Optomechanical Nonlinearity and Bistability in Dielectric Metamaterials

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

Metamaterials provide a unique platform for confining and manipulating light, and therefore optical forces, on the nanoscale [2]. We consider here an optomechanical metamaterial comprising an array of dielectric (silicon) asymmetric meta-molecules supported on free-standing elastic beams (of silicon nitride) as illustrated in Fig. 1a. This metamaterial structure supports a Fano-type optical resonance around which strong, illumination-direction-dependent optical forces are generated within and among the meta-molecule cells. Numerical analyses, based on computationally simulated electromagnetic field distributions and the Maxwell stress tensor, reveal that these forces provide a strong nonlinear optical response mechanism (Fig. 1b) delivering optical bistability at intensity levels of only a few hundred $\mu W/\mu m^2$. It is also found that the structure manifests nonlinear asymmetric transmission with an extinction ratio (forward:backward) greater than 30 dB at an intensity of order one hundred $\mu W/\mu m^2$.

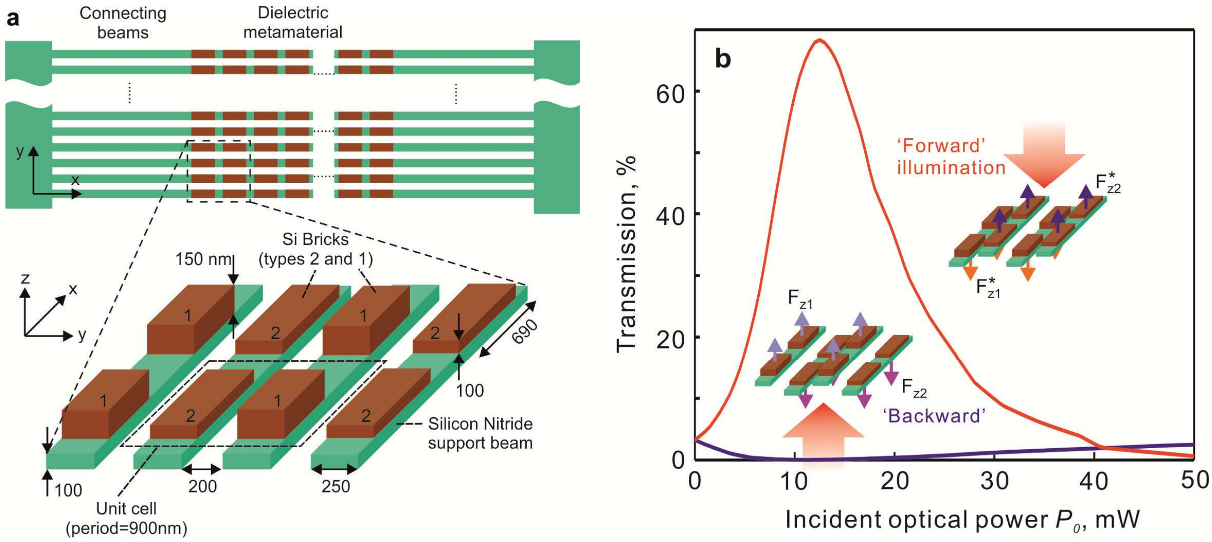

Fig. 1 Asymmetric optomechanical forces in a dielectric photonic metamaterial. (a) Artistic impression and dimensional details of the parallel silicon nitride beam, silicon 'nano-brick' metamaterial configuration studied; (b) Dependencies of metamaterial optical transmission on total incident power at a wavelength of 1551 nm under normally-incident x-polarized illumination for both forward (-z) and backward (+z) directions of light propagation, showing a forward:backward extinction ratio>30 dB at an incident power (on a nano-bar metamaterial array area of 10.6 µm x 10.6 µm) of 12.5 mW.

Optomechanical metamaterials merge 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. They may exploit unique technological and manufacturing opportunities provided by semiconductor membrane technology and, in being driven by forces generated among their constituent parts (as opposed to external actuators), hold notable advantages over conventional M/NEMS structures, particularly in relation to size scaling for different operational wavelength bands.

References

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