Quantitative microstructural analysis of nitride thin films in the scanning electron microscope

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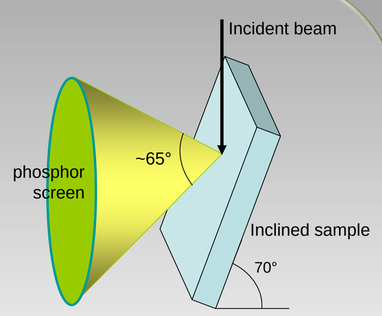
Motivation

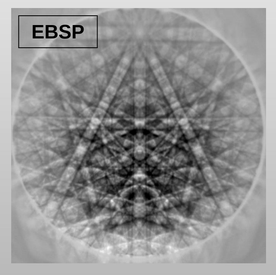
Production of nitride-based LEDs and transistors is presently taking place in a rapidly moving and competitive market, and there is a commercial imperative to develop cheaper and more efficient devices. Non-optimal structural properties, (i.e., high defect densities and presence of strain) still limit performance. Rapid and non-destructive feedback of microstructural information would greatly enhance the optimisation of new growth methodologies and device structures.

Exploitation of diffraction based measurements, namely electron backscatter diffraction (EBSD) and electron channelling contrast imaging (ECCI), in the scanning electron microscope, can deliver quantitative information on the defects and strain in nitride thin films on length scales from tens of nanometres to tens of micrometres.

Electron backscatter Diffraction (EBSD)

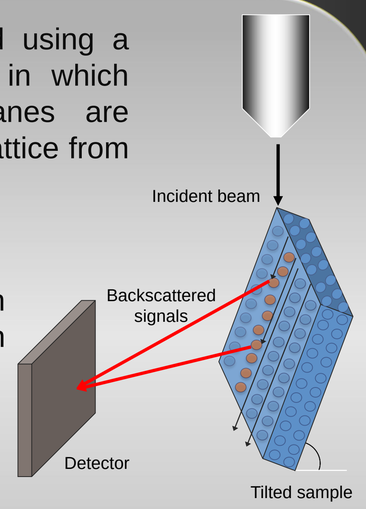
- In EBSD an electron beam is incident on a sample which is tilted at an angle of typically 70°.
- The impinging electrons are scattered inelastically through high angles forming a diverging source of electrons that can be diffracted.
- The resultant electron backscatter diffraction pattern (EBSP) consists of a large number of overlapping Kikuchi bands and is a 2-D projection of the crystal structure.
- EBSPs acquired from a mesh of points on a sample may be used to produce maps of twist (rotation), tilts and strain.
- By using cross-correlation techniques, EBSD can provide a sensitivity of less than 1 part in 10,000 to changes in tilt, rotation and strain [1].



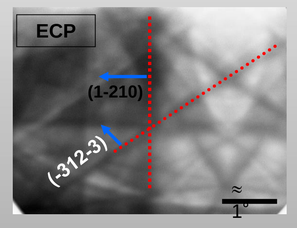


Electron Channelling Contrast Imaging (ECCI)

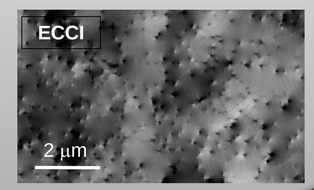
- Electron channelling contrast images are produced using a field emission gun scanning electron microscope in which electrons which channel down the atomic planes are backscattered if there is any distortion in the crystal lattice from a suitably oriented sample [2].
- In ECCI, vertical threading dislocations appear as spots with back–white (B-W) contrast.
- From the direction of the B-W contrast, dislocation types namely edge, screw and mixed dislocations can be identified [3].



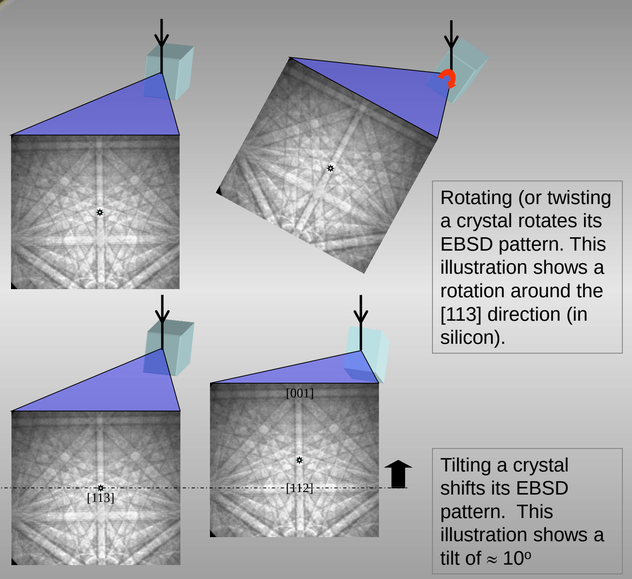
Electron Channeling Contrast Patterns (ECPs)



ECPs are a 2-D projection of the crystal lattice. They enable the channeling conditions, for a given tilt and rotation of a sample, to be determined.

