Nanoscale characterisation of nitride semiconductor thin films using EBSD, ECCI, CL and EBIC

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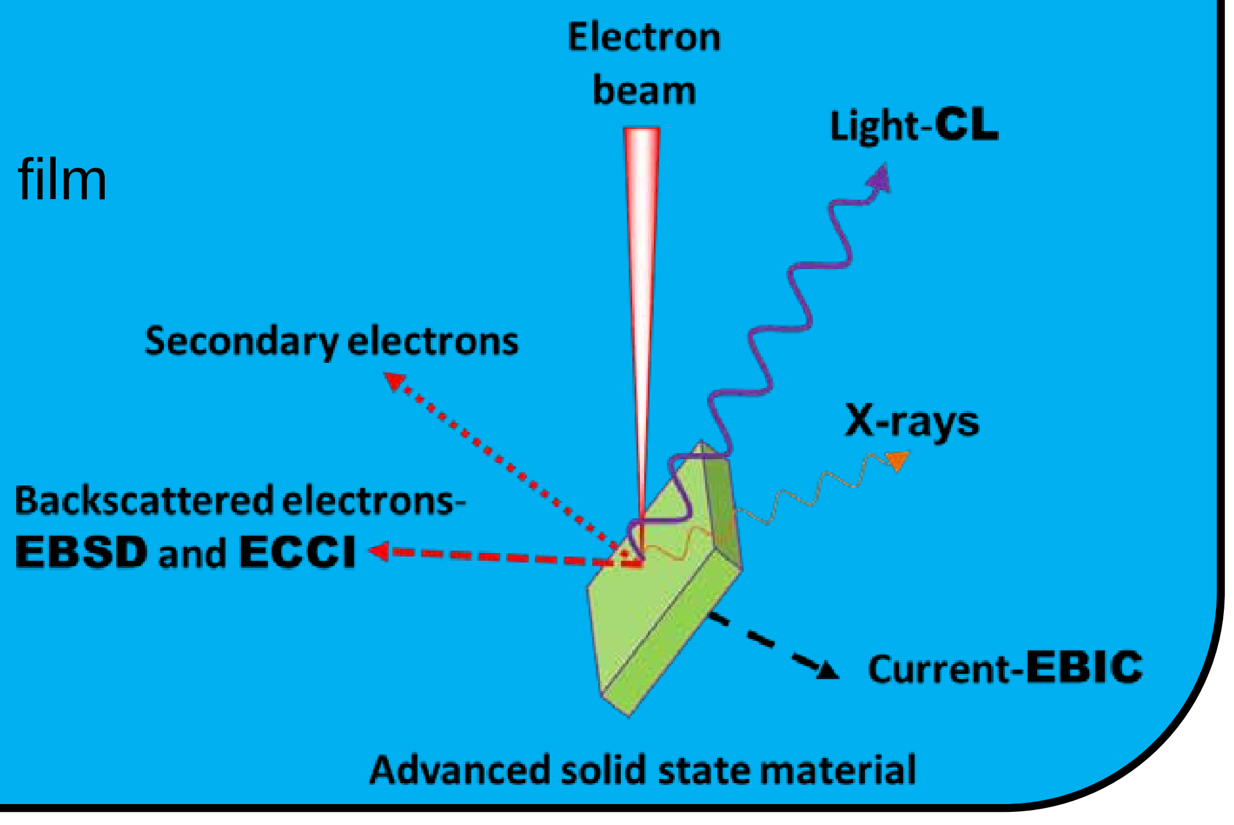
Aims and objectives:

