DY 27: Focus Session: Nanomechanical Systems for Classical and Quantum Sensing II (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: Wednesday 15:00–17:45 Location: EW 202

DY 27.1 Wed 15:00 EW 202

Quantum backaction evasion in cavity magnomechanics — •Victor Augusto Sant Anna V Bittencourt[1], Clinton A. Potts[2], John P. Davis[3], and Anja Metelmann[1,4,5] — [1]ISIS (UMR 7006), Universite de Strasbourg, 67000 Strasbourg, France — [2]Kavli Institute of NanoScience, Delft University of Technology, PO Box 5046, 2600 GA Delft, Netherlands — [3]Department of Physics, University of Alberta, Edmonton, Alberta T6G 2E9, Canada — [4]Institute for Theory of Condensed Matter, Karlsruhe Institute of Technology, 76131, Karlsruhe, Germany — [5]Institute for Quantum Materials and Technology, Karlsruhe Institute of Technology, 76344, Eggenstein-Leopoldshafen, Germany

Magnetic excitations (magnons) hosted in a solid can couple to mechanical vibrations of the material (phonons) via a radiation-pressure like interaction due to magneto-elastic effects. When the magnet is loaded on a microwave cavity, phonons can be driven and measured via the microwave while having the tunability of the magnetic excitations. Nevertheless, the noise added to mechanics can hinders both potential applications of the system at the quantum level and measurements of the phonon mode. Here, we propose a scheme to evade quantum backaction on a phonon mode of a cavity magnomechanical system by using a two-tone microwave drive. We study the robustness of the different possible backaction evading schemes, and show that measurements of the phonon mode can be performed with added noise below the standard quantum limit.

DY 27.2 Wed 15:15 EW 202

Optical detection of guided GHz acoustic phonons in a semiconductor hybrid microcavity — •Mingyun Yuan[1], Antonio Crespo-Poveda[1], Alexander S. Kuznetsov[1], Klaus Biermann[1], Alexander Poshakinskiy[2], and Paulo V. Santos[1] — [1]Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., Hausvogteiplatz 5, 10117 Berlin, Germany — [2]ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels, Spain

The interaction between acoustic phonons and optical quasiparticles has profound implication in both understanding of light-matter interaction and acousto-optical applications. We report on the optical detection of phonon echos resulting from the interaction between acoustic phonons and exciton polaritons in a hybrid (Al,Ga)As microcavity grown by molecular beam epitaxy. The microcavity spacer embedding multiple quantum wells is surrounded by Bragg mirrors designed to enable polariton formation. Simultaneously, the spacer-quantum wells and the Bragg reflectors act as the core and cladding regions, respectively, of an acoustic waveguide sustaining GHz acoustic phonons propagating along [110], excited by side bulk-acoustic-wave transducers. The acoustic modulation gives rise to an optical comb in the polariton photoluminescence, in which both the guided phonon modes and the substrate phonon modes are identified via Fourier transform. Our results demonstrate the robust generation of guided acoustic phonons above 6 GHz as well as their effective coupling to the polaritons, and showcase the sensitive optical detection of acoustic modes.

DY 27.3 Wed 15:30 EW 202

Topological phononic waveguides with ultralow loss — •Ilia Chernobrovkin[1], Xiang Xi[1], Jan Kosâta[2], Oded Zilberberg[3], Anders Sørensen[1], and Albert Schliesser[1] — [1]Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, 2100 Copenhagen, Denmark — [2]Institute for Theoretical Physics, ETH Zürich, 8093 Zürich, Switzerland — [3]Department of Physics, University of Konstanz, 78464 Konstanz, Germany

Topological insulators have long intrigued researchers in terms of fundamental physical properties as well as potential applications. The advantages of topological insulators have been extended to the realm of bosonic defects or waveguiding systems and overturned some of conventional views of photonic or phononic wave manipulation. However, the existing topological phononic waveguides still have large transportation loss, which limits its applications.

