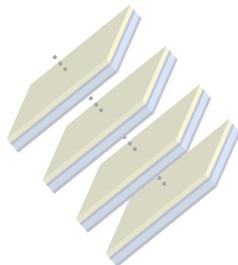
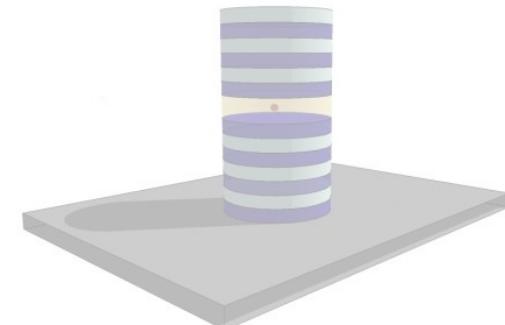
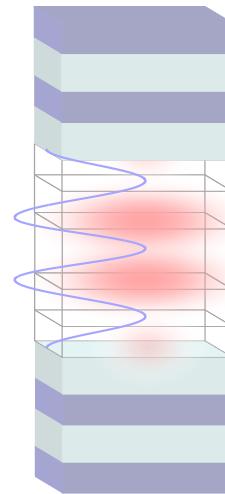


Optophononic Devices Based on Semiconductor Multilayers

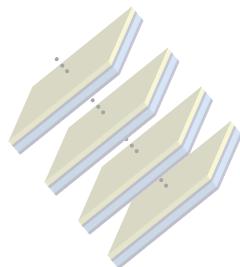


Daniel LANZILLOTTI-KIMURA

Laboratoire de Photonique et de Nanostructures, CNRS



Towards the Phonon Engineering around a Single Quantum Dot



Daniel LANZILLOTTI-KIMURA

Laboratoire de Photonique et de Nanostructures, CNRS

Pascale Senellart, Marcoussis

Ivan Favero, Paris

Loic Lanco, Marcoussis

Alejandro Fainstein, Bariloche

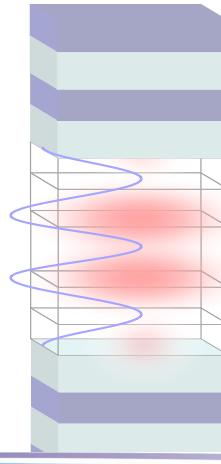
Bernard Jusserand, Paris

Bernard Perrin, Paris

Aristide Lemaitre, Marcoussis

Isabelle Sagnes, Marcoussis

Carme Gomez-Carbonell, Marcoussis

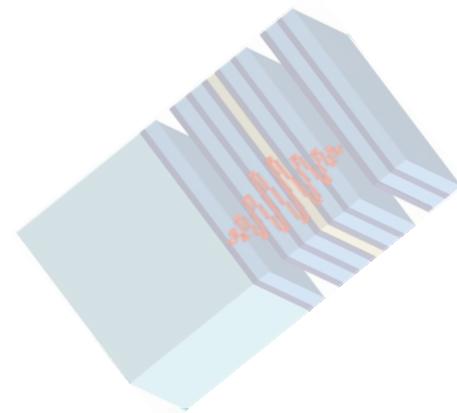


Nanophononics: playing with sound at sub-THz frequencies and nm wavelengths

What is it about?

Control the generation and detection of ultra high-frequency acoustic phonons using optical methods

Manipulate and control hypersound at the nm scale



Why?

Use of hypersonic vibrations to **control sound, light and charge** in **nanometric scales** and at **ultra high frequencies**.

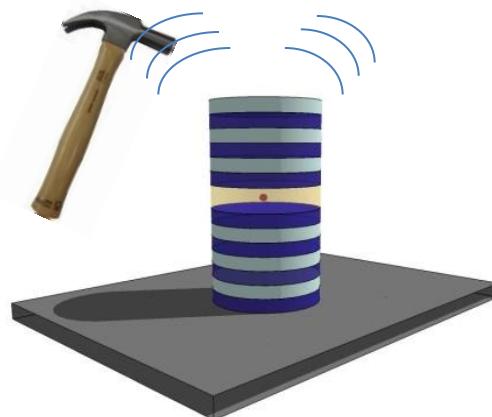
How?

1. Using **acoustic devices** to control the sub-THz vibrations
2. Using **photonic/phononic systems** to tailor exciton-phonon interactions

Nanophononics: engineering of acoustic phonons at GHz-THz frequencies

Acoustic phonons interact virtually
with any other excitation

Usually seen as harmful,
we can engineer and use them
to control light and charge



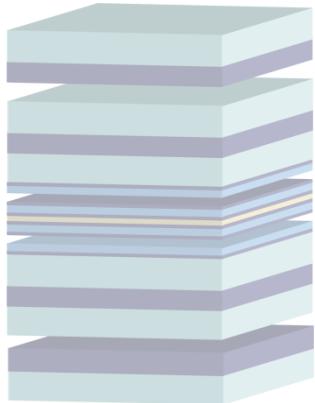
Acoustic phonons modulate:

- Physical shape
- Electronic properties
- Optical properties
- Magnetic properties
- etc...

Outline

A. Acoustic phonon devices

Phonon mirrors and cavities

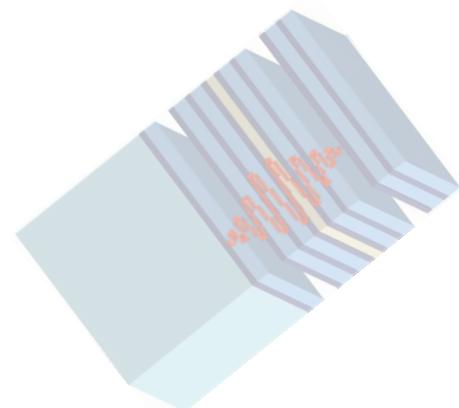


B. Magic resonators for light and hypersound

Cavities, phonon dynamics, future perspectives

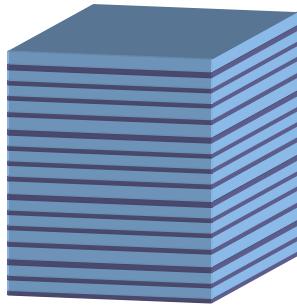
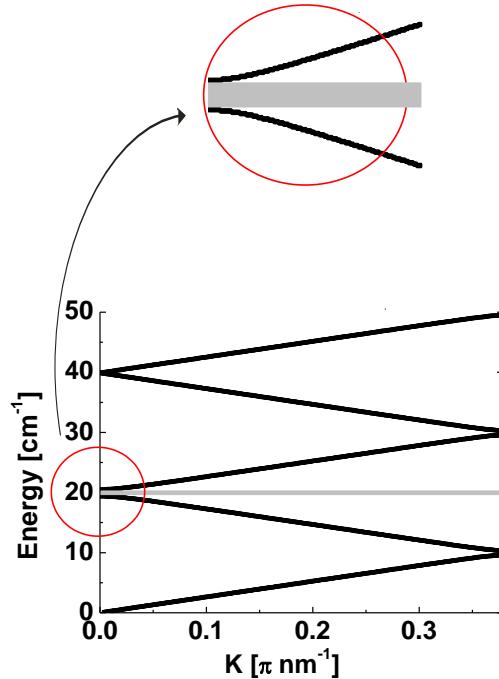
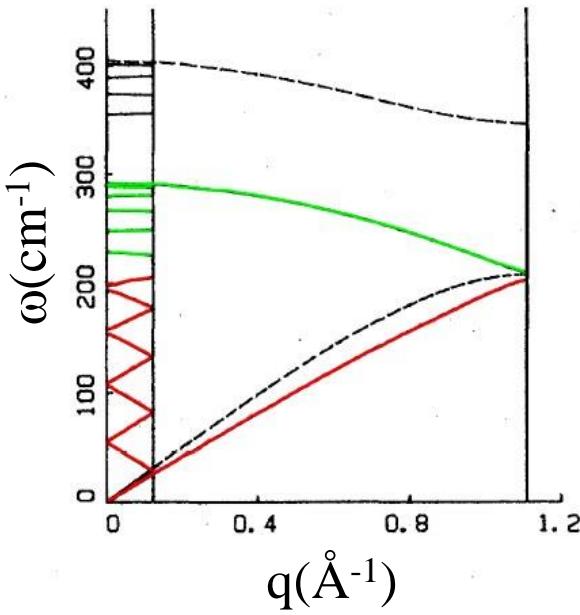
C. Micropillar and QD nanophononics

Phonons in pillars, optimization of the QD position



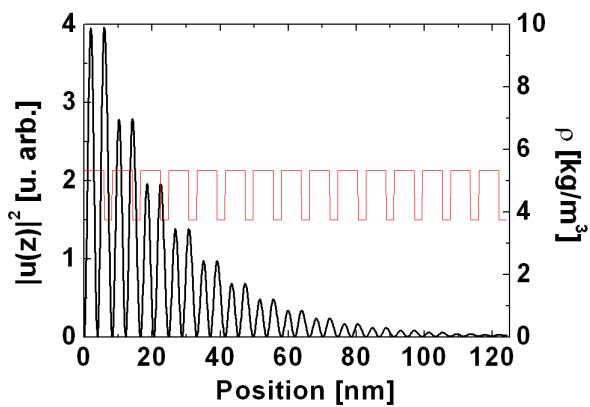
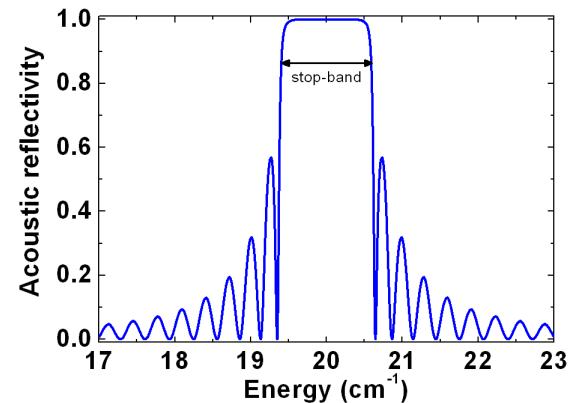
Periodic multilayers act as phonon reflectors

