Spin-opto-nanomechanics

Principle investigators: Prof. Dr. Philipp Treutlein, Prof. Dr. Patrick Maletinsky
Swiss Nanoscience Institute and Department of Physics, University of Basel, Switzerland

In this PhD project we will investigate an interface between a nanomechanical membrane oscillator and a spin system that can be manipulated on the quantum level. The coupling between the membrane and the spin will be engineered and controlled by light. The resulting spin-opto-nanomechanical system offers new possibilities for cooling, control and detection of mechanical vibrations with potential applications in quantum metrology. Moreover, it will allow us to investigate a range of fundamental questions on the remote Hamiltonian coupling of quantum systems and the quantum behavior of massive mechanical objects. In our experiments, different types of nanomechanical oscillators and spin systems will be explored.

Hybrid mechanical systems in which a nanomechanical oscillator is coupled to a well-controlled microscopic quantum system currently receive great interest [1]. Such systems offer a powerful approach to cooling, control and detection of mechanical systems, including the generation of non-classical states. This is of interest for applications in quantum sensing, quantum signal transduction and fundamental tests of quantum physics.

The Treutlein group has pioneered the investigation of hybrid mechanical-atomic systems [1]. In previous experiments, we developed an interface between a nanomechanical membrane and ultracold atoms in an optical lattice. We observed that the membrane vibrations can be cooled via their coupling to laser-cooled atoms, demonstrating a temperature reduction of the membrane fundamental mode by a factor of 10^3 [2]. Moreover, we observed coupled oscillations of atoms and membrane [3]. In those experiments, the vibrations of the membrane were coupled to the motion of the atoms.

In this PhD project, we want to go a crucial step further and couple the membrane vibrations to the collective spin of the atoms instead of their motion. This is beneficial since the atomic spin state can be prepared, controlled and detected with much higher fidelity on the quantum level [4]. Based on the theory described in [5,6] we developed a scheme for coherent Hamiltonian coupling of the membrane vibrations to the atomic spin, employing a Faraday interaction of the atoms with the light. We will implement this scheme in our setup and perform a range of experiments on quantum control of nanomechanical motion and the remote coupling of quantum systems [6]. As mechanical oscillators, we will use SiN membranes in an optical cavity. To reduce thermal decoherence, the oscillators will be placed in a cryostat. Alternatively, we will explore diamond oscillators in a collaboration with the Maletinsky group. These oscillators can host "Nitrogen-Vacancy" (NV) center electron spins, which interact with the mechanical vibrations via strain, as has been demonstrated in pioneering experiments by the Maletinsky group [7]. In a close collaboration we will explore the new possibilities that arise from integrating such oscillators into our system, such as cavity optomechanical control and readout of an electron spin in a solid or the optomechanical coupling of an electron spin to an atomic spin.

References

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