Experimental demonstration of resonant coupling to a dipole absorber inside a metamaterial: hybridization of the negative index response

S. Smolev[1], Zahyun Ku[1], S. R. J Brueck[1], I. Brener[2], M.B. Sinclair[2], G. A. Ten Eyck[2], W. L. Langston[2] and L.I. Basilio[2]
[1]*Center for High Technology Materials, University of New Mexico*
[2]*Sandia National Laboratories*
Email: smolev@chtm.unm.edu

Abstract: We demonstrate a resonant coupling and hybridization between the structural resonance in the permeability of a fishnet and a material resonance in the dielectric spacer layer. Experimental data shows a good agreement with theory.

There is a large and growing activity in the physics and applications of the negative index metamaterials. The infrared spectral region is of a particular interest because metal properties are in-between their very high conductive properties in the RF and the lossey plasmonic characteristics in the visible. For some applications it is interesting to consider the coupling between the metamaterial resonance and an absorbing species located in the metamaterial unit cell. We present modeling and experimental results for a fishnet metamaterial with the dielectric spacer layer containing a simple Lorentzian electric-dipole resonance where a classical anti-crossing behavior was observed. Detection of absorption in novel sensors and use of absorption excitation to alter and switch the metamaterial optical properties are possible applications.

A simple resonance coupling model was constructed to investigate the effect of adding a dielectric with a dipole absorption peak to a fishnet metamaterial. Anti-crossing behaviors and an exchange of oscillator strength as metamaterial structural resonance is tuned through the absorption resonance were observed.

Rigorous coupled wave analysis (RCWA), an algorithm used to calculate the normal incidence transmission and reflection of periodic structures, was used for detailed numerical modeling. Response of the fishnet structure with a dielectric material without an absorber shows only a single resonant peak, resulting from the coupling of the broadband negative ε with the structurally resonant negative μ associated with the LC circuit between the two metal plates. With the addition of a dipole absorber in the dielectric, the fishnet exhibits doubly resonant behavior. Presence of an *electric dipole* resonance in the dielectric of the fishnet structure manifests itself in a modification of the *magnetic permeability*, which in turn modifies the negative index behavior. Anti-crossing behavior of the two resonances is observed. The RCWA calculation and the simple model are in good agreement.

A set of experimental samples with structural resonances spanning 7.4 (0.167 eV) to 10.3 (0.12 eV) μm were fabricated using standard lithographic and cleanroom processing. An Al-bisbenzocyclobutene (BCB)-Al fishnet structure was used. Transmission data were obtained by FTIR. Plotting positions of the resonance peaks in the transmission response against ω_0 clearly shows coupling between the resonances with classical anti-crossing behavior and is in the good agreement with the modeling. Detailed results will be presented.

Acknowledgment: This research was supported by the Laboratory Directed Research and Development program at Sandia National Laboratories. Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation, a Lockheed-Martin Company, for the U. S. Department of Energy under Contract No. DE-AC04-94AL85000.

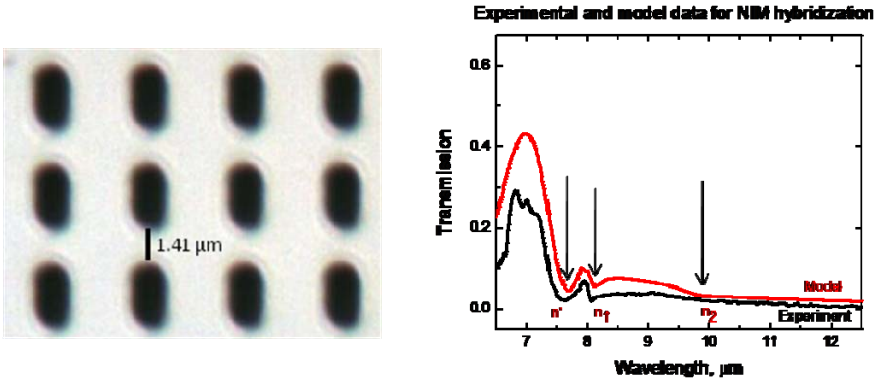

Figure 1. Optical microscope image of a Al-BCB-Al fishnet sample manufactured using standard lithographical and cleanroom process (left); Transmission curves obtained by RCWA model and FTIR measurement (right) for the sample with a metamaterial structural resonance at 7.4 μm (0.167 eV). Structural and absorption resonances (*n'* and n_1) are shifted from their original positions, though hybridized.

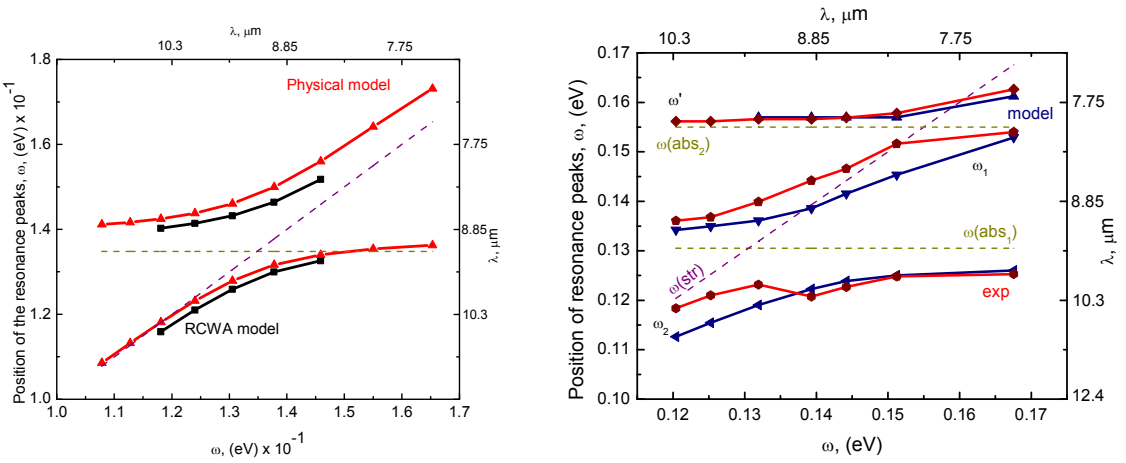

Figure 2. Theoretical physical and RCWA models for a single absorption resonance (left) and experimental data (right) demonstrates the classical anti-crossing behavior of the fishnet structure with a BCB absorber, with two dipole resonances at 7.9 μm (0.157 eV) and 9.5 μm (0.13 eV) in the dielectric material. Resonant frequencies of the fishnet structure are tuned through the electric dipole resonances of the bare absorber. Hybridization and an anti-crossing behavior are clearly observed in both experimental and model data with good agreement. The red curves (right) are obtained from experimental data; blue curves (right) are from the RCWA model.