Nonlocal electro-optic metasurfaces for free-space light modulation

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Optical metasurfaces, comprising planar arrays of nanoscale resonant subwavelength elements, constitute one of the most promising and rapidly developing fields in optics and photonics. In recent years, increasing efforts have been made to realize dynamic (tunable) optical metasurfaces. Dynamic optical metasurfaces with ultrafast temporal response, i.e., spatiotemporal optical metasurfaces, provide attractive solutions and open fascinating perspectives for modern highly integrated optics and photonics [1].

To achieve more efficient modulation, one can increase the refractive index modulation, e.g., by increasing the modulation voltage or the Pockels coefficient. An alternative way is to utilize a narrower resonance, which is equivalent to increasing the effective interaction length. In this case, it will require a smaller shift of the resonance to achieve a large intensity difference. In this work, electro-optically controlled nonlocal optical metasurfaces operating in reflection and utilizing resonant waveguide mode excitation are demonstrated from the viewpoint of free-space propagating light modulation. This builds on our previous work on dynamic flat optics components based on a thin film LN platform, but significantly superior characteristics in comparison with previous research are achieved by utilizing a sharper resonance [2-4].

The modulation of reflected light power is achieved by identifying a suitable low-loss waveguide mode and exploiting its resonant excitation. The electro-optic Pockels effect in a 300-nm-thick lithium niobate (LN) film sandwiched between a continuous thick gold film and an array of gold nanostripes, serving also as control electrodes, is exploited to realize fast and efficient light modulation. LN is an appealing platform for dynamic optical components, due to the inherently fast Pockels effect, high electro-optic coefficients, a wide transparency range, excellent chemical and mechanical stability, and a large Curie temperature [5,6].

By means of numerical calculations and extensive experiments, we design, fabricate, and characterize compact (active area <1000 μm^2) free-space intensity modulators operating in the wavelength range of 850-950 nm. The maximum intensity modulation depth of ~42 % at the driving voltage of ±10 V [Fig. 1] is demonstrated within the bandwidth of 13.5 MHz (with the potential bandwidth of 6.5 GHz) [4].

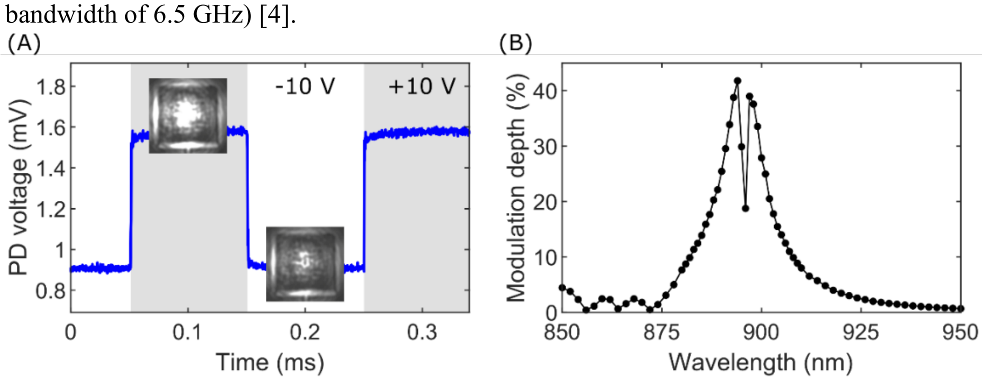

Fig. 1. (A) Measured intensity with a photodetector (PD), visualizing the modulation when cycling a square voltage signal between +10 V and -10 V indicated by grey and white backgrounds, respectively. Insets: Optical images of the device for a modulation voltage of +10 V (upper left image) and -10 V (lower right image), clearly displaying the modulation of reflected intensity. (B) Experimentally measured modulation depth for varying wavelengths at a modulation voltage of ±10 V and signal frequency of 5 kHz.

The introduced nonlocal electro-optic metasurface configuration opens new avenues towards the realization of ultrafast, efficient and robust free-space light modulators based on an LN flat optics approach.

References

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Summary:
We design, fabricate, and characterize nonlocal lithium niobate-based compact free-space intensity modulators with a maximum intensity modulation depth of ~42 % at the driving voltage of ±10 V within the bandwidth of 13.5 MHz.