

Nano Electro Mechanical Systems and Beyond
3-5 June 2015, Bordeaux (France)



Nano Electro Mechanical Systems and Beyond

Bordeaux, 3-5 June 2015.

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Organizers : F. Pistolesi and R. Avriller, LOMA.
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PROGRAM

Wednesday, 3rd June

8:00-8:50	Arrival, badge/program	
8:50-9:00	Organizers	Opening
9:00-9:30	I. Favero	<i>Miniature Optomechanical Disks : Quantum to Liquid Applications.</i>
9:30-10:00	D. Vitali	<i>Microwave Quantum Illumination.</i>
10:00-10:30	M. Abdi	<i>Nano-mechanical quantum states in a circuit quantum electrodynamics device.</i>
10:30-11:00	Coffee Break/registration	
11:00-11:30	E. Weig	<i>Nonlinear dynamics of strongly coupled nanomechanical resonator modes.</i>
11:30-12:00	G. Hadziioannou	<i>The emerging technology of Organic Flexible and Printable Electronics.</i>
12:00-12:20	E. Krali	<i>Silicon suspended nano-beams with exceptional electronic and electromechanical properties.</i>
12:20-14:15	Lunch	
14:15-14:45	A. Bachtold	<i>Mechanical resonators based on nanotubes and graphene.</i>
14:45-15:15	W. Wernsdorfer	<i>Quantum Einstein-de-Haas effect.</i>
15:15-15:35	G. Micchi	<i>Signatures of the current blockade instability in suspended carbon nanotubes.</i>
15:35-17:00	Posters (with Coffee)	
17:00-17:30	J. Pekola	<i>Information powered cooling in a single-electron circuit.</i>
17:30-18:00	A. Auffeves	<i>Reversible work extraction in a hybrid opto-mechanical system.</i>

Thursday, 4th June

9:00-9:30	B. Lounis	<i>Probing local electric fields using single molecules spectroscopy.</i>
9:30-10:00	M. Orrit	<i>Single-molecule optical lines at cryogenic temperatures as nanomechanical sensors.</i>
10:00-10:30	J. Tamayo	<i>Biosensors based on Nanomechanical Systems.</i>
10:30-11:00	Coffee Break	
11:00-11:30	S. Ilani	<i>Engineering an Artificial Electron-Phonon Coupling in Ultra-Clean Nanotube Mechanical Resonators.</i>
11:30-12:00	I. Wilson-Rae	<i>Anomalous phonon-broadened exciton spectra in a nano-optomechanical system.</i>
12:00-12:20	I. Tsioutsios	<i>Detecting the Motion of Carbon Nanotube Resonators in a Scanning Electron Microscope.</i>
12:20-14:15	Lunch	
14:15-14:45	J. Ruitenbeek	<i>Single molecules: current excitation of vibration, rotation, and translation.</i>
14:45-15:15	A. Levy Yeyati	<i>Electron-phonon interactions and quantum noise in molecular junctions.</i>
15:15-15:45	C.A. Perroni	<i>Charge and heat transport of soft nanosystems in the presence of time-dependent perturbations.</i>
15:45-16h30	Posters (with Coffee)	
16:30-17:00	F. Marquardt	<i>Topologically Protected Transport of Photons and Phonons.</i>
17:00-17:30	J. Cayssol	<i>Persistent and dissipative currents around two-dimensional topological insulators.</i>
17:30-18:00	L. Foa Torres	<i>Using light as a topological switch: The road towards Floquet topological insulators.</i>
20:00	Conference dinner, La Belle Epoque, Bordeaux.	

Friday, 5th June

9:00-9:30	A. Heidmann	<i>Micro- and nano-optomechanics towards quantum state and hybrid devices.</i>
9:30-10:00	O. Arcizet	<i>Hybrid spin-nanomechanical system.</i>
10:00-10:30	J.-P. Poizat	<i>Strain-mediated coupling in a quantum dot-mechanical oscillator hybrid system.</i>
10:30-11:00	Coffee Break	
11:00-11:30	A. Clerk	<i>Non-reciprocal interactions via reservoir engineering.</i>
11:30-12:00	P. Verlot	<i>Cavity Optomechanics with Free Electrons.</i>
12:00-12:30	A. Ayary	<i>Synchronization and phase inertial in a field emission NEMS.</i>
12:30	Closing/Lunch Departure	

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Nano Electro Mechanical Systems and Beyond
3-5 June 2015, Bordeaux (France)



Oral

Miniature Optomechanical Disks : Quantum to Liquid Applications

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I will present our recent research on Gallium Arsenide disk optomechanical resonators confining photons and phonons in a sub-micron interaction volume¹, and yielding ultra-strong coupling between light and mechanical motion^{2,3}. The understanding of mechanical and optical dissipation in these resonators⁴, together with its control to the ultra-low dissipation limit^{5,6}, will be exposed. With their strong optomechanical cooperativity, these miniature disks are also compatible with on-chip integration⁷ and optoelectronics technologies based on III-V semiconductors. We have taken advantage of these assets to explore the fluidic operation of Gallium Arsenide devices⁸, their close-to-quantum operation, and their interface with Quantum Dots or Quantum Wells for novel polariton-optomechanical scenarios⁹. The talk will provide an overview of these advances.

References

- ¹ L. Ding et al. *Physical Review Letters* **105**, 263903 (2010).
- ² L. Ding et al. *Applied Physics Letters* **98**, 113108 (2011).
- ³ C. Baker et al. *Optics Express* **22**, 14072 (2014).
- ⁴ D. Parrain et al. *Applied Physics Letters* **100**, 242105 (2012).
- ⁵ D. T. Nguyen et al. *Applied Physics Letters* **103**, 241112 (2013).
- ⁶ D. T. Nguyen et al. *New Journal of Physics* **17**, 023016 (2015)
- ⁷ C. Baker et al. *Applied Physics Letters* **99**, 151117 (2011).
- ⁸ E. Gil-Santos et al. *arXiv* 1503.03472 (2015).
- ⁹ J. Restrepo et al. *Physical Review Letters* **112**, 013601 (2014).

Microwave Quantum Illumination

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Jeffrey H. Shapiro⁵, and Stefano Pirandola⁶

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Quantum illumination is a quantum-optical sensing technique in which an entangled source is exploited to improve the detection of a low-reflectivity object that is immersed in a bright thermal background. Here we describe and analyze a system for applying this technique at microwave frequencies, a more appropriate spectral region for target detection than the optical, due to the naturally-occurring bright thermal background in the microwave regime. We use an electro-optomechanical converter to entangle microwave signal and optical idler fields, with the former being sent to probe the target region and the latter being retained at the source. The microwave radiation collected from the target region is then phase conjugated and up-converted into an optical field that is combined with the retained idler in a joint-detection quantum measurement. The error probability of this microwave quantum-illumination system, or quantum radar, is shown to be superior to that of any classical microwave radar of equal transmitted energy.

[1] Shabir Barzanjeh, Saikat Guha, Christian Weedbrook, David Vitali, Jeffrey H. Shapiro, and Stefano Pirandola, *Microwave Quantum Illumination*, Phys. Rev. Lett. **114**, 080503 (2015).

Nano-mechanical quantum states in a circuit quantum electrodynamics device

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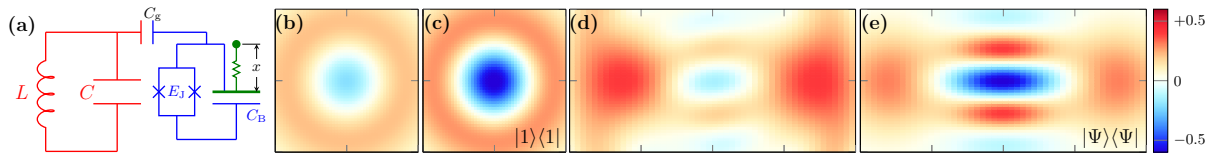
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Mechanical resonators in their quantum regime are of fundamental and technical interest. However, having a full quantum behavior on these harmonic oscillators requires strong coupling between them and another controllable quantum system, e.g. photons or qubits.

Here, we introduce and study a hybrid system with quantum mechanical interactions between photons, phonons, and excitations of a superconducting qubit. The interactions happen in a circuit QED device featuring a transmon qubit [1,2] with a mechanical resonator mounted in its shunt capacitor (See Fig. 1(a) for a circuit scheme). This system offers a strong nonlinear transmon–mechanical interaction. Moreover, when combined with a strong cavity–transmon interaction, it allows for a wide range of manipulations of the system due to the anharmonicity of the transmon qubit. We will show that in terms of polaritons (a hybridization of the microwave excitations in the resonator and the transmon qubit) two kinds of three-body interactions in the strong coupling regime between the mechanics and the polaritons emerge: One couples the number of polariton quanta to the mechanical position, $\hat{p}_j^\dagger \hat{p}_j \hat{x}$, and the other couples a conversion between two polariton types to the position of the mechanical resonator, $(\hat{p}_1^\dagger \hat{p}_2 + \hat{p}_1 \hat{p}_2^\dagger) \hat{x}$. An important innovation of the architecture is the combination of strong three-body coupling and the anharmonicity of the polaritonic modes that provides for exquisite control of the mechanical mode.

In a few examples we will exploit the advantages of these features. In particular, the interactions can be employed for cooling the mechanical mode to its ground state and preparing it in non-classical states of different categories. Examples therefore are mechanical Fock and cat states, non-Gaussian optomechanical, and hybrid tripartite entangled states. Therefore, we believe that the setup proposed here offers a quantum toolbox for broad control of the mechanical resonator [3].

Our simulations based on current experimental parameters affirm the abilities of the device. The dynamics of the system is described by a quantum optical master equation in Lindblad form. The results are summarized in Fig. (b)–(e) where we plot the Wigner quasi-probability distribution function for the mechanical resonator in such a system when prepared in the Fock state $|1\rangle$ and in the cat state $|\Psi\rangle = \frac{1}{\sqrt{2}}(|\alpha\rangle + |-\alpha\rangle)$. We also show the relevant ideal Wigner distributions for comparison. The negative feature of the Wigner functions, which is a pure quantum mechanical signature, is visible in the simulated plots.



