HL 41: Focus Session: Nanomechanical Systems for Classical and Quantum Sensing III (joint session HL/DY/TT/QI)

Nanomechanical and cavity-optomechanical systems have been recently established as a controllable and configurable platform that can be engineered to tackle outstanding sensing challenges both in the classical and in the quantum regime. With this focus session, experts from different but synergetically overlapping fields of nanomechanical sensing pursuing classical, non-linear and quantum approaches are brought together. The session shall provide an overview over the recent exciting developments of the techniques explored in micro- and nanomechanical systems and sensing concepts exploring quantum measurement schemes.

Organized by Eva Weig, Hubert Krenner, and Hans Hübl.

Time: Thursday 9:30–13:00 Location: EW 202

Invited Talk HL 41.1 Thu 9:30 EW 202

Quantum sensors and memories based on soft-clamped phononic membrane resonators — •Albert Schliesser — Niels Bohr Institute, Copenhagen University, Denmark

Soft-clamping of membrane resonators using a phononic pattern enables Q-factors above 1 billion and coherence times exceeding 100 ms at low temperature. We monitor the motion of such membranes with optical interferometry. This allows us to measure force and displacement at and beyond the standard quantum limit, and control the motional quantum state, even at room temperature. This platform lends itself for sensing applications; as an example, we image individual viruses and nanoparticles using the membrane as a force sensor. In a different set of experiments, we demonstrate mechanical storage and subsequent retrieval of optical pulses with an efficiency of 40%, suggesting applications as quantum memory for light.

Invited Talk HL 41.2 Thu 10:00 EW 202

Quantum mechanics-free subsystem with mechanical oscillators — •Laure Mercier de Lepinay[1], Caspar Ockeloen-Korppi[1], Matthew Woolley[2], and Mika Sillanpää[1] — [1]Department of Applied Physics, Aalto University, P.O. Box 15100, FI-00076 Aalto, Finland — [2]School of Engineering and Information Technology, UNSW Canberra, ACT, 2600, Australia

Quantum mechanics sets a limit on the precision of the continuous measurement of an oscillator's position. However, with an adequate coupling configuration of two oscillators, it is possible to build an oscillator-like subsystem of quadratures isolated from quantum and classical backaction which therefore does not suffer from this limit. We realize such a quantum mechanics-free subsystem using two micromechanical drumheads coupled to microwave cavities. Multitone phase-stable microwave pumping of the system allows to implement the necessary effective coupling configuration. We first demonstrate the measurement of two collective quadratures, evading backaction simultaneously on both of them, obtaining a total noise within a factor of 2 of the full quantum limit. Secondly, this measurement technique is directly adapted to the detection of continuous variable entanglement which is based, according to the Duan criterion, on variance estimates of two collective quadratures. We therefore verify the stabilized quantum entanglement of the two oscillators deeper than had been possible before for macroscopic mechanical oscillators.

Invited Talk HL 41.3 Thu 10:30 EW 202

Electrothermally tunable metal-graphene-siliconnitride membrane mechanical device — •Elke Scheer, Mengqi Fu, and Fan Yang — Department of Physics, University of Konstanz, 78457 Konstanz

Controlling the properties of mechanical devices over a wide range is important for applications as well as for fundamental research. In this work, we demonstrate an on-chip tunable device composed of a suspended siliconnitride (SiN) membrane with a graphene (G) layer on top which is connected to Au electrodes. Taking advantage of the electrical and thermal conductance properties of G and the difference in the thermal expansion coefficients of SiN and Au, we developed a device in which the G-Au interface serves as local heater by injecting a dc current. The force induced by the thermal expansion difference tunes the residual stress in the SiN membrane and deflects the membrane when the loading power overcomes the threshold to the buckling transition. With this device we realize an extreme large eigenfrequency tuning (more than 50 %) of the vibration mode. By injecting an ac voltage instead, and thus applying a periodic force to the membrane, we achieve strong excitation of the membrane resonator into the nonlinear vibration. This device may act as proof-of-principle for a compact on-chip excitation scheme for multidimensional and composite nanomechanical resonators.

15 min. break

Invited Talk HL 41.4 Thu 11:15 EW 202

From Nanomechanics to Spins — •Christian Degen — ETH Zurich, Switzerland

Nanomechanical resonators are exquisite sensors for weak magnetic forces, with exciting prospects in nanoscale detection and imaging of nuclear and electronic spins. In this talk, I will give an overview of our laboratory's activities in this field, including force detection with optomechanical membranes and strings, and nuclear spin imaging with the technique of magnetic resonance force microscopy.

Invited Talk HL 41.5 Thu 11:45 EW 202

Enhanced cooling efficiency in nonlinear cavity optomechanics — •Anja Metelmann[1], Nicolas Diaz-Naufal[2], David Zoepfl[3], Lukas Deeg[3], Christian Schneider[3], Mathieu Juan[4], and Gerhard Kirchmaier[3] — [1]Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Free University Berlin, Berlin, Germany — [3]University of Innsbruck, Innsbruck, Austria — [4]Universite de Sherbrooke, Sherbrooke, Canada

Unlocking the quantum potential of mechanical resonators hinges on achieving ground state cooling, a key milestone for quantum information processing and ultra-precise quantum measurements. In the vibrant field of cavity optomechanics, dynamical backaction cooling and feedback protocols have successfully nudged macroscopic mechanical elements toward the quantum ground state. While linear regime cooling is well-explored, recent theoretical insights suggest that a nonlinear cavity could amplify cooling efficiency. We explore this intriguing nonlinear regime, focusing on the cooling dynamics of a mechanical resonator coupled to a nonlinear cavity, embodying the characteristics of a high-Q Duffing oscillator. In this talk we present a comparative analysis between theoretical predictions and experimental results from a magnetomechanical platform. The findings unveil a captivating enhancement in cooling efficiency attributed to the Duffing nonlinearity. This breakthrough not only enriches our understanding of optomechanical interactions but also holds promise for advancing cooling strategies in quantum technologies.

