Studying Sb distribution in heterostructured GaAs/GaAsSb nanowires with quantitative HAADF-STEM

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GaAs nanowires are a promising candidate for optoelectronic applications, such as solar cells, light emitting diodes and nanolasers [1]. Nanowires enable dislocation-free growth on lattice-mismatched substrates, and different heterostructures can be grown in both radial and axial direction. Depending on the growth conditions, pure GaAs nanowires adapt either to the wurtzite (WZ) or zinc blende (ZB) crystal phase. Band gap engineering is achieved by alloying the nanowires with for instance Al or Sb; alloying might however introduce strain, defects and phase transformations. To obtain nanowires with the desired properties, it is crucial to be able to study the composition in axial as well as radial direction at a high spatial resolution and to relate the compositional variations to changes in the crystal phase.

High-angle annular dark field scanning transmission electron microscopy (HAADF-STEM) holds a promise for compositional imaging due to its sensitivity to atomic number (Z) [2]. By comparing experimental intensities with simulated intensities - a method referred to as quantitative HAADF-STEM - specimen composition can be studied with high spacial resolution and accuracy [3]. HAADF-STEM intensity is however sensitive to several non-compositional factors as well, such as distortions in the atomic column symmetry and static atomic displacements (SAD) caused by alloying elements in the lattice [4,5]. These have to be considered in the intensity quantification.

Here we have applied quantitative HAADF-STEM for studying Sb concentration and distribution in axial ZB GaAs\textsubscript{1-x}Sb\textsubscript{x} inserts in otherwise pure ZB/WZ GaAs nanowires (growth direction [111]/[0001]). Prerequisite for quantitative work is the normalization of the experimental images to incident beam intensity, which was obtained by scanning the ADF detector prior to the imaging [3]. Simulations including the SAD were performed with a frozen-lattice multislice software STEMSim [6]. The work was done on a non-corrected microscope (JEOL 2010F) at a relatively low magnification.

The hexagonal cross-sectional shape and easy specimen preparation render the nanowires especially suited for quantitative HAADF-STEM work (Fig. 1(a,b)). Using intensity profiles taken across the nanowire images, the intensity could be studied as a function of thickness. At the pure ZB GaAs part, a perfect match was obtained for the whole thickness range when directly comparing normalized experimental and simulated intensities (Fig. 2(a)). At the GaAs\textsubscript{1-x}Sb\textsubscript{x} insert, deviation was observed at the wedges, where the thickness is varying (Fig. 2(b)). This deviation results either from a non-uniform radial distribution of Sb, or changes in the cross-sectional shape at the insert. A peak Sb concentration of 14% was found from both the direct intensity comparison and from comparison via an intensity ratio I/I\textsubscript{GaAs}, where I\textsubscript{GaAs} is the pure ZB GaAs intensity at the maximum nanowire thickness. The HAADF intensity was additionally analyzed along the evenly thick central part of the nanowire (Fig. 1 (c)).

This study demonstrates that quantitative HAADF-STEM is well suited for analyzing Sb concentration and distribution in ZB GaAs\textsubscript{1-x}Sb\textsubscript{x} nanowire segments with high spatial resolution. Information about the Sb distribution and precise Sb concentration levels were obtained in both radial and axial direction [7].
References

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Figure 1. (a) A schematic image of a GaAs nanowire segment with a GaAs$_{1-x}$Sb$_x$ insert (gray), (b) a HAADF-STEM image of the insert area of a nanowire and (c) intensity profile along the central part of the HAADF image.

Figure 2. Experimental and simulated intensity profiles across the nanowire (a) at the pure ZB GaAs region and (b) at the insert. Areas from which the intensity profiles are quantified are marked with rectangles in Fig. 1(b) (lower box: pure ZB GaAs, upper box: ZB GaAs$_{1-x}$Sb$_x$).