**Direct visualization of selective indium incorporation in InGaN/GaN core-shell nanorods using scanning transmission electron microscopy cathodoluminescence**

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For a detailed understanding of complex semiconductor heterostructures and the physics of devices based on them, a systematic determination and correlation of the structural, chemical, electronic, and optical properties on a nanometer scale is essential. Luminescence techniques belong to the most sensitive, non-destructive methods of semiconductor research. The combination of luminescence spectroscopy - in particular at liquid He temperatures - with the high spatial resolution of a scanning transmission electron microscope (STEM) ($\delta x$ < 1 nm at RT, $\delta x$ < 5 nm at 10 K), as realized by the technique of low temperature scanning transmission electron microscopy cathodoluminescence microscopy (STEM-CL), provides a unique, extremely powerful tool for the optical nano-characterization of semiconductors, their heterostructures as well as their interfaces.

We present a nanometer-scale correlation of the structural, optical, and chemical properties of InGaN/GaN core-shell microrods. The core-shell microrods have been fabricated by metal organic vapor phase epitaxy (MOVPE) on c-plane GaN/sapphire templates covered with an $SiO_2$-mask. The MOVPE process results in a homogeneous selective area growth of n-doped GaN microrods out of the mask openings. Surrounding the n-GaN core, a nominally 5 nm thick GaN shell and 30 nm thick InGaN layer were deposited.

Highly spatially resolved cathodoluminescence (CL) directly performed in a scanning transmission electron microscope (STEM) was applied to analyze the selective Indium incorporation in the thick InGaN shell and the luminescence properties of the individual layers. Cross-sectional STEM analysis reveal a hexagonal geometry of the GaN-core with m-plane side-walls. Directly at the edges of the hexagon a-plane nano-facets with a width of 45 nm are formed. The overgrowth of the GaN core with InGaN leads to a selective formation of Indium-rich domains with triangular cross-section exactly at these nano-facets as evidenced by Z-contrast imaging. Probing the local luminescence properties, the most intense CL emission appears at the m-plane side-facets with 392 nm peak wavelength. As expected, the Indium-rich triangles emit a red-shifted luminescence around 500 nm.

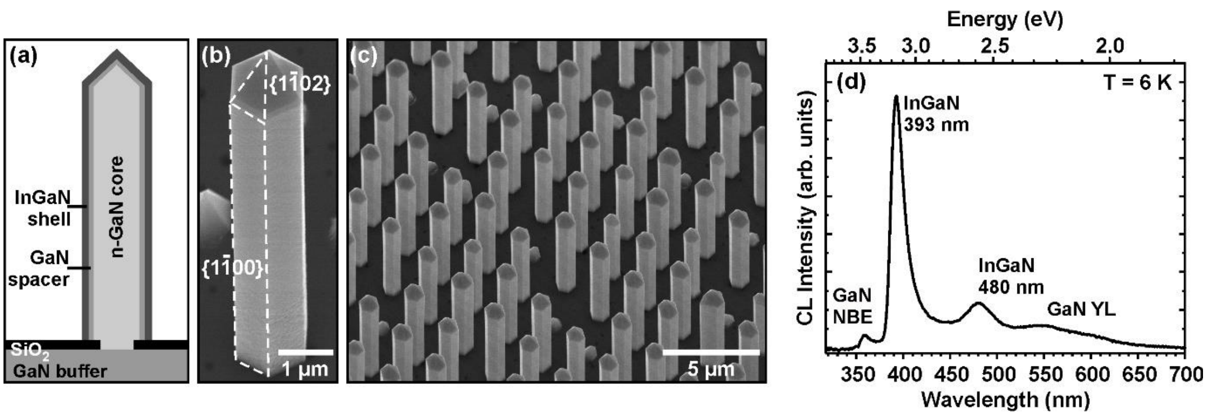


**Figure 1:** (a) cross-section scheme of the nanorod heterostructures, (b) SEM image of a single nanorod with labeling its sidewall facets, and (c) the as-grown nanorod array in bird's eye view, (d) spatially averaged CL spectrum of nanorod ensemble measured at T = 6 K.

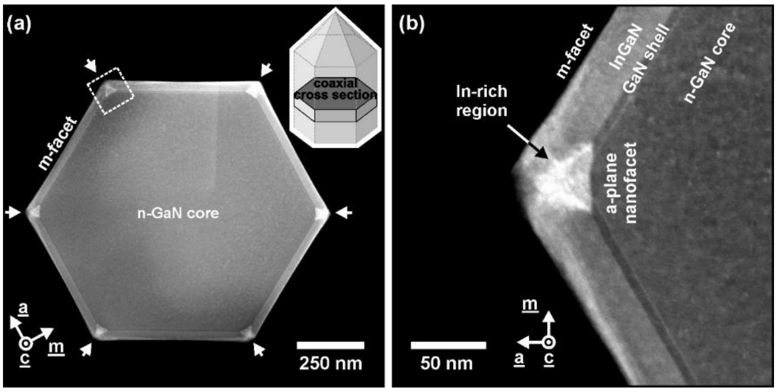


**Figure 2:** HAADF image of the coaxial cross-section of a single nanorod in overview (a) as well as in higher magnification (b). The magnified image (b) is marked in the overview (a) in the upper left nanorod corner with a white dashed square. The full layer structure is resolved: the n-GaN-core, the following GaN shell buffer and the thick InGaN layer. A brighter HAADF contrast is found at the edges of the NR hexagon (marked as arrows in (a)) forming a triangle along a self-formed a-facet, indicating the formation of In-rich domains.

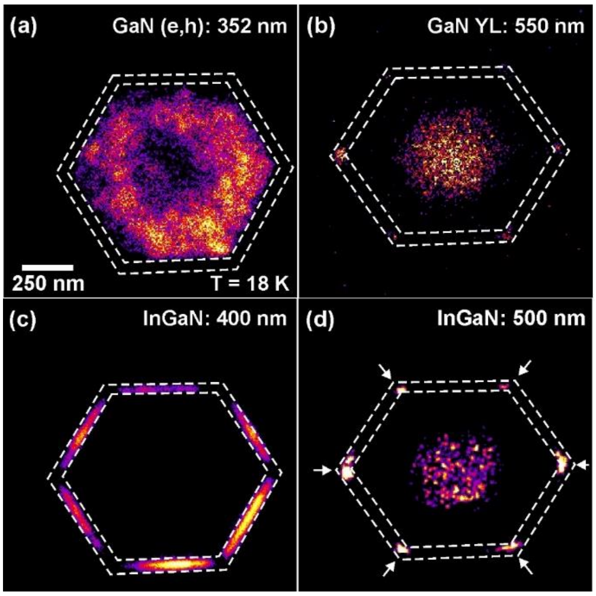


**Figure 3:** Monochromatic CL intensity distribution at 18 K for (a) GaN (e,h) recombination ($\lambda$ = 352 nm), (b) GaN yellow luminescence ($\lambda$ = 550 nm), (c) m-plane InGaN ($\lambda$ = 400 nm), and (d) InGaN ($\lambda$ = 500 nm), respectively.