Cathodo- and Photoluminescence Studies of Nanorods with Embedded InGaN/GaN Disks

Jochen Bruckbauer[1*], Paul. R. Edwards[1], Carol Trager-Cowan[1], Paul Renwick[2], Tao Wang[2] and Robert W. Martin[1]

[1]*Department of Physics, SUPA, University of Strathclyde, Glasgow, G4 0NG, UK*

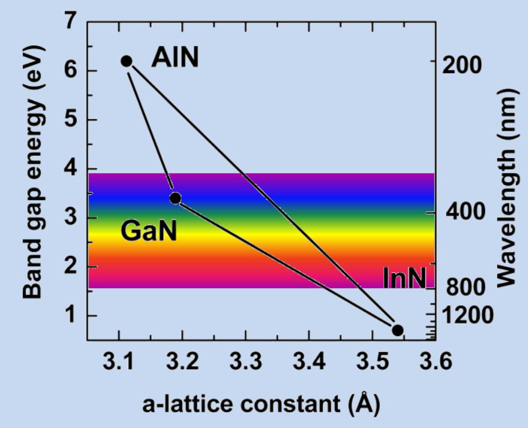
[2]*Department of Electronic and Electrical Engineering, The University of Sheffield, Sheffield, S1 3JD, UK*

* jochen.bruckbauer@strath.ac.uk

University of Strathclyde Glasgow

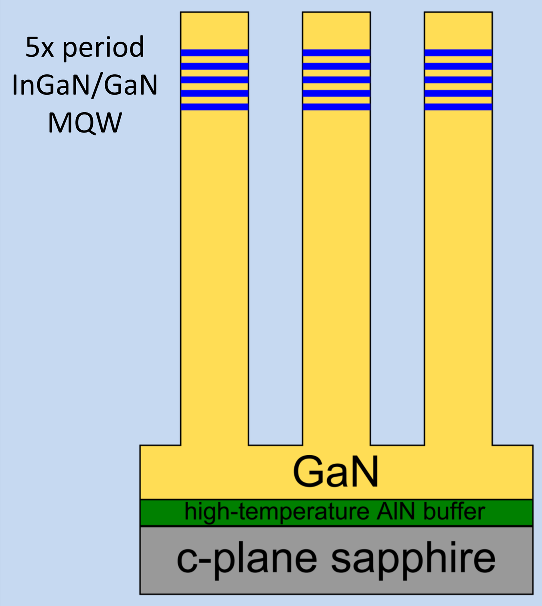
Motivation:

- Group III-nitrides (i.e. GaN, InN, AlN) and their alloys (e.g. InGaN, AlInN) cover the entire visible and part of the UV spectrum (*top*)
- The nanostructures have the advantage of increased light extraction in comparison to planar structures (Keller et al., *JAP* **100**, 054314 (2006)
- Space in between nanorods can be filled in with functional materials to be in direct contact with the active InGaN well region
- Considering the inefficiency of current light sources and the global need to preserve energy solid-state lighting is a promising application (*bottom*)



(Billy Currie from flickr.com)

Sample Fabrication:



Samples are fabricated by T. Wang's group at the University of Sheffield:

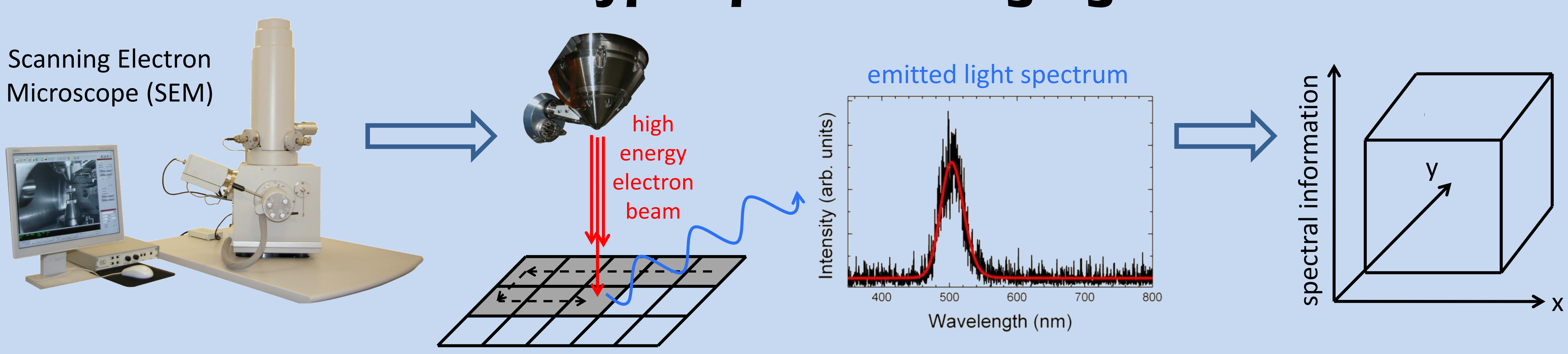
Step 1: Metal-organic chemical vapour deposition of InGaN/GaN epilayers

