Trench defects and threading dislocations in III-nitride structures investigated using scanning electron microscopy

Jochen Bruckbauer[1,*], Paul R. Edwards[1], Suman-Lata Sahonta[2], G. Naresh-Kumar[1], Menno J. Kappers[2], Colin J. Humphreys[2], Rachel A. Oliver[2], Carol Trager-Cowan[1], and Robert W. Martin[2]

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

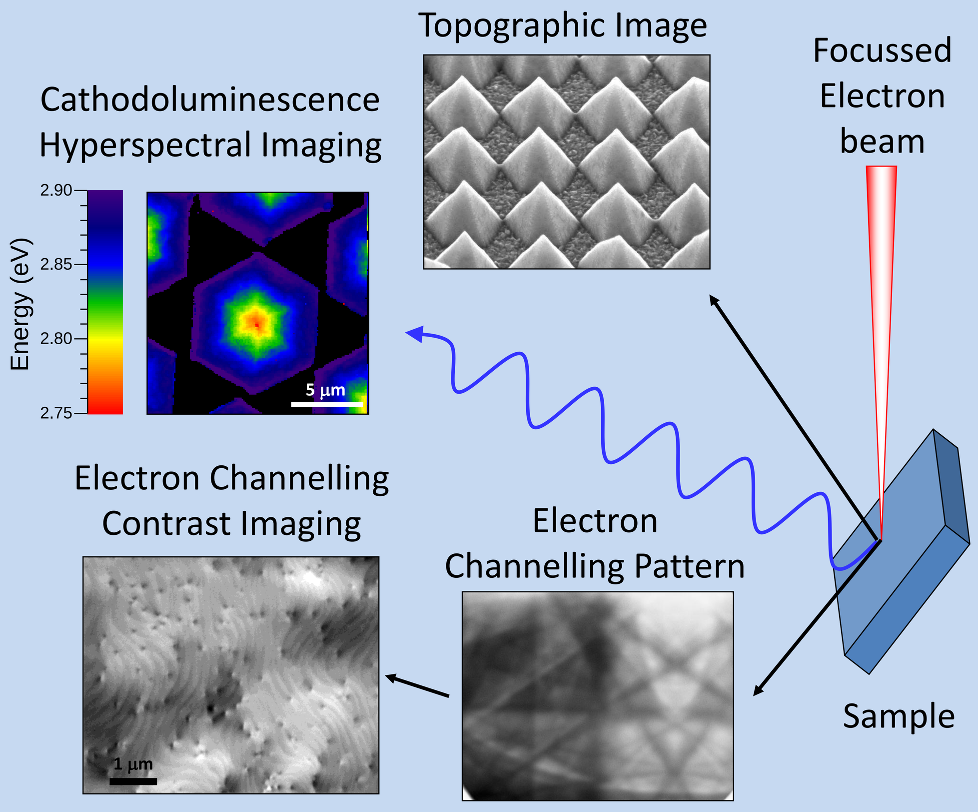
[2]*Department of Materials Science and Metallurgy, University of Cambridge, Cambridge, CB2 3QZ, United Kingdom*

