9th International Congress on Advanced Electromagnetic Materials in Microwaves and Optics – Metamaterials 2015
Oxford, United Kingdom, 7-12 September 2015

Random Access Photonic Metamaterials

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***Abstract* – We demonstrate the first addressable reconfigurable photonic metamaterials thus enabling control over optical material properties with simultaneous spatial and temporal resolution. Potential applications of random access metadevices include active focusing, beam steering, dynamic transformation optics and video holography.**

I. Introduction

Metamaterials are a paradigm for engineering electromagnetic space and controlling propagation of waves [1]. They provide a large range of novel functionalities, however, these are typically narrowband and fixed by design. Here we report the first solution for optical properties on demand in time and space: random access photonic metamaterials. In these metadevices, thermal, Lorentz or Coulomb forces drive a structural reconfiguration of the metamolecules which controls the near-field coupling between resonators and thus the local optical properties. In principle, this approach enables dynamic control over focusing, diffraction, polarization, propagation direction, intensity and phase of light.

II. Electrically Addressable Metamaterials

As photonic metamaterials derive their properties from the interaction of local fields between different plasmonic resonators, their properties are ultimately determined by the shape and spatial distribution of their metamolecular building blocks on the nanoscale. Therefore, by dynamically rearranging metamaterials on the

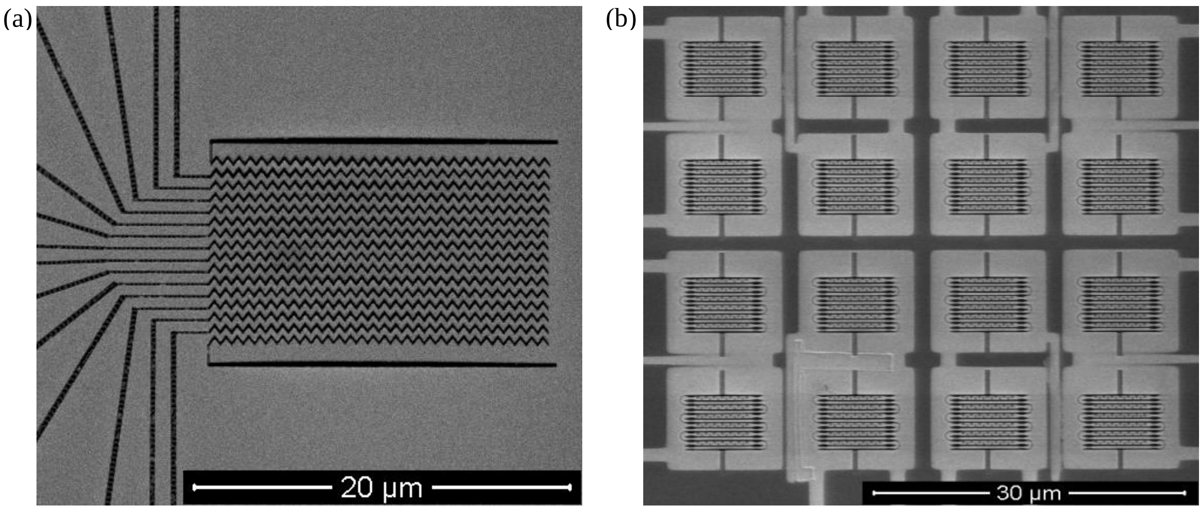

Fig. 1. Electrically addressable random access photonic metamaterials. (a) Photonic metamaterial with randomly addressable electrothermally reconfigurable rows of metamolecules. (b) Randomly addressable array of electrostatically reconfigurable metamaterials.

nanoscale one can control the interaction of the resonators with the incident fields and tune the optical properties of the metamaterial. Recently, we have introduced reconfigurable photonic metamaterials as a flexible platform for modulation of metamaterial properties in time, establishing a technology for fast, high-contrast tuning and modulation of metamaterial optical properties [2, 3]. However, applications from transformation optics to holography require also spatial resolution.

An ideal random access photonic metamaterial is a structure in which the resonant optical properties of every individual metamolecule can be controlled continuously. In case of metamaterials for the visible and near infrared, this requires rearranging metamaterials at the nanoscale.

Fig. 1 shows two implementations of random access photonic metamaterials manufactured by focused ion beam milling from a 50 nm gold layer supported by a 50 nm thick silicon nitride membrane. In both cases, the plasmonic resonators have been supported by separate free-standing bridges to allow for mechanical deformation in response to an electrical control signal.

Fig. 1a shows a one-dimensionally randomly addressable metamaterial consisting of free-standing gold-on-silicon nitride bridges, which have been cut into a chevron shape to introduce plasmonic resonances and to increase elasticity. These chevron bridges can be individually electrically addressed and deform out of the device plane due to differential thermal expansion in response to resistive heating by an applied electrical current. Further action of a transversal magnetic field gives rise to Lorentz forces that can reinforce or oppose to thermal displacement of the elastic chevron metamaterials. Electrothermal modulation is limited to 10s of kHz by the conductive cooling timescale of the nanostructure, while magnetic modulation can be driven to the mechanical resonances of the bridges at 100s of kHz.

Fig. 1b shows a two-dimensional 4x4 array of individually addressable metamaterials that deform within the device plane due to electrostatic forces between free-standing conductive beams in response to an applied voltage. The much stiffer design enables much faster electromechanical modulation of the nanostructure up to its mechanical resonances at 10s of MHz.

In random access photonic metamaterials local deformation of the nanostructure modulates the amplitude and phase of transmission and reflection of the semi-transparent nanostructure locally by modifying the near-field coupling between different metamolecules and their plasmonic components, introducing means for creating arbitrary wave fronts in time and space.

III. Conclusions

Dynamic control of the metamolecules enables simultaneous spatial and temporal modulation of optical properties, taking photonic metamaterials to the next level of functionality: metadevices on demand.

Applications of such metadevices include homogeneous or massively parallel phase and intensity modulators, gratings of switchable period, tunable focusing devices, high resolution spatial light modulators and - in principle - even tunable transformation optics devices and 3D holographic displays.

Acknowledgement

This work is supported by the Leverhulme Trust, the MOE Singapore (grant MOE2011-T3-1-005), the UK's Defence Science and Technology Laboratory (grant DSTLX1000064081) and the UK's Engineering and Physical Sciences Research Council through the Nanostructured Photonic Metamaterials Programme Grant.

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