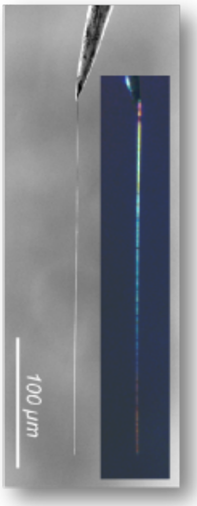
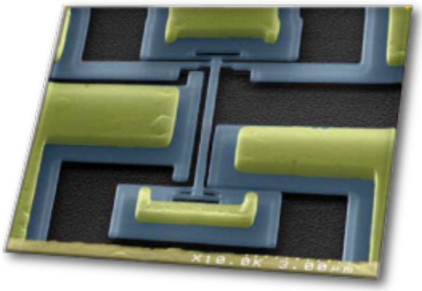
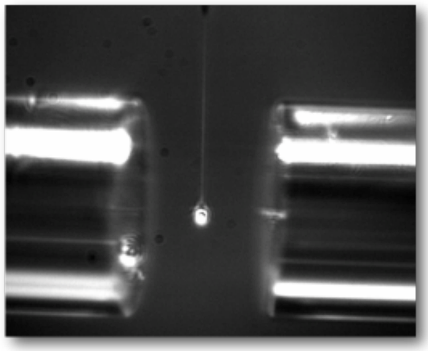
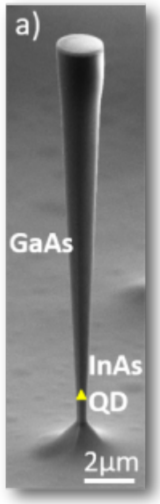


GdR MecaQ 5th Annual Meeting
9 October 2020
Institut Néel, Grenoble







Book Of Abstracts

The GDR MecaQ gathers the French community of scientists sharing an interest for quantum optomechanics, nanomechanics and associated phenomena and applications.

This fifth edition of the Annual Meeting of the GDR MecaQ will focus on advances in the field, while at the same time open to related research fields

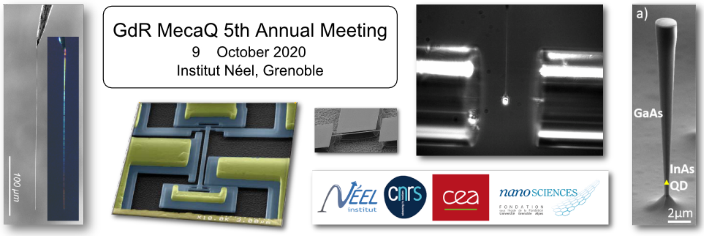
Tutorial talks: 30 minutes invited tutorials will be given by internationally renowned speakers who will introduce their research topic and present their latest advances.

Confirmed tutorial speakers:

- Dr Natalia Ares, *Oxford University.*
- Dr Lucien Besombes, *CNRS - Institut Néel*
- Dr Audray Bienfait, *CNRS - ENS Lyon*
- Dr Silvia Viola Kusminskiy, *Max Planck Institute Erlangen*
- Pr Philipp Treutlein, *University of Basel*

Contributed presentations (20 minutes): 10 contributed talks of 15 minutes have been selected upon abstract submission.

After careful consideration we decided to organise the GDR MécaQ 2020 days entirely by videoconference. We will be using the videoconference tool Big Blue Button.



Schedule

8:45 - 9:00 Connecting to Big Blue Button and introductory remarks

9:00 - 9:40 *"Quantum erasure with entangled surface acoustic wave phonons"*, Audrey Bienfait, CNRS-ENS Lyon

9:40 - 10:00 *"Coupling VLSI Nanomechanical systems with microwave resonators"*, Kazi Rafsanjani Amin, CNRS-Institut Néel

10:00 - 10:20 *"Anomalous spikes in the apparent vibration amplitude of nanomechanical strings"*, Sumit Kumar CNRS-Institut Néel

10:30 - 11:10 "Light-mediated strong coupling between a mechanical oscillator and atomic spins one meter apart", Philipp Treutlein, Basel University

11:10 - 11:30 *"Rare-Earth Doped Crystals for strain-coupled optomechanics"*, Signe Seidelin, CNRS-Institut Néel

11:30 - 11:50 *"Magneto-optical confinement of the orientation of diamond particles"*, Maxime Perdriat, CNRS-ENS Paris

11:50 - 12:30 *"Cavity Optomagnonics"*, Silvia Viola Kusminskiy, Max Planck Institute Erlangen

12:30 - 13:30 Lunch break

13:30 - 14:10 *"Circuit optomechanics for thermodynamics at the nanoscale"*, Natalia Ares, University of Oxford

14:10 - 14:30 *"Towards a carbon nanotube mechanical qubit"*, Christoffer B. Møller, ICFO Barcelona

14:30 - 14:50 *"Landauer erasure and Szilard engine in carbon nanotubes single electron transistors"*, Florian Vigneau, University of Oxford

14:50 - 15:10 *"Permanent Directional Heat Currents in Lattices of Optomechanical Resonators"*, Zakari Denis, MPQ Université de Paris

15:20 - 16:00 *"Individual magnetic atoms in semiconductors as spin qubits for nano-mechanical systems"*, Lucien Besombes, CNRS-Institut Néel

16:00 - 16:20 *"An investigation of proximity forces above nanostructures with an ultrasensitive nanowire probe based on quasi real time sensing protocols"*, Philip Heringlake, Institut Néel

16:20 - 16:40 *"Thermal noise of a micro-cantilever submitted to a temperature contrast over one hundred"*, Alex Fontana, CNRS-ENS Lyon

16:40 - 17:00 *"Multiplexing of optomechanical resonators for biological and mass sensing"*, Fabrice-Roland Lamberti, CEA-Leti Grenoble

The GDR MécaQ

The years 2010 were marked by the emergence of "quantum" mechanical systems, which literally designate mechanical resonators with a sensitivity whose dynamics description requires quantum processing.
The GDR "Quantum Optomechanics and Nanomechanics" federates activities around these themes of quantum measurement and control at the macroscopic scale, with new and extremely ambitious stakes and challenges.

