GATAN

Experiment Brief

Vulcan Cathodoluminescence Detector

Title

Nano-cathodoluminescence enables the design of light emitting diodes with higher efficiencies

Gatan instrument used

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

Background

Modern blue or white light emitting diodes (LED) use multiple InGaN quantum wells (QW) with GaN quantum barriers (QB) between the QWs to confine carriers for high brightness devices. However, a key challenge to the development of higher efficiency LEDs is the presence of a polarization-induced electric field that renders the device less efficient as a result of the quantum confined Stark effect (QCSE), which also gives rise to a red-shift of the emission wavelength. It has been proposed that the internal electric field can be suppressed by silicon-doping the QBs, and thus improve device efficiency. In order to validate this it is crucial to resolve the spectral properties of individual QWs.

Materials and Methods

Common luminescence characterization techniques, such as electroluminescence, photoluminescence and CL in a scanning electron microscope (SEM) lack the spatial resolution to resolve individual QWs. However, through use of the Vulcan detector, the spectral properties of individual InGaN QWs were recorded to reveal that QBs with silicon concentrations $>10^{18}$ cm^3 could mitigate the QCSE. As shown in Figure 1, distinct luminescence was observed from each QW with the central wavelength varying between 430 – 457 nm; a systematic blue shift in the emission wavelength in the upper QWs was measured, demonstrating a significant reduction in the QCSE compared to a conventional LED.

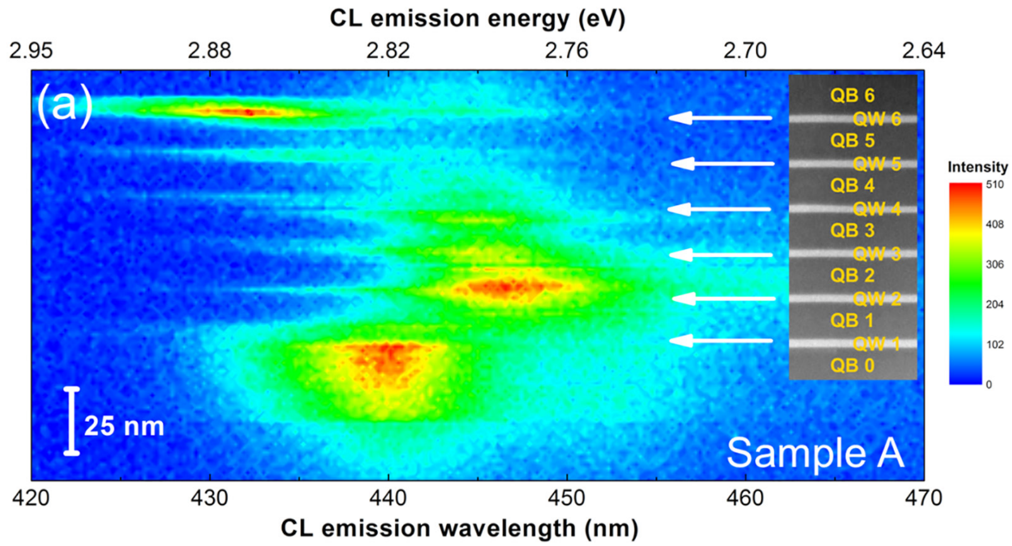

Figure 1. The spectral properties of individual QW in a blue LED revealed by a CL spectrum line scan. The inset dark field scanning TEM (STEM) image shows the structure of the LED active region containing six, high quality, 2.5 nm thick InGaN QWs separated by GaN QBs. A series of CL spectra was acquired by scanning a 0.2 nm electron beam in the direction orthogonal to the QW plane from below QB0 to QB6 as shown in the color plot, the y-axis shows the electron beam position and the x-axis the CL spectrum at each (spatial) point; the inset STEM image is displayed with the same spatial calibration as the y-axis of the CL line scan and can be used as a reference to correlate the QW position with the luminescence. Distinct luminescence features were observed from each QW (indicated by the white arrows), with the peak emission varying between 432 – 448 nm (2.78 – 2.87 eV). The blue-shift of QW1 and QW3 -- QW6 relative to QW2 demonstrates a reduction in electric field and corresponds well to the relative silicon-doping concentration in the quantum barriers. *Image courtesy of J. Griffiths (University of Cambridge).*

Summary

The Vulcan detector is a powerful tool to optimize optoelectronic device design. NanoCL reveals the spectral properties of individual InGaN quantum wells in high efficiency light emitting diodes enabling optimized device design for higher brightness LEDs.

Credit(s)

A special thanks to: Dr. J. Griffiths, University of Cambridge and the Experimental Technique Centre, Brunel University. For further information, see: J. T. Griffiths et al., *NanoLetts.*, 15, 7639, (2015).

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.

EB-Vulcan-NanoCL-CA-FL1-July16