ESRF	**Experiment title:** Spatially resolved strain and composition analysis in radial InGaN/GaN core shell rods by nano x-ray diffraction and fluorescence	**Experiment number**: HC-1949
Beamline: ID13	**Date of experiment**: from: 15.04.2015 to: 19.04.2015	**Date of report**: 10.09.2015
Shifts: 12	**Local contact(s)**: Dr. Martin Rosenthal	*Received at ESRF:*

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Report:

During our recent beamtime at ID13 in April 2015, we studied (In,Ga)N/GaN rods grown by MOVPE in the selective area growth regime. The rods comprise a n-doped GaN core surrounded by a five-fold $In_{0.1}Ga_{0.9}N$/GaN multi quantum well (QW) sequence covered by a p-doped GaN shell and have a height and diameter of about 7 and 1 µm, respectively. In order to obtain information about individual objects, we used a focused ion beam (FIB) to isolate a single row of neighbouring, free-standing rods within a lamella. Figure 1 shows a x-ray transmission scan of the lamella which we used for adjusting the sample. In our experiment we scanned horizontally over the three rods labelled with A, B, C. Exploiting the high spatial resolution of 150 x 150 nm^2 spot size we scanned with a step size of 100 nm and varied the incident angle around the Bragg condition of GaN(10.0) for each position. As a direct result of this scanning method we found that rod C is twisted by 0.1° compared to rod A and B. When scanning horizontally over a single rod the beam is particularly sensitive to the strain in two opposing facets. This becomes clear when looking at the FEM simulation shown in Fig. 2(c). The predominant strain direction is radial towards the rod centre, hence, if the x-ray beam is in Bragg condition for the {10.0} lattice planes only the (10.0) and (-10.1) facets will show significant strain from the (In,Ga)N QWs whereas the adjacent facets will have a weak contribution. Figure 2(a) shows an excerpt of a horizontal scan series on rod A at a height of approximately 6µm. The labels #1 to #7 in the reciprocal space maps (RSMs) describe a movement of the beam from left to right as sketched in Fig. 2(b). Positions #1 to #3 show the strain in the left facet. As expected, the peak intensity related to relaxed GaN stays constant. However, the intensity of the (In,Ga)N-related peak approximately 1 % below the GaN peak decreases as the beam moves towards the centre and vanishes completely at position #4. A further movement of the beam shows the strain in the right facet at positions #5 to #7. Hence, the high spatial resolution allows a facet resolved strain analysis with high lateral resolution.

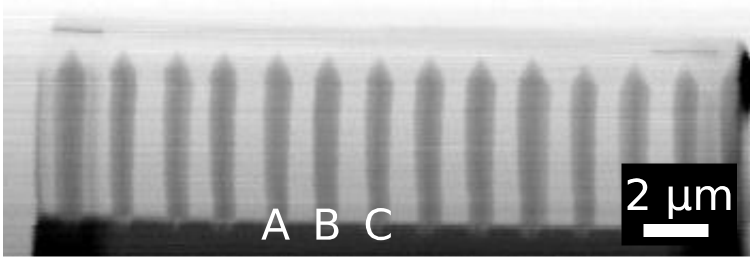

Fig. 1: X-ray transmission scan of the lamella containing a row of isolated (In,Ga)N/GaN rods.