Longitudinal

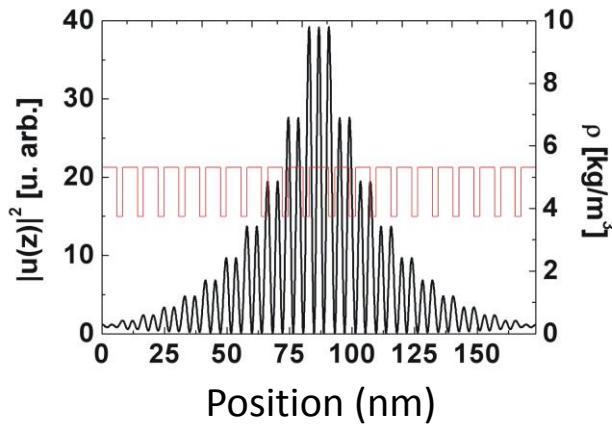
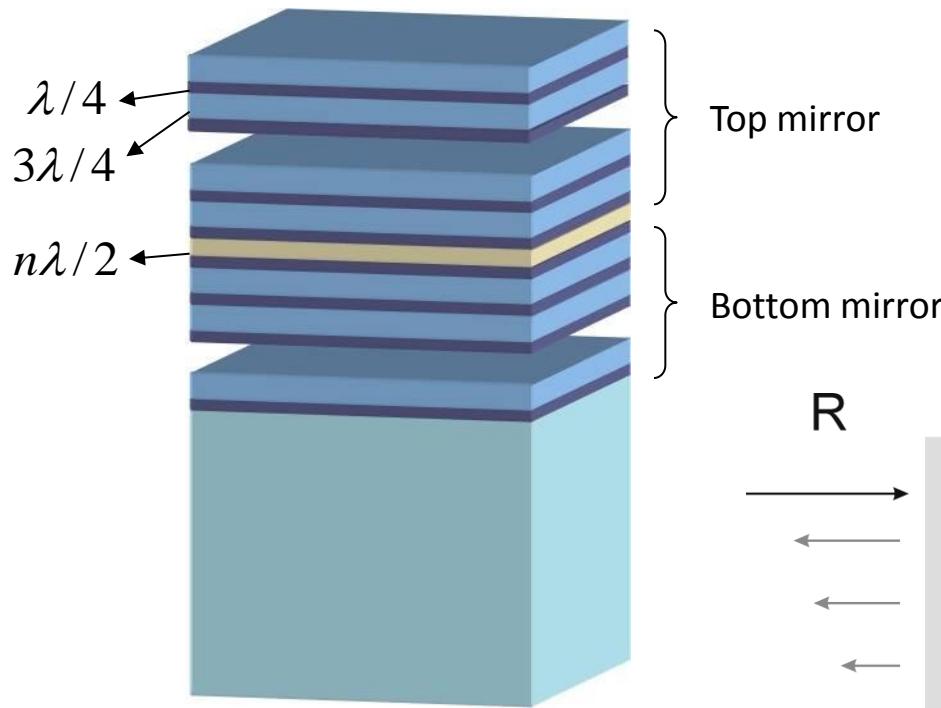
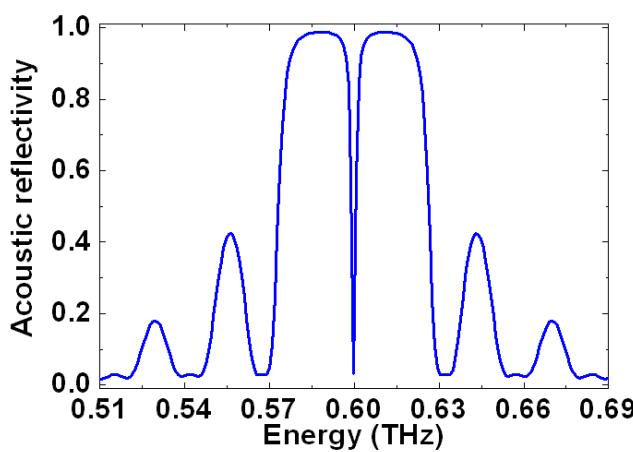


Period $\sim 10 \text{ nm}$

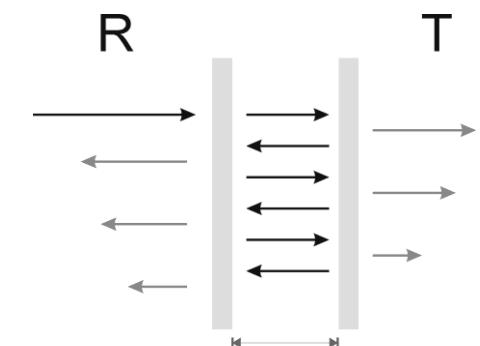
Frequencies $\sim \text{GHz} - \text{THz}$ range