(a) Scheme for the proposed device. The Wigner function for the mechanical resonator prepared in: (b) Fock state $|1\rangle$ and (d) cat-state $|\Psi\rangle$. (c) and (e) show the ideal cases for comparison.

[1] J. Majer, J. Chow, J. Gambetta, J. Koch, B. Johnson, J. Schreier, L. Frunzio, D. Schuster, A. Houck, A. Wallraff, A. Blais, M. Devoret, S. Girvin, and R. Schoelkopf, *Coupling superconducting qubits via a cavity bus*, Nature **449**, 443 (2007).

[2] J. Koch, T. Yu, J. Gambetta, A. Houck, D. Schuster, J. Majer, A. Blais, M. Devoret, S. Girvin, and R. Schoelkopf, *Charge-insensitive qubit design derived from the Cooper pair box*, Phys. Rev. A **76**, 042319 (2007).

[3] M. Abdi, M. Pernpeintner, R. Gross, H. Huebl, and M. J. Hartmann, *Quantum state engineering with circuit electromechanical three-body interactions*, to appear in Phys. Rev. Lett. (2015) (arXiv:1502.03787 [quant-ph]).

Nonlinear dynamics of strongly coupled nanomechanical resonator modes

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Doubly-clamped pre-stressed silicon nitride string resonators excel as high Q nanomechanical systems enabling room temperature quality factors of several 100,000 in the 10 MHz eigenfrequency range. They are complemented by electrically induced gradient fields to implement dielectric transduction as an ideal platform for actuation, displacement detection and frequency tuning. The two orthogonal fundamental flexural modes of a single string vibrating in- and out-of-plane with respect to the sample surface can be engineered to tune reversely. This allows bringing both modes into resonance where a pronounced avoided crossing is observed, indicating strong mechanical coupling [1].

The dynamics of the resulting classical two-mode system is coherently controlled by means of electromagnetic pulse techniques adopting the well-known Bloch sphere picture: Analogous to the coherent control of two-level systems in atoms, spin ensembles or quantum bits, full Bloch sphere control is achieved by a combination of Rabi, Ramsey and Hahn echo experiments [2]. Subject to parametric actuation both modes enter the instable regime and start oscillating, which gives rise to a rich nonlinear response. I will discuss independent oscillation, frequency locking and sideband formation, evidencing the complexity of strongly coupled nanomechanical systems [3].

[1] T. Faust et al., *Nonadiabatic dynamics of two strongly coupled nanomechanical resonator modes*, Phys. Rev. Lett. **109**, 037205 (2012).

[2] T. Faust et al., *Coherent control of a classical nanomechanical two-level system*, Nature Physics **9**, 485 (2013).

[2] M. Seitner et al., in preparation

The emerging technology of Organic Flexible and Printable Electronics

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A brief presentation will be given on the evolution over the last century of two major parallel developments, namely communication and information science and technology as well as polymer science and engineering, on the shoulders of which the emerging “Polymer Organic Electronics” science and technology sits. Then two examples will be given to illustrate how polymer material science and engineering can be of extreme help for the rise and consolidation, from technology and manufacturing points views the emerging industry of “Organic Electronics”. These are: i) the formulation of new materials for transparent conducting electrodes on the basis of semiconducting polymers and polyionic polymers as well as their integration to OLEDs and OPVs and ii) the happy marriage of semiconducting and ferroelectric polymers towards new optoelectronic properties and devices.

Silicon suspended nano-beams with exceptional electronic and electromechanical properties

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Suspended silicon nano-beams fabricated by a new, fast, simple and flexible fabrication method^{1,2} present exceptional electronic and electromechanical properties. The fabrication method is described in figure 1. Starting with a SOI (Silicon On Insulator) chip, the first step consists on gallium ion implantation (performed directly on top of a silicon surface by means of a Focused Ion Beam (FIB)). In the next step, the chip is anisotropically wet etched by TMAH, to obtain free suspended structures by the removal of non-irradiated silicon (figure 1c). Finally, the irradiated silicon is recrystallized and doped via high temperature annealing in a boron environment (figure 1d). The devices fabricated by this method present good electrical characteristics (electrical resistivity between 10^{-3} and 10^{-4} [$\Omega \cdot m$]).

Figure 2a shows an example of a silicon nanobeam suspended between two electrical pads and a side-gate, by a combination of ion implantation and ion milling.² A large enhancement of piezoresistive transduction is observed, which is attributed to the generation of built-in geometrical asymmetries during the fabrication process.³ This effect enables the electrical detection of the mechanical response of these devices at high frequencies. The electromechanical response of the device obtained by a frequency down-mixing method is shown in figure 2b.⁴ In addition, we have demonstrated the operation of the suspended beams as single hole transistors. Single hole behavior is caused by the generation of nanocrystals in the beams during the fabrication process. This effect is employed to study acoustic-phonon modes in nanocrystals by electrical means⁵.

1. J. Llobet, M. Sansa, M. Gerbolés, N. Mestres, J. Arbiol, X. Borrisé, F. Pérez-Murano. *Nanotechnology* 25, 135302 (2014).
2. J. Llobet, M. Gerbolés, M. Sansa, X. Borrisé, F. Pérez-Murano. *Proc. SPIE 9423, Alternative Lithographic Technologies VII*, 94230K (March 19, 2015)
3. M. Sansa, M. Fernández-Regúlez, J. Llobet, Á. San Paulo, F. Pérez-Murano. *Nat. Commun.* 5, (2014).
4. M. Sansa, M. Fernández-Regúlez, A. San Paulo, F. Perez-Murano. *Applied Physics Letters* 101, 243115 (2012)

5. J. Llobet, E. Krali, C. Wang, J. Arbiol, M.E. Jones, F. Pérez-Murano, Z.A.K Durrani. Submitted.

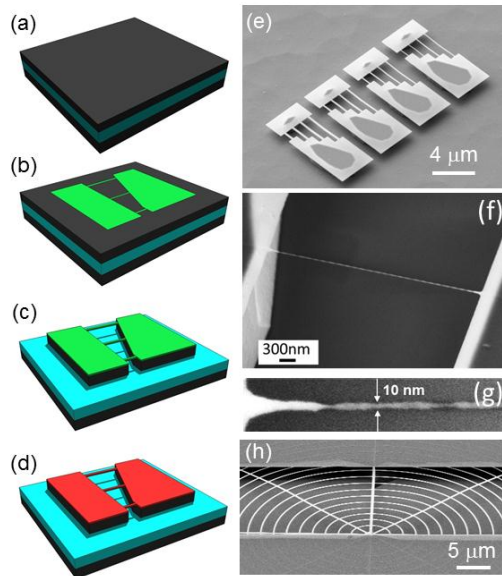


Figure 1. From 1a to 1d: Three step approach for the fabrication of free suspended structures. In this scheme (a) represents the starting silicon on insulator chip, (b) the implanted gallium volume created on top of the silicon device layer, (c) the silicon anisotropic wet etching, and (d) the high temperature diffusive boron doping step. From e to h: SEM images of devices fabricated by this method, (e) nanowires of different length and width, (f) and (g) a nanowire of 4 μm length and 10 nm of diameter and (h) a three dimensional structure suspended between two silicon anchors.

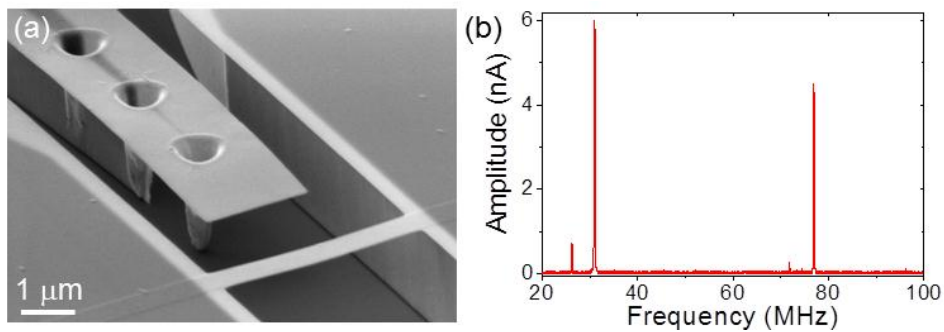


Figure 2. (a) SEM image of a suspended nanoribbon and a side-gate for the electrostatic actuation. (b) Electromechanical readout obtained from the device.

Mechanical resonators based on nanotubes and graphene

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When a carbon nanotube is suspended and clamped at the ends, the nanotube vibrates in way similar to a guitar string. However, one difference is the mass, since the diameter of nanotubes is about 1 nm. Another difference is that the quality factor Q becomes extremely large at cryogenic temperature, up to 5 million [1]. This large Q -factor reflects the high crystallinity of nanotubes and their lack of dangling bonds at the surface. Because of this combination of low mass and high quality factor, the motion is enormously sensitive to the environment - the mechanical eigenstates of the nanotube are extremely fragile and easily perturbed by the measurement. But, if nanotube resonators can be properly harnessed, they become incomparable sensors of mass [2] and force [3]. From a fundamental point of view, nanotube resonators are very interesting to study the physics of noise; see e.g. Ref. [4].

[1] J. Moser, A. Eichler, J. Güttinger, M. I. Dykman, A. Bachtold, *Nature Nanotechnology* **9**, 1007 (2014).

[2] J. Chaste, A. Eichler, J. Moser, G. Ceballos, R. Rurali, A. Bachtold, *Nature Nanotechnology* **7**, 301 (2012).

[3] J. Moser, J. Güttinger, A. Eichler, M. J. Esplandiu, D. E. Liu, M. I. Dykman, A. Bachtold, *Nature Nanotechnology* **8**, 493 (2013)

[4] Y. Zhang, J. Moser, J. Güttinger, A. Bachtold, M. I. Dykman, *Phys. Rev. Lett.* **113**, 255502 (2014).

