CdSe/ZnSe

Heterostructures containing CdSe with a nominal thickness of a few ML embedded in a ZnSe matrix have been a subject of interest for many years which is motivated by the prospect of obtaining CdSe QD structures for fundamental studies and the perspective of their incorporation in LDs for the emission in the green and blue-green visible spectral range. We have studied single und multiple CdSe/ZnSe-heterostructures by transmission electron microscopy, that were fabricated by different cooperating groups in Germany, Japan, England and Russia. Two main aspects are considered: the determination of the Cd-distribution of CdSe quantum-dot (QD) structures embedded in ZnSe and the defect configuration in the CdSe/ZnSe-heterostructures.

As an example, in Fig.1 presents the Cd-distribution in a cross-sectional view that was obtained for a CdSe/ZnSe QD sample by applying the CELFA technique. The colours from blue to red correspond to an increasing Cd-concentration.

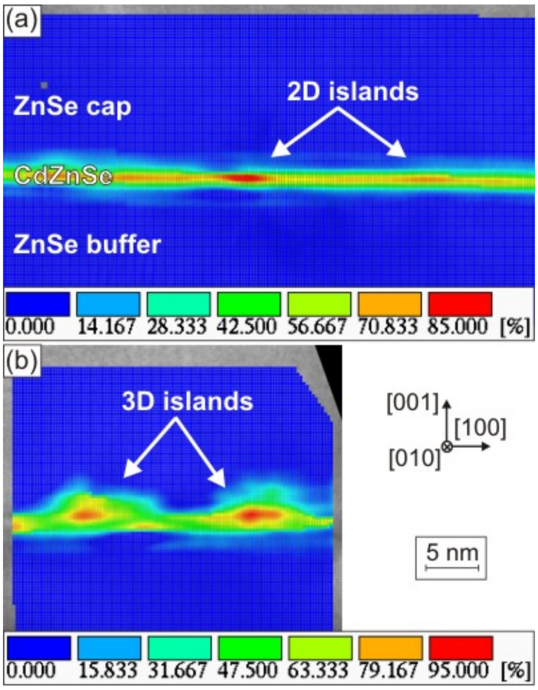

Fig.1

The structures were grown by molecular-beam epitaxy on GaAs (001) substrates. 3 ML CdSe were deposited at 230 °C on a strain-relaxed 1000 nm thick ZnSe buffer layer. The first sample (Fig.1a) was immediately covered by ZnSe, while the second sample (Fig.1b) was thermally activated for 40 min at 310 °C before the ZnSe overgrowth. During this thermal activation, the RHEED pattern undergoes a distinct transition from a streaky to spotty. ZnSe cap layers of several 10 nm were grown at 310 °C.

Generally, none of the investigated CdSe layers consisted of pure CdSe. Instead, we observed a strong intermixing with the ZnSe buffer and cap layers. Small Cd-rich regions with a lateral extension of less than 5 nm embedded in a quantum well with a lower Cd concentration are observed in the sample without thermal activation (Fig.1a). Along the growth direction, the extension of the islands did not significantly exceed the height of the homogeneous CdZnSe layer in between the islands, indicating their two-dimensional (2D) character. For that reason, the Cd-rich regions can be considered as 2D islands. Note that a similar Cd-distribution – 2D islands embedded in the CdZnSe layer with a lower Cd-concentration - was observed in many

investigated CdSe/ZnSe samples that were grown by different growth groups with different techniques, independent of the growth temperature and the amount of deposited CdSe.
For the sample with thermal activation, the character of the Cd-distribution (Fig. 1b) is completely different. Pronounced three-dimensional (3D) islands with a height significantly larger than the surrounding CdZnSe layer are observed. It can be assumed that the core of the islands consists of pure CdSe because the TEM sample thicknesses are in the range between 10 and 20 nm which can lead to a reduction of the measured Cd-concentration if an island with high Cd-concentration is embedded in the ZnSe at the investigated sample area. CELFA analyses of further areas containing 3D islands show that the lateral island extensions vary between 5 and 15 nm.
The broadening of the CdZnSe layer with respect to the nominal CdSe coverage in all samples could be induced by Cd/Zn interdiffusion or Cd-segregation during the ZnSe cap-layer growth. The shape of the Cd-concentration profiles which can be extracted from the CELFA maps show a pronounced asymmetry with a steep increase at the lower interface and a gradual decline of the Cd-concentration towards the ZnSe cap. The profile asymmetry is typical for segregation which can be considered to be the dominant mechanism for the layer broadening and an important consequence of the ZnSe cap-layer growth.
The lifetime of CdSe/ZnSe devices depends on the density of defects which is responsible for its degradation. In this context, the investigation of the configuration of defects in CdSe/ZnSe heterostructures is important because the reduction of the defect density requires the understanding of their nature and origin.
If the deposited CdSe amount in the CdZnSe layer exceeds 2.5-3 ML, "coffee-bean"-like contrast features are observed in TEM images of plan-view specimens of CdSe/ZnSe heterostructures taken under zone-axis conditions. The occurrence of the "coffee-bean" contrast is usually explained by the shape of the strain field of coherently strained 3D islands in a matrix, which appears after the transition from 2D to 3D morphology (Stranski-Krastanow growth mode). However, as will be shown below, dark-field weak-beam TEM images of plan-view samples combined with the investigation of cross-sectional specimens reveal the difference between 3D islands and defects in CdSe/ZnSe structures.