Two phononic mirrors enclosing a spacer confine and “amplify” acoustic fields

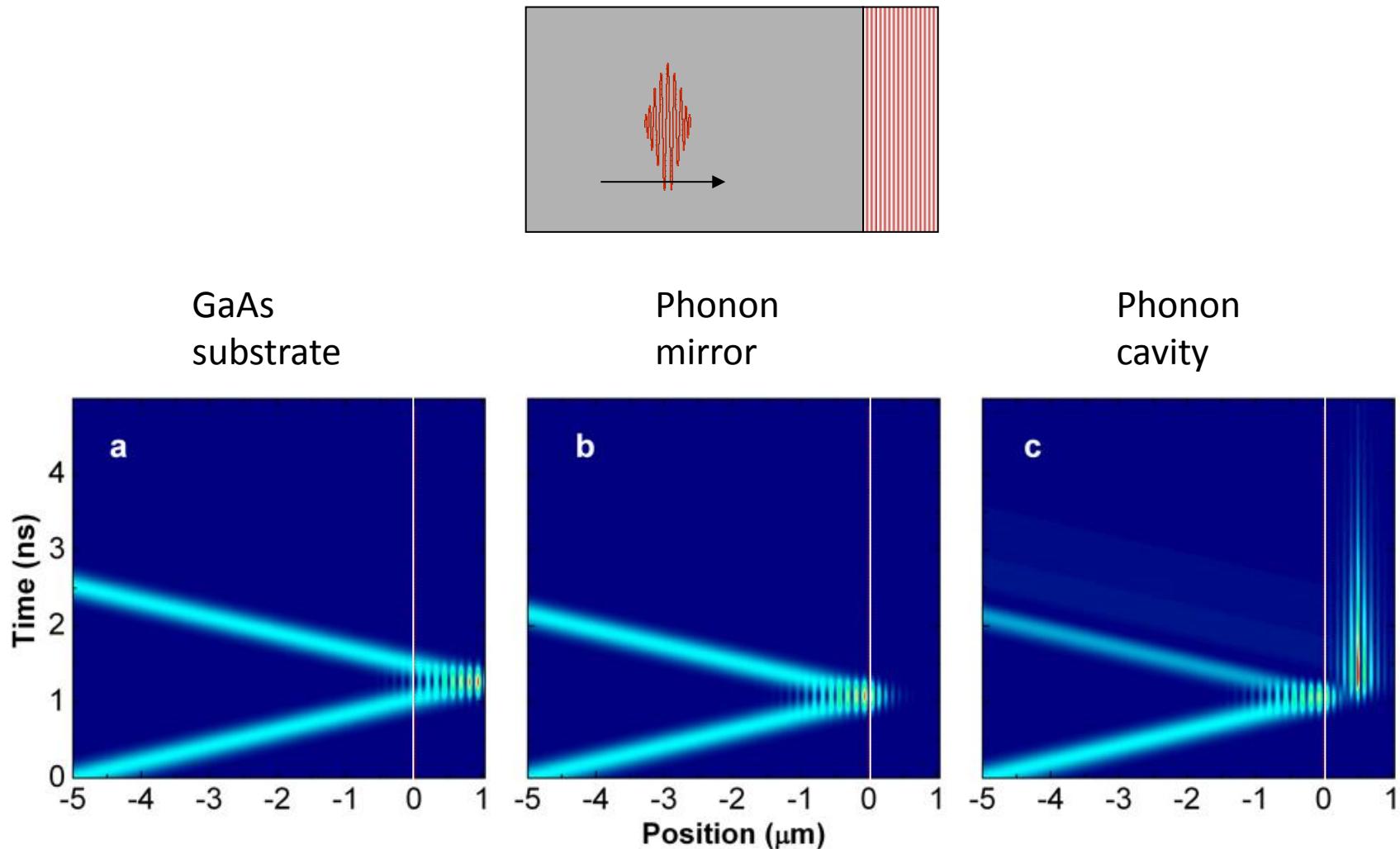


Superlattice → Phonon mirror
periods: reflectivity → Q factor

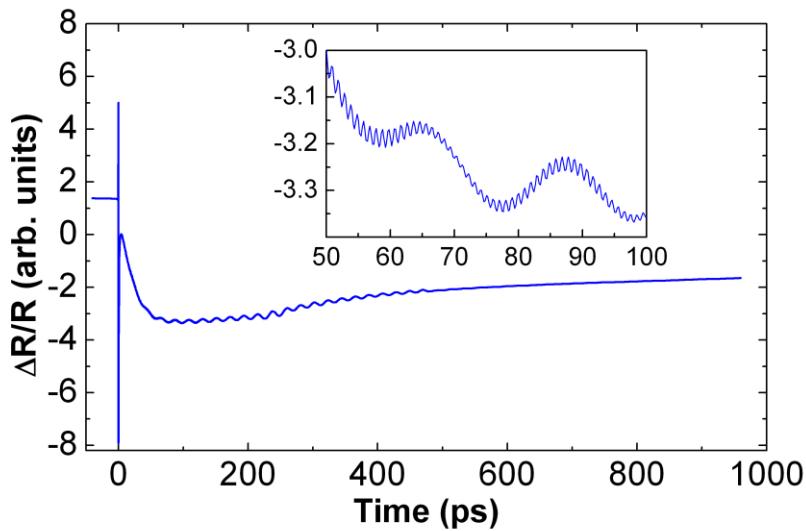
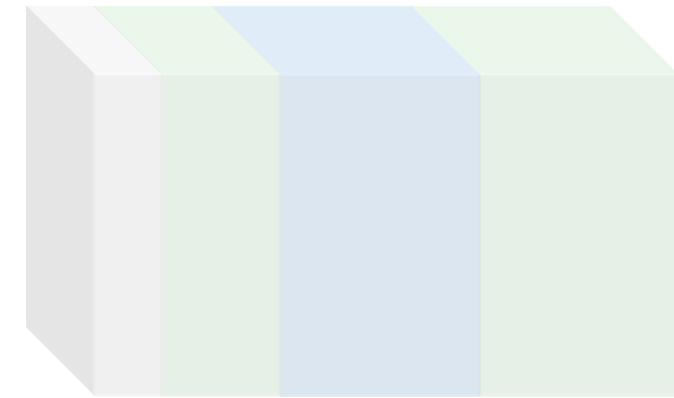
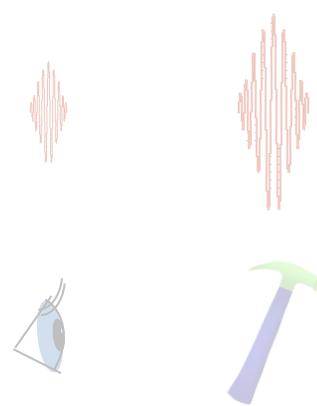
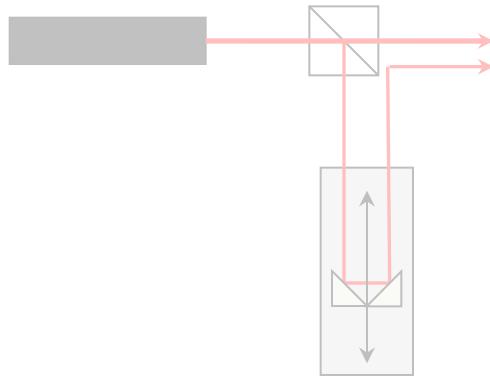


Similar to a
Fabry-Perot
interferometer

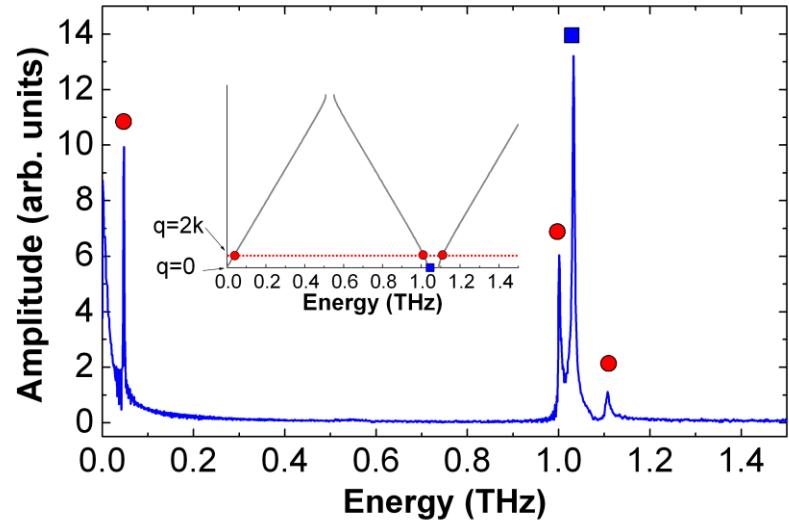
Two phononic mirrors enclosing a spacer confine and “amplify” acoustic fields



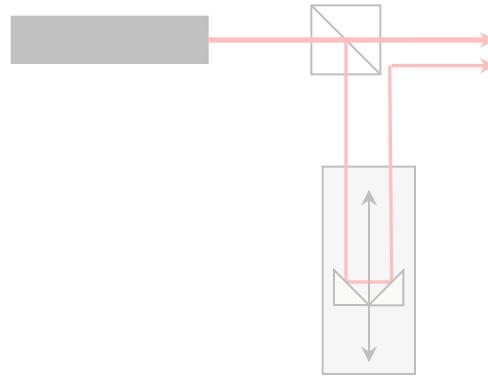
How can we generate and detect sub-THz acoustic phonons?



FT
→



How can we generate and detect sub-THz acoustic phonons?



Generation

$$w(\omega) \propto \int K(z) \frac{\partial u(\omega)}{\partial z} |E(\lambda)|^2 dz$$

Light-hypersound
coupling constant

Acoustic
strain eigenstates

Electric field
(pump)

Detection

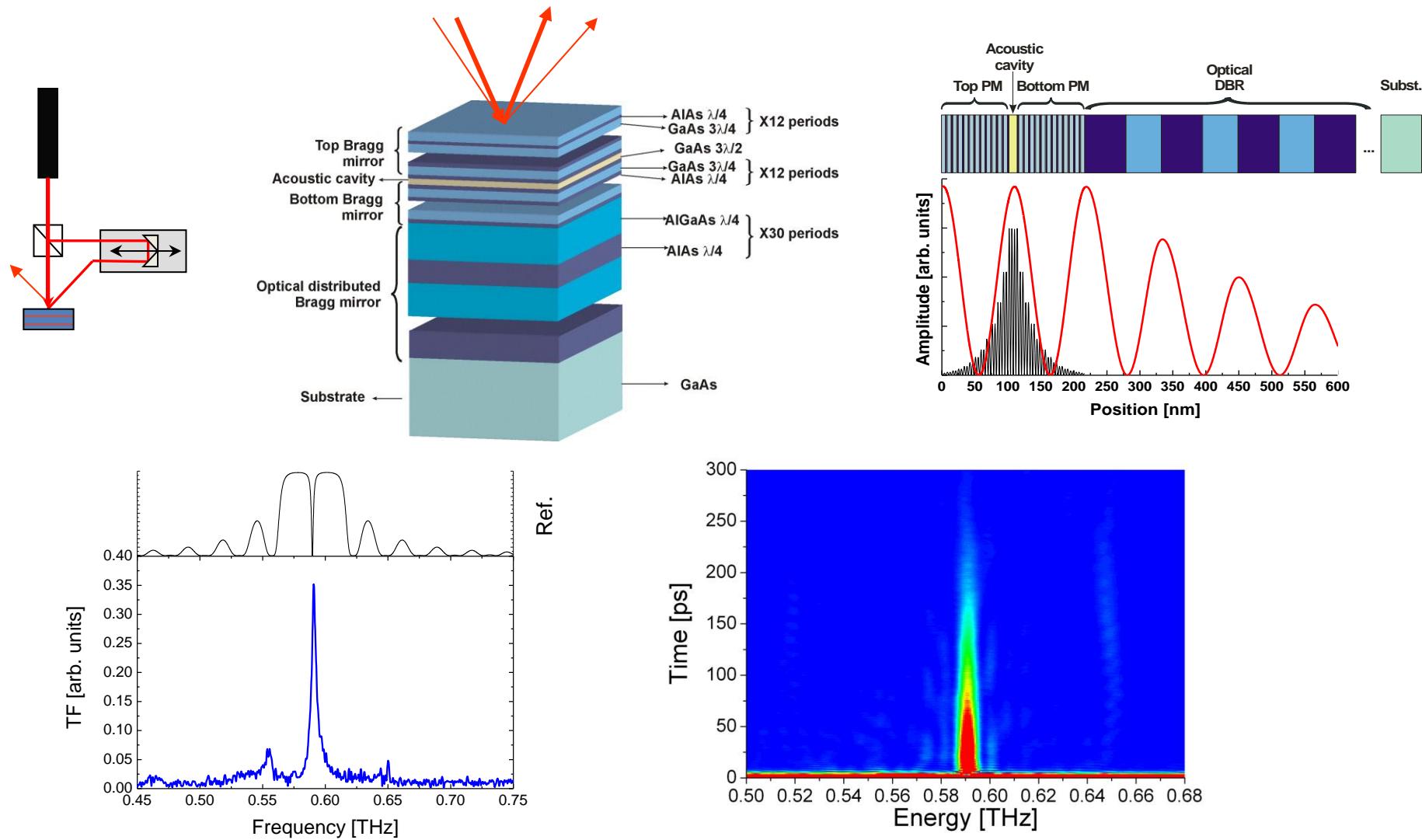
$$w(\omega) \propto \int K(z) \frac{\partial u(\omega)}{\partial z} E(\lambda)^2 dz$$

