Nonlinear Dielectric Optomechanical Metamaterials

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Abstract: We introduce a dielectric photonic metamaterial presenting a giant nonlinear optical response driven by resonant optomechanical forces. It exhibits optical bistability and nonlinear asymmetric transmission at intensity levels of only a few hundred μW/μm^2.

Optical forces are extremely important in mesoscopic systems: they are exploited in all forms of optical tweezing, manipulation and binding, as well as for actuation of nanophotonic devices [1]. Here we introduce the concept of optomechanical metamaterials – a new type of dielectric metamaterial that provides strongly nonlinear and asymmetric optical properties via the mutual interaction of optical and mechanical responses to low intensity illumination.

Metamaterials provide a unique platform for manipulating electromagnetic fields, and thereby optical forces, on the nanoscale [2]. The optomechanical metamaterial considered here comprises an array of dielectric meta-molecules supported on free-standing elastic beams (Fig.1a). The metamaterial supports a Fano-type optical resonance in the vicinity of which strong, illumination-direction-dependent optical forces are generated within and among the dielectric meta-molecule cells (Fig.1b). Numerical analyses reveal that these optomechanical forces provide a strong nonlinear optical response mechanism delivering optical bistability at intensity levels of only a few hundred μW/μm^2. Furthermore, it is found that the structure manifests nonlinear asymmetric transmission with a forward:backward optical extinction ratio of more than 30 dB at an intensity level of less than one hundred μW/μm^2.

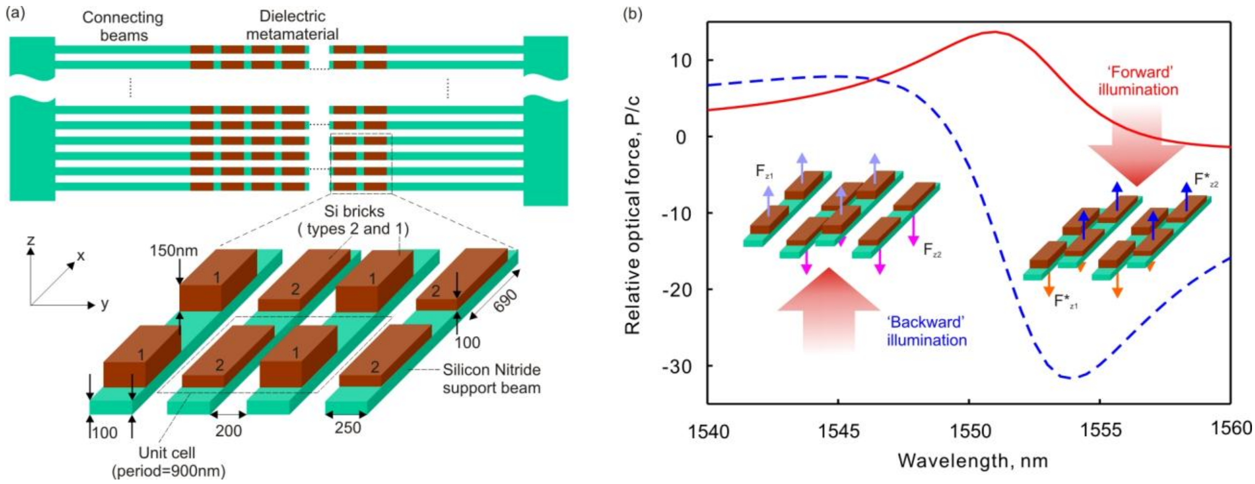

Figure 1: Asymmetric optomechanical forces in a dielectric photonic metamaterial. *(a) Artistic impression and dimensional details of the parallel silicon nitride beam, silicon 'nano-brick' metamaterial configuration studies; (b) Spectral dispersion of the relative optical force F on the two nano-brick elements of a single metamaterial unit cell under normally-incident x-polarized illumination for both forward (-z) and backward (+z) directions of light propagation. [*$F^{cell}_{opt.} = F_{z2} - F_{z1}$*, where* F_{z1} *and* F_{z2} *are the optical forces on the thick and thin bricks respectively; Optical force is presented in units of P/c, where* $P = P_0/N^2$ *is the incident power per unit cell,* P_0 *being the total power incident on the metamaterial array of* N^2 *cells.]*

Optomechanical metamaterials merges concepts of nanophotonics and nanomechanics to present considerable potential for all-optical operation of nanomechanical systems, reconfigurable and ultra-widely tuneable nanophotonic devices, and novel nonlinear and self-adaptive nanomechanical photonic functionalities.

References:

[1] D. Van Thourhout, and J. Roels, Nat. Photon. 4, 211 (2010).
[2] J. Zhang, K. F. MacDonald, and N. I. Zheludev, Phys. Rev. B 85, 205123 (2012).