ECCI of AlGaN/GaN HEMT structures grown on Si

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Motivation

- AlGaN/GaN heterostructures have good properties for HEMTs
  - High efficiency
  - High power density
  - High operating voltages
  - High operating temperatures

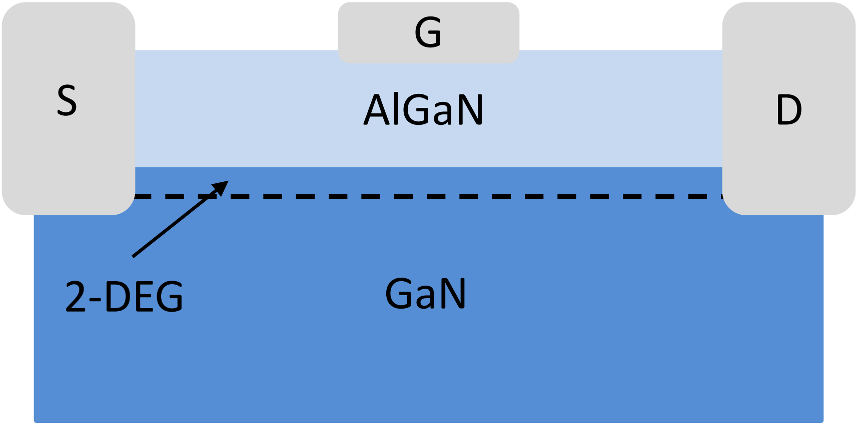
- Si substrates
  - Cheap
  - Easy to integrate into existing Si technologies

- One problem - nanoscale fissures
  - Form due to tensile strain between AlGaN and GaN layers
  - Reduce efficiency
  - Device failure

Umesh K. Mishra, Proceedings of the IEEE, **90**, 1022 (2002)
Peter J. Parbrook *et al.,* phys. stat. sol. (c) **0**, 2055 (2003)
Junji Kotani *et al.,* phys. stat. sol. (c) **10**, 808 (2013)

What is a HEMT?

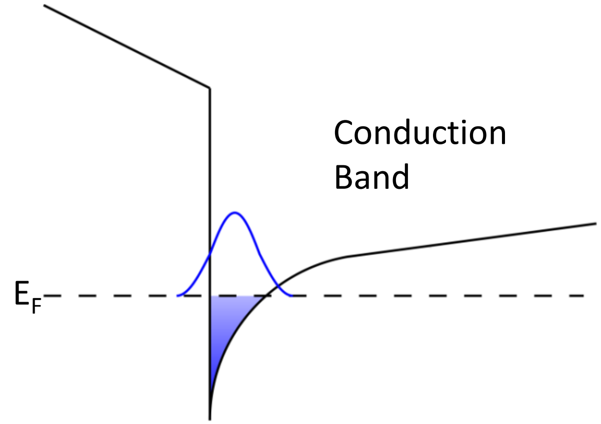
- HEMT - High Electron Mobility Transistor
- Fabricated from 2 semiconductor materials with different band gap energies
- Can operate at higher frequencies and voltages than Si MOSFETs
- Higher power density, efficiency and operating temperatures
- Nitride HEMTs do not require doping to generate a 2-DEG

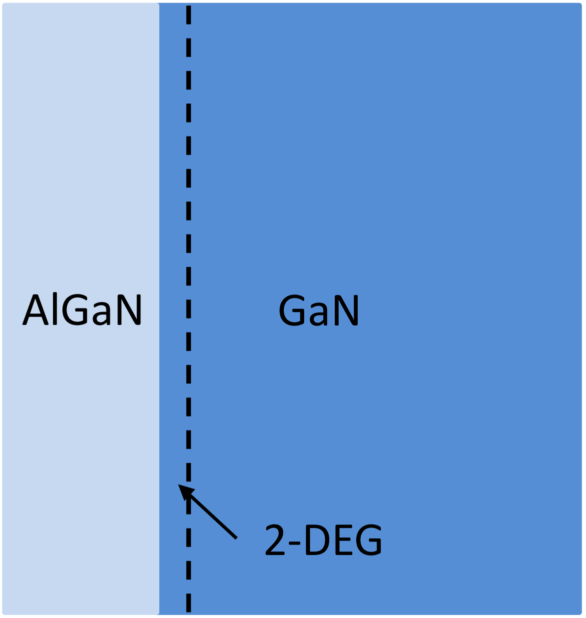


Umesh K. Mishra, Proceedings of the IEEE, **90**, 1022 (2002)

Nitride HEMTs

- 2DEG arises due to polarisation difference between layers
- Spontaneous polarisation
  - Intrinsic to the material
  - Arises due to crystal structure
- Piezoelectric polarisation
  - Arises due to difference in lattice constants between layers
- Larger 2DEG density leads to better device efficiency
- 2DEG density controlled by applying a voltage to the gate contact

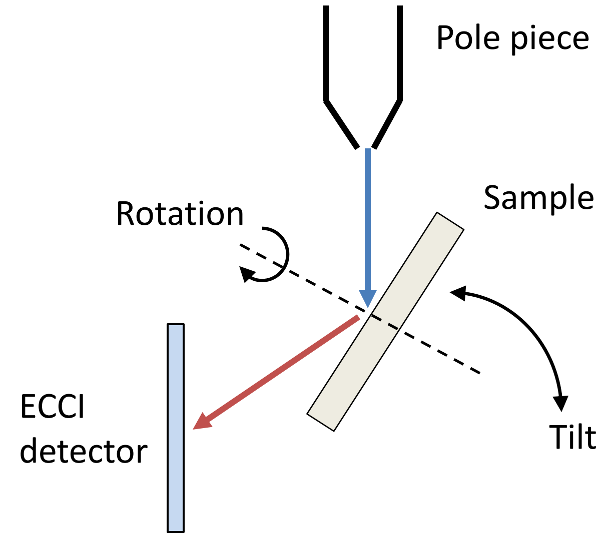


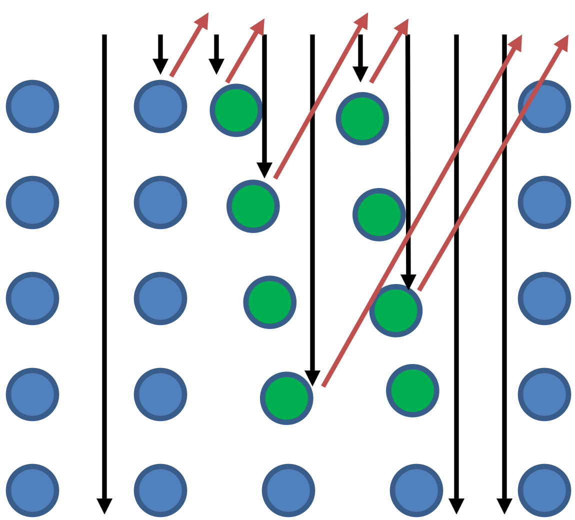


Lunchun Guo *et al.,* Microelectronics Journal **39**, 777 (2008)

Electron Channelling Contrast Imaging

- Sample is oriented to allow electron channelling – that is electrons are diffracted by the crystal lattice
- Changes of the crystal lattice change backscattered electron intensity
- Diffracted backscattered electrons are used to produce an image showing strain associated with dislocations
- Images also show crystal grains with different orientations
- Depth resolution of tens of nanometers

