HL 3: Focus Session: Progress in Hybrid Phononic Quantum Technologies I

Phonons, the quanta of lattice vibrations, are the fundamental excitations in a crystal and couple to literally any type of excitation in a solid. This universal coupling makes them ideally suited for hybrid quantum architectures which synergistically harness the strengths of its components and at the same time mitigate individual shortcomings. For chip-based hybrid quantum devices, phonons are particularly attractive because they can be routed in integrated circuits with very little dissipation over macroscopic distances in the solid state or confined in small mode volume phononic cavities. Although the research of phonons has a long-lasting history, only recently important breakthroughs were made that will unleash the full potential of acoustic waves in quantum technologies. For example, the rapid progress in the development of surface acoustic wave resonators now allows to generate desired phonon quantum states which promotes the field of quantum acoustics.

Organized by Hubert J. Krenner and Daniel Wigger

Time: Monday 9:30–13:00 Location: POT 151

Invited Talk HL 3.1 Mon 9:30 POT 151

Schrödinger cat states of a 16-microgram mechanical oscillator — •Yiwen Chu[1,2], Marius Bild[1,2], Matteo Fadel[1,2], Yu Yang[1,2], Uwe von Lüpke[1,2], Phillip Martin[1,2], and Alessandro Bruno[1,2] — [1]Department of Physics, ETH Zürich — [2]Quantum Center, ETH Zürich

While the principle of superposition in quantum physics is routinely validated for microscopic systems, it is still unclear why we do not observe macroscopic objects to be in superpositions of states that can be distinguished by some classical property. I will present our experiments that harness the resonant Jaynes-Cummings interaction between a high overtone resonator mode of a bulk acoustic wave resonator and a superconducting qubit to demonstrate the preparation of Schrödinger cat states of motion. In such a state, the constituent atoms oscillate in a superposition of two opposite phases with an effective oscillating mass of 16 micrograms. Making use of the circuit quantum acoustodynamics toolbox we have developed, we furthermore show control over amplitudes and phases of the created Schrödinger cat states, and investigate their decoherence dynamics by observing the disappearance of Wigner negativities. Our results can find applications in continuous variable quantum information processing and in fundamental investigations of quantum mechanics in massive systems.

Invited Talk HL 3.2 Mon 10:00 POT 151

High-fidelity quantum information processing with spins and phonons — •Peter Rabl — Atominstitut, TU Wien, Stadionallee 2, 1020 Wien, Austria — Physik-Department, Technische Universität München, 85748 Garching, Germany — Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany

Phonons in solids are usually uncontrolled and therefore represent one of the main sources of decoherence for many solid-state quantum systems. However, when appropriately designed, isolated mechanical modes offer fascinating new opportunities for engineering coherent interactions between systems that cannot be coupled efficiently otherwise. In this talk, I will discuss the prospects of this approach for engineering phonon-mediated quantum gate operations between spin qubits associated with SiV defect centers in a diamond phononic crystal. Specifically, I will show how the application of continuous spin-echo techniques can substantially boost the coherence times in this system and suppress gate errors below 10^{-4} for experimentally realistic noise parameters. Therefore, although the field is still in its infancy, this analysis outlines a realistic path toward moderate- and large-scale quantum devices with spins and phonons, at a level of control that is comparable to other leading quantum-technology platforms.

HL 3.3 Mon 10:30 POT 151

Acoustically-induced pseudo-gauge fields and anomalous transport phenomena in graphene — •Pai Zhao[1], Lars Tiemann[1], Lev Mourokh[2], Vadim M. Kovalev[3], and Robert H. Blick[1] — [1]University of Hamburg, Germany — [2]Department of Physics, Queens College, New York, USA — [3]Novosibirsk, Russia

One of many remarkable consequences of the low-energy Dirac description of graphene is the emergence of synthetic gauge fields under lattice deformation that affect the carrier dynamics. We show that acoustically stimulated carrier transport in graphene at 4 Kelvin signals the presence of artificial gauge fields through the build-up of a transversal voltage at zero magnetic field. We fabricated a gate-tunable, large-scale CVD graphene Hall bar on a hybrid piezoelectric $LiNbO_3$ on insulator substrate. An interdigitated transducer launches a surface acoustic wave (SAW) that acoustically accelerates the carriers in the graphene. At zero magnetic field, we observe large anomalous acoustically-induced synthetic Hall voltages up to 200 μV, depending on the carrier type, concentration and SAW power. The synthetic Hall voltage can modulate a conventional Hall voltage arising in a large external magnetic field [1]. Our observation is consistent with studies of strain-induced pseudo-gauge fields [2-4].

