DS 27: New Twists for Nanoquakes on a Chip - Emerging Applications of Surface Acoustic Waves in Condensed Matter Physics (Focussed Session): Session I

Surface acoustic waves (SAWs) with gigahertz frequencies and micrometre size wavelength can be elegantly generated using piezoelectric transducers fabricated with standard integrated circuit technology. Their small propagation velocity, tight surface confinement, as well as low susceptibility to decoherence and dissipation have been exploited over the past decades in numerous devices, in particular for electronic and optical signal processing. Today, the interaction of SAWs with electrical, optical, magnetic, and mechanical excitations in condensed matter is a highly active field of research. It is driven by the vision to harness the power of this technique in a broad spectrum of emerging applications including advanced sensors, the control of magnetization and collective excitations, as well as the coherent interactions between charge and spin excitations, photons, and phonons down to the fundamental level of single quanta. We propose a symposium that brings together experts for emerging and future applications of surface acoustic waves. For the proposed symposium we have identified potential speakers covering the large palette of fields which this versatile technique is successfully applied or currently evolving towards. These encompass nanoscale acousto-optic integrated circuits and plasmonics, the control of single quantum systems and collective excitations in hybrid systems. Because the proposed symposium covers a wide range of frontier research in which SAWs are employed with greatest success, it will serve as an ideal platform for scientific exchange. Thus, it aims to foster new interactions between the different scientific communities. Its most important goal is to introduce this exciting field of research to the many young Masters and PhD students, and postdocs attending the joint DPG-EPS Spring meeting and gives them the opportunity to present contributed talks at the symposium or associated sessions.

Organized by

Hubert Krenner, Universität Augsburg, Germany, hubert.krenner@physik.uni-augsburg.de

Jorge Pedros, Universidad Politécnica de Madrid, Spain, j.pedros@upm.es

Chris Ford, University of Cambridge, UK, cjbf@cam.ac.uk

Time: Thursday 9:30–13:15 Location: H 2032

Invited Talk DS 27.1 Thu 9:30 H 2032

Coupling RF-driven acoustic wave devices with nanocavity optomechanics — •Kartik Srinivasan, Marcelo Wu, Marcelo Davanco, and Krishna Balram — National Institute of Standards and Technology, Gaithersburg, MD 20899, USA

Nanocavity optomechanical systems are being developed for a variety of sensing and signal transduction applications. Optomechanical crystal cavities, which co-localize optical modes within a photonic bandgap and mechanical modes within a phononic bandgap, have been of particular interest due to the strong interactions they support. Here, I will describe our efforts in connecting such devices to radio frequency (RF) waves, through the development of a piezoelectric cavity optomechanics platform. Frequency and time-domain characterization of devices within this platform will be presented, as will efforts to improve the overall efficiency of microwave-to-optical transduction.

Invited Talk DS 27.2 Thu 10:00 H 2032

Quantum Spin-Mechanics with Color Centers in Diamond — •Hailin Wang — Department of Physics, University of Oregon, Eugene, OR 97403, USA

Quantum acoustics is an emerging field focusing on interactions between acoustic waves and artificial atoms that can be exploited in quantum science. Acoustic waves propagate at a speed that is five orders of magnitude slower than the speed of light and couple to artificial atoms through mechanical processes, enabling a new paradigm for on-chip quantum operation and communication.

Among the various artificial atoms or qubits that have been explored, nitrogen vacancy (NV) color centers in diamond are of special interest because of their robust spin coherence and the ease with which these qubits can be measured and controlled. In this talk, I will discuss our recent experimental advance in coupling NV centers to surface acoustic waves (SAWs). By exploiting strain coupling to orbital degrees of freedom, we are able to induce strong and coherent spin-mechanical interactions with SAW amplitudes at only a fraction of a picometer. This platform opens a new avenue for experimental exploration of spin-based quantum acoustics, including quantum control of both spin and mechanical degrees of freedom.

