TT 98: Transport: Nanomechanics

Time: Thursday 15:00–18:00 Location: BEY 81

TT 98.1 Thu 15:00 BEY 81

Phonon lasing and non-linear phenomena with nitrogen-vacancy centers in diamond — •Kosmas Kepesidis — Institut of Atomic and Subatomic Physics, TU Wien, Wien, Austria

I this talk, I will describe a new approach for manipulating and detecting the state of single and multiple vibrational modes in nanoscale diamond structures by making use of the strain-induced coupling to a nitrogen-vacancy impurity. I will first show how this coupling can be used to either cool the resonator close to its vibrational ground state or drive it to a large-amplitude coherent state (phonon lasing). In the second part of the talk I will then describe the complex non-linear phenomena that can arise in an array of coupled phonon-lasers under parity-time symmetric conditions, where phonon modes with alternating gain and loss of equal strength are coupled together.

TT 98.2 Thu 15:15 BEY 81

Nano-scale rotor driven by single-electron tunneling — •Alan Celestino[1], Alexander Croy[2], Marcus Werner Beims[3], and Alexander Eisfeld[1] — [1]MPIPKS, Dresden, Germany — [2]Chalmers University of Technology S-412 96, Göteborg, Sweden — [3]Federal University of Paraná, Curitiba, Brazil

We study theoretically the dynamics and the electronic transport in a nano-scale rotor. The rotor is driven by electron tunneling in the Coulomb-blockade regime. We show that a static bias can lead to self-excitation of intermittent oscillatory/rotatory or continuous rotational motion. We establish the connection between the dynamical regimes and the current through the device. The relevant device's parameters are identified and we study the dynamics' dependence on these parameters. Notably, in the intermittent regime we find a negative differential conductance. The current-voltage characteristics can be used to infer details of the surrounding environment which is responsible for damping. Finally, we show how to break the system's symmetry in order to recast it as a rectifier.
[1] A. Croy and A. Eisfeld, EPL 98, 68004

TT 98.3 Thu 15:30 BEY 81

Cooling a nanomechanical resonator using spin-dependent transport — •Pascal Stadler[1], Gianluca Rastelli[2], and Wolfgang Belzig[1] — [1]Fachbereich Physik, Universität Konstanz, 78457 Konstanz, Germany — [2]Zukunftskolleg, Fachbereich Physik, Universität Konstanz, 78457, Konstanz, Germany

We study spin-dependent transport in a quantum dot contacted to two ferromagnets and magnetically coupled to a nanomechanical oscillator in the quantum regime. Due to the magneto-vibrational coupling, the nanomechanical oscillator induces spin-flips of the electrons on the quantum dot. In such a spin-valve, owing to the sensitivity of the electron transport to the spin orientation, signatures of the nanomechanical motion appears in the I-V characteristic even for weak spin-vibrational coupling. Additionally, the feed-back action of the spin-polarized current on the state of the oscillator leads to an active cooling of the oscillator's eigenmode controlled by the applied voltage to the leads and by the parallel or antiparallel magnetization configuration.

TT 98.4 Thu 15:45 BEY 81

Optomechanical Metamaterials: Dirac polaritons, Gauge fields, and Instabilities — •Vittorio Peano, Michael Schmidt Schmidt, and Florian Marquardt — Friedrich Alexander Universität Erlangen

Freestanding photonic crystals can be used to trap both light and mechanical vibrations. These "optomechanical crystal" structures have already been experimentally demonstrated to yield strong coupling between a photon mode and a phonon mode, co-localized at a single defect site. Future devices may feature a regular superlattice of such defects, turning them into "optomechanical arrays". We predict that tailoring the optomechanical band structure of such arrays can be used to implement Dirac physics of photons and phonons, to create a photonic gauge field via mechanical vibrations, and to observe a novel optomechanical instability.