[1] P. Zhao et al., Phys. Rev. Lett. 128, 256601 (2022); [2] N. Levy et al., Science 329, 544 (2010); [3] F. Guinea, M. I. Katsnelson and A. K. Geim, Nat. Phys. 6, 30 (2010); [4] M. Oliva-Leyva and G. G. Naumis, J. Phys.: Condens. Matter 28, 025301 (2015).

HL 3.4 Mon 10:45 POT 151

On-chip waveguides for hypersound with planar semiconductor optical microcavities — Antonio Crespo-Poveda, •Alexander Kuznetsov, Alberto Hernández-Mínguez, Abbes Tahraoui, Klaus Biermann, and Paulo Santos — Paul Drude Institute for Solid State Electronics, Berlin, Germany

In solid-state systems, coherent oscillations of the atomic lattice (phonons) couple to the majority of elementary excitations. This motivates studies that aim at creating phonon-based interfaces between photons and quantum systems. In this work, we show piezoelectric excitation of 6 GHz hypersound in a buried (Al,Ga)As planar waveguide. Acoustic echo spectroscopy reveals that phonons propagate over mm-long distances. Furthermore, the waveguide contains quantum wells and is embedded into an optical microcavity. The strong-coupling between nIR photons and excitons leads to the formation of light-matter quasiparticles – polaritons. Due to the excitonic component, polaritons act as a sensitive local optical probe for gAPs. Thus, we demonstrated a conversion of microwave signals to guided hypersound with the subsequent polariton-mediated transduction to photons. In a broad context, the results are important for the remote coherent control of optoelectronic resonances and the realization of the on-chip phonon circuitry and a microwave-to-optical interface.

30 min. break

Invited Talk HL 3.5 Mon 11:30 POT 151

Control of spin centers in silicon carbide using acoustic fields — •Alberto Hernández-Mínguez — Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., Berlin, Germany

Atom-like color centers in solids are attractive for applications in quantum technologies because their spin states exhibit long coherence times and can be controlled by optical, microwave and acoustic fields. In this contribution, we report on acoustically driven spin transitions in silicon vacancy centers in SiC. Specifically, we use the dynamic strain of surface acoustic waves to selectively excite room-temperature spin transitions with magnetic quantum number differences of ±1 and ±2 in the absence of external microwave fields [1]. Compared to the ground states, spin levels in the optically accessible excited states possess even stronger interaction with acoustic vibrations, thus giving rise to novel and, so far, largely unexploited physical phenomena. A remarkable example is the acoustically induced coherent spin trapping [2], which consists in the quenching of the optically detected spin resonance due to the precession of the spin around the same axis in both ground and excited states. Our findings provide new opportunities for the coherent control of spin qubits with dynamic strain fields that can lead towards the realization of future spin-acoustic quantum devices.

[1] A. Hernández-Mínguez *et al.*, Phys. Rev. Lett. **125**, 107702 (2020)

[2] A. Hernández-Mínguez *et al.*, Sci. Adv. **7**, eabj5030 (2021)

HL 3.6 Mon 12:00 POT 151

Storage and retrieval of telecom single photons from a semiconductor quantum dot in a rubidium ORCA memory — •Lukas Wagner[1], Sarah Thomas[2], Cornelius Nawrath[1], Simone Luca Portalupi[1], Patrick Ledingham[3], Ian Walmsley[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen (IHFG), Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany — [2]Faculty of Natural Sciences, Department of Physics, Imperial College London, Imperial College Rd, South Kensington Campus, London SW7 2AZ, United Kingdom — [3]Department of Physics and Astronomy, University of Southampton, Southampton SO17 1BJ, United Kingdom

Photons are highly attractive as carriers of information thanks to their propagation at the speed of light and their low interaction with matter. Furthermore, various implementations of photonic quantum technologies will strongly benefit from the possibility of storing quantum information. Indeed, quantum memories would allow synchronizing the arrival time of multiple photons. Semiconductor quantum dots (QDs) are highly attractive as sources of quantum light. Atomic vapors are known as a very powerful platform to realize on-demand storage and retrieval of light. For these reasons a hybrid quantum system combining these two elements was for long sought after. Here, we will report on our progress to interface single photons from an In(Ga)As QD emitting at telecom wavelength with a rubidium off-resonance cascaded absorption (ORCA) quantum memory.