Invited Talk DS 27.3 Thu 10:30 H 2032

Acoustic Traps and Lattices for Electrons in Semiconductors — Martin Schuetz[1,2], •Johannes Knörzer[1], Géza Giedke[3,4], Lieven Vandersypen[5], Mikhail Lukin[2], and Ignacio Cirac[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]Physics Department, Harvard University, Cambridge, MA 02318, USA — [3]Donostia International Physics Center, Paseo Manuel de Lardizabal 4, E-20018 San Sebastián, Spain — [4]Ikerbasque Foundation for Science, Maria Diaz de Haro 3, E-48013 Bilbao, Spain — [5]Kavli Institute of NanoScience, TU Delft, P.O. Box 5046, 2600 GA Delft, The Netherlands

We propose and analyze a solid-state platform based on surface acoustic waves (SAWs) for trapping, cooling and controlling (charged) particles, as well as the simulation of quantum many-body systems. We develop a general theoretical framework demonstrating the emergence of effective time-independent acoustic trapping potentials for particles in two- or one-dimensional structures. As our main example we discuss in detail the generation and applications of a stationary, but movable acoustic pseudo-lattice (AL) with lattice parameters that are reconfigurable in situ. We identify the relevant figures of merit, discuss potential experimental platforms for a faithful implementation of such an acoustic lattice, and provide estimates for typical system parameters. With a projected lattice spacing on the scale of about 100nm, this approach allows for relatively large energy scales in the realization of fermionic Hubbard models, with the ultimate prospect of entering the low-temperature, strong-interaction regime.

Invited Talk DS 27.4 Thu 11:00 H 2032

Manipulating single electrons on the fly using a sound wave — •Christopher Bauerle — Institut Neel, CNRS Grenoble

Surface acoustic waves (SAW) provide a promising platform to realize quantum optics experiments with electrons at the single particle level. Earlier single-shot experiments have shown SAW-assisted electron transport between spatially separated quantum dots over a distance of 4 μm with an efficiency of about 92 % [1,2]. Here we go an important step further. We couple two quantum channels by a tunnel barrier along a region of 2 μm. At the ends of each channel respectively a quantum dot is placed serving as single electron source and detector. We demonstrate single electron transport over a distance of 22 μm with extremely high efficiency above 99 %. Changing the energy detuning in the coupling region we can partition the electron on-demand into two paths. By gradually changing the barrier height we additionally observe tunnel oscillations of the probability that the electron ends up at the upper or the lower detector quantum dot. This finding demonstrates coherent manipulation of the electron quantum state on the fly. Our results pave the way for the implementation of a solid state flying qubit having high relevance in fundamental research and quantum information technology.

[1] Hermelin et al., Nature 477, 435-438 (2011) [2] McNeil et al., Nature 477, 439-442 (2011)

15 min. break.

DS 27.5 Thu 11:45 H 2032

Surface acoustic wave modulation of a coherently driven quantum dot in a pillar microcavity — •Bruno Villa[1,2], Anthony J. Bennett[1], David J. P. Ellis[1], James P. Lee[1,3], Joanna Skiba-Szymanska[1], Thomas A. Mitchell[2], Jonathan Griffiths[2], Ian Farrer[2], David A. Ritchie[1], Christopher J. B. Ford[2], and Andrew J. Shields[1] — [1]Toshiba Research Europe Limited, Cambridge Research Laboratory, 208 Cambridge Science Park, Milton Road, Cambridge CB4 0GZ, United Kingdom — [2]Cavendish Laboratory, University of Cambridge, J. J. Thomson Avenue, Cambridge CB3 0HE, United Kingdom — [3]Engineering Department, University of Cambridge, 9 J. J. Thomson Avenue, Cambridge, CB3 0FA, United Kingdom

In this work we demonstrate the generation of a high-frequency pulsed single-photon stream. A quantum dot embedded in a pillar microcavity efficiently scatters photons when driven coherently with a narrow-band continuous wave laser. Simultaneously, the transition energy is periodically tuned by a surface acoustic wave (SAW) propagating along the substrate at 1 GHz. The combined action of the light and strain fields on the quantum dot yields a periodic signal displaying anti-bunching. In addition we are able to resolve multiple phonon sidebands in the emission spectrum.

