Towards a quantitative concentration analysis in InGaAs-heterostructures using HAADF-STEM

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For the growth of semiconductor heterostructures it is important to know the composition distribution in the grown structure to further improve the growth process. We have investigated the Indium concentration in InGaAs quantum wells grown by molecular beam epitaxy (MBE) via high angle annular dark field – scanning transmission electron microscopy (HAADF-STEM).

In HAADF-STEM only the electrons scattered by high angles are detected. The main contribution to the measured signal stems from thermal diffuse scattering (TDS) and is sensitive to the nuclear charges of the scattering atoms (Z-contrast). Simulations were performed with the frozen lattice approach for different specimen thicknesses and Indium concentration values [see figure 1]. Static atomic displacements and non-homogenous detector sensivity have not been taken into account. For quantitative analyses the measured intensity has to be normalized with respect to the intensity of the incident beam [1]. Comparing the simulated reference intensity with the normalized intensity in regions of known concentration leads to the specimen thickness. This is in good agreement with scanning electron microscopy control measurements of the specimen thickness for GaAs.

In regions of unknown concentration the thickness is also not known. So we interpolated the thickness between regions of known concentration, which requires plane specimen preparation with focused ion beam (FIB). Taking the interpolated thickness and the simulated reference values into account, we evaluate the Indium-concentration [see figure 2].

To estimate the accuracy of this method we measured the concentration with the precise composition evaluation by lattice fringe analysis (CELFA) method [2]. Here the undiffracted (000) and the chemical sensitive (002)-beam are used for imaging and for the concentration evaluation. For calculating (002)-Fourier components of the image intensity, electron redistribution [3] and static atomic displacements have been taken into account.

We find that our simulations lead to an overestimation the Indium-concentration. Possible reasons are neglection of the influence of static atomic displacements [4] and inhomogeneous detector sensitivity. Broadening of the beam by dynamic electron diffraction might also be a problem.

Furthermore we investigated the influence of a brief heating (flash-off) of the specimen before the growth of the quantum wells with HAADF-STEM and CELFA. This was done in order to remove physisorbed Gallium atoms from a possible surface layer to suppress segregation. Different flash-off temperatures were used, but both methods reveal no significant influence of the flash-off temperature on the concentration profiles of the quantum wells.

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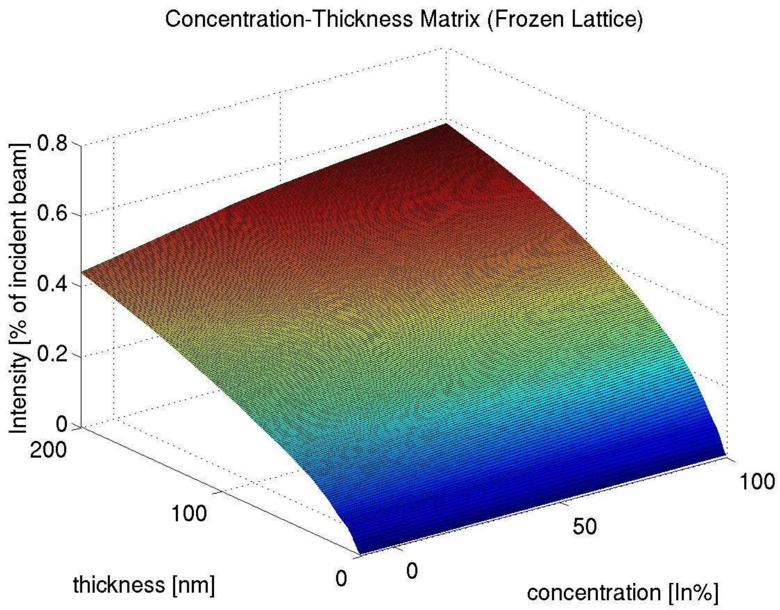

Figure 1. Simulated HAADF-detector signal as a function of the specimen thickness and the Indium-concentration.

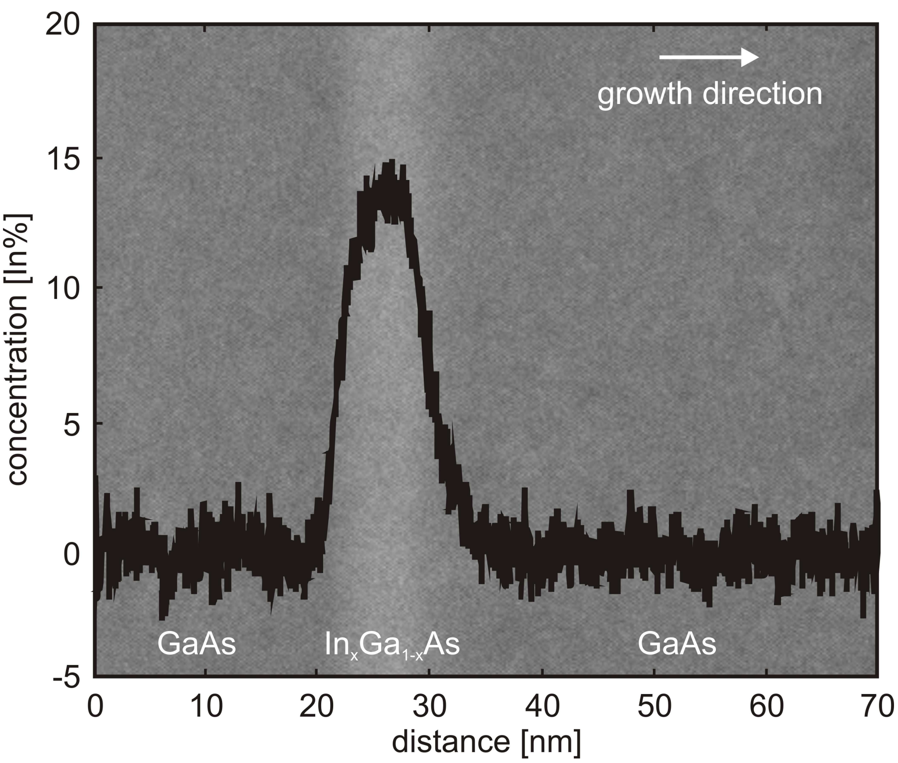

Figure 2. Measured HAADF-STEM image (background) and evaluated concentration profile

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