* jochen.bruckbauer@strath.ac.uk

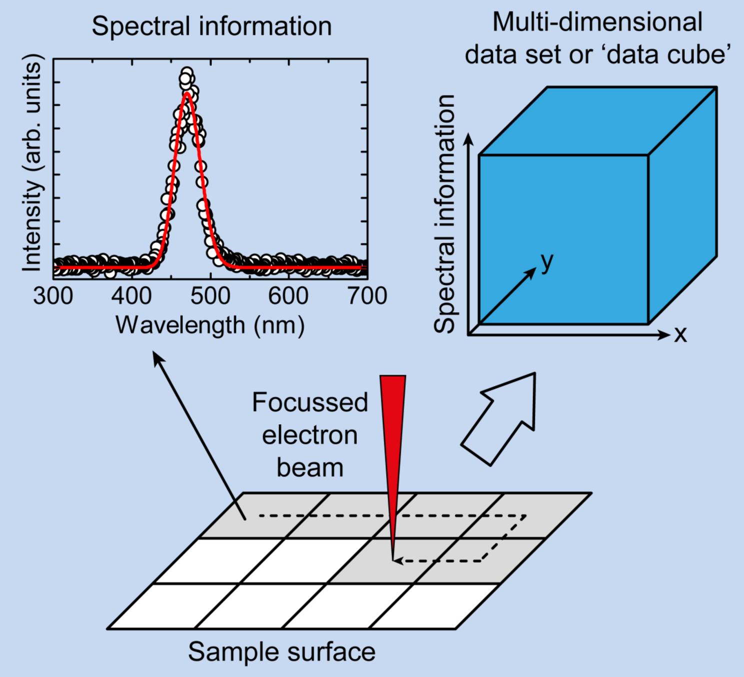
University of Strathclyde Glasgow

Motivation

- For the success of optoelectronic devices (e.g. laser diodes and white LEDs) efficiencies have to be further improved
- Despite improvements of the growth of InGaN/GaN layers, there are still quite a few remaining challenges (e.g. growth temperatures, carrier gases, mismatched substrates, miscibility, etc.)
- These challenges lead to a variety of defects that have a strong impact on the luminescence behaviour
- Here we use a scanning electron microscope, which is a powerful tool combining structural and luminescence characterisation techniques in one instrument



Cathodoluminescence Hyperspectral Imaging



A scanning electron microscope is used to investigate nanoscale features on the sample surface. The electron beam is scanned across the surface while simultaneously acquiring an entire cathodoluminescence (CL) spectrum at each point. The result is a large multi-dimensional data set, or hyperspectral image, which then can be numerically fitted to extract 2D maps of physical parameters, such as peak energy, line width or peak intensity.

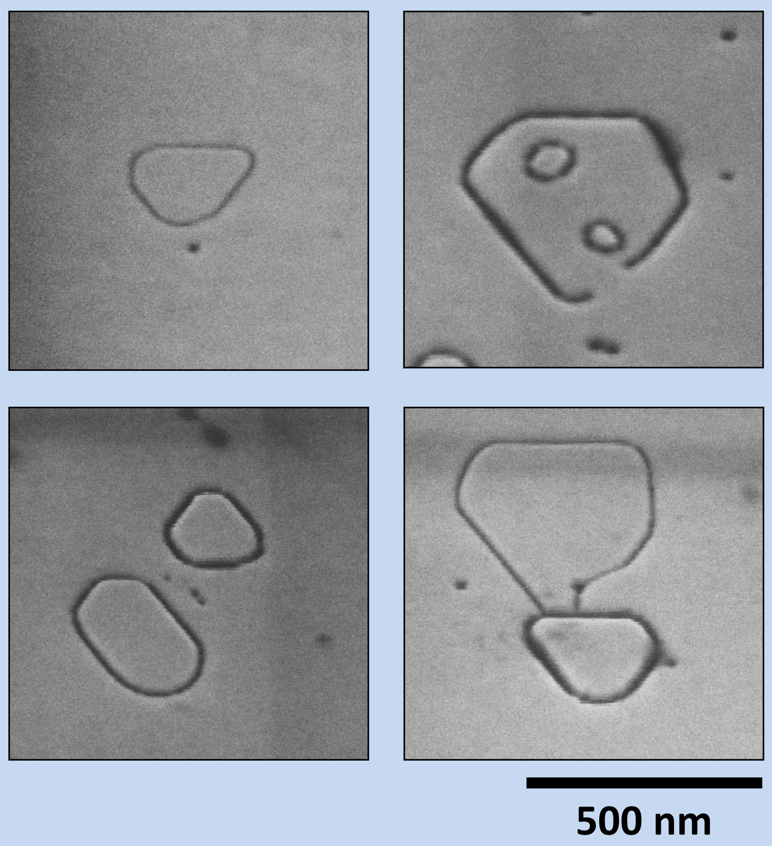
Edwards et al., *Semicond. Sci. Technol.* **26**, 064005 (2011) and *Microsc. Microanal.* (2012) in press

Trench defects in InGaN/GaN MQWs

Sample Fabrication

- Growth by metal-organic chemical vapour deposition at the University of Cambridge
- 5 or 10 period InGaN/GaN quantum well structure on c-plane sapphire