HL 3.7 Mon 12:15 POT 151

Excitation and read-out of macroscopic mechanical motion by phase-modulated optical driving of a single-photon emitter — •Thilo Hahn[1], Jacek Kasprzak[2], Ortwin Hess[3], Tilmann Kuhn[1], and Daniel Wigger[3] — [1]Institute of Solid State Theory, University of Münster, Germany — [2]Université Grenoble Alpes, CNRS, France — [3]School of Physics, Trinity College Dublin, Ireland

Resonance phenomena provide an access to drive inert systems out of equilibrium by applying a periodic force. In this contribution we will investigate a hybrid quantum system consisting of a single photon emitter (SPE) that is on the one hand coupled to a single phonon mode, e.g., in the form of a mechanic resonator, and on the other hand driven by a laser field. To convert a series of laser pulses into a measurable displacement of the phonon mode, originally a synchronization between the pulse repetition and the mode frequency was suggested [2] and demonstrated. Here, we discuss a different excitation scheme that is adapted from the heterodyne four-wave mixing (FWM) technique: We consider a series of pulse pairs which drives the phonons into a far displaced quasi-coherent state by tuning the harmonically oscillating phase relation within the pulse pairs in resonance with the phonons. Conversely, the optical properties of the SPE are dynamically affected by the phonon motion. Conveniently this can directly be measured by the FWM signal emitted by the SPE in order to detect the mechanical motion. Consequently, we combine resonant driving and read-out in a single method.

[1] Phys. Rev. A 90, 023818 (2014) [2] Nat. Nanotechnol. 16, 283 (2021)

HL 3.8 Mon 12:30 POT 151

Imaging surface acoustic waves on 2D materials using atomic force microscopy — •Mingyun Yuan[1], Alberto Hernández-Mínguez[1], Igor Aharonovich[2], and Paulo V. Santos[1] — [1]Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., Berlin, Germany — [2]School of Mathematical and Physical Sciences, University of Technology Sydney, Ultimo, Australia

There is an increasing interest in coupling the dynamic strain of surface acoustic waves (SAWs) to electronic excitations in 2D-material-based nanostructures to acoustically manipulate their optoelectronic properties. While optical phenomena in 2D nanostructures can be conveniently mapped by photoluminescence, local probing of mechanical properties remains challenging. This task can, nevertheless, be assisted by high-frequency (GHz) SAWs, which are particularly suitable for probing very thin objects due to their micron-size wavelengths and their confinement near the surface. Here, we use atomic force microscopy (AFM) to image SAWs propagating along a LiNbO3 acoustic resonator containing a multilayer hexagonal Boron Nitride (hBN) flake irradiated with Ar ions to create color centers. The high spatial resolution of AFM enables us to investigate the SAW strain transferred to the flake. We observe spatial inhomogeneities, revealing that the strain transferred to 2D materials can exhibit large spatial fluctuations. Possible mechanisms that affect the coupling will be discussed. Our method demonstrates a straight-forward way to characterize dynamic strain fields in hybrid SAW/2D-material systems.

HL 3.9 Mon 12:45 POT 151

Effect of helium ion implantation on nanomechanical resonators in 3C-SiC — •Nagesh Shamrao Jagtap[1,2], Yannick Klass[3], Felix David[3], Philipp Bredol[3], Eva Weig[3], Manfred Helm[1,2], Georgy Astakhov[1], and Artur Erbe[1,2] — [1]Helmholtz-Zentrum Dresden - Rossendorf, Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany — [2]Dresden University of Technology, 01062 Dresden, Germany — [3]Technical University of Munich, Chair of Nano and Quantum Sensors, 85748 Munich, Germany

Silicon carbide (SiC) is a suitable candidate for nanoelectromechanical systems due to its superior mechanical properties. It is also an interesting material platform to study the coupling of mechanical modes with localized spins associated with irradiation-induced defects. Such a spin-mechanical system can be used for quantum sensing applications [1]. The nanomechanical resonators in 3C-SiC are fabricated by standard semiconductor processing techniques such as electron beam lithography and reactive ion etching. They are characterized using Fabry-Pérot interferometer. In the preliminary experiments, we focus on the material modification by helium ion broad beam implantation on strained 3C-SiC resonators. The effect of varying fluence on resonance frequencies and quality factors is studied (see contribution of Philipp Bredol).

[1] A. V. Poshakinskiy and G. V. Astakhov, ”Optically detected spin-mechanical resonance in silicon carbide membranes*, PhysRevB.100.094104 (2019)