- High-temperature AlN buffer layer on c-plane sapphire (Bai et al., *JAP* **99**, 023513 (2006))
- 5 period InGaN/GaN multiple quantum well (MQW) structure with GaN capping layer

Step 2: Nanorod fabrication

- Deposited metal droplets act as etching mask
- Nanorods were fabricated using a dry etching process an in inductively coupled plasma (ICP)

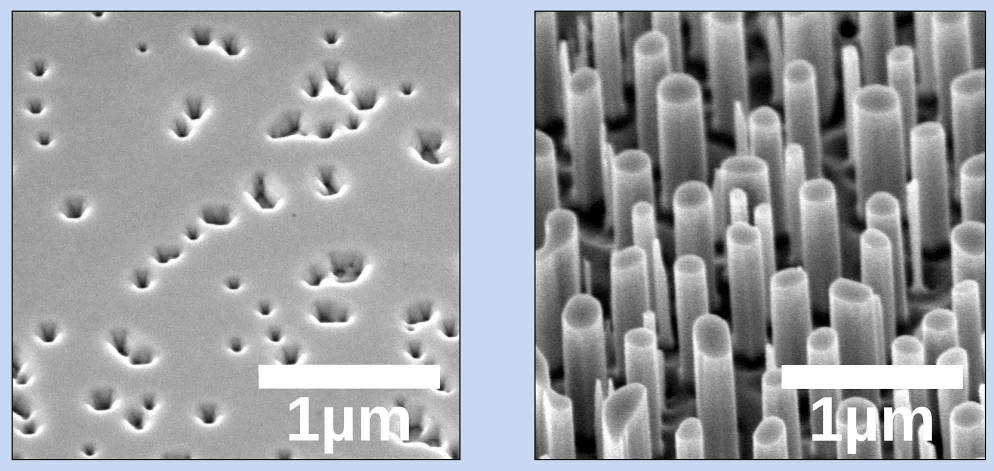
Cathodoluminescence Hyperspectral Imaging:



A Scanning Electron Microscope is used to investigate nanoscale features on the sample surfaces. In order to examine the light emitted from the sample, the electron beam is scanned across the surface while simultaneously acquiring a cathodoluminescence (CL) spectrum at each point on the sample. The result is a large 3D data set, or hyperspectral image, which can be treated mathematically to extract important patterns of behaviour.

Edwards et al., *Semicond. Sci. Technol.* **26**, 064005 (2011) ; Bruckbauer et al., *APL* 98, 141908 (2011)

Surface Morphology:

