NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2023-2024

Ultra-Coherent Nanomechanical Resonators

General Scope : The unparalleled sensitivity of quantum sensors promises a plethora of important applications. In particular, resonators with mechanical coherence times of order 10 to 100 milliseconds at 10 mK have recently been demonstrated. These devices could be used as quantum memories in hybrid systems for quantum communication and computation. They could also be used for testing fundamental aspects of quantum mechanics. At the same time, nuclear demagnetization refrigeration (NDR), yielding microkelvin cryostat temperatures, has been applied to microwave optomechanics, yielding passive ground state cooling of ~10 MHz mechanical modes. However, researchers in these two fields have not yet combined NDR with functionalized ultra-high Q mechanical resonators with mechanical coherence times exceeding 10 ms. Since the mechanical damping rate Γ_m of these devices increases with temperature even at 10 mK, present experiments appear to lack the full potential mechanical coherence time $1/(\Gamma_m \bar{n}_{\mathrm{th}})$ for thermal phonon occupation $\bar{n}_{\mathrm{th}}$ that can be achieved by cooling to lower bath temperatures.

Further reading: D. Cattiaux *et al.* Nature Communications, **12**, 6182 (2021) https://doi.org/10.1038/s41467-021-26457-8; A. Youssefi *et al.* *Nature Physics* (2023) https://doi.org/10.1038/s41567-023-02135-y

Research topic and facilities available : We will use state-of-the-art optomechanical devices fabricated by the Kippenberg group (https://www.epfl.ch/labs/k-lab/) for the project. The devices are known to have exceptionally low mechanical dissipation near 10 mK. Using the microkelvin microwave optomechanics cryostats of the Néel Ultra-Low Temperatures group, which are unique in the world, we will cool the devices to temperatures below 1 mK in order to achieve a record mechanical quantum coherence time of 1 second. We will then apply this extreme coherence to quantum memory protocols and experiments probing the implications of general relativity in quantum mechanics.

Possible collaboration and networking : As mentioned above, the project relies on a collaboration with the Kippenberg group at EPFL, Switzerland.

Possible extension as a PhD : Yes

Required skills: Enthusiasm for carrying out challenging experiments at ultra-low temperatures and a strong background in quantum mechanics.

Starting date : Negotiable

Contact :

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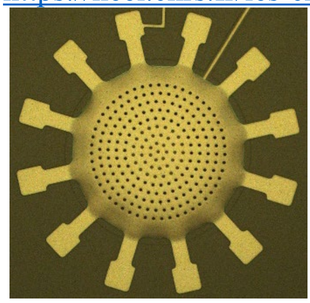

Left: A nanomechanical "drum" fabricated at EPFL. Right: an ultra-low resistance superconducting heat switch for nuclear demagnetization refrigeration fabricated at Institut Néel/CNRS