Ultrasensitive Force Microscopy and Cavity Optomechanics using Nanowire Cantilevers

PIs: Prof. Dr. Martino Poggio, Dr. Floris Braakman
Department of Physics, University of Basel

Nanoscale mechanical resonators such as thin membranes or nanowire crystals have the potential to uniquely enrich the capabilities of force microscopy. Currently, force microscopy techniques rely heavily on micron-sized cantilevers as force transducing elements, such as silicon beams or quartz tuning forks. In recent years, a new direction has emerged which replaces these more conventional cantilevers with bottom-up grown nanoscale structures, such as carbon nanotubes or nanowires. Their small size and nearly defect-free crystal structures leads to potentially record force sensitivities, low mechanical losses and high operation frequencies. Several experiments have very recently demonstrated the potential and versatility of this approach. In our own lab, we have demonstrated a new type of force microscopy using nanowires, in which we have shown sensitivity not only to the magnitude of forces, but also their direction.

Furthermore, nanomechanical resonators enable fundamental studies into the hybridization of different physical quantities, such as light and mechanical motion. Such hybrid systems form a promising platform to implement measurements operating at the limits imposed by quantum uncertainty and quantum non-demolition measurements. They may also allow investigation of quantum decoherence mechanisms, entanglement, and ultimately the transition from quantum to classical physics. Nanowire heterostructures are particularly interesting hybrid systems, as they can combine excellent mechanical properties with bright optically active qubits in the form of embedded quantum dots.

The major aim of this proposal is to increase the sensitivity of nanowire mechanical resonators to enable operation in regimes dominated by quantum effects. We will accomplish this by: 1) integrating nanowire cantilevers into high-finesse optical cavities. Read-out of both the mechanical motion of the nanowires and of the photons emitted by embedded quantum dots can be much improved by placing the nanowire inside an optical cavity. Moreover, such a cavity allows to strongly couple the nanowire motion as well as quantum dots to the cavity light field. In particular, in the case of nanowires with embedded quantum dots this provides a straightforward path to the realization of a tri-partite hybrid system. Such a hybrid system allows to significantly enhance optical cooling and will allow the observation and utilization of quantum states of motion. We also intend to: 2) implement resonant excitation of quantum dots in a force microscopy setup. This will significantly reduce the optical linewidth of the dots and should allow for mechanical displacement sensitivity reaching the Heisenberg uncertainty limit.