Electrically Controlled Liquid-Crystal Cell Enhanced with Plasmonic Metamaterial

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We demonstrate high-contrast electro-optical modulator based on a hybrid liquid-crystal cell incorporating a nano-structured plasmonic metamaterial. With the control signal of only 7V we achieved fivefold, hysteresis-free transmission modulation at the wavelength of 1.55um.

In this work we show that the functionality of an electrically controlled liquid-crystal (LC) optical cell can be substantially enhanced with a nano-structured plasmonic metamaterial. The metamaterial replaces all three essential components of the LC device, namely: (i) LC-alignment layer; (ii) transparent electrode; and (iii) polarizer; simultaneously providing resonant spectral selectivity in the optical response of the resulting hybrid cell. While the electrical control of liquid crystal properties has been exploited in the past for tuning negative-index microwave and nonlinear optical metamaterials, to the best of our knowledge, this is the first demonstration of high-contrast electro-optical modulation in a metamaterial-enhanced LC cell in the optical part of the spectrum.

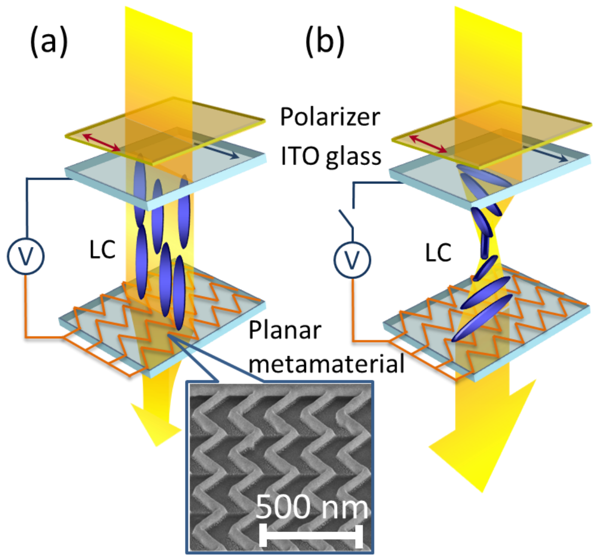

Figure 1. Design and operational principle of a hybrid metamaterial-based liquid-crystal optical cell. Panels (a) and (b) show the hybrid cell in ON (planar) and OFF (twisted) states correspondingly. Inset shows SEM micrograph of the fabricated metamaterial array taken at 52° to the array's normal.

Figure 1 illustrates the design and the operation principle of the hybrid LC-metamaterial cell. The cell comprises a layer of nematic liquid crystal, which is confined between a nano-structured planar metamaterial and a transparent electrode, coated with the LC-alignment layer. Importantly, direct contact with the metamaterial nano-structure provides both the anchoring and the alignment for the LC molecules at the bottom of the cell, in such a way that they align perpendicularly with respect to the molecules at the top of the cell. Due to elastic forces in the nematic phase, the twisted ordering of the mesogenes is formed in the bulk, making the LC cell optically active.

While the metallic network of the metamaterial structure serves here as the bottom electrode, its polarization sensitive plasmonic resonance determines the optical response of the entire hybrid cell. In particular, the incident light with the resonant polarization, i.e. the polarization that couples to the plasmonic excitation, will be substantially attenuated within the engineered resonance band in the planar cell ("ON" state, Figure 1a), but transmitted by the twisted cell, since the polarization state becomes non-resonant following a 90° rotation ("OFF" state, Figure 1b).

Introducing this nano-structured plasmonic metamaterial into the design of an electrically controlled liquid-crystal cell also makes the resulting hybrid device more compact and easy to integrate with plasmonic and nano-photonic circuits. The relative ease of on-demand engineering of resonant bands (i.e. colours) in plasmonic nano-structures can be particularly relevant for applications in the liquid-crystal display and light modulators technologies.