Light-hypersound
coupling constant

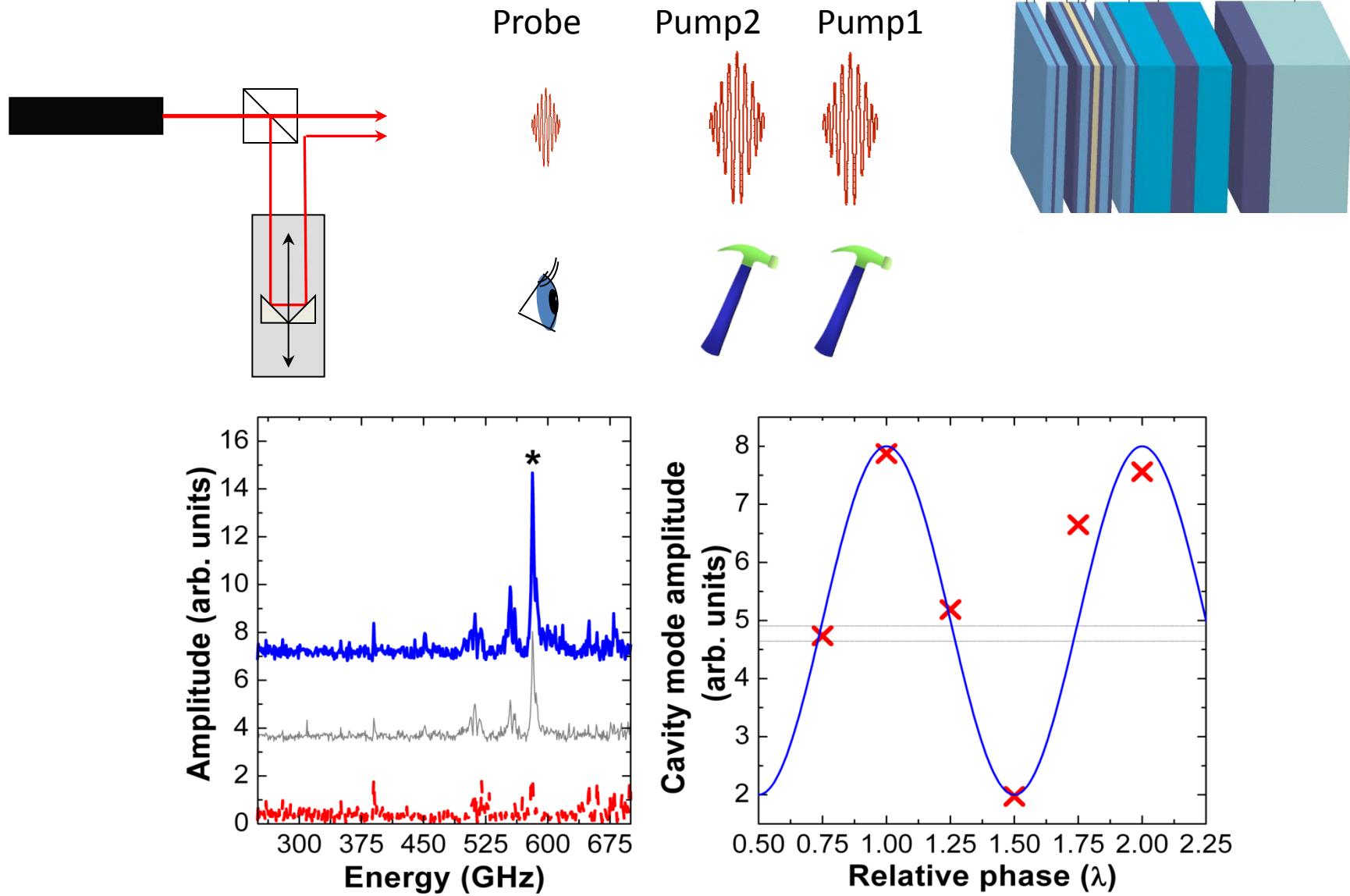
Acoustic
strain eigenstates

Electric field
(probe)

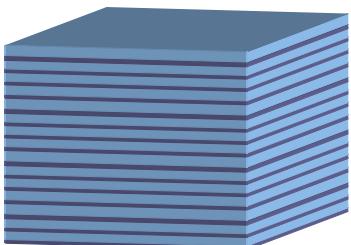
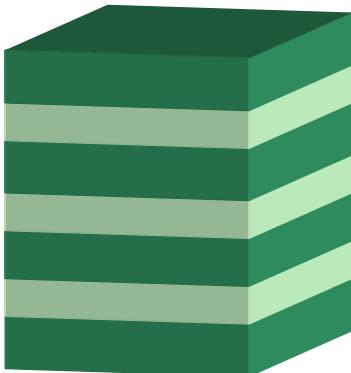
The acoustic cavity can be used as phonon transducer by itself



Multiple hammers control the generation and annihilation of phonons

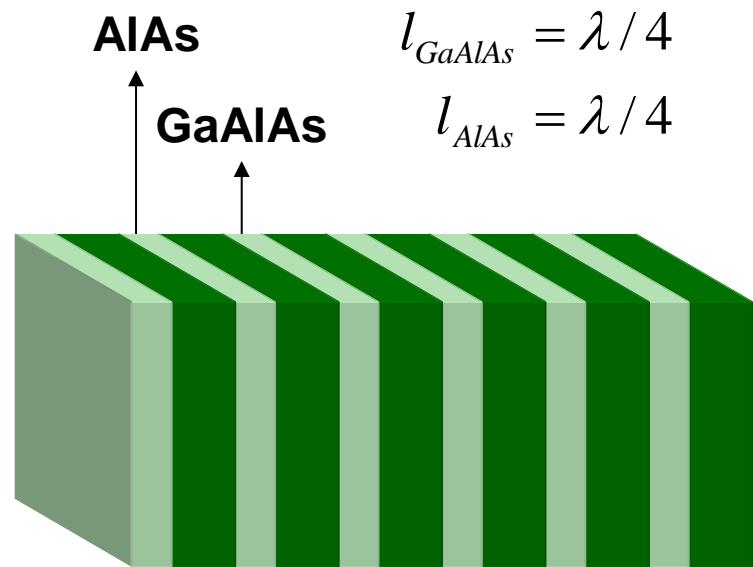
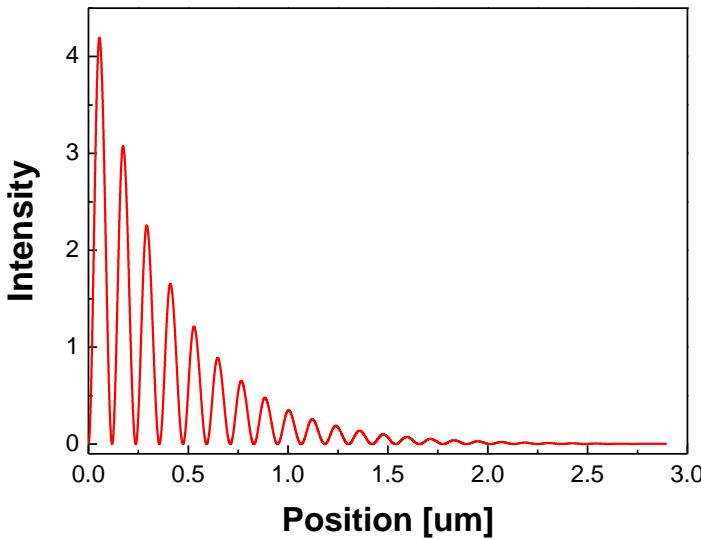
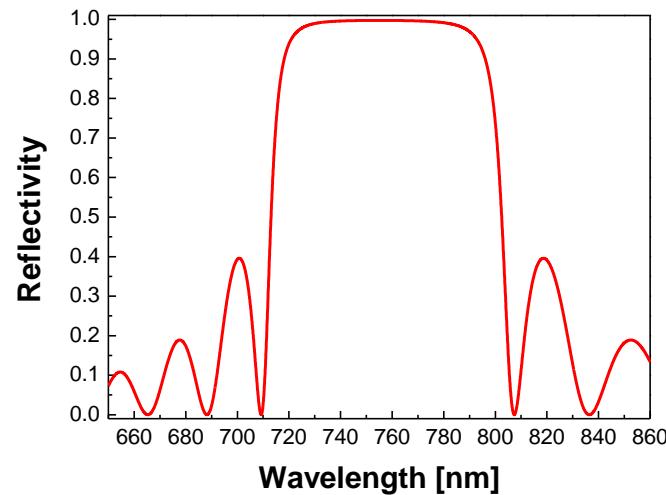


