Hyperspectral cathodoluminescence imaging of semi-polar (11-22) GaN

C. Trager-Cowan[1*], P. R. Edwards[1], J. Bruckbauer[1], G. Naresh-Kumar[1], C. Brasser[1], M. Morrison[1], S. Vespucci[1], B. Hourahine[1], R. W. Martin[1], Y. Zhang[2], M. Athanasiou[2], Y. Gong[2], J. Bai[2], K. Xing[2], X. Yu[2], B. Xu[2], Z. Li[2], Y. Hou[2], R. M. Smith[2] and T. Wang[2]

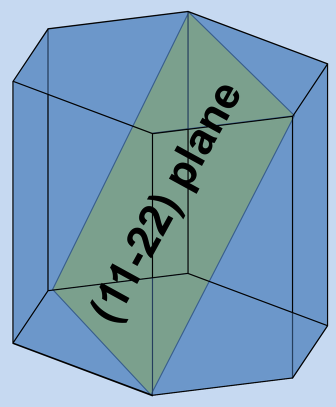
[1]Department of Physics, SUPA, University of Strathclyde, UK
[2]Department of Electronic and Electrical Engineering, University of Sheffield, Sheffield, UK

* c.trager-cowan@strath.ac.uk

The University Of Sheffield.

University of Strathclyde Glasgow

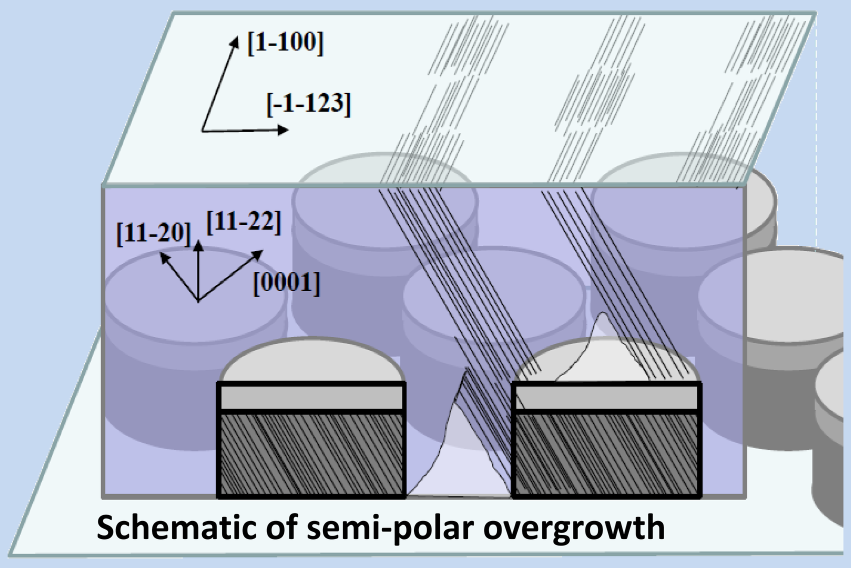
Introduction and motivation



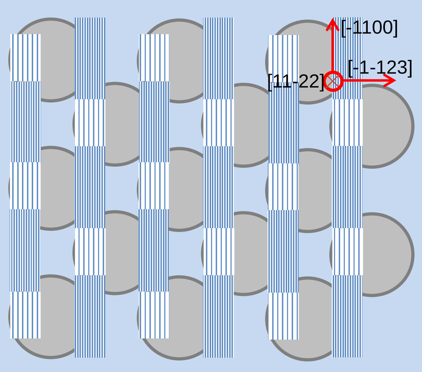
- Our aim is to produce high quality semi-polar (11-22) GaN thin films.
- The application of semi-polar GaN can produce higher performance devices due to reduction of piezo and polar electric fields.
- Growth on the (11-22) semi-polar plane is also attractive as it enables higher indium incorporation into InGaN quantum wells.
- Unfortunately the growth on the (11-22) plane can give rise to material with a high density of extended defects such as threading dislocations and stacking faults.
- Here we report the study of luminescence properties of semi-polar GaN using hyperspectral cathodoluminescence (CL) imaging and we report the study of their structural properties using electron channelling contrast imaging (ECCI).

Sample details: Growth and fabrication

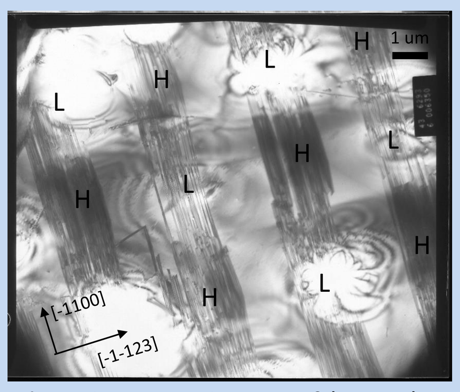
- Substrate: *m*-plane sapphire.
- Growth: Metalorganic chemical vapour deposition.
- Semi-polar (11-22) GaN thin films are produced by overgrowth on regularly arrayed microrods fabricated using a combination of photolithography and dry-etching techniques.
- The overgrowth initiates from the exposed sidewalls of the microrods and the lateral growth is dominated by the growth along the [0001] (*c*-direction) and [11-20] (*a*-direction). A higher density of defects, particularly basal plane stacking faults (BSFs), are produced for [11-20] growth.
- The growth rate in the *c*-direction is faster than in the *a*-direction, this leads to the *a*-direction growth being stopped by that in the *c*-direction, terminating the propagation of defects in the *a*-direction.



Schematic of semi-polar overgrowth



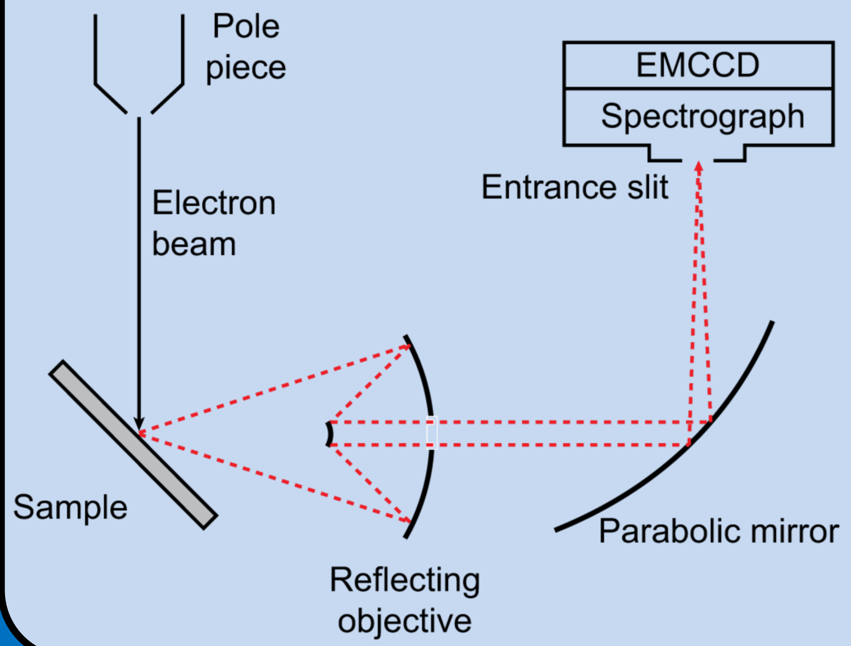
Plan-view schematic diagram of BSF distributions



Plan-view TEM image of (11-22) overgrown GaN with a diffraction vector g=1-100.

Y. Zhang et al., *AIP Advances* **6** 025201 (2016)

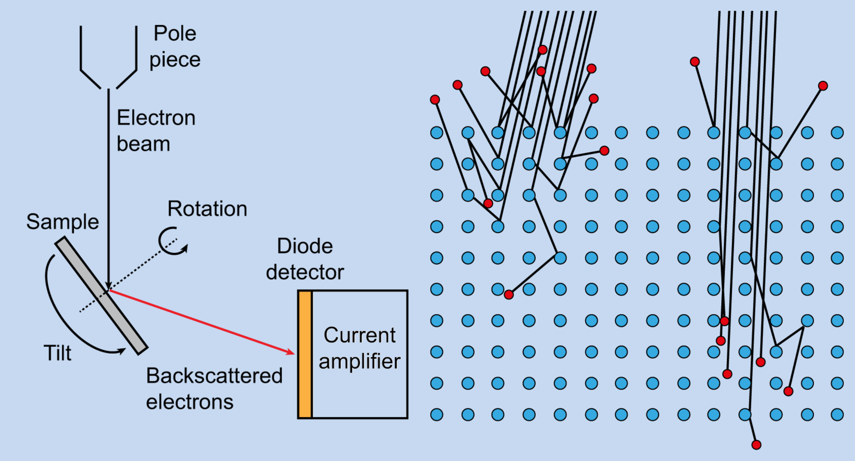
Cathodoluminescence (CL) hyperspectral imaging



- CL imaging is a powerful tool to investigate the luminescence behaviour of sample features and defects
- The electron beam is scanned across the sample surface while simultaneously acquiring an entire CL spectrum at each pixel, resulting in a multi-dimensional (hyperspectral) data set
- Numerical peak fitting can be applied to each spectrum in order to extract 2D maps of parameters such as peak energy, peak intensity or line width

P. R. Edwards et al., *Microsc. Microanal.* **18** 1212 (2012)

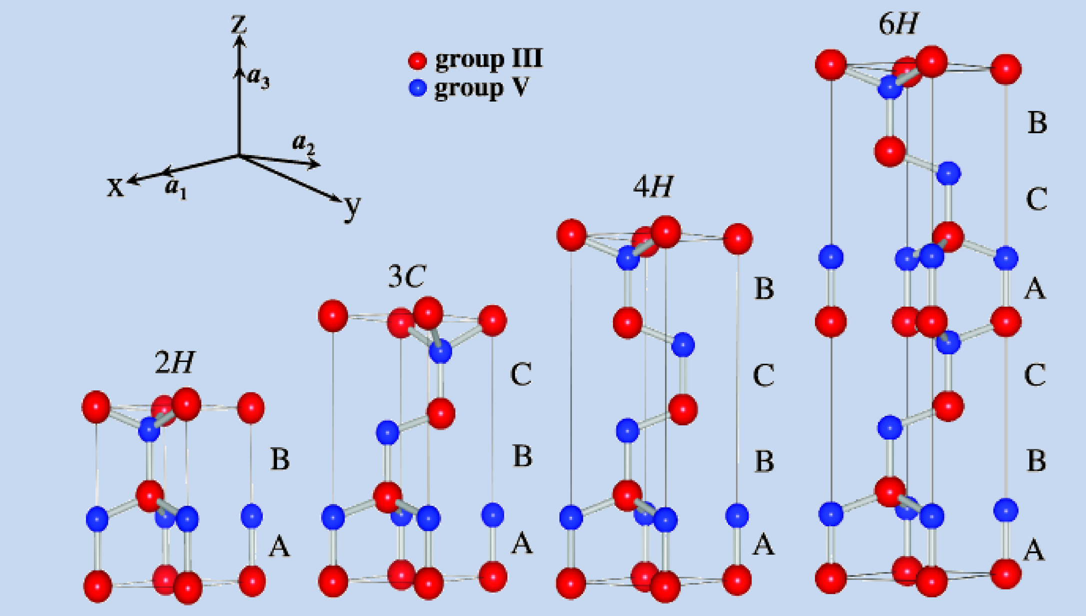
Electron channelling contrast imaging (ECCI)



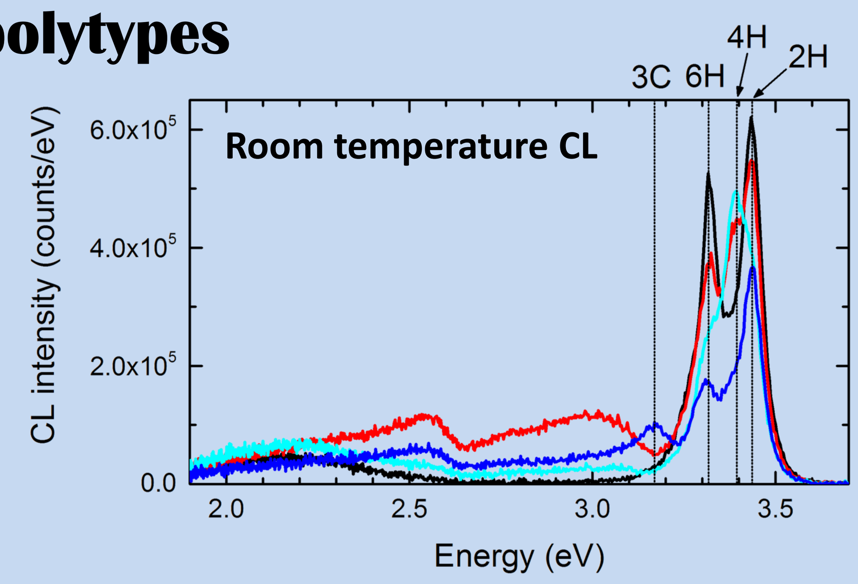
C. Trager-Cowan et al., *Phys. Rev. B* **75** 085301 (2007)
G. Naresh-Kumar et al., *Phys. Rev. Lett.* **108**,135503 (2012)

