Nanowires: Technology, physics and perspectives

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Nanowires are currently highlighted as strong contenders in several areas of semiconductor research, including the integration of III-V compounds with Si, the ultimate scaling of CMOS devices, high speed and low power circuitry ("green transistor"), and the realization of quantum information technology. This versatility has prompted numerous research groups to develop nanowire fabrication and characterization methods. However, despite substantial progress over the last years and the demonstration of prototype devices, some fundamental transport properties of nanowires have not been studied in sufficient depth.

Silicon nanowires are typically either grown by the vapor-liquid-solid mechanism using Au particles as catalysts or fabricated by nanolithography. The latter allows carving nanowires into strained Si, leading to structures providing uniaxial strain. The nanowire structure is well suited to wraparound gating, providing optimized electrostatic control of the transistor channel compared to planar CMOS technology. Also, nanowires can be combined with novel transistor concepts, like Schottky barrier transistors or tunnel transistors to optimize carrier injection, speed and power consumption. Moreover nanopatterned Si substrates have great potential in serving as compliant templates for epitaxial growth of III-V nanostructures, as their nanometer-sized footprint can accommodate large lattice mismatch via elastic deformation.

Indium-rich III-V nanowires, namely In(Ga)N, In(Ga)As and In(Ga)Sb nanowires, are of particular interest due to their high electron mobility and low effective mass. The latter leads to the observation of quantum effects in reasonably "large" nanowires. These In-rich nanowires have the peculiarity that the Fermi level is pinned at the surface within the conduction band, leading to a metallic like behavior in the conductivity for narrow wires, with an electron gas at the circumference. Indeed, magnetotransport measurements reveal pronounced magnetic flux periodic oscillations in the conductivity. These are explained by the contribution of coherent circular quantum states along the surface of the nanowires. For undoped In-rich nanowires the conductivity decreases with rising temperatures (metallic transport), the doped nanowires exhibit an increase with temperature (semiconductor). This counterintuitive phenomenon is explained by the dominance of surface states in the transport.

The large surface to volume ratio in nanowires also leads to a strong impact of surface scattering on the mobility. Thus the mobility reported in In-rich nanowires falls short compared to quantum well or even bulk structures. Possible solutions are core/shell structures providing a well-defined clean interface for electron confinement. The introduction of lateral and vertical heterointerfaces while growing the nanowires are envisioned as a first step to exactly control the growth and positioning of quantum dots. Ultimately, this route may provide a suitable concept for quantum information processing.