From microphotonics to nanophononics... and viceversa



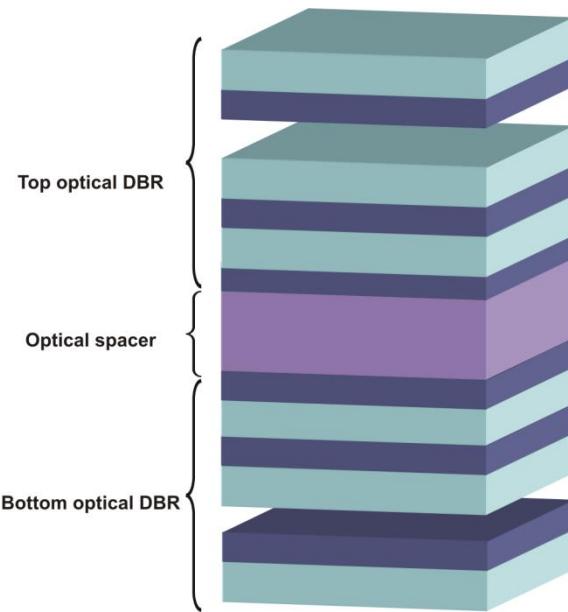
	Light (Photons)	Sound (Phonons)
Equation	Maxwell	Elasticity
Design	n	$z = v \cdot \rho$
Wavelength	$\sim 200 \text{ nm}$	$\sim 10 \text{ nm}$
Thickness relation	$\lambda/4 - \lambda/4$	$3\lambda/4 - \lambda/4$
Air surface	$n=1$	$z \approx 0$
GaAs/AlAs contrast	0.836	0.839

A periodic stack can act as a reflector of light

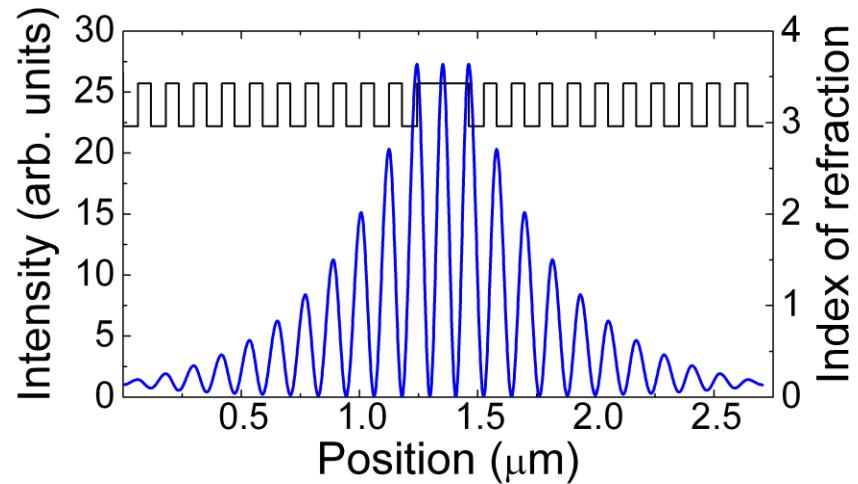
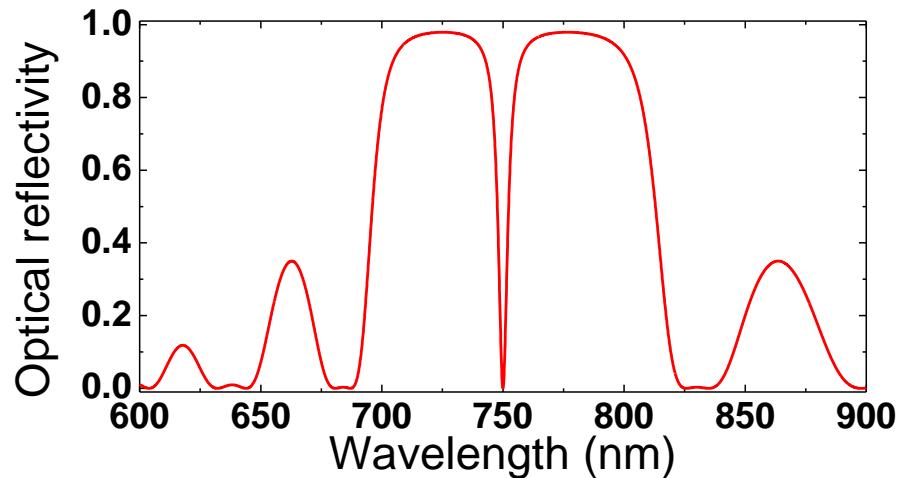
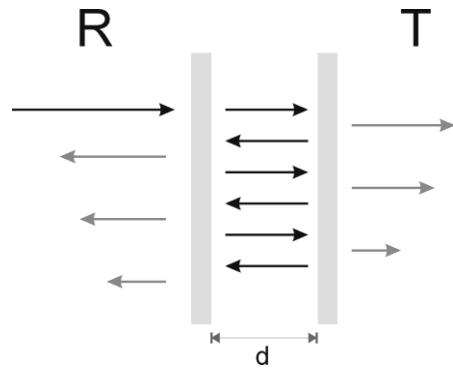


$$Z_{GaAs/AlAs}^{optic} = \frac{n_2}{n_1} \approx 0.84$$

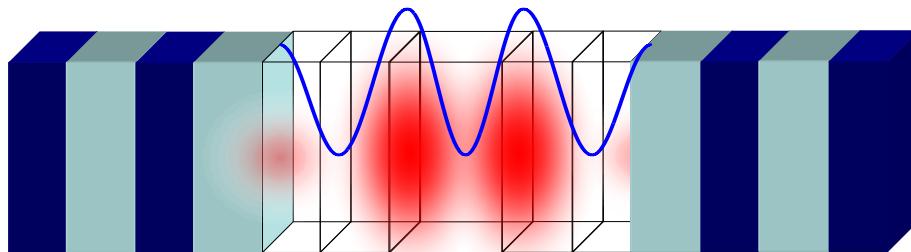
An optical microcavity confines and “amplify” light



$(\lambda/4, \lambda/4)$ AlAs/AlGaAs $\sim 100\text{nm}/\text{period}$

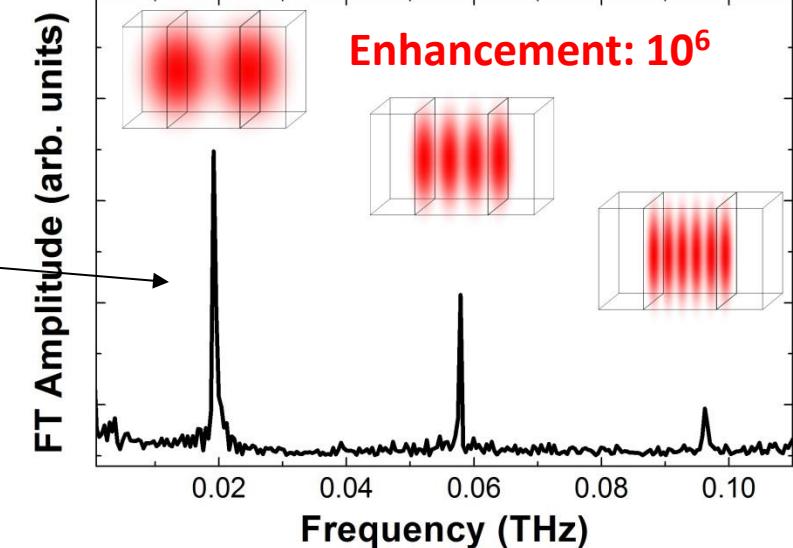
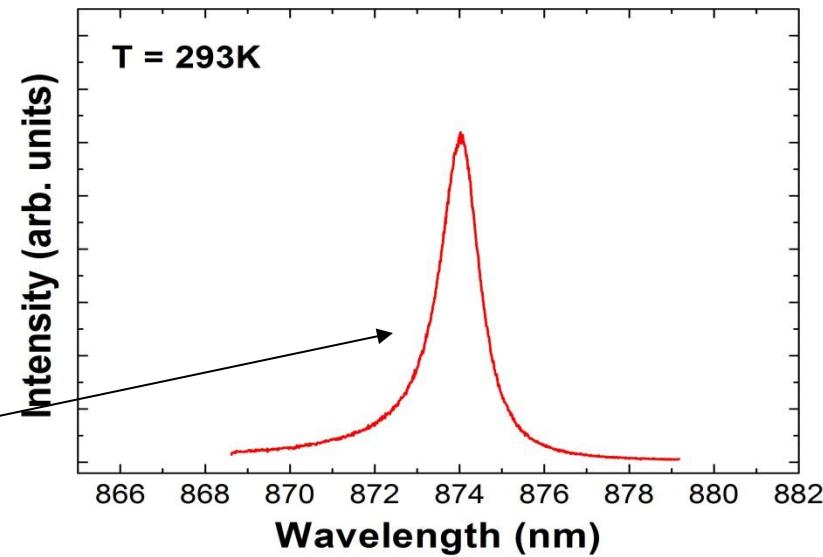
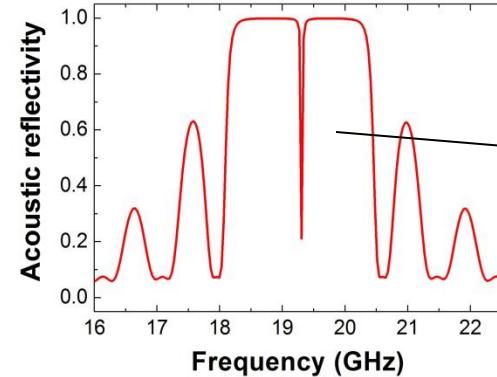
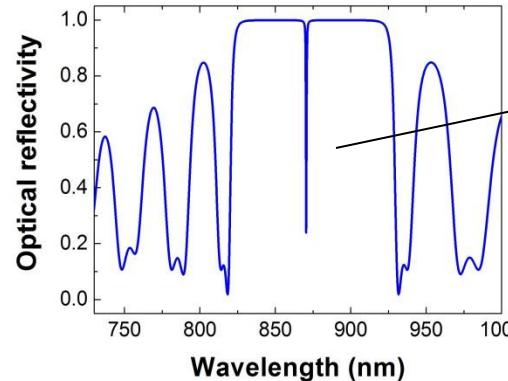


An optical microcavity confines visible light and GHz sound simultaneously!