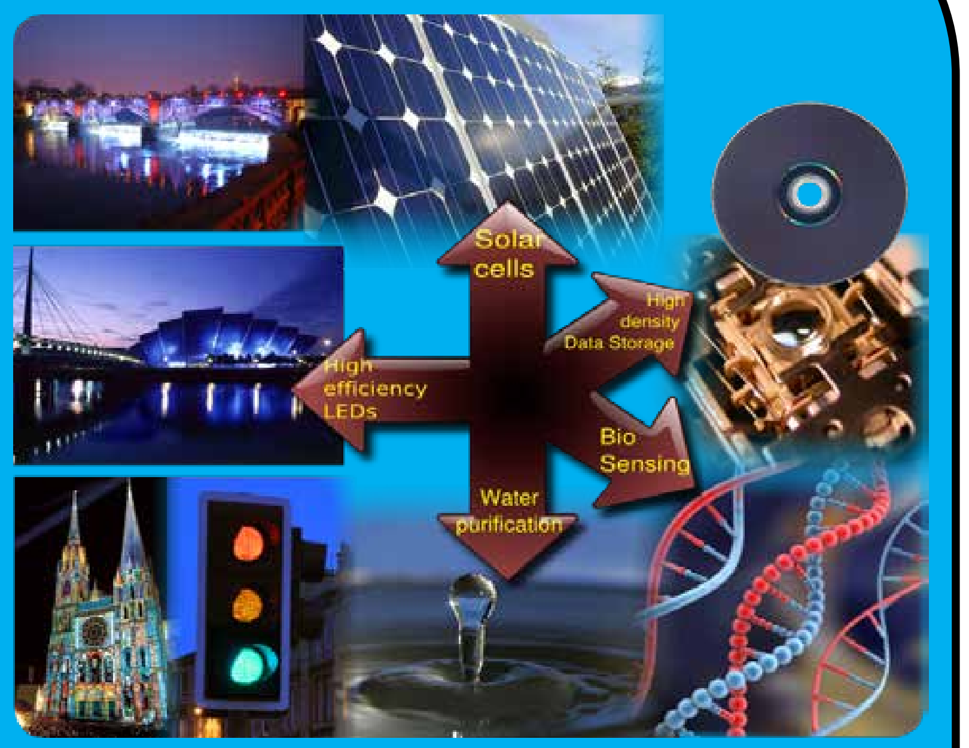
- Develop and apply novel, rapid, high resolution and non-destructive characterisation techniques such as Electron back scatter diffraction (EBSD), Electron channelling contrast imaging (ECCI), cathodoluminescence (CL) and Electron beam induced current (EBIC) to the optimisation of III-nitride semiconductor structures and devices.
- Provide structural and optical characterisation for III-nitride thin film growers in UK.
- Establish the best routes for development and commercialisation of new instrumentation, and nitride thin film growth processes.



Project overview:

- Use the EBSD/ECCI/CL/EBIC techniques to optimise the quality of nitride semiconductor thin films, namely

