Non-destructive Imaging of Extend Defects in III-nitride Thin film Structures Using Electron Channelling Contrast Imaging

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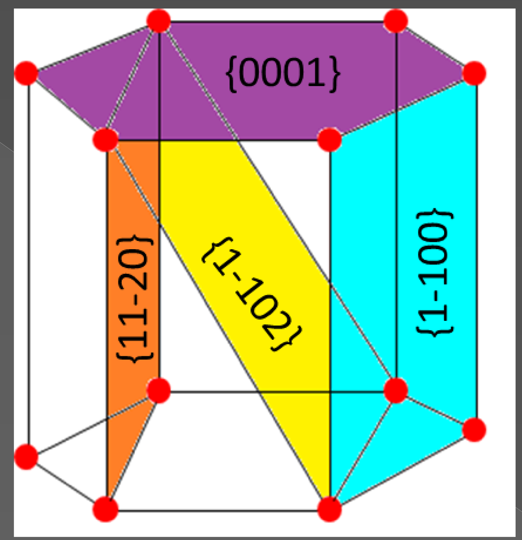
Motivation

- Irrespective of the substrates, the growth plane, or the growth conditions employed, extended defects such as dislocations , stacking faults, misfit dislocations and grain boundaries are generally observed in the as–grown III-nitride thin film structures.

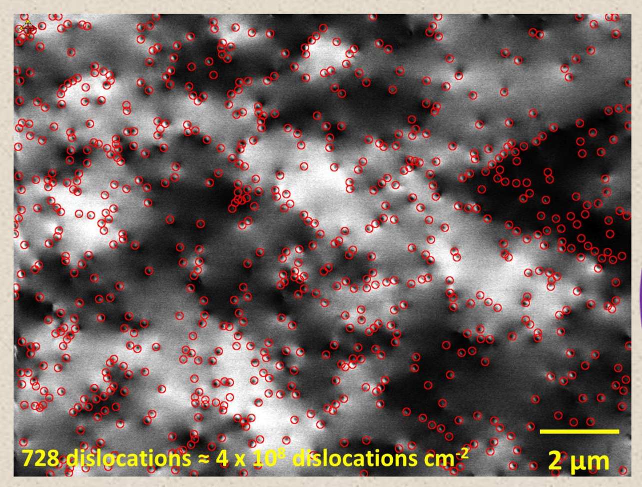


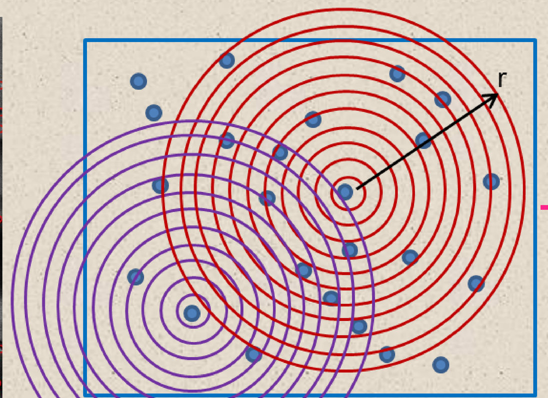
Polar c- plane {0001}
Non-polar a- plane {11-20}
Non-polar m- plane {1-100}
Semipolar r- plane {1-102}

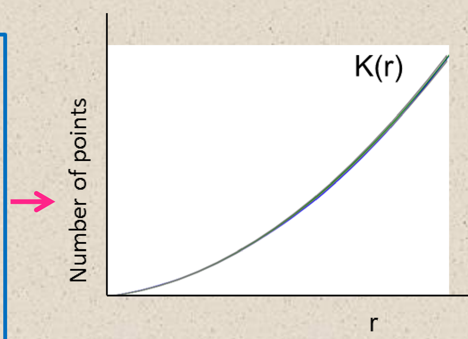
Crystal planes used for growing III- nitrides

- Often these defects are electrically active and are problematic for optoelectronic devices such as AlGaN based UV- LEDs and high electron mobility transistors. Hence resolving these defects using structural characterisation techniques which are simultaneously rapid to use, and structurally definitive on the nanoscale become a prerequisite.
- Electron channelling contrast imaging (ECCI) performed in a scanning electron microscope (SEM) is a quick and non-destructive structural characterisation technique for imaging, identifying and quantifying extended defects in III-nitride thin films .
- Here, we show some of our recent work on experimental protocols, dynamical electron scattering simulations, and statistical methods that would make ECCI a reliable and quantitative method for the analysis of extended defects.

