Coincident Cathodoluminescence and Electron Channelling Contrast Imaging of Threading Dislocations in GaN

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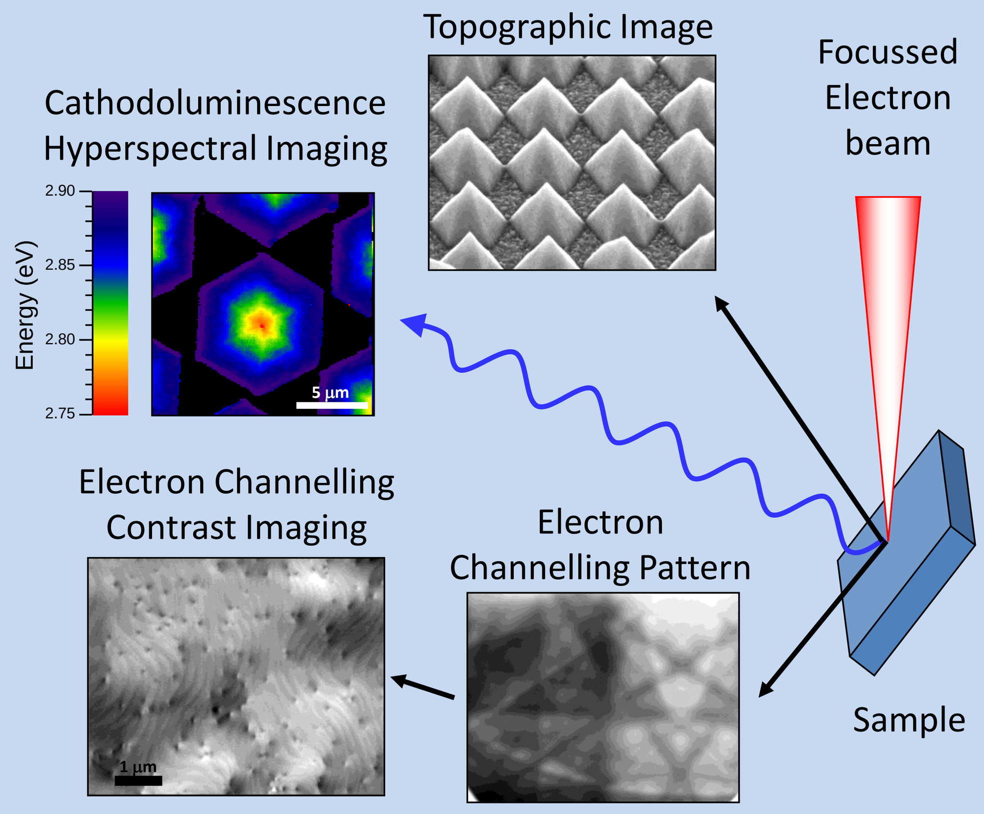
Motivation

- Thick GaN templates commonly used for the growth of optoelectronic devices exhibit a relatively large *threading dislocation* (TD) density
- The impact of TDs on the optical properties shows a strong ambiguity in the literature
- Here we use a scanning electron microscope in a multi-mode configuration (CL & ECCI) to probe the structural and luminescence properties of a sample in one instrument

