A nanoscale cathodoluminescence study of nitride semiconductor nanowires

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MOTIVATION

III-nitride semiconductor nanowires are a potentially important class of materials for future LED and solar cell applications.

In order to realise the full potential of these materials characterisation and correlation of individual nanowire morphology, microstructure, composition and optical and electronic properties is required.

This has been enabled by the recent development of cathodoluminescence (CL) detectors suitable for (scanning) transmission electron microscopes [1-3], Figure 1.

EXPERIMENTS

The nanowires investigated were self assembled $In_{18}Ga_{32}N$ nanowire heterostructures. A single nanorod contains many quantum discs with AlN barriers and AlN shell, shown schematically in Figure 2. Samples were mechanically exfoliated onto a holey carbon grid for analysis.

Spectroscopic CL was performed using a Gatan Vulcan™ detector installed on a FEI Titan™ 80-300 microscope. Data was collected with the sample at -170 °C and the microscope operating at an accelerating voltage of 80keV and a probe current of ~200pA; all data was collected and analyzed using DigitalMicrograph®.

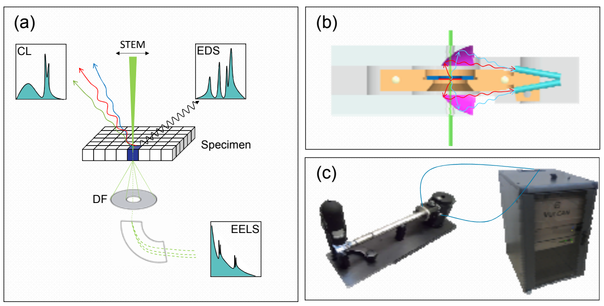

Figure 1. Experimental setup: (a) signals in the STEM; (b) cross section of the tip of the Gatan Vulcan™ system's specimen holder; luminescence is collected by 2 ellipsoidal mirrors and (c) coupled to a detection system consisting of an optical spectrometer and PMT and CCD detectors.

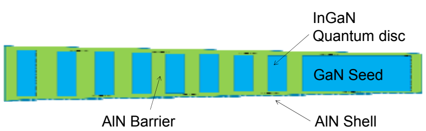

Figure 2. Schematic representation of the microstructure of a typical nanowire. A series of 2-3nm thick $In_{18}Ga_{32}N$ quantum discs are grown along the length of the nanorod with AlN barrier layer and shell.

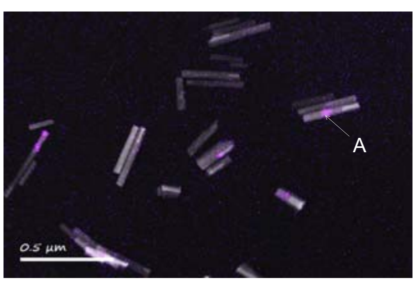

Figure 3. Colour overlay of the HAADF (greyscale) and panchromatic cathodoluminescence (violet) signals. Large variation between and within individual nanorods was observed. Measured at room temperatures.

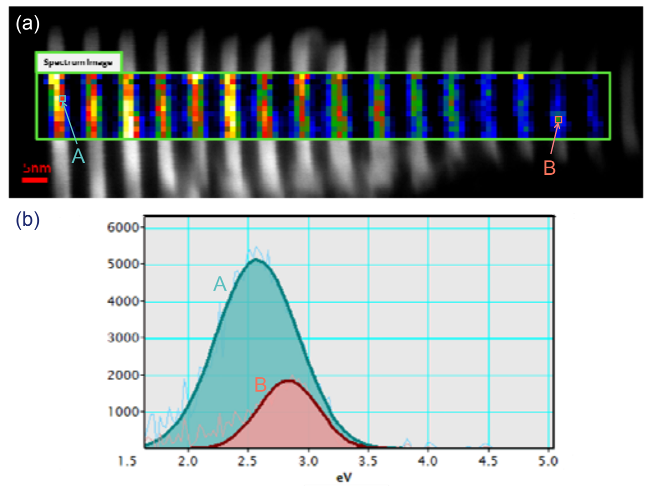

Figure 4. .(a) An integral intensity map extracted from a cathodoluminescence spectrum-image superimposed on the HAADF image of the same nanorod. (b) Two individual spectra extracted from locations A and B showing a change in intensity and change in central wavelength.

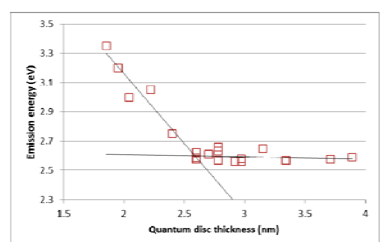

Figure 5. A blue shift in emission energy associated with quantum confinement was observed for quantum discs with a diameter less than 2.6nm

RESULTS AND DISCUSSION

Large variation in the luminescence intensity between nanowires was observed (Figure 3). This could be explained by: i) an incomplete AlN shell resulting in a high rate of surface recombination at surface non-radiative states (usually passivated by the AlN shell) and/or ii) the nanowire being N-faced (rather than Ga-faced).

Large variation in the luminescence intensity within an individual nanowire was observed, for example see nanowire A in Figure 3. The reason for this is as yet unclear and requires further investigation; no correlation with morphology or microstructure was found.

A nanowire with relatively uniform CL intensity from its entire length was selected for hyperspectral analysis (Figure 4); CL spectra from individual 2nm quantum discs could be resolved. The CL intensity was found to be maximum for the larger volume discs, probably as a result of the larger interaction volume with the electron beam with a radiative proportion of the sample. A blue shift of 1eV/nm was observed for quantum discs of thickness less than 2.6nm.

CONCLUSIONS

Large variation in the optical and electronic behaviour of self-assembled III-N nanowires was observed.

CL analysis in the STEM was demonstrated to be a valuable tool in the correlation of individual nanowire morphology and optical and electronic properties.

Luminescence from individual quantum discs was observed; a blue shift 1eV/nm was observed for quantum discs of thickness <2.6nm.

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[2] Zagonel L. F., Mazzucco S., Tence M., March K., Bernard R., Laslier B., Jacopin G., Tchernycheva M., Rigutti L., Julien F. H., Songmuang R. and Kociak M., Nanoletters 11 (2011) p568

[3] Stowe D.J., Microscopy and Microanalysis 19, (2013)

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