Surface Morphology Scanning Electron Microscopy



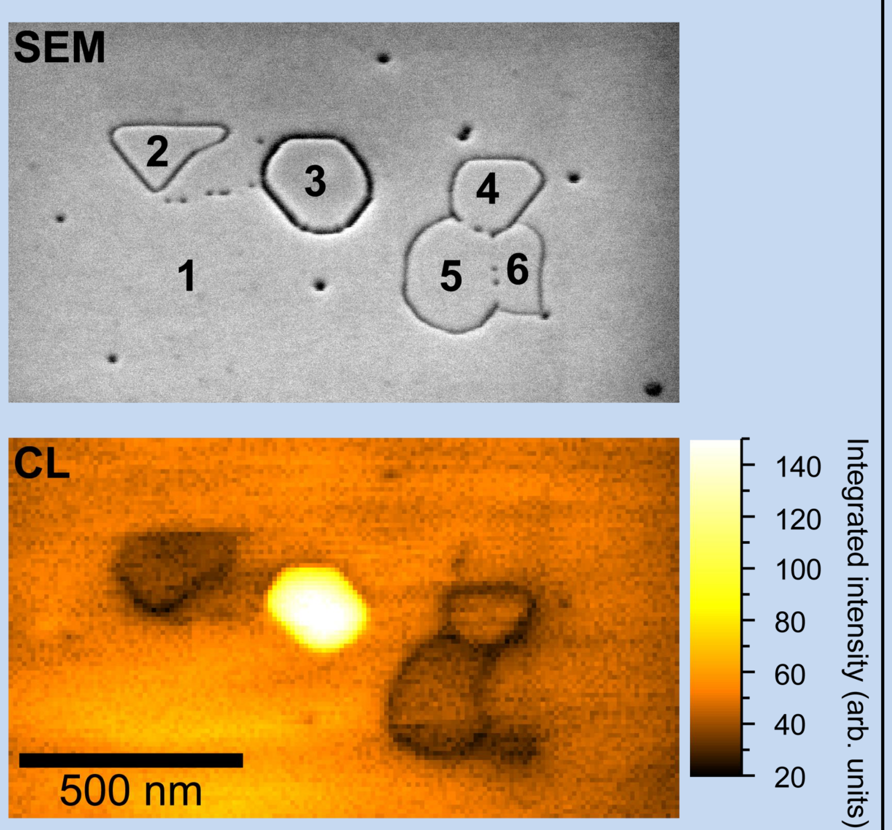
Three types of trench defects:

1. ***Narrow*** trenches forming closed loops
2. ***Wide*** trenches forming closed loops
3. Trenches forming ***open*** loops

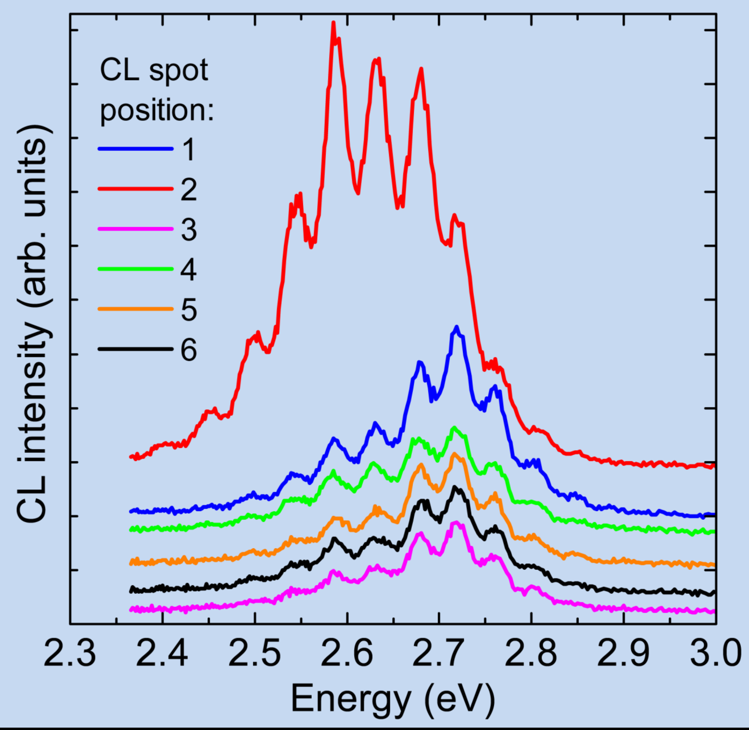
- The surface exhibits trench and V-defects/pits
- Sometimes trenches connect or intersect trenches of another kind or V-defects

Ting et al., *J. Appl. Phys.* **94**, 1461 (2003)
Kumar et al., *J. Phys. D: Appl. Phys.* **40**, 5050 (2007)