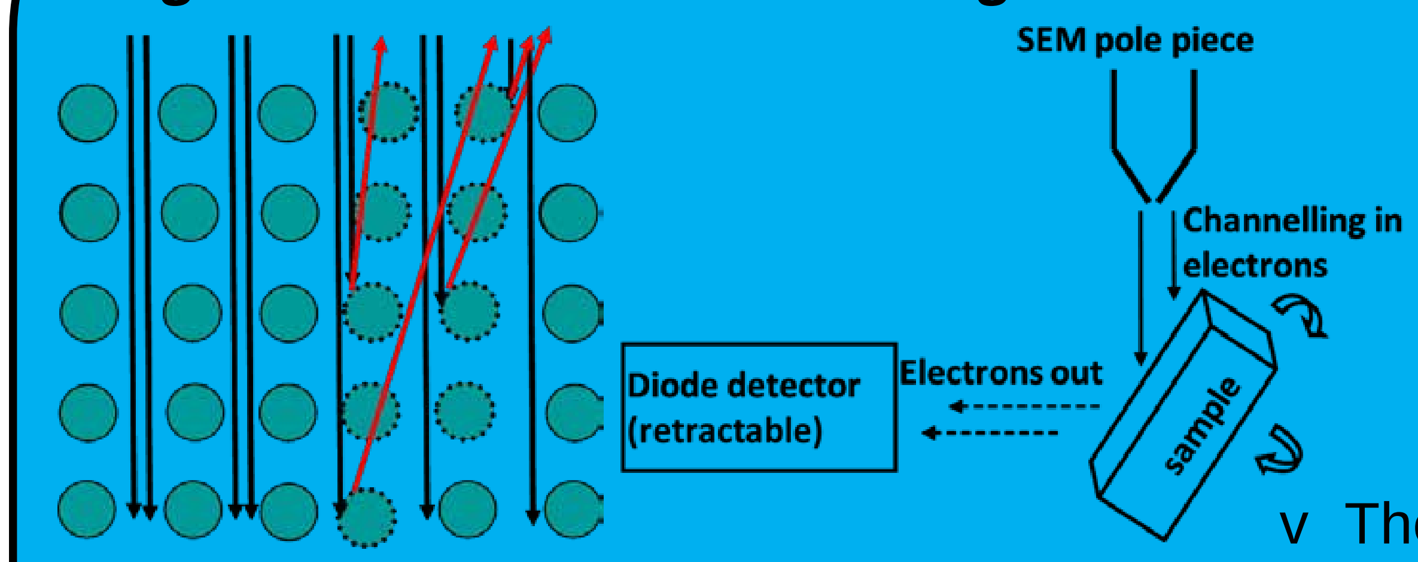
I. Nonpolar and semi-polar nitride thin films.
II. Epitaxially overgrown nitride thin films and nitride thin films grown on native substrates.
III. High aluminium content nitride thin films (including films grown on silicon).
IV. High indium content nitride thin films.
V. Zinc blende nitride thin films.

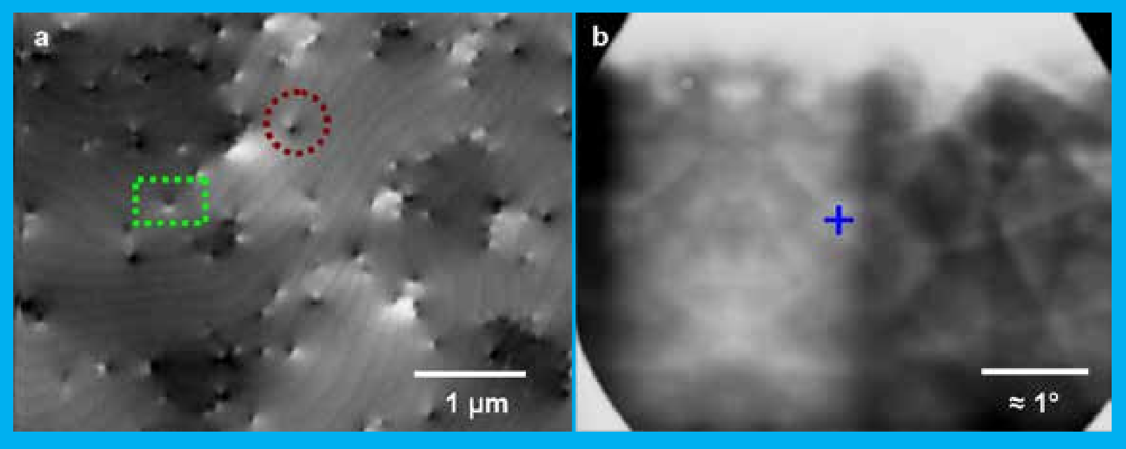


- These novel nitride semiconductor structures will allow the production of higher power LEDs, high electron mobility transistors (HEMTs) and new nitride-based devices - solar cells for example.

