HL 10: Focus Session: Progress in Hybrid Phononic Quantum Technologies II

Time: Monday 15:00–18:30 Location: POT 151

Invited Talk HL 10.1 Mon 15:00 POT 151
Surface Acoustic Wave Cavity Optomechanics with 2D Materials — •Galan Moody — University of California, Santa Barbara, CA, USA

Surface acoustic waves (SAWs) are a versatile tool for coherently interfacing with a variety of solid-state quantum systems spanning microwave to optical frequencies, including superconducting qubits, spins, and quantum emitters. In this presentation, I will discuss our progress on integrating 2D material quantum emitters with planar lithium niobate SAW resonators driven by superconducting electronics. Using steady-state photoluminescence spectroscopy and time-resolved single-photon counting, we map the temporal dynamics of modulated 2D emitters under coupling to different SAW cavity modes, showing energy-level splitting consistent with strong deformation potential coupling. We leverage the large anisotropic strain from the SAW to modulate the exciton and biexciton fine-structure splitting of 2D semiconductors, which may find applications for on-demand entangled photon-pair generation from 2D materials. I will conclude with a discussion on the prospects and outlook for SAW cavity optomechanics with 2D quantum emitters for high-speed single-photon modulators, efficient transducers, compact sensors, and exploring quantum electro-optomechanics with 2D materials.

Invited Talk HL 10.2 Mon 15:30 POT 151
Phononic Microresonators Coupled by Surface Acoustic Waves — •Sarah Benchabane, Maciej Baranski, Feng Gao, Olivier Gaiffe, Valérie Soumann, Roland Salut, and Abdelkrim Khelif — FEMTO-ST, CNRS, Université Bourgogne-Franche-Comté, Besancon, France.

The implementation of scalable phononic circuits has become an appealing prospect in view of increasing the versatility of electro-acoustic devices for radio-frequency signal processing. Recent demonstrations have made convincing steps towards this objective by proposing phononic architectures inspired by photonic integrated circuits or combining the rich dynamics of micro- and nano-electromechanical (M/NEMS) resonators with propagating elastic waves. In this work, we propose to exploit the interaction between surface acoustic waves (SAW) and locally-resonant, micron-scale mechanical resonators in order to achieve coherent driving of the resonator motion with SAW and, reciprocally, to control the elastic energy distribution at a deep subwavelength scale. Optical measurements by laser scanning interferometry allows retrieving both the resonator frequency response and mode shape, hence enabling direct observation of the vectorial nature of the interaction. We investigate the proposed physical system both in the linear and non-linear regimes and reveal that the elastic field behavior can be further controlled through resonator-to-resonator coupling, leading to a variety of interaction schemes. The proposed devices illustrate the potential of SAW-based architectures for the implementation of high-frequency phononic-NEMS circuits.

HL 10.3 Mon 16:00 POT 151
On-chip generation and dynamic piezo-optomechanical rotation of single photons — •Matthias Weiss[1,2], Dominik D. Bühler[3], Antonio Crespo-Poveda[4], Emeline D. S. Nysten[1,2], Jonathan J. Finley[5], Kai Müller[5,6], Paulo V. Santos[4], Mauricio M. de Lima Jr.[3], and Hubert J. Krenner[1,2] — [1]Physikalisches Institut, WWU Münster, Germany — [2]Institut für Physik, Universität Augsburg — [3]Materials Science Institute, University of Valencia, Spain — [4]Paul-Drude Institute for Solid State Electronics, Berlin, Germany — [5]Walter Schottky Institut, TU München, Germany — [6]Department of Electrical and Computer Engineering, TU München, Germany

Integrated photonic circuits are key components for photonic quantum technologies and for the implementation of chip-based quantum devices. Future applications demand flexible architectures to overcome common limitations of many current devices, for instance the lack of tuneability or built-in quantum light sources.

Here, we report on a dynamically reconfigurable integrated photonic circuit comprising integrated quantum dots (QDs), a Mach-Zehnder interferometer (MZI) and surface acoustic wave (SAW) transducers directly fabricated on a monolithic semiconductor platform. We demonstrate on-chip single photon generation by the QD and its sub-nanosecond dynamic on-chip control, enabling dynamic single photon routing with frequencies exceeding one gigahertz.