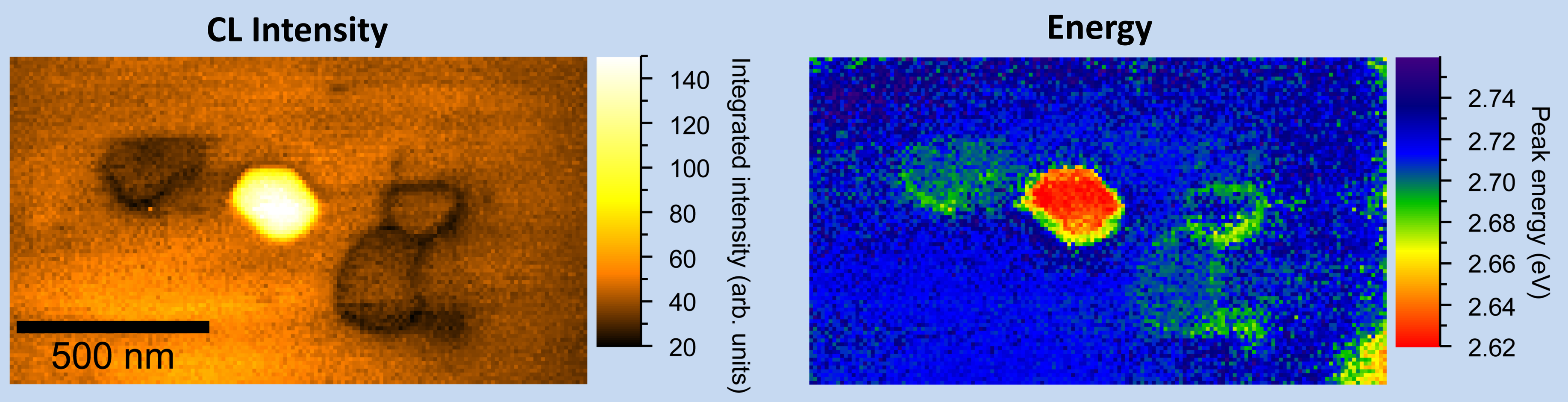
Panchromatic CL



- Trench defects with wide trenches show increased intensity compared to surrounding
- Loops with narrower trenches exhibit lower intensity than adjacent area
- Open loop shows no impact on luminescence