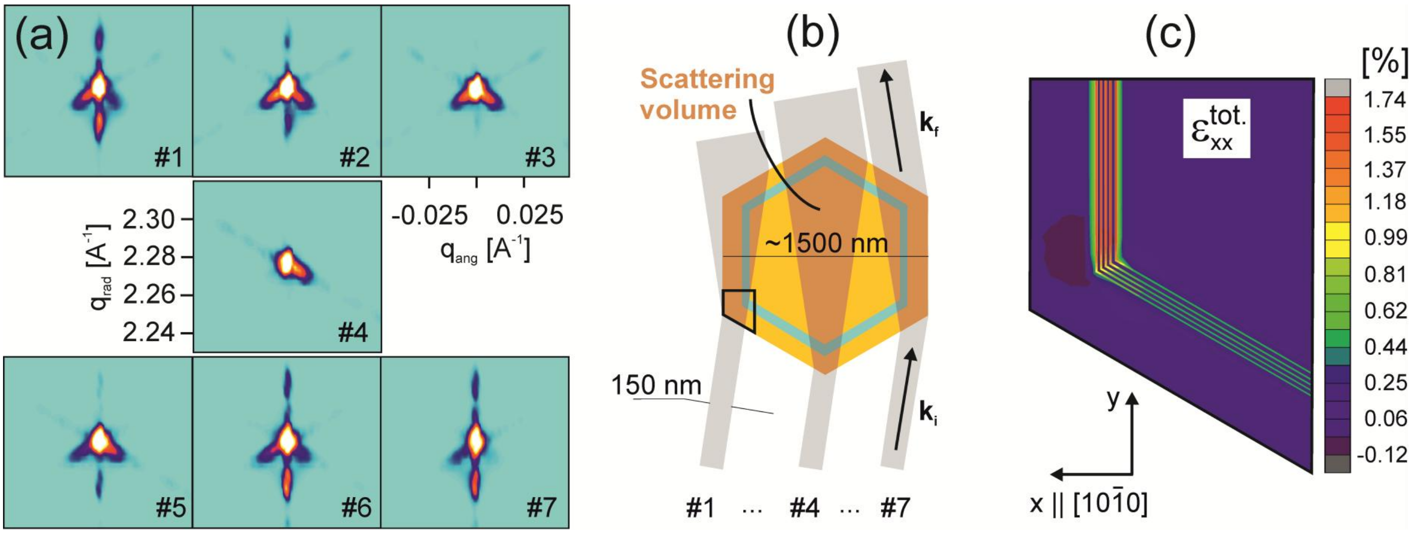

Fig. 2: Reciprocal space maps of the GaN(10.0) reflection (a). Positions #1 to #7 represent a horizontal movement of the beam. The beam positions on the rod and the illuminated volume are sketched in (b). The finite element simulation in (c) shows the in-plane strain normal to the {10.0} lattice planes which is the beam sensitive direction.

We repeated the horizontal scans at different heights on the rod to detect a possible alteration of strain field along the growth direction. Figure 3(a) shows RSMs of the GaN(10.0) reflection at different heights on the left facet of rod A as indicated by white spots on the x-ray transmission image. All RSMs show a peak at the expected position of relaxed GaN. However, the (In,Ga)N-related peak is not visible until a height of approximately 2.5 µm. Then an additional peak appears below the GaN reflection which shifts down to smaller q_{rad} values. This means that the strain field even along a single rod changes by approximately 1%. Figure 3(b) shows a spatially resolved cathodoluminescence map of a single rod. Here, we see that at the bottom part of the rod the QWs emit at a wavelength of approximately 380 nm which is close to the wavelength of 365 nm emitted from GaN. At a height of 2.5 µm we observe a red-shift up to a wavelength of 450 nm in the tip region. This complements very well the results obtained by nanofocus -x-ray diffraction and shows that this effect is substantial for the device performance and demands a reconsideration of the growth process. Furthermore, it shows that nanofocus x-ray diffraction is an ideal method for a destruction-free investigation of µm-sized heterostructure objects. A publication which will report on these results in more detail is currently under preparation.

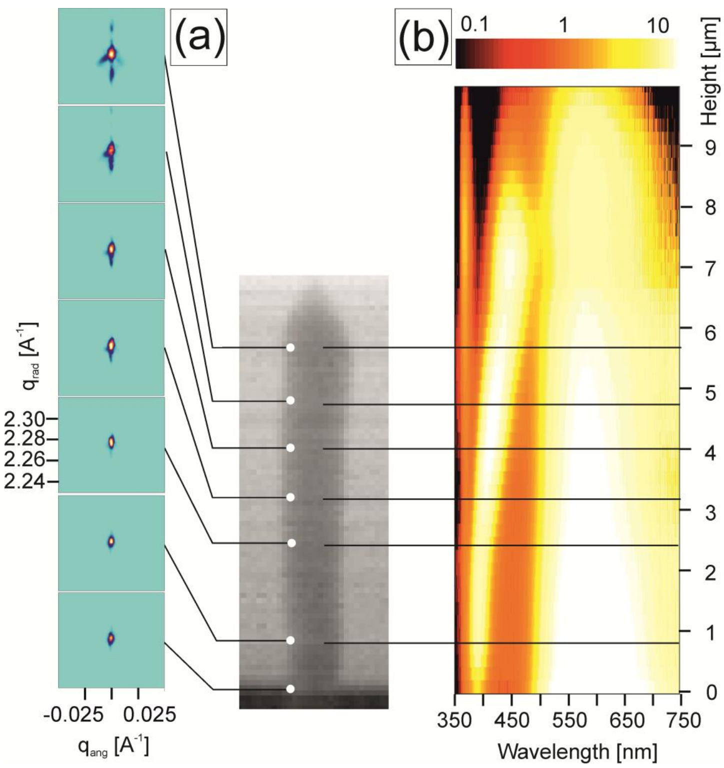

Fig. 3: Reciprocal space maps of the GaN(10.0) reflection recorded at different vertical positions on left facet (a). Spatially resolved cathodoluminescence map of a single rod (b). The increasing in-plane strain in the QW sequence along the rod height yields a red-shift of the emitted wavelength.