Optical Magnetic Response in All-dielectric Metamaterial

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Abstract: We experimentally demonstrate a new mechanism to achieve magnetic resonances at visible and near-infrared frequencies in purely dielectric metamaterials, realized through a coupling between pairs of closely spaced, dissimilar dielectric rods.

For a decade and more, considerable effort has been focused on the engineering of metamaterials to achieve artificial optical magnetism, not least for applications in negative refractive media. However, these efforts have been hampered by the fact that the metals conventionally employed as the foundation of photonic metamaterials suffer from high inherent energy dissipation due to resistive losses. It has recently been suggested that dielectric structures may deliver an optical magnetic response based on Mie/cavity resonances [1] and we demonstrate experimentally here that near-infrared magnetic resonances akin to the well-known 'trapped mode' response of metallic asymmetric split rings [2], can be realized in all-dielectric metamaterials through a coupling between closely spaced, dissimilar dielectric nano-rods.

Samples were fabricated in PECVD silicon on a silica substrate via electron-beam lithography and RIE or by focused ion beam milling. The metamaterials comprise square arrays of 900 nm unit cells - each cell containing two silicon bars of matching height and width but different lengths (Fig. 1a). Optical transmission, reflection and absorption spectra for the metamaterial show a resonance at around λ = 1700 nm for normally incident light polarized (i.e. with electric field) parallel to the long axis of the dielectric bars. The resonance depends critically on the asymmetry between the pairs of dielectric bars. Indeed, control samples with unit cells comprising pairs of identical bars show no resonance (Fig. 1b).

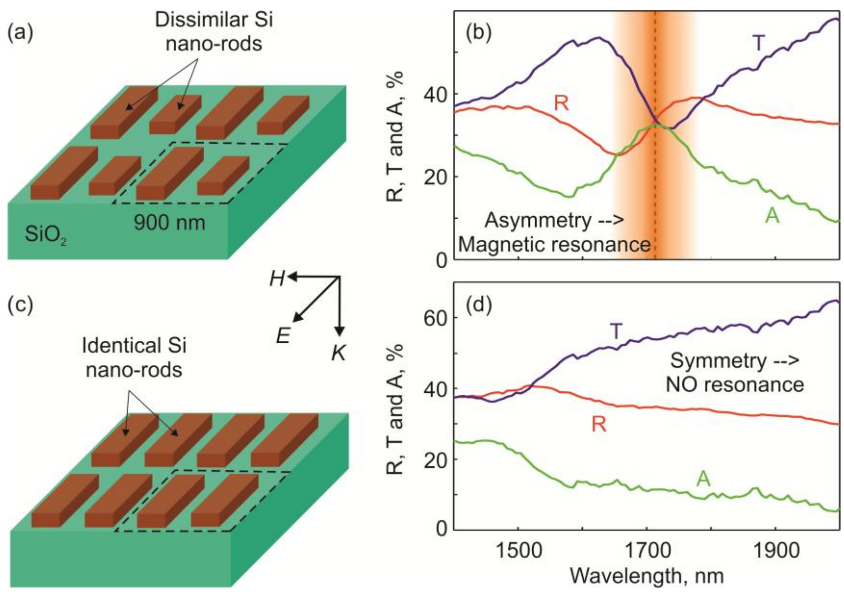

Figure 1: Near-IR magnetic resonance in an all-dielectric metamaterial. *(a) Schematic fragment of an all-dielectric (silicon on silica) metamaterial array with unit cells comprising asymmetric nano-rod pairs. (b) Experimentally measured reflection, transmission and absorption spectra for such a structure. (c, d) Equivalent schematic illustration and spectral data for a symmetric structure in which all Si nano-rods are of equal length (no magnetic resonance).*

Full-wave electromagnetic numerical simulations reveal that the resonance in the asymmetric array originates from electric coupling to the magnetic resonances of the dielectric structure. Manufacturing imperfections limit magnetic resonances quality factors to values Q ~15 in current experimental samples, but computational models indicate that values of several hundred may be achieved at visible and near-infrared wavelengths in silicon metamaterials.

In summary, we have experimentally demonstrated a new type of planar dielectric metamaterial composed of asymmetric silicon nano-rods, which exhibits sharp magnetic resonances in the VIS-NIR range. These structures offer a new route to the realization of low loss optical magnetism at such frequencies and new opportunities in the development of lasing spasers.

References:

[1] V. Khardikov, E. Iarko, and S. Prosvirnin, *J. Opt.* **14,** 035103 (2012)
[2] V. A. Fedotov, M. Rose, S. L. Prosvirnin, N. Papasimakis, and N. I. Zheludev, *Phys. Rev. Lett.* **99,** 147401 (2007)