Quantum Einstein-de-Haas effect

W. Wernsdorfer

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In analogy to the classical Einstein-de-Haas effect, the magnetization reversal via quantum tunneling of magnetization (QTM) in a single molecule magnet (SMM) is generally associated with a mechanical rotation and change of orbital angular momentum of the molecule. Here we demonstrate that QTM is fully suppressed in a bis(phthalocyaninato)terbium(III) SMM (TbPc_2) coupled to a carbon nanotube resonator. We find that the probability for QTM in such a supramolecular spintronic device is zero, independent on external parameters like temperature or transverse magnetic field. We attribute this spin tunneling blockade to the absence of a phonon mode in the carbon nanotube resonator, capable of absorbing the energy and the change of angular magnetic momentum associated with the SMM's magnetization reversal. See also Ref. [1] and Figure 1.

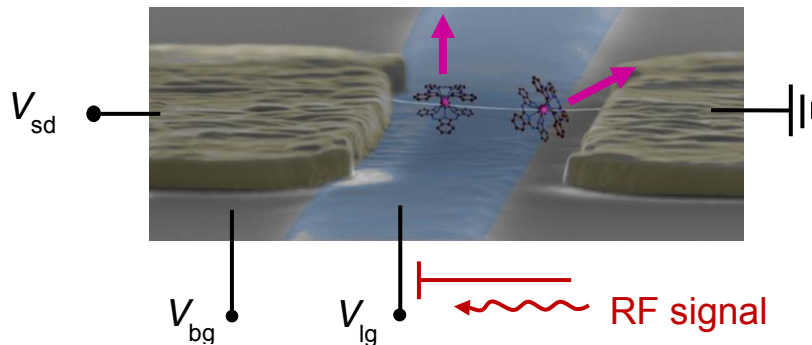


Figure 1: False color SEM image of a suspended carbon nanotube NEMS with a local metallic backgate (blue) functionalized with TbPc_2 SMMs (shown as chemical structures overlaid on the image).

[1] M. Ganzhorn, S. Klyatskaya, M. Ruben, W. Wernsdorfer, *Nature Nanotech.* 8, 165 (2013)

Signatures of the current blockade instability in suspended carbon nanotubes

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Transport measurements allow sensitive detection of nanomechanical motion of suspended carbon nanotubes. It has been shown that bi-stability and current blockade appear for sufficiently large values of the electrostatic force induced on the nanotube by the addition of a single electron. We investigate the signatures of the transition in the mechanical mode, which motion can be measured using available experimental techniques. We find that close to the transition the mechanical mode softens and broadens with non-linearities dominating its behavior. These findings can allow the detection of the transition in devices currently used by several groups.

Information powered cooling in a single-electron circuit

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Single-electron circuits allow for precise experiments on thermodynamics of small systems. Here I present experiments on Maxwell Demons in them [1-4].

[1] *Jonne V. Koski, Ville F. Maisi, Jukka P. Pekola, Dmitri V. Averin*, **Experimental realization of a Szilard engine with a single electron**, Proc. Nat. Acad. Sciences **111**, 13786 (2014).

[2] *Jonne V. Koski, Ville F. Maisi, Takahiro Sagawa, Jukka P. Pekola*, **Experimental study of mutual information in a Maxwell Demon**, Phys. Rev. Lett. **113**, 030601 (2014).

[3] *J. P. Pekola*, **Towards quantum thermodynamics in electronic circuits**, Nature Physics **11**, 118–123 (2015).

[4] J. V. Koski et al., in preparation (2015).

Reversible work extraction in a hybrid opto-mechanical system

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With the progress of nano-technology, thermodynamics also has to be scaled down, calling for specific protocols to extract and measure work. Usually, such protocols involve the action of an external, classical field (the battery) of infinite energy, that controls the energy levels of a small quantum system (the calorific fluid). Here we suggest a realistic device to reversibly extract work in a battery of finite energy : a hybrid optomechanical system [1]. Such devices consist in an optically active two-level quantum system interacting strongly with a nano-mechanical oscillator that provides and stores mechanical work, playing the role of the battery. We identify protocols where the battery exchanges large, measurable amounts of work with the quantum emitter without getting entangled with it. When the quantum emitter is coupled to a thermal bath, we show that thermodynamic reversibility is attainable with state-of-the-art devices, paving the road towards the realization of a full cycle of information-to-energy conversion at the single bit level. Hybrid systems could therefore offer an experimental playground to investigate the peculiarities of quantum information, like for instance the work extractable from entanglement [2–3], or from engineered heat baths.

[1] C. Elouard, M. Richard and A. Auffèves, *Reversible work extraction in a hybrid opto-mechanical system*, to appear in Special Focus on Quantum Thermodynamics of New Journal of Physics (2015), arXiv : 1309.5276

- . [2] L. Del Rio, J.Aberg, R. Renner, O. Dahlsten and V. Vedral, *The thermodynamic meaning of negative entropy*, Nature 474, 61-63 (2011).
- . [3] J. Oppenheim, M. Horodecki, P.Horodecki, and R. Horodecki, *Thermodynamical Approach to Quantifying Quantum Correlations*, Phys. Rev. Lett. 89, 180402 (2002).

Probing local electric fields using single molecule spectroscopy

Brahim Lounis

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Single molecules trapped in crystalline hosts at cryogenic temperatures display an excellent and unequaled photostability among fluorescent nano-objects. Behaving as an optical resonator with a high quality factor up to 10^8 , single molecules embedded in well-chosen matrices can be used as extremely sensitive probes of local fields.

In a theoretical work, we have shown that single molecule spectroscopy can be used as an efficient tool for detecting and manipulating nano-oscillators, such as carbon nanotubes attached to an AFM tip and interacting with the molecule via electrostatic forces. Various experimental approaches can be used to obtain specific information on the oscillator displacements. Very large values of the molecule-oscillator coupling constant are estimated and the back-action of the molecule on the oscillator can be made sufficiently large to enable strong cooling of the oscillator.

In an experimental work, we use single molecule spectroscopy to directly reveal the interplay between magnetism and electricity in multiferroic materials, which attracts growing theoretical and experimental interests. These materials offer the possibility to control the magnetization without applying electric currents, opening the way for the development of new nanoscale memory elements with low power consumption. An electric field applied to such materials can produce substantial changes in the magnetic moment distribution. Conversely, an inhomogeneous magnetization can induce an electric polarization in systems with broken inversion symmetry. Although this "flexomagnetoelectric" effect was theoretically predicted more than twenty years ago, its unambiguous experimental evidence was still lacking. Here, we provide the first direct experimental evidence of electric polarization induced by the magnetization inhomogeneity in an iron garnet film, using Stark shifts of single molecule resonances.

Single-molecule optical lines at cryogenic temperatures as nanomechanical sensors

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The optical zero-phonon line of a single molecule in a proper organic solid is lifetime-limited and behaves as an oscillator with a quality factor as high as 100 million. Such oscillators are exquisitely sensitive to all kinds of weak perturbations, as has been demonstrated in the past. Because of the small physical size of a molecule, it could be placed very close to a nanomechanical oscillator, thereby achieving size matching and optimized opto-mechanical coupling. In this talk, I shall report experiments of our group showing that such mechanical oscillators can be already spontaneously present as defects in molecular crystals. Although their structure is still unknown, their robustness and ease of preparation makes them attractive candidates to demonstrate efficient opto-mechanical couplings.

Previous studies of the alternating-current (ac) Stark effect with single molecules have shown surprising resonances at ultralow frequencies, between some 10 Hz to 100 kHz (see Fig.1). A long and careful study of single dibenzoterrylene (DBT) molecules in anthracene single crystals [1] stuck to source-drain electrodes with a gate electrode showed that those resonances have an acoustic or mechanical nature. They couple to the applied fields because of charges injected into the organic material from the electrodes, but they pre-exist to the charges, and are only more efficiently excited by electric fields when charges are present. We believe these oscillators to be related to the quasi-local or Boson peak modes in disordered systems. They are found at the extreme low-frequency wing of their distribution. We also believe that this explanation applies to earlier, similar findings for terrylene in n-alkane matrixes (Shpol'skii matrixes) when these matrixes were deposited on top of highly doped semiconducting films [2]. The explanation we proposed then, charge carrier density oscillations in the semiconductor, would not apply to our more recent observations in anthracene, because no semiconductor is present in the new experiments (the electrodes are metallic).

To clarify these optomechanical effects, we have simulated them with a single DBT molecule in an anthracene crystal coupled to a macroscopic oscillator driven by electrodes: a quartz tuning fork [3]. This system qualitatively reproduces the observations made with the FET geometry, thereby strengthening our new interpretation. The next step of this work will be to reduce the oscillator's size, to achieve coupling between a molecule and a mechanical nano-oscillator. This could be done either through a top-down approach, by micro-machining smaller tuning forks, or similar oscillators. Alternatively, a bottom-up approach would require understanding the nature of the spontaneous defects responsible for the observations in [1,2], and controlling their concentration and properties. The latter program requires a broader set of characterization methods to study and control these mechanical defects.

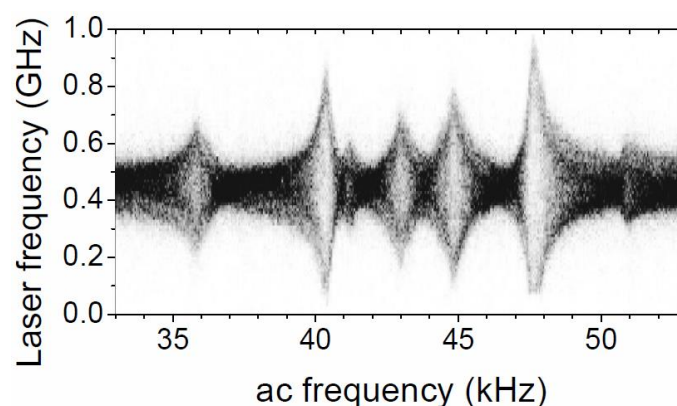


Figure 1: Example of mechanical resonances in an anthracene single crystal at 2 K, monitored through the fluorescence intensity of a single DBT molecule (level of gray) as the laser excitation frequency is scanned (vertical axis) while the frequency of an ac voltage is varied. The voltage is applied to electrodes contacted to the crystal hosting the molecule [1].

