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Ultrafast acousto-plasmonics in complex nanostructures

Plasmonics has emerged as a promising field in physics, with the potential to overcome the diffraction limit in classical photonics, and to develop a myriad of applications. Spatially localized surface plasmons show strong electronic resonances that allow their use for the design of optical nanoantennas and metamaterials, enabling new ways of capturing and controlling light [1]. These resonances can be strongly dependent on polarization, allowing a selective coupling and control of the light with the nanostructures [2]. Usually, short laser pulses are used to excite coherent acoustic phonons in metallic and semiconductor thin-films, multilayers, and microcavitiies. Great efforts have been made in the optimization of the light-matter interaction in these systems, and in the confinement of the acoustic and electric fields [3-5].

Here, we propose the integration of plasmonics concepts into the field of nanophononics using metallic nanoantennas as coherent phonon generators and detectors. The polarization-dependent optical resonances and the phononic modes of metallic nanostructures are determined by their geometry –size and shape– and material properties (index of refraction and sound velocity, respectively). We show how an array of metallic optical nanoantennas optimized to work at visible wavelengths (see Fig. 1) can be tailored to generate and detect acoustic phonons of variable frequencies in the GHz range, and how the interactions of these modes with plasmons can be put in evidence. The structures are designed to be doubly resonant so both excitation and detection can take advantage of the plasma resonance. Using multiple pulse excitation we demonstrate control over the mechanical motion along two axes. We show that optical probing of the two axes of a Swiss-Cross produces distinctly different phononic spectra due to interference effects (see Fig. 2) [6].

We report two-color pump-probe experiments which demonstrate that a nanostructured thin-film composed of crossed gold nanobars and Swiss-cross nanostructures of different sizes (of the order of 100 nm) can generate acoustic phonons with GHz frequencies; and how the generated frequency can be controlled by using multiple excitation pulses. We also discuss how the selection of the geometrical parameters of the crosses enables the design and engineering of optimized hypersound sources, with tailored and tunable spectra. We find that the detected phonon spectrum changes significantly when the polarization of the probe light is rotated 90 degrees. This ability to distinguish in the far field the response from local regions of nanostructures is a powerful metrology tool. One can envision actively controlling the refractive index while monitoring a nonlinear process in order to gain information about the origin of the nonlinearity. The presented results open new ways toward the design of novel nanophononic systems and the development of opto-acoustically functionalized surfaces.

References:

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Figures:

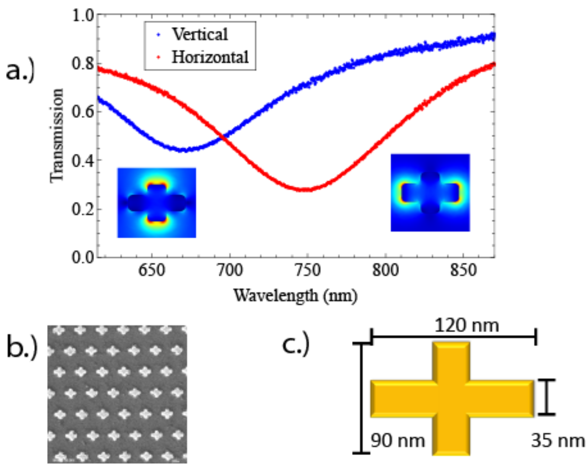

Figure 1: Panel a. Optical transmission for two different polarizations showing the resonances of the structures. In the inset the modes are ilustrated. Panel b. SEM micrography of the fabricated array of Swiss crosses. Panel c. Schematics of an individual nanostructure.

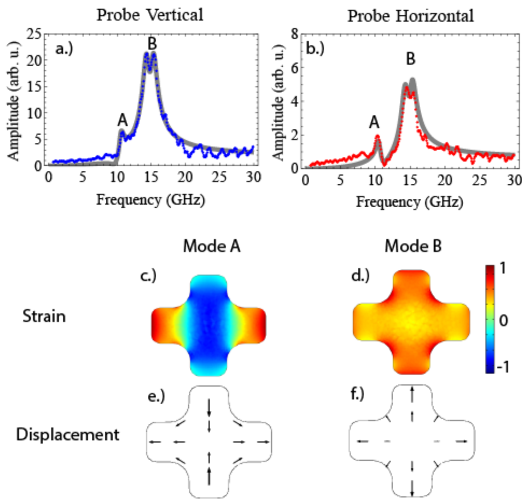

Figure 2. Top panels. Fourier transform of the transient transmission for a vertically (panel a) and horizontally (panel b) polarized probe. The interference effect at 11 GTHz in the transient transmission spectrum for a horizontally polarized probe pulse originates from the two phonon modes changing the optical transmission with equal magnitude and opposite signs. Bottom panels show the strain and displacement profiles for the two studied acoustic modes.