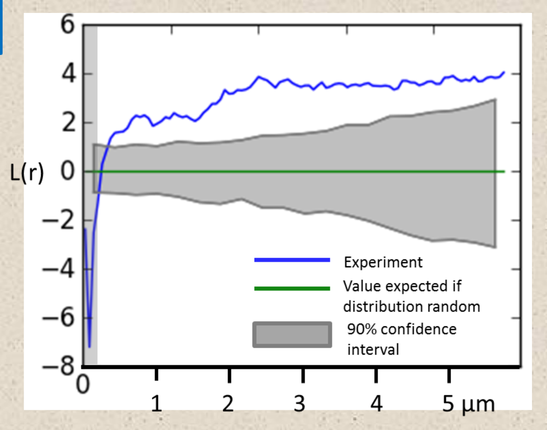
Measuring spatial distribution of defects







Ripley's K(r) function approach
Ripley's K(r) function analyses point pattern images by using the number of points (defects) within a distance r of each other in the image.



Deviation of experiment outside this confidence envelope indicates statistically significant clustering (+ve) or uniformity (-ve) compared with complete spatial randomness case [3]

Clustered distribution clearly observed here [3]

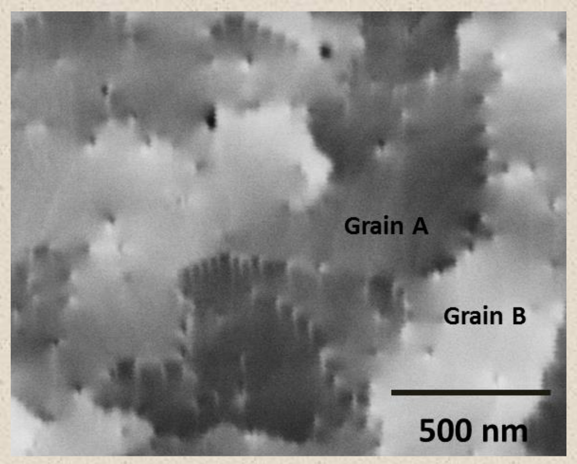
L(r) is the deviation between the measured K(r) and points having the same density but with complete spatial randomness (CSR).

Measured K(r)

