All-optical switching on plasmonic-lithium niobate metasurfaces

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Introduction

Photonic integrated circuits (PICs) and flat optics rely on passive optical elements made from high index dielectrics, (eg silicon and silicon nitride) or plasmonic metals.[1] Phase change materials,[2]and nano-mechanical systems[3] have been the major material platforms to realise active nonlinearities and reconfigurable optical elements. However, such systems are difficult to incorporate with PICs. In this work, we report a method for flat all-optical switches based on lithium niobate ($LiNbO_3$) substrates, as we exploit photogalvanic and photorefractive effects to develop all-optical switchable metasurfaces on $LiNbO_3$ substrates.

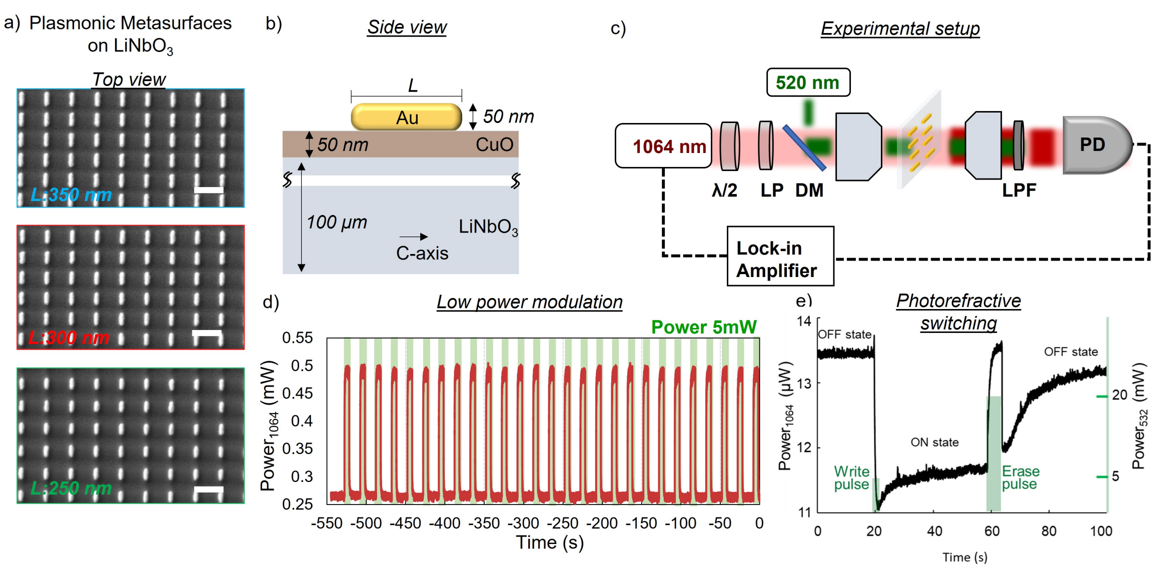

Figure 1: a) Top view SEM images of the plasmonic nano-bar arrays of various length (L) as annotated, scale bar: 400 nm. b) Schematic side view of a single unit cell with annotated dimensions of each film. c) Experimental setup of the characterisation setup. $\lambda/2$: half-waveplate, LP: linear polariser, DM: dichroic mirror, HPF: High pass filter, PD: photodiode. d) Stable all-optical switching performed over many repetition cycles, shaded green areas corresponds to the timeframe that the pump laser is ON. e) Two-level memory system of optical bits encoded on the transmission level of the metasurface. The pump pulses of different duration and power perform the write and erase function, while the probe beam is used for the reading.

Methods/Results

The metasurfaces consist of periodic arrays (fixed period at 400 nm) of gold nano-bars of variable length. The plasmonic metasurfaces are produced by top-down methods. After depositing a thin layer of Au, namely 50 nm on a CuO/$LiNbO_3$ substrate, the Au films are patterned via FIB milling. The SEM images of the fabricated samples, as well as the schematic of a single unit cell, are presented in figure 1a and b, respectively. A pump-probe setup was built based on a inverted microscope to perform the all-optical switching. The probe laser (1064 nm) is electrically modulated at 1 KHz via a lock-in amplifier, while the pump beam (520 nm) is a diode laser of variable pulse width controlled by a function generator. A pair of objectives is used to focus the laser beams on the samples and to collect the probe beam in an InGaAs photodiode.

The transmission level of the metasurface at the probe wavelength is modified by the green laser, as presented in Figure 1 d and e. The plasmonic metasurfaces introduce optical absorption at the wavelength of the green laser, while at the probe wavelength the switching ratio is controlled by the length of the Au nano-bars. The absorbed light result in the carrier generation and thermal expansion, thereby the opto-thermal heating in combination with the photogalvanic effect, induce the motion of charges, that alter the optical properties of the metasurfaces. In low power regime, we have managed to record transmission contrast ratio up to 2.2:1, see Figure 1d.

For the samples that we have annealed at 800 ^{o}C before the deposition of Au, we record a different response. The transmission changes are not reversible as before, but irreversible. We can explain this behaviour as the thermal diffusion of Cu in the $LiNbO_3$ lead to the generation of deep carriers that give rise to this type of photorefractive switching. The transmission contrast is polarisation dependent and is associated with the orientation of the polarisation of the probe beam with the c-axis of the substrate, while the photorefractive switching is recorded for light polarised parallel to the c-axis.

Conclusions

We have presented a novel method to perform all-optical switching in flat photonic architectures based on the combination of photonic metasurfaces with $LiNbO_3$ substrates. The reversible and irreversible transmission contrast between different types of samples paves the way for a new family of adaptive optical devices based on the $LiNbO_3$ platform. The transmission contrast ratio of 2.2:1 demonstrated here is already adequate for short-reach (intra-/interchip) optical interconnect applications in data processing architectures.[1] The plasmonic metasurfaces may form essential functions such as optical modulators and/or optical waveplates towards the development of optical components with active tuning capabilities. Furthermore, the rewritable optical properties could be used in planar switchable optical devices.

References

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