# Quantum Opto-Electronics in Semiconductor Nanowires

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We are experimentalists studying quantum phenomena in nanostructures. By carefully shaping the nanostructures and choosing optimal material properties we design the system in such a way that we obtain desirable electronic and optical properties, i.e. *quantum engineering*. Particularly, the quantum phenomena of *superposition* and *entanglement* are interesting to control at the level of individual electrons and photons. Applications of this control are foreseen in the field of quantum information science. In this field superposition and entanglement are used for encoding information in quantum mechanical bits; the *qubits*.

Various systems are being investigated for realizing quantum hardware. Our favourite systems consists of nanowires (~40 nm in diameter and micrometers long) made out of various semiconducting materials, such as InAs, InSb, Si, etc. See the figure for nanowire examples.

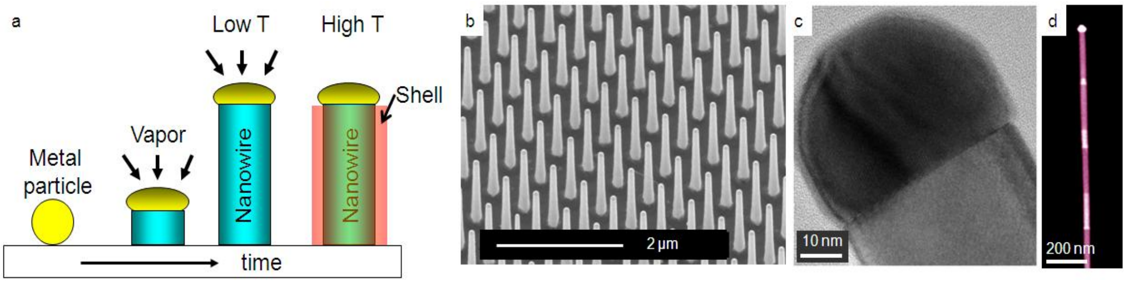

***Figure*** *a) Illustration of the growth mechanism of nanowires. The Au particle catalyses the nanowire growth. After axial growth, radial growth can be initiated covering the wire with a shell of different material. b) SEM image of an array of nanowires grown from a pattern of Au particles. c) TEM image of a nanowire with the Au-particle on top. D) dark field TEM image of a GaP-GaAs heterostructured nanowire.*

For the quantum transport studies we fabricate electronic devices in such a way that we can trap individual electrons. These electrostatic traps, called *quantum dots*, are highly stable and flexible such we can deplete all mobile electrons except for the last one. We then study the spin properties of this last electron. The spin-up or spin-down states are our qubit states, so quantum control over the spin states provides the qubit control. See figure below.

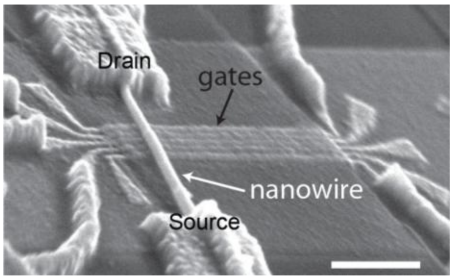

***Figure****: An InAs nanowire crossing 5 gates (horizontal strips made of Au) with electrical source and drain contacts. This device allows to define two quantum dots each containing one electron. The device has been used to operate qubits based on the spin-orbit interaction in InAs.*

For optical studies we incorporate different materials in the nanowire. For instance in the first figure the GaP sections are optically inactive, whereas the GaAs sections show luminescence. When the GaAs section are made small enough, the optical transitions are determined by the quantum confined states. Such quantum optical transition we have investigated in particular in InAsP quantum dots. In these experiments we have shown that we can control the spin of the electron and holes that determine the polarization of the out coming light. This light, importantly, is demonstrated to be a one-by-one emission of individual photons, each photon polarization determined by the spin of the electron and hole.

We are currently pushing two new directions. First of all we wish to convert electron spin superpositions into photon polarization superpositions. This would demonstrate a transfer of the quantum state from an electron-particle to a photon-particle. Quantum state transfer is important for quantum information.

The second new direction is a hunt for a new particle: Majorana Fermion. In solid state systems one can not only engineer a quantum state, one may also be able to engineer particles. A Majorana Fermion is a fundamental particle but never observed. Now theoretical schemes exist that propose using semiconductor nanowires with strong spin-orbit interaction in order to create states that accommodate Majorana Fermions.

## References

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