Universität Basel

Research Project

Ultrasensitive detection of quantum phenomena in nanowire hybrids

Third-party funded project

Project title Ultrasensitive detection of quantum phenomena in nanowire hybrids
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The fabrication of artifical nanostructures has matured over the last decades to its current state in which it is straightforward, though not always trivial, to create objects with well-defined geometry and crystal structure. This leads to a large degree of control over electronic, vibrational, and photonic properties of nanoscale structures such as nanobeams, photonic and phononic crystals, membranes, nanotubes, and nanowires. In my research proposal for an SNF Ambizione grant I plan to use such well-designed nanoscale objects, in particular self-assembled nanowires. This I plan to do in two projects that aim to study with ultrahigh precision the internal structure of nanowires, and use the nanowires in hybrid systems in which multiple degrees of freedom are coupled. Both projects build upon existing knowledge and expertise, and do not require complicated measurement apparatus. The coupling of different physical quantities forms the very foundation of fundamental experiments investigating quantum measurement. Through such coupling, it becomes possible to implement quantum non-demolition (QND) and weak measurements, and investigate decoherence mechanisms, quantum entanglement, and ultimately the transition from quantum to classical physics. An object which combines the coupled quantities in one, monolithic, unit forms a very powerful platform for the study of such effects. Nanowires are such objects, as they are excellent nanomechanical resonators, can host optically active quantum dots and additionally are prototypical systems expected to exhibit intruiging mesoscopic physics, such as that of emergent Majorana fermions and Luttinger liquids. In the lab in Basel, with which I am currently affiliated as a Postdoctoral researcher, we have demonstrated two types of coupling in nanowires which I intend to exploit in this context. First, nonlinear coupling has been shown to exist between transverse motional modes of nanowires, which could be used to implement QND measurements and bidimensional sensing protocols. The second kind of coupling is a strain-induced interaction between a quantum dot two-level system and mechanical dynamics in nanowire heterostructures. Also this type of coupling can be used to implement QND measurements, and furthermore can be used to study the unexplored physical regime of complex nonlinear dynamics coupled to quantum two-level systems. 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 in an optical cavity. Moreover, such a cavity allows to strongly couple the nanowire motion as well as the quantum dots to the light field. In particular, in the case of nanowires with embedded quantum dots this provides a straightforward path to the experimental realization of a tripartite hybrid system. I aim to use cavities formed by the ends of fiber pairs, specifically modified for this purpose. Such fiber cavities have recently attracted a lot of interest, and are particularly useful for the study of nanowires due to their small dimensions and ease of integration in scanning probe setups. A second, related, project has as a goal to study the internal electronic structure of nanowires using capacitive sensing. Through capacitive coupling of a nanowire to a microwave resonant circuit, the nanowire's quantum capacitance can be determined. By placing the nanowire and resonant circuit in a

standard scanning probe setup, spatial information on the electronic density of states can be obtained through the measured quantum capacitance. This kind of imaging finds potential application in localization of charge defects on nanoscale objects with ultrahigh spatial resolution, quantum dot physics, and possibly even in detecting signatures of strongly interacting electrons and Majorana fermions.

Keywords Nanowires, Scanning probe, Quantum dots, Hybrids, Fiber cavities, Superconducting resonators

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