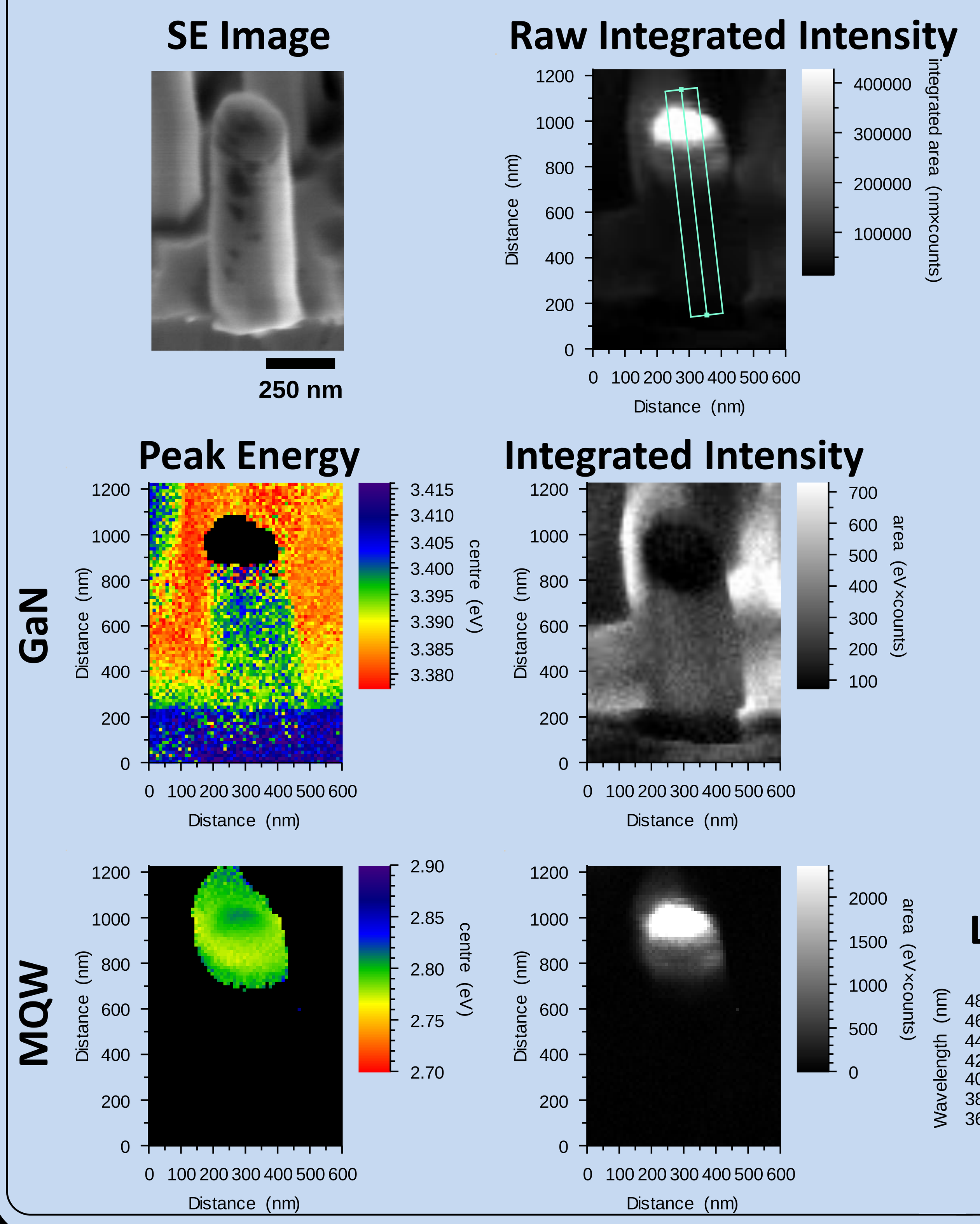


Before etching After etching

- Above secondary electron (SE) images show the surface of the as-grown and etched InGaN/GaN MQW sample
- The as-grown sample exhibits a high density of V-defects
- The diameter of nanorods ranges between 100 nm and 200 nm with an average length of 600 nm

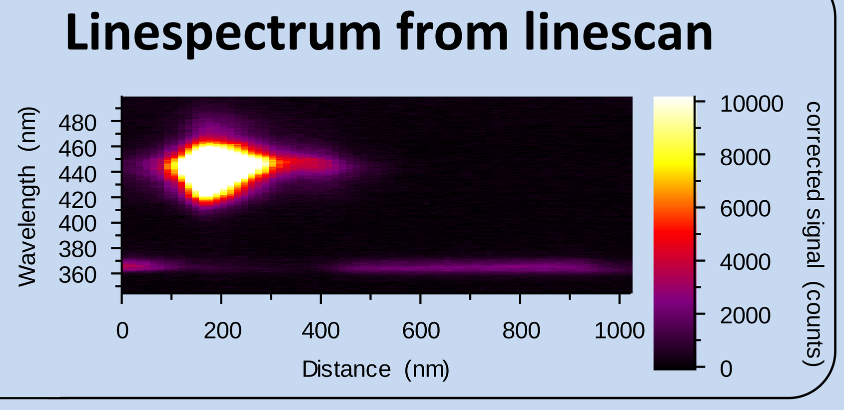
Cathodoluminescence Hyperspectral Imaging of InGaN/GaN Nanorods:

