Electric and magnetic field dependent conductivity of strain-free modulation-doped InAs/CdSe core/shell nanowires

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A completely innovative approach of using CdSe, i.e. II-VI group material, as a shell for the III-V InAs core nanowire (NW) (Fig. 1, inset) has been recently demonstrated [1]. In this material system one benefits from the low band gap, the small electron effective mass and the high g-factor of the InAs core material, which is in addition strain free and has atomic sharp interface between the core and shell layers due to the extremely small lattice mismatch (approximately 0.5%) of the InAs/CdSe material system. Moreover, In atoms diffusing from the InAs core into the CdSe shell during its growth provide n-type doping of the shell. These doping atoms are remote from the electrons, which are efficiently confined in the core due to the relatively large CdSe/InAs conduction band offset. This enables the control of the core conductivity, while avoiding the inclusion of additional scattering centers into the conductive channel.

We report on a theoretical study of the electric conductance of InAs/CdSe core-shell nanowires at room and low (4 K) temperature. We consider two cases, namely without magnetic field and with magnetic field applied parallel to the NW axis. In order to estimate theoretically an electrical conductance of the core-shell nanowires we assume that the nanowire has a circular cross-section (Fig. 1, inset) and solve coupled Poisson and Schroedinger equations for an envelope function in the conduction band within the effective mass approximation. The electric conductance is estimated using the relaxation time approximation. We show that thickness of the shell and the core strongly determine whether electrons are confined in the InAs core or populating both the CdSe shell and the InAs core. The electron density can be efficiently controlled by the applied external gate voltage. In agreement with the experimental data [1], the calculated dependence of the conductance on the gate voltage (Fig. 1, a) represents three typical intervals with different slopes, where the conductance is determined by the electrons mainly populating either the core (Fig. 1, b1), or the shell (Fig. 1, b3) or both of them (Fig. 1, b2). If the nanowire is subjected to magnetic field parallel to the NW axis, increase of the magnetic field value leads to quasi-periodic oscillations of the electron conductance. If electrons are mainly confined in the core, the Fourier transform of the oscillations shows presence of one dominating frequency (Fig. 1, c1). This peak occurs at the frequency when the magnetic flux enclosed by the average electronic radius is close to the elementary magnetic flux. The second type of the spectra (Fig. 1, c2 and c3) shows some distribution of frequencies, which is due to the electron ensemble distributed over the core and the shell of the NW. The study contributes in exploring fundamental quantum transport physics in low-dimensional systems.

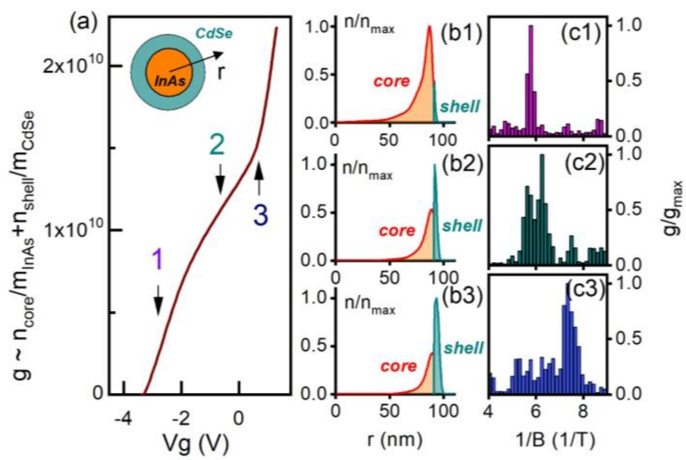

Fig.1. (a) Electron density (n) as a function of the gate voltage (V_g) for the InAs/CdS NW; Inset: InAs/CdSe core-shell structure; (b) Electron density as a function of the radial coordinate r; (c) Normalized Fourier transform of the oscillating magnetoconductance g(B). The NW core radius is set to 91 nm and the shell thickness is 19 nm..

References

[1] M. Kaladzhian *et al*., ACS Appl. Mater. Interfaces **16**, 11035 (2024).