- [1] M. A. Kol'chenko, A. A. L. Nicolet, M. D. Galouzis, C. Hofmann, B. Kozankiewicz, M. Orrit, *Single molecules detect ultra-slow oscillators in a molecular crystal excited by ac voltages*, *New J. Phys.* B **11** (2009) 023037.
- [2] J.-M. Caruge and M. Orrit, *Probing local currents in semiconductors with single molecules*, *Phys. Rev. B* **64** (2001) 205202.
- [3] Yuxi Tian, P. Navarro, M. Orrit, *Single molecule as a local acoustic detector for mechanical oscillators*, *Phys. Rev. Lett.* **113**, 135505 (2014).

Biosensors based on Nanomechanical Systems

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The advances in micro- and nanofabrication technologies are enabling increasingly smaller mechanical transducers capable of detecting the forces, motion, mechanical properties and masses that emerge in biomolecular interactions and fundamental biological processes. Thus, biosensors based on nanomechanical systems have gained considerable relevance in the last decade[1]. This talk will provide insight into the mechanical phenomena that occur in suspended mechanical structures when either biological adsorption or interactions take place on their surface. The talk will guide through the parameters that change as a consequence of biomolecular adsorption: mass, surface stress, effective Young's modulus and viscoelasticity. The mathematical background needed to correctly interpret the output signals from nanomechanical biosensors will also be outlined. Other practical issues reviewed are the immobilization of biomolecular receptors on the surface of nanomechanical systems and methods to attain that in large arrays of sensors. I will describe then some relevant experiments running in our laboratory that harness some of the mechanical effects cited above and at the frontier between nanomechanics and nanooptics to achieve ultrasensitive biological detection: i) ultrasensitive cancer biomarker detection in blood by optomechanoplasmonics², ii) cancer cell nanomechanics, iii) silicon nanowire optomechanics³⁻⁴, and iv) protein nanomechanical spectrometry..

[1] Tamayo, J., Kosaka, P. M., Ruz, J. J., San Paulo, Á. & Calleja, M. *Biosensors based on nanomechanical systems*. Chemical Society Reviews **42**, 1287-1311 (2013).

[2] Kosaka, P.; Pini, V.; Ruz, J.; da Silva, R.; González, M.; Ramos, D.; Calleja, M.; Tamayo, J., *Detection of cancer biomarkers in serum using a hybrid mechanical and optoplasmonic nanosensor*. Nature Nanotechnology **9**, 1047-1053 (2014).

[3] Gil-Santos, E. *et al.* Nanomechanical mass sensing and stiffness spectrometry based on two-dimensional vibrations of resonant nanowires. Nature Nanotechnology **5**, 641-645 (2010).

[4] Ramos, D. *et al.* *Optomechanics with silicon nanowires by harnessing confined electromagnetic modes*. Nano letters **12**, 932-937 (2012).

Engineering an Artificial Electron-Phonon Coupling in Ultra-Clean Nanotube Mechanical Resonators

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The coupling between electrons and phonons is at the heart of many fundamental phenomena in physics. In nature, this coupling is generally predetermined for both, molecules and solids. Tremendous advances have been made in controlling electrons and phonons in engineered nano systems, yet, control over the coupling between these degrees of freedom is still widely lacking. In this talk I will describe our pristine multi-gated carbon nanotube devices in which we can tailor an artificial electron-phonon coupling at will. In these devices, we can form highly-tunable single and double quantum dots at arbitrary locations along a nanotube mechanical resonator. The high degree of control over the electrons allows us to explore the dynamics of the coupling and engineer its structure in real-space. I will further present a new technique for measuring the system in the time-domain with which we can now probe the coupling even in the absence of electronic transport. This technique allows us to study the interaction between the mechanical motion and electronic degrees of freedom that are completely isolated from the random environment of the leads.

Anomalous phonon-broadened exciton spectra in a nano-optomechanical system

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Excitons in suspended carbon nanotubes (CNT) constitute a promising alternative for both quantum optomechanics (e.g. quantum-limited nanotransduction) [1] and quantum photonics [2]. In both of these scenarios, it becomes important to understand their interactions with soft phonons. Here we focus on a CNT system where an inhomogeneous electric field induces strong exciton localisation, i.e. generates an optically active quantum dot, and induces a tunable parametric coupling of the exciton to the flexural modes of the nanotube mediated by deformation-potential interactions [1]. We calculate the corresponding phonon-broadened fluorescence spectra under weak laser excitation for large suspended CNT length. We show that, at low temperature, this regime realises the “localised” phase of a subohmic spin-boson model [3] with spectral density $J(\omega) \propto \sqrt{\omega}$, as evidenced by a “complete collapse” of the zero-phonon line (ZPL).

This “complete collapse” is found to differ from the standard Markovian pure-dephasing of the ZPL, characterising weak-coupling ohmic scenarios [4], in that the ZPL is not replaced by a broadened peak but instead gives way to an exponential suppression of the absorption (cf. Figure 1). Additionally, this Non-Markovian dephasing leads to sideband spectra characterised by half-integer power-law decays. These features are illustrated by the limit of zero-temperature and vanishing radiative decay Γ , in which the absorption profile reads

$$A(\delta)|_{T=0, \Gamma=0} \propto \Theta(\delta) \frac{e^{-\omega_*/\delta - \delta/\omega_U}}{\delta^{3/2}},$$

where δ is the laser detuning from the ZPL and ω_U is a “high-frequency” cutoff determined by the size of the excitonic quantum dot. In contrast to ohmic scenarios, fractional decays can also be present at higher temperatures even when the sideband spectra become symmetric due to phonon absorption. As these phenomena are characterised by an energy scale $\hbar\omega_*$ that can lie in the micro-electron-volt range, strong laser excitation could allow to tune across the corresponding “localised-delocalised” quantum-dissipative phase transition [3]. Finally, we analyse the relative contributions to the absorption spectrum of coherent and incoherent photon scattering and find that their relation markedly differs from the standard Markovian result.

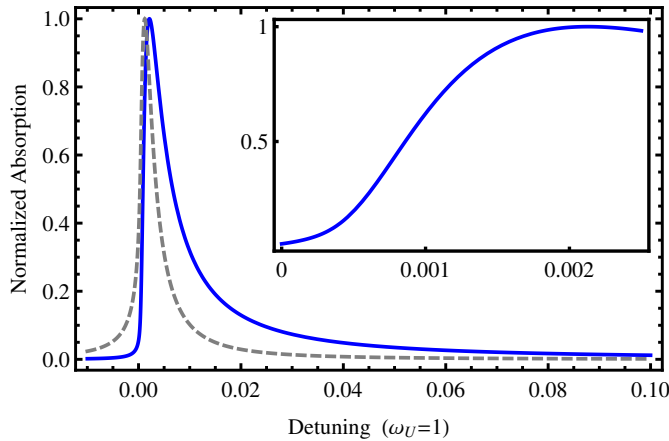


Figure 1: Calculated absorption spectrum (solid lines) as a function of laser detuning from the ZPL (for $\omega_*/\omega_U = 3 \times 10^{-3}$, $\Gamma/\omega_* = 0.1$ and $T = 0$) exhibiting an exponential suppression at the ZPL and half-integer power-law decay on the blue side of its maximum. The dashed line indicates the profile that would be inferred from the contribution of coherent (i.e. elastic) photon scattering. The ZPL frequency could be measured via a comparison with the emission spectrum.

References

- [1] I. Wilson-Rae, C. Galland, W. Zwerger, and A. Imamoglu, “Exciton-assisted optomechanics with suspended carbon nanotubes,” *New J. Phys.* **14**, 115003 (2012).
- [2] Ibrahim Sarpkaya, Zhengyi Zhang, William Walden-Newman, Xuesi Wang, James Hone, Chee W. Wong, and Stefan Strauf, “Prolonged spontaneous emission and dephasing of localized excitons in air-bridged carbon nanotubes,” *Nature Comm.* **4**, 2152 (2013).
- [3] R. Bulla, N.-H. Tong, and M. Vojta, “Numerical renormalization group for bosonic systems and application to the sub-Ohmic spin-boson model,” *Phys. Rev. Lett.* **91**, 170601 (2003).
- [4] G. Lindwall, A. Wacker, C. Weber, and A. Knorr, “Zero-phonon linewidth and phonon satellites in the optical absorption of nanowire-based quantum dots,” *Phys. Rev. Lett.* **99**, 087401 (2007).

Motion Detection of Thermally Driven Carbon Nanotube Resonators using Scanning Electron Microscopy

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Single molecules: current excitation of vibration, rotation, and translation

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Single-molecule junctions permit studying the interaction of an electron current with local degrees of freedom, at high current density. This interaction leads to corrections in the conductance of the junction at specific bias voltages, corresponding to the excitation energy of the local mode. This results in steps in the differential conductance, with a sign that depends on the transmission probability of the conductance channel. The properties of the vibration modes can be tested as a function of parameters such as isotope substitution, or strain in the junction. The excitation of local modes also results in a contribution to the higher moments of electron transmission, notably in shot noise. This non-equilibrium noise contribution can be positive or negative, depending again on the transmission of the conductance channel.

While we have made good progress in understanding of the excitation of local modes, there is also a prospect of gaining more understanding of other non-equilibrium processes such as electromigration and non-conservative forces at the single-molecule level. First steps towards this goal will be presented.

Electron-phonon interactions and quantum noise in molecular junctions

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Noise in nanoscale devices contains valuable information on interactions and quantum correlations between electrons. In atomic or molecular junctions current noise is affected by the coupling of electrons to localized vibrational modes. The aim of this presentation is to summarize work done by our group for analyzing the effect of electron-phonon interactions in this type of systems in different parameters regimes and under different biasing conditions.

I will discuss first the case of weak coupling where phonons can either enhance or decrease the current noise, in agreement with experimental measurements for atomic chains [1]. Then I shall consider the regime of strong coupling and present results obtained using different approximations for the stationary and the transient regime [2,3]. The possibility of bistable behavior will be analyzed.

[1] M. Kumar, R. Avriller, A. Levy Yeyati and J. M. van Ruitenbeek, Phys. Rev. Lett. **108**, 146602 (2012).