Technological stakes and challenges
The main technological challenges in the development of quantum mechanical systems accompany those of emerging quantum technologies and are in line with the prospect of a new generation of ultra-sensitive sensors and future communication means, as well as their ultra-compact integration for widespread use. Examples include the development of coherent opto-electromechanical converters, quantum hybrid systems (association of a mechanical resonator and a degree of quantum freedom), nano-optomechanical crystals (which could be used as topological insulators), nano-optomechanical local probes, the definition of new metrological standards, etc. The technological challenges associated with these issues are essentially related to the sensitivity of these systems to the effects of decoherence, which must be minimised as far as possible. Very spectacular progress has very recently been made in this direction, with the appearance in 2017 of nanomechanical systems with quality factors exceeding one billion at ambient temperature. However, the development of processes that make it possible to combine very low optical and mechanical dissipation coefficients remains a challenge that fuels intense research.

Fundamental issues and challenges
Technological advances in ultra-sensitive mechanical systems are also fuelled by fundamental issues that are essentially related to the so-called "second quantum revolution", such as the observation and overcoming of the fundamental limits of sensitivity in displacement measurements, the observation of the quantification of mechanical energy at the macroscopic scale (and thus the non-destructive quantum measurement of motion), the preparation of non-classical macroscopic mechanical states, or the observation of the influence of gravity on quantum decoherence phenomena. These issues are today the subject of much research aimed at understanding the consequences of these phenomena on a macroscopic scale, at proposing measurement protocols compatible with quantum theory, and at modelling systems that present themselves as the best candidates.

Thematic structure
The GdR MecaQ is characterised by its very transversal nature: the scientific problem of the interaction between electromagnetic and mechanical degrees of freedom is at the heart of many physical systems. Conversely, the fundamental study of optomechanical effects requires the design and development of advanced systems to explore the quantum regime.

Thus, the GdR MecaQ is today based on 11 themes covering all the scientific activities taking place there. These range from the study of the foundations of quantum measurement to the development of ultra-sensitive hybrid sensors, via the detection of gravitational waves and quantum thermodynamics.

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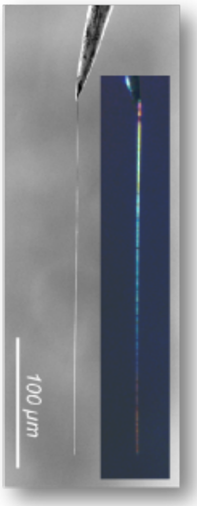

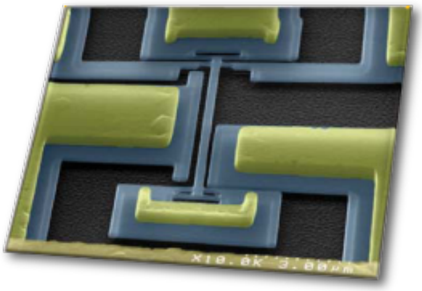

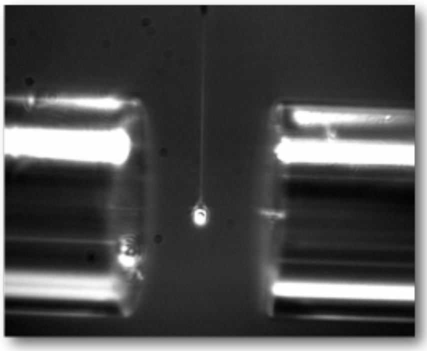

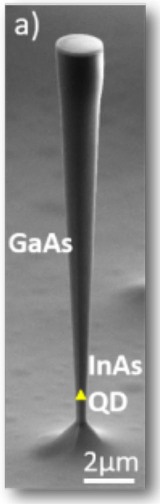

Abstracts

Coupling VLSI Nanomechanical systems with microwave resonators

Kazi Rafsanjani Amin[a*], Guillaume Jourdan[b], Carine Ladner[b], Sebastien Hentz[b,] Nicolas Roch[a] and Julien Renard[a]

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Hybrid quantum systems involving nanoelectromechanical systems (NEMS) and microwave or optical cavities have been of tremendous interest in modern days research from both fundamental and applied perspectives [1]. Radiation pressure cooling of a nanomechanical system to its quantum ground state, generation of entangled radiation, squeezing of mechanical motion and many more effects have been thoroughly studied over the last decade. Since NEMS couple with both microwave and optical cavities, bidirectional conversion of microwave and optical photons using NEMS is actively investigated as a major application for quantum technology network [2].

Major requirements of such a hybrid quantum system for application in future technologies are large coupling between NEMS and microwave cavities, and robustness of device fabrication technique. Here, we combine silicon-on-insulator (SOI) NEMS devices with superconducting microwave resonators. These devices are entirely fabricated in the industry-grade LETI clean room. Our approach benefits from VLSI compatibility while maximizing electromechanical coupling. We have fabricated and characterized high-impedance microwave resonators with state-of-the-art internal quality factors. Coupling of such resonators with NEMS on SOI platform is now being studied.

