InAs/GaAs

The lattice mismatch f between $In_xGa_{1-x}As$ and GaAs reaches values up to 7 % for binary InAs on GaAs. Depending on the In-concentration x, $In_xGa_{1-x}As$ on GaAs can be grown either as layers/quantum wells (QWs) or as quantum dots (QDs).

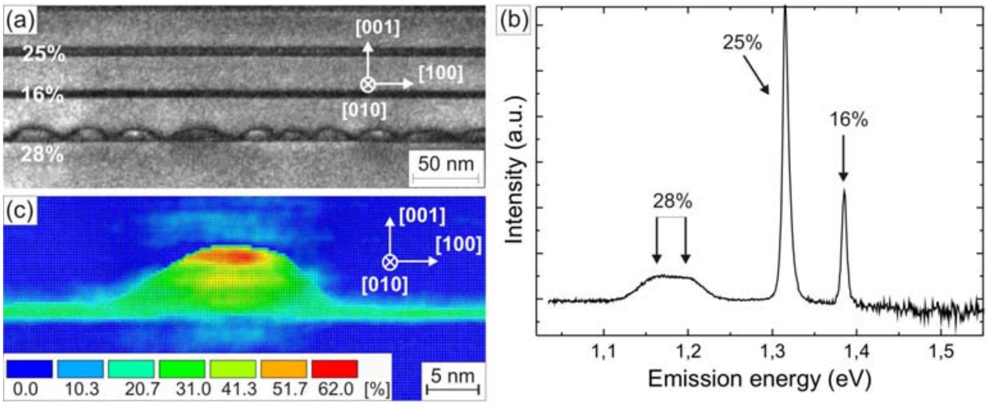

Fig.1. a) Cross-section TEM image of a sample containing three InGaAs layers with different In-concentration embedded in GaAs and b) corresponding photoluminescence spectrum. c) In-concentration map of an InGaAs QD embedded in GaAs.

Fig. 1a shows a cross-section transmission electron microscopy (TEM) image of a sample containing three InGaAs layers embedded in a GaAs matrix. The image was taken with the (002) reflection which is composition sensitive in the sphalerite structure. The bottom layer containing on the average 28 % of indium consists of defect-free islands with lateral sizes up to 40 nm. In contrast, the upper two layers with nominal In-concentrations of 22 % and 16 % have not undergone a transition from layer to island growth mode. Fig. 1b presents low-temperature (5 K) photoluminescence (PL) spectra of the same sample containing characteristic peaks for all the three layers which are labelled by the nominal In-concentration. Two sharp emission lines with a full width at half maximum of 8 and 7 meV occur at 1.315 eV and 1.385 eV. These lines can be attributed to the two InGaAs QWs. A broad emission band with a full width at half maximum of 77 meV is visible at approximately 1.18 eV which corresponds with the observation of islands by TEM. A red shift of the PL peak positions with increasing nominal In-concentration is observed. In contrast to the narrow emission from the quantum wells, the width of the PL peak of the island layer is 10 times broader as a result of the distribution of island sizes and probably slightly different In-concentrations within the islands (Fig. 1a).

The deposition of a few MLs (monolayers) of InAs leads always to QD formation. InAs QDs do typically not consist of binary InAs but ternary InGaAs with a composition that may vary continuously over the QD volume. The distribution of Ga and In is strongly inhomogeneous and affects the shape of the confinement potential and the energy levels of localized electronic QD states. The sizes and shape of QDs depend strongly on the growth parameters.

With the composition evaluation of lattice fringe analysis (CELFA) method or the digital analysis of lattice images (DALI) technique it is possible to measure the composition on an atomic scale. Fig. 1c presents a colour-coded map of In-concentrations in a single “InAs” QD embedded in GaAs. The QD layer was grown by deposition of 2.4 ML InAs on GaAs at a very low deposition rate. The colours from blue to red correspond to an increasing In-concentration Fig. 1c. It is observed, that the In-concentration in the island increases in the growth direction.

Segregation of indium is a dominant effect during the epitaxial growth of InGaAs which may lead to significant deviations between the intended and real In-distribution in InGaAs nanostructures.

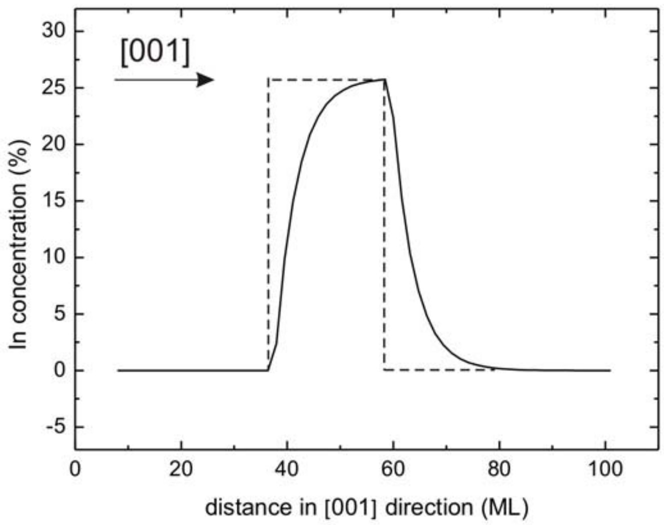

Fig. 2: In-concentration profile (solid line) of the upper InGaAs layer from Fig. 1a with 22 % of indium along the [001] growth direction obtained with CELFA. The dashed line shows the In-concentration profile in the case of the absence of the In-segregation.

Experimental segregation profiles can be well described by the phenomenological model suggested by Muraki et al. (Appl. Phys. Lett. 61, 557 (1992)). This is illustrated by the example shown in Fig. 2. The asymmetry of the experimental In-concentration profile (solid line) is caused by In-segregation during the InGaAs deposition. In the ideal case without segregation, the In-concentration profile corresponds to the dashed line in Fig. 2. In-segregation originates from the fract that In-atoms impinging on the growth surface are not immediately chemisorbed into the growing material but accumulate in a "floating layer" on the growth surface. Atoms in the floating layer are only weakly bound to the crystalline surface by a Van-der-Waals type bonding. If the InGaAs layer is overgrown with GaAs the In-atoms contained in the floating layer are incorporated only gradually into the growing material. This delayed incorporation of the In-atoms leads to chemically non-abrupt interfaces of the quantum well. Note that the amount of indium missing at the lower interface of the QW can be found at the upper QW interface.

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