Switching the Response of Metasurfaces in Polarization Standing Waves

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***Abstract* – We demonstrate experimentally that standing waves of polarization, as opposed to intensity, can be engaged to coherently control light-matter interactions in planar photonic nanostructures, presenting unique opportunities for all-optical data processing and polarization-dependent molecular spectroscopy. Such waves, formed by counter-propagating (linear or circular) orthogonally polarized beams can, for example, uniquely detect polarization conversion, planar chirality and related asymmetric transmission effects.**

I. INTRODUCTION

It has been demonstrated recently that interactions between light and ultrathin (sub-wavelength) photonic media, including absorption [1], optical activity [2] and anomalous refraction [3], can be coherently controlled with high contrast and THz bandwidth [4] at energy levels down to the single-photon regime [5] by precisely positioning the metamaterial in a standing wave formed by counter-propagating light beams. This coherent control paradigm has relied to date on the local intensity variations generated by the interference of co-polarized incident beams. We now demonstrate the coherent control of polarization-sensitive interactions using intensity-invariant polarization standing waves.

II. METHODS, RESULTS & DISCUSSION

The polarization standing wave generated by a pair of linearly polarized travelling waves is illustrated in Fig. 1. Its local polarization is a periodic function of position along the light propagation direction, oscillating through linear, left- and right-circular states (the linear states being at ±45° to the input states), while the intensity is invariant. While the optical response of any subwavelength-thickness film can be modulated by changing the local field intensity (as between the nodes and antinodes of an intensity standing wave [1-5]), only media possessing an ability to convert light between orthogonal polarization states will be sensitive to the local variations within a polarization standing wave.

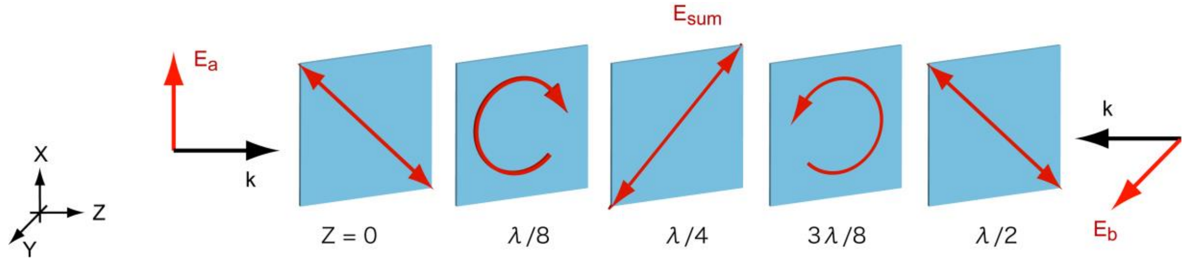

Fig. 1. Polarization standing wave formed by counter-propagating orthogonally linear polarized beams.

Our experiments employ counter-propagating, linearly polarized ultrashort laser pulses (originating from the same 130 fs, 800 nm source) to generate either an intensity standing wave using co-polarized beams or, as shown in Fig. 1, a polarization standing wave using orthogonally polarized beams. A variety of planar photonic metamaterials (manufactured by focused ion beam milling typically in 50 nm, i.e. ~λ/16, thin Au films) are interrogated under both modes of standing wave illumination. For example, Fig. 2 shows coherent absorption modulation for these two cases for a sample comprising a square array of *L*-shaped slots. In the intensity standing wave (incident beams co-polarized in the *y*-direction; Fig. 2a) absorption oscillates between coherently-enhanced and suppressed levels achieved respectively at the intensity anti-nodes and nodes according to the time delay (i.e. mutual phase) of the pulses at the sample position, within an envelope defined by their temporal overlap [c.f. Ref 4]. In the polarization standing wave (crossed incident polarizations along *x* and *y*; Fig. 2b) a similar pattern of delay-dependent coherent absorption modulation is maintained for this sample via the (intensity invariant) oscillation of the local polarization state.

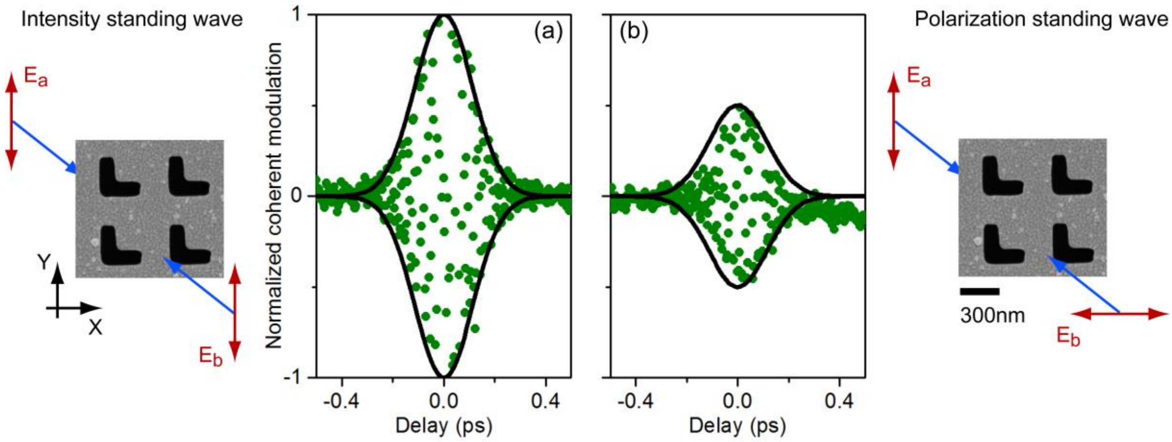

Fig. 2. Normalized coherent absorption modulation for a gold *L*-slot array metamaterial [a section of which is shown in the electron microscope images in the two schematics illustrating the configuration of incident beam polarizations] as a function of counter-propagating pulse delay at the sample in standing waves of (a) intensity and (b) polarization. Experimental data (green points) are overlaid with analytical Gaussian fittings (black lines) based on the temporal overlap of the incident pulses.

VI. Conclusion

Polarization standing waves formed by counter-propagating orthogonally polarized beams are shown to bring a new dimension to the coherent control of light-matter interactions in ultrathin media. Indeed, polarization coherent control offers a new degree of freedom in coherent-illumination spectroscopy, alongside selectivity based on the magnetic/electric nature of incident fields [3], and the concept may readily be harnessed in coherent networks [4] where data is encoded not only in the amplitude, but also the phase and polarization of signals.

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