TT 98.5 Thu 16:00 BEY 81

Arbitrarily large steady-state bosonic squeezing via dissipation — •Andreas Kronwald[1], Florian Marquardt[1,2], and Aashish A. Clerk[3] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 7, D-91058 Erlangen, Germany — [2]Max Planck Institute for the Science of Light, Günther-Scharowsky-Straße 1/Bau 24, D-91058 Erlangen, Germany — [3]Department of Physics, McGill University, Montreal, Quebec, Canada H3A 2T8

We discuss how large amounts of steady-state quantum squeezing (beyond 3 dB) of a mechanical resonator can be obtained by driving an optomechanical cavity with two control lasers with differing amplitudes. The scheme does not rely on any explicit measurement or feedback, nor does it simply involve a modulation of an optical spring constant. Instead, it uses a dissipative mechanism with the driven cavity acting as an engineered reservoir. It can equivalently be viewed as a coherent feedback process, related to the quantum non-demolition measurement of a single mechanical quadrature. We analyze how to optimize the scheme, how the squeezing scales with system parameters, and how it may be directly detected from the cavity output. Our scheme is extremely general, and could also be implemented with, e.g., superconducting circuits.

15 min. break.

Invited Talk TT 98.6 Thu 16:30 BEY 81

Real-Space Tailoring of the Electron-Phonon Coupling in Ultra-Clean Nanotube Mechanical Resonators — •Shahal Ilani[1], Avishai Benyamini[1], Assaf Hamo[1], Silvia Viola Kusminskiy[2], and Felix von Oppen[2] — [1]Dept. of Cond. Matt. Phys., Weizmann Institute — [2]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin

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. Although tremendous advances have been made in controlling electrons and phonons in engineered nanosystems, to date the control over the coupling between these degrees of freedom is still widely lacking. Here we demonstrate the ability to fully tailor electron-phonon interactions in a new class of suspended carbon nanotube devices, in which we can form highly-tunable single and double quantum dots at arbitrary locations along a nanotube mechanical resonator. We find that electron-phonon coupling can be turned on and off by controlling the position of a quantum dot along the resonator. Using more elaborate double quantum dots we structure the interactions in real space to couple specific electronic and phononic modes. Exploiting this tailored coupling we measure the parity of phonons in real space and directly image their mode shapes. Interestingly, we demonstrate tailored coupling of phonons to internal electrons in an isolated system, decoupled from the random environment of the electronic leads, a crucial step towards fully-engineered quantum coherent electron-phonon systems.

TT 98.7 Thu 17:00 BEY 81

Microwave Cavity Readout of Graphene NEMS — •Peter Weber, Johannes Guettinger, Ioannis Tsioutsios, and Adrian Bachtold — ICFO-Institut de Ciencies Fotoniques, 08660 Castelldefels (Barcelona), Spain

Graphene is an interesting material for the realization of nano-electromechanical systems (NEMS), because of its high mechanical strength and its ultra low mass density. In optomechanical sideband cooling experiments [1] the low mass offers the advantage that graphene has a comparatively large motional amplitude in the quantum mechanical ground state. Additionally, mechanical nonlinearities of graphene could still remain significant in the quantum regime. We developed a new method to detect the mechanical vibrations of a graphene resonator by coupling it capacitively to a superconducting microwave cavity. The cavity resonance frequency is modulated by the graphene motion and leads to sideband peaks in the cavity spectrum [2]. In particular, we present fabrication, microwave readout and characterisation of few-layer graphene NEMS at millikelvin temperatures. The fabrication is based on a graphene transfere process on predefined gate structures being part of the superconducting cavity. Our measurements demonstrate, that microwave readout of graphene NEMS is a promising technique enabling the possibility to detect thermal vibrations as well as making cooling experiments feasible with graphene.
[1] J. D. Teufel et al., Nature 475, 359 (2011)

[2] X. Song et al., Nano Letters 12, 198 (2012)

