ESRF	**Experiment title:** **Strain analysis in quantum well lasers nano-structured by a planar lateral stressor**	**Experiment number**: **SI 1090**
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Report:

Vertical carrier confinement is the basis for the most optoelectronic devices, since the dimensional reduction opens a wide variety of physical effects that can be exploited. Additionally, a lateral carrier confinement offers another degree of freedom for device design, i.e. in laser diodes a higher modal gain and a better thermal stability can be achieved. It has been shown that a lateral carrier confinement can be induced into an InGaAs single quantum well (SQW) by lateral strain modulation due to patterning of an InGaP stressor layer on top of it [1]. After optimisation of the vertical and lateral sample geometry up to 50 meV photoluminescence energy shift between the unpatterned and patterned material can be obtained [2]. However, for device application a planarization of the structure in a second epitaxial step is needed.

We have developed a special growth procedure and layer sequence for planarization while keeping the lateral carrier confinement as high as possible and maintaining high crystalline perfection. Grazing incidence x-ray diffraction (GID) measurements carried out during this experiment are used to study the real 3D strain distribution in the samples before and after MOVPE overgrowth. We found that the lateral strain modulation in the InGaAs-QW region is only slightly reduced after overgrowth with a layer sequence of compressively strained InGaP and GaAs. Two spatially distinct optical transitions with a 10K-photoluminescence line separation of 39 meV were observed.

A key issues of our experiments is to introduce a periodic elastic strain while preventing any plastic deformation of the lattice. For the determination of the lateral lattice mismatch caused by this elastic strain modulation we used the longitudinal scans at the (200) reflection. In Figure 1a the GID intensity curves with respect to the angle between the incoming x-ray beam and the sample surface α_i are shown for the free standing grating. It is seen that for small α_i the intensity maximum is shifted to H >2 indicating a smaller lateral lattice parameter compared to GaAs. This is due to the relaxation at the free surfaces of the grating, since the InGaP stressor layer was chosen to have a smaller lattice parameter than GaAs. For α_i > 0.4 a local intensity maximum emerges which is due to a region with a larger lateral lattice parameter than GaAs. This is the InGaAs QW region below the valley of the grating. Thus, in this region an additional tensile strain ($\varepsilon_{\|}$ = 0.4 %) is observed. In Figure 1b the corresponding GID scans for the sample overgrown with InGaP/GaAs are presented. For small α_i almost no grating side peaks are observed. That means there is no lateral periodicity of the lattice parameter in the GaAs region. Only at deeper penetration of the x-ray beam into the sample the lateral periodicity becomes visible due to a lateral change of the refractive index and strain. At α_i = 0.45° the local intensity maximum (indicated by arrow) reaches its maximum. From an estimation of the penetration depth for α_i = 0.45° it is known that this is the depth where the InGaAs QW is located. Thus it can be concluded that the lateral strain periodicity can be maintained even after overgrowth of the grating.

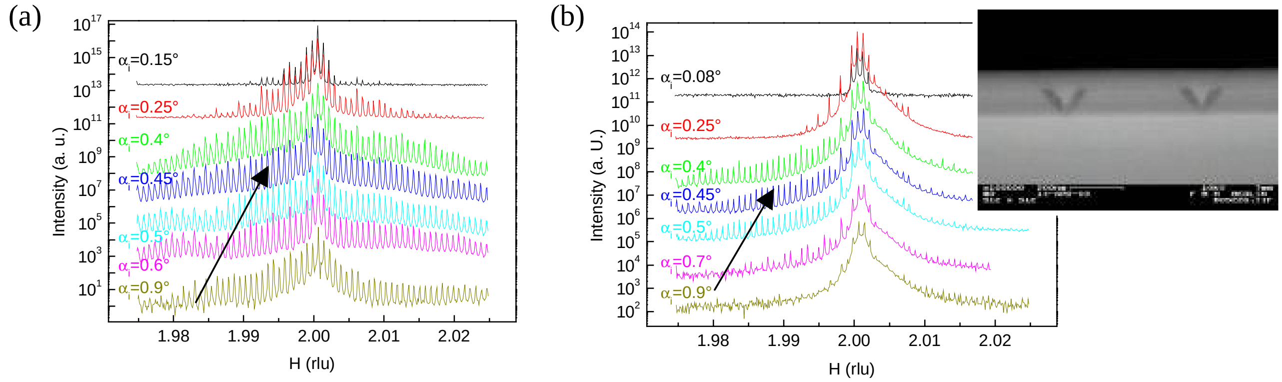

Figure 1: GID intensity scans with respect to H in reciprocal lattice units (rlu) for different α_i for the free standing grating (a) and the sample overgrown with InGaP/GaAs (b); the inset shows SEM-BSE image of the cleaved egde of a grating overgrown with 17 nm InGaP

For the sample overgrown with GaAs the GID scans at (200) reflection are symmetrical. In this case only the lateral periodicity of the refractive index originates the side peaks in the curves (not shown here). As expected from the FEM calculations the overgrowth with GaAs leads to a suppression of the lateral strain modulation and therefore to a loss of the lateral carrier confinement. The experimental results are in excellent agreement with the our FEM predictions

We have shown that a lateral strain modulation is induced in an InGaAs-QW after lateral patterning and over growth of an InGaP stressor layer on top of it. If a single GaAs layer is used for the planarization the lateral strain modulation in the InGaAs-QW vanishes almost completely. To maintain the lateral strain modulation in the InGaAs_QW we used a two-layer system, namely a combination of a thin compressively strained InGaP layer and a GaAs layer for overgrowth of a free standing triangular grating structure. GID measurements revealed, that in this case the lateral strain modulation in the InGaAs-QW was maintained. FEM calculations can be used to predict the strain distribution within the complete structure after overgrowth. Thus we have shown that by choosing appropriate MOVPE growth conditions and materials for the second growth step it is possible to preserve the lateral carrier confinement in the InGaAs-QW. This technology was used for the growth of a complete laser structure (due to the large thickness of the optical waveguide GID measurements of the overgrown structure were not possible). A first experiment demonstrated the that a such modified laser is operable, however a further device optimisation is necessary.

References

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