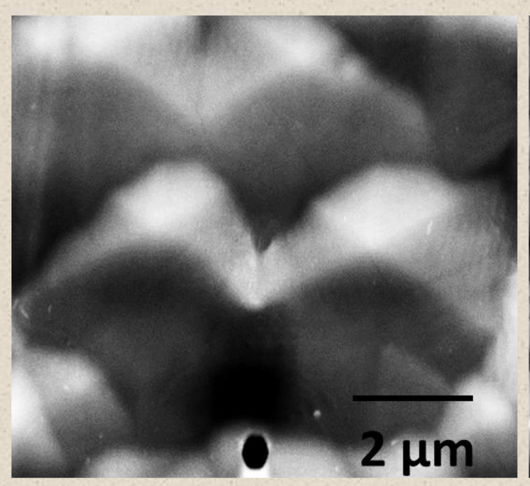
The deviation between

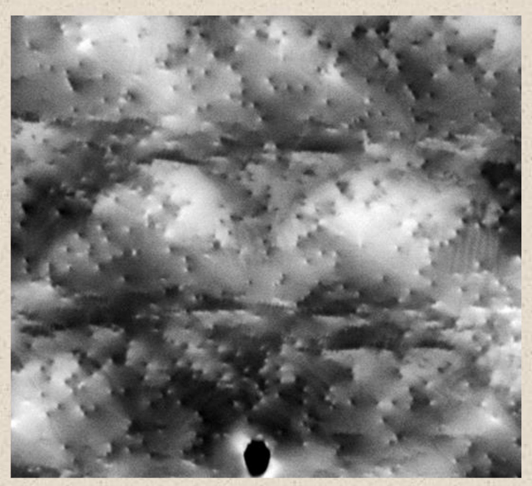
Expected K(r) for CSR

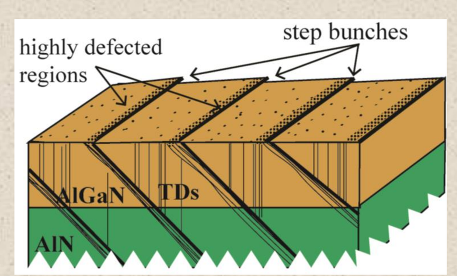
Imaging low-angle sub-grain boundaries



Topographic contrast Vs Channelling contrast





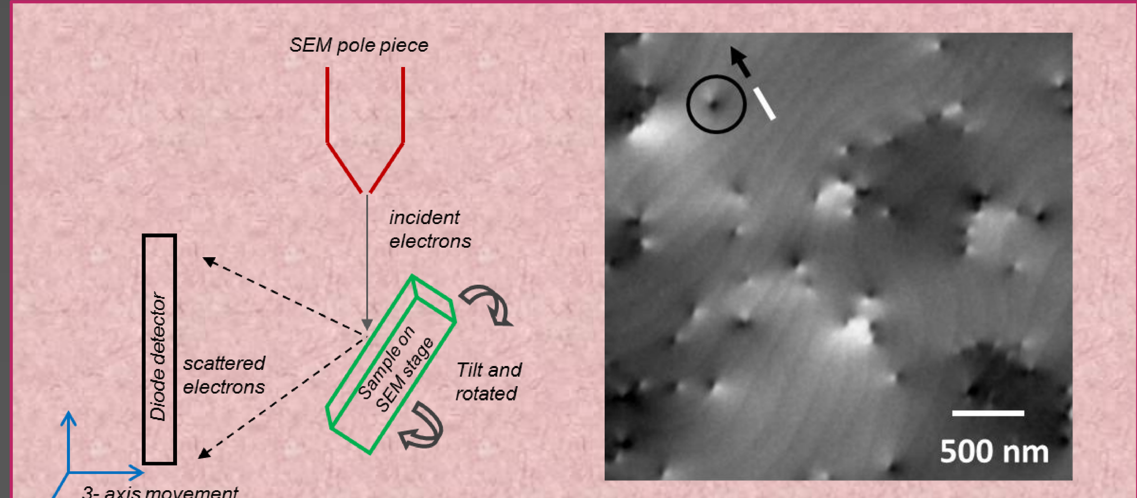


≈ 1.2 × 10⁹ dislocations cm⁻²

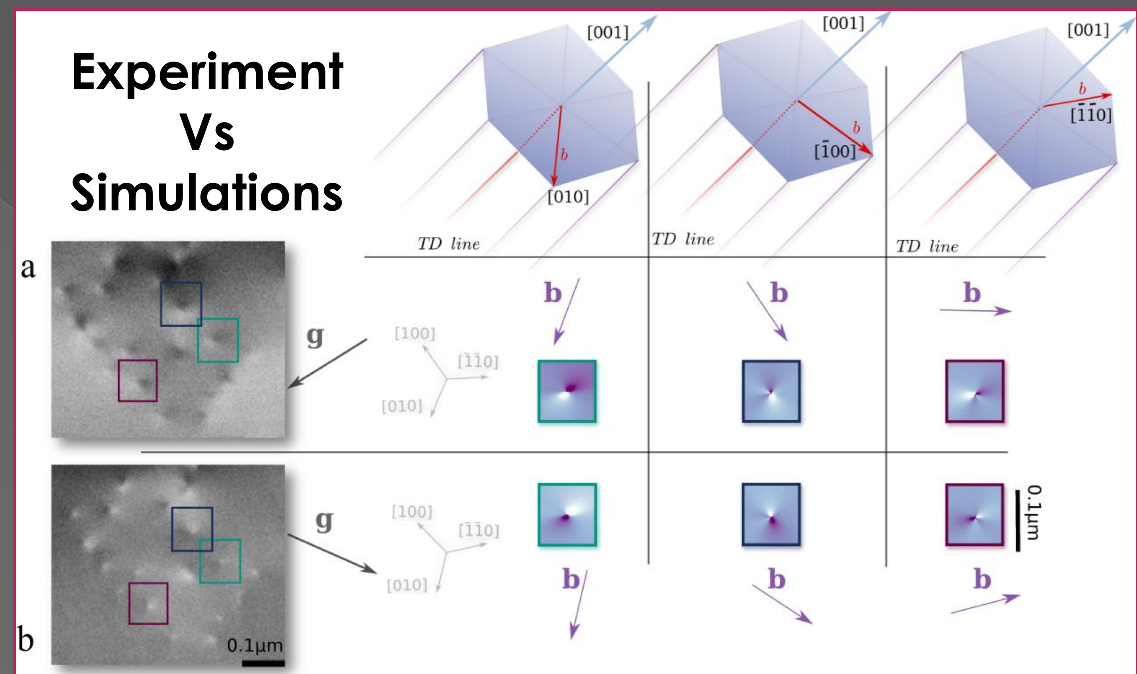
≈ 97% edge dislocations

Screw dislocations are located at apex of pyramids

ECCI in a forward scattering geometry



Dislocations in (0001) GaN



Changes in crystallographic orientation or in lattice constant due to local strain are revealed by changes in contrast in the channelling image constructed by monitoring the intensity of backscattered electrons (BSE) as the focused electron beam is scanned over the sample.