In our work, we combine the so-called soft-clamping technique - which can dramatically suppress mechanical losses - with non-trivial topology, designed to enable valley-locked propagation along a topological edge. Our systems are based on sub-100 nm thin, highly stressed membrane made of silicon nitride membranes. Our preliminary experimental results show a measured Q-factor above 1 million for whispering-galley megahertz-frequency elastic modes along a closed triangular path of length of ~10 mm, which corresponds to a classical coherent length of tens of meters. Our system can be considered promising for use in phononic circuits for coherent microwave signal processing or interconnection.

DY 27.4 Wed 15:45 EW 202

Dry processing of high Q 3C-silicon carbide nanostring resonators — •Felix David, Philipp Bredol, and Eva Weig — Technical University of Munich - Chair of Nano and Quantum Sensors, Garching, Germany

We fabricate string resonators from strongly stressed 3C-silicon carbide (SiC) grown on a silicon substrate. The conventional fabrication process involves electron-beam lithography with PMMA to define a metallic hard mask for the subsequent dry-etching step via a liftoff process. This requires some wet-chemical process steps, which can destroy our samples. Here we describe an alternative process, which avoids all wet-chemical process steps to enable superior quality. It involves the use of a negative electron-beam resist as an etch mask, as well as the completely reactive-ion etching-based release of the nanostrings. The dry-processed nanostrings can be fabricated with a high yield and exhibit high mechanical quality factors at room temperature. Due to the high reliability combined with the high process speed, it also allows us to investigate material-intensive questions, such as the influence of etching depth and undercut on the mechanical quality factor.

DY 27.5 Wed 16:00 EW 202

Spatial Mode Mapping of 2D Mechanical Resonators — •Lukas Schleicher, Leonard Geilen, Alexander Holleitner, and Eva Weig — TU München, Garching, Deutschland

We present studies on the spatial mapping of mechanical modes of 2D resonators based on monolayer transition-metal dichalcogenides. A spatially resolved mode mapping allows us to investigate non-isotropic pre-strain and other transfer-related artefacts, such as cracks and surface contaminations, which may result from the fabrication process. We compare the mechanical properties of drums with various sizes and fabrication methods of the 2D resonators.

15 min. break

DY 27.6 Wed 16:30 EW 202

Electrochemical etching strategy for shaping monolithic 3D structures from 4H SiC wafers — •André Hochreiter, Fabian Gross, Morris Niklas Möller, Michael Krieger, and Heiko Weber — Lehrstuhl für Angewandte Physik Universität Erlangen-Nürnberg, Germany

Silicon Carbide's (SiC) as wide bandgap semiconductor has outstanding material properties, which enable applications like already available commercial power-electric devices, and applications in quantum sensing. For mechanical applications of SiC, extremely high quality factors are predicted, but on-chip 3D shaping of SiC is difficult due to its chemical robustness. We report on an electrochemical etching (ECE) strategy, which solely relies on a doping contrast introduced by targeted ion-implantation of p-dopants on n-type material. With such a dopant-selective etching, n-doped regions remain inert and p-type regions are removed. We present devices as diverse as monolithic cantilevers, membranes and disk-shaped optical resonators etched out a single crystal wafer. The electrochemically etching process leaves the etched surface with low roughness, which can even be improved by annealing.

DY 27.7 Wed 16:45 EW 202

Probing the Mechanical Loss of Individual Surfaces of a Nanomechanical String Resonator — •Philipp Bredol, Felix David, and Eva Weig — Technical University of Munich, Chair of Nano and Quantum Sensors, 85748 Munich, Germany

Stressed nanostring resonators are a promising platform for sensing applications and quantum technologies because of their small footprint and high mechanical quality factors. In this contribution we show that the dissipation caused by sidewall surfaces and the dissipation caused by bottom and top surfaces can be individually determined from the mechanical response spectrum. This information helps to evaluate and adjust fabrication parameters such as etchant chemistry, etch mask materials and possible annealing steps. Being able to characterize the mechanical loss mechanisms that limit a given device is important for integration with other structures and to further push the performance of nanostring resonators.

