Quantum Nanomechanics

(Prof. Mika Sillanpää)

Nanomechanical systems in the quantum limit, superconducting qubits, magneto-acoustic hybrid systems. Experimental work is carried out in the premises of the Low Temperature Laboratory.

The projects are designed to be suitable as a special assignment or bachelor's thesis work. In many cases they can also be extended as a diploma work. The experimental projects involve design and simulations, and hands-on work in the laboratory with device fabrication and measurements. The projects give an excellent overview of cutting-edge experimental research on an exciting topic with a strong relevance to quantum technologies.

Superconducting – mechanical hybrid quantum systems

Quantum bits made with Josephson junctions are considered the most promising platform for realization of quantum computer. In addition, superconducting qubits can be useful for exploring hybrid quantum systems, and testing quantum mechanics in nearly macroscopic systems. We investigate hybrid systems using transmon qubits coupled to High-Overtone Bulk Acoustic (HBAR) resonances that extend through the chip (Figure 1).

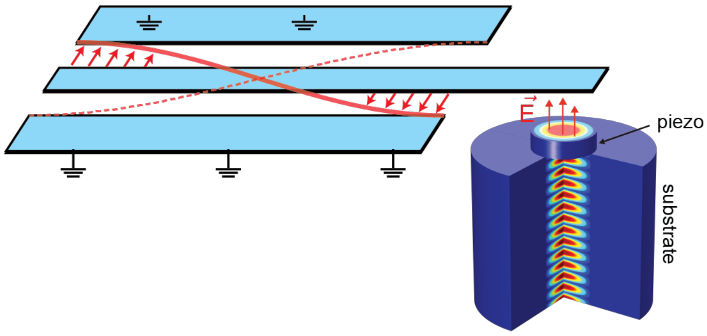


Figure 1: GHz acoustic resonances in a substrate are coupled to electromagnetic fields via piezoelectricity.

1. Ultrastrong coupling of transmon qubits to HBAR modes

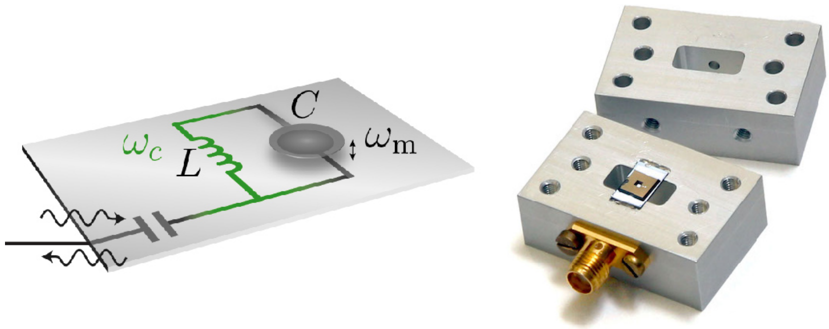
This project is fully computational/theoretical. We have carried out measurements where the qubit-phonon coupling energy is a very large fraction of the free spectral range between the overtones. This creates a system where tens of phonon modes couple simultaneously to the qubit and indirectly to one another. You will calculate the coupling energy from piezoelectric theory, evaluate the expected spectrum from multimode qubit-oscillator theory, and fit the result to the measured spectrum.

2. GHz phononic waveguides

A longer-term goal of qubit-acoustic hybrids is to couple these systems to propagating acoustic waves, creating phononic quantum circuit. The benefits include very dense packaging due to short wavelength, and low energy losses of the acoustics. To this end, in this work you will explore a basic scheme where phononic waveguide is excited electrically. You will design this type of device, and carry out preliminary fabrication and room-temperature measurements.

Microwave optomechanics

"Microwave optomechanics" (Fig. 2) is in analogy to optomechanics which studies optical Fabry-Perot cavities with one end mirror movable. The cavity can be realized as an on-chip thin film resonator, or in 3D fashion.



2. An interesting setup for investigating micromechanical resonators is that of coupling them to superconducting cavities at microwave frequency for detection and manipulation near the quantum limit.

3. Functionalized membrane resonators for gravity studies

Loading millimeter-sized silicon nitride membranes with a "heavy" mass is a promising route for studying gravity with 1 milligram-scale source masses and at small distances. In this project, you will investigate smaller source masses approaching the Planck mass ~22 μg, starting by Comsol simulations to predict energy losses due to phonon radiation. Subsequently, you will position small masses on the membranes with micro manipulation. The vibration properties of the actual devices are also investigated at room temperature with an optical vibrometer. Depending on the progress, low-temperature measurements may also be carried out.