Cross-section CL of a nanorod within the array

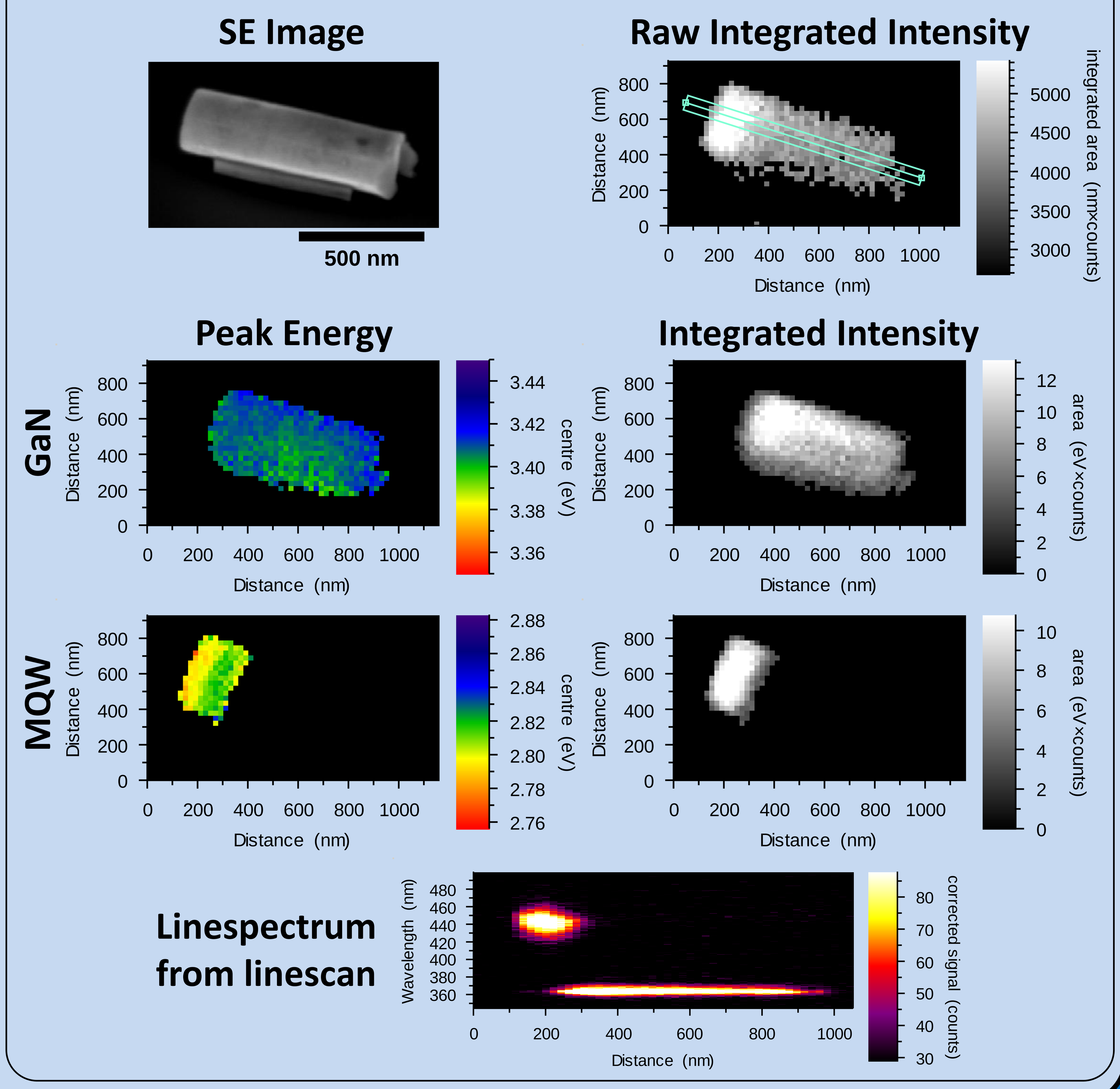


- Comparison of cross-section CL of a single nanorod at the sample edge with CL of a single isolated nanorod transferred to Si substrate
- The sample is tilted by 45°. This CL collection geometry increases the importance of self-absorption effects
- The peak energy and integrated intensity CL maps are produced by fitting the recorded spectra with a Voigt (GaN emission) or Gauss function (QW emission)
- Strong emission from the quantum well structure can be can be identified at the top of the nanorod
- Emission below the wells arises from a thick GaN layer

