Structural and compositional characterization of InAs/InAsP heterostructure nanowire

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Due to their quasi one-dimensional morphology and large surface to volume ratio, semiconductor nanowires (NWs) exhibit unusual physical properties which differ drastically from the properties of the respective bulk materials. Since the last decade, they are a subject of intensive research activities from the point of view of both fundamental physics and their possible application in nanoscaled electronic and optoelectronic devices [1].

In this contribution, we report the fabrication and Transmission Electron Microscopy (TEM) studies of heterostructured $InP_{core}InAs_{shell}/InAs$ NWs. The NWs were grown on the (111)B InP substrate by Metal-Organic Chemical Vapor Deposition (MOCVD) in two steps: (i) Au nanoparticles catalyzed axial growth of the InP NWs followed by (ii) simultaneous axial growth of the InAs NWs on the top of the InP NWs and radial growth of the InAs shell at the surface of the InAs NWs.

TEM characterization including Energy-Dispersive X-ray (EDX) spectroscopy was conducted on a field-emission Tecnai F20 TEM/Scanning TEM (STEM) Supertwin microscope (operating voltage of 200 kV equipped with thin window energy-dispersive (EDAX.SUTW) Si(Li) detector with an energy resolution of 134 eV.

TEM observation reveals that the nanowires with a 150-200 nm diameter and a length of about 20 µm consist of two distinct fragments separated by a typical junction (Fig. 1a and 2b). Some branch-like structure along the wire (Fig. 1b) can be clearly seen.

Using STEM mode with an electron nanoprobe of around 1nm, we performed line-scan measurements across the NW and simultaneously acquired the x-ray signals generated from the area under the electron beam. Fig. 1 shows representative High Angle Annual Dark Field (HAADF) STEM images and corresponding EDX spectroscopic analysis results obtained from the different parts of a heterostructured NW. Two line-scans, conducted perpendicular to the growth direction left and right from the junction (Fig. 1a), indicate that the left part has a co-axial core-shell structure with an InP core of approximately 100 nm diameter covered with a 70 nm thick InAs shell. The right part of the NW is made of InAs. For the InAs fragment, the elemental mapping indicates that the shape of the nanowires may be in a special triangular form rather than a round one. However, such a projected two-dimensional (2D) image is insufficient to describe the three-dimensional (3D) object. Furthermore, a comprehensive knowledge about the heterostructure, defects distribution and morphology of these NWs could be extremely helpful for deep understanding of their structure and relevant properties. Therefore, we turn to electron tomography technique to retrieve 3D structural information. The tomography experiments are still ongoing.

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The branch-like wires are composed of InAs and grown at the $InP_{core}InAs_{shell}$ fragment of the NW at an angle of 70-80 degrees (Fig.1b). The Branch-wires have a uniform diameter of about 100 nm and a broad length distribution from 200 nm up to 1 µm.

HRTEM and Selected Area Electron Diffraction (SAED) studies yield a cubic zinc-blende structure with <111> grown direction for the InAs part of the composite NWs (Fig. 2a, 2b). Interesting, the highly crystalline InAs part is free of usually observed stacking-faults. These stacking-faults-free InAs NWs are expected to exhibit superior electrical properties in comparison with those possessing defects. However, for the $InP_{core}InAs_{shell}$ part HRTEM and SAED indicate a high-density of stacking-faults (Fig. 2b, 2c).

1. W. Lu and Ch. M. Lieber, J. Phys. D: Appl. Phys. 39 (2006) pR387.
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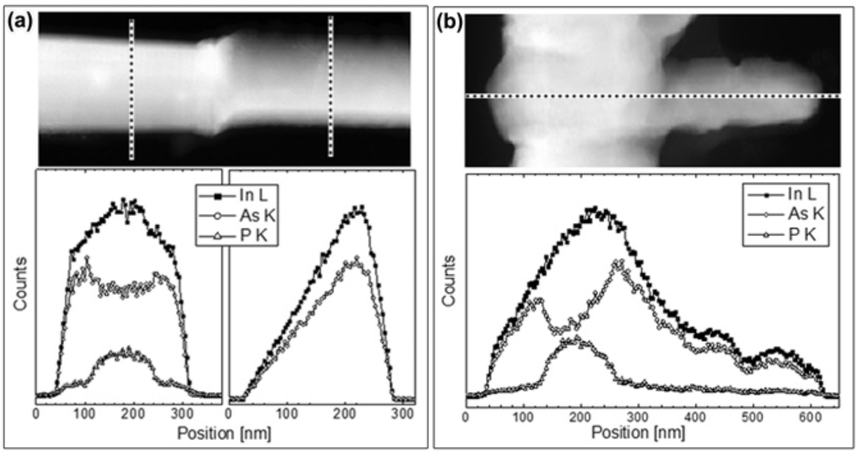

Figure 1. Representative HAADF-STEM images and line profiles of the element distribution evaluated from the EDX line-scans for different fragments of the NW. (a) Left from the junction, $InP_{core}InAs_{shell}$ co-axial NW fragment is shown. Right from the junction, the line-scan yields InAs, probably triangular NW fragment. (b) The line-scan EDXS shows that the branch-like NW is made of InAs and grown at the coaxial $InP_{core}InAs_{shell}$ NW fragment.

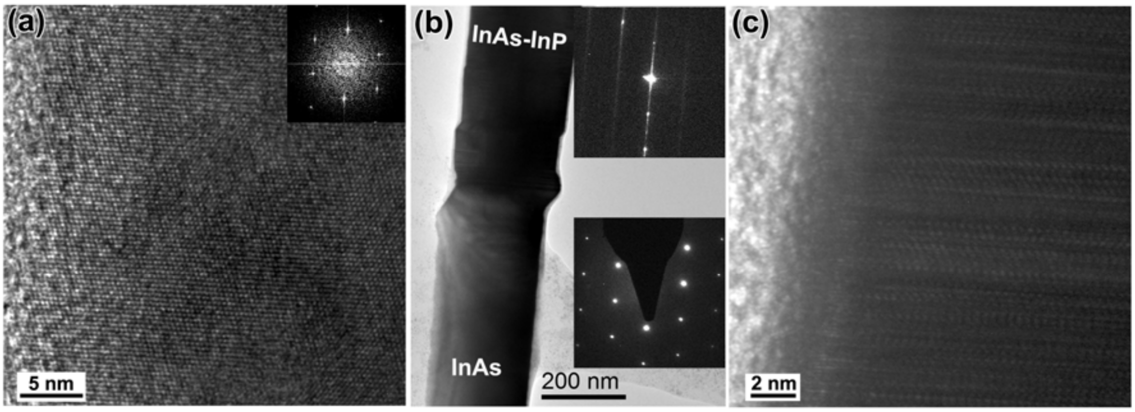

Figure 2. Typical HRTEM images and SAED patterns taken from different fragments of a heterostructured $InP_{core}InAs_{shell}$/InAs NW around the junction. (a) HRTEM image of an InAs NW fragment below the junction. SAED pattern taken from the same part of the NW is show in lower part in (b). (c) HRTEM image of an $InP_{core}InAs_{shell}$ NW fragment above the junction. SAED pattern taken from the same part of the NW is show in upper part in (b).

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