Experiment Brief

Vulcan Cathodoluminescence Detector

Title

Nano-cathodoluminescence reveals the effect of indium segregation on the optical properties of nitride semiconductor nanorods

Gatan instrument used

The Vulcan™ system is the first commercial cathodoluminescence (CL) system for the (scanning) transmission electron microscope (STEM) to enable the direct correlation of the optical and structural properties of materials at the nanoscale.

Background

Most commercially available light emitting diode (LED) chips are manufactured from nitride semiconductors grown as thin films on foreign substrates. While successful for high power devices emitting blue light, significant material challenges exist prevent the development of high-efficiency nitride semiconductor devices emitting at green and red wavelengths; consequently compromising their usefulness for solid state lighting applications. A promising approach to address these issues is to develop devices based on nanorods where an increase in the effective light emitting area could lead to improved radiative efficiencies. However, many challenges in design and manufacture still exist, and the development of nanorod-based devices requires understanding and control of the structural and optical properties at the nanoscale.

Materials and Methods

CL performed in the STEM has proven to be an incredibly powerful characterization technique to correlate the optical and structural properties directly at the length scale of individual device features. With the Vulcan system, the impact of structural and compositional changes in the optical properties of hexagonal GaN nanorods with an 11 nm indium gallium nitride (InGaN) shell could be determined. Observations revealed intense blue emissions from the InGaN shell grown on the non-polar side walls. However, at the intersection of the sidewalls, a significant reduction in luminescence intensity, as well as a red-shifted spectrum, was found. The luminescence quenching could be correlated directly to an enhanced indium segregation at the sidewall intersect together with a small residual polar GaN segment.

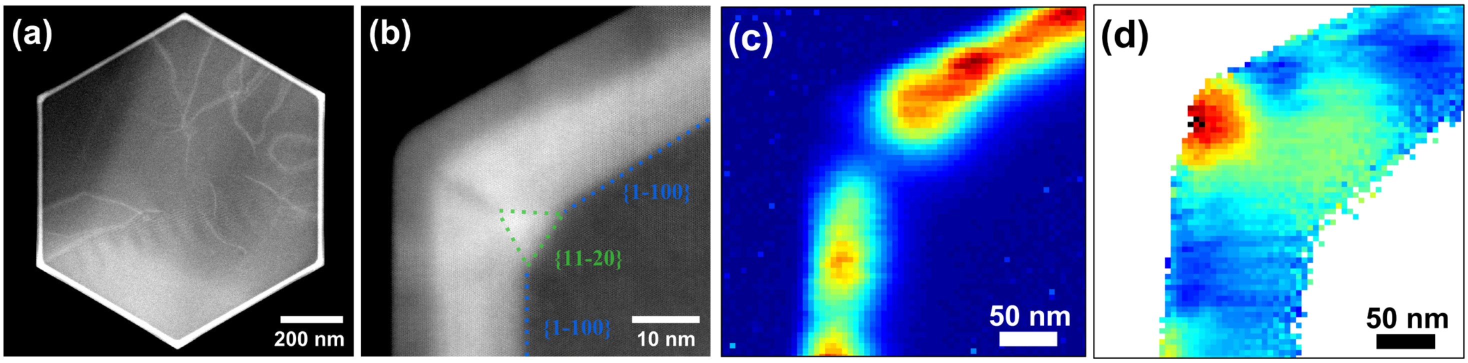

Figure 1. (a) and (b) atomic resolution annular dark field STEM images of a section of the nanorod taken through the axial direction; the $In_{15}Ga_{85}N$ shell shows bright contrast relative to the GaN. Dislocations were observed propagating from the GaN core. However, no additional extended defects were observed at the InGaN/GaN interface. At the intersection of the sidewalls, small residual non-polar regions bounded by {11-20} facets were observed together with preferential In segregation (up to 22%). CL spectrum imaging (c) and (d) of the intersection of the sidewalls revealed intense blue emissions from the InGaN shell along the non-polar sidewalls (emission energy 2.69 – 2.73 eV or wavelength 453 – 460 nm). >75% reduction in light output was observed at the intersection of the sidewalls which could be attributed to a reduction in the luminescence efficiencies in the In-rich region and polar GaN segment; a 90 meV (23 nm) red-shift was also observed at the In-rich region consistent with the change in In-fraction. The sample was prepared by focused ion beam milling, and CL analysis was performed in a JEOL 2100F STEM operating at 80 keV with the sample held at a temperature of ~100 K. Published in J.T. Griffiths et al., Appl. Phys. Lett. 2017, 110, DOI: 10.1063/1.4982594 Copyright © 2017

Summary

The Vulcan system is a powerful tool to optimize optoelectronic device design. Nano-CL allows the spectral properties of InGaN shells in InGaN/GaN core-shell nanorods to be correlated directly with structural properties. Such detailed characterization will enable the development of optimized devices.

Credit(s)

A special thank you to Dr. J. Griffiths, University of Cambridge and the Experimental Technique Centre, Brunel University. For further information, see J. T. Griffiths et al., Appl. Phys. Lett., 110, 172105 (2017).

Gatan, Inc. is the world's leading manufacturer of instrumentation and software used to enhance and extend electron microscopes—from specimen preparation and manipulation to imaging and analysis.

The Cambridge Centre for Gallium Nitride, Department of Materials Science and Metallurgy, University of Cambridge is one of a small number of places in the world to have, in close proximity and on the same site, extensive gallium nitride growth equipment, characterization facilities for understanding structural, optical and electrical properties, and basic theory for understanding physical properties in detail.

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