DY 27.8 Wed 17:00 EW 202

Parametric normal mode splitting for coupling strength estimation — •Ahmed A. Barakat, Avishek Chowdhury, Anh Tuan Le, and Eva M. Weig — Technical University of Munich, Munich, Germany

The experimental estimation of the linear coupling strength between two nanomechanical modes is a challenging task. For dielectrically actuated nano-string resonators, the coupling strength between in-plane and out-of-plane modes is usually estimated by tuning the modal eigenfrequencies using a bias voltage up to the occurrence of the avoided crossing. In this contribution, we introduce a novel approach using parametric excitation to estimate the linear coupling strength at any bias voltage.

In addition to a broadband noise excitation, the proposed approach involves parametrically driving in the direction of at least one of the eigenmodes with a frequency that resonates with the difference between both eigenfrequencies causing a parametric normal mode splitting. Using the dependence of the splitting width on the coupling strength, a mathematical model is introduced and perturbed around the parametric excitation frequency using the multiple scales method. The locus of the splitting is derived analytically and agrees well with the experimental results, leading to an accurate estimation of the coupling strength.

DY 27.9 Wed 17:15 EW 202

Tunable near-infrared exciton-polariton optomechanical GHz rulers of light — •Alexander Kuznetsov, Klaus Biermann, and Paulo V. Santos — Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., Hausvogteiplatz 5-7, 10117 Berlin, Germany

Frequency combs, which consist of many equidistant optical lines, are photonic analogues of spatial rulers. Such rulers of light can be used for high-resolution spectroscopy, ranging, optical and atomic clocks, and for large-scale quantum systems. On-chip miniaturized and low-power comb-sources are, therefore, of great importance. Here, we demonstrate generation of tunable combs using spatially confined light-matter quasiparticles – exciton-polaritons – coherently modulated by GHz phonons inside a hybrid photon-phonon (Al,Ga)As patterned microcavity. Using non-resonant optical excitation, we create polariton Bose-Einstein-like condensates (BEC) with long temporal coherence reaching $\tau_{BEC} \approx 2$ ns. The BEC is modulated by piezoelectrically generated strain of bulk acoustic wave (BAW) phonons with frequency $f_{BAW} = 7$ GHz and RF-tunable amplitude. Since $\tau_{BEC} \gg 1/f_{BAW}$, the modulation is coherent and leads to the emergence of well-resolved phonon sidebands, separated by f_{BAW}, in the polariton emission spectrum. For large BAW amplitudes, the comb contains up to 50 well-resolved lines with nearly-flat profile. The demonstrated RF-induced comb functionality may be useful for the realization of on-chip arrays of tunable GHz optical combs as well as coherent optical-to-microwave bi-directional conversion.

DY 27.10 Wed 17:30 EW 202

Imaging acoustic fields on metasurfaces — •Alessandro Pitanti[1,2,3], Mingyun Yuan[1], Simone Zanotto[3], and Paulo Ventura Santos[1] — [1]Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., 5-7 Hausvogteiplatz, Berlin 10117, Germany — [2]Dipartimento di Fisica E. Fermi, Università di Pisa, Largo B. Pontecorvo 3, Pisa 56127, Italy — [3]NEST, CNR Istituto Nanoscienze and Scuola Normale Superiore, piazza San Silvestro 12, Pisa 56127, Italy

The last decades have witnessed a rich activity towards the integration of acoustic technologies within electro-optical circuits in high-frequency hybrid devices. The main role in this trend has been played by surface acoustic waves (SAW), easily integrable in several material platforms via piezoelectricity. Given their high frequency and quality factors, simple SAW delay-line resonators have found application as sensors, filters, and oscillators for telecommunication applications. More complex manipulation of acoustic waves would boost SAW-based technologies, becoming a key for the transition to 6G; complete wave manipulation and control in the GHz range would offer the most promise for integration with modern communication technologies.

In this context, we illustrate the use of light-interferometry and atomic force microscopy based scanning probe techniques for a fine investigation of GHz acoustic fields in mechanical metasurfaces. Focusing on the role of symmetries in wave scattering, we show complex wave manipulation, leading to asymmetric negative refraction and anisotropic transmission of mechanical waves.