MS-8-P-2819 TEM investigations of In$_x$Ga$_{1-x}$As quantum dots in GaP

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For optoelectronic applications, InGaAs quantum dots (QDs) in GaAs are a well-known materials system with various advantageous properties. However, the integration of GaAs-based devices with standard silicon based technologies remains challenging, because of the large lattice mismatch between these materials. Within the III-V semiconductors GaP allows a pseudomorphic growth on Si due to the small lattice mismatch of only 0.4%. But GaP is an indirect semiconductor, thus not very suitable for optoelectronic applications. Calculations show [1] that InGaAs-QDs in a GaP matrix allow radiative direct transitions under certain composition, size and strain conditions. Such QDs are a promising way to combine their advantageous optoelectronic properties with the structural advantages of GaP.

By metalorganic vapor-phase epitaxy, InGaAs-QDs were successfully grown within GaP. Prior to the InGaAs, a few monolayer (ML) thick GaAs-layer was deposited onto the substrate [2]. After the InGaAs-layer, the growth was interrupted for several seconds to allow for QD-formation. The subsequent deposition of a few ML GaAs facilitates a further strain engineering of these dots. A strong increase in the photoluminescence intensity of these structures indicate the switching from indirect to direct optical transitions within these dots [3].

As the quaternary InGaAsP system is zinc blende structure, the strong composition dependence of the {200}-structure factor (Fig. 1) can be exploited to investigate the structural properties of these dots within the TEM. Therefore, all samples were prepared as cross-section along <100> zone axis. For instance, zone-axis HRTEM combined with Fourier filtering of the (020)-coefficient reveals the shape of a truncated pyramid, which is typical for QDs (Fig. 2). Furthermore, fourier-filtered micrographs under two-beam conditions can be used to obtain further details of the structure. For instance, a comparison of a conventional (200) darkfield (intensity of diffracted beam) with the amplitude of the (200) image Fourier coefficient (amplitude of complex product between direct and diffracted beam) reveals an InP-enriched layer, 7 nm above the InGaAs-layer (Fig. 3). This enriched layer could be attributed to In segregation during growth.

References:
[3] G. Stracke, et al., Indirect and direct optical transitions in In0.5Ga0.5As/GaP quantum dots. Submitted

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Fig. 1: Composition dependency of the (200) structure factor in Volts. Calculated using the isolated atom approximation and Doyle&Turner atom form factors.

Fig. 2: Real part of Fourier-filtered (020) reflection of HRTEM micrograph (a.u.). The filtered intensity is proportional and sensitive to compositional changes.

Fig. 3: Comparison of contrasts in conventional (200) darkfield micrograph (left) and Fourier-filtered (200)-coefficient of image under two-beam conditions-revealing an InP-enrichment due to segregation above the InGaAs-layer.