- Differences in crystal orientation or different lattice constants give rise to contrast in backscattered electron images from a suitably oriented sample
- This allows low-angle tilt and rotation boundaries, atomic steps, threading dislocations (TDs) and stacking faults to be imaged
- With ECCI it is also possible to unambiguously determine the three types of TDs in GaN

Possible CL signature for polytypes



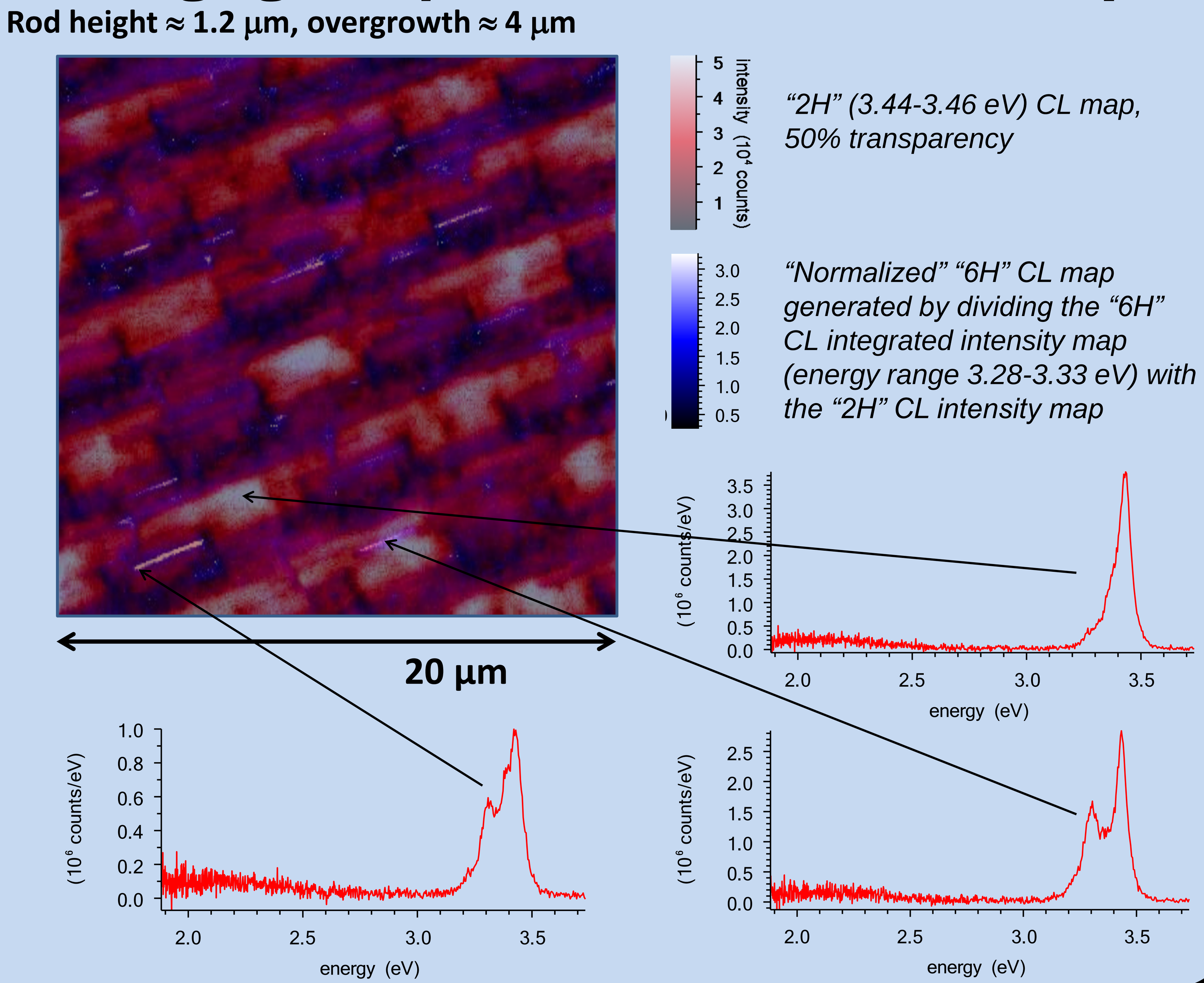
From F. Bechstedt and A. Belabbes, *J. Phys.: Condens. Matter* **25** 273201 (2013)



The observation of a number of peaks ranging from 3.2 eV to 3.45 eV indicates the presence of polytypes in our semi-polar GaN samples.