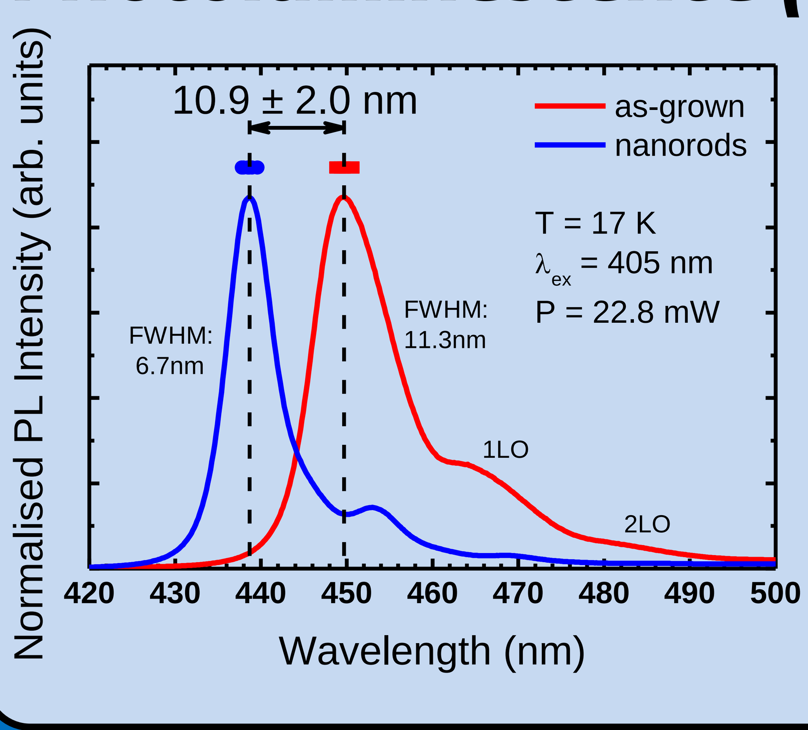
Linespectrum from linescan



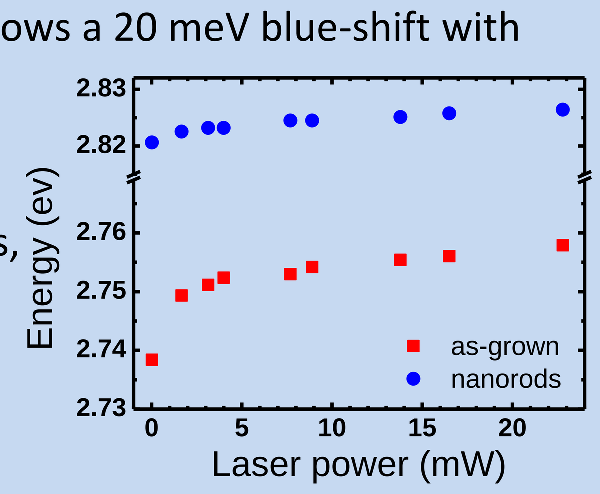
CL of a single isolated nanorod



Photoluminescence (PL):



- Emission from the nanorods is blue-shifted by 10.9 ± 2.0 nm in comparison to the as-grown layer
- This blue-shifts indicates a relaxation of the nanorods and/or quantum confinement effects
- Excitation power-dependent PL shows a 20 meV blue-shift with increasing excitation in contrast to a 6 meV for the nanorods
- This indicates relaxation of the piezoelectric fields inside the wells, which results in a larger screening effect in the as-grown layer (Chen et al., *Nanotechnology* **17**, 1454 (2006))



Conclusion:

- Nanorods were fabricated by a dry etching process of MQW layers
- CL maps show a strong emission coming from the top of the nanorod indicating the MQW region
- CL maps of a single isolated nanorod were acquired, demonstrating luminescence measurements on a length scale of tens of nanometre
- PL measurements showed a 11 nm blue-shift of the QW emission after the fabrication of the nanorod array indicating strain relaxation

Acknowledgements:

department of physics at the university of strathclyde; SUPA; The University Of Sheffield.; EPSRC Engineering and Physical Sciences Research Council