[1] M. Aspelmeyer, T. J. Kippenberg, and F. Marquardt, Cavity optomechanics. Rev. Mod. Phys. 86, 1391–1452 (2014)

[2] Y. Chu and S. Gröblacher, A perspective on hybrid quantum opto- and electromechanical systems, arXiv:2007.03360 (2020)

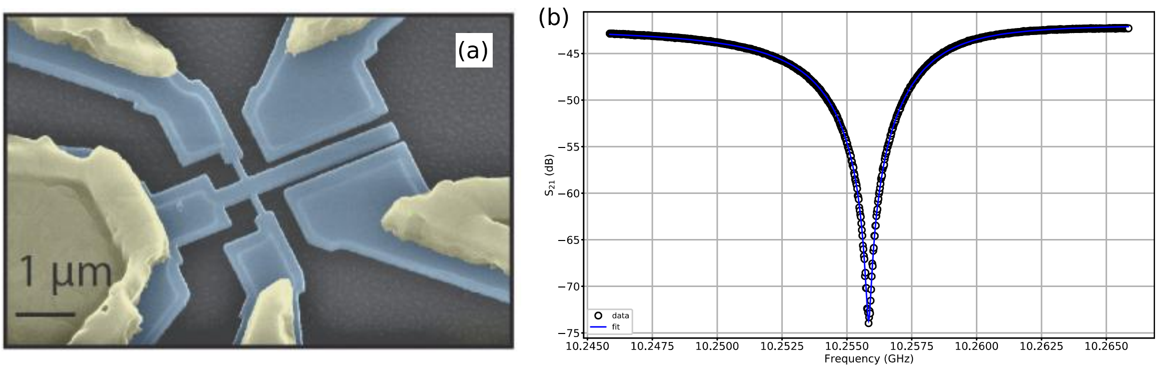

Figure 1: (a) Typical NEMS fabricated routinely at CEA-LETI. (b) Typical microwave resonance observed in our device.

Anomalous spikes in the apparent vibration amplitude of nanomechanical strings

Sumit Kumar[a*], Dylan Cattiaux[a], Ilya Golokolenov[a], Xin Zhou[b], Eddy Collin[a] and Andrew Fefferman[a]

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Microwave optomechanics is a powerful technique for measuring the thermal vibrations of nanomechanical modes all the way down to the quantum ground state [1]. However, not all of the observed phenomena can be explained in the framework of optomechanical theory. In particular, Zhou *et al.* reported enormous fluctuations in the apparent vibration amplitude of a nanomechanical mode that could not be explained by thermal agitation (Zhou19). These fluctuations, called "spikes", appeared below 100 mK. Such spikes have also been observed in the apparent vibration amplitude of other nanomechanical devices with varying magnitudes and onset temperatures. In this work, we report detailed measurements of the spikes in the device of Zhou *et al*. It consists of a 50 μm x 120 nm x 300 nm Al on SiN string coupled to a high impedance Nb microwave cavity. At 250 mK, the device behaved in agreement with the predictions of optomechanical theory (Fig. 1). With the sample cell at 10 mK, we applied a pump tone at the microwave resonance $\omega_c/2\pi$ =6 GHz and monitored the output power p_{out} around $\omega_c+\Omega_m$, where $\Omega_m/2\pi$=4 MHz is the mechanical resonance. At constant pump power, we observed spikes in p_{out} with a decay time of 100 msec. Quiet periods with no spikes lasting thousands of seconds were also observed. These spikes were only observed at ω_p+/-Ω_m, where ω_p is the pump frequency, demonstrating that their origin must involve motion of the nanomechanical string. Therefore, the spikes in p_{out} must arise either from true changes in the vibration amplitude of the string or from changes in the gain of the optomechanical transduction. In order to distinguish between these two possibilities, we then determined the apparent rms vibration amplitude x_0 of the string from p_{out} using standard optomechanical theory. We did not observe a reproducible dependence of x_0 on pump power, which seems to be inconsistent with an explanation of the spikes in terms of optomechanical gain changes. Instead, this points toward a true anomaly in the string vibration amplitude. We observed a maximum value x_0=300 pm, which is much greater than the 400 fm vibration amplitude due to thermal agitation at 10 mK.

[1] J. Teufel *et al.*, *Nature* **475**, 359 (2011), [2] X. Zhou *et al. Phys. Rev. Appl.*, **12**, 044066 (2019).

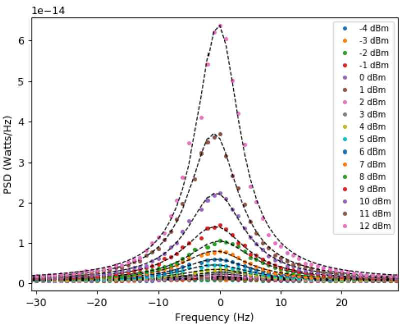

Figure 1 : Dependence of the Stokes sideband on pump power in the blue-detuned pumping scheme at 250 mK. Dashed lines are fits of the predictions of optomechanical theory to the measurements.