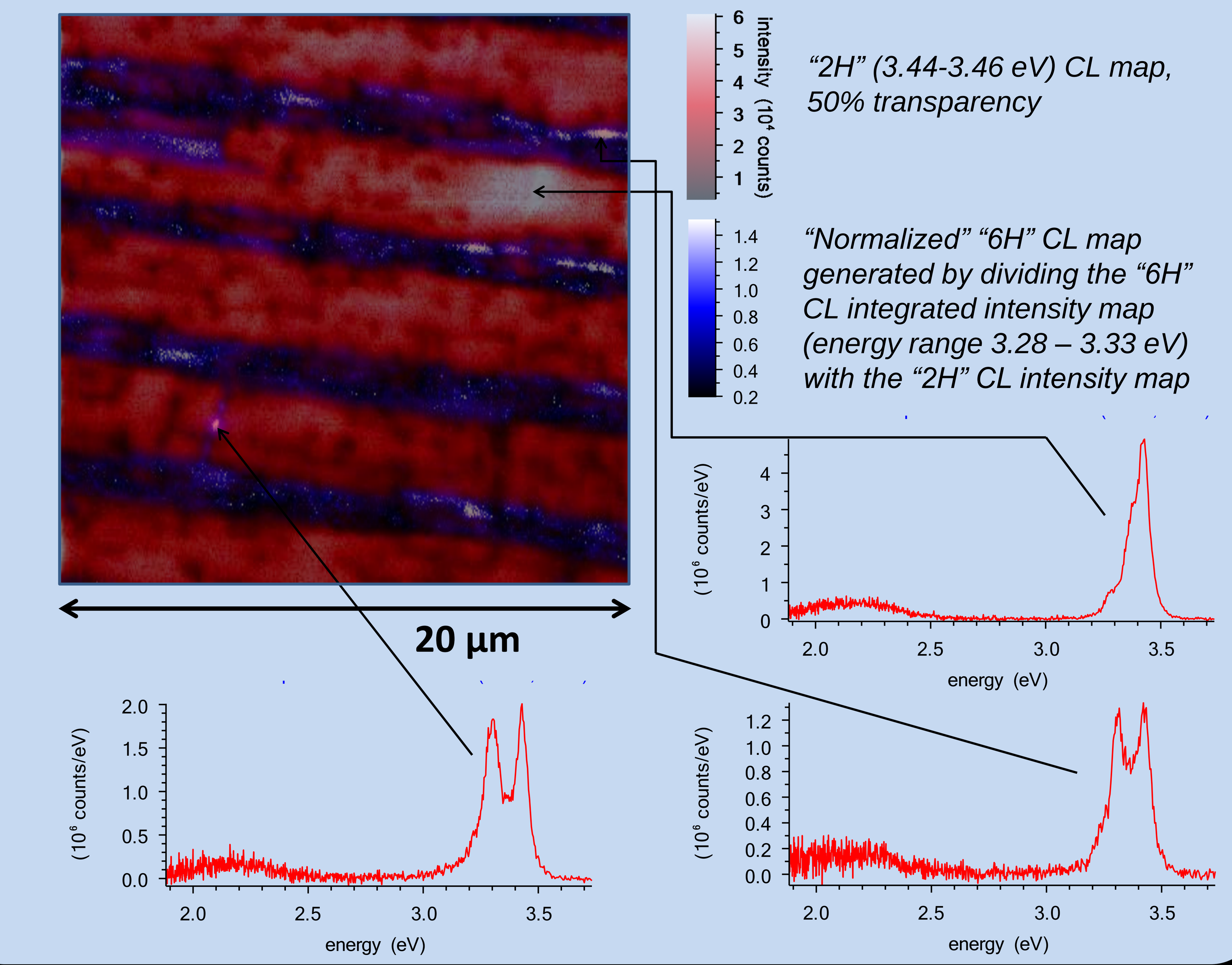
CL imaging of 4 μm diameter microrod sample

