Q 49: Optomechanics I

Time: Thursday 11:00–13:00 Location: f342

Q 49.1 Thu 11:00 f342

Ro-Translational Cavity Cooling of Dielectric Needles and Discs — •Benjamin A. Stickler[1], Lukas Martinetz[1], Stefan Nimmrichter[1], Stefan Kuhn[2], Markus Arndt[2], and Klaus Hornberger[1] — [1]Faculty of Physics, University of Duisburg-Essen, Lotharstraße 1, 47048 Duisburg, Germany — [2]Faculty of Physics, VCQ, University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria

Motivated by recent experiments [1] demonstrating optical manipulation of thin silicon nanorods, we investigate the interaction between dielectric needles or discs and the laser field of a high finesse cavity. We show that such anisotropic nanoparticles can be captured from free flight, at velocities much higher than those required to trap dielectric spheres, and that ro-translational cavity cooling should be achievable. We discuss potential applications of these systems for high mass quantum interference experiments as well as for ro-translational cavity optomechanics.

[1] S. Kuhn, P. Asenbaum, A. Kosloff, M. Sclafani, B.A. Stickler, S. Nimmrichter, K. Hornberger, O. Cheshnovsky, F. Patolsky, and M. Arndt, Nano Lett. 15, 5604 (2015).

Q 49.2 Thu 11:15 f342

Feedback Cooling of a Si_3N_4 membrane inside a cryogenic Fiber-Fabry-Pérot cavity — •Philipp Christoph[1], Tobias Wagner[1], Christina Staarmann[1], Andreas Bick[1], Klaus Sengstock[1], Christoph Becker[1], Hai Zhong[2], Alexander Schwarz[2], and Roland Wiesendanger[2] — [1]Center for Optical Quantum Technologies, Hamburg, Germany — [2]Institute for Applied Physics, Hamburg, Germany

In this talk we present our progress towards a new quantum hybrid system, which aims at coupling ultracold atoms to an ultra-high-Q Si_3N_4 membrane oscillator inside a cryogenic Fiber-Fabry-Pérot cavity. Our approach promises to open new avenues for the manipulation, preparation and detection of the mechanical oscillator.

As an excellent starting point to reach the ground state of the membrane motion we cryogenically cool the membrane-in-the-middle system to a base temperature of 480mK. For further cooling we track the motion of the membrane through balanced homodyne detection and apply a velocity dependent feedback. We observe a substantial further reduction of the fundamental mode temperature, which marks an important step towards the ground state.

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Q 49.3 Thu 11:30 f342

Optical trapping and control of nanoparticles inside hollow core photonic crystal fibers — •David Grass, Julian Fesel, Nikolai Kiesel, and Markus Aspelmeyer — University of Vienna

Optical levitation of nano-particles has attracted significant attention as ultra-high Q mechanical oscillators for room temperature quantum optomechanics, stochastic thermodynamics and force sensing applications. We report an optical conveyor belt for the transport of levitated nano-particles over several centimeters in air or vacuum inside a hollow-core photonic crystal fiber. Detection of the transmitted light field allows three-dimensional read-out of the particles' center of mass motion. An additional laser enables 1-dimensional radiation pressure based feedback cooling over the whole fiber length. Based on the particle motion we characterize the optical intensity distribution inside the HCPCF and measure the local pressure along the fiber when a pressure gradient is applied. A targeted application is the clean and controlled delivery of nanoparticles into a high-finesse optical cavity for levitated cavity optomechanics.

Q 49.4 Thu 11:45 f342

A Hybrid Quantum Architecture Consisting of a Diamond Mechanical Oscillator and Embedded Spins — •Seyed Ali Momenzadeh[1], Marcus W. Doherty[2], Felipe Favaro de Oliveira[1], Philipp Neumann[1], Andrej Denisenko[1], Durga B Rao Dasari[1,3], and Jörg Wrachtrup[1,3] — [1]3. Physikalisches Institut, Universität Stuttgart, Stuttgart — [2]Laser Physics Centre, Research School of Physics and Engineering, Australian National University, Australian Capital Territory 0200, Australia — [3]Max Planck Institute for Solid State Research, Stuttgart

Quantum hybrid systems are promising for futuristic quantum technologies [1]. Among others, color centers in diamond, namely nitrogen vacancy centers (NVCs), coupled to their mechanical degrees of freedom [2-4] form such a hybrid device. With robust control of the spin properties of the NVCs and their coupling to the mechanical modes, they can be used for sensing experiments at the nanoscale and also for scalable quantum information processing. In this talk, I will present our recent progress on the design and fabrication of such hybrid devices. To further demonstrate the robustness of the device, we show how the spin readout could be done through mechanical motion and vice versa.

