Nanomechanical photonic metamaterials

Eric Plum[1]

1. University of Southampton, UK

The optical properties of materials are determined by the spatial arrangement of their building blocks. For example, graphite, diamond and nanotubes are different arrangements of the same carbon atoms with vastly different properties. Over the past decade, actuation of photonic metamaterials has been enabled by nanostructuring of membranes of nanoscale thickness to form metamaterial arrays with flexible beams or cantilevers. Such structures can be deformed by temperature (Fig. 1a) [1], electrical current and voltage, magnetic field, sound and light [2]. They can be used as sensors, e.g. nanobolometers [3] and magnetic field sensors [4]. They can modulate light from Hz to 100s of MHz [5]. Control over individual mechanical elements promise spatial light modulators with sub-wavelength resolution (Fig. 1b) [6]. Nanomechanical photonic metamaterials can be engineered to exhibit effects that are orders of magnitude stronger than in natural materials, e.g. optical nonlinearities [5, 7], electrostriction [8] and electrogyration [9]. They can also exhibit phenomena that are not present in natural materials, e.g. nonlinear asymmetric transmission (Fig. 1c) and low-power optical bistability (Fig. 1d) [10].

This talk will provide an overview, focusing on recent breakthroughs such as the optical detection of thermal motion in nanomechanical metamaterials [11], sensing based on metamaterial nanomechanics [3,4], electrogyration a million times stronger than in natural materials [9], the demonstration of nonlinear asymmetric transmission and the realization of an optically bistable device at microwatt power levels [10].

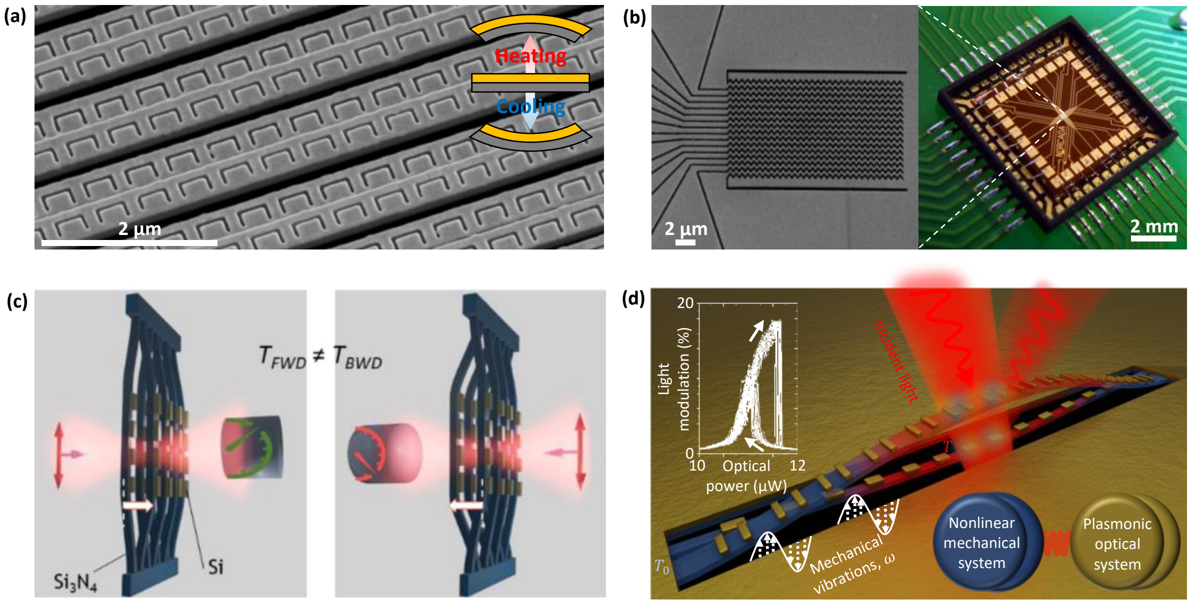

Fig. 1 Nanomechanical photonic metamaterials that are (a) thermally reconfigurable [1], (b) electrically addressable [6], (c) deformed by light causing nonlinear asymmetric transmission and (d) optically bistable [10].

References

[1] J. Y. Ou, E. Plum, L. Jiang, and N. I. Zheludev, "Reconfigurable photonic metamaterials," Nano Lett. 11(5), 2142-2144 (2011).
[2] N. I. Zheludev and E. Plum, "Reconfigurable nanomechanical photonic metamaterials," Nature Nanotech. **11**, 16 (2016).
[3] D. Papas, J. Y. Ou, E. Plum, and N. I. Zheludev, "Optomechanical metamaterial nanobolometer," APL Photonics 6, 126110 (2021).
[4] G. Lan, J. Y. Ou, D. Papas, N. I. Zheludev, and E. Plum, "Non-contact optical magnetic field sensor based on metamaterial nanomechanics," APL Photonics 7, 036101 (2022).
[5] A. Karvounis, J. Y. Ou, W. Wu, K. F. MacDonald, N. I. Zheludev, "Nano-optomechanical nonlinear dielectric metamaterials," Appl. Phys. Lett. **107**, 191110 (2015).
[6] P. Cencillo-Abad, J. Y. Ou, E. Plum, J. Valente, and N. I. Zheludev, "Random access actuation of nanowire grid metamaterial," Nanotechnology **27**, 485206 (2016).
[7] J. Y. Ou, E. Plum, J. Zhang, and N. I. Zheludev, "Giant nonlinearity of an optically reconfigurable plasmonic metamaterial," Adv. Mater. 28, 729-733 (2016).
[8] A. Karvounis, B. Gholipour, K. F. MacDonald, and N. I. Zheludev, "Giant electro-optical effect through electrostriction in a nanomechanical metamaterial," Adv. Mater. 31, 1804801 (2019)
[9] Q. Zhang, E. Plum, J. Y. Ou, H. Pi, J. Li, K. F. MacDonald, and N. I. Zheludev, "Electrogyration in metamaterials: Chirality and polarization rotatory power that depend on applied electric field," Adv. Opt. Mater., 9(4), 2001826 (2021).
[10] D. Papas, J. Y. Ou, E. Plum, N. I. Zheludev, "Volatile optical bistability enabled by mechanical nonlinearity," arXiv:2112.11087 (2021).
[11] J. Li, D. Papas, T. Liu, J. Y. Ou, K. F. MacDonald, E. Plum, and N. I. Zheludev, "Thermal fluctuations of the optical properties of nanomechanical photonic metamaterials," Adv. Opt. Mater. **10**(5), 2101591 (2022).