Rare-Earth Doped Crystals for strain-coupled optomechanics

A particularly appealing coupling mechanism between a resonator and an “atom” is based on material strain. Here, the oscillator is a bulk object containing an embedded artificial atom (dopant, quantum dot, ...) which is sensitive to mechanical strain of the surrounding material. Vibrations of the oscillator result in a time-varying strain field that modulates the energy levels of the embedded structure. We have suggested to use rare-earth doped crystals for strain-coupled systems [1] and proposed a mechanism to cool down the resonator [2]. In this talk, I will report on our progress towards realizing experimentally these protocols. We are using an yttrium silicate (Y_2SiO_5) crystal containing triply charged europium ions (Eu^{3+}), which are optically active. The reason behind this choice stems from the extraordinary coherence properties of this dopant, combined with its high strain-sensitivity: the Eu^{3+} in an Y_2SiO_5 matrix has an optical transition with the narrowest linewidth known for a solid-state emitter, and the transition is directly sensitive to strain. We have successfully fabricated mechanical resonators, designed and set up the experiment, and achieved a signal-to-noise ratio compatible with the planned measurements, as well as measured the strain sensitivity of europium ions in bulk Y_2SiO_5 crystals [3,4].

[1] K. Mølmer, Y. Le Coq and S. Seidelin, *Dispersive coupling between light and a rare-earth ion doped mechanical resonator*, Phys. Rev. A **94**, 053804 (2016).

[2] S. Seidelin, Y. Le Coq and K. Mølmer, *Rapid cooling of a strain-coupled oscillator by an optical phase-shift measurement*, Phys. Rev. A **100**, 013828 (2019)

[3] N. Galland, N. Lučić, B. Fang, S. Zhang, R. Le Targat, A. Ferrier, P. Goldner, S. Seidelin and Y. Le Coq, *Mechanical Tunability of an Ultranarrow Spectral Feature of a Rare-Earth-Doped Crystal via Uniaxial Stress*, Phys. Rev. Applied **13**, 044022 (2020)

[4] S. Zhang, N. Galland, N. Lučić, R. Le Targat, A. Ferrier, P. Goldner, B. Fang, Y. Le Coq and S. Seidelin, *Inhomogeneous response of an ion ensemble from mechanical stress*, Phys. Rev. Research **2**, 013306 (2020)

Magneto-optical confinement of the orientation of diamond particles

Maxime Perdriat[1], Paul Huillery[1], Clément Pellet-Mary[1] and Gabriel Hétet[1,*]

1 Laboratoire de Physique de l'Ecole Normale Supérieure, PSL Research University, CNRS, Sorbonne Universités, Université de Paris, Sorbonne Paris-Cité, 24 rue Lhomond, 75231 Paris Cedex 05, France

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Observing and controlling macroscopic quantum systems has long been a driving force in research on quantum physics. The angular degrees of freedom of levitating diamonds coupled to embedded NV centers offer bright prospects towards this purpose [1,2]. As a first result, center of mass and librational confinements have been experimentally achieved for levitating micro-diamonds in an ion trap (see Figure 1-Left)). Our group has observed and demonstrated both a spin-dependent torque and spin-cooling of the diamond angular motion pushing spin-mechanics a step closer towards generation of non-classical states [3].

More recent works of our team have brought to light a new method to align levitating diamonds in the very specific [111] direction of the crystalline structure (to be published) using NV centers inside the diamond (see Figure 1-Right)). The technic is purely magneto-optical in the sense that it only requires a strong constant magnetic field (around 0.1T), a green laser beam focused on the diamond and no microwave. This angular control of levitating diamond could find interesting applications in NMR or in optically levitating nano-diamonds experiments.

[1] T. Delord, L. Nicolas, Y. Chassagneux and G. Hétet, Strong coupling between a single nitrogen-vacancy spin and the rotational mode of diamonds levitating in a ion trap, Phys. Rev. A **96**, 063810 (2017)
[2] Y. Ma, T.M. Hoang, M. Gong, T. Li and Z. Yin, Proposal for quantum many-body simulation and torsional matter-wave interferometry with a levitated nanodiamond, Phys. Rev. A **96**, 023827 (2017)
[3] T. Delord, P. Huillery, L. Nicolas and G. Hétet, Nature **580**, 56-59 (2020)

