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

Coherent Image Processing with Plasmonic Metasurfaces

M. Papaioannou [1], E. Plum [1], J. Valente [1], E. T. F. Rogers [1, 2], N. I. Zheludev [1, 3]

[1] Optoelectronics Research Centre and Centre for Photonic Metamaterials,
University of Southampton, Southampton SO17 1BJ, United Kingdom
[2] Institute for Life Sciences, University of Southampton, Southampton SO17 1BJ, United Kingdom
[3] Centre for Disruptive Photonic Technologies, Nanyang Technological University, Singapore 637378, Singapore
mcp1g13@soton.ac.uk

***Abstract* – We demonstrate spatial and temporal control over metamaterial properties using coherent interactions of beams of light on plasmonic metasurfaces. This is illustrated by all-optical logical operations between two images.**

I. Introduction

Since metamaterials have enabled the design of almost arbitrary landscapes of static optical properties and functionalities, simultaneous temporal and spatial control over metamaterial properties has become the next big challenge. Recently, it has been demonstrated that the interaction of two coherent waves of arbitrarily low power on a metasurface can provide ultrafast control over the material excitation and thus over the expression of the nanostructure's functionalities [1-5]. Here we report simultaneous spatial and temporal control of metasurface excitation. We show first experimental proof-of-principle demonstrations of such all-optical image processing by demonstrating logical operations between two beams of light.

II. All-Optical Logical Operations with Coherent Absorption

A functional thin film of sub-wavelength thickness may be placed at a node or anti-node of the standing wave pattern formed by counter-propagating coherent waves, leading to suppression or enhancement of its excitation. In our case, coherent material excitation is achieved by splitting a 785 nm laser beam into coherent signal and control beams illuminating front and back of an absorptive thin gold film perforated with an array of asymmetrically split ring slits (Fig. 1). This way, the metamaterial's absorption can be controlled, resulting in perfect transparency or coherent perfect absorption of the impinging energy at metasurface areas that coincide with a standing wave node or anti-node, respectively. Spatial control is realized by imaging masks onto the absorptive thin film, while phase modulation of the control beam provides temporal control.

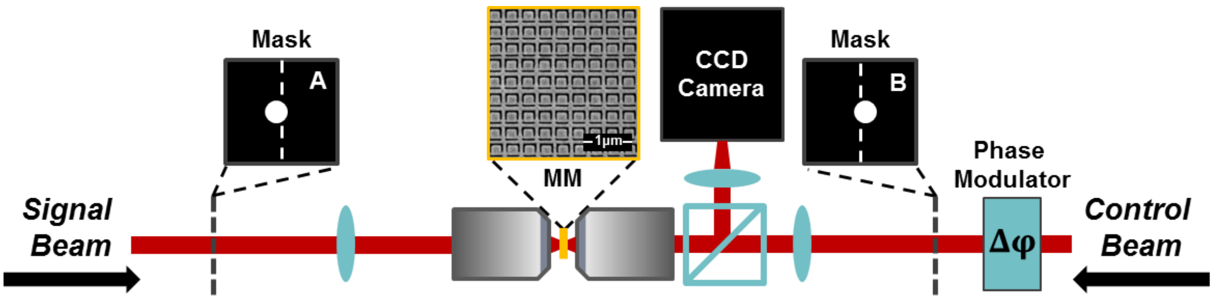

Fig. 1. Schematic of the experimental setup where spatial modulation of the coherent control and signal beams is provided by masks and temporal modulation is provided by a phase modulator. A CCD camera monitors the system output. An SEM image of the fabricated metamaterial (MM) sample is shown by the yellow inset. The intensity mask designs A and B across signal and control beam paths are employed to demonstrate the logical operations shown in Fig. 2.

Below, we illustrate logical operations between two sets, A and B, represented by circular signal and control beam masks that are imaged onto the metasurface, where they partially overlap [Fig. 2(a, b)]. Depending on the relative phase of the control and signal beams the interaction with the metasurface may be enhanced (constructive interference), reduced (destructive interference) or not affected, and thus several logical operations can be selected by setting the relative phase of signal and control beam: A xor B [overlapping area vanishes, Fig. 1(c)], A and B [overlapping area 3-fold enhanced, Fig. 1(d)] and A or B [uniform intensity profile, Fig. 1(e)].

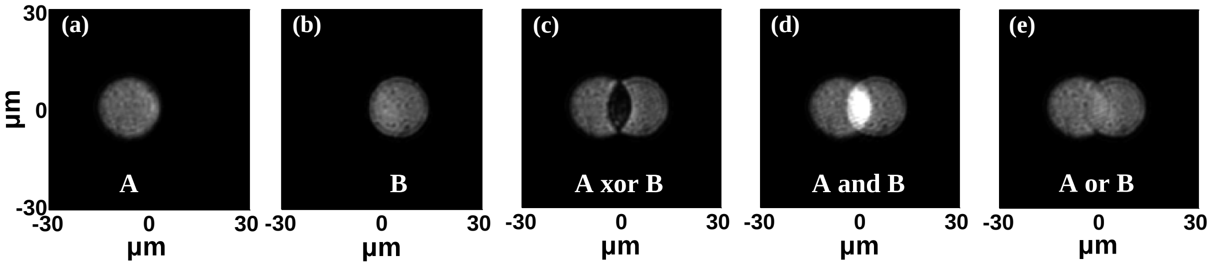

Fig. 2. Images of a metasurface illuminated by (a) signal beam only: set A, (b) control beam only: set B. Logical operations: (c) A xor B, (d) A and B, (e) A or B. Intensity levels are shown on the same grayscale in all images.

III. Conclusion

We have introduced addressable coherent control of metasurfaces as a way of controlling the expression of metasurface functionalities with spatial and temporal resolution. This method exploits the interaction of coherent waves at the metasurface to enhance or completely suppress the light-matter interaction, resulting in an ultrafast way of controlling light with light at arbitrarily low intensities and with high contrast. We have demonstrated all-optical logical operations between two partially overlapping beams experimentally. This concept can be applied to a broad range of applications including all-optical processing of complex images, massively parallel modulation of amplitude and polarization of optical signals, as well as selective amplification or deletion of modes from multimode signals to provide solutions for mode selection in spatial mode multiplexing for higher bandwidth optical telecommunications.

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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