Nanoplasmonics for all-optical control of devices

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We have designed and developed an all-optical technique for reversible in-plane and out-of-plane switching of liquid crystal (LC) devices by leveraging the highly localized electric fields generated in the near-field region of a densely packed gold nanoparticle array when excited on-resonance with its localized surface plasmon absorption. We observe this switching effect over a broad temperature range, starting at room temperature, and at very low power densities, less than 0.03 W/cm^2. Using discrete dipole simulations and control measurements, we establish spectral selectivity in this new and interesting perspective for photonic application using low light power.

INTRODUCTION

The electron clouds in metallic nanoparticles (NPs) exhibit coherent oscillations in response to incident time-varying electromagnetic radiation. These oscillations are known as localized surface plasmons (LSPs) [1], the confined counterparts of propagating surface plasmon-polaritons observed in continuous metallic thin films. LSPs, in turn, scatter the incident electric field via dipolar interactions. At specific spectral ranges of the incident field, the resultant scattered field has a significantly amplified intensity. This frequency (localized plasmon resonance, LPR) is set by a specific relation between the frequency-dependent NP permittivity and the dielectric constant of the surrounding medium, known as Frohlich's condition [1]. In an ensemble of densely packed NPs, the far-field scattering is strongly suppressed. The result is highly localized scattered fields in the space between the NPs, creating what are popularly known as "hot spots". In this study, we use the highly confined scattered field generated during resonant excitation in the interstitial regions of a densely packed layer of AuNPs to switch directionality of a nematic LC film deposited on top of the gold layer.

Fig. 1 [2] shows the structure of a typical sample. With only white light (WL) illumination, the LC transmission is dark ('OFF' state, Fig. 1a). When the sample is additionally illuminated with excitation resonant with the LPR of the AuNPs, the transmission gets brighter ('ON' state, Fig. 1b). This effect is caused by re-alignment of the LC molecules due to the locally generated electric fields in the AuNP array, and is completely reversible (Fig. 1c). Fig. 2b is a plot of the variation of WL transmission voltage with time, as measured by a photo-detector when excitations are turned on and off (dashed lines), and clearly demonstrates the absence of the switching effect when non-resonant excitation is used. The simulations [3] in Figs. 2c and 2d support the experimental results. Fig. 3 shows the switching times observed in our samples. With AuNP deposited on one side, the switching times are on the order of seconds, but this is significantly reduced when AuNPs are deposited on both surfaces of the sample, to less than half a second.

Our findings offer a novel way to develop LC based devices with reduced ohmic losses by removal of electrical hardware and spectrally-selective response that opens the doors for entirely novel applications.

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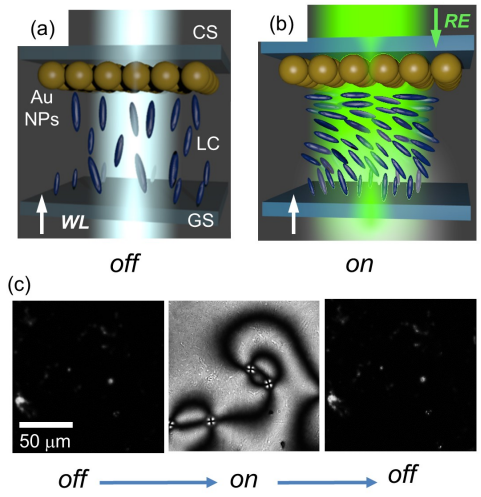

Fig. **1**. Schematic of experimental set up demonstrating (a) 'Off' configuration with only white light (WL) beam, and (b) 'On' configuration with WL and resonant excitation (RE) beams. CS: Cover slip; AuNPs: gold nanoparticles; LC: Liquid crystal; GS: glass slide (c) series of polarized microscopy images of LC sample at 30°C starting with resonant beam off, then turned on and then off again.

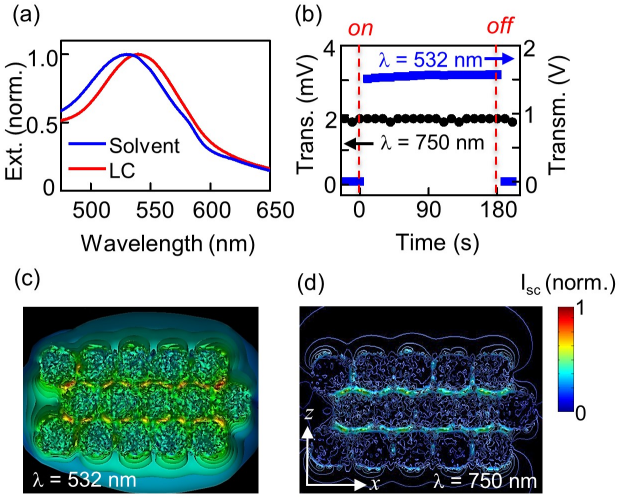

Fig. **2**. (a) Extinction spectra of 30 nm AuNPs suspended in its buffer solvent (blue) and in 5CB (red). (b) Transmission of WL as measured by photo-detector for resonant (blue squares) and non-resonant (black circles) excitation. Dashed lines indicate when the excitation light is turned on and off. Near–field simulations of scattered E-field intensity when incident excitation is (c) resonant (532 nm) and (d) non-resonant (750 nm) with the AuNP extinction peak in (a). The incident light is incident along the y-axis and polarized along the z-axis.

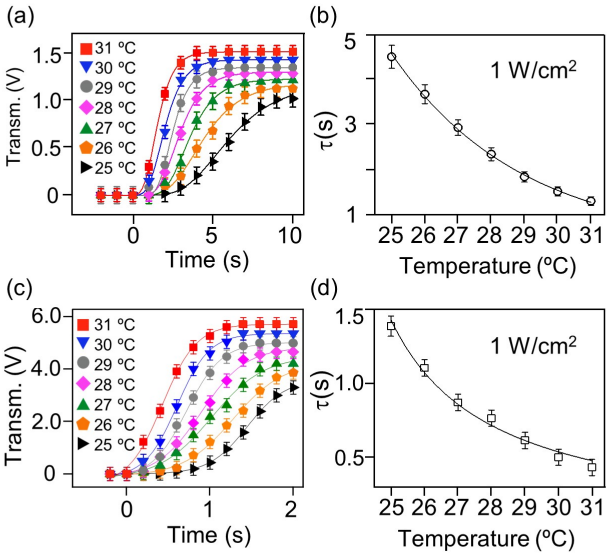

Fig. **3**. Transmission measured as a function of time. The AuNPs are drop casted on (a) only the cover slip and (c) both the cover slip and the glass slide. The rise times at different temperatures for (b) a cover slip and (d) both a cover slip and glass slide samples. Time = 0 s denotes when resonant excitation is switched on.