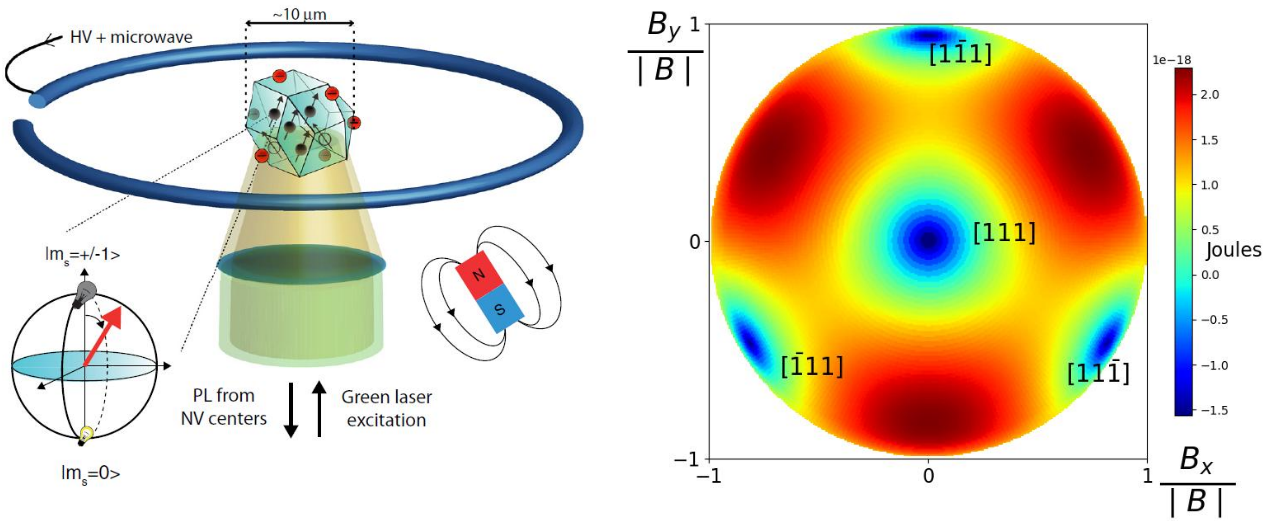

Figure 1 : Left) Illustration of the set-up of a micro-diamond levitating in the ion trap **Right)** Potential energy of the NV-induced angular potential in the presence of a green laser and under 0.15T. Energy minima correspond to a magnetic field aligned with [111] directions.

Towards a carbon nanotube mechanical qubit.

Christoffer B. Møller[a*], R. Q. Tormo[a], S. L. De Bonis[a], C. Samanta[a], W. Yang[a,†] , C. Urgell[a], D. Czaplewski[b], B. Stamenic[c], B. Thibeault[c], F. Pistolesi[d], A. N. Cleland[b,e], A. Bachtold[a]

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b. Center for Nanoscale Materials, Argonne National Laboratory, Argonne, IL 60439, USA
c. ECE Department, University of California Santa Barbara, Santa Barbara, CA, 93106, USA
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We present our efforts towards the realization of the first ever mechanical qubit based on mechanical vibrations [1]. We employ a pristine suspended carbon nanotube with state-of-the-art exceptional cryogenic mechanical coherence [2] and seek to significantly tailor the mechanical energy potential. This is done by strongly coupling its motion to a double quantum dot localized along the nanotube.

Towards this goal, we present measurements which demonstrate that we have reached the ultra-strong electromechanical coupling regime [3] generated by an electrostatic force between a biased gate electrode and a single charge quantum dot on an ultra-high quality factor suspended carbon nanotube.

We further present results related to extending these capabilities to a short, high frequency nanotube, suspended above 5 independently biased gate electrodes allowing for the localization of multiple coupled quantum dots[4]. These gates grant control of the interaction between the quantum dots, and their coupling with the mechanical vibrations allows the mechanical energy potential to become tunably anharmonic, essential in the formation of the mechanical qubit.

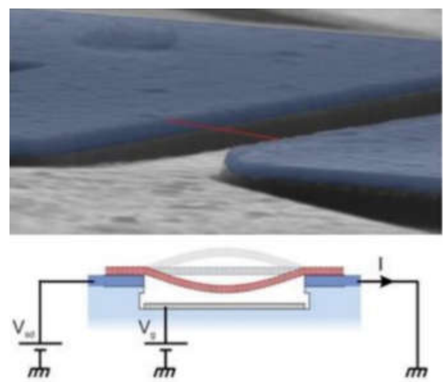

Figure 1: (top) False colour SEM image of a carbon nanotube (red) suspended from source and drain electrodes (blue) over a gate electrode (grey). **(bottom)** Schematic of the electromechanical device shown above. A current *I* flows due to a controllable source/drain voltage V_{sd} and may be blockaded due to a localized quantum dot on the carbon nanotube induced by tuning the gate electrode voltage V_g. The charge localized on the quantum dot depends on the nanotubes mechanical position above the gate electrode, thus enabling the electromechanical coupling.

[1] F. Pistolesi, A. N. Cleland, A. Bachtold, arXiv:2008.10524, (2020).
[2] J. Moser et al., Nature Nanotech. 9, 1007 (2014).
[3] S. L. De Bonis et al., Under review, (2019).
[4] I. Khivrich, A. A. Clerk and S. Ilani, Nature Nanotechnology 14, 161-167 (2019).

Landauer erasure and Szilard engine in carbon nanotubes single electron transistors.

Florian Vigneau[a*], Juliette Monsel[b,c], Lea Bresque[b], Jorge Tabanera[d], Federico Fedele[a], Janet Anders[e], Juan Parrondo[d], Alexia Auffeves[b], Natalia Ares[a]

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Thermodynamics of small systems have long been restricted to conjectures and though experiments. In 1929 Leo Szilard devised a thought experiment in which $k_B T\log(2)$ of work was extracted from the information acquired on a system composed of one particle in a box connected to a heat bath. Following this idea, in 1961 Rolf Landauer deduced a minimum energy of $k_B T\log(2)$ required to process one bit of information, establishing a fundamental limit to the energy cost of information processing. With current technologies miniaturizing devices, various ideas emerge to verify or challenge these principles.

Carbon nanotube mechanical resonators fascinated scientist during the 2000 decade. Single electron transistors were used to couple electrical current to the motion of carbon nanotube in order to study their mechanical properties. A common observed behavior was a softening of the mechanical frequency when the charge in the single electron transistor varied [1,2]. We present here a new interpretation as Landauer erasures and Szilard engine cycles. We will develop this idea and present an experimental protocol that could allow us to measure directly the work involved in this cycles through the motion of a carbon nanotube resonator. We will support our ideas with numerical simulations and present our means to realize them experimentally.