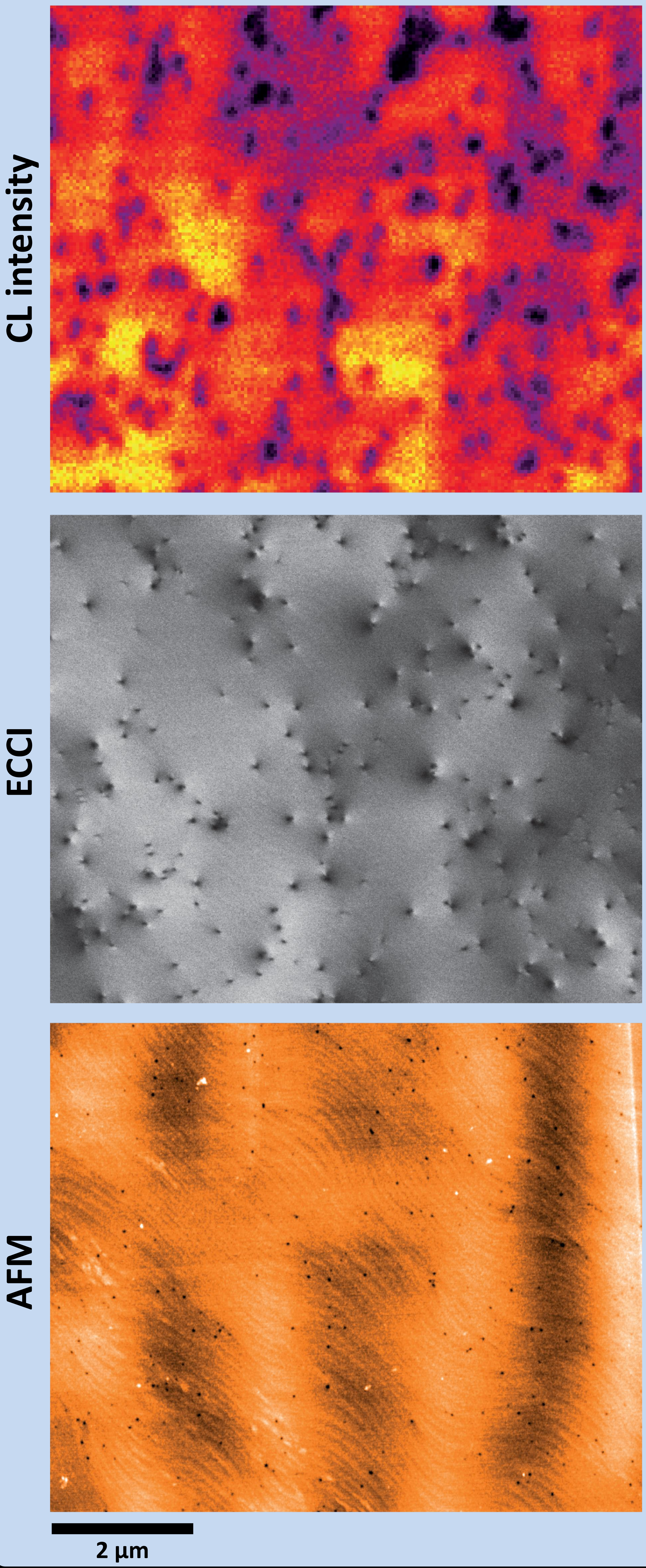


T. Hino et al., *Appl. Phys. Lett.* **76**, 3421 (2000)
M. Albrecht et al., *Appl. Phys. Lett.* **92**, 231909 (2008)

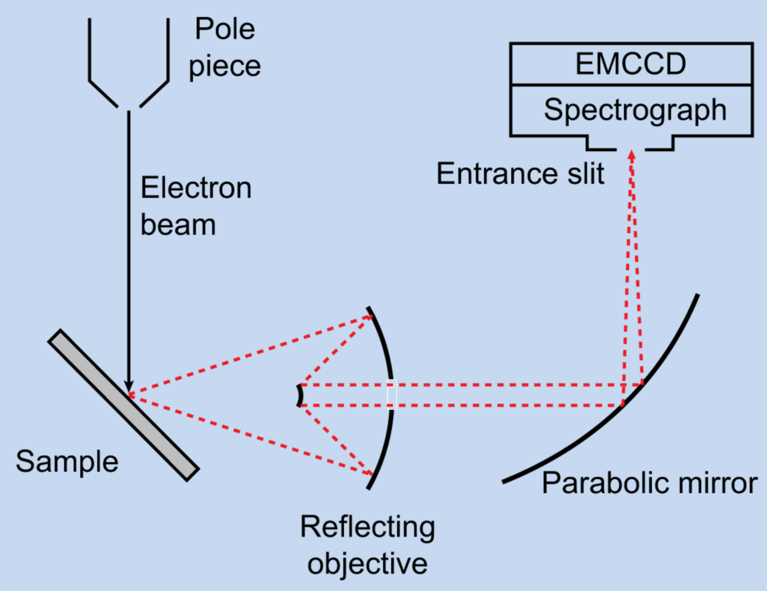
Sample description

- Grown by metal-organic vapour phase epitaxy on a 5 µm GaN template on *c*-plane sapphire
- Intermediate structure: four n-doped 200 nm thick GaN layers with increasing Si-doping concentration ([Si]=5.5×10^{17}-1.0×10^{19} cm^{-3}) separated by 200 nm thick undoped GaN spacer layers
- top layer: 200 nm thick Si-doped GaN layer ([Si]=1.0×10^{18} cm^{-3}) on GaN spacer