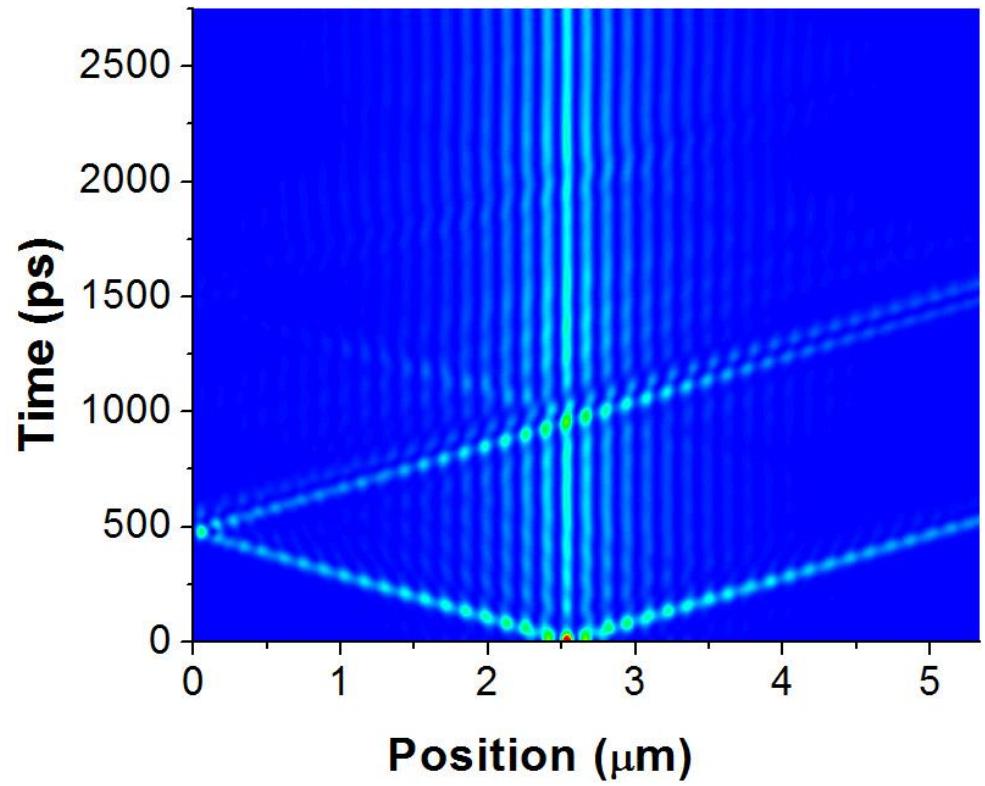
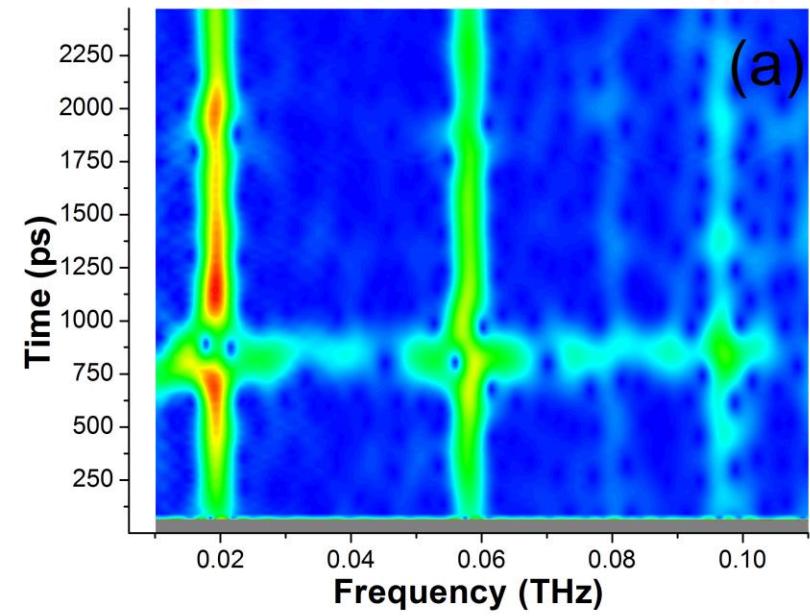
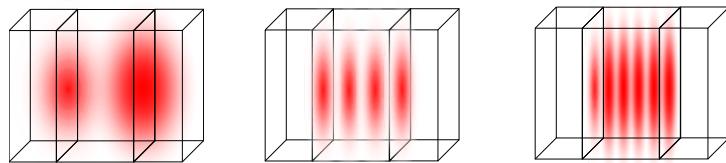
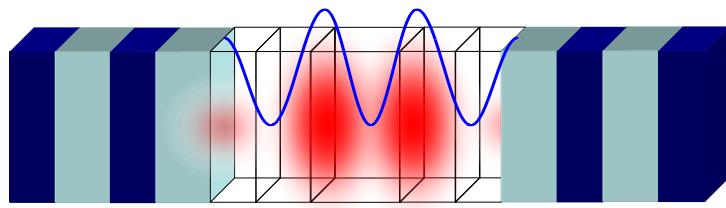


$$Z_{GaAs/AlAs}^{optic} = \frac{n_2}{n_1} \approx 0.84$$

$$Z_{GaAs/AlAs}^{acoustic} = \frac{v_2 \rho_2}{v_1 \rho_1} \approx 0.84$$

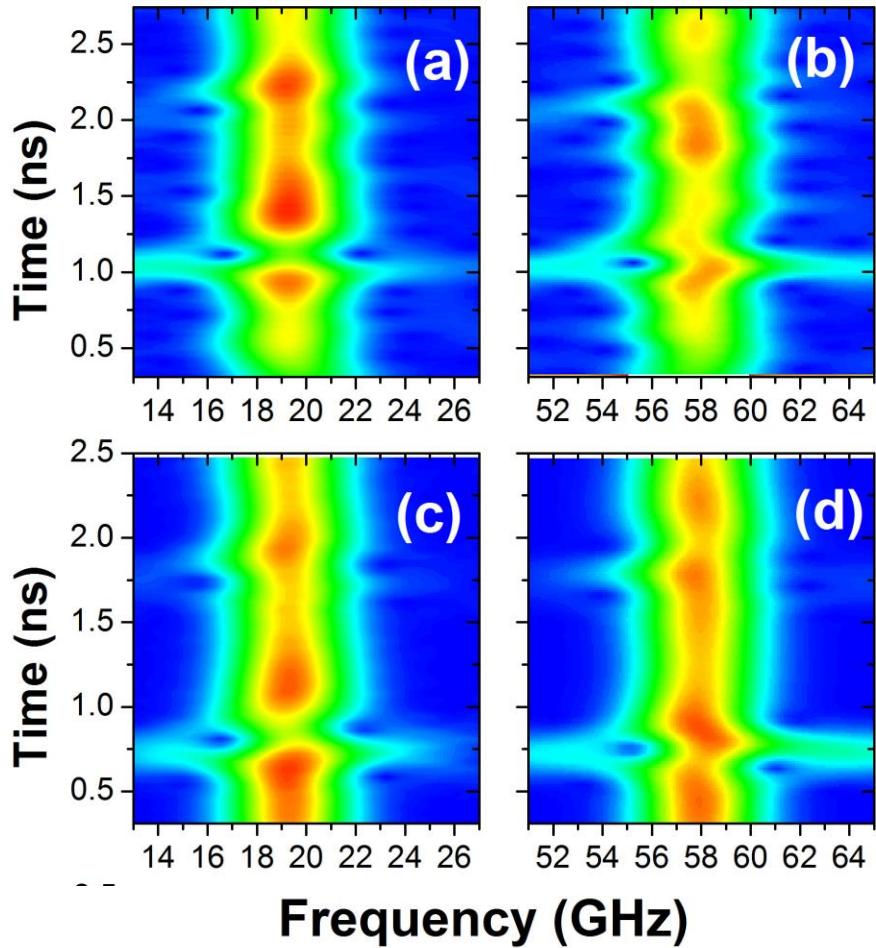
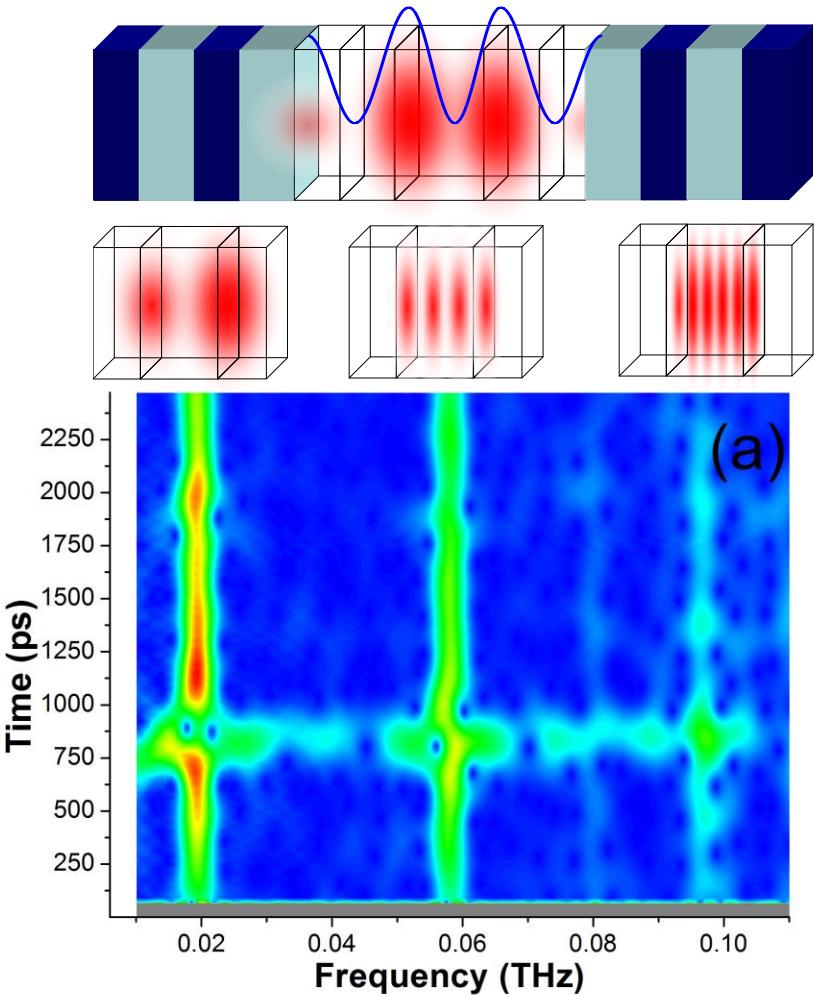


