ESRF	**Experiment title:** **Depth resolved strain analysis in lateral structured buried quantum well structures**	**Experiment number**: **SI 897**
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Report:

Lateral modulation of strain in semiconductor structures on the nanometer length scale is one of the possibilities to tailor their optical and structural properties, i.e. the strain dependence of the electronic band gap can be exploited to achieve a lateral carrier confinement. In our project we used the concept of introducing the lateral strain modulation after growth. In this case the quantum well (QW) itself is not affected by etching and regrowth.

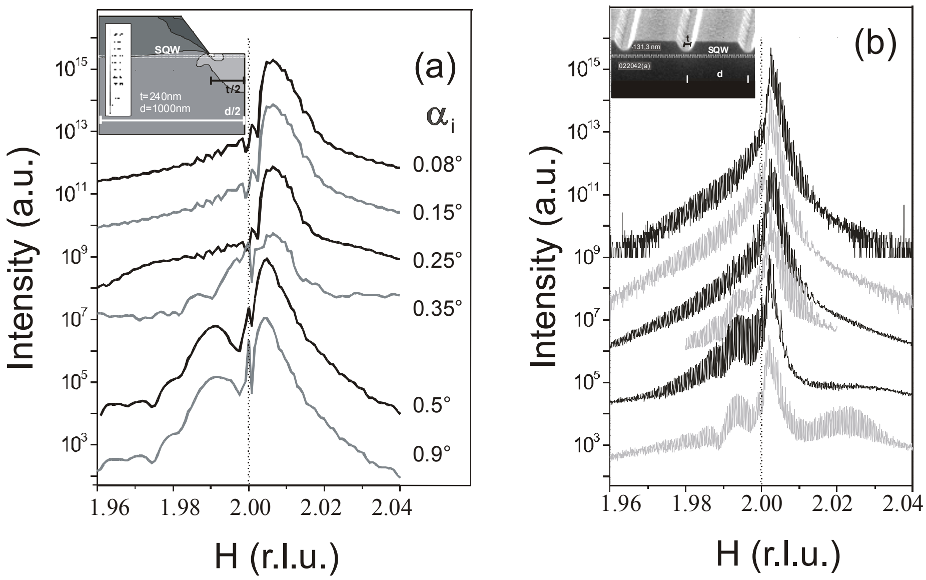

Figure 1: Simulated (a) and experimental (b) GID X-ray pattern (longitudinal scans) for different penetration depths for the sample as a shown in the inset (inset (a): model; inset (b) real structure).

The lateral strain modulation was realized by lateral patterning of a pseudomorphically strained InGaP stressor layer grown on top of an InGaAs-QW via strain relaxation of the etched ridges of the stressor layer. The QW remains unaffected by the etching process thus avoiding defect formation and subsequent nonradiative recombination of charge carriers.

Device structures, however, require a planarisation of the grating surface using a second epitaxy step. First tests of a second epitaxy with GaAs showed that out-diffusion of In from the sidewall facets occurs followed by a diffusion of In to the bottom of the etched valleys [see report SI-727]. These effects compensate the induced strain and are origins of structural defects.

Following the results of our last measurements a new sample design was created. After a series of FEM calculations a special stressor layer sequence was found which is able to introduce a very high strain into the InGaAs-QW. On the other hand an improvement of the growth procedure lead to a suppression of In out-diffusion from the stressor layer sidewalls. Figure 1 shows the grazing incidence diffraction (GID) pattern of a free standing surface grating with an InGaP stressor layer with a homogeneous In concentration. Figure 1a shows the simulated GID X-ray pattern of the model structure as depicted in the inset. The model data (layer sequences, composition, geometry) were used as an input for the fabrication of this nanostructure providing a maximum bandgap shift under the given geometrical restrictions. Figure 1b shows the measured grazing incidence diffraction X-ray pattern of the nanostructure. Due to the induced strain a PL line shift of 18 meV was estimated using a deformation potential approach. The experimental result was only slightly smaller; a PL line shift of 16 meV was measured at 10 K.