[2] K.F. Albrecht, A. Martín-Rodero, R.C. Monreal, L. Mühlbacher and A. Levy Yeyati, Phys. Rev. B **87**, 085127 (2013).

[3] R. Seoane Souto, A. Levy Yeyati, A. Martín-Rodero, and R. C. Monreal, Phys. Rev. B **89**, 085412 (2014).

Charge and heat transport of soft nanosystems in the presence of time-dependent perturbations

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Effects of the electron-vibration coupling on the charge and heat transport of soft nanoscopic systems are theoretically investigated in the presence of time-dependent perturbations, such as forcing antennas or pumping terms between the leads and the nanosystem. A well established approach, valid for non-equilibrium adiabatic regimes [1], is generalized to the case where external time-dependent perturbations are present. In particular, we consider a number of relevant applications of the method for systems composed by a of a quantum dot (or molecule) described by a single electronic level coupled to a vibrational mode.

Stimulated by recent experimental results on carbon nanotube electromechanical devices working in the semi-classical regime (resonator frequencies in MHz range compared to an electronic hopping frequency of the order of tens of GHz) with extremely high quality factors, the nonlinear vibrational regime induced by the external antenna has been discussed reproducing quantitatively the characteristic asymmetric shape of the current-frequency curves [2,3]. Within the same set-up, we have proved that the antenna is able to pump sufficient charge close to the mechanical resonance making single-parameter adiabatic charge pumping feasible in carbon nanotube resonators [4]. The pumping mechanism that we observe is different from that acting in the two parameter pumping and, instead, is based on an important dynamic adjustment of the mechanical motion of the nanotube to the external drive in the weakly non-linear regime. Finally, stochastic forces induced by quantum and thermal fluctuations due to the electron charging of the quantum dot are shown to affect a Thouless charge pump realized with an elastically deformable quantum dot [5]. Although the two-parameter pumping is strongly reduced with temperature, when the external driving frequency is close to the resonator's frequency, the pumping can be enhanced of more than one order of magnitude leading to measurable pumping effects up to very high temperatures.

The most interesting effects induced by time-dependent perturbations are obtained when the external forcing is nearly resonant with the vibrational modes. Indeed, not only the external forcing can enhance the electronic response, but it also induces nonlinear regimes where the interplay between electronic and vibrational degrees of freedom plays a major role.

[1] A. Nocera, C.A. Perroni, V. Marigliano Ramaglia, and V. Cataudella, *Stochastic dynamics for a single vibrational mode in molecular junctions*, Phys. Rev. B **83**, 115420 (2011).

[2] A. Nocera, C. A. Perroni, V. Marigliano Ramaglia, and V. Cataudella, *Probing nonlinear mechanical effects through electronic currents: The case of a nanomechanical resonator acting as an electronic transistor*, Phys. Rev. B **86**, 035420 (2012).

[3] A. Nocera, C. A. Perroni, V. Marigliano Ramaglia, G. Cantele, and V. Cataudella, *Magnetic effects on nonlinear mechanical properties of a suspended carbon nanotube*, Phys. Rev. B **87**, 155435 (2013).

[4] C. A. Perroni, A. Nocera and V. Cataudella, *Single-parameter charge pumping in carbon nanotube resonators at low frequency*, Europhysics Letters **103** 58001 (2013).

[5] C. A. Perroni, F. Romeo, A. Nocera, V. Marigliano Ramaglia, R. Citro and V. Cataudella, *Noise-assisted charge pump in elastically deformable molecular junctions*, J. Phys.: Condens. Matter **26** 365301 (2014).

Topologically Protected Transport of Photons and Phonons

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Optomechanical systems, coupling light to nanomechanical motion, have now reached the stage where one can envisage making them into larger-scale arrays, coupling many vibrational and optical modes. In this talk I will first recount our theoretical ideas on how to produce synthetic magnetic fields for photons via the optomechanical interaction. I will then go on to describe our proposal for achieving topologically protected transport of sound waves, which is an outstanding challenge in any solid-state platform.

[1] Vittorio Peano, Christian Brendel, Michael Schmidt, and Florian Marquardt, "Topological Phases of Sound and Light", arXiv:1409.5375 (2014)

[2] M. Schmidt, S. Keßler, V. Peano, O. Painter, F. Marquardt, "Optomechanical creation of magnetic fields for photons on a lattice", arXiv:1502.07646 (2015)

Persistent and dissipative currents around two-dimensional topological insulators

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LOMA and Université de Bordeaux

Quantum spin Hall insulators are two-dimensional band insulators characterized by protected counter-propagating one-dimensional (1D) metallic edge states. This 1D edge metal is unique because the spin of its carriers is tied to their direction of motion, and backscattering between right and left movers is forbidden by time-reversal symmetry.

I will describe the response of these helical edge states under flux biasing. For a static flux, the edge Dirac fermions carry a persistent current which is robust to non magnetic disorder [1]. For time-dependent flux biasing, the response of the 1D helical liquid is characterized by a complex susceptibility. The relaxation time of the edge carriers can be determined from a measurement of the dissipative part of this susceptibility [2]. The effects of various perturbations, including Zeeman coupling and disorder, will also be discussed.

In conclusion, I will also discuss briefly the connexion with the Floquet topological insulators with photo induced edge states [3].

[1] D. Sticlet and J. Cayssol, Phys. Rev. B 90, 201303 (2014).

[2] D. Sticlet, B. Dóra, and J. Cayssol, Phys. Rev. B 88, 205401 (2013).

[3] J. Cayssol, B. Dóra, F. Simon, and R. Moessner, Phys. Status Solidi RRL, 7, 101 (2013).

Using light as a topological switch: The road towards Floquet topological insulators

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Light-matter interaction is at the heart of many intriguing phenomena and its understanding has led to many practical applications like, for instance, Raman spectroscopy. But beyond characterization, several studies have gone deeper into actually using light to modify the electrical properties of a material. This can be done, for example, by using light to switch off the conduction in graphene[1,2] (or other materials [3]), thereby allowing to tune the material's response with optical means, or even inducing tunable topological states in materials that would otherwise lack them [1,4,5,6,7,8] (i.e. a Floquet topological insulator). The latter is very promising as it would expand the playground of topological insulators to a broader set of materials. Recently, laser-induced bandgaps have been experimentally verified at the surface of a topological insulator [3] adding much interest to this area.

In this talk I will provide an overview of the recent developments in this field with a focus on the generation of Floquet chiral edge states in graphene [6,9] (Fig. 1(a)), and other materials including topological insulators [10]. The emergence of a Hall response without Landau levels [11,12] (see scheme in Fig. 1(b)) and open problems will also be highlighted.

- [1] T. Oka and H. Aoki, “*Photovoltaic Hall effect in graphene*”, *Phys. Rev. B* **79**, 081406 (2009).
- [2] H. L. Calvo, H. M. Pastawski, S. Roche, and L. E. F. Foa Torres, “*Tuning laser-induced band gaps in graphene*”, *Appl. Phys. Lett.* **98**, 232103 (2011).
- [3] Y. H. Wang, H. Steinberg, P. Jarillo-Herrero, and N. Gedik, “*Observation of Floquet-Bloch States on the Surface of a Topological Insulator*”, *Science* **342**, 453 (2013).
- [4] N. H. Lindner, G. Refael, and V. Galitski, “*Floquet topological insulator in semiconductor quantum wells*”, *Nature Physics* **7**, 490 (2011).
- [5] T. Kitagawa, T. Oka, A. Brataas, L. Fu, and E. Demler, “*Transport properties of nonequilibrium systems under the application of light: Photoinduced quantum Hall insulators without Landau levels*”, *Phys. Rev. B* **84**, 235108 (2011).
- [6] P. M. Perez-Piskunow, G. Usaj, C. A. Balseiro, and L. E. F. Foa Torres. “*Floquet chiral edge states in graphene*”, *Phys. Rev. B* **89**, 121401(R) (2014).
- [7] E. Suárez Morell and L. E. F. Foa Torres, “*Radiation effects on the electronic properties of bilayer graphene*”, *Phys. Rev. B* **86**, 125449 (2012).
- [8] H. L. Calvo, L. E. F. Foa Torres, P. M. Perez-Piskunow, C. A. Balseiro and G. Usaj, “*Floquet interface states in illuminated three dimensional topological insulators*”, arxiv:1502.04098
- [9] G. Usaj, P. M. Perez-Piskunow, L. E. F. Foa Torres, and C. A. Balseiro, “*Irradiated graphene as a tunable Floquet topological insulator*”, *Phys. Rev. B* **90**, 115423 (2014); P. M. Perez-Piskunow, L. E. F. Foa Torres and G. Usaj, “*Hierarchy of Floquet gaps and edge states for driven honeycomb lattices*”, arxiv:1503.01797
- [10] V. Dal Lago and L. E. F. Foa Torres, “*Floquet topological transitions in driven one-dimensional models*”, to be published.
- [11] L. E. F. Foa Torres, P. M. Perez-Piskunow, C. A. Balseiro, and G. Usaj, “*Multiterminal Conductance of a Floquet Topological Insulator*”, *Phys. Rev. Lett.* **113**, 266801 (2014).
- [12] Related publications and updates available at <http://nanocarbon.famaf.unc.edu.ar/>

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Reaching the quantum ground state of macroscopic and massive mechanical objects is a major experimental challenge at the origin of the rapid emergence of cavity optomechanics. We develop a new generation of optomechanical devices, either based on microgram 1-mm long quartz micropillar with very high mechanical quality factor or on 100-pg photonic crystal suspended nanomembranes. Both are used in high finesse Fabry-Perot cavities, leading to ultra-sensitive interferometric measurement of the resonator displacement. We expect to reach the ground state of such optomechanical resonators combining cryogenic cooling with a dilution fridge at 30 mK and radiation-pressure cooling. We already carried out a quantum-limited measurement of the micropillar thermal noise at low temperature, and the cold damping of the nanomembrane. We also investigate the possibility to develop a hybrid platform which may be very helpful for quantum engineering and quantum information processing, by coupling our suspended nanomembranes to cold atoms or to microwave circuits.

