Composition quantification by backscattered electron imaging in scanning electron microscopy

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Backscattered electron (BSE) imaging is widely used in scanning electron microscopy (SEM). The contrast is strongly related to the atomic number of the specimen, providing information of the element distribution in the sample. For quantification of the material contrast comparison with calculations or simulations is needed [1].

In this work a method for quantification of the BSE contrast of images taken with a semiconductor detector is presented. The measured intensities are calibrated within one single image in a region with known composition to eliminate the influence of the detection and amplification system. The intensity ratios are then compared with calculations based on an analytical model which considers single electron scattering as well as electron diffusion [2]. No additional instrumentation is needed. For finding optimal imaging parameters and enhancing the reliability, measurements are performed at different primary electron energies. The influence of beam broadening is discussed and considered for quantification.

The sample is a system of $In_xGa_{1-x}As$ layers of 25 nm thickness embedded in a GaAs matrix. The layers contain In in concentrations of x=0.1, 0.2, 0.3 and 0.4 defined by molecular beam epitaxy growth conditions and verified by quantitative scanning transmission electron microscopy [3]. Cross-section samples with wedge-shaped thickness profiles are cut perpendicular to the InGaAs/GaAs layer system by means of focused-ion-beam (FIB) techniques. A FEI Quanta ESEM equipped with an annular BSE semiconductor detector is used. Only electrons with energies higher than 2 keV are detected.

Figure 1 shows a BSE image of a wedged cross-section of the layer system taken with a primary electron energy of 25 keV. The image shows the $In_xGa_{1-x}As$ layers with bright contrasts, which are separated by GaAs with lower intensity. A Pt-layer was deposited prior to FIB milling which exhibits an intense brightness. An intensity linescan along the wedge in the GaAs matrix region with known composition is performed (arrow parallel to the layers along increasing sample thickness). For calibration of the grayscale values, intensity ratios related to the intensity in the thickest part (maximum intensity of the linescan) are calculated. By comparison with analytical calculations [2], the thickness in each point of the linescan can be determined (Figure 2).

Subsequently linescans perpendicular to the layer system (see Figure 1) are performed at constant thickness in a thin and thick region of the wedge (Figure 3). The linescan at a thickness of 50 nm shows a constant intensity for the embedding GaAs matrix material. For the linescan in the thicker region the intensity of the GaAs in between the quantum layers increase. This can be explained by the broadening of the penetrating beam and the In-concentrations of the neighbouring $In_xGa_{1-x}As$ layers. For calibration of the grayscale levels, intensity ratios of the $In_xGa_{1-x}As$ quantum wells with respect to the GaAs substrate are calculated. These ratios are compared with the calculated curves (Figure 4) showing good agreement within the error bars.

It is shown that contrast quantification of BSE images taken with a standard semiconductor detector is possible with a high lateral resolution. The sample thickness and the material composition can be determined within one single image if some a priori information is available. The standard SEM provides the possibility for a flexible change of the primary electron energy enhancing the reliability of the measurements and finding the optimal imaging conditions. For small structures beam broadening must be considered. Quantifications are performed by comparison with analytical models.

References

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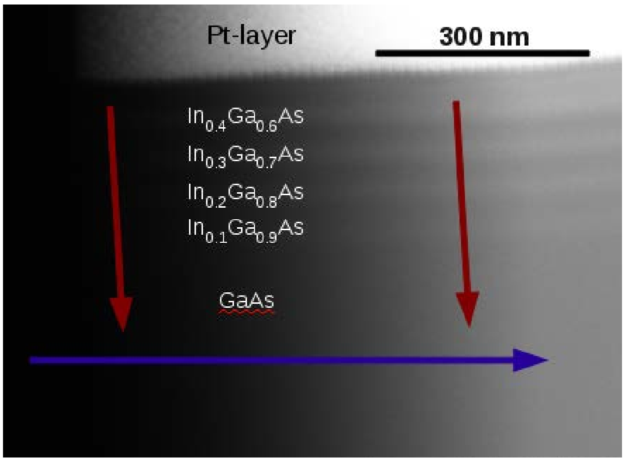

Figure 1. *BSE image taken at 20 keV of a wedge-shaped cross-section sample of an $In_xGa_{1-x}As$/GaAs heterostructure covered with a Pt-layer. Linescan along the wedge for increasing thickness (blue), linescans perpendicular to quantum layers at constant thickness (red).*

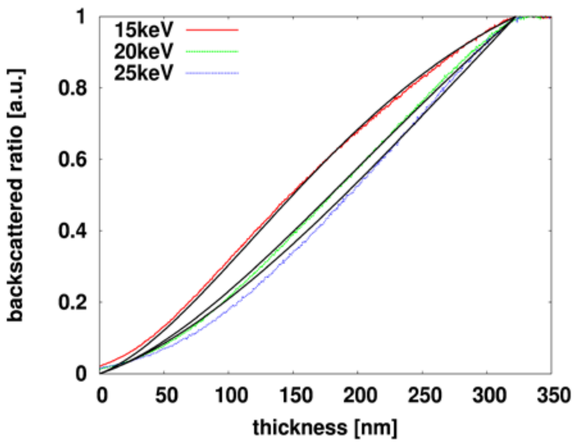

Figure 2. Normalized BSE intensities in the GaAs wedge for different primary electron energies. Color lines: measured linescans along the wedge, black lines: calculated values.

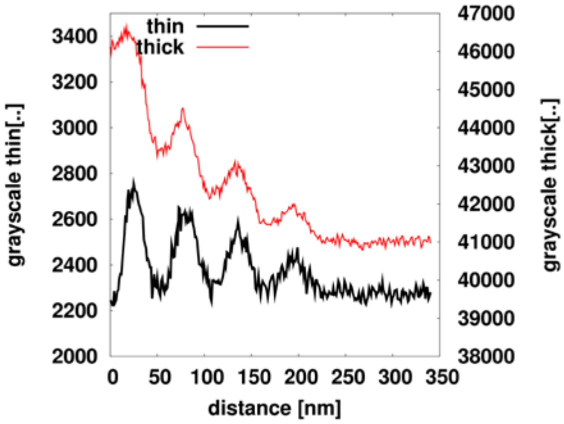

Figure 3. *BSE intensity linescans perpendicular to the $In_xGa_{1-x}As$/GaAs heterostructure at a constant thickness of 280 nm (red) and 50 nm (black).*

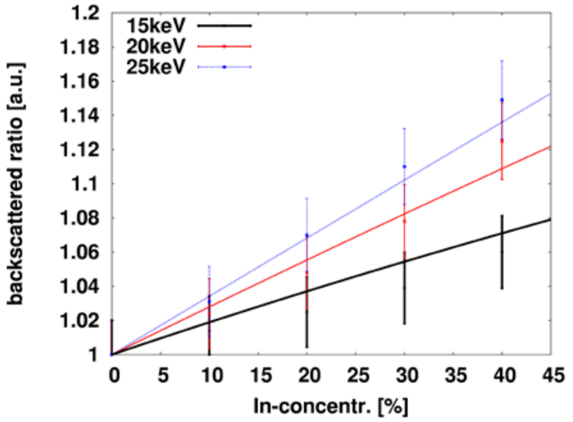

Figure 4. *BSE intensities of the $In_xGa_{1-x}As$ quantum wells normalized with respect to the GaAs BSE intensity for different primary electron energies. Color dots: measurements, lines: calculated values.*