DS 27.6 Thu 12:00 H 2032

Surface acoustic wave regulated single photon emission of a coupled quantum dot-nanocavity system — •Matthias Weiss[1], Stephan Kapfinger[1], Thorsten Reichert[2], Jonathan Finley[2], Achim Wixforth[1], Michael Kaniber[2], and Hubert Krenner[1] — [1]Lehrstuhl für Experimentalphysik 1, Universität Augsburg, 86159 Augsburg, Germany — [2]Walter Schottky Institut, TU München, 85748 Garching, Germany

Here we report on a coupled quantum dot-nanocavity system in the weak coupling regime, that is dynamically tuned by the coherent elastic field of a $f_{SAW} \cong 800\,\text{MHz}$ surface acoustic wav (SAW).[1] The SAW induced strain fields lead to a dynamic modulation of the cavity resonance by a combination of mechanical deformation and photo-elastic coupling and of the QD by deformation potential coupling. These effects lead to a dynamical tuning of the energy splitting between the single QD and the cavity. By applying a phase locked stroboscopic laser excitation scheme and the use of time and spectral resolved detection the SAW induced modulation of the interaction can be observed. These measurements show clearly a spectral resonance between QD and cavity at a well defined time during the acoustic cycle and the resulting increase of the QD-cavity interaction by the Purcell effect. This leads to a precisely timed single photon emission as confirmed by a direct measurement of the second order photon correlation function, $g^{(2)}$, at the resonance.

[1] M. Weiß et al., Appl. Phys. Lett. 109, 033105 (2016)

DS 27.7 Thu 12:15 H 2032

Development of a SAW-driven source of single photons — •A. Rubino[1], T-K Hsiao[1], Y. Chung[1], S-K Son[1], H. Hou[1], A. Nasir[2], J Pedros[3], R. T. Phillips[1], G. Éthier-Majcher[1], M. Stanley[1], M. Atatüre[1], K. Niang[1], G. Rughoobur[1], A. Flewitt[1], T. Mitchell[1], J. P. Griffiths[1], I. Farrer[1], D. A. Ritchie[1], and C. J. B. Ford[1] — [1]U. of Cambridge — [2]The National Physical Laboratory (NPL) — [3]Universidad Politécnica de Madrid

We have developed devices in which both electrons and holes can be induced in an undoped GaAs/AlGaAs well by gates to form a lateral n-i-p junction. SAWs, generated by a transducer, collect electrons in the n-region and transport them into the p-region where they recombine with holes. If the stream is composed of single electrons, the recombination with holes should produce a stream of single photons We observe light emission in DC forward bias when the voltage applied is above the flat- band condition. Alternatively, we can bias the junction 100 mV below the flat-band condition, so that no current flows until a 1 or 3 GHz SAW drives a current and light emission, by pumping electrons over the hill in the intrinsic region. We have characterised this SAW-driven electroluminescence in the regime where less than one electron is transported per cycle on average. Time-resolved electroluminescence has been used to extract the electron recombination time and to quantify the contributions from electromagnetic crosstalk and the SAW. In a device without significant crosstalk, the degree of second-order coherence, g2(0), was measured using a Hanbury Brown and Twiss interferometer, and it shows the signature of antibunching.

