ESRF	**Experiment title:** **Depth selective investigation of the strain distribution in buried quantum wire structure**	**Experiment number**: SI 488
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Shifts: 15	**Local contact(s)**: B. Struth, O. Konovalov	*Received at ESRF:*

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Report:

In recent years lateral carrier confinement in semiconductors attracted more and more interest to improve the optical and electrical properties of device structures. One way to achieve a lateral carrier confinement is to exploit the strain dependence of the electronic band gap. Lateral strain variation can be realized by lateral patterning of a pseudomorphically strained InGaP layer grown on top of a $In_{0.16}Ga_{0.84}As$-quantum well (QW). The QW is sandwiched between a thin GaAs layer, serving as a barrier and etching stop layer, and the GaAs substrate. The pseudomorphic strain of the InGaP stressor layer can easily be controlled by its In/Ga ratio, i.e. the layer can be strained either tensily or compressively. Lateral modulation of the electronic band gap within the QW is achieved via strain relaxation of the etched ridges of the InGaP layer. The InGaAs-QW remains unaffected by the etching process thus avoiding defect formation and subsequent nonradiative recombination of charge carriers. Due to the lateral strain modulation the optical properties of such structures, investigated by photoluminescence (PL) at 10 K, show a splitting of the emission wavelength of the InGaAs-quantum well into two spatially separated PL-lines.

For the lateral patterning of the stressor layer we applied holographic photolithography and subsequent wet chemical etching. Depending on the etching conditions the InGaP layer is partially removed down to the GaAs etch stop layer. The prepared ridges and valleys are aligned parallel [1-10]. The valley sidewall facets have a nearly {111} orientation. For the present experiment a grating period of 1 µm was chosen to prevent an overlap of the strain fields of adjacent valleys and lateral quantization effects.

Detailed knowledge of the 3D strain distribution within sample is necessary to calculate the real band structure of the system which requires nondestructive analysis. X-ray diffraction in grazing-incidence geometry (GID) is capable to obtain in-plane strain information within a surface grating structure. Its particular depth sensitivity provides information about the in-plane strain in different depths below the sample surface.

The aim of the present experiment was to collect data about the 3D strain distribution for samples with different residual strain implemented by different Indium concentrations of the InGaP stressor layer and a different ridge to valley geometry. The obtained information will be employed for the optimization of the device structure.

GID investigations were carried out at beamline ID10B using the vertical sample setup. For the definition of the reciprocal space we used a coordinate system rotated by 45 degrees around the [001] surface normal. Scans were performed in reciprocal space at two symmetry equivalent in-plane reflections. Transverse scans, which keep the length of the scattering vector constant, were measured at (0-20) reflection (equivalent to (2-20) in the cubic coordinate system). These scans provide information about the shape of the grating ridges. Longitudinal scans, where the length of the scattering vector Q changes, were measured at (200) reflection (equivalent to (220) in the cubic coordinate system). These scans are sensitive for in-plane strains. Running line scans for different incidence angles α_i the strain distribution can be obtained for different depths below the sample surface.

High-resolution in reciprocal space was achieved by mounting a silicon (111) analyzer crystal in front of the scintillation detector resulting in an in-plane resolution smaller than $2*10^{-4}$ nm^{-1} for both scan types. Thus the resolution in reciprocal space was limited by the accuracy of the goniometer movement only. To separate the patterned and non-patterned sample areas we had to use 400 µm high and 10 µm wide slits in the incoming beam path. Fig.1 shows transverse (a) as well as longitudinal (b) scans for sample A (tensily strained InGaP layer) depending on α_i. Due to the extremly parallel beam delivered by beamline ID10B we were able to separate the narrow spaced grating truncation rods of the 1 µm grating period (fig.1a). The intensity of the grating peaks is symmetrical with respect to the substrate Bragg peak. Since the thickness of the InGaP layer is 120 nm, the strength of oscillations becomes smaller at higher α_i. From the intensity distribution over adjacent grating peaks the ridge/valley ratio is estimated to about 3/1.

