Segregation in InGaAs/GaAs Quantum Wells: MOCVD versus MBE

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Low-dimensional semiconductor heterostructures grown by metal organic chemical vapour deposition (MOCVD) and molecular beam epitaxy (MBE) are one of the main research topics in solid-state physics at present. Most applications of semiconductor nanostructures are found in the field of optoelectronic devices such as light-emitting diodes and laser diodes. Especially InGaAs/GaAs is being studied intensively owing to the formation of self-organized quantum dots (QDs) by Stranski-Krastanow growth mode under certain conditions. The development of QD lasers is expected to lead to an increased quantum efficiency and to lower threshold current densities [1]. Although MOCVD and MBE can, in principle, be used to control epitaxial growth on a monolayer (ML) scale, kinetic growth effects such as segregation [2], diffusion and adatom migration [3] must be taken into account. Especially segregation is crucial in InGaAs/GaAs structures, because it leads to a significant broadening of interfaces at conditions of growth used commonly.

The presence of segregation of Ga was demonstrated nearly twenty years ago in AlGaAs [4]. Two years later, segregation of In was found in InGaAs [5]. In InGaAs/GaAs, segregation is most probably caused by the formation of an In floating layer (FL) close to the growth surface. Garcia et al. [6] showed that the FL does not have a bulk-like bonding because it does not contribute to the accumulated stress in the sample. If an InGaAs layer is capped by GaAs, In atoms from the FL are incorporated into the cap layer, leading to an exponential decrease of the In-concentration in the cap layer along the growth direction. The resulting concentration profiles are described well by the phenomenological model by Muraki et al. [7] which implies an underoccupied metal sublattice under certain conditions [8]. An atomistic and physically well-founded model for segregation is missing still.

In this contribution we demonstrate the effect of segregation by a quantitative measurement of In-concentration profiles of InGaAs quantum wells by high-resolution transmission electron microscopy (HRTEM). The images were evaluated with the composition evaluation by lattice fringe analysis (CELFA) technique [9], using structure amplitudes of the chemically sensitive 002 beam obtained by density functional theory. The samples were grown by MOCVD and MBE. In MOCVD, growth was performed in an AIXTRON 200 AIX facility equipped with a rotating substrate holder, at 20 mbar with TMGa, TMIn solution, and pure AsH$_3$ as source materials; palladium purified H$_2$ with a flow rate of 7slm was used as carrier gas. The growth was performed on (100) exactly oriented semi-insulating GaAs. The InGaAs layers were grown at 550 °C at a rate of 1 ML/s and subsequently covered by a 30 nm GaAs layer. The AsH$_3$ partial pressure was in the range 1.4-5.7x10$^{-1}$ mbar during the growth of the InGaAs layers and 5.7x10$^{-1}$ mbar during the growth of the GaAs cap layers.
mbar during the capping process. The MBE growth of the InGaAs layers with nominal In concentration between 5 and 30% was performed at 510 °C and 450 °C, respectively. The partial pressures were As4: $1.8 \times 10^{-5}$ Torr and Ga: $4.4 \times 10^{-7}$ Torr. The growth rate was 0.278 nm/s for GaAs. For the layer with 15% In, the growth rate was 0.05 nm/s and the In partial pressure $1.5 \times 10^{-5}$ Torr.

FIG 1 shows an example profile of an MOCVD grown sample. The center layer consists nominally of $\text{In}_{0.5}\text{Ga}_{0.5}\text{As}$ with a thickness of 6 ML, embedded in a 10 nm thick $\text{In}_{0.1}\text{Ga}_{0.9}\text{As}$ layer. The measurements were fitted using the segregation model of Muraki. The following quantities are used as fit parameter: the segregation efficiency $R$, which describes the probability with which an In-atom changes from the topmost ML into the FL, the “nominal” In concentration $x_0$ which the profile would approach after infinitely long growth time, and the number $N$ of MLs deposited. For the MBE samples we find segregation efficiencies $R$ of $0.82\pm0.02$ at 510 °C and $0.73\pm0.03$ at 450 °C, and for the MOCVD samples we obtain $0.67\pm0.03$ at 550 °C.

In conclusion, we find that the segregation efficiency decreases with decreasing temperature in MBE grown samples. For the given growth parameters, the MBE grown samples show a larger segregation efficiency than the samples grown by MOCVD.

References: