Universität Basel

Research Project

Quantum structures in nanowires: physical properties on demand by hydrogen irradiation

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Project title Quantum structures in nanowires: physical properties on demand by hydrogen irradiation
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Nanowires (NWs) are filamentary crystals with diameters of tens of nanometers and several microns in length. The great interest attracted by semiconductor NWs has been triggered by the growing demand for compact and powerful nanoscale devices, where NWs may act as both interconnects and functionalized components. A lot of emphasis in today research in NWs is put on the engineering of complex quantum structures in NWs, for they encode new functionalities and/or enhance existing performances. This project aims at developing unexplored strategies for embedding site-controlled quantum structures in III-V NWs and at finding fast and effective routes to engineer the physical properties of NWs. The pursued routes will involve mainly *post-growth* hydrogen implantation, thus allowing to achieve different NW properties *on demand* with no need to change and re-optimize NW growth conditions. Remarkably, the changes in the NW properties will be reversible, as hydrogen can be removed by thermal or laser annealing.

Hydrogen is a ubiquitous, highly mobile, and reactive impurity able to passivate most deep and shallow defects purposely or accidentally embedded in semiconductor crystals, and it is present in most steps of semiconductor growth and device processing. In this project, controlled low-energy H^+ incorporation will be performed on single NWs and large NW arrays. Among all hydrogen effects, two striking effects well known for bulk samples will be investigated and engineered in the field of NWs: the band gap opening in InN and In-rich InGaN, and the passivation of N atoms in dilute nitrides III-N-V semiconductors such as GaAsN and GaPN. The unique growth environment offered by NWs will allow to benefit from a much greater flexibility with respect to conventional, planar, epitaxial growth, owing to the seamlessly enhanced ability of NWs to accommodate elastic strain and to host even lattice-mismatched material combinations.

A variety of quantum structures in NWs will be achieved within this project, mostly but not only by using hydrogenation: quantum dots, quantum wires, quantum rings, quantum well tubes, and quantum wells. The structural characterization of the NWs will be coupled to optical spectroscopy techniques (inelastic light scattering and photoluminescence), also under intense magnetic fields and in a time-resolved regime. The experimental studies will be complemented by a robust theoretical support. In this way, a full picture of the electronic, optical, magnetic, and thermal properties of the quantum structures in NWs will be achieved and controllably tuned.

The strength of the proposed approach will be proven by obtaining NWs with desired magnetic, photonic, and thermoelectric properties: in quantum rings and tubes, magnetic states that should appear due to

the circular symmetry of their carrier wavefunction will be probed for the first time; in quantum dots deterministically positioned in NWs, single photon emission and enhanced light extraction will be achieved in prototypical light emitting devices; in NWs with embedded (non-)periodic superlattices of quantum dots and quantum wells, an enhancement of the thermoelectric power factor and thus of the thermoelectric figure of merit will be pursued. Moreover, potential uses in other fields, including photovoltaics and quantum sensing are envisioned.

In this project, fundamental scientific investigation and technological applications will be strongly entangled and benefit from each other, as many advanced functionalities are deeply rooted in the way physical laws work in the nanoscale realm.

Keywords Semiconductor nanowires, Quantum confinement, Raman spectroscopy, Photoluminescence spectroscopy, Hydrogen irradiation, Photonics, Thermoelectrics, Magnetic states
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