Advances in Nanomechanical Metamaterials

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Abstract

We report recent breakthroughs in nanomechanical metamaterials including (i) a giant acousto-optical effect, (ii) on/off switching of metasurfaces, (iii) selective electrical and optical actuation of metamaterials elements with sub-wavelength spatial resolution, (iv) phase-change metasurfaces with bistable optical and mechanical properties and (v) metamaterials tuned by electrostriction.

1. Introduction

The optical properties of metamaterials, and indeed any other material, depend strongly on the spatial arrangement of their components. This has enabled giant thermo-optical, electro-optical, magneto-electro-optical and nonlinear optical phenomena in photonic metamaterials fabricated on dielectric membranes of nanoscale thickness, where the nanostructure is rearranged by thermal, electrical, magnetic and optical forces [1]. Here we provide an overview focusing on recent advances.

2. Results

High-contrast modulation of light is of great practical importance. We observe giant acousto-optical modulation in a nanomechanical metamaterial that is actuated by ultrasound frequency vibrations. Such modulation exhibits strong nonlinearities and reaches relative reflectivity changes of up to 75% in a structure of only 100 nm thickness.

Exploiting electrostatic forces in nanomechanical metamaterial structures, we demonstrate novel approaches to electro-optical modulation based on (i) MEMS modulation of the interaction of light with a metasurface, essentially switching the metasurface on and off [2], and (ii) electrostriction in a nanomechanical metamaterial [3].

Dynamic control over optical properties at any point in space and time is arguably the ultimate metamaterials vision. We demonstrate both electrical and optical methods that enable selective actuation of nanomechanical metamaterial elements with sub-wavelength spatial resolution [4, 5].

Phase transitions enable bistable nanomechanical actuation associated with bistable optical properties. Exploiting phase change materials such as shape memory alloys [6] and chalcogenide glasses, we demonstrate nanomechanical metamaterials with optical memory functionalities.

3. Conclusions

In summary, we report recent advances in nanomechanical metamaterials, including light modulation based on acousto-optical, coherent electro-optical and electrostriction effects, optical and mechanical bistability based on phase transitions, and electric as well as optical nanomechanical actuation with sub-wavelength resolution.

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References

[1] N. I. Zheludev, E. Plum, Reconfigurable nanomechanical photonic metamaterials, *Nature Nanotech.* 11: 16, 2016.

[2] P. Cencillo-Abad, J. Y. Ou, E. Plum, N. I. Zheludev, Electro-mechanical light modulator based on controlling the interaction of light with a metasurface, *Sci. Rep.* 7: 5405, 2017.

[3] A. Karvounis, B. Gholipour, K. F. MacDonald, N. I. Zheludev, Giant electro-optical effect through electrostriction in a nano-mechanical metamaterial, *Adv. Mater.* 31: 1804801, 2019.

[4] 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.

[5] J. Y. Ou, E. Plum, N. I. Zheludev, Optical addressing of nanomechanical metamaterials with subwavelength resolution, *Appl. Phys. Lett.* 113 : 081104, 2018.

[6] Y. Nagasaki, B. Gholipour, J. Y. Ou, M. Tsuruta, E. Plum, K. F. MacDonald, J. Takahara, N. I. Zheludev, Optical bistability in shape-memory nanowire metamaterial array, *Appl. Phys. Lett.* 113 : 021105, 2018.