Q 33: Micromechanical oscillators

Time: Thursday 10:30–12:30 Location: DO24 1.101

Q 33.1 Thu 10:30 DO24 1.101

Diamond High-Q Mechanical Resonators Integrated In On-Chip Mach-Zehnder-Interferometers — •Patrik Rath[1], Sandeep Ummethala[1], Georgia Lewes-Malandrakis[2], Dietmar Brink[2], Christoph Nebel[2], and Wolfram Pernice[1] — [1]Institute of Nanotechnology, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany — [2]Fraunhofer Institute for Applied Solid State Physics, Tullastr. 72, 79108 Freiburg, Germany

Optical circuits made from diamond-on-insulator (DOI) thin films are used to fabricate integrated Mach-Zehnder-Interferometers (MZIs) [1]. Via chemomechanical polishing the surface roughness of the polycrystalline diamond films is reduced below 3 nm, allowing for high resolution e-beam lithography. Using the DOI platform hundreds of devices can be fabricated on one chip allowing to sweep several geometric parameters [2]. The high sensitivity of the MZIs in the fm/(Hzˆ1/2) range allows detecting the thermomechanical motion of evanescently coupled mechanical resonators. A fourfold clamped geometry was optimized and shows high mechanical Q factors up to 28.800 for mechanical resonators in the MHz regime.

[1] P. Rath, S. Khasminskaya, C. Nebel, C. Wild, W.H.P. Pernice, Diamond-integrated optomechanical circuits, Nature Communications. 4 (2013) 1690. [2] P. Rath, N. Gruhler, S. Khasminskaya, C. Nebel, C. Wild, W.H.P. Pernice, Waferscale nanophotonic circuits made from diamond-on-insulator substrates, Optics Express. 21 (2013) 11031.

Q 33.2 Thu 10:45 DO24 1.101

Immersing carbon nanotubes in cold atomic gases — •Polina Mironova[1], Carsten Th. Weiss[2,3], and Reinhold Walser[1] — [1]Technische Universität Darmstadt, Darmstadt, Deutschland — [2]Universität Ulm, Ulm, Deutschland — [3]Eberhard-Karls-Universität Tübingen, Tübingen, Deutschland

We investigate the sympathetic relaxation of a free-standing, vibrating carbon nanotube that is mounted on an atom-chip and is immersed in a cloud of ultra-cold atoms. Gas atoms colliding with the nanotube excite phonons via a Casimir-Polder potential. We use Fermi's Golden Rule to estimate the relaxation rate for the relevant experimental parameters. Based on currently available experimental data, we identify the relaxation rates as a function of atom density and temperature that are required for sympathetic ground state cooling of carbon nanotubes.

Q 33.3 Thu 11:00 DO24 1.101

Interfacing Optomechanics with Rydberg Atoms — •Adrian Sanz Mora, Alexander Eisfeld, Sebastian Wüster, and Jan-Michael Rost — Max Planck Institute for the Physics of Complex Systems, Dresden

We investigate the mutual coupling of a three-level ultracold gas and a micro mechanical oscillator via electromagnetic radiation. The atoms interact with the probe- and control beams that electromagnetically induce transparency (EIT) [1] in the gas.

Both of these couple to the mechanical motion of a vibrating mirror via radiation pressure forces. The power of the probe light field is modulated by the absorption of the atoms, providing coupling of the gas to the mirror.

The control light field is phase-modulated by mirror vibrations, providing coupling of the mirror to the gas. For classical light fields and simplified response of the gas, we explore damping or driving of the mirror. By assuming that the third level is a Rydberg state, our setup can interface optomechanics [2] with Rydberg physics.

[1] M. Fleischhauer, A. Imamoglu, and J. P. Marangos, Rev. Mod. Phys. 10, 633 (2005).

[2] T.J. Kippenberg and K.J. Vahala, Optics Express, 15, 17172 (2007).

Q 33.4 Thu 11:15 DO24 1.101

Hybrid optomechanics with ultracold atoms and a micromechanical membrane — •Tobias Kampschulte, Aline Faber, Andreas Jöckel, Maria Korppi, Thomas Lauber, Matthew T. Rakher, and Philipp Treutlein — Universität Basel, Departement Physik, CH-4056 Basel

We have used laser-cooled atoms to sympathetically cool the vibrations of a micromechanical membrane from room-temperature to 2 Kelvin, thereby demonstrating significant coupling between a macroscopic solid-state system and a well-controllable microscopic quantum system. Such a hybrid optomechanical system offers exciting prospects of quantum control of mechanical oscillators via ultracold atoms.

In our experiment, a Si_3N_4 membrane oscillator is mounted inside an optical cavity. A laser beam couples to the cavity and, at the same time, creates an optical lattice for the atoms outside the cavity. Vibrations of the membrane shift the phase of the reflected light and thereby displace the lattice potential for the atoms. Conversely, when the atoms oscillate in the lattice they imprint their motion onto the light and thereby modulate the radiation pressure force acting on the membrane. Compared to our previous results [1], the cavity increases the sympathetic cooling rate by about 10^4. With cryogenic pre-cooling and suppression of laser noise, sympathetic cooling of the membrane to the quantum ground state is feasible [2].