S. Das Bakshi et al., *J. Cryst. Growth* **311**, 232 (2009)



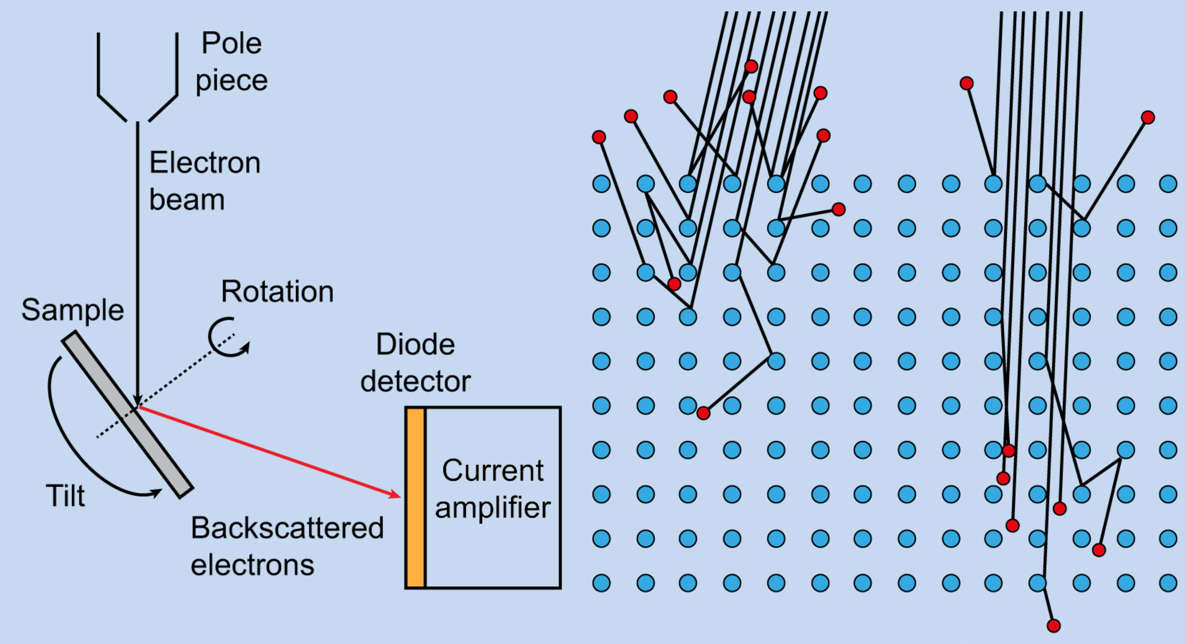
Cathodoluminescence (CL) hyperspectral imaging



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

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

Electron channelling contrast imaging (ECCI)