Hybrid spin-nanomechanical system

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Coupling a single qubit to a nanomechanical oscillator is a promising direction for generating non classical states of motion. We will expose our developments on hybrid systems combining SiN nanowires whose vibrations are magnetically coupled to a single NV spin qubit [1] attached to its vibrating extremity. This functionalization grants a mechanical degree of freedom to the single photon source, which can be used to probe the nanoresonator vibrational thermal noise [2]. Immersing the system in a strong magnetic field gradient render the spin state position dependent and parametrically coupled to the nanoresonator vibrations. We explore the dynamics of the hybrid spin-nanomechanical system in the resolved sideband regime.

Reminiscent of the bound character of a qubit's dynamics confined on the Bloch sphere, the observation of a Mollow triplet in the resonantly driven qubit fluorescence spectrum represented one of the founding signatures of Quantum Electrodynamics. Here we report on its observation in our hybrid spin-nanomechanical system, A resonant microwave field turns the originally parametric hybrid interaction into a resonant process [3], where acoustic phonons are now able to induce transitions between the dressed qubit states, leading to synchronized spin-oscillator dynamics. We further explore the vectorial character of the hybrid coupling to the bidimensional deformations of the nanowire [4].

Finally, we will explore the spin qubit coherence properties in presence of random thermal noise and its modified spectral sensitivity in presence of the microwave dressing field. We will expose how a weak coherent mechanical drive can protect the spin qubit from the motional decoherence induced by the thermal noise of the nanoresonator.

[1] O. Arcizet, V. Jacques, A. Siria, P. Poncharal, P. Vincent and S. Seidelin, A single NV defect coupled to a nanomechanical resonator, *Nature Physics* **7**, 879 (2011)

[2] L. Mercier de Lépinay, B. Pigeau, S. Rohr, A. Gloppe, A. G. Kuhn, P. Verlot, E. Dupont-Ferrier, O. Arcizet Nano-optomechanical measurements in the photon counting regime, arXiv:1503.03200 (2015)

[3] S. Rohr, E. Dupont-Ferrier, B. Pigeau, P. Verlot, V. Jacques, O. Arcizet, Self-synchronization of a NV spin qubit on a radio-frequency field enabled by microwave dressing, *Phys. Rev. Lett.* **112**, 010502 (2014)

[4] B. Pigeau, S. Rohr, L. Mercier de Lépinay, A. Gloppe, V. Jacques, O. Arcizet, Observation of a phononic Mollow triplet in a hybrid spin-nanomechanical system, arXiv:1502.07071 (2015).

Strain-mediated coupling in a quantum dot-mechanical oscillator hybrid system

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Dielectric photonic wires have been shown to be extremely efficient antennae to collect light emitted by a single quantum dot [1] (see fig.a). We will show here that these objects feature also outstanding optomechanical properties by exhibiting large coupling between the wire motion and the transition energy of embedded light emitters. In this quantum dot-mechanical oscillator hybrid system, the coupling is mediated by the strain experienced by the quantum dot as the wire oscillates (see fig.b) [2]. The prospect of such systems is that the quantum nature of a macroscopic degree of freedom of the oscillator can be revealed and manipulated by a single two-level system. This opens up appealing perspectives for quantum information technologies, and for the exploration of quantum-classical boundary.

The inverted conical shape of the wire has been designed for efficient single photon production [1]. Additionally, it turns out that this shape contributes to concentrating the strain field produced by the fundamental flexural mode at the bottom of the wire where the quantum dot is located. The oscillation of this mechanical mode ($\Omega_0/2\pi \simeq 500$ kHz) causes the photoluminescence spectra of the quantum dot to be modulated (see fig.c). The corresponding coupling ($g/2\pi=450$ kHz) is comparable to the mechanical coupling, almost entering the ultra-strong coupling regime [2]. In this regime, the quantum dot state can in principle be read out mechanically in a quantum non-demolition way. More generally, depending on parameters, the back action of the quantum dot on the oscillator can lead to motion amplification or cooling.

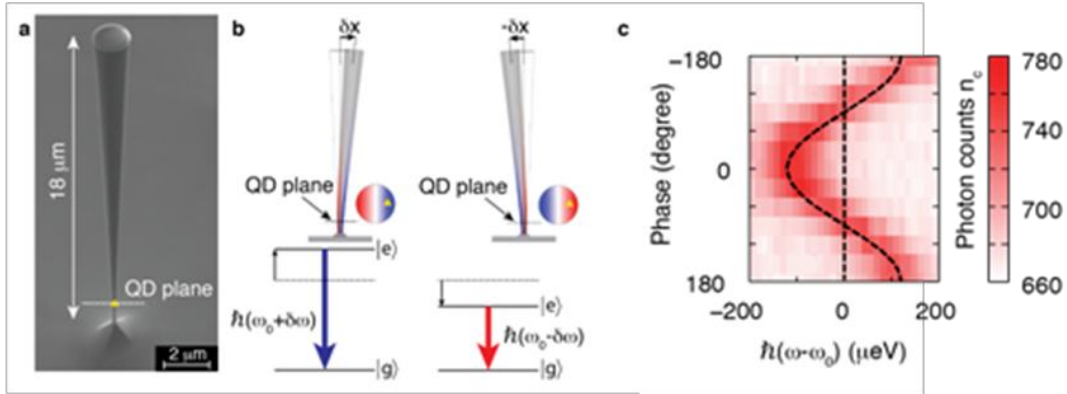


Fig. a, Scanning electronic microscope image of the photonic wire. **b** The strain field (color scale) induced by the wire oscillation shifts the quantum dot energy. **c**, Energy shift as the wire oscillates (stroboscopic data)

[1] M. Munsch, N.S. Malik, E. Dupuy, A. Delga, J. Bleuse, J.M. Gérard, J. Claudon, N. Gregersen, and J. Mørk, *Dielectric GaAs Antenna Ensuring an Efficient Broadband Coupling between an InAs Quantum Dot and a Gaussian Optical Beam*, Phys. Rev. Lett. **110**, 177402 (2013)

[2] I. Yeo, P.-L. de Assis, A. Gloppe, E. Dupont-Ferrier, P. Verlot, N. S. Malik, E. Dupuy, J. Claudon, J.-M. Gérard, A. Auffèves, G. Nogues, S. Seidelin, J-Ph. Poizat, O. Arcizet, M. Richard, *Strain-mediated coupling in a quantum dot-mechanical oscillator hybrid system*, Nature Nano **9**, 106 (2014),

Non-reciprocal interactions via quantum reservoir engineering

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I'll discuss recent theoretical work [1] where we present an extremely general method for making a wide class of interactions between two systems A and B explicitly directional, such that system A influences system B, but not vice-versa. Our approach is based on quantum reservoir engineering, and simply involves balancing a given coherent interaction against its dissipative counterpart. It can be used to enable both non-reciprocal transport and quantum-limited amplification of photons and phonons, and is well suited to implementation in cavity optomechanics and superconducting microwave circuits.

[1] A. Metelmann and A. A. Clerk, *Nonreciprocal Photon Transmission and Amplification via Reservoir Engineering*, arXiv:1502.07274 (2015).

Cavity Optomechanics with Free Electrons

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In 40 years, the paradigm of laser cooling has solidly established as the method of reference for controlling mechanical motion down to the quantum level [1]. Its principle essentially relies on the interaction between a mechanical system and a resonant degree of freedom that can efficiently harvest the mechanical energy. In this work, we demonstrate the first dynamical backaction cooling mechanism that is not mediated by a resonant interaction [2]. Using a focused electron beam, we report a 50-fold reduction of the motional temperature of a nanowire. Our result primarily relies on the sub-nanometer confinement of the electron beam and generalizes the phenomenology of cavity optomechanics [3] to any delayed and topologically confined interaction, with important consequences for near-field microscopy and fundamental nanoscale dissipation mechanisms.

Our experimental setup is depicted on Fig. 1(a): A focused beam of electrons is sent onto a vibrating Silicon Carbide nanowire (length $150\ \mu\text{m}$, diameter $250\ \text{nm}$) inside a Scanning Electron Microscope (SEM). The Secondary Electrons (SE) resulting from this interaction are detected by means of an Everhart-Thornley Detector (ETD), whose output is further sent onto a spectrum analyser. The sharp dependence of the SE emission rate with respect to the position of the nanowire enables sensitive detection of the thermally induced nanomechanical fluctuations. When displacing the point of impact of the electron beam towards the edge of the nanowire a strong suppression of the thermal motion is observed, proportional to the increase of the mechanical damping rate (see Fig. 1(b)). This reveals the presence of strong dissipative gradients, similar to those encountered in cavity optomechanics. We find that these gradients are to be attributed to the extreme topological confinement of the electro-thermal force exerted by the electron beam.

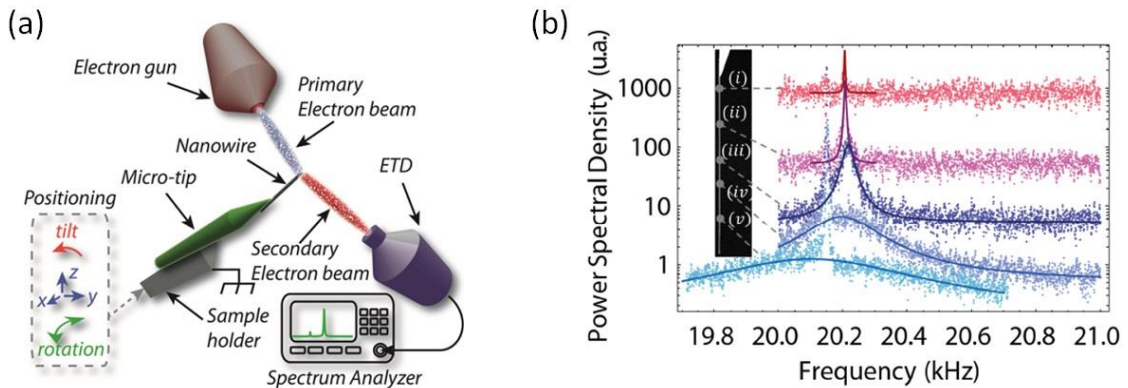


Fig. 1 (a) Experimental Setup. A focused electron beam is sent onto a vibrating nanowire inside a Scanning Electron Microscope. The secondary electrons resulting from this interaction are detected by means of an Everhart-Thornley Detector (ETD), whose output fluctuations are sent onto a spectrum analyser. (b) Dynamical backaction cooling using free electrons. When displacing the point of impact of the electron beam towards the tip of the nanowire (see SEM image on the inset), a strong suppression of the nanomechanical fluctuations is observed, proportional to the increase of the measured damping rate.