HL 41.6 Thu 12:15 EW 202

Brillouin scattering selection rules in elliptical optophononic resonators — •Anne Rodriguez[1,2], Priya Priya[1], Edson Cardozo de Oliveira[1], Abdelmounaim Harouri[1], Isabelle Sagnes[1], Florian Pastier[3], Martina Morassi[1], Aristide Lemaître[1], Loic Lanco[1], Martin Esmann[1], and Daniel Lanzillotti-Kimura[1,4] — [1]Centre de Nanosciences et de Nanotechnologies, Université Paris-Saclay, CNRS, Palaiseau, France — [2]present address: Chair for Nano and Quantum Sensors, Technische Universität München, Garching, Germany — [3]Quandela SAS, Palaiseau, France — [4]Institut für Physik, Universität Oldenburg, Germany

The selection rules of spontaneous Brillouin scattering in bulk crystalline solids are intrinsic material properties that formally constrain the energy, direction and polarization of the scattered photons for a given input state. In this work, we manipulate the polarization states of the input laser and Brillouin signal independently using polarization-sensitive optical micropillar cavities. The ellipticity of the micropillars lifts the degeneracy of the optical cavity modes, and induces a wavelength-dependent rotation of polarization [1,2], altering the Brillouin scattering selection rules. We developed a Brillouin spectroscopy scheme based on polarization filtering, allowing to measure acoustic phonon resonances with frequencies in the range of 20-100 GHz [3], with background-free spontaneous Brillouin scattering spectra.

[1] H. Wang et al., Nat. Phot. 13, 770 (2019). [2] B. Gayral et al., APL 72, 1421 (1998). [3] A. Rodriguez et al., ACS Photonics 10, 1687 (2023).

HL 41.7 Thu 12:30 EW 202

3D Microwave Cavity-Assisted Detection of High-Q Silicon Nitride Nanomechanical String Resonators — •Run Fa Jonny Qiu, Anh Tuan Le, Avishek Chowdhury, and Eva Weig — Technical University of Munich, Chair of Nano- and Quantum Sensors, Hans-Piloty Str. 1, 87548 Munich, Germany

Amorphous, low-pressure chemical vapor deposition (LPCVD)-grown silicon nitride (Si3N4) is a highly pre-stressed material due to its thermal-coefficient mismatch and is exploited in our fabrication of doubly-clamped freely suspended nanomechanical string resonators with superjacent electrodes for dielectric drive and detection. High-quality factor (Q-factor) nanomechanical string resonators with a Q-factor of roughly 300000 were fabricated. Two large gold-coated antennas connected to the electrodes are deposited on-chip which permits for a direct coupling of the mechanical displacement-induced change of the capacitance between the electrodes to the electric field of the three-dimensional (3D) rectangular cavity. Research on the quarter-wave coaxial cavity together with a capacitive loop and disk coupling revealed the possibility of both coupling schemes for the detection of mechanical modes. Applying direct current (DC) voltage to the electrodes allows for a frequency tuning of the mechanical flexural modes in the opposite direction, which due to the inherent coupling of the two in-plane (ip) and out-of-plane (oop) modes leads to an avoided crossing.

HL 41.8 Thu 12:45 EW 202

Optomechanical acceleration beats in confined polariton condensates — Alexander Kuznetsov, Klaus Biermann, and •Paulo Ventura Santos — Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e. V., Hausvogteiplatz 5-7, 10117 Berlin, Germany

High-frequency optomechanics involving optoelectronic systems with long temporal coherences enable access to the regime of non-adiabatic modulation, where the optomechanical modulation quantum $\hbar\Omega_M$ exceeds the typical energy decoherence rate of the optoelectronic resonances. Characteristic for this regime is the appearance of modulation sidebands around the optoelectronic resonance line displaced by energy multiples $m\Omega_M$,$(m = 0, \pm1, \dots)$ with amplitude and number determined by the energy modulation amplitude ΔE_M. Here, we experimentally demonstrate a novel regime of temporal coherence invoked by the harmonic modulation of an optomechanical resonance at extreme energy modulation amplitudes $\Delta E_M/(\hbar\Omega_M) > 150$. We show that the resonance energy of a confined exciton-polariton Bose-Einstein condensate harmonically driven at these high relative modulation amplitudes exhibit temporal correlations with timescales much shorter than the modulation period [Kuznetsov et al., DOI:10.21203/rs.3.rs-3197243/v1]. These correlations manifest themselves as comb of spectral resonances with energy scale determined by the ratio $\Delta E_M/(\hbar\Omega_M)$. We show that they arise from accelerated rates of energy change during the harmonic cycle and are, thus, termed the acceleration beats.