Nitrides

GaN and InN and their composites InGaN are a suitable material system for the fabrication of high performance optoelectronic devices as light emitting diodes (LEDs) and laser diodes (LDs) in the wide spectral range. Nitrides can be grown on the different substrates, such as Al_2O_3, SiC, GaAs, $LiGaO_2$ and Si. The growth of wurtzite III–V nitrides by molecular beam epitaxy (MBE) on Si (111) is quite appealing due to the doping capability, crystal quality, thermal stability and potential integration offered by these inexpensive substrates. However, because of the mismatch of lattice constants (about 17 %) and thermal expansion coefficients (about 37 %) between GaN and the Si substrate, high defect densities occur in the GaN thin film as well as residual strain. To relax the strain and reduce the defects, researchers usually use a buffer layer for the epitaxial growth of high-temperature GaN thin film. Fig.1 presents a cross-section TEM image of a group-III nitride heterostructure gown on a Si(111) substrate. Here a low-defected GaN layer of 160 nm thickness was grown by MBE on the Si (111) substrate with an AlN buffer of 130 nm thickness. The growth was performed in the group of D. Schaadt (junior research group of the Center for Functional Nanostructures CFN).

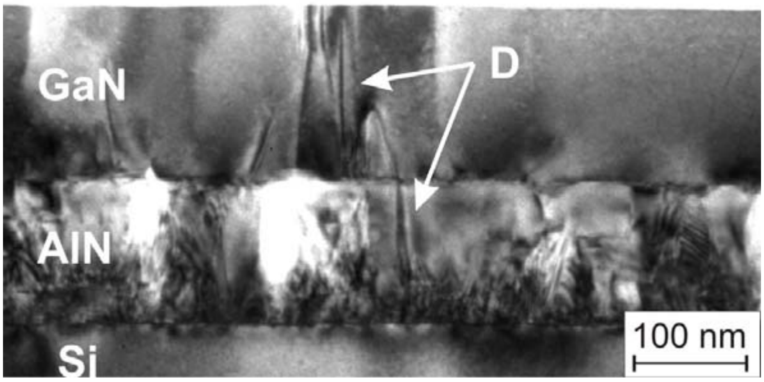

Fig. 1: Bright-field cross-section image of a GaN/AlN/Si(111) structure taken close to $[11\bar{2}0]$- *zone axis. Threading dislocations (D) are marked by arrows.*

The low defect density of the GaN layer is important for the further growth of the InGaN-nanostructures or for the doping of the GaN layer.

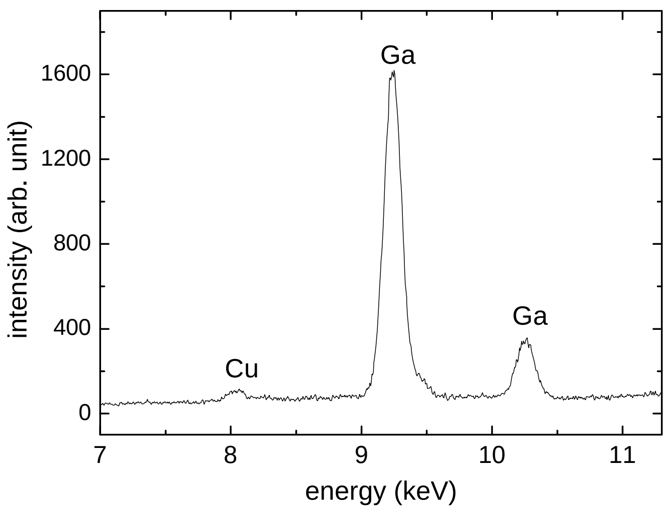

Fig. 2: EDX spectrum from a Cu-doped GaN layer.

It is predicted by theoretical calculations that doping of n-GaN with Cu leads to ferromagnetic behaviour which is interesting for applications in spintronics. By different analytic methods EDX, STEM and EFTEM we investigate the Cu distribution in GaN layers grown similar to sample presented in Fig. 1. Fig. 2 presents part of EDX spectra from the doped GaN layer obtained in scanning electron microscopy from sample prepared by FIB.
The average Cu concentration in the doped GaN layer is about 2 %. A slight enrichment of Cu is observed at defects and at the GaN/AlN interface (arrows in the Cu map, right-hand side of Fig. 3) that can be caused by the segregation of Cu to the strain areas of the GaN during the deposition.