Escaping phonons interact with the confined cavity phonons



A. Fainstein, N. D. Lanzillotti-Kimura, et al. PRL 2013.

The time evolution reveals interesting features in the acoustic cavity modes

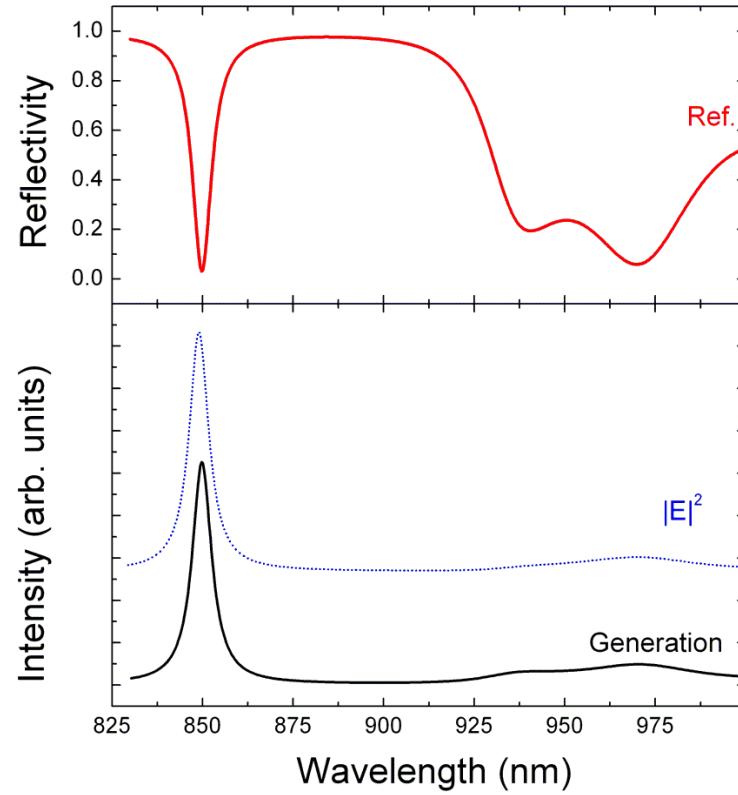
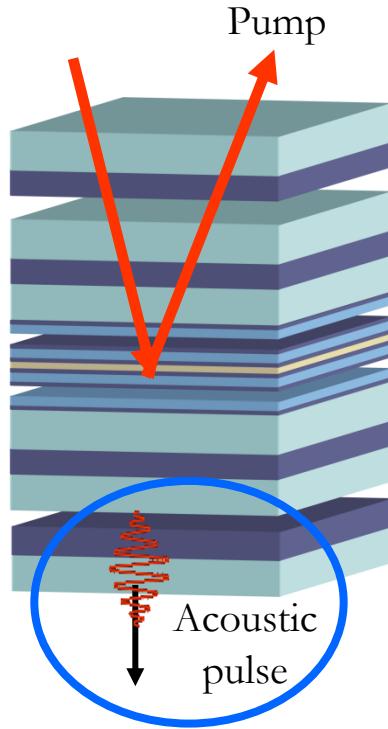


Experiments

Simulations

An optical microcavity confines and “amplify” light

Enhanced generation

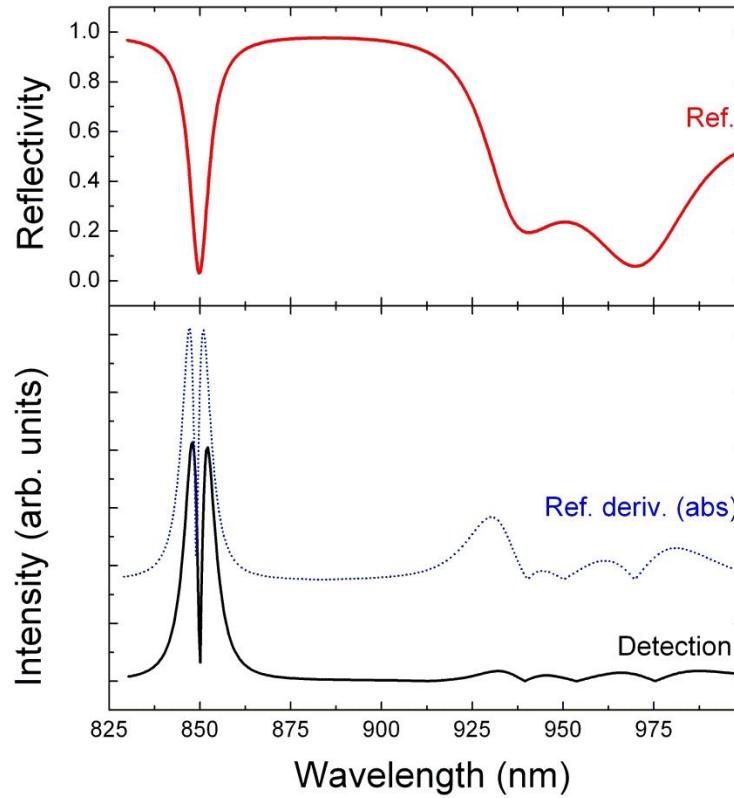
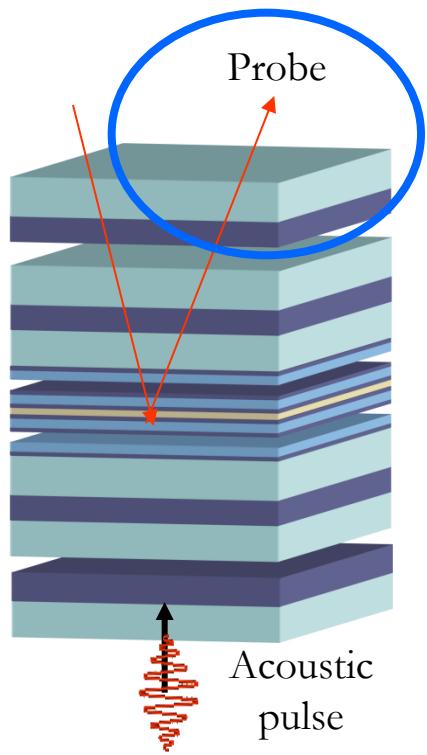


$$\eta(\lambda) \propto |E(\lambda)|^2 \longrightarrow \text{Photoelastic interaction}$$

Intensity of the confined acoustic frequency

- Generation follows the electric field intensity
- Minimum at the mirror edge
- Maximum at the cavity mode center