Demonstrating ECCI , EBSD and CL imaging in a field emission SEM

Origin of electron channelling contrast

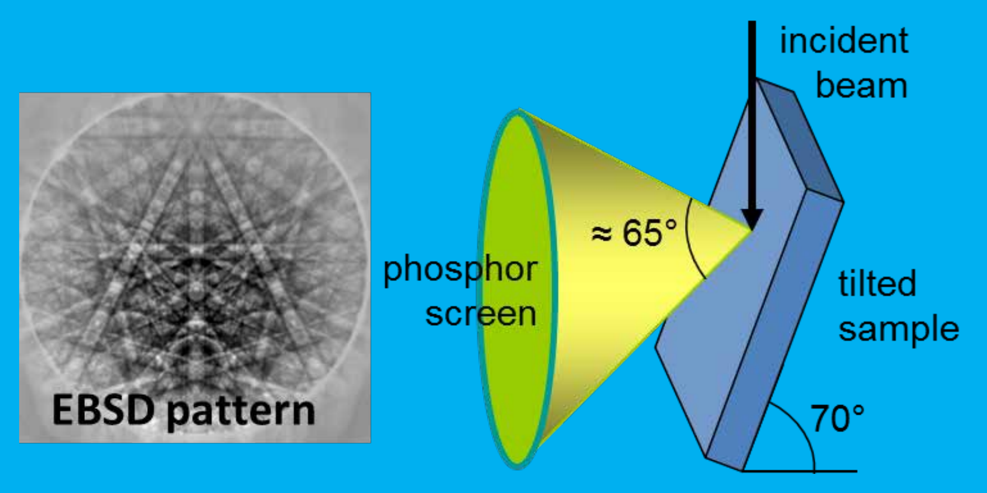




(a) Multibeam ECCI showing TDs, atomic steps and (b) ECP, both acquired at 30 keV

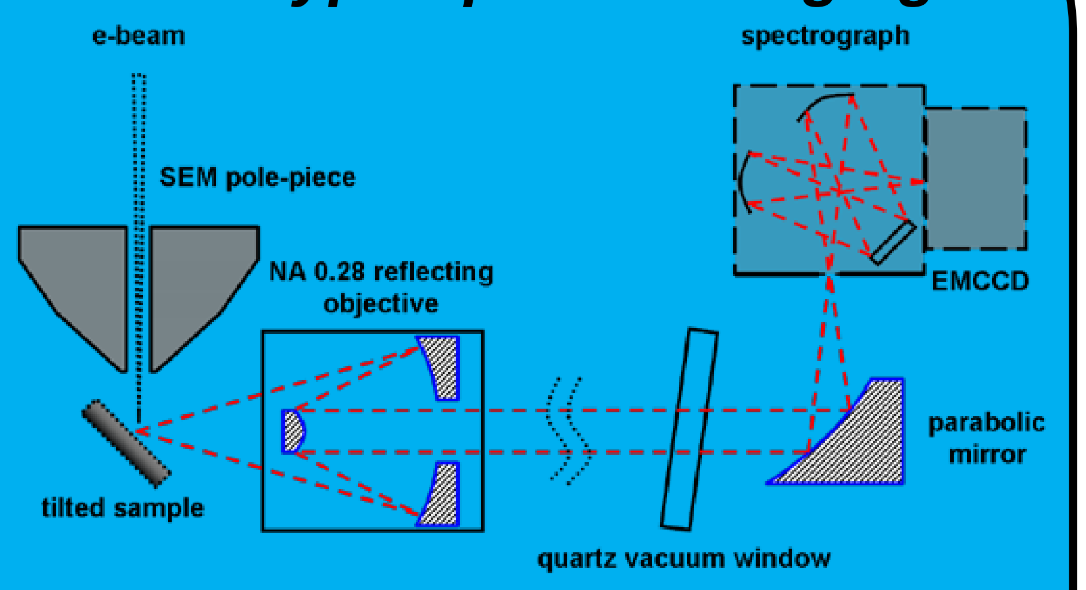
- In ECCI TDs appear as spots with black-white (B-W) contrast [1].
- Spatial and depth resolution of tens of nano metres can be achieved
- The circle highlights a dislocation with a screw component and the rectangle highlights an edge dislocation. The cross on the ECP marks the pattern centre.
- Choosing appropriate crystal planes for channelling and from the direction of B-W contrast, TD types can be identified [2].