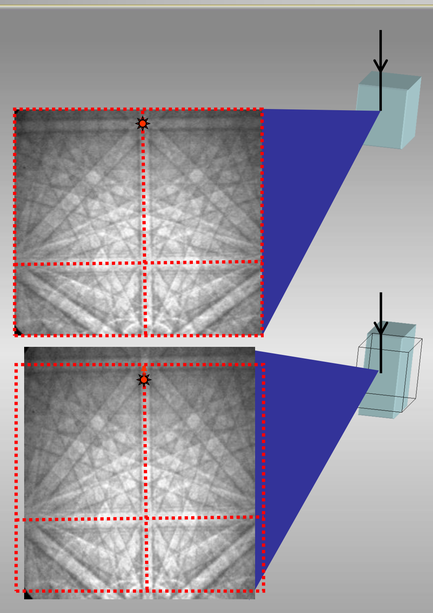


Example EBSD Results

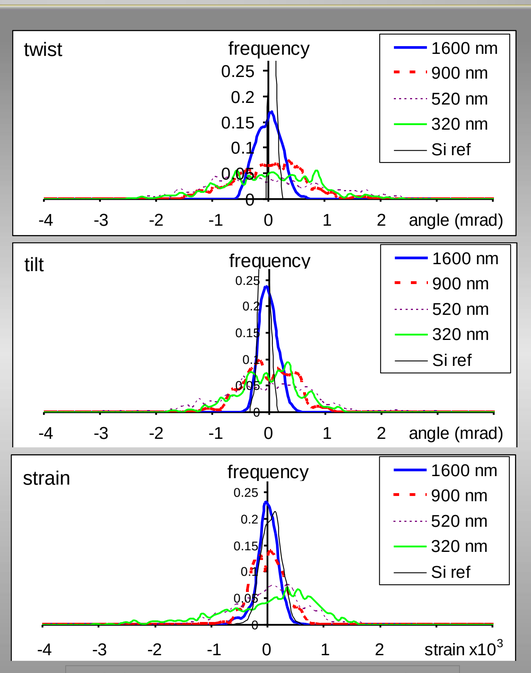


Rotating (or twisting a crystal rotates its EBSD pattern. This illustration shows a rotation around the [113] direction (in silicon).

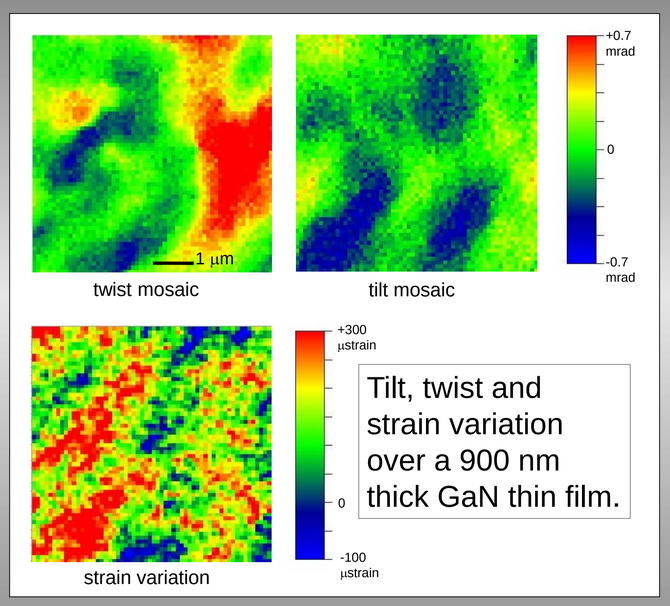
Tilting a crystal shifts its EBSD pattern. This illustration shows a tilt of ≈ 10º



A distortion of a crystal will produce a distortion of the EBSD pattern.



