Measuring of Segregation Profiles from HAADF-STEM Images

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Due to their tunable band gaps, ternary III-V semiconductor heterostructures containing $In_xGa_{1-x}As$ or $Al_xGa_{1-x}Sb$ are used for applications in communication technology, such as light emitting diodes. Unfortunately, the growth of these structures by molecular beam epitaxy (MBE) is considerably affected by segregation, which leads to blurred interfaces between layers of different composition [1] with a characteristic shape of the concentration profile.

We have investigated segregation in $In_xGa_{1-x}As/GaAs$ heterostructures with high angle annular dark field - scanning transmission electron microscopy (HAADF-STEM) on a TITAN 80/300 TEM. In HAADF-STEM only electrons scattered under high angles are detected and thus the main contribution stems from thermal diffuse scattering (TDS) and is sensitive to the nuclear charge of the scattering atoms (Z-contrast). Introducing normalized intensities by normalizing the measured intensity with respect to the intensity of the incident electron beam allows quantitative interpretation of HAADF-STEM images [2]. Comparison of the measured intensity with reference intensities obtained from simulated STEM images in regions of known composition (GaAs) results in the specimen thickness [3]. The thickness is interpolated over regions of unknown composition ($In_xGa_{1-x}As$), so that the Indium concentration can be determined.

The image simulations were carried out with the STEMsim program [4] using the multislice approach in the frozen lattice approximation. Static atomic displacements (SADs), which are caused by the difference of the atomic radii of Ga and In sharing the same sublattice, are considered in the simulations.

To check the precision of the HAADF-STEM method, the In-concentration was also determined with the composition evaluation by lattice fringe analysis (CELFA) technique [5]. Figure 1 shows the concentration profiles measured with both techniques, which are nearly identical. Finally the concentration profiles were fitted following an empirical model by Muraki [6] that describes segregation and segregation coefficients R were calculated (Figure 2).

References

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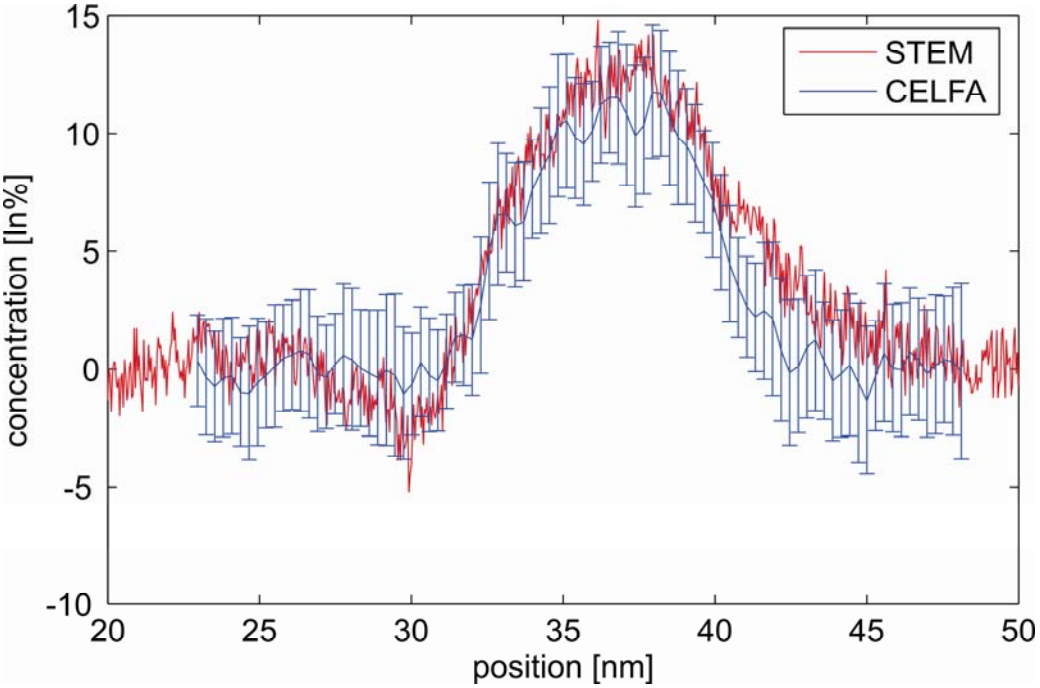

FIG. 1 Indium concentration measured with CELFA and HAADF-STEM.

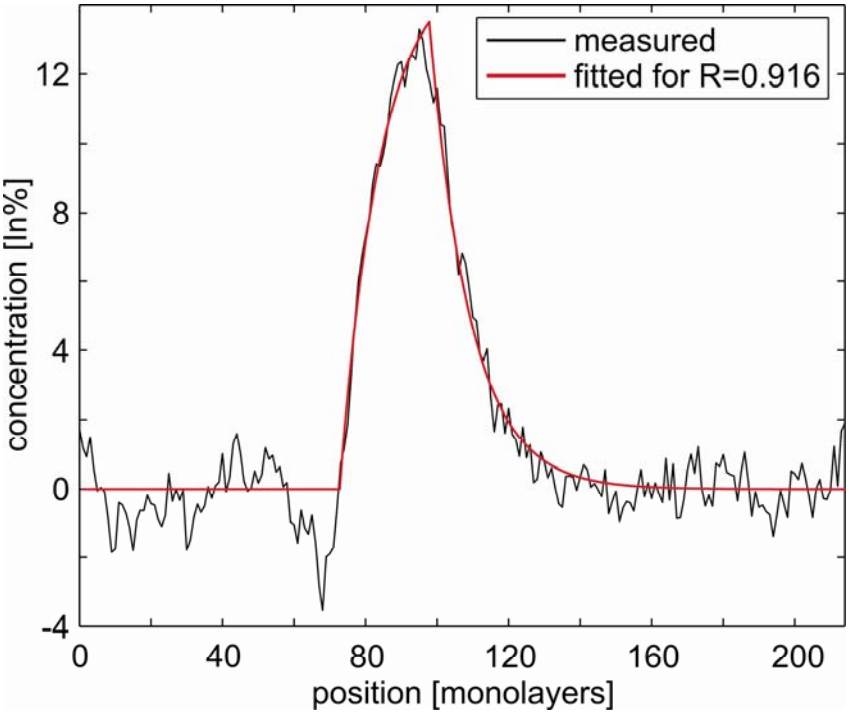

FIG. 2 Measured STEM-concentration profile and fitted Muraki profile for a segregation efficiency R of 0.916.