Rod height ≈ 1.2 μm, overgrowth ≈ 4 μm

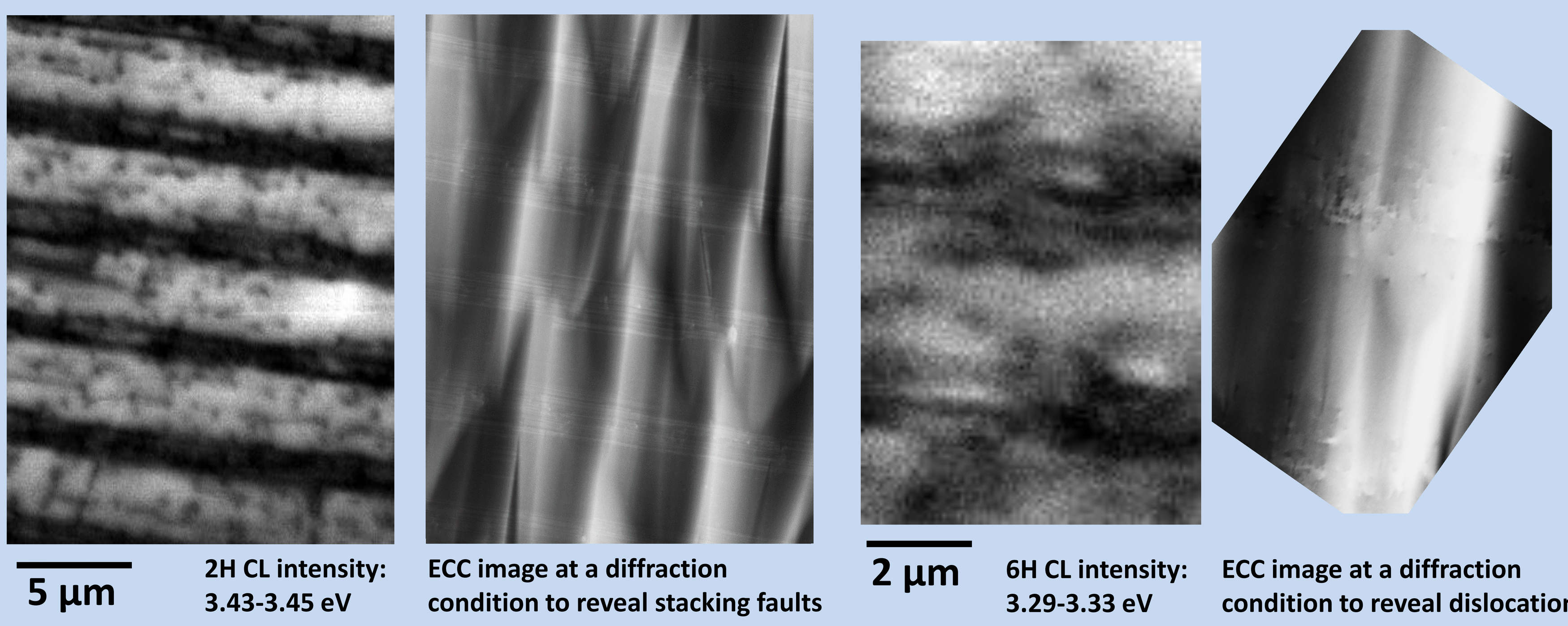


CL imaging of 5 μm diameter microrod sample

Rod height ≈ 0.4 μm, overgrowth ≈ 4 μm



Comparing ECC and CL imaging of a 5 μm diameter microrod sample



2H CL intensity: 3.43-3.45 eV; ECC image at a diffraction condition to reveal stacking faults. Same scale, but different areas

6H CL intensity: 3.29-3.33 eV; ECC image at a diffraction condition to reveal dislocations. Same scale, but different areas.

ECCI reveals the presence of dislocations and stacking faults in our samples. The CL reveals that these defects result in a reduction in luminescence intensity.

Dislocation density:
High density region: $\approx 2 \times 10^{9}$ cm^{-2}
Lower density region: $\approx 2 \times 10^{8}$ cm^{-2}
Average stacking fault density: $\approx 4 \times 10^{4}$ cm^{-1}

Summary

- CL reveals the presence of polytypes which are formed as a result of stacking faults (revealed by TEM and ECCI) present in our samples
- Increasing the diameter of the microrods led to an improvement in the uniformity of the luminescence

SUPA

Acknowledgements

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EPSRC Engineering and Physical Sciences Research Council