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Quantitative Transmission Measurements in a Scanning Electron Microscope

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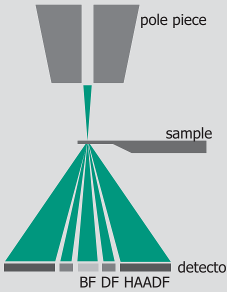
Motivation

- Scanning transmission electron microscopy (STEM) in high-angle annular dark-field mode (HAADF) ⇨ strong material (Z-) contrast
- Energies ≤ 30 keV ⇨ reduced knock-on damage
- Thin samples ⇨ high lateral resolution of 1-2 nm
- Standard scanning electron microscope (SEM) ⇨ easy handling and quick variation of parameters (e.g. electron energy, detection angles, ...)

Instrumentation

- Combined focused ion beam (FIB)/SEM ⇨ FEI Strata 400S
- Annular semiconductor STEM-detector ⇨ bright-field (BF), dark-field (DF) and HAADF segments
- HAADF scattering angle range ⇨ 0.2 - 0.7 rad
- electron energy ⇨ 25 keV



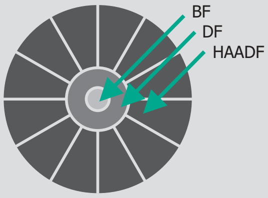


Fig.1 (left): Schematic principle of STEM instrumentation
Fig.2 (right): Schematic detector layout

Samples and preparation

- Heterostructure with four $In_xGa_{1-x}As$ quantum wells of 25 nm thickness separated by GaAs layers of 35 nm thickness
- In-concentrations x = 10, 20, 30 and 40 %
- grown on GaAs (001) substrate by molecular beam epitaxy (MBE)
- cross-section lamella preparation by FIB-technique
- wedge-shaped thickness profiles

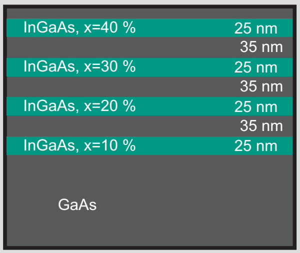


Fig.3: Schematic composition of sample material

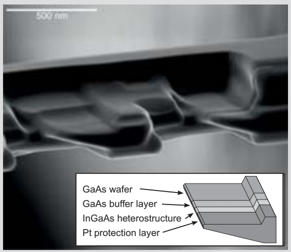


Fig.4: Top-view SE-image of lamella showing two wedges
Inset: Schematic composition of sample wedge

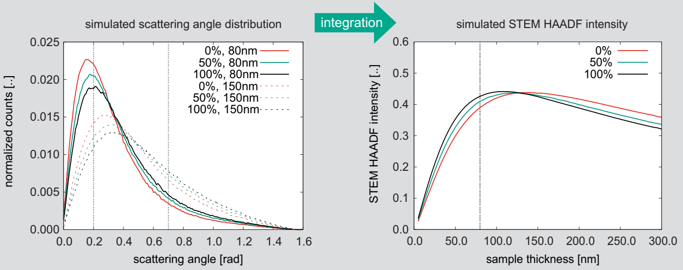
Monte Carlo simulations

- Monte Carlo simulations with NISTMonte package
- Use of screened Rutherford cross-sections and continous slowing down approximation for energy loss
- Input ⇨ sample composition and geometry, electron energy
- Output ⇨ energy and scattering-angle distributions
- Consideration of detector influences
- Calculation of electron transmission in HAADF angular range ⇨ direct comparison with image intensity

Acknowledgement

- This work was partly funded by the DFG Research Center for Functional Nanostructures (CFN) and by the DFG grant Ge 841/20. It has been further supported by a grant from the Ministry of Science, Research and the Arts of Baden-Württemberg (Az: 7713.14-300).

Results - Simulation



- Similar but still distinguishable curves for different In-concentrations
- Transmission curves show chracteristic shape and maximum

Results - Sample thickness determination

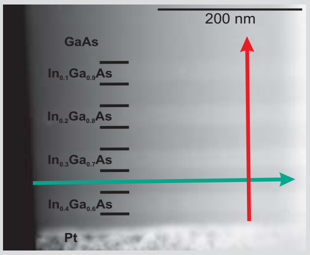
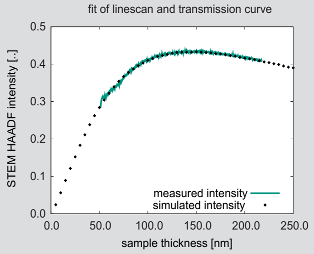
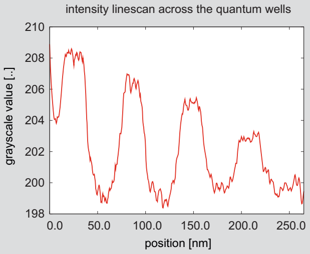


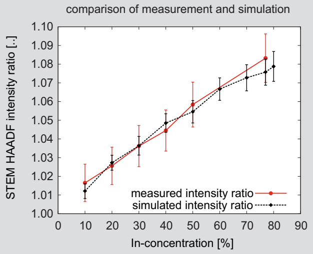
Fig.5: STEM cross-section image with marked linescans



- Intensity linescan (Fig.5, green arrow) along wedge (perpendicular to the edge) in region with known composition (GaAs)
- Transformation of linescan position d into sample thickness ⇨ $t(d) = t_0 + d \cdot \tan\alpha$
- Fit of linescan and transmission curve ⇨ precise values for thickness offset t_0 and wedge angle α
- Calculation of local sample thickness possible for every pixel

Results - Composition quantification





- Intensity linescan (Fig.5, red arrow) at chosen sample thickness (80 nm) across quantum wells (parallel to the edge)
- Constant sample thickness assured by constant intensity in GaAs layers
- Differences of 4 - 9 gray levels sufficient for quantification
- Calculation of intensity ratios with respect to GaAs intensity ⇨ I_{InGaAs} / I_{GaAs}
- Comparison of measured intensity ratios with simulated intensity ratios ⇨ good agreement and reproduction of layer compositions

Summary and conclusions

- Sample preparation with wedge-shaped profile by FIB
- Reduction of knock-on damage due to electron energies < 30 keV
- Strong material contrast in HAADF STEM images
- Quantification by comparison with Monte Carlo simulations
- Determination of local sample thickness and composition with high lateral resolution
- More details ⇨ T.Volkenandt et. al, *Microsc. Microanal.*, available on CJO 16. July 2010, doi: 10.1017/S1431927610000292

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