Optical Magnetism in all-dielectric Metamaterials

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For more than ten years now, significant effort has been focused on the engineering of metamaterials to achieve artificial optical magnetism, most notably for applications in negative refractive media. However, the challenges associated with the fact that the metals conventionally employed as the foundation of photonic metamaterials suffer from high inherent energy dissipation due to resistive losses remain. It has been shown recently that dielectric structures can provide optical magnetic responses based on Mie/cavity resonances [1] and here we experimentally demonstrate that near-infrared magnetic resonances, analogous to the 'trapped mode' response familiar to metallic asymmetric split rings [2], can be realized in all-dielectric metamaterials via coupling between pairs of closely spaced, geometrically dissimilar nano-bars.

Metamaterial samples were fabricated in PECVD silicon films on silica substrates by focused ion beam milling. These comprise square arrays of 900 nm unit cells, each containing a dissimilar pair of silicon bars with identical height and width but differing 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 nano-bars (Fig. 1b). The critical importance of the asymmetry within the metamaterial unit cell to this resonance is illustrated by control samples with symmetric unit cells, comprising pairs of identical bars, which display no resonance (Fig. 1c).

Full three-dimensional numerical simulations reveal that the resonance in the asymmetric dielectric array originates from electric coupling to the magnetic resonances of the structure. The magnetic resonance quality factor to values Q ~15 in current experimental samples by fabrication imperfections but the computational model indicates that Q-factors of several hundred may be achieved by silicon-based metamaterials in the visible and near-infrared spectral range.

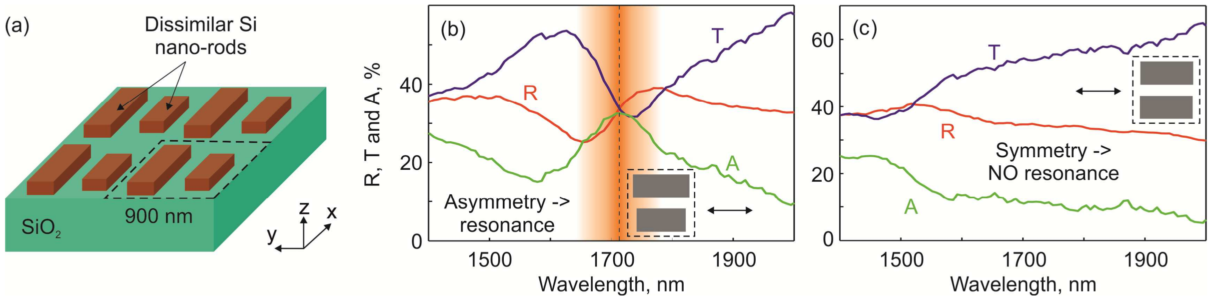

Fig. 1 Near-IR magnetic resonance in an all-dielectric metamaterial. (a) Schematic fragment of an all-dielectric (silicon on silica) metamaterial array with unit cells comprising asymmetric nano-rod pairs. (b, c) Experimentally measured reflection, transmission and absorption spectra for such a structure, with a clear resonance at a wavelength of ~1700 nm, and for a symmetric control sample in which all Si nano-bars are of equal length (no magnetic resonance).

In summary, we experimentally demonstrate a new form of planar dielectric metamaterial, comprising asymmetric silicon nano-bar unit cells, exhibiting a sharp magnetic resonance in the VIS-NIR range. Such structures open new paths to the realization of low loss magnetism at optical frequencies and the exploitation of optical forces on the nanoscale, and they present new opportunities for controlling the output of quantum emitters and developing ‘lasing spasers’.

References

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