Tunable Liquid Crystal-Based Metamaterials for Photonic Applications
O. Buchnev¹,²,*, N. Podoliak¹, M. Kaczmarek¹, N. I. Zheludev¹,²,⁴ and V. A. Fedotov¹,²

¹ Optoelectronics Research Centre, University of Southampton, Southampton SO17 1BJ, UK
² EPSRC Centre for Photonic Metamaterials, University of Southampton, Southampton SO17 1BJ, UK
³ School of Physics and Astronomy, University of Southampton, Southampton SO17 1BJ, UK
⁴ Centre for Disruptive Photonic Technologies, Nanyang Technological University, Singapore 637371, Singapore

Metamaterials in photonics represent a large class of nano-structured artificial media with optical characteristics unavailable, or superior, to those exhibited by natural materials [1, 2]. One of the important steps towards practical application of the metamaterials is the implementation of an efficient active control over their exotic optical response. This can be achieved by functionalising the fabric of these man-made photonic materials with liquid crystals (LCs).

In this work we report the development of an active planar metamaterial, a nano-structured thin gold film deposited on a dielectric substrate and hybridised with a nematic LC. We show that the plasmonic response of the hybrid LC-metamaterial can be electrically tuned in terms of its magnitude, which is, to the best of our knowledge, the first experimental demonstration of high-contrast electro-optical modulation achieved in an LC-based active metamaterial structure in the optical part of the spectrum [3]. We also demonstrate efficient spectral tuning of the hybrid LC-metamaterial system in the optical part of the spectrum, which so far has been challenging due to a strong anchoring of LC molecules to the surface of nano-structures [4]. This became possible with the development of the first anchoring-free LC-metamaterial surface based on an array of suspended zig-zag plasmonic nano-resonators. This metamaterial, when immersed into a LC twisted structure, features an anchoring-free state for LC molecules in between the resonator stripes and enables the complete LC switching at the nano-scale at the applied in-plane electric field. The mechanism of nano-scale in-plane switching is confirmed by simulating the distribution of LC director near the metamaterial resonators.

We also show that the active metamaterial concept can by readily exploited by the existing LC display technology. In particular, we found that the metamaterial nano-structure can replace all three essential components of the typical LC cell, namely: (i) LC alignment layer; (ii) transparent electrode; and (iii) polarizer; simultaneously providing resonant spectral selectivity in the optical response of the cell.

The relative ease of on-demand engineering of resonant bands (i.e. colours) in plasmonic nano-structures can be particularly relevant for applications in high-resolution and emerging micro-display technologies, such as near-to-eye and virtual retina displays. Given the wide range of exotic photonic functionalities demonstrated by planar metamaterials and also their potential to replace bulk optical components, a whole new generation of extremely compact metamaterial-based LC cell switchers and modulators and other photonic components exploiting electro-optical control can be envisaged.

References:

* presenting author; E-mail: O.Buchnev@soton.ac.uk