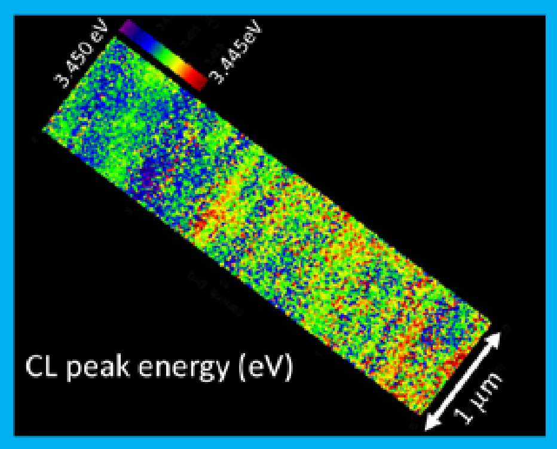
Acquisition of EBSD patterns



- A distortion of a crystal will produce a distortion of the EBSD pattern.
- EBSD patterns acquired from a mesh of points on a sample can thus be used to produce maps of strain in that sample.
- Strain changes of order 1 x 10^{-4} can be resolved.

CL hyperspectral imaging



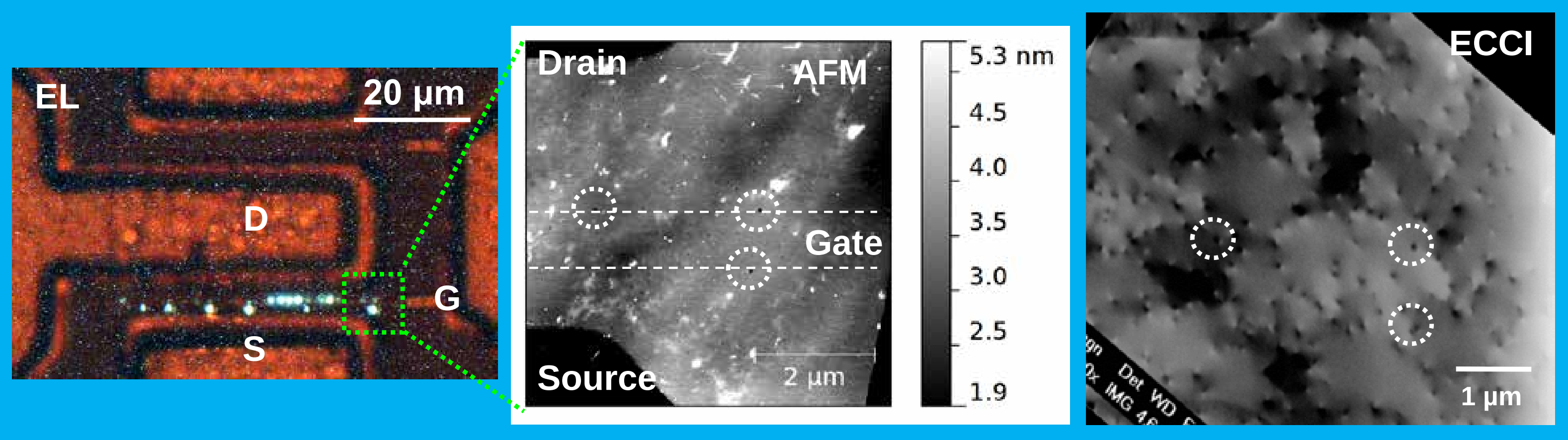


CL hyperspectral image of m-plane GaN

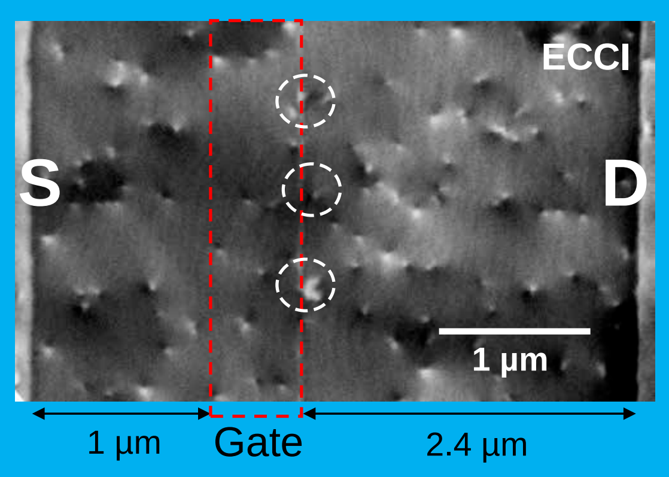
- Luminescence properties can be probed with a resolution of tens of nanometres

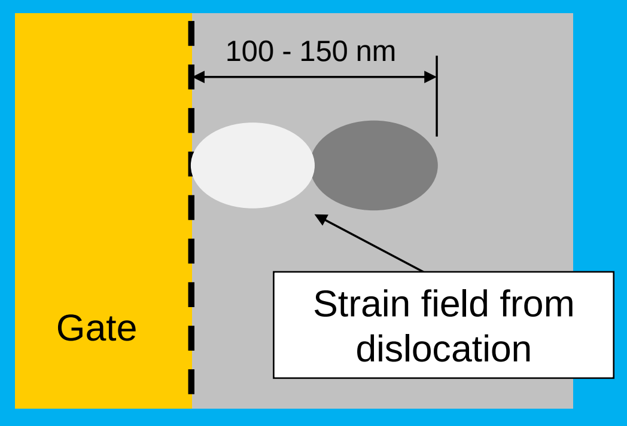
Key results:

Reliability and impact of dislocations in GaN HEMTs



I_g degradation ⟷ EL spots ⟷ Surface pits ⟷ Dislocations?





Dislocation density ~10^9 cm^{-2}

100 µm-wide devices

⇨

Can expect to find ~100 dislocations "close enough" to gate edge, i.e. 1 per µm device width

Dislocations may be quite detrimental to GaN HEMT reliability !

Structural characterisation of InAlN HEMTs

$In_{0.21}Al_{0.79}N$ (10 nm)	**$In_{0.18}Al_{0.82}N$ (10 nm)**
AlN (4 nm)	**AlN (4 nm)**
GaN buffer (1.7 µm)	**GaN buffer (3 µm)**
AlGaN nucleation layer	**GaN nucleation layer**
SiC (semi insulating)	**Al_2O_3**
Compressive strain	**Tensile strain**

