Tuning the morphology and structure of In-rich InGaN nanocolumns suitable for biomedical application

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Developing wearable transdermal biosensors for real-time health monitoring is a very attractive and promising field of research and medical application. Among the materials studied, InGaN heterostructures stand out for their chemical stability, biocompatibility, low cytotoxicity, and high carrier mobility. Biosensors based on InN/InGaN quantum dots (QDs) exhibit twice the sensitivity and five times faster response compared to InN thin films, surpassing the classical Nernstian limit by leveraging the super-Nernstian behavior enabled by InN QD surface nanostructuring[1]. The study presented analyzes the nanostructured InGaN growth made using Plasma-Assisted Molecular Beam Epitaxy (PA-MBE) on Si (111) substrates. The significant lattice mismatch is used to promote a nanocolumnar morphology, while achieving high indium content, critical for optimizing surface energy states and enabling ohmic contact, requires low substrate temperatures to prevent indium desorption and InN decomposition[2].

Accurate structural analysis, detailed surface morphology, and key growth parameters as In/Ga ratio, substrate temperature, and III/V flux ratio, were carried out using X-Ray Diffraction (XRD) and Atomic Force Microscopy (AFM). To monitor the individual nanocolumns' chemical composition and local structure, Energy Dispersive X-ray Spectroscopy (EDX), Electron backscatter diffraction (EBSD), and Transmission Electron Microscopy (TEM) measurements were performed, confirming the high indium content (60%) with nanocolumns exhibiting excellent epitaxial alignment along the (001) plane with a negligible misorientation of only 1° (Figure 1b). Samples with elevated indium levels displayed larger column diameters, correlating with indium higher thermal diffusion coefficient (Figure 1c). The mechanisms governing the growth and geometry of InGaN nanocolumns were investigated through scanning electron microscopy (SEM), examining both top and side views (Figure 1). SEM observations also uncovered fascinating phenomena during nanocolumn vertical growth, contributing to the optimized design and enhanced performance of biosensor materials.

This study is fundamental for enabling a comprehensive understanding of the growth mechanisms of InGaN nanocrystals (NCs) on silicon (Si) substrates. It establishes a foundation for optimizing the crystal quality, dealing with the formation of different crystal structures (i.e. wurtzite and zinc-blende) and the size of the nanocrystals, which is crucial for future QDs depositions. Moreover, it represents a significant step in the optics of assembly of the biosensor and in testing its overall performance.

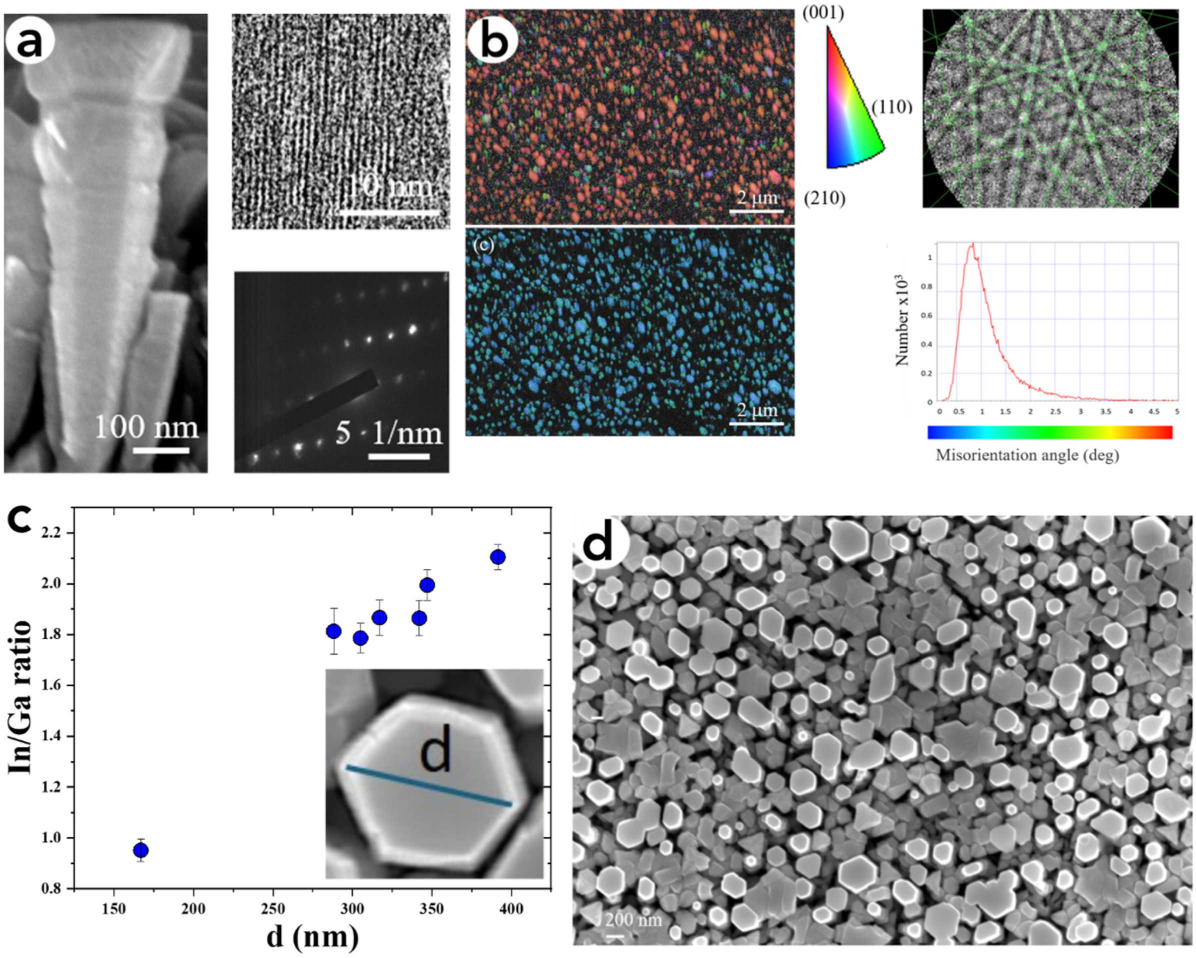

Figure 1. a) SEM side view and TEM images of a nano-column (NC). b) EBSD analysis of the sample and corresponding Kikuchi pattern. The Kernel Average Misorientation map shows a negligible misorientation of 1°. Data acquired using a FE-SEM JEOL IT710HR microscope with QUANTAX EBSD & EDS Bruker detectors. c) Relation between the NCs basis radii with the In/Ga ratio made via EDX analysis. D) SEM top view of a sample with nanocolumns.

References:

[1] Richard Nötzel, National Science Review, **2017**, 4, 184-195.

[2] Azadmand, Vichi, Cesura, Bietti, Chrastina, Bonera, Vanacore, Tsukamoto, Sanguinetti, *Nanomaterials*, **2022**, 12, 3887.

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