Photo-generated THz resonances and surfaces waves

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Abstract: We demonstrate the excitation of surface lattice resonances on a flat semiconductor by optical illumination of the surface. This illumination is done with a spatial light modulator that defines periodic arrays of resonant structures by local photo-excitation of free charges on the semiconductor. This approach enables a full optical control of surface modes at THz frequencies.
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1. Introduction and motivation

The resonant interaction of electromagnetic waves with structured surfaces can lead to a fascinating phenomena, such as excitation of surface waves with large electromagnetic field enhancements, anomalous refraction due to interference of the coherently scattered partial waves [1], and electromagnetically induced transparency with large group velocity reduction [2]. These and other phenomena can profit tremendously if they can be actively controlled.

In this paper we demonstrate an all-optical active control of the excitation of THz surface waves on flat semiconductor surfaces. This control is achieved by the photo-generation of resonant conducting structures on the semiconductor with the illumination of an optical pump beam. This pump beam is spatially structured with the shape of the resonant structures by means of an spatial light modulator (SLM). In this way we achieve full control of the dimensions and location of the structures onto the surface and gives unprecedented possibilities for actively tuning the response of photo-excited materials to THz radiation.

2. Photogenerated semiconductor resonators and gratings

The experimental setup used for the all-optical control of surface waves consists of an optical parametric amplifier that produces high energy pulses at 1 kHz rate. These pulses are used for the generation and detection of broadband THz radiation and for pumping the sample. The sample consists of a flat and thin layer (1 μm) of GaAs on top of a quartz substrate and bonded to it by a mercapto-ester based polymer layer. The optical beam passes through a SLM and a polarizer beam splitter that defines the shape of the illumination pattern. The pixel size of the structures that can be defined is 8x8 μm^2. This size is much smaller that the THz wavelength, which enables the realization of subwavelength features. SLMs have been used in past to optically define diffraction gratings [3,4], resonant structures [5,6], metasurfaces [7], and more complex structures [8] onto the surface of semiconductors. We illustrate here the excitation of THz surface waves using this approach.

Figure 1 shows several images of illumination patterns used for the measurements. These images have been obtained by replacing the semiconductor layer with a CCD camera. Figures 1(a) and (b) correspond to random arrays of squared structures with different dimensions, while (c) and (d) are images of square lattices with equal period. The illuminated areas on the sample surface with the optical pump (represented by the red color in Fig. 1) undergo a dielectric to conductor transition due to the photo-excitation of free-charge carriers when the pump energy is larger than the semiconductor bandgap energy and the intensity is high enough.

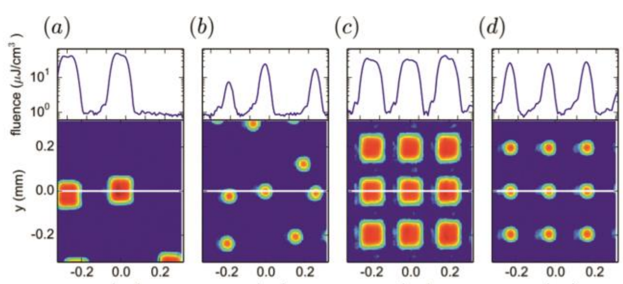

Fig 1. Images of illumination patterns used for the photo-generation of THz resonant structures (a), (b), and THz surface waves (c), (d) on flat semiconductor layers. The upper plots are cuts to the images along the horizontal lines, indicating the optical fluence as a function of position.

If a THz pulse arrives after a time delay, which is long enough to allow the thermalization of hot carriers but shorter than the carrier recombination time, free-charge carriers interact with the THz electric field. This interaction can be resonant if the dimensions of the conducting structures are comparable to the wavelength of THz radiation. Measurements illustrating this resonant interaction are shown in Fig. 2(a). These measurements correspond to the extinction efficiency, defined a 1 minus the transmittance normalized the fraction of the surface that is illuminated, of four different random arrays of structures with different dimensions. The maximum extinction shifts to lower frequencies and the extinction efficiency increases as the size of the structures is increased. This red shift indicates that the maximum in the extinction has its origin in the $\lambda/2$ resonance along the lateral dimension of the structures. The increased volume occupied by the structures as their lateral size increases gives rise to the increase in the extinction.

An interesting situation arises when the resonant scattering of THz radiation with structures is combined with diffraction orders in periodic arrays. If a diffracted order is grazing to the surface of the array, in the so-called Rayleigh anomaly (RA) condition, there is an enhanced radiative coupling between the structures defining the array. This enhanced coupling leads to surface lattice resonances (SLRs). SLRs can be regarded as surface waves with a high field enhancement at the surface originating from the resonant interaction of the incident wave with the structures and the array [9]. Figure 2(b) shows measurements of the extinction spectra of four square arrays with lattice constant of 190 μm formed by structures with the same dimension as those of the random arrays shown in Fig. 2(a). The dotted vertical line indicates the frequency of the lowest order Rayleigh anomaly. We observe that in contrast to the measurements of the random arrays, the maximum extinction remains at the same frequency for all the arrays. This characteristic indicates that the periodic lattice plays a dominant role in the extinction and that this extinction efficiency is determined by the radiative coupling efficiency between the resonant structures and the RAs.

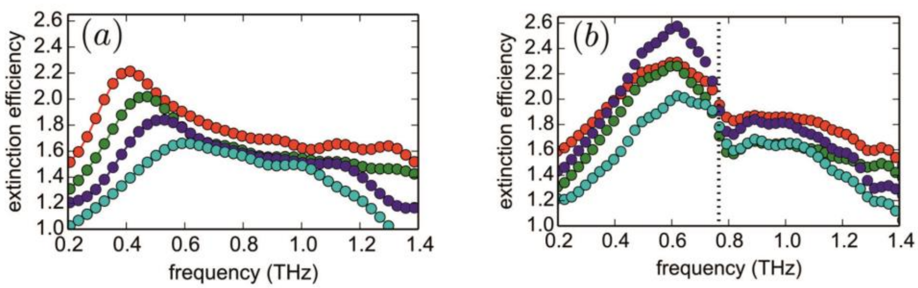

Fig 2. (a) Extincion efficiency of random arrays of photo-generated squared structures of different dimensions (110 μm, red; 90 μm, green; 70 μm,dark blue; 50 μm, cyan). (b) Extinction efficiency of squared arrays with lattice constant of 190 μm formed by photo-generated structures similar to those of (a).

3. References

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