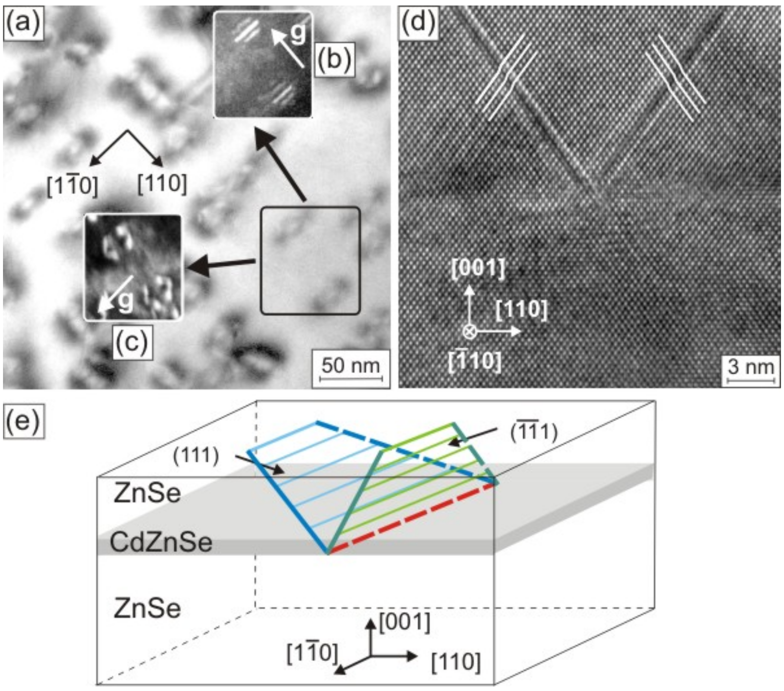

Fig. 2

Fig.2a-c shows plan-view TEM micrographs of the same region of a CdSe/ZnSe sample, imaged under various conditions. The bright-field image along the [001]-zone axis (Fig. 2a) depict "coffee-bean" regions with a density of $\sim 10^{10}$ cm^{-2}. The (220) weak-beam image Fig. 2b reveals a stripe contrast that is typical for stacking faults. In the (2-20) weak-beam image (Fig. 2c) two pairs of partial dislocations with a V-shaped dislocation-line arrangement are observed. Fig.2d is a HRTEM image taken along the [110]-zone axis, which displays a stacking fault pair lying on the (111) and (-1-11) planes. The white lines show a deviated faulted atomic sequence from the ideal atomic sequence. The two stacking faults intersect at a point close to the CdSe/ZnSe interface. The analysis of plan-view and cross-section images allows the determination of the defect configuration in the CdSe/ZnSe structure which is depicted in the Fig. 2e. The configuration of the defects which are generated close to the CdZnSe layer consists of two intrinsic stacking faults on {111}-type crystal planes bound by Shockley partial dislocations. The stacking faults are often observed to be generated in regions of the CdZnSe layer with a high Cd-concentration. At the intersection line of the stacking faults, a stair-rod dislocation with b = 1/6<110> is formed (red line). The contrast of the stacking faults is mainly determined by the thickness of the cap layer.
Quantitative evaluation of Fig. 2d with the DALI (digital analysis of lattice images) procedure is used to derive the displacement vectors of the atomic bi-columns (white points in Fig. 2d) in the vicinity of the stacking faults. In combination with the analysis of plan-view images it is shown that the stair-rod dislocations at the intersection of the stacking faults reduce the misfit between the CdSe layer and the ZnSe buffer. The averaged length of the stair-rod dislocations increases with increasing total amount of deposited CdSe revealing an increasing plastic relaxation.
Thus, "coffee-bean" contrast in plan-view strong-beam TEM images of CdSe/ZnSe structures is primarily induced by a pair of stacking faults on {111} planes which are inclined against each other. The application of weak-beam imaging is therefore required for the distinction between stacking faults and three-dimensional Stranski-Krastanow islands.

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