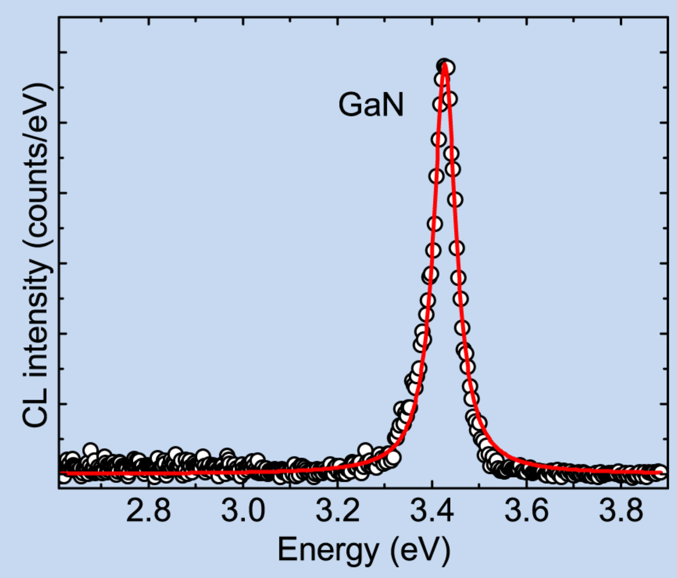


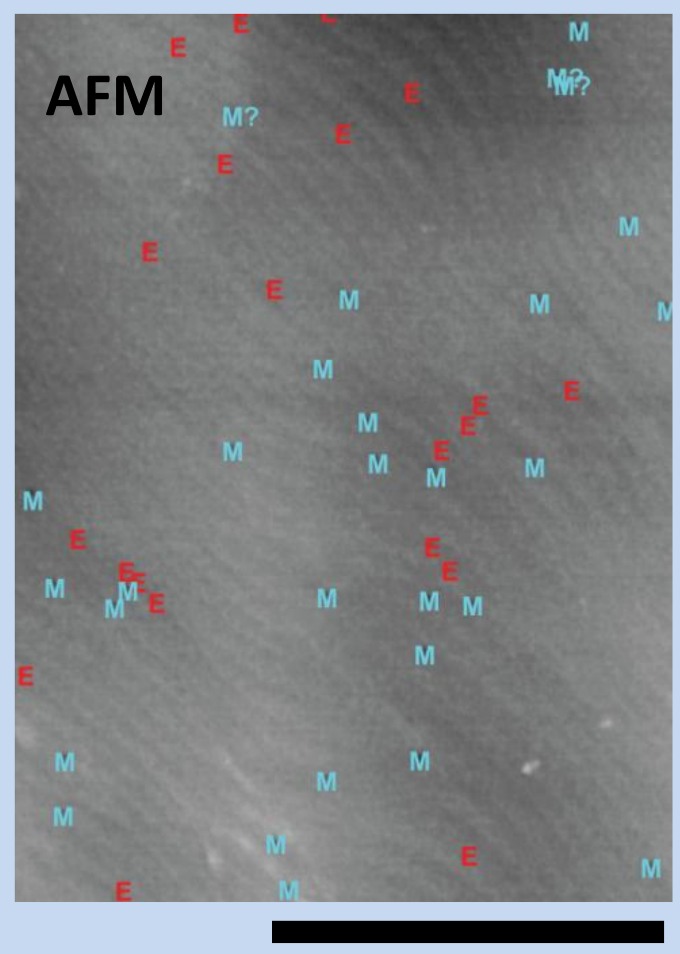
- Differences in crystal orientation or different lattice constants give rise to contrast in backscattered electron images from a suitably orientated sample
- This allows low-angle tilt and rotation boundaries, atomic steps and threading dislocations to be imaged
- With ECCI it is also possible to unambiguously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

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

Results

- The CL intensity map (generated by fitting each spectrum with a Voigt function) exhibits dark spots of various diameters, which are associated with non-radiative recombination at TDs
- Due to clustering a single and isolated TD is defined as a dark spot, separated by at least 400 nm from its nearest neighbour
- TDs appear as spots with black—white contrast in the ECCI image
- ECCI determined a TD density of $(5.1\pm0.4)\times10^8$ cm^{-2} with 60% of the TDs being edge-type, <2% being screw-type and the remainder being mixed-type
- Atomic force microscope (AFM) measurements were performed on the same area to verify the TD density and their type by analysing etch pits created by a post-growth silane treatment
- A *one-to-one* correlation was found between the dark spots in the CL map, spots with B—W contrast in the ECCI image and pits in the AFM image for single and isolated TDs
- From the AFM image it was possible to identify the TDs as being either of edge-type (labelled "E") or as TDs having a screw component, i.e. screw- or mixed-type (labelled "M")
- A comparison showed that single and isolated spots correspond to TDs of both edge- and screw-/mixed type
- It can be concluded that that pure edge TDs and TDs with a screw-component act as centres for non-radiative recombination in the investigated Si-doped GaN layer





Summary

- CL, ECCI and AFM have been performed on the same micron-scale area of a n-GaN sample
- A one-to-one correlation was observed for single and isolated TDs in these three images
- Pure edge TDs and TDs with a screw component act as centres for non-radiative recombination

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