HL 35: Acoustic Waves and Nanomechanics

Time: Thursday 15:00–16:00 Location: H34

HL 35.1 Thu 15:00 H34

A hybrid (Al)GaAs-$LiNbO_3$ surface acoustic wave resonator for cavity quantum dot optomechanics — •Emeline Nysten[1], Armando Rastelli[2], and Hubert Krenner[1] — [1]Physikalisches Institut, WWU Münster, Germany — [2]Institute of Semiconductor and Solid-State Physics, Johannes Kepler Universität Linz, Austria

Surface acoustic waves (SAW) are a useful tool to control the emission of quantum dots (QDs). In particular, SAWs enable the modulation of their energy levels through the deformation potential coupling [1]. Here, we explore the possibility to enhance the interaction between the SAW and the QDs by transferring them on a strong piezoelectric $LiNbO_3$ substrate by epitaxial lift-off [2,3]. Additionally, the membrane is transferred inside a SAW resonator confining the acoustic field inside the cavity. High acoustic quality factors of $Q > 4000$ are demonstrated for the SAW resonator for an operation frequency of $f = 300\,\text{MHz}$ and stay high even after the hybridization. The frequency and position dependent optomechanical coupling of single quantum dots with the resonator modes is recorded and quantified. A possible non-linear coupling between the QDs and the resonator modes is also observed [4]. [1] Appl. Phys. Lett. 93, 081115 (2008) [2] Phys. Rev. B 88, 085307 (2013) [3] J. Phys. D: Appl. Phys. 50, 43LT01 (2017) [4] Appl. Phys. Lett. 117, 121106 (2020)

HL 35.2 Thu 15:15 H34

Determining Amplitudes of Standing Surface Acoustic Waves via Atomic Force Microscopy — •Jan Hellemann[1], Filipp Müller[1], Madeleine Msall[2], Paulo V. Santos[1], and Stefan Ludwig[1] — [1]Paul-Drude-Institut für Festkörperelektronik, Berlin, Deutschland — [2]Bowdoin College, Maine, USA

Our aim is the realization of strong coupling between cavity phonons and a few electron double quantum dot as an on-chip hybrid system for quantum information applications. For this purpose, we develop radio frequency surface-phonon cavities containing a double quantum dot laterally defined in a GaAs/AlGaAs heterostructure. To characterize a phonon cavity we generate standing surface acoustic waves (SSAW) by driving the cavity defining interdigital transducers and image the SSAW using atomic force microscopy (AFM), which is able to resolve submicron wavelengths of the SSAW at a few GHz. Alternative techniques are discussed in a related contribution by N. Ashurbekov.

Here, we focus on the AFM cantilever deflection, which substantially overestimates the SSAW amplitude because the cantilever with an eigenfrequency in the kHz range is driven by energy transfer from the much faster oscillating surface. We demonstrate a method to nevertheless determine the actual SSAW amplitude by comparing the hystereses of force curve measurements with model predictions based on solving the equation of motion of the driven cantilever [1]. Finally we present our first characterization measurements of a double quantum dot coupled to a phonon cavity.

[1] J. Hellemann et al, PRApplied **17**, 044024 (2022)

HL 35.3 Thu 15:30 H34

Radio Frequency Surface Acoustic Wave Cavities near 6 GHz — •Nazim Ashurbekov[1], Michael Hanke[1], Edoardo Zatterin[2], Madeleine Msall[3], Jan Hellemann[1], Paulo Santos[1], Tobias Schulli[2], and Stefan Ludwig[1] — [1]Paul-Drude-Institut, Berlin, Germany — [2]European Synchrotron, Grenoble, France — [3]Bowdoin College, Maine, USA

Aiming at strong coupling between confined phonons and confined electrons in hybrid quantum circuits, we develop radio frequency (rf) surface-phonon cavities. The cavities are defined by focusing surface gate Bragg mirrors. They also serve as interdigital transducers, which we use to generate standing surface acoustic waves (SSAWs) for characterizing the cavities. At frequencies >3 GHz corresponding to wavelengths <1 μm most methods to measure the SSAWs become increasingly difficult.

Here, we explore two experimental methods with superior resolutions, scanning X-ray diffraction microscopy (SXDM) and atomic force microscopy (AFM). We present AFM measurements of focused rf SSAWs near 6 GHz and compare them with SXDM measurements. While AFM provides a basic characterization of the SSAW, SXDM in addition yields its complete 3D strain field, relevant for the electron-phonon coupling.

Finally, comparing our experimental results with finite elements method simulations allows us to explore design variations for future optimizations of the electron-phonon coupling in quantum devices.

HL 35.4 Thu 15:45 H34

A quantum dot coupled to a mechanical resonator — •Clemens Spinnler[1], Giang Nam Nguyen[1], Liang Zhai[1], Alisa Javadi[1], Andreas D. Wieck[2], Arne Ludwig[2], Ying Wang[3], Peter Lodahl[3], Leonardo Midolo[3], and Richard J. Warburton[1] — [1]Department of Physics, University of Basel — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum — [3]Niels Bohr Institute, University of Copenhagen

Coupling a single-photon emitter to a mechanical resonator is a promising route towards operations involving a single photon and a single phonon. Semiconductor quantum dots (QDs) are bright sources of coherent single-photons, and their optical two-level transition can be coupled to mechanical motion via deformation potential coupling.

Here, we present a membrane-design resonator: a cantilever with a fundamental in-plane mode at 3.1 MHz with a quality factor as high as 22'000. The membrane design hosts a heterostructure diode for stabilising the QD's charge state. This results in narrow optical linewidths and a high mechanical sensitivity. We probe the Brownian motion at low temperature, 4 K, of the mechanical resonator via the resonance fluorescence from a single quantum dot. The mechanical noise imprinted on the QD's photons is extracted via an autocorrelation measurement. A single photon coupling strength of around 100 kHz is estimated. The in-plane mechanical motion probed here, together with the membrane design, allows a translation to higher frequencies using phononic-crystal resonators for which operation in the resolved-sideband regime becomes viable.