More generally, we demonstrate that the phenomenology of cavity optomechanics extends to any topologically confined interaction in principle, with prominent consequences for the fundamental understanding of nanoscale dynamics.

References

- [1] Cohen-Tannoudji, C., Dupont-Roc, J. & Grynberg, G. *Atom-photon interactions: basic processes and applications*. (Wiley Online Library, 1992).
- [2] Niguès, A., A. Siria, and P. Verlot. "Dynamical Backaction Cooling with Free Electrons." arXiv preprint arXiv:1411.0548 (2014).
- [3] Kippenberg, Tobias J., and Kerry J. Vahala. "Cavity optomechanics: back-action at the mesoscale." *science* 321.5893 (2008): 1172-1176.

Synchronization and phase inertial in a field emission NEMS

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Synchronization is an ubiquitous phenomenon appearing in various systems such as neural networks, lasers, charge density waves, Josephson junction arrays, heart/breathing systems and population of flashing fireflies, and it is expected to be exploited for the treatment of Parkinson's disease, signal processing or optomechanical systems to name a few. Synchronization is only possible in systems demonstrating self-oscillations. Self-oscillating device in nanomechanics have been recently fabricated for optical and electrical systems but synchronization experiments are rather scarce and do not exploit the potentiality of strong non-linearity's in nanomechanics to unveil new phenomena.

We performed transport measurements with SiC nanowires in a single clamped geometry by applying a DC voltage [1]. At the free end of the nanowire electrons can tunnel into vacuum due to the electric field tip amplification. Above a threshold voltage, this electromechanical nano-object self-oscillates. Applying an additional AC electrostatic excitation locks the selfoscillation natural frequency of the nanowire to the external frequency even for frequencies deviating from each other by roughly 10 %. In the regime of strong driving, unusual behaviors of the phase of the locked self-oscillator are observed showing very distinct features compared to a driven resonator. Transition from overdamped to damped phase dynamics is clearly demonstrated as well as spontaneous phase modulation motion close to the boundary of the Arnold tongue similar to some form of self-oscillation of the self-oscillator (also called phase trapping).

[1] Barois, T.; Perisanu, S.; Vincent, P.; Vincent, P; Purcell, ST; Ayari, *Frequency modulated self-oscillation and phase inertia in a synchronized nanowire mechanical resonator*, New J. of Phys. **16**, 083009 (2014).

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Poster

Modifying the Fundamental Interaction between Electrons in Ultraclean Carbon Nanotubes

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Recent years have seen the development of several experimental systems capable of tuning local parameters of quantum Hamiltonians, including ultracold atoms, trapped ions, superconducting circuits and photonic crystals. These systems excel in studying the physics of bosons in disorder-free settings. A solid state analog, in which Hamiltonians of interacting electrons are designed and studied, remains a major open challenge, since in conventional solids electrons exist inside an imperfect host material that generates uncontrolled disorder. Here we describe our platform for realizing in suspended carbon nanotubes such disorder-free, locally-tunable electronic systems. This platform becomes possible due to a developed technique for nano-assembly of carbon nanotubes on complex electrical circuits without damaging their pristine electronic behavior. We will show a new experiment in which we have used this system to radically change the nature of interactions between electrons.

Ultra-sensitive force detection with carbon nanotube mechanical resonators

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Carbon nanotubes allow studying a broad range of phenomena, from many-electron transport in one-dimensional systems to nonlinear dynamics and fluctuations of bending modes. They also provide unique tools for mass and charge measurements with unprecedented sensitivity [1,2]. Another important new application is force measurement [3]. I will present our recent force sensing experiments in which our nanotube mechanical resonators display quality factors as high as 5 million, and experience a force noise as low as 10^{-21} N Hz^{-1/2} [4]. This force noise has a thermal origin and is associated with the Brownian motion of the nanotube at a temperature of 0.04 K. To detect the low amplitude vibrations of the nanotube in the Brownian motion regime at such a low temperature, we employ an ultrasensitive method based on correlated electrical noise measurements, in combination with parametric down-conversion. Force sensing with nanotube resonators may offer new opportunities for detecting and manipulating individual nuclear spins.

[1] K. Jensen, K. Kim, and A. Zettl, *Nature Nanotech.* **3**, 533 (2008). J. Chaste, et al., *Nature Nanotech.* **7**, 301 (2012).

[2] G. A. Steele, et al., *Science* **325**, 1103 (2009). B. Lassagne, et al., *Science* **325**, 1107 (2009).

[3] J. Moser, J. Güttinger, A. Eichler, M. J. Esplandiu, D. E. Liu, M. I. Dykman, and A. Bachtold, *Nature Nanotech.* **8**, 493 (2013).

[4] J. Moser, A. Eichler, J. Güttinger, M. I. Dykman, and A. Bachtold, *Nature Nanotech.* **9**, 1007 (2014).

A novel probe for local imaging of interacting electrons in 1D with minimal invasiveness
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Interacting electrons in a one dimensional channel are a unique physical system, which can exhibit a variety of correlated electron phases. Many of these phases, such as the quantum Wigner crystal, have a distinct signature in their real-space electronic structure. Recently, we have developed pristine multi-gate nanotube (NT) devices, which allow for precise engineering of 1D microscopic potentials along the NT, while maintaining strong electron interactions. This makes them ideal for realizing correlated electron phases, and calls for development of a local probe that can resolve their electronic spatial structure, without destroying it due to large potential modulations. For this purpose we created a novel experimental setup, where we use a second NT device as a sensitive charge detector in a scan probe microscope configuration. Its main advantage is that the probe invasiveness can be tuned, and is limited in principle only by the quantum back-action of single electrons in the detector. We will demonstrate how the invasiveness of the probe-NT can be controlled and drastically reduced. In addition, we will present initial results of wavefunction imaging using this platform.

Using Mechanical Motion of a Carbon Nanotube to Probe Its Electronic States

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The recent generation of carbon nanotube devices, which allow to engineer the potential landscape along a pristine one-dimensional system, forms a versatile playground for studying a large variety of correlated electronic ground states. While some of these ground states are conducting, other are fundamentally insulating, thus hindering their measurement via transport. Here we demonstrate a new method that allows us to directly measure these insulating states by probing the interaction between the electrons and the mechanical motion of the nanotube. The key feature of this method is a new capability to control and measure the nanotube's mechanical motion in the time domain while quickly switching between different electronic configurations. We can thus actuate the mechanical motion, let the electronic system of interest interact with it, and coherently measure the motion after the interaction took place by turning on the conductivity. We will demonstrate how this technique opens a new venue for observing electronic states that were previously impossible to probe.

Spin Crossover Materials - Part II: Mechanical properties and actuators

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The spin crossover phenomenon involves a spontaneous change in volume of the material up to 15 % and is often cooperative in the solid state, producing first-order phase transitions. Starting from this fact, we have developed a series of actuating devices from a range of spin crossover materials as a macroscopic proof of concept [1-2]. The work density found in these devices is 10^4 - 10^5 times greater than that expected from thermal expansion alone, which is currently used to drive actuation in some MEMS devices [3]. In addition, spin crossover is a molecular phenomenon, and as such there is no fundamental restriction on the functionality at the nano-scale. These facts together with the versatility of their chemistry and the range of different external stimuli which can trigger the spin-state switching make these materials attractive candidates for incorporation into NEMS devices.

The present work aims to explore the mechanical properties of spin crossover materials in their two phases (high and low spin) [4-6] as well as to explore their potential as actuators for future applications in NEMS and MEMS devices (figure 1).

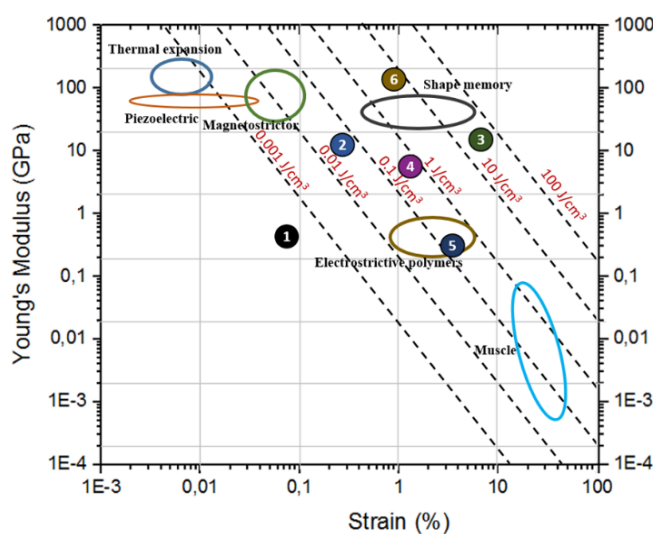


Fig 1. Young's modulus versus linear strain plot for selected actuation material families [3]

[1] Helena J. Shepherd, et al., *Molecular actuators driven by cooperative spin-state switching*, Nature Commun, **4**, 2607 (2013).

[2] Il'ya A. Gural'skiy, et al., *Spin crossover composite materials for electrothermomechanical actuators*, J. Mater. Chem C, **2**, 2949 (2014).