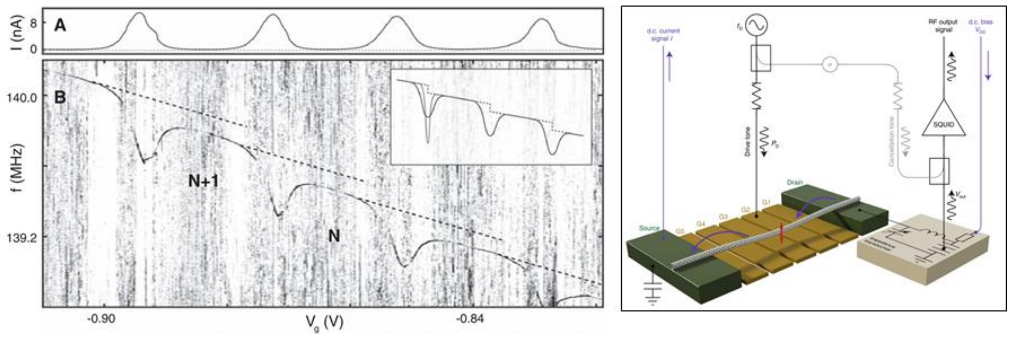

Figure 1 : Left: Coulomb peak (A) and frequency softening (B) at the charge transition. Taken from [1]. Right: Our carbon nanotube device and experimental setup that inspire our protocol. Taken from [3].

[1] G. A. Steele *et al.* SCIENCE 1103-1107 (2009). [2] B. Lassagne *et al.* SCIENCE 1107-1110 (2009).
[3] Y. Wen *et al.* Nature Physics 16, 75–82(2020).

Permanent Directional Heat Currents in Lattices of Optomechanical Resonators

Zakari Denis[a*], Alberto Biella[b], Ivan Favero[a] and Cristiano Ciuti[a]

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We study the phonon dynamics in lattices of optomechanical resonators where the mutually coupled photonic modes are coherently driven and the mechanical resonators are uncoupled and connected to independent thermal baths.
We present a general procedure to obtain the effective Lindblad dynamics of the phononic modes for an arbitrary lattice geometry, where the light modes play the role of an effective reservoir that mediates the phonon nonequilibrium dynamics. In our picture, quantum fluctuations of the optical fields mediate effective long-range interactions between mechanical sites of both coherent and dissipative nature, whose range is tunable via the correlation length of the reservoir.
A remarkable feature is the possibility to flow phonon streams in ways that seem to contradict common thermodynamic intuition, for example, a permanent phonon heat flow can be generated in the absence of thermal gradient.

[1] Z. Denis, A. Biella, I. Favero, and C. Ciuti, Permanent Directional Heat Currents in Lattices of Optomechanical Resonators, Phys. Rev. Lett. **124**, 083601 (2020)

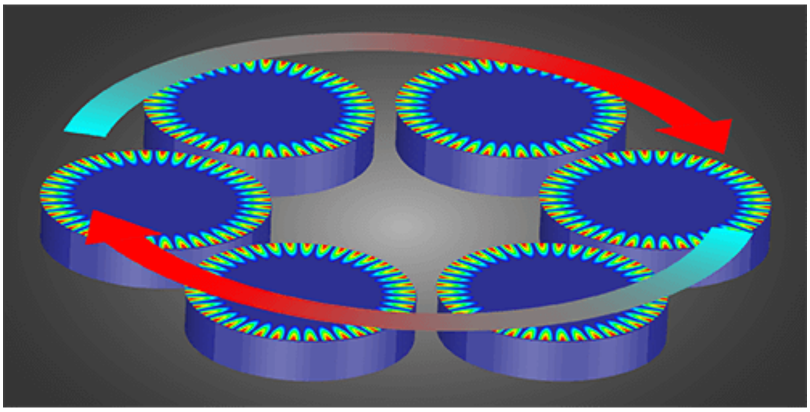

Figure 1: Artist's view of the system. Taken from *Physics* 13, s27.

Individual magnetic atoms in semiconductors as spin qubits for nano-mechanical systems

L. Besombes[1,†], V. Tiwari[1], H. Boukari[1], T. Crozes[1]
K. Makita[2], M. Arino[2], M. Morita[2], S. Kuroda[2]
[1] *Univ. Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, 38000 Grenoble, France*
[2] *University of Tsukuba, Institute of Materials Science, Tsukuba 305-8573, Japan*
† *lucien.besombes@neel.cnrs.fr*

A variety of magnetic atoms can be incorporated in conventional semiconductors giving a large choice of localized electronic spin, nuclear spin as well as orbital momentum. In a semiconductor quantum dot (QD) doped with a magnetic atom the exchange interaction of the localized spin with the confined carriers shift the energy of the dot. Emission lines corresponding to the different spins states of the atom are observed offering a possibility of optical control.

Among the magnetic transition elements that can be incorporated in semiconductors, Chromium is of a particular interest: when incorporated as Cr^{2+} ion in a II-VI semiconductor it carries an electronic spin S=2 and an orbital momentum L=2. The non-zero orbital momentum provides a large sensitivity of the electronic spin to local strain through the modification of the crystal field and the spin orbit coupling. This makes Cr^{2+} a very promising spin qubit for the realization of hybrid spin-mechanical systems.

