Plasmonics and Metamaterials: Linear and Nonlinear Optical Properties

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Recently, there have been dramatic advances in our ability to fabricate nano-photonic materials exhibiting important new optical properties in the near-infrared and optical regions. In particular, interferometric lithography has emerged as a promising technique for the fabrication of large-area (several cm^2) samples that allow thorough investigations of the linear and nonlinear optical properties of these materials. Two related structures have recently been demonstrated: *i*) a plasmonic structure composed of a 2D array of coaxial apertures in a metal sheet, and *ii*) a negative index material consisting of a metal/dielectric/metal-film stack perforated with a 2D array of nanoscale apertures. For the plasmonic structure a transmission of 80% of the incident light through an ~16% open area has been demonstrated. The angular dependence of the transmission spectra clearly show Fano couplings between the two surface plasma waves (Au-glass and Au-air) and the cutoff of the TE_{11} coaxial mode of the aperture. The tuning of these resonances to mid-IR on a high-index substrate (GaAs) has been demonstrated. The first demonstration of second-harmonic generation in these structures using a material with a strong, allowed $\chi^{(2)}$, experimentally confirming the enhancement of the electric fields in the vicinity of the apertures, as well as a spectral simulation in excellent agreement with the experiment will be presented. These structures have potential applications as plasmonic antennas, allowing subwavelength detectors with reduced noise, throughout the infrared. The nonlinear optical experiments point towards applications as infrared and optical mixers without the need for phase matching. For the metamaterials, both the amplitude and phase of the reflection and transmission of the negative index material have been experimentally determined, allowing extraction of the complex refractive index without resorting to a model calculation. The experimentally determined refractive index is as large as –2 at 2 μm. A parametric optimization of this structure is presented and an improved material with a transmission > 40% in the negative index region and a significantly improved loss figure of merit, -Re(n)/Im(n), is experimentally demonstrated. The evolution of these results to thicker negative index materials using multiple layers will be discussed.