[1] S. Camerer et al., Phys. Rev. Lett. **107**, 223001 (2011)

[2] B. Vogell et al., Phys. Rev. A **87**, 023816 (2013)

Q 33.5 Thu 11:30 DO24 1.101

Mechanical state control and tomography using pulsed optomechanics — •Ralf Riedinger[1], Michael Vanner[1], Joachim Hofer[1], Sungkun Hong[1], Alex Krause[2], Garrett D. Cole[1], Oskar Painter[2,3], and Markus Aspelmeyer[1] — [1]Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, A-1090 Vienna, Austria — [2]Thomas J. Watson, Sr., Laboratory of Applied Physics, California Institute of Technology (Caltech), Pasadena, CA 91125, USA — [3]Max Planck Institute for the Science of Light (MPL),D-91058 Erlangen, Germany

Quantum-non-demolition measurements have become an indispensable tool in quantum science for preparing, manipulating, and detecting quantum states of light, atoms, and other quantum systems. Here we demonstrate first steps into this regime for massive, mechanical oscillators that interact with laser light. Specifically, we exploit ultrashort optical pulses, i.e. of duration much shorter than a period of mechanical motion, to realize a quantum non-demolition interaction for the position readout of a mechanical oscillator. We demonstrate both state preparation via 'cooling-by-measurement' and full state tomography of the mechanical motional state. The obtained position uncertainty is limited only by the quantum fluctuations of the optical pulse. We discuss future improvements to this technique, including a route towards quantum squeezing of mechanical motion even from room temperature.

Q 33.6 Thu 11:45 DO24 1.101

Laser Theory for Optomechanics: Limit Cycles in the Quantum Regime — •Niels Lörch[1,2], Jiang Qian[3], Aashish Clerk[4], Florian Marquardt[5,6], and Klemens Hammerer[1,2] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover and Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), 30167 Hannover, Germany — [2]Institut für Theoretische Physik, Leibniz Universität Hannover, 30167 Hannover, Germany — [3]Arnold Sommerfeld Center for Theoretical Physics, Center for NanoScience and Department of Physics, Ludwig-Maximilians-Universität München, 80333 München, Germany — [4]Department of Physics, McGill University, Montreal, Quebec, Canada H3A 2T8 — [5]Friedrich-Alexander-Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany — [6]Max Planck Institute for the Science of Light, D-91058 Erlangen, Germany

Optomechanical systems can exhibit self-sustained limit cycles where the quantum state of the mechanical resonator possesses nonclassical characteristics such as a strongly negative Wigner density, as was shown recently in a numerical study [Qian et al., Physical Review Letters, **109**, 253601 (2012)]. We use laser theory to derive a Fokker-Planck equation describing mechanical limit cycles in the quantum regime which correctly reproduces the numerically observed nonclassical features. As one main conclusion, we predict negative Wigner functions to be observable even for surprisingly classical parameters, i.e. outside the single-photon strong coupling regime, for strong cavity drive, and rather large limit cycle amplitudes.

Q 33.7 Thu 12:00 DO24 1.101

Thermal nonlinearities in a nanomechanical oscillator — •Jan Gieseler[1], Lukas Novotny[2], and Romain Quidant[1,3] — [1]ICFO-

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Nano- and micromechanical oscillators with high quality (Q) factors have gained much attention for their potential application as ultrasensitive detectors. In contrast to micro-fabricated devices, optically trapped nanoparticles in vacuum do not suffer from clamping losses, hence leading to much larger *Q*-factors. We find that for a levitated nanoparticle the thermal energy suffices to drive the motion of the nanoparticle into the nonlinear regime. First, we experimentally measure and fully characterize the frequency fluctuations originating from thermal motion and nonlinearities. Second, we demonstrate that feedback cooling can be used to mitigate these fluctuations. The high level of control allows us to fully exploit the force sensing capabilities of the nanoresonator. Our approach offers a force sensitivity of $20\,\mathrm{zN\,Hz^{-1/2}}$, which is the highest value reported to date at room temperature, sufficient to sense ultra-weak interactions, such as non-Newtonian gravity-like forces.

Q 33.8 Thu 12:15 DO24 1.101

Cavity cooling of an optically levitated submicron particle

— •Florian Blaser, Nikolai Kiesel, Uros Delic, David Grass, Rainer Kaltenbaek, and Markus Aspelmeyer — Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Vienna, Austria

The coupling of a levitated dielectric particle to an optical cavity field promises access to a unique parameter regime both for macroscopic quantum experiments [1] and for high-sensitivity force detection [2]. We present the experimental demonstration of such interactions by cavity cooling the center-of-mass motion of an optically trapped sub micron particle with a mass of 10^{10} amu [3]. A detailed experimental analysis of this new system reveals interesting features not present in other optomechanical systems, such as the ability to control the mechanical frequency in situ or a non-trivial dependence of the optomechanical coupling on the cooling power.

Our results pave the way for a new light-matter interface enabling room-temperature quantum experiments [4]. We discuss the next steps in this direction, in particular the implementation of ultra-high quality mechanical resonators and ground state cooling of the sub-micron particle motion.

[1] Romero-Isart et al., NJP 12, 33015 (2010), Chang et al. PNAS 107, 0912969107, (2009), Barker et al., PRA 81, 023826 (2010). [2] Geraci et al, PRL, 105, 101101 (2010) [3] Kiesel et al. PNAS 110, 35, 14180-14185 (2013) [4] Romero-Isart et al., PRL, 107, 020405 (2011), Kaltenbaek, et al., MAQRO, Exp. Astro., 1-42 (2012)