[3] María D. Manrique-Juárez, et al., *Switchable molecule-based materials for micro- and nanoscale actuating applications: achievements and prospects*, Coord. Chem. Rev. (2015), In press, doi:10.1016/j.ccr.2015.04.005

[4] Helena J. Shepherd, et al., *Antagonism between Extreme Negative Linear Compression and Spin Crossover in [Fe(dpp)₂(NCS)₂]-py*, Angew. Chem. Int. Ed. **51**, 3910 (2012)

[5] Edna M. Hernández, et al., *AFM Imaging of Molecular Spin-State Changes through Quantitative Thermomechanical Measurement*, Adv. Mater. **26**, 2889 (2014)

[6] Gautier. Félix, et al., *Lattice dynamics in spin-crossover nanoparticles through nuclear inelastic scattering* Phys. Rev. B **91** 024422 (2015)

Dissipation in nanomechanical graphene resonator

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Sensing properties of NanoElectroMechanical Systems (NEMS) rely on the possibility to achieve high quality factor resonator. Accurate understanding of dissipation mechanisms in such resonators is a key point for the design of reproducible and efficient sensors based on NEMS.

Due to their low dimensions – both size and mass – graphene and nanotube mechanical oscillators are extremely sensitive to their environment. Recently, they showed outstanding force sensitivity [1] as well as ultra-small mass resolution capability [2].

In this contribution, we aim at exploring dissipation mechanisms in a graphene nano-mechanical resonator at cryogenic temperature. We achieved graphene membrane resonator with very high quality factor $Q > 10^6$ at temperature below 1K. Surprisingly, the quality factor is found to exhibit a linear temperature dependence down to the lowest temperature in our experiment (20 mK).

In this regime of very low-temperatures, few mechanisms for dissipation are playing a role [3]. We compare these different dissipation mechanism to our results. We argue that dissipation in our system might be limited by two-level systems located in the oxide layer covering the gate electrode.

[1] J. Moser, J. Güttinger, A. Eichler, M. J. Esplandiú, D. E. Liu, M. I. Dykman, A. Bachtold, *Ultrasensitive force detection with a nanotube mechanical resonator*, Nature Nanotechnology **8**, 493-496 (2013)

[2] J. Chaste, A. Eichler, J. Mose, G. Ceballos, R. Rurali and A. Bachtold, *A nanomechanical mass sensor with yoctogram resolution*, Nature Nanotechnology **7**, 301 (2012).

[3] M. Imboden and P. Mohanty, *Dissipation in nanoelectromechanical systems*, Physics Reports, 534, pp89-146 (2014)

Spin Crossover Materials for MEMS/NEMS - Part I: Thin film deposition and nanopatterning

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With the versatility of their chemistry and the range of different external stimuli which can trigger the spin-state switching, spin crossover (SCO) materials are attractive candidates for incorporation into MEMS/NEMS devices [1]. The spin crossover phenomenon involves a spontaneous change in volume of the material up to 15 % and is often cooperative in the solid state, producing first-order phase transitions. The synthesis of nanometer sized spin crossover materials, their manipulation at reduced length scales and the investigation of their size dependent properties contribute to explore their possible practical applications in future nanophotonic, nanoelectronic and nanomechanical devices. An important challenge in this context is to preserve the bistability and the cooperative spin transition properties during the downsizing of the compound at the nanoscale.

SCO materials have been successfully deposited as thin films using various methods (spin coating, thermal evaporation, layer by layer assembly) and nanopatterned (photolithography, electron beam lithography, soft lithography) [2-5]. The present work aims to show proof of concept examples of these techniques to specific SCO materials for their implementation in NEMS applications.

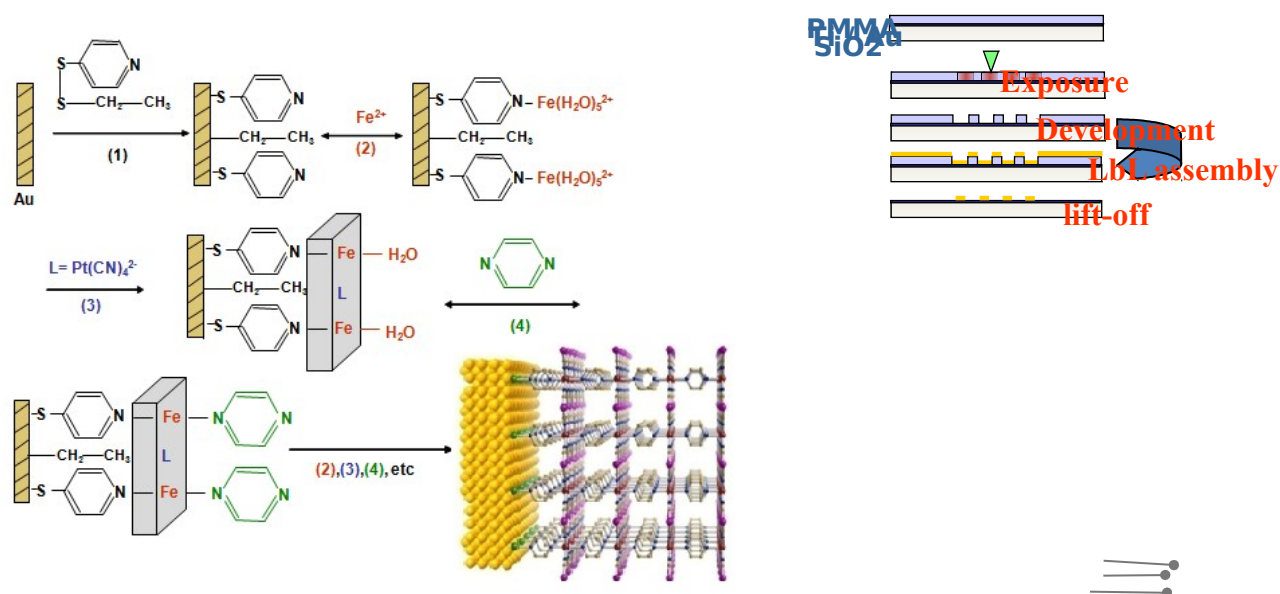


Figure 1 : Process for layer by layer assembly of Fe(pyrazine)[Pt(CN)₄] thin films followed by electron beam lithographic patterning.

- [1] María D. Manrique-Juárez, et al., *Switchable molecule-based materials for micro- and nanoscale actuating applications: achievements and prospects*, *Coord. Chem. Rev.*, In press, [doi:10.1016/j.ccr.2015.04.005](https://doi.org/10.1016/j.ccr.2015.04.005) (2015).
 [2] Saioa Cobo et al., *Multilayer Sequential Assembly of Thin Films That Display Room-Temperature Spin Crossover with Hysteresis*, *Angew. Chem. Int. Ed.*, **45**, 5786, (2006).
 [3] Carlos Bartual-Murgui et al., *Guest Effect on Nanopatterned Spin-Crossover Thin Films*, *Small*, **23**, 3385, (2011).
 [4] Haonan Peng et al., *Re-Appearance of Cooperativity in Ultra-Small Spin-Crossover [Fe(pz){Ni(CN)₄}] Nanoparticles*, *Angew. Chem. Int. Ed.*, **53**, 10894, (2014).
 [5] Amal Akou et al., *Soft lithographic patterning of spin crossover complexes. Part 2: stimuli-responsive diffraction grating properties*, *J. Mater. Chem.*, **22**, 3752, (2012).

Non-stationary transport properties of molecular junctions in the polaronic regime

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Localized vibrations (phonons) may have an important impact in the transport properties of nanoscale conductors [1]. Such effects have been observed in many different systems such as atomic chains, semiconducting quantum dots, carbon nanotubes and other molecular junctions. In spite of this variety, from a theoretical point of view all these situations can be qualitatively described by the rather simple Anderson-Holstein model. This model considers a single resonant level coupled to fermionic reservoirs and to a localized phonon mode. While the stationary properties of this model have been extensively analyzed, by many approximations, the way the system reaches the steady-state is not yet well understood.

In this work we focus in the so called polaronic regime, where the coupling between electrons and phonons is strong, compared with the coupling of the level to the electrodes. In order to study the transient regime properties of the system we use an approximation studied in a previous work, based on on a resummation of the dominant Feynman diagrams from the perturbation expansion in the coupling to the leads [2].

Using this approximation we are able to analyze the evolution of the current and the average population of the level, observing long transient behavior when increasing the electron-phonon coupling and no bistability at long time. These results are compared with numerical exact results obtained from path-integral Monte Carlo [3], showing a good agreement for different range of parameters and initials preparations of the system. Using the expressions developed by Mukamel et. al. [4], we are able to evaluate the single electron probabilities transfer through the junction and the evolution of the current cumulants, showing an universal oscillatory behavior for higher order cumulants.

- [1] M. Galperin, M. A. Ratner and A. Nitzan, Journal of Physics: Condensed Matter **19**, 103201 (2007).
- [2] R. Seoane Souto, A. Levy Yeyati, a. Martín-rodero and R.C. Monreal, Phys Rev B **89**, 085412 (2014)
- [3] K. F. Albrecht, A. Martin-Rodero, R. C. Monreal, L. Mühlbacher, and A. Levy Yeyati, Phys Rev B **87**, 085127 (2013)
- [4] M. Esposito, U. Harbola and S. Mukamel, Rev. mod. phys. **81** (4), 1665 (2009)

Quality factors reaching 1 million in graphene mechanical resonators

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I will present recent progress in demonstrating a new readout method for graphene mechanical resonators capacitively coupled to a superconducting microwave cavity. In particular, we developed a ring down detection technique, which allows to perform time-resolved measurements of the mechanical oscillation amplitude and frequency. Thereby, we are able to detect mechanical energy dissipation times in the milliseconds regime corresponding to quality factors larger than $Q=10^6$. Here we have direct access to the mechanical dissipation free of dephasing processes, in contrast to standard spectral techniques. We are also able to detect cryogenic thermal motion with phonon occupation numbers as low as $n_m=20$. This allows to compare the ring down measurement of the mechanical dissipation to indirect measurements of the mechanical line width extracted from thermal noise power spectra. Moreover, we are able to characterize the mechanical dissipation, with an unprecedented quality, as a function of different physical parameters such as the bath temperature or the intracavity photon number. We observe a linear temperature dependence of the quality factor down to temperatures as low as $T=15\text{mK}$, which gives a first hint at the limiting factor for the mechanical dissipation in our devices.

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