TT 98.8 Thu 17:15 BEY 81

Coupled Graphene Mechanical Resonators — •Ioannis Tsioutsios[1,2], Joel Moser[1,2], José Antonio Plaza[3], and Adrian Bachtold[1,2] — [1]ICFO, Av. Carl Friedrich Gauss, 08860 Castelldefels, Barcelona, Spain — [2]ICN, CIN2-CSIC, Campus UAB, 08193 Barcelona, Spain — [3]IMB-CNM (CSIC), E-08193 Bellaterra, Barcelona, Spain

Coupled mechanical resonators show reach variety of non-linear dynamics such as synchronization and chaos. Moreover, they offer new strategies to improve the quality factor and detect charge and mass with high sensitivity. Such devices have been mainly fabricated form metallic and silicon-based materials using top-down micromachining.

Single mechanical resonators based on alternative materials like carbon nanotubes and graphene sheets have been demonstrated and show a wide variety of useful properties like very high resonant frequency, extremely high mass and force sensitivity, and strong mechanical nonlinearities. However, so far it has not been possible to use them as building blocks to create coupled resonator devices.

In this work, we demonstrate a multi-element resonant structure consisting of two graphene sheets linked by a carbon nanotube beam. The mechanical vibrations are actuated and detected electrically using the mixing technique. Two mechanical eigenmodes are measured, each corresponding to vibrations localized in a different graphene sheet. Coupling between the eigenmodes is observed and is evaluated by measuring the shift of the resonance frequency of one graphene sheet as a function of the vibration amplitude of the other.

TT 98.9 Thu 17:30 BEY 81

Intrinsic mode-coupling and thermalization in nanomechanical graphene drums — •Daniel Midtvedt[1], Zenan Qi[2], Alexander Croy[1], Harold S. Park[2], and Andreas Isacsson[1] — [1]Chalmers University of Technology, Sweden — [2]Boston University, Boston, MA, United States

Nanomechanical graphene resonators display strong nonlinear behavior, which leads to coupling between normal modes. This coupling allows for intermodal energy-transfer, which facilitates the redistribution of energy initially localized in a single mode. Further, the mode-coupling intrinsically limits the quality factor of the device. We study the mode-coupling in a circular graphene resonator using molecular dynamics and continuum mechanics. Mimicking a ring-down setup, the fundamental mode is excited with a given energy, and the time-evolution of this energy is computed. At $T > 0$, we find a relaxation rate independent of system size and proportional to $T^*/\epsilon_{\mathrm{pre}}^2$, where T^* is the effective temperature and ϵ_{pre} is the pre-strain of the system [Midtvedt et al, arXiv:1309.1622]. At low temperatures, the system enters a metastable state where only very few low-frequency modes are excited, the life-time of which increases exponentially with decreasing excitation energy. This is similar to what is seen in the much studied Fermi-Pasta-Ulam (FPU) problem. We make a detailed comparison between the dynamics of a graphene drum and the FPU system, and propose to use graphene drums as test beds for FPU physics.

TT 98.10 Thu 17:45 BEY 81

Dissipation-induced entanglement and excitation transport in quantum nanomechanical systems — Aurora Voje, Andreas Isacsson, and •Alexander Croy — Department of Applied Physics, Chalmers University of Technology, Göteborg, Sweden

Nanoelectromechanical (NEM) resonators are important systems for the study of quantum phenomena in macroscopic, mechanical man-made objects. Only recently, cooling of NEM resonators to the ground state was experimentally demonstrated. We investigate possibilities to generate non-classical states in carbon-based resonators, which are highly promising for the study of nonlinear mechanical systems in the quantum regime. Our proposals are based on the presence of nonlinear (two-phonon) dissipation found in those systems. We show that the latter facilitates the emergence of non-classical states for a single oscillator [1] and leads to generation of entanglement of two oscillators, which are individually subject to two-phonon dissipation [2]. Finally, the implications and prospects for arrays of such NEM resonators are discussed.

[1] A. Voje, A. Croy, and A. Isacsson, NJP **15**, 053041 (2013).
[2] A. Voje, A. Isacsson, and A. Croy, PRA **88**, 022309 (2013).