Birth of an hypersonic surface acoustic wave

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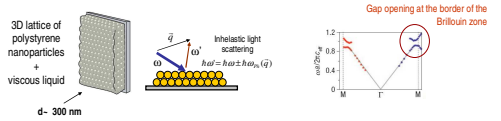
INTRODUCTION

The possibility to prepare macroscopic areas of ordered arrays of metallic nano-objects on different substrates led to intensive efforts toward the use of these structures as potential transducers and sources of coherent acoustic excitations in the GHz and THz range.

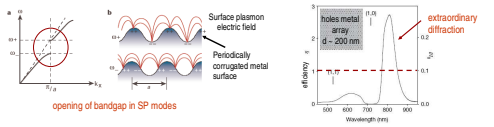
- COUPLING OF THE SOUND WAVES TO THE PERIODICITY: HYPERSONIC BANDGAPS [1]

→ Phononic crystals in the GHz range

• Acoustic waves at GHz frequencies are generated by **thermal excitation**, i.e. phonons

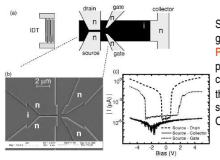


- COUPLING OF SURFACE PLASMONS TO THE PERIODICITY: EXTRAORDINARY TRANSMISSION & SUBWAVELENGTH OPTICS IN THE VISIBLE [2,3]

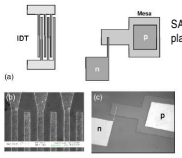


- ACOUSTIC CHARGE TRANSPORT [4,5]

LONG RANGE EXCITON TRANSPORT [6]



Surface acoustic waves generated by a Piezoelectric transducer pick up electrons from a current flowing through the *n-i-n* junction and steer them towards the Ohmic output contact

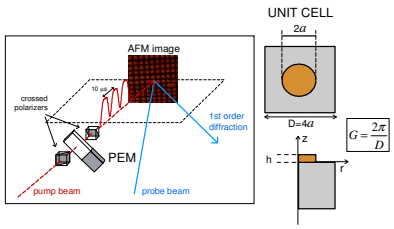


Time-resolved reflectivity experiments have been performed on gratings of metallic nanometric stripes (2D confined) on semitransparent (Si) substrate, evidencing oscillations in the GHz range [7-10]. However, the attribution of the measured modulations to one-dimensional SAWs, induced in the substrate, or to the oscillation modes of the single nano-objects has been a debated question.
Less data are available on the mechanical properties of 3D confined nanoparticles, as a consequence of the difficulties in measuring and modeling the elastic and thermodynamic properties of these systems.

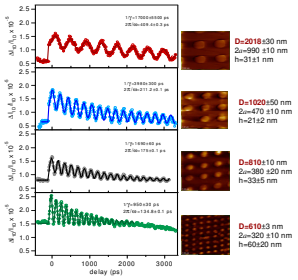
TIME-RESOLVED DIFFRACTION MEASUREMENTS

A dedicated diffraction time-resolved optical technique has been developed, in order to investigate the mechanical and thermodynamic properties of square arrays of permalloy ($Fe_{20}Ni_{80}$) nanodisks deposited on a Si(100) surface [11]. Exploiting the periodicity of the system, we have measured the relaxation dynamics of the intensity of the first-order diffracted beam, after the excitation by sub-ps laser pulses. And by changing the parameters of the samples, we demonstrated that:

- Two-dimensional surface acoustic waves (SAW), are excited in the silicon.



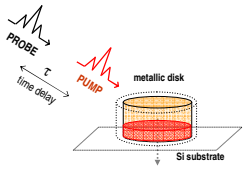
Time-resolved measurements of the diffracted pattern



BIRTH OF A HYPERSONIC SURFACE ACOUSTIC WAVE

In order to clarify the interaction between the nanodisks and the substrate, numerical calculations of both the elastic eigenmodes and the time-dynamics of the system, following the impulsive heating excitation by the laser, are performed.
Simulations based on finite-elements analysis, together with a wavelet analysis of our experimental data, show the detailed thermal mechanism responsible for surface acoustic waves generation in the substrate.