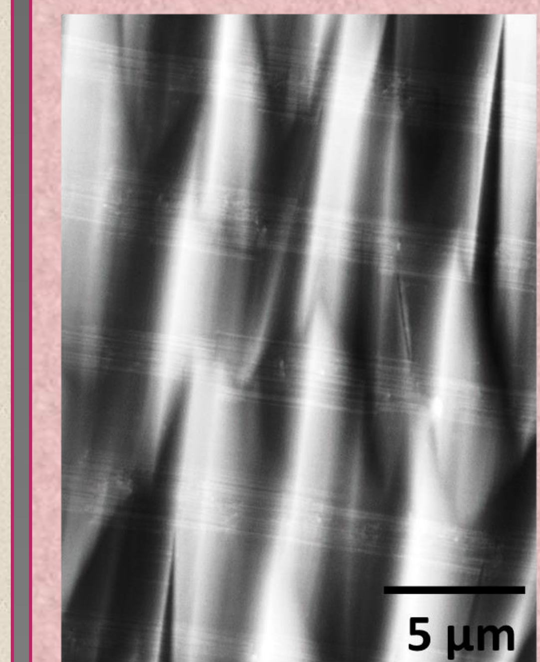
In ECCI, vertical threading dislocations appear as spots with black–white (B–W) contrast. The B-W contrast is basically due to strain fields around a dislocation.

By exploiting differences in the direction of the B-W contrast between two ECC images acquired from crystal planes whose diffraction vector (***g***) are known, it is possible to identify dislocation types [1].

(a) and (b) are the two experimental images from the same area but the crystal has been tilted a few degrees to access the new diffraction condition. The green box corresponds the contrast produced by an edge dislocation with **b** = [010] (green box), **b** = [-100] (dark blue box), **b** = [-1-10] (purple box). We have used the Bravais three index notation.

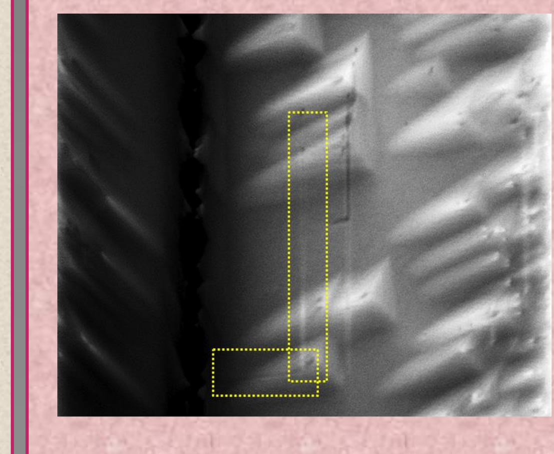
From our experiments and simulations, we propose that the dislocation contrast is uniquely predicted by the strain profile and the dislocation contrast will always follow the edge component of the Burgers vector (b) and that the diffraction condition will not affect its symmetry [2].

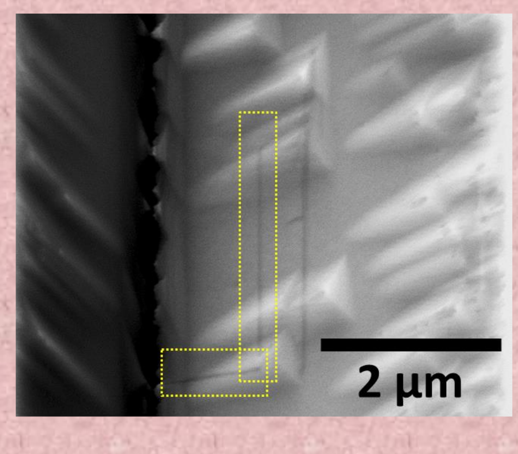
Imaging Basal plane Stacking Faults (BSFs)



BSFs in (11-22) GaN **BSFs in (1-100) GaN**

Imaging Misfit Dislocations (MFDs)





Contrast reversal for MFDs in (10-11) GaN

Summary and Conclusion

- Careful selection of BSE detector position together with appropriate channelling-in conditions and optimum electron beam quality will help to produce high quality ECC images.
- Combination of suitable hardware/software interface, image processing methods combined with dynamical electron scattering simulations for understanding the strain contrast effects , will make ECCI an invaluable tool for structural characterisation of advanced materials.
- Coincident acquisition of ECCI with other SEM based techniques is also possible to correlate compositional, optical, electrical and structural characteristics [4].

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www.ManuGaN.org

References

[1] G. Naresh-Kumar et al., Phys. Rev. Lett., **108**, 135503 (2012).
[2] E. Pascal et al., Mat. Today Proc. (2017), *in press*
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[4] G. Naresh-Kumar et al., Microsc. Microanal., **20**, 55 (2014).