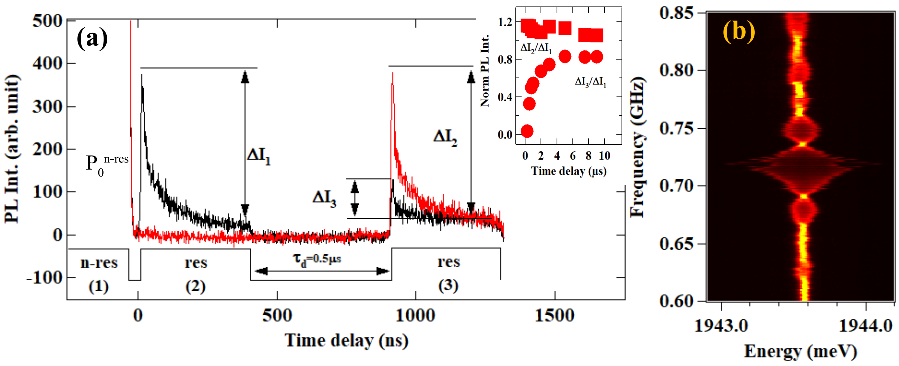

Figure 1: (a) Cr spin dynamics observed in a three pulses resonant optical pumping experiment. (b) Modulation of the energy of a CdTe QD by the strain field of a SAW. An electro-mechanical resonance is observed around 0.72GHz

We analysed the spin dynamics of an individual Cr^{2+} ion embedded in a CdTe/ZnTe QD. Under resonant excitation we demonstrated an optical pumping of the spin of the atom in a few tens of ns. An analysis of the resonant PL shows that an efficient transfer from the Cr spin states $S_z=\pm1$ to $S_z=0$ takes place. This transfer, responsible for the pumping, is induced by hole-Cr flip-flops. A model shows that hole-Cr flip-flops arise from an interplay of the hole-Cr exchange interaction and the coupling to the strain field of acoustic phonons.

Using a pump-probe technique (Fig. 1(a)), we have shown that the spin relaxation for an isolated Cr^{2+} strongly depends on the optical excitation conditions. We observed a heating time in the dark shorter than a few hundreds *ns* after an initial high power non-resonant excitation (pulse (1) in Fig. 1(a)). A cooling time larger than a few tens of μs, independent on the excitation, is obtained in the same experimental conditions. We demonstrated that a tunable spin-lattice coupling dependent on the density of optically generated non-equilibrium phonons can explain the observed dynamics [1].

Despite this interaction with non-equilibrium phonons, low energy excitation conditions are found where the Cr^{2+} spin states $S_z=\pm1$ can be populated by a non-resonant optical excitation, prepared and read-out by resonant optical pumping (pulses (2) and (3), Fig. 1(a)) and conserved in the dark during a few μs. This opens the possibility to coherently control the $\{-1;+1\}$ Cr spin *qubit* with the resonant strain field of Surface Acoustic Waves (i.e. particular non-equilibrium phonons travelling at the surface of a sample) in the GHz range. We will show that efficient SAW transducers can be realized on non-piezoelectric II-VI QD samples [1] and that the emission of a QD can be used has an efficient sensor for the dynamical strain field of SAW pulses (Fig. 1(b)).

We will finally show that the fluctuation of the charge state of the Cr limits the probability to isolate a single Cr^{2+} ion. Cr^{+} with a $3d^5$ configuration is indeed observed in the optical spectra of some QDs. This negatively charged excited state of the Cr is stabilized by the ferromagnetic exchange interaction with the spin of a confined heavy-hole. We will show that the resulting hole-Cr^{+} complex forms a stable ferromagnet with a spin memory in the 50 μs range at zero magnetic field and discuss some possible applications of this new nanomagnet.

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An investigation of proximity forces above nanostructures with an ultrasensitive nanowire probe based on quasi real time sensing protocols

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We demonstrate an advanced nanowire-based force field nanoscopy experiment capable of near real-time imaging of two dimensional force fields. This is achieved by optical detection of the driven motion of a vertically oriented singly clamped nanowire. The nanowire is free to oscillate in the horizontal plane with two perpendicular eigenmodes with quasi identical frequencies. When inserted in an external force field, the oscillation's properties will be dressed by the force field's local gradients. By tracking the dressed frequencies and mode orientations we can reconstruct the force field gradients and the force field itself.

In previous experiments based on thermal noise analysis in 2D, our group has characterized force fields like the electrostatic force field around a metallic tip [2] and analyzed their impact on the nanowire probe's dynamics, including the case of a rotational force field [1,3].

Here we use instead a coherent driven trajectory produced by the optical force of an intensity modulated laser beam that is superimposed with the readout laser. Both eigenmodes are simultaneously optically driven and we employ one phase locked loop (PLL) per resonance to efficiently track both resonance frequencies and the oscillation amplitudes in real time, from which the eigenmode orientations are deduced. This allows to accelerate the measurement time by a factor 100, and furthermore to access to a determination of the force field gradients in quasi real time. The advanced approach also allows for better control of the experiment and access to more evolved experiments such as the detection of magnetic forces or the investigation of the single spin-oscillator interaction.

In this talk we will expose the experimental achievements consisting in analyzing the force field experienced by the nanowire above a nano-structured metallic surface for varying bias voltages. In doing so we explore the forces at play at close distances from the surface, and investigate in particular the electrostatic forces which arise from the nano-structured sample topology or from the presence of surface contaminants. We analyze the residual force field that remains after subtraction of quadratic and linear electrostatic contributions which particularly includes the Casimir forces. At a typical distance of tens of nanometers the Casimir Force has a magnitude in the measurable range of tenths to hundreds of aN. We compare the experimental results to simulations of the electrostatic and the Casimir forces and discuss the perspectives of the work.

