Large-Area Negative Index Metamaterials and Plasmonic Devices by Printing and Molding

John A Rogers
Department of Materials Science and Engineering, University of Illinois, Urbana, IL 61801
jrogers@ad.uiuc.edu

This talk will focus on two of our recent efforts in fabrication techniques for large-area photonic materials. The first involves negative index metamaterials (NIMs), which are engineered structures with optical properties that cannot be obtained in naturally occurring materials. Recent work demonstrates that focused ion beam and layer-by-layer electron beam lithography can be used to pattern the necessary nanoscale features over small areas (100's of µm2) for metamaterials with three-dimensional (3D) layouts and interesting characteristics, including negative index behavior in the optical regime. A key challenge is in the fabrication of such 3D-NIMs with sizes and at throughputs necessary for realistic applications in high resolution lenses, compact resonators and highly directional sources , zero-index materials for reversed Doppler effect and optical tunneling devices, and other advanced photonic components. In this talk, we describe a simple printing approach capable of forming large-area, high-quality NIMs with 3D, multilayer mesh (i.e. fishnet) formats. Here, a silicon substrate with deep, nanoscale patterns of surface relief serves as a reusable stamp. Blanket coating alternating layers of silver (Ag) and magnesium fluoride (MgF_2) onto such a stamp represents a process for 'inking' it with thick, multilayer assemblies. Transfer printing this ink material onto rigid or flexible substrates completes the fabrication in a high throughput manner. Experimental measurements and modeling results show that macro-scale, 3D-NIMs (> 75 cm^2) nano-manufactured in this way exhibit strong, negative index of refraction behavior in the near-infrared (NIR) spectral range, with excellent figures of merit.

The second effort is in the field of plasmonics, which has emerged as an interesting area for fundamental studies, with important application possibilities in biosensing, photovoltaics, sub-wavelength lithography, miniaturized photonics and others. Two and three dimensional plasmonic crystals are of particular relevance due to large field enhancements and extraordinary transmission that occur due to plasmonic interactions between periodic arrays of metallic structures. This talk describes methods to enhance and modify the plasmonic resonances in such structures by strongly coupling them to optical modes of Fabry-Perot type cavities, in monolithic assemblies formed over large areas using the techniques of soft imprint lithography. The underlying effects are examined through combined experimental and modeling studies, and demonstrate means to exploit them in two different ways. First, we illustrate a type of plasmonic, narrow-band (~15 nm), high constrast (>20 dB) absorber and an opto-fluidic modulator based on this component. Second, we use optimized samples as substrates to achieve strong amplification (> 350%) and modulation (>4x) of surface enhanced Raman scattering from surface bound monolayers. Cavity coupling strategies appear to be useful not only in these two examples, but also in many applications of plasmonics for optoelectronics, photovoltaics and related areas.