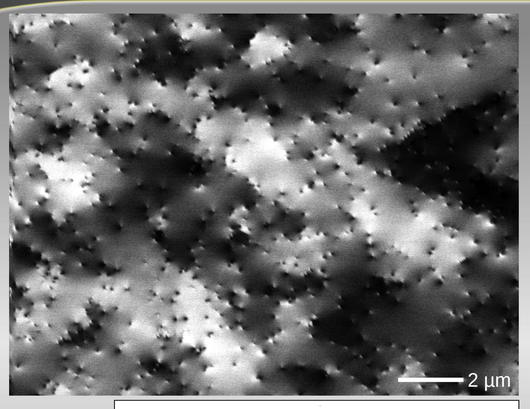
Variation in twist, tilt and strain respectively, in GaN thin films of various thickness.



Tilt, twist and strain variation over a 900 nm thick GaN thin film.

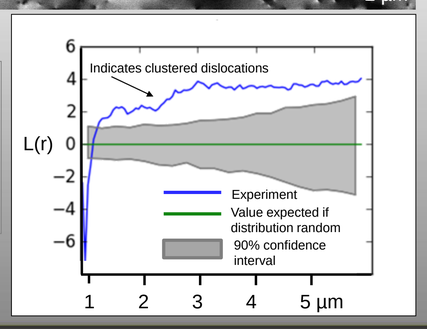
Example ECCI Results

Dislocation density and distribution

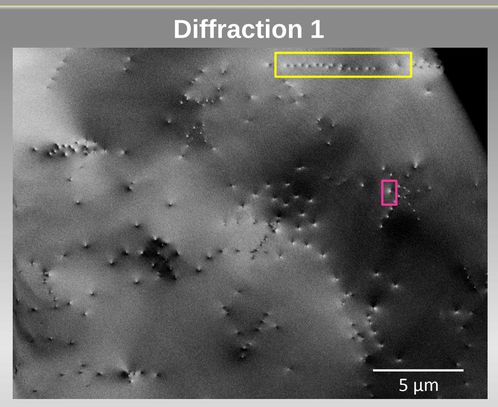


728 dislocations

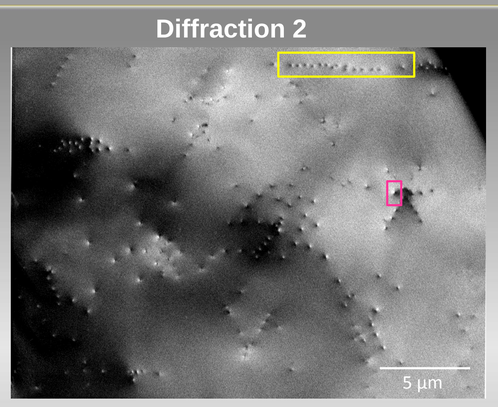
Average dislocation density 4×10^8 cm^{-2}



Diffraction 1

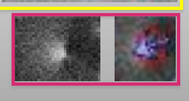


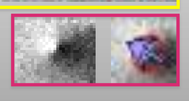
Diffraction 2



Edge

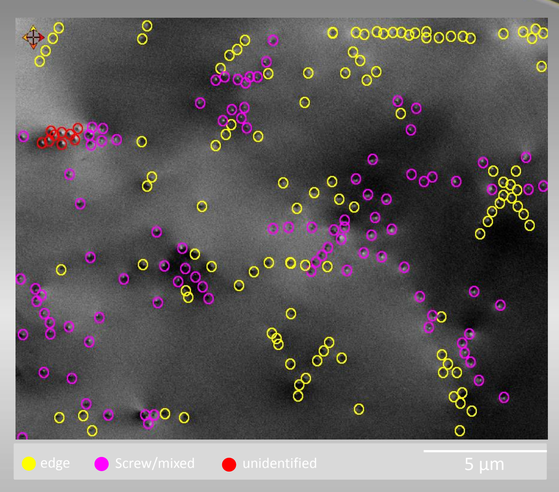
Screw/Mixed





To Identify the TDs, we compare the B-W contrast direction in at least two ECCI with different diffraction conditions acquired from the same area on the sample.

- **If the B-W contrast direction flips or remains the same ⟶ edge dislocation.**
- **If the B-W contrast changes direction ⟶ either screw or mixed dislocation.**



Total dislocations 205	
Edge	50%
Screw/mixed	46%
Unidentified	4%

References

[1] A. J. Wilkinson, et al., Ultramicroscopy **106**, 307 (2006)

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

[3] G. Naresh-Kumar, et al., Phy. Rev. Lett. **108**, 135503 (2012)

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