InAs nanowires with surface states as a building block for tube-like electrical sensing devices

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Cylindrical nanowires have recently become of special interest due to their high surface-to-volume ratio and tunable charge carrier transport properties. The properties of confined carriers in one-dimensional structures, *i.e.* nanowires, are strongly influenced by minor perturbations, which is especially apparent for use in electrical sensing devices as well as field-effect transistors.

Here, we report on a theoretical study of the electron density and low-field electron mobility in rod-shaped, intrinsic and *n*-doped InAs nanowires with a cylindrical electron gas confined by the interplay between vacuum level, surface state density and doping of the nanowires. Special emphasis is put on the impact of surface states. For the calculation of the electron conductivity, we first describe the density of the surface states as a function of energy by the U-type dependence in accordance with the experimental data for InAs presented in [1]. Second, we calculate the band structure of the conduction band by the self-consistent solution of Poisson and Schrödinger equations in cylindrical coordinate system where the Schrödinger equation is solved for the envelope functions within the effective mass approach. Third, we employ the one-particle Monte Carlo method to simulate electron motion in a static electric field applied along the nanowire axis and take into account the most relevant scattering mechanisms, namely acoustic and optical phonon scattering and surface roughness scattering. We show that the conduction band bending and electron density in the nanowires are strongly affected by the charged surface states at both low and room temperature. The Fermi level is pinned at about 0.16 eV [2] above the conduction band edge for a total surface state density exceeding 10^{12} cm^{-2}. The nanowires show significant electron density even without doping due to the donor-type surface states providing free electrons. The doping increases the electron density and redistributes the electrons over the surface states, such that the acceptor-type states predominantly define the electron density for the doping level exceeding 10^{18} cm^{-3}. The calculation of the low-field electron mobility reveals that surface roughness scattering substantially reduces the electron mobility and acts as the main scattering mechanism. The study delivers criteria for development of building blocks for tube-like electrical sensing devices and field-effect transistors.

1. H. Hasegawa and T. Sawada, *J. Vac Sci. Technol*. **21**, 457 (1982).
2. C. Affentauschegg and H. Wieder, *Semicond. Sci. Technol*. **16**, 708 (2001).