Bühler, D.D., Weiß, M., Crespo-Poveda, A. et al. Nat Commun 13, 6998 (2022)

HL 10.4 Mon 16:15 POT 151
Towards room temperature polaromechanics — •Ismael dP. Embid, Alexander S. Kuznetsov, Klaus Biermann, and Paulo V. Santos — Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., Berlin, Germany

Microcavity exciton-polaritons have emerged as a promising platform for novel solid-state devices ranging from low threshold lasers to quantum and classical simulators. The transition to a polariton condensate at high particle densities with long (ns) temporal coherence and enhanced sensitivity to vibrations has opened the way for polariton-based optomechanics in the GHz frequency domain [1]. Such highly coherent states have, however, so far been observed only at low temperatures (10K). Here, we show that long coherences can be maintained by confining the polariton condensates within μm-sized intracavity traps in (Al,Ga)As microcavities. In particular, we demonstrate temporal coherences in the GHz range up to temperatures exceeding 77K. Furthermore, we show that these condensates can be non-adiabatically modulated at these temperatures by electrically injected GHz phonons, leading to the formation of several phonon side bands. These results enable the generation of GHz optical frequency combs tunable by the electrical power, a relevant feature for the precise control of quantum states.

1. Kuznetsov et al., arXiv:2210.14331v1

30 min. break

HL 10.5 Mon 17:00 POT 151
Readout of phonon statistics via resonance fluorescence of a single photon emitter — •Daniel Groll[1], Thilo Hahn[1], Ortwin Hess[2], Paweł Machnikowski[3], Tilmann Kuhn[1], and Daniel Wigger[2] — [1]Institute of Solid State Theory, University of Münster, Germany — [2]School of Physics, Trinity College Dublin, Ireland — [3]Department of Theoretical Physics, Wrocław University of Science and Technology, Poland

Single photon emitters in a solid state environment are inevitably coupled to phonon modes of the host material. On the one hand, decoherence induced by this coupling is often detrimental for harnessing the full potential of such emitters. On the other hand, this interaction in principle allows for control of the emitter not only optically, but also acoustically. Hybrid systems, comprised of optical, acoustic and excitonic components thus offer a high degree of flexibility by making use of all available interaction channels.

We consider here a single photon emitter located inside a phononic resonator and driven by an external laser. We derive analytical expressions for the resonance fluorescence (RF) spectrum, depending explicitly on the quantum statistics of the resonator mode. We show that, in principle, the statistics of the phonon mode can be determined from a given RF spectrum using our analytical model. We thus establish a simple and direct connection between the optical and acoustic components of such a hybrid system, paving the way for using single photon emitters as quantum transducers between the optical and acoustic domain.

HL 10.6 Mon 17:15 POT 151
Dry processing of high Q 3C-silicon carbide nanostring resonators — •Felix David, Philipp Bredol, Eva Weig, and Yannick Klass — Technical University of Munich, Chair of Nano and Quantum Sensors, 85748 Munich, Germany

We fabricate string resonators from strongly stressed 3C-silicon carbide (SiC) grown on a silicon substrate. In the conventional fabrication process, we do 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.

HL 10.7 Mon 17:30 POT 151

Acousto-optoelectric spectroscopy on transition metal dichalcogenide monolayers with surface acoustic waves — Matthias Weiss[1,2], Benjamin Mayer[1], Tobias Petzak[2], Clemens Strobl[1], •Emeline Nysten[1,2], Ursula Wurstbauer[1], and Hubert Krenner[1,2] — [1]Physikalisches Institut, WWU Münster, Germany — [2]Lehrstuhl für Experimentalphysik 1, Universität Augsburg, Germany

Surface acoustic waves have proven to be a useful tool for the control of semiconductor nanostructures optical properties and the dynamical transport of charge carriers [1,2,3]. For instance, SAW spectroscopy was already used to probe the electrical transport inside CVD-grown MoS_2 on $LiNbO_3$ in a contact-free manner [1]. In this work, we integrated transition metal dichalcogenide monolayer flakes into $LiNbO_3$ surface acoustic wave devices through a classical exfoliation process. The impact of the SAW on the photoluminescence of the monolayer was systematically studied. The results show a clear increase in the photoluminescence intensity of the monolayer as well a SAW-periodic modulation which can be linked to the SAW-controlled diffusion of the excitons inside the monolayer. [1] Nature Communications 6:8593 (2015) [2] Nano Letters 19:8701-8707 (2019) [3] IEEE Transactions on Quantum Engineering 3:1-17 (2022)

HL 10.8 Mon 17:45 POT 151

Strongly Stressed 3C-SiC Nanostring Resonators With High Quality Factors — •Philipp Bredol[1], Yannick Klass[1], Felix David[1], Eva Weig[1], Nagesh S. Japtap[2,3], Manfred Helm[2,3], Georgy Astakhov[2], and Artur Erbe[2,3] — [1]Technical University of Munich, Chair of Nano and Quantum Sensors, 85748 Munich, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany — [3]Dresden University of Technology, 01062 Dresden, Germany

Strongly stressed SiC nanostring resonators are a promising platform for sensing applications. SiC is mechanically, chemically, and thermally robust and process compatible with many Si technologies. Mechanical quality factors in the 10^5 range are achieved at room temperature with devices of $\approx 70 \times 1\,\mu m^2$ footprint.

