Electrically Tunable Liquid Crystal Plasmonic Metamaterials

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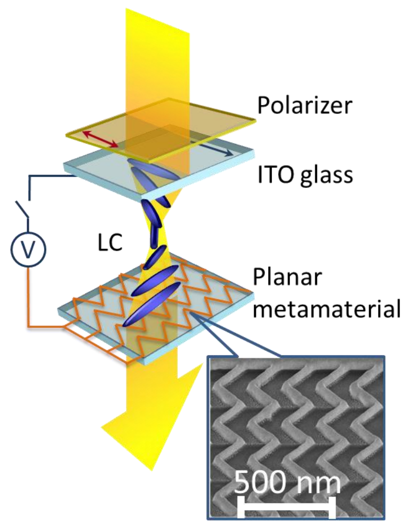
We experimentally demonstrate an efficient electrical modulation and control of the near-IR response of liquid crystal (LC) loaded plasmonic metamaterials by exploiting micro-scale volume and (for the first time) nano-scale in-plane LC-switching modes. We also show that in the resulting hybrid optical cell the metamaterial nano-structure can replace all three essential components of an LC device: (i) LC-alignment layer; (ii) transparent electrode and (iii) polarizer; making the hybrid cell more compact than the conventional LC devices and easier to integrate into plasmonic and nano-photonic circuits. The relative ease of on-demand resonant band engineering (i.e. colours) and tailoring reflection/refraction phenomena in metamaterials is particularly appealing for application in emerging, high-resolution display technologies including near-to-eye and virtual retina displays, holographic and 3D imaging.



Design of a hybrid metamaterial-based liquid-crystal optical cell. Inset shows SEM micrograph of the fabricated metamaterial nano-structure.

The control of the metamaterial response using volume LC-switching was achieved by integrating the metamaterial into a twisted LC cell. It was comprised of a 15 μm thick layer of nematic LC confined between the metamaterial and a transparent electrode coated with an LC-alignment layer (see Figure). The structure of the metamaterial was formed by a continuous zig-zag wire nano-pattern that was milled by the FIB technique in an 80 nm thick Au film deposited on a glass substrate. Direct contact between the liquid crystal and nano-structure provided anchoring and aligned LC molecules along the metamaterial rows, leading to the twisted LC ordering. While the metallic layer of the metamaterial served as the second electrode, its polarization sensitive resonance determined the optical response of the hybrid cell. In particular, the resonant polarization of 1.5 μm incident light that excites plasmons in the nano-structure becomes non-resonant while propagating in the twisted cell and is transmitted. By applying electric field of up to 7 V we can reversibly switch the twisted state and reduce the metamaterial transmission by a factor of five.

The in-plane LC switching was demonstrated for a substrate-free negative (complimentary) version of 80 nm thick metamaterial nano-structure, which was suspended on 100 nm thick silicon-nitride bridges. The absence of the substrate material in the gaps between the zig-zag elements of the metamaterial network substantially reduced the anchoring of the LC-molecules. This permitted their reorientation in the gaps under electric field applied in the plane of the nano-structure. The in-plane switching allowed us to control both the amplitude and spectral position of the metamaterial transmission band and bring the operating voltage below 2 V, by engaging the LC layer near the metamaterial with a thickness of only few hundreds of nanometers.

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