Nano-opto-mechanical Nonlinear Dielectric Metamaterials

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We report on the realization of free-standing all-dielectric metamaterials in a variety of ultra-thin, low-loss, high-index media. With sharply resonant optical properties in the near-IR (telecoms) wavelength range, nanoscale dimensions and mechanical Eigenfrequencies in the hundreds of MHz range such structures may be dynamically reconfigured by optical forces at low illumination intensities.

Recent efforts to circumvent the strong energy dissipation (resistive losses) inherent to noble metal platforms for plasmonics and photonic metamaterials have seen the emergence of alternative architectures based on a range of low-loss, high-index dielectrics and semiconductors. All-dielectric photonic metamaterial designs are almost invariably 'positive' structures based on assemblies of discrete nanoparticles/rods/rings supported by transparent low-index substrates, engineered to present resonant responses based on (often coupled) Mie/cavity modes. Here, we experimentally demonstrate free-standing all-dielectric photonic metamaterials based on 'negative' slot patterns in continuous nano-membranes of media such as silicon nitride, silicon and diamond.

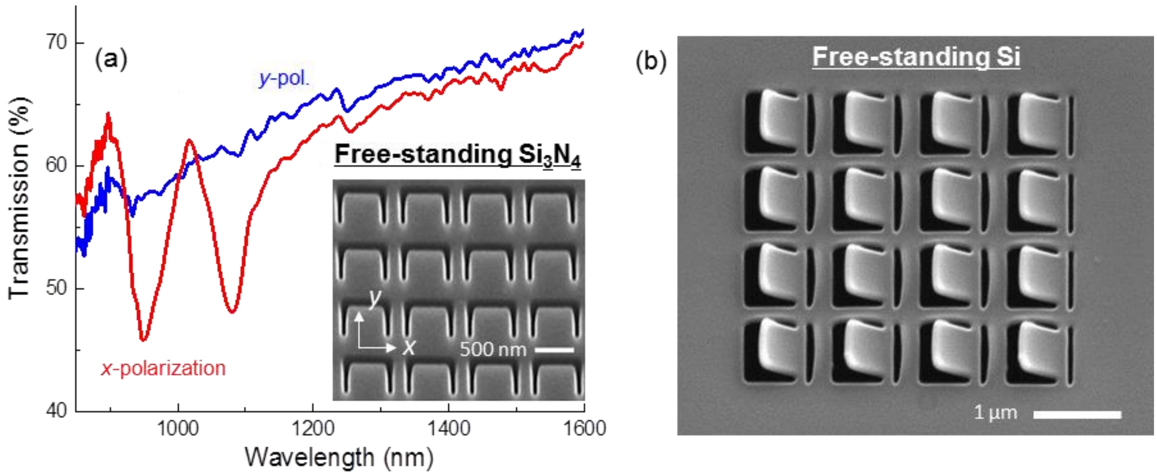

Fig. 1 Free-standing dielectric nano-membrane metamaterials: (a) Measured transmission spectra, for *x*- and *y*-polarized normally incident on a 100 nm thick free-standing silicon nitride ⊓–slot metamaterial array [a section of which is shown in the inset electron microscope image]. (b) Asymmetric split ring metamaterial array in 100 nm thick free-standing silicon (with stress-induced pre-tilt of the cantilever arms).

Samples are fabricated in membranes of deeply sub-wavelength thickness via focused ion beam milling. The metamaterials typically comprise square arrays of micron scale unit cells - each cell containing a slot pattern such as the ⊓ shape illustrated in Fig. 1a. High-*Q* resonances at near-infrared wavelengths are observed in optical transmission spectra for normally incident light polarized parallel to the opening of the ⊓-slots. Full-wave numerical simulations reveal that the resonances relate to interactions among a family of bright and dark modes excited within the dielectric structure. Manufacturing imperfections/inhomogeneities thus far limit resonance quality factors to Q ~80, but computational models indicate that values several times higher may ultimately be achieved.

Such structures can exploit the unique technological and manufacturing opportunities provided by dielectric/semiconductor membrane technology, not least their mechanical flexibility – the optical forces generated in low-loss dielectric metamaterials at sub-mW/µm^2 intensities [1] are sufficient to deform elements of the structure (e.g. deflecting the nano-cantilever within each cell of structures shown inset to Fig. 1a and in Fig. 1b), providing a mechanism for fast, strongly nonlinear tuning of optical properties at low intensity. Deformations of just a few nanometres are sufficient to dramatically change the optical properties of such structures and will be maximized at their mechanical Eigenfrequencies, offering potentially huge opto-mechanically nonlinear responses at frequencies in the hundreds of MHz range.

References

[1] J. Zhang, K. F. MacDonald, and N. I. Zheludev, "Giant Optical Forces in Planar Dielectric Photonic Metamaterials," Opt. Lett. **39**, 4883 (2014); "Nonlinear Dielectric Optomechanical Metamaterials," Light Sci. Appl. **2**, e96 (2013).