Because the mechanical quality factor often determines sensitivity and resolution of nanomechanical sensors, the understanding of mechanical loss mechanisms is important for possible applications. In this contribution we show how to separate intrinsic material losses and dissipation dilution effects by analyzing mechanical response spectra. We apply these methods to analyze how He^+ irradiation damage affects the mechanical properties of SiC nanostring resonators (see contribution of Nagesh S. Jagtap).

HL 10.9 Mon 18:00 POT 151

Coupling single electrons and photons at photonic-chip based microresonators — •Armin Feist[1,2], Guanhao Huang[3,4], Germaine Arend[1,2], Yujia Yang[3,4], Jan-Wilke Henke[1,2], Arslan Sajid Raja[3,4], F. Jasmin Kappert[1,2], Rui Ning Wang[3,4], Hugo Lourenço-Martins[1,2], Qiu Zheru[3,4], Junqiu Liu[1,2], Ofer Kfir[3,4], Tobias J. Kippenberg[3,4], and Claus Ropers[1,2] — [1]MPI for Multidisciplinary Sciences, Göttingen, Germany — [2]4th Physical Institute, University of Göttingen, Germany — [3]Institute of Physics, Swiss Federal Institute of Technology Lausanne, Switzerland — [4]Center for Quantum Science and Engineering, Swiss Federal Institute of Technology Lausanne, Switzerland

Integrated photonics facilitates control over fundamental light-matter interactions in manifold quantum systems. Extending these capabilities to electron beams [1] fosters free-electron quantum optics.

Here, we show the coupling of single electrons and photons at a high-Q integrated photonic microresonator [2]. Spontaneous scattering at empty resonator modes creates electron-photon pair states [3], enabling single-particle heralding schemes and noise-supressed mode imaging. This provides a pathway toward novel hybrid quantum technology with entangled electrons and photons, as well as the capability for quantum-enhanced electron imaging and Fock-state photon sources.

[1] J.-W. Henke *et al.*, Nature **600**, 653 (2021).
[2] A. Feist *et al.*, Science. **377**, 777 (2022).
[3] X. Bendaña *et al.*, Nano Lett. **11**, 5099 (2011).

HL 10.10 Mon 18:15 POT 151

Brillouin scattering selection rules in polarization-sensitive photonic resonators — Anne Rodriguez[1], Priya Priya[1], Edson Cardozo[1], Abdelmounaim Harouri[1], Isabelle Sagnes[1], Florian Pastier[2], Martina Morassi[1], Aristide Lemaître[1], Loic Lanco[1], •Martin Esmann[1,3], and Daniel Lanzillotti-Kimura[1] — [1]Université Paris-Saclay, CNRS, Centre de Nanosciences et de Nanotechnologies, Palaiseau, France — [2]Quandela SAS, Palaiseau, France — [3]Institut für Physik, Universität Oldenburg, Germany

Spontaneous Brillouin scattering in bulk crystalline solids is governed by intrinsic selection rules which lock the relative polarization of excitation laser and Brillouin signal. In this work, we independently manipulate the polarization states of the two, using polarization-sensitive optical resonances in elliptical micropillars [1,2].

The induced wavelength-dependent polarization rotation [3] enables a polarization-based filtering technique [4]. We employ it to experimentally detect acoustic phonon resonances with frequencies in the range of 20-100 GHz, difficult to access with both standard Brillouin and Raman spectroscopy techniques. The strong modification of selection rules extends to any optical system with polarization-sensitive modes: plasmonic resonators, photonic crystals, birefringent micro- and nanostructures. It is thus relevant for applications in optomechanical, optoelectronic, and quantum optics devices [1,2].

[1] H. Wang et al. Nat. Phot. 13, 770 (2019). [2] S. Gerhard et al. PRB 100, 115305 (2019). [3] B. Gayral et al. APL 72, 1421 (1998). [4] A. Rodriguez et al. arXiv:2209.12659 (2022).