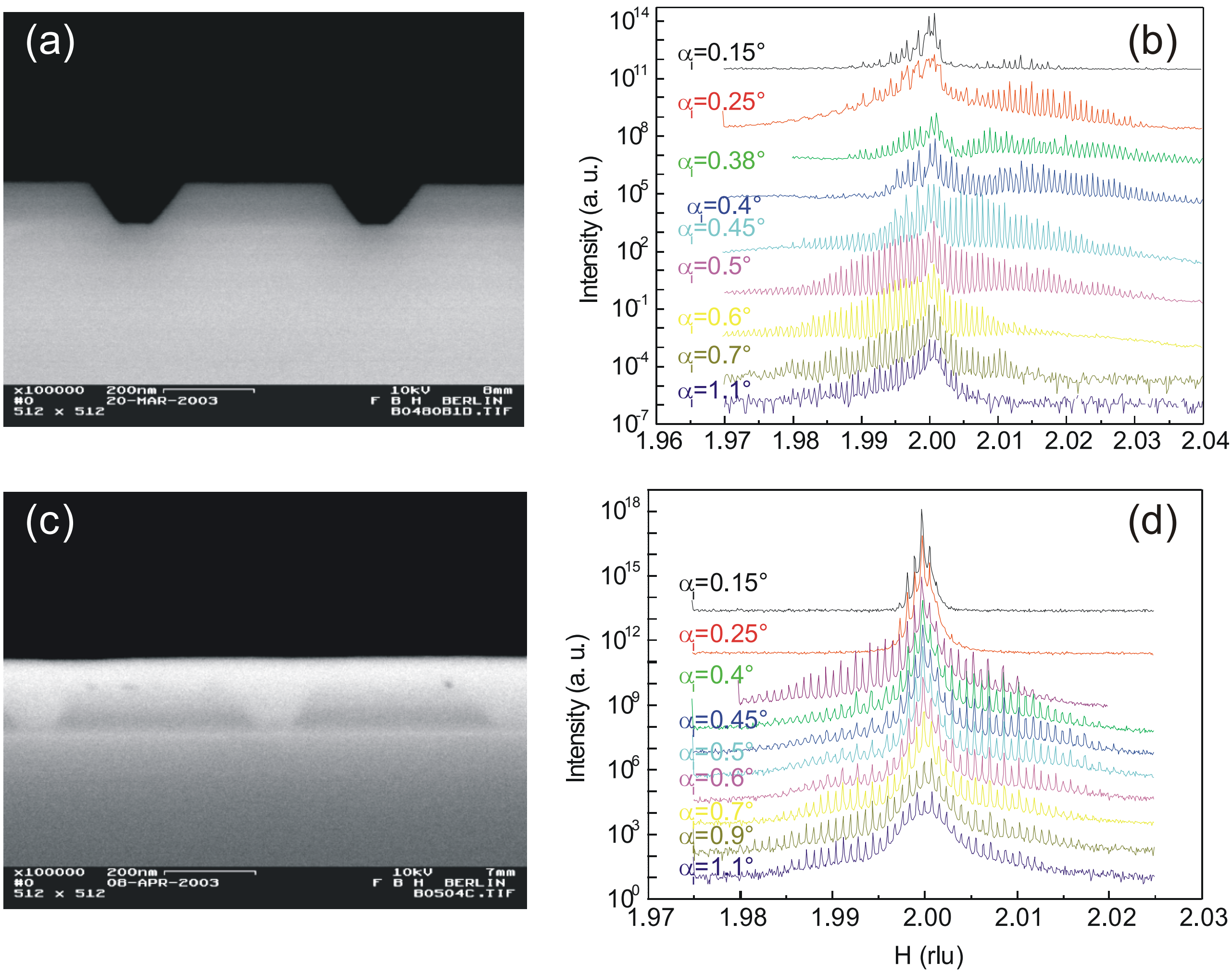

Figure 2: SEM pictures of the of freestanding (a) and overgrown (c) gratings using the optimized stressor layer sequence; the corresponding X-ray pattern are shown in (b) and (d), respectively.

Using this experience we were able to enhance the bandgap variation further. An especially designed strain graded layer sequence was developed to increase the strain as high as possible thereby preventing misfit dislocation formation even for relatively thick stressor layers. Figure 2 shows the experimental results of such a structure. In Figure 2a a SEM picture of the freestanding grating is seen. The patterned InGaP stressor consists of two layers, the lower one with a higher strain (ε = 0.6%) and the upper one with less strained material. Figure 2b shows the GID X-ray pattern of this structure. At incidence angles between α_i=0.45° and 0.6° the induced lateral tensile lattice mismatch due to relaxation of the stressor layer can clearly be seen.

The SEM picture of the structure after overgrowth with GaAs is shown in Fig. 2c. Due to a different heating-up-procedure before regrowth almost no out-diffusion of In from sidewalls took place. Figure 2d shows the X-ray pattern of the structure. Due to the overgrowth the strain modulation is now reduced and is now found at larger penetration depths Λ, at incidence angles between α_i=0.6° and 0.7°. There is almost no strain and material contrast variation at low penetration depths which demonstrates the high quality of the overgrowth. However, the overgrowth reduced the PL line shift from 31 meV to a value of 17 meV.

Our finite element simulation shows, that for the overgrowth a complementary strained material with respect to the stressor layer should be used. This would lead to a much lower reduction of the PL wavelength shift after regrowth.

An additional task during our last experiment a the beamline ID10B was to investigate the strain behavior of a 2D patterned stressor layer. We expected an increase in strain by a factor of $\sqrt{2}$ in comparison to an 1D grating. However, due to difficulties connected with the holographic photolithography the patterning turned out to be very inhomogeneous. That's why we decided not to carry out GID measurements on this structures.

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Publications resulting from the last experiments

/1/ S. A. Grigorian, J. Grenzer1, S. Feranchuk, U. Zeimer and U. Pietsch "Grazing-incidence diffraction study of strain-modulated single quantum well nanostructures"
J. Phys. D: Appl. Phys. 36 (2003) A222-A224

/2/ U. Zeimer, J. Grenzer, S. Grigorian, J. Fricke, S. Gramlich, F. Bugge, U. Pietsch, M. Weyers and G. Tränkle "Influence of Lateral Patterning Geometry on Lateral Carrier Confinement in Strain-Modulated InGaAs-Nanostructures"
phys. stat. sol. 195 (2003) 178

/3/ J. Grenzer, S.A. Grigorian, S. Feranchuk, U. Pietsch and U. Zeimer, J. Fricke, H. Kissel,A. Knauer, M. Weyers, and G. Tränkle "Nanoengineering of lateral strain modulation in quantum well heterostructures"
to be published 2003

/4/ U Zeimer, H Kirmse, J Grenzer, S Grigorian, H Kissel, A Knauer, U Pietsch, W Neumann, M Weyers and G Tränkle "Analysis of strain and composition distribution in laterally strain-modulated InGaAs nanostructures after overgrowth with GaAs or InGaP"
Microscopy of Semiconducting Materials, Cambridge, U. K. 2003 to be published