Quantum Mechanics of Millimetre-Sized Mechanical Resonators

Integrating Low-Loss Massive Mechanical Resonators with Single-Electron Devices

In this work, I present an insight into the dynamics and dissipation of millimetre-sized piezoelectric oscillators with masses in the mg range and resonance frequencies of some MHz. I also explore the possibility of measuring their ground state vibrations using several different measurement typologies of Single Electron devices. Furthermore, I suggest the use of nanocrystalline diamond resonators as an alternative mechanical system and study its dissipative behaviour.

Since the formulation of the current quantum theory, in the mid-1920s, there has been a debate over the extent to which it can be applied to macro-world objects. Recently small but nevertheless macroscopic systems portraying quantum-mechanical behaviour in some of their degrees of freedom have been demonstrated. The motion of a body is one of the aimed physical quantities to measure in the quantum limit. The observation of macroscopic mechanical resonators in the quantum ground state is not only motivated by the demonstration of some of the fundamental paradoxes of quantum measurement theory. Quantum-limited motion detection requires extremely sensitive and noise-free displacement sensing, leading to an engineering breakthrough in other areas where motion/displacement sensing is needed. Finally, it also has relevance in the field of quantum engineering, where high-Q mechanical resonators in the ground state can be used as blank pages for a variety of implementations.

Monolithic quartz resonators are inexpensive, resilient and can exhibit high quality factors up to 1 billion. The strain-generated piezoelectric charge offers a transduction option to measure the mechanical vibrations of the oscillator with charge detectors, at which superconducting single electron devices excel. In the most promising and sensitive typology the device can be treated as a cavity optomechanical scheme where a charge Qubit, capacitively coupled to the piezo charge, mediates and enhances the interaction between the mechanical oscillator and a microwave cavity.

Cooling MHz mechanical resonators to the ground state calls for temperatures well below the limit of dilution cryostats. I delve into using optomechanical cooling of the mechanical resonator by back-action of the cavity, show results demonstrating modest cooling power, and predict that the ground state can be reached by some realistic tuning to the piezoelectric dissipation profile and Qubit design, opening opportunities for macroscopic quantum experiments. The low intrinsic dissipation of diamond resonators and its high frequency-mass ratio is also studied and the possibility/advantages of using them as mechanical elements in quantum electrodynamics experiments is analysed.

Field of the dissertation
Engineering Physics; Quantum Physics; Low Temperature Physics; Optomechanics

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