# Towards quantification of the In-concentration in InAs quantum dots

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**Abstract:** Segregation of indium during molecular beam epitaxy of InAs quantum dots (QDs) embedded in GaAs often leads to significant discrepancies between the real and intended composition. In this work we present an approach to measure and reconstruct the In-concentration in InAs QDs on the basis of transmission electron microscopy images.

The structural and chemical properties of self-assembled InAs quantum dots (QDs) in a GaAs matrix are of great interest because numerous devices were already realized or are envisioned on the basis of InAs QD structures, e.g. in quantum information processing [1]. Due to the small QD size the In-concentration within a QD is difficult to control during epitaxy and may differ from the intended value. Usually, In-segregation causes an inhomogenous In-concentration with an increase towards the top of the QD [2]. As the optoelectronic properties strongly depend on the shape, size and composition of the QDs, these properties are of significant interest for the understanding of the device performance. We present here an approach towards measurement and reconstruction of the In-concentration in $In_xGa_{1-x}As$ QDs which is based on high-resolution transmission electron microscopy (TEM) using composition-sensitive (002) lattice-fringe images and the composition evaluation by lattice fringe analysis (CELFA) technique [3]. The analyzed InAs QD structure was grown by molecular beam epitaxy (MBE) on a GaAs(001) substrate and GaAs buffer. 2.4 monolayers of InAs were then deposited with a low deposition rate of 0.0057 ML/s at 753 K. After a 10 s growth interruption a 28 nm thick GaAs cap layer was grown.

TEM data yields information averaged over the thickness of a typically 10 to 40 nm thin TEM sample whose thickness cannot be determined in a straightforward way. Measuring the composition of a three-dimensional small In-rich QD embedded in a GaAs cap layer requires the determination of the TEM sample thickness and assurance that the QD is completely embedded and not only partially contained in the TEM sample. This situation will typically lead to a measured In-concentration which is lower than the real one. Using high-angle tilts of the TEM sample the TEM sample thickness and location of QDs in the TEM sample were obtained. The QD shape was determined to correspond to a truncated pyramid by high-angle annular dark-field scanning TEM. Based on this information the measured In-concentration (color-coded In-concentration of a single QD shown in a side perspective in Fig. 1a) can be corrected by an appropriate post-processing procedure. Fig. 1b shows the In-concentration after correction where an increase of the In-concentration from about 50 % at the interface to almost 100 % at the top is observed which can be understood by In-segregation during the MBE growth.

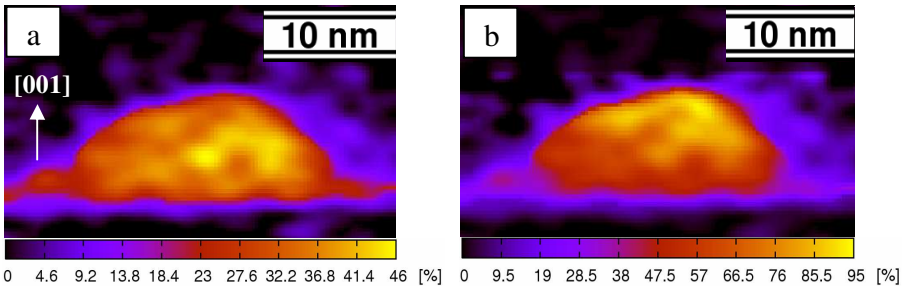


Fig 1. a) Color-coded In-concentration x of a single $In_xGa_{1-x}As$ QD shown in a side perspective after the evaluation with CELFA and b) after post processing.

## References

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