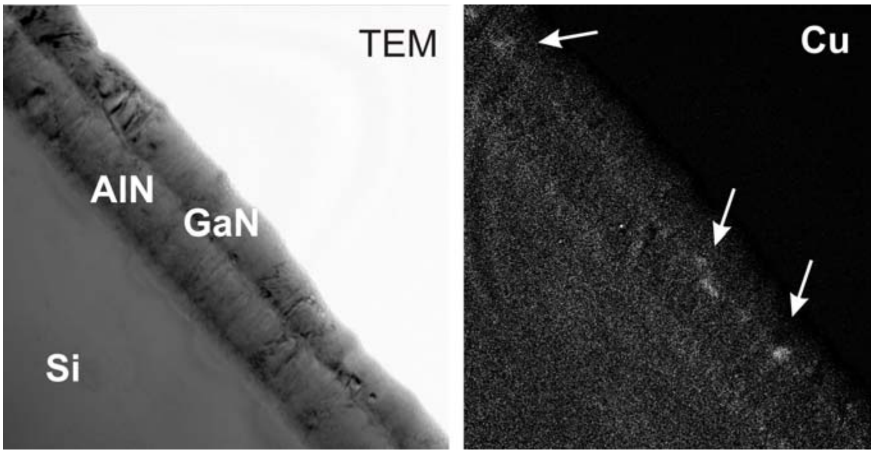

Fig. 3: (left-hand side) Cross-section TEM image and (right-hand side) EFTEM Cu map of the same sample area with enrichment of Cu indicated by arrows.

Most LEDs nowadays are based on InGaN/GaN heterostructures. The spectral range of emitted light is determined by the width and In concentration of the quantum well where recombination of electrons and holes occurs. To further increase the LED efficiency, the determination of the In concentration and In distribution of the InGaN QWs is important for device optimization. The In-concentration can be obtained by strain-state analysis by digital analysis of lattice images (DALI), which is based on the measurement of the local-lattice parameters (LLPs) as outlined in detail in Refs. [1,3]. Fig. 4 presents a colour-coded map of the LLPs of InGaN QW normalized with respect to the lattice parameter of the GaN barrier layers, i.e. a LLP of 1 corresponds to GaN.

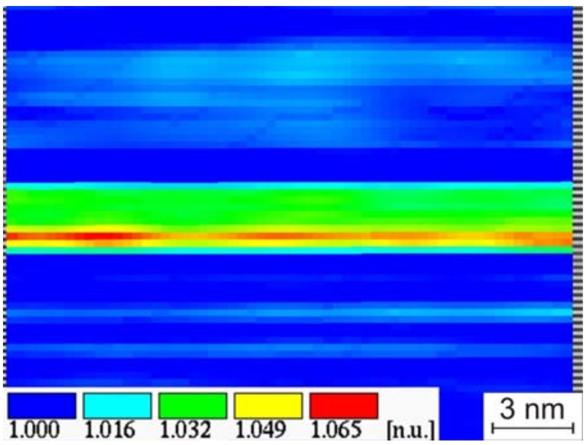

Fig. 4: Colour-coded map of normalized local lattice parameters of an InGaN QW embedded in GaN as evaluated by DALI.

Taking into account that the InGaN is coherently strained on GaN, the evaluated average In concentration of the InGaN layer is about 20 %. The red color in Fig.2 corresponds to a high In concentration of 48 %.

References

[1] D. Gerthsen, E. Hahn, B. Neubauer, A. Rosenauer, O. Schön, M. Heuken, A.Rizzi, *Analysis of composition fluctuations in InGaN by transmission electron microscopy*, phys. stat. sol. (a) **177**, 145 (2000)

[2] I. P. Soshnikov, N. N. Ledentsov, A. F. Tsatsul'nikov, A. V. Zakharov, W. V. Lundin, E. A. Zavarin, A. V. Fomin, D. Litvinov, E. Hahn, and D. Gerthsen, *Special features of structural interaction in (AlGaIn)N/GaN heterostructures used as dislocation filters*, *Semiconductors* **39**, 100 (2005)

[3] A. Rosenauer, D. Gerthsen, V. Potin, *Strain state analysis of InGaN/GaN –sources of error and optimised imaging conditions*, Phys. Stat. Sol. **A 203**, 176 (2006)

[4] T. Li, C. Simbrunner, A. Navarro-Quezada, M. Wegscheider, M. Quast, D. Litvinov, D. Gerthsen, A. Bonanni, *Phase-dependent distribution of Fe-rich nanocrystals in MOVPE-grown (Ga,Fe)N*, J. Cryst. Growth **310**, 3294 (2008).