[1] G. Kurizki et al. PNAS 2015, 112, 3866-3873
[2] A. Barfuss et al. Nat. Phys. 2015, 11, 820-824
[3] E. R. MacQuarrie et al. Phys. Rev. Lett. 2013, 111, 227602
[4] L. M. D. Lepinay et al. arXiv:1503.03200v1 [quant-ph]

Q 49.5 Thu 12:00 f342

Light scattering in hybrid optomechanical systems — •Luigi Giannelli[1], Marc Bienert[1,2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Hohenzollern Gymnasium, 72488 Sigmaringen, Germany

Nitrogen-vacancy (NV) centers in Diamond are a promising platform for quantum technological realizations. We investigate hybrid quantum systems based on a NV-center coupled to a vibrating structure which is also a light resonator (cavity). The NV center interacts with the strain field associated to a high Q vibrational mode of the structure and with the cavity photon field. The mechanical resonator and the cavity also interact via radiation pressure coupling. We discuss the cooling dynamics of the mechanical resonator in these settings. The cooling regime, the stationary temperatures, the cooling rate, and the resonance fluorescence spectrum are theoretically evaluated. The features associated with the cooling dynamics are identified in the spectrum of resonance fluorescence.

Q 49.6 Thu 12:15 f342

Position-Squared Coupling in a Tunable Optomechanical Cavity — •Taofiq Paraiso[1], Mahmoud Kalaee[3], Leyun Zang[1], Hannes Pfeifer[1], Florian Marquardt[2], and Oskar Painter[3] — [1]MPI for the Science of Light, Germany — [2]FAU Erlangen-Nürnberg, Germany — [3]Caltech, Pasadena, CA, USA

Position-squared optomechanical coupling has been proposed as a means of performing the long-sought-after continuous quantum non-demolition (QND) measurements of a mechanical field. The stored energy in a mechanical resonator, proportional to its average squared displacement (x^2), can be used to infer quantum jumps of photons or phonons. Despite significant technical advances made in recent years, achieving a x^2 coupling large enough for preparing non-classical quantum states of mesoscopic mechanical resonators remains an open challenge. Here we demonstrate giant x^2 coupling in a multimoded optomechanical resonator [1]. The device is a double-slotted quasi-2D photonic crystal cavity supporting a pair of optical resonances that both couple to the motion of the structure. Integrated capacitors are used to drive the system from the linear regime into the x^2 coupling regime and to tune the optical normal mode splitting to arbitrarily small values. From independent measurements of the avoided crossing of the optical modes and of the static and dynamical spring effects, we measure a vacuum x^2 coupling rate up to 5 orders of magnitudes larger than in conventional systems. We anticipate these novel platforms to enable the demonstration of quantum nonlinearities in optomechanics.

[1] T. Paraiso *et al.*, Phys. Rev. X **5**, 041024 (2015)

Q 49.7 Thu 12:30 f342

Phononic bandgap membranes for high quantum cooperativity optomechanics — Yeghishe Tsaturyan, Andreas Barg, William Nielsen, Christoffer Moller, Eugene Polzik, and •Albert Schliesser — Niels Bohr Institute, Copenhagen, Denmark

We combine an engineered phononic density of states with stress-induced mechanical dissipation dilution to obtain nanomechanical membrane resonators with Qf-products exceeding $k_B T/h$ already at room temperature. At moderate (^{4}He) cryogenic temperatures, these devices feature quantum cooperativities well above unity when combined with a compact Fabry-Perot resonator, enabling the observation of quantum backaction, optomechanical light squeezing and preparation of the quantum ground state with high probability ($\bar{n} \lesssim 1$). In addition, the intrinsic multi-mode nature of the Fabry-Perot cavity, and the relatively open access to the membrane lend itself to multimode entanglement and quantum coherent conversion schemes both in the optical-optical and electro-optical domains.

Q 49.8 Thu 12:45 f342

Optimizing electro-optomechanical transduction using equivalent circuits — •Emil Zeuthen[1], Albert Schliesser[1], Jacob M. Taylor[2], and Anders S. Sørensen[1] — [1]Niels Bohr Institute, University of Copenhagen, DK-2100 Copenhagen, Denmark — [2]Joint Quantum Institute & Joint Center for Quantum Information and Computer Science, National Institute of Standards and Technology and the University of Maryland, College Park, Maryland 20742 USA

A mechanical oscillator can serve as an efficient link between electromagnetic modes of different frequencies. We find that such a transducer can be characterized by two key parameters, the signal transfer efficiency and added noise temperature. In terms of these, we evaluate its performance in various tasks ranging from classical signal detection to quantum state conversion between, e.g., superconducting circuitry and traveling optical signals. Having established the requirements for efficient performance, we turn to the question of optimization. We address this by developing a unifying equivalent-circuit formalism for electro-optomechanical transducers. This approach accommodates arbitrary linear circuits and integrates the novel optomechanical transduction functionality into the well-established framework of electrical engineering, thereby facilitating its implementation in potential applications such as nuclear magnetic resonance imaging and radio astronomy. We consider such optomechanical sensing of weak electrical signals and discuss how the equivalent circuit formalism can be used to optimize the electrical circuit design. We also discuss the parameter requirements for transducing microwave photons in the quantum regime.