FROM PUMP & PROBE TECHNIQUE TO FINITE ELEMENTS ANALYSIS

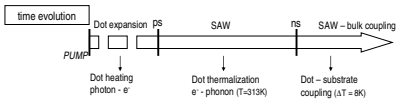


- IMPULSIVE HEATING

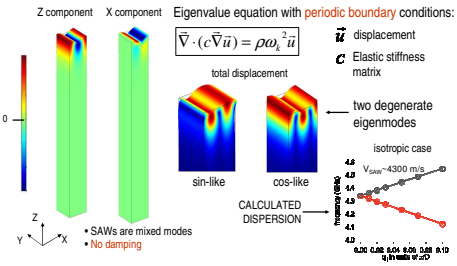
→ 3 TIMESCALES

- INDUCED STRESS IN THE SUBSTRATE

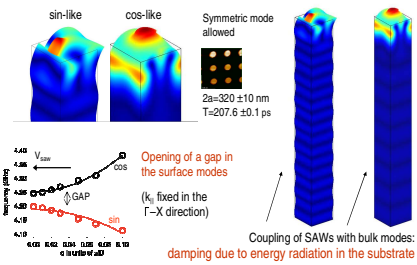
→ Surface Acoustic Waves



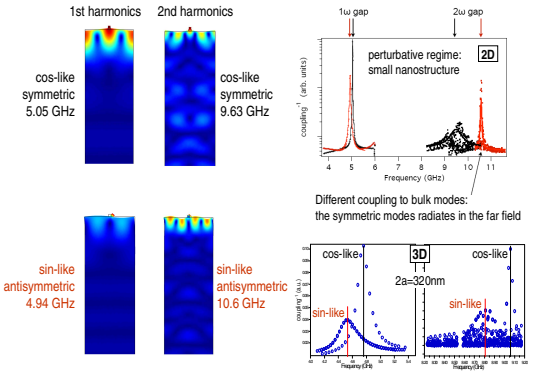
EIGENMODES ANALYSIS: Si SUBSTRATE (NO DISKS)



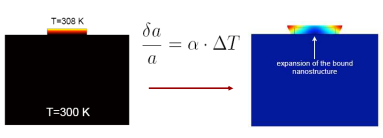
EIGENMODES ANALYSIS: ORDERED ARRAY (WITH DISKS)



COUPLING TO BULK MODES AND LIFETIME

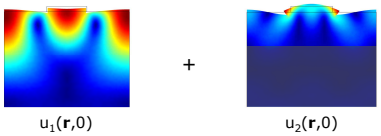


DISPLACEMENT RELATED TO IMPULSIVE HEATING

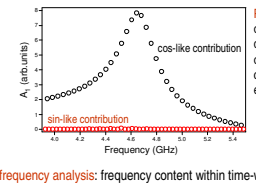


The initial displacement is the superposition of the calculated eigenmodes:

$$u(\mathbf{r},t)=\Sigma A_n u_n(\mathbf{r},t)$$



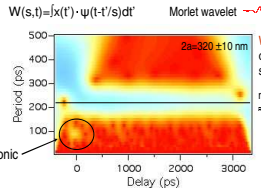
WAVELET ANALYSIS OF THE DIFFRACTED SIGNAL



Projection of the initial displacement on the calculated eigenmodes

Time-frequency analysis: frequency content within time-windows

$W(s,t)=\int x(t')\cdot\psi(t-t'/s)dt'$ Morlet wavelet



Wavelet of the diffracted signal

main period ≈ 207ps

FUTURE

- Study of localization of SAWs in disordered systems.
- Decoupling the thermal and elastic contribution → CALORIMETRY ON NANOPARTICLES

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