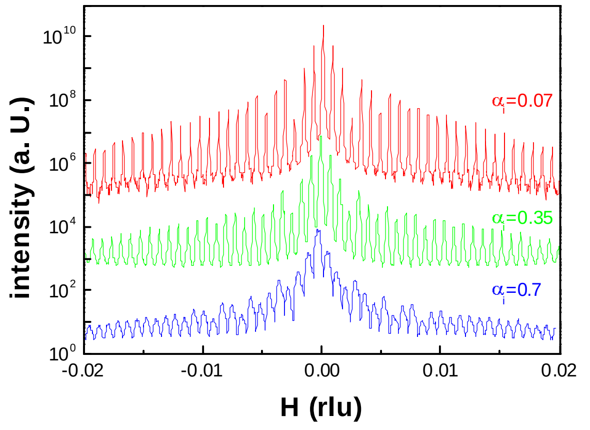

Fig. 1a transverse scans for sample A depending on α_i

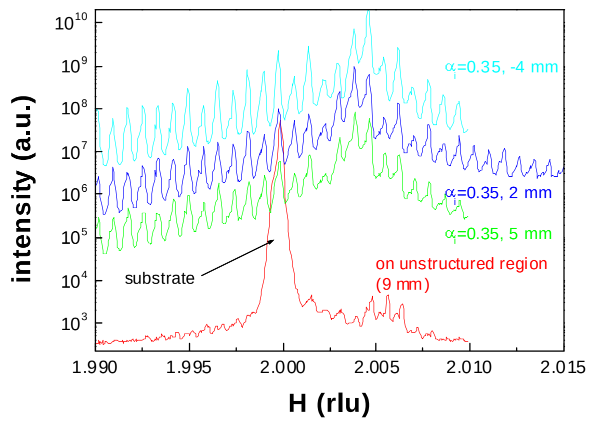

Fig. 1b longitudinal scans for sample A depending on lateral beam position on sample

The maximum intensity of the longitudinal scans does not correspond to the Bragg reflection of the substrate. The later one can be identified by moving the probing beam to an unpatterned sample area (see Fig.1b). The residual strain of the patterned areas can roughly be estimated from the difference in H between substrate peak and the maximum of the envelope function over the grating peaks. From $\Delta H/H = -\Delta a_{//} / a_{//}$ follows that the lattice parameter of the top region of sample is smaller than the GaAs substrate. Thus a relaxation of the InGaP layer near the free surface has to be taken into account. The similar shape of the scans taken at different lateral positions on the grating region shown in fig.1b indicates the good homogeneity of the strain distribution.

To evaluate the influence of the ridge/valley ratio on the strain distribution sample B (valley width 100 nm) and C (250 nm) were investigated. Fig. 2 shows the respective longitudinal scans for different α_i. As already observed for sample A, the highest intensity peak is observed at a higher H value compared to the GaAs substrate (H=2) indicating a smaller parallel lattice constant. This is attributed to the relaxed part of the patterned InGaP, where the total strain is compressive. As a consequence the total strain in other sample regions is tensile leading to additional features in the scans, indicated by arrows. The broader the valley width, the more pronouced this features are. From the additional thickness fringes in fig. 2b the width of the tensily strained region (total strain) can be estimated to be about 350 nm. For the smaller valley width a clear depth dependence of the tensily strained region can be observed (see fig. 2a). Therefore the location of the this region is well below the surface near the InGaAs-QW.

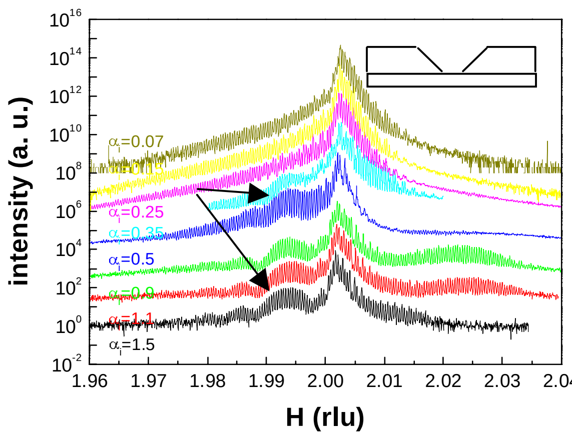

Fig. 2a longitudinal scans for 100 nm valley width (sample B)

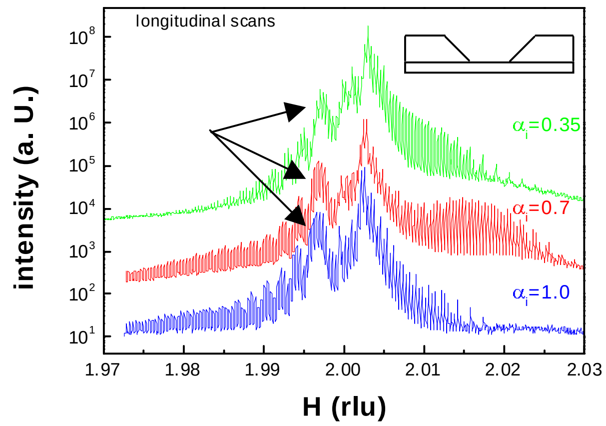

Fig. 2b longitudinal scans for 250 nm valley width (sample C)

Finite-element calculations will be performed to verify the observed strain distribution. Using the strain distribution at the QW the band structure can be calculated and conclusions for device optimization can be drawn.

Literature:

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