic efficient components can be fashioned. Metamaterials are candidate materials since, one can construct “unit cells” which offer magnetic, or electric response. As such, and since μ and ε are the only two materials parameters which enter Maxwell’s equations, in principle metamaterials may be constructed to yield any desirable EM response, consistent with causality.

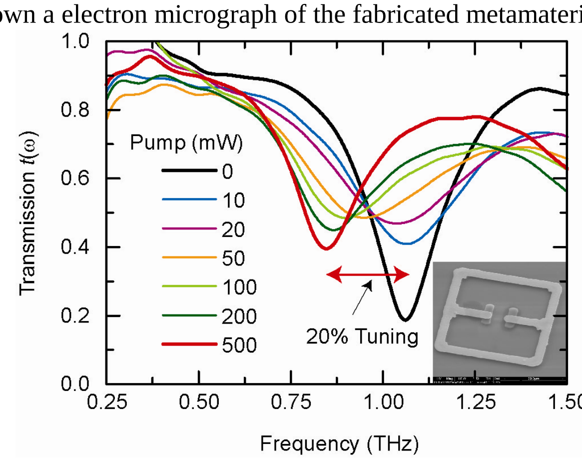
We experimentally demonstrate state-of-the-art performance of metamaterials operating at THz frequencies, thus evincing their superiority over naturally occurring materials and verifying their potential for the construction of novel devices.

II. Results

In 2007 we demonstrated the first active MM device capable of efficient real-time control and manipulation of THz radiation[2]. Modulation of the THz transmission was accomplished by voltage control of substrate properties using Schottky diode electric MM structures. The observed performance indicates that MM devices have significant potential to operate as narrowband THz switches/modulators or real-time filters as we demonstrated a 50% modulation of the transmitted THz intensity. This represents an order of magnitude improvement in comparison to the previous existing state-of-the-art.

We further experimentally demonstrate new metamaterial designs which yield frequency agility at terahertz frequencies (see Figure). Through optical photodoping we demonstrate tuning of the resonance by 20% in frequency. Methods utilized here are highly integrable with current semiconductor technologies, and can be implemented in other ranges of the electromagnetic spectrum, including the mm-wave regime.

Figure: THz electric field transmission amplitude of the metamaterial. Experimental measurements as a function of photoexcitation power, thus demonstrating 20% tuning. Inset shown a electron micrograph of the fabricated metamaterial.



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