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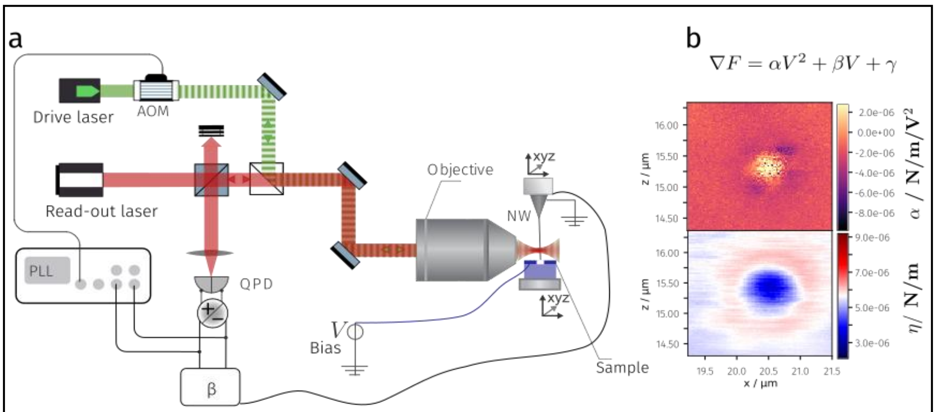

Figure 1: **a** Simplified illustration of the improved experimental setup. **b** Measured force divergence above a nano-structured metallic surface (hole). Plots show the quadratic and residual coefficient of the electrostatic force divergence parabola.

Thermal noise of a micro-cantilever submitted to a temperature contrast over one hundred

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Thermal noise manifests itself as a tiny variance around the mean value of an observable *x* of a physical system. Usually too small to be noticed, it becomes important in an increasing number of applications, such as quantum systems operated close to their ground state, MEMS and NEMS, frequency standards, or the next generation of gravitational wave detectors[1]. Since in many cases the systems are cooled down in order to facilitate the measurements, the understanding of thermal noise in these extreme conditions is thus fundamental.

When in equilibrium, the Fluctuation-Dissipation Theorem (FDT) is a cardinal tool that allows us to couple the fluctuations of *x*, to the temperature of the system in the form of the Equipartition Principle (EP). Unfortunately, this assumption is often not possible. Our goal is thus probing its validity out of this region.

In our experiment we study a system in a Non-Equilibrium Steady State: a silicon micro-cantilever subject to a heat flux due to a laser heating. Whilst in previous experiments we place the sample in contact with a thermal bath at room temperature[2,3], in this case the base of the cantilever is cooled to cryogenic temperatures (around 10 K). The tip of the sample is brought almost the melting point of silicon (1700 K), this we approach closely the highest possible temperature difference ΔT of the material.

We then measure the thermal noise driven deflection and torsion and quantify the amplitude of fluctuations with a temperature T^{fluc}, extending the FDT:

$$k_B T^{fluc} = k \langle x^2 \rangle$$

with k_B the Boltzmann constant, k the stiffness, $\langle x^2 \rangle$ the variance of the observable, i.e. the thermal noise. As in the previous experiments[2,3], we demonstrate that the system shows a strong *lack* of fluctuations with respect to what its average temperature T^{avg} dictates. Indeed, the cantilever oscillates close to the lowest temperature of the system for any temperature imposed at its free end. Thanks to a simultaneous estimation of the dissipation of the system, we give a theoretical interpretation of our findings.

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Multiplexing of optomechanical resonators for biological and mass sensing

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Early diagnostics often requires detecting tiny amounts of biological material in a large sample, such as antibodies, proteins or viruses. Nano-optomechanical resonating disks have demonstrated their ability to transduce their mechanical vibrations with high sensitivity even in viscous media such as liquids, unlike other geometries or electrical transductions [1]. Specific biological sensing in liquid has thus been demonstrated [2], as well as single particle mass spectrometry [3]. Species adsorb –specifically or not- onto the surface of the disk, inducing an effective mass change, and a resonance frequency shift. Measuring this shift allows the determination of the specie concentration or mass.
For real-life applications, it is crucial to be able to simultaneously read the mechanical resonance frequency of multiple optomechanical resonators. This is required to reach practical analysis times and improve resolution by increasing capture cross section or to detect multiple analytes simultaneously for fingerprint analysis [4,5].
In this work we demonstrate the simultaneous monitoring of the resonance frequency of three silicon microdisks coupled to a single waveguide terminated with standard photonics grating couplers. Each disk has a slightly different diameter, hence different resonance wavelengths (around 1.55um) and mechanical resonance frequencies (around 250 MHz). Their motion is driven electrostatically and the signals are demultiplexed with three parallel demodulators. This allows us the real time monitoring of their mechanical resonance frequencies, both in open and closed loop, and to determine their frequency stability $\Delta f/f$ (in the 10^{-7} range in air). We show that our multiplexing technique does not affect the frequency stability, and perform the first demonstration of real-time optomechanical resonant sensing with multiplexing.

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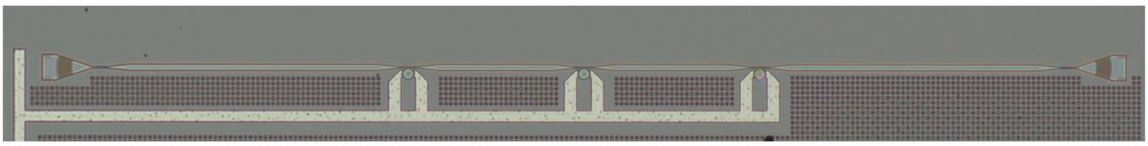

Figure 1 : Optical image of optomechanical microdisks coupled to a single waveguide