An optical microcavity confines and “amplify” light



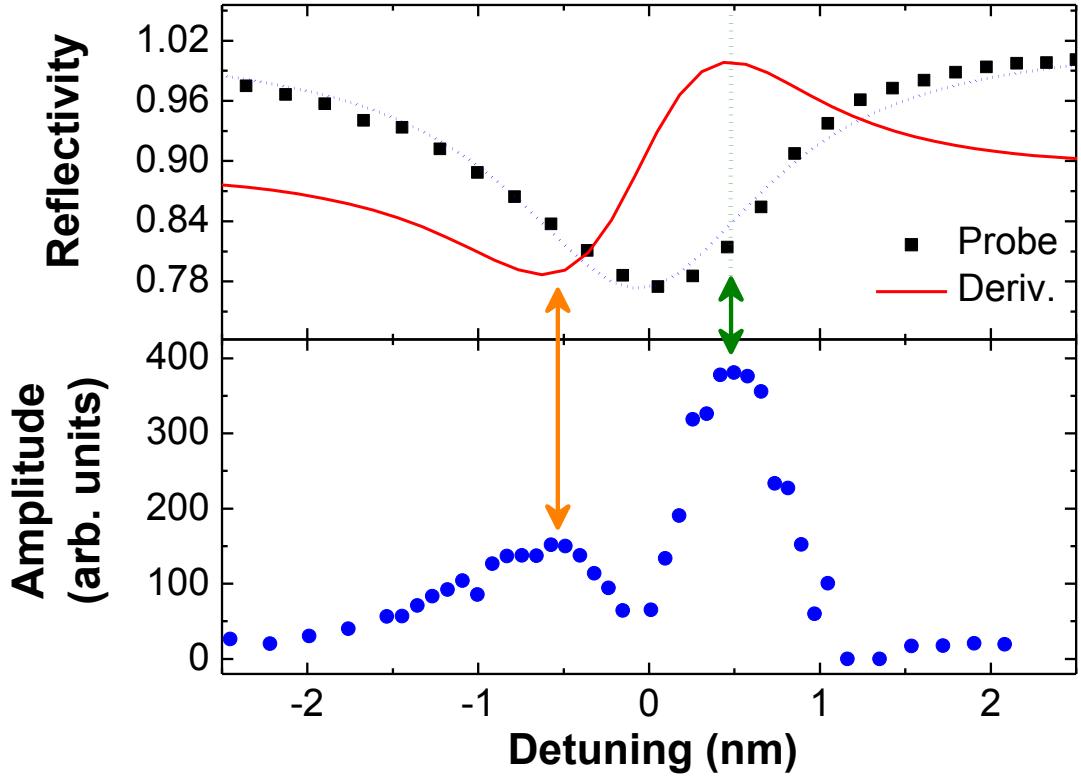
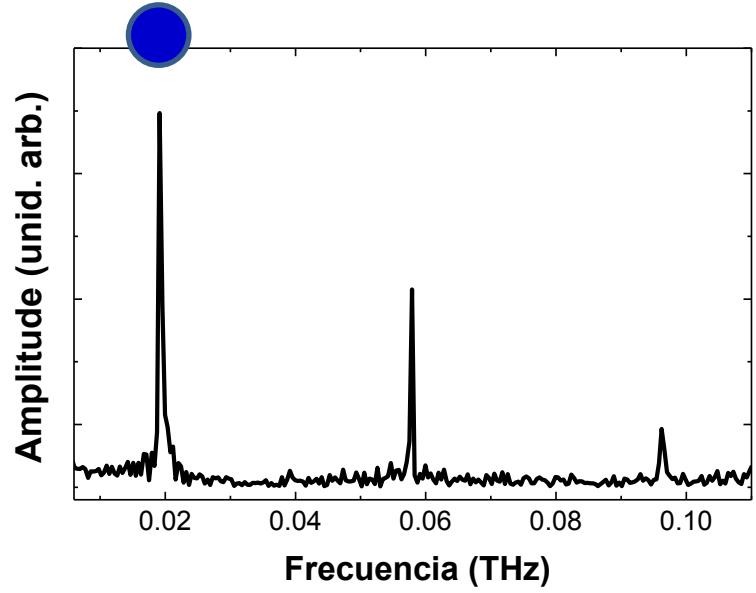
$\eta(\lambda) = 1 \longrightarrow$ Independent strain source

$\Delta n \propto \eta \longrightarrow$ Photoelastic interaction

Detection of the acoustic cavity mode frequency

- Detection follows the reflectivity derivative
- Minimum at the cavity mode center
- Maxima at the cavity mode edges

An optical microcavity confines and “amplify” light



Magic resonators for light and hypersound

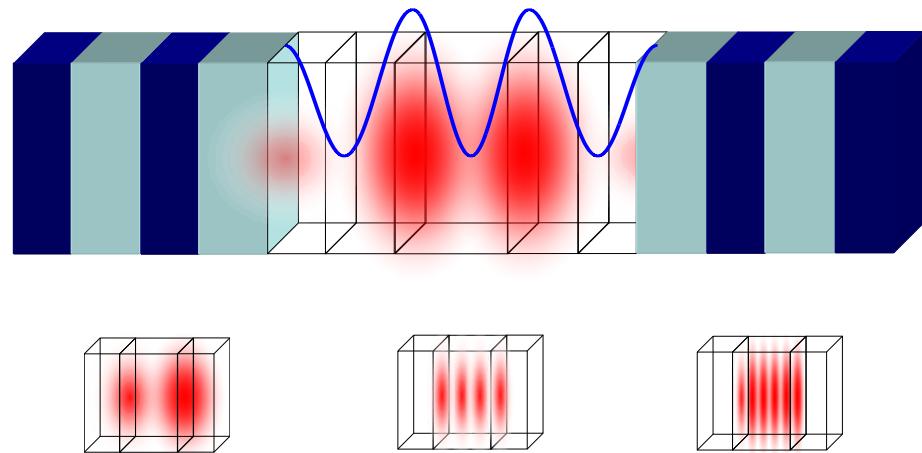
Perfect matching between the acoustic and optical modes

High-Q, frequencies ~20 GHz, wavelengths of 900 nm

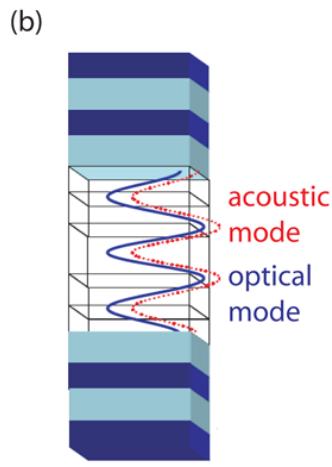
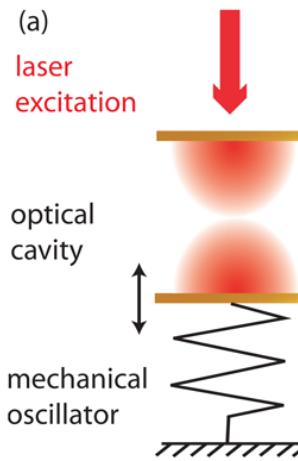
Acoustic dynamics in this system

$$Z_{\text{GaAs / AlAs}}^{\text{optic}} = \frac{n_2}{n_1} \approx 0.84$$

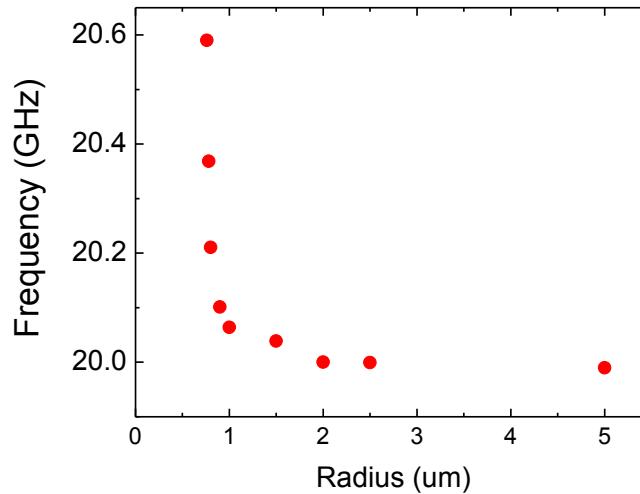
$$Z_{\text{GaAs / AlAs}}^{\text{acoustic}} = \frac{v_2 \rho_2}{v_1 \rho_1} \approx 0.84$$



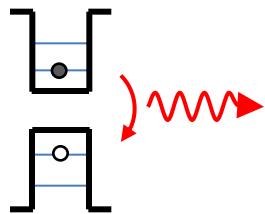
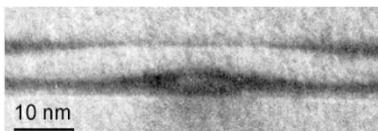
Novel platform for nano-optomechanics



Higher frequencies (> 1GHz)
Lower mass (<100 pg)
High optomechanical coupling (> 1GHz/nm)



Novel optophononic platform



The exciton interacts with
mechanical strain

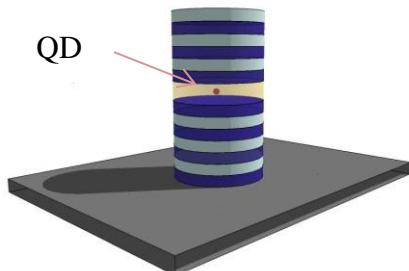
In-situ
lithography

Deterministic QD-EM overlap



Deterministic QD-strain overlap

GaAlAs opto-phononic resonators
single quantum dot coupling



N. D. Lanzillotti-Kimura, et al. Submitted, 2015

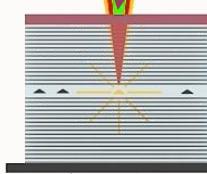
Deterministic QD-strain overlap

Excitation
laser

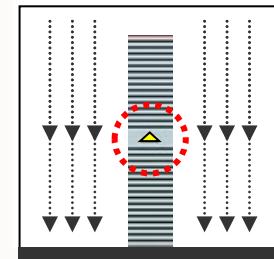
Emission mapping
50 nm precision

Exposure laser

4 K



Piezostage



In-situ lithography

PRL 2008 Senellart's group

Concluding remarks:

- New platform to confine photons and phonons
- Optimization of the coupling between a QD and a phonon field



Thank You!