From **XRD**
(004) reflex planes
FWHM= 184 arc sec

From **XRD**
(004) reflex planes
FWHM= 212 arc sec

From **ECCI**, TD density is 1.4 ± 0.2 X 10^9 cm^{-2}

From **ECCI**, TD density is 2.4 ± 0.5 X 10^9 cm^{-2}

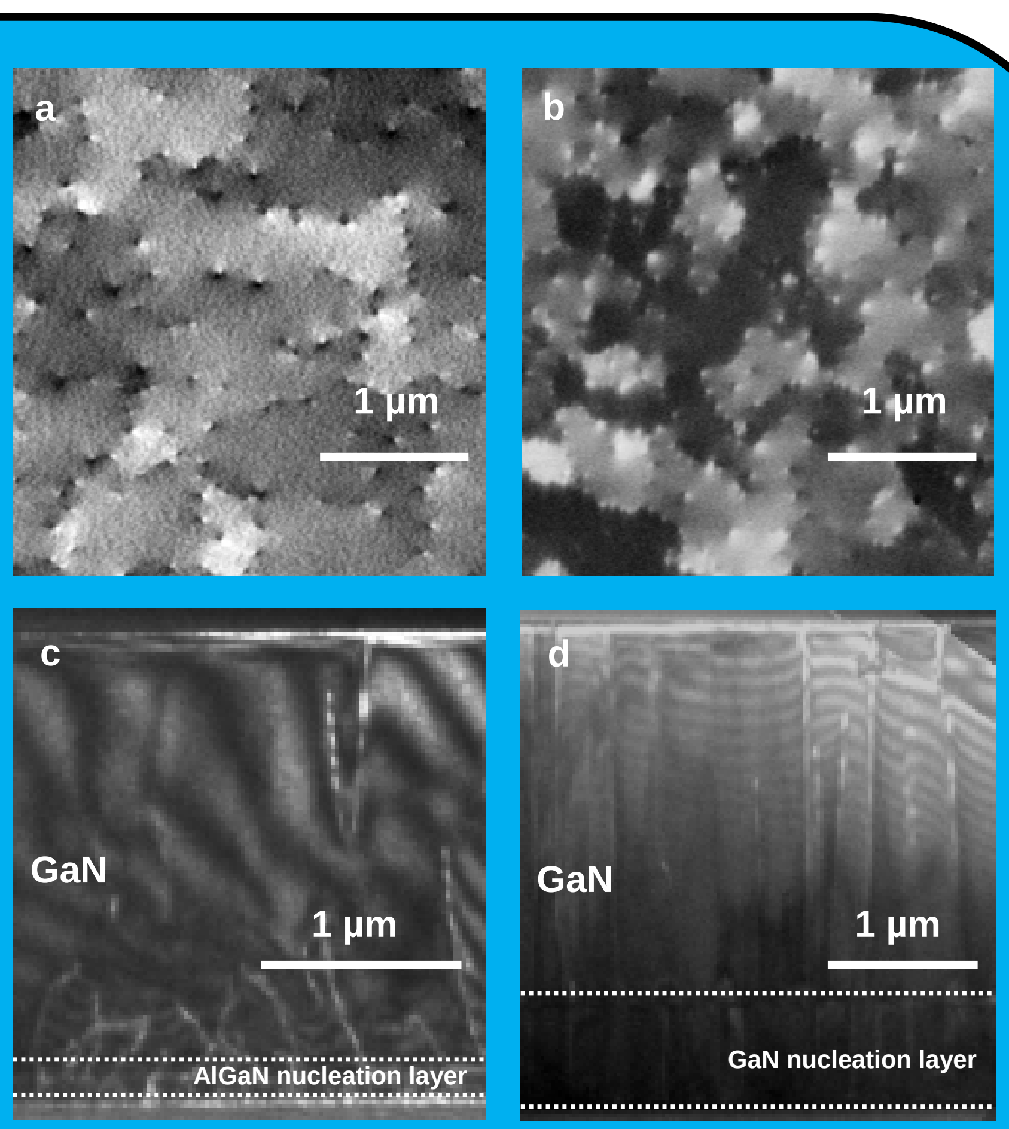
Individual dislocations types from cross section ***TEM***

Screw(≈1%),mixed(≈42%) & edge(≈57%)

Screw(≈10%),mixed(≈39%) & edge(≈51%)

Electron mobility
1240 cm^{2}V^{-1}s^{-1}

Electron mobility
1050 cm^{2}V^{-1}s^{-1}



(a) ECCI of InAlN HEMTs on SiC, (b) on sapphire showing tilt and rotation boundaries (c) cross section TEM of InAlN HEMTs on SiC, (d) on sapphire. [3]

Summary

- Combining ECCI/EBSD/CL/EBIC in a SEM can be a powerful characterisation approach for nitride semiconductors.
- Preliminary results on GaN HEMTs reveals that dislocations may be detrimental to device reliability.
- A considerable increase in electron mobility isobtained for InAlN HEMTs grown on SiC, probably due to fewer TDs when compared to the HEMTs grown on sapphire.

References and acknowledgements

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