DS 27.8 Thu 12:30 H 2032

SAW Transducers with Gouy Phase Adjustments for Minimal Beam Waist — •Madeleine Msall[1,2] and Paulo Santos[2] — [1]Bowdoin College, Brunswick, USA — [2]Paul-Drude-Institut für Festkörperelektronik, Berlin, DE

High frequency surface acoustic waves can effectively probe and control low-dimensional electron systems. SAW provide localized control of band structure through dynamic strain coupling that can be exploited for switching applications or to drive transport. Applications that rely upon SAW coupling to quasi 0-D systems (e.g., quantum dots) require highly tuned SAW cavities with near-field focusing transducers. IDTs are formed by electrode fingers placed on lines of equal phase, requiring pattern correction for both material anisotropy and the expected Guoy phase shift for a Gaussian beam. [1] Our models show that appropriate pattern adjustments can provide significant enhancement of local strain in sub-wavelength focal spots without frequency broadening. These model improvements inspire new strategies for creating high-Q cavities with optimized coupling between phonons and qubits.

[1] Holme, et al. 2003 DOI.org/10.1063/1.1590405

DS 27.9 Thu 12:45 H 2032

Multi-harmonic quantum dot optomechanics in fused $LiNbO_3$-(Al)GaAs hybrids — •Emeline Nysten[1,2], Yong Heng Huo[3,4], Hailong Yu[5], Guo Feng Song[5], Armando Rastelli[3], and Hubert J. Krenner[1,2] — [1]Lehrstuhl für Experimentalphysik 1, Universität Augsburg, Augsburg, Germany — [2]Nanosystems Initiative Munich (NIM), München, Germany — [3]Institute of Semiconductor and Solid State Physics, Johannes Kepler Universität Linz, Linz, Austria — [4]University of Science and Technology of China, Shanghai, China — [5]Chinese Academy of Sciences, Beijing, China

Surface acoustic waves (SAW) are used to control the emission of quantum dots (QDs) and, in particular, SAWs enable the injection of charge carriers into the dot or the modulation of their energy levels [1,2,3]. Here we explore the possiblity to enhance the interaction between the SAW and epitaxial GaAs QDs by tranferring them on a strong piezoelectric $LiNbO_3$ substrate by epitaxial lift-off [4]. By employing multiharmonic transducers, we generated sound waves on $LiNbO_3$ over a wide range of radio frequencies. We monitored their coupling to and propagation across the semiconductor membrane, both in the electrical and optical domain. We demonstrate the enhanced optomechanical tuning of the embedded quantum dots with increasing frequencies. This effect was verified by finite element modelling of our device geometry and attributed to an increased localization of the acoustic field within the semiconductor membrane. References: [1]Appl.Phys.Lett. **93**, 081115 (2008), [2]Nano Lett. **10**, 3399-3407 (2010), [3]Phys.Rev.B **88**, 085307 (2013), [4]Appl.Phys.Lett. **106**, 013107 (2015)

DS 27.10 Thu 13:00 H 2032

Zero-group-velocity acoustic waveguides for high-frequency resonators — •Muhammad Hamidullah and Cinzia Caliendo — Institute of Photonics and Nanotechnologies, IFN-CNR, Via Cineto Romano 42, 00156 Rome, Italy

Zero group velocity (ZGV) Lamb-like modes resonator based on a silicon-on-insulator (SOI)/AlN suspended thin film was simulated to design high-frequency electroacoustic resonators that do not require metal strip gratings or suspended edges to confine the acoustic energy. The electroacoustic standing wave can be obtained with only one interdigital transducer (IDT) and no reflectors, thus reducing both the device size and the technological complexity. The ZGV resonant conditions in the SOI/AlN composite plate, i.e. the frequencies where the mode group velocity vanishes while the phase velocity remains finite, were investigated in the frequency range from few hundreds of MHz up to 1900 MHz with the wavelength range from 50 um to 22 um. Phase velocity at ZGV resonant condition (>15000m/s) is higher than bulk longitudinal phase velocity. By reducing the film thickness and the wavelength in sub-micrometer range, ultra-high frequency resonator with a resonant frequency higher than 10 GHz can be achieved. Furthermore, as the energy is locally trapped in the source area, these modes are expected to be highly sensitive to the plate thickness and mechanical properties changes, therefore, can be exploited for sensing application.

Keyword: Lamb wave, thin film, zero group velocity, SOI, AlN