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Combined EELS and Cathodoluminescence analysis in a STEM microscope of GaN / InGaN quantum wells for LED applications

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The correlation between a material's luminescence properties and its nanoscale morphology, microstructure and local chemistry offers great benefit in the understanding of many technologically important materials and devices. This has encouraged a growing interest in performing cathodoluminescence (CL) microscopy at high spatial resolution in a STEM microscope [1,2]. Here, we use combined electron energy loss spectroscopy (EELS) and CL analysis of the GaN / InGaN quantum well (MQW) from a light emitting diode (LED) to investigate the role of In clustering in luminescence efficiency; sub-nanometer compositional information is correlated with the luminescence from individual quantum wells with the MQW.

III-nitride semiconductors are technologically important materials with GaN / InGaN MQWs being the source of light emission in current generation blue and white LEDs. However, efficient white LEDs based entirely of III-nitride semiconductors remain elusive due to poor efficiency at green emission wavelengths, the so-called 'green-droop'. The reason for low efficiencies at high In content is not well understood; auger electrons fluctuations in quantum well and In composition are two of the many proposed mechanisms [3]. Thus, understanding how the structure, composition and luminescence (intensity and emission wavelength) of MQW structures are correlated is ultimately very important for improving device performance.

For the results of this paper, compositional information was obtained from sub-nanometer scale EELS analysis using means of MLLS fitting to extract the composition and the local luminescence was measured simultaneously using CL. The CL light was acquired using miniature elliptical mirrors (solid angle of about 7.3 sr) integrated into the tip of a conventional cryogenic TEM holder. Light is coupled out of the holder through two optical fibres to an optical spectrometer fitted with a PMT and CCD detectors. This combined EELS / CL system offers the advantage of the best in spectral resolution (up to 4 meV), spatial resolution analysis and sensitivity to microstructural changes. Simultaneous EELS / CL data was collected with the sample at -171C minimizing the influence of the electron beam on the sample and increasing the spatial resolution of the Cl data as result of the enhanced rate of radiative recombination within the QWs. The analysis was carried out across the GaN / InGaN MQWs and superlattice layers where each layer is just a couple of nanometers wide. Variations of the luminescence quantum efficiency by more than an order of magnitude was observed between regions separated by only a few nanometers and free extended defects; we analyse how the composition measured by EELS affects the luminescence.

Figure 1a shows an ADF STEM image taken during the simultaneous acquisition of the CL and EELS data. The image shows the alternating InGaN bright and GaN dark layers. The interface GaN / InGaN as shown in the ADF STEM image in Figure 1a appears to be fairly abrupt. Figure 1b shows a CL band pass image obtained by integrating the signal at 450 nm in the CL spectrum shown in Figure 1c over a 30nm wavelength window across the entire area in the ADF STEM image in Figure 1. The change in intensity observed in Figure 2 could be caused by variations in the alloy concentration. Local In clustering or change in the composition can easily cause such variations in the CL emission. Change in composition at a subnanometer level has been obtained using EELS and further details of the analysis will be given during the oral presentation.

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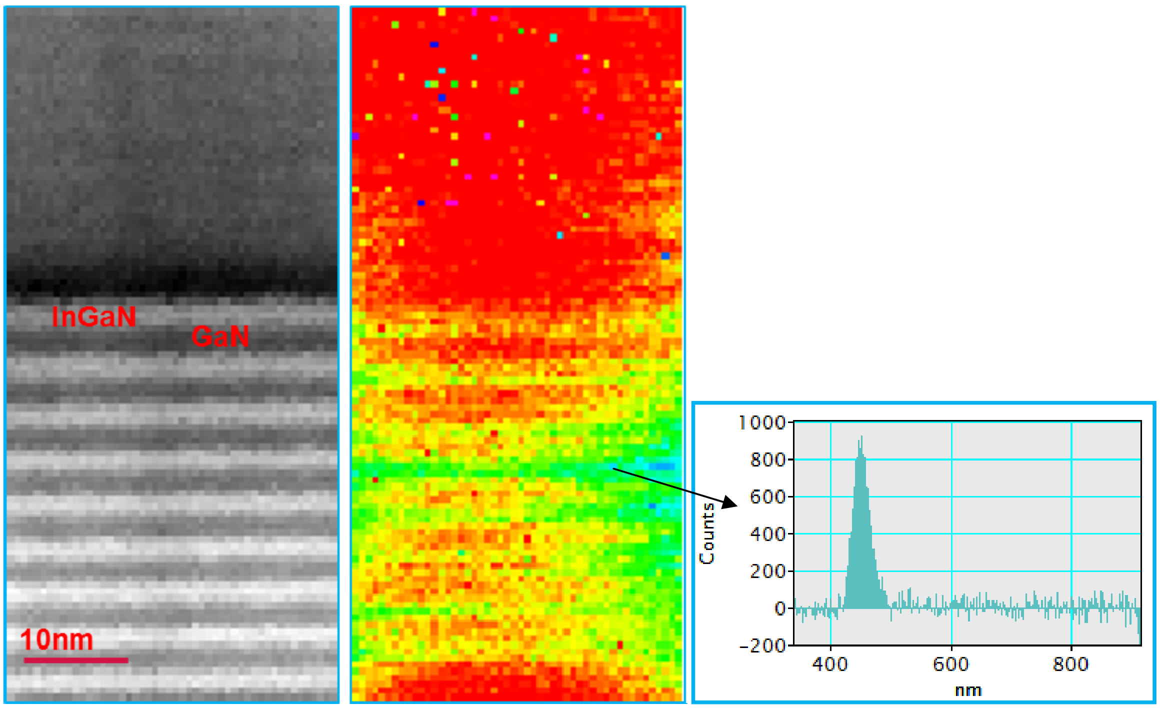

Figures 1: a) Analog STEM Image acquired during the simultaneous acquisition of the EELS and CL data. It clearly shows the alternating InGaN and GaN multilayers. The former is bright whereas the latter dark in the image. The InGaN / GaN interfaces across the entire image appear fairly uniform; b) band pass image obtained by integrating the signal at 450nm in the CL spectrum in Figure 1c over the 435 nm – 465 nm wavelength window. This shows the good spatial resolution that can be obtained using CL in STEM microscope. The change in intensity can be probably caused by variations in the local composition and this can be assessed using EELS; c) CL spectrum extracted from the selected region in the band pass image. The emission band at ~ 450 nm is well pronounced.

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