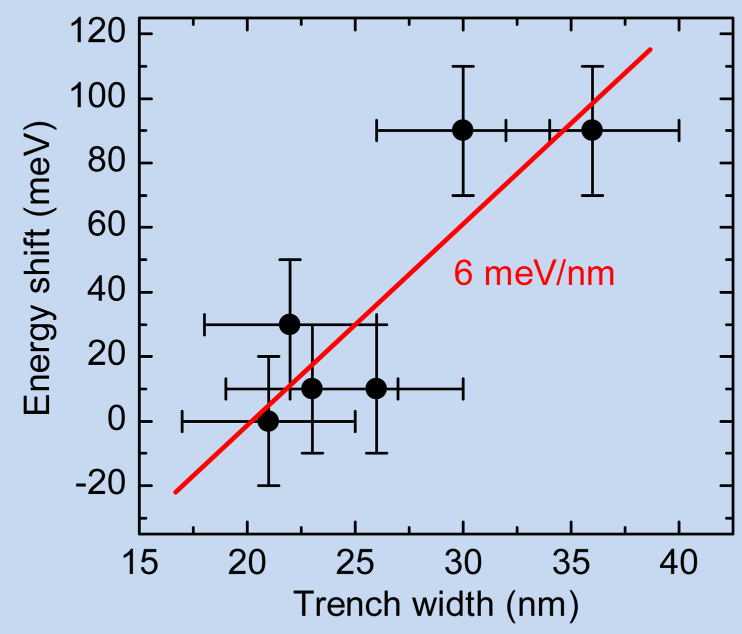


Cathodoluminescence hyperspectral imaging of trench defects

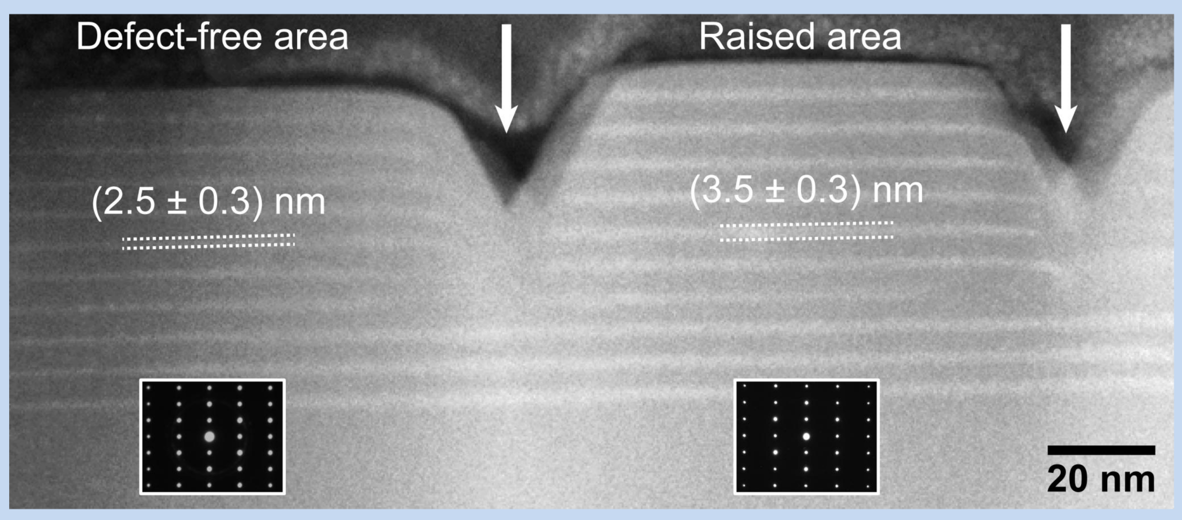


- The CL intensity and energy maps (above) are obtained by numerically fitting the multiple quantum well (MQW) emission peak with a Gauss function
- Besides intensity changes the peak energy also shifts
- The loop with wider trenches shows an increase of energy of about 90 meV, whereas the adjacent loops with narrow trenches only redshift the emission by 10 meV
- Wider trenches penetrate further into the MQW region and thereby disrupt them more
- The large difference of emission between loops with wide and thin trenches suggest two different causes
- The enhanced emission of the wide trench loops suggest strong localisation, which might be caused by InN rich clusters or quantum-dot-like states in the InGaN well layer in the area enclosed by the loops

Florescu et al., *Appl. Phys. Lett.* **83**, 33 (2003)
Kumar et al., *Mater. Chem. Phys.* **113**, 192 (2009)
Bruckbauer et al., *Appl. Phys. Lett.* 98, 141908 (2011)



- The slight redshift and small intensity decrease of the narrow trench loops suggest that the inside region is similar to the surrounding region, which could be caused by wider wells

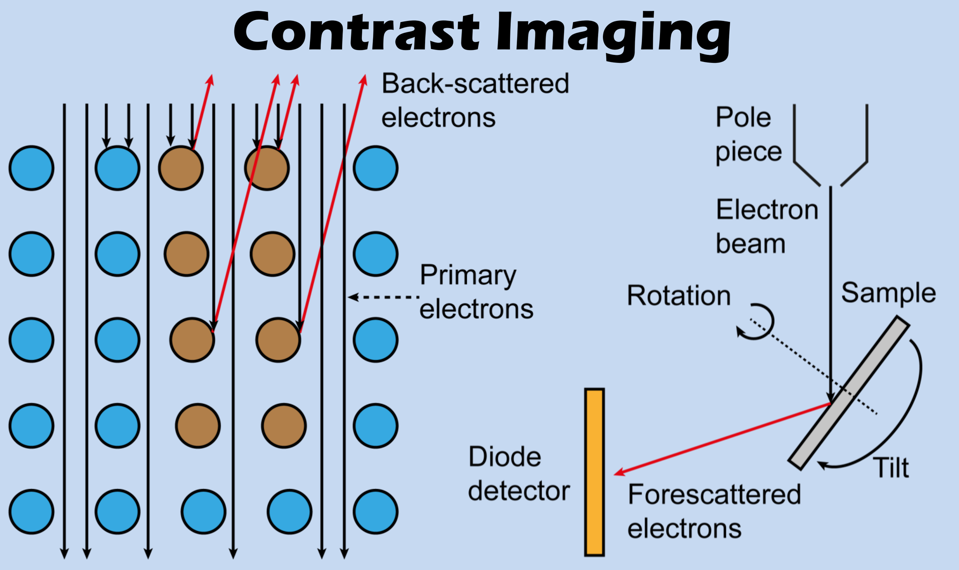


Transmission Electron Microscopy

- TEM images shows a raised central area between trenches
- The width of InGaN quantum wells is increased, while the barriers remain unchanged

Sahonta et al., *Phys. Status Solidi* (2012) in press

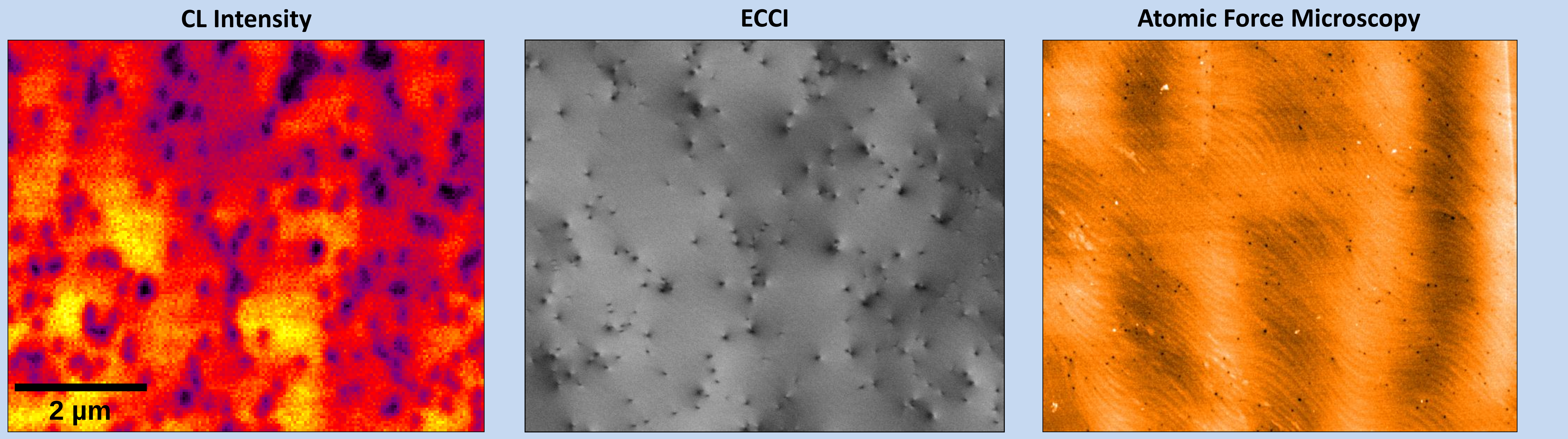
Electron Channelling Contrast Imaging



- Crystal imperfections lead to scattering of the primary electrons and give contrast in backscattered electron images from a suitably orientated sample
- Imperfections can be low angle tilt and rotation boundaries, changes in crystal orientation and lattice constants due to strain
- This makes it possible to image tilt, rotation, atomic steps and *threading dislocations*

C. Trager-Cowan et al., *Phys. Rev. B* **75**, 085301 (2007)

Imaging threading dislocations in GaN



- Sample: Si-doped c-plane GaN epilayer (MOCVD growth at Cambridge)
- CL, ECCI and AFM imaging were performed on the same micrometre area
- Dark spots in the CL intensity map correspond to centres of non-radiative recombination
- Threading dislocations (TDs) in electron contrast images (ECCI) are shown as spots with black and white contrast
- Total TD density: $5.1 \pm 0.4 \times 10^8$ cm^{-2} with 60 % edge, 38 % mixed and 2 % screw dislocations
- Strong correlation between isolated TDs in ECCI and dark spots (CL)
- AFM/ECCI: isolated TDs have edge or screw/mixed character
- This suggests that TDs with edge character or a screw component act as centres for non-radiative recombination

Summary

- Three types of trench defects are identified by CL imaging
- Loops with wide trenches show a more intense and redshifted emission, whereas loops with narrower trenches have lower intensity and a small redshift
- TDs in a n-GaN epilayer are imaged using ECCI and CL from the same micron scale area
- One-to-one correlation of isolated TDs in ECCI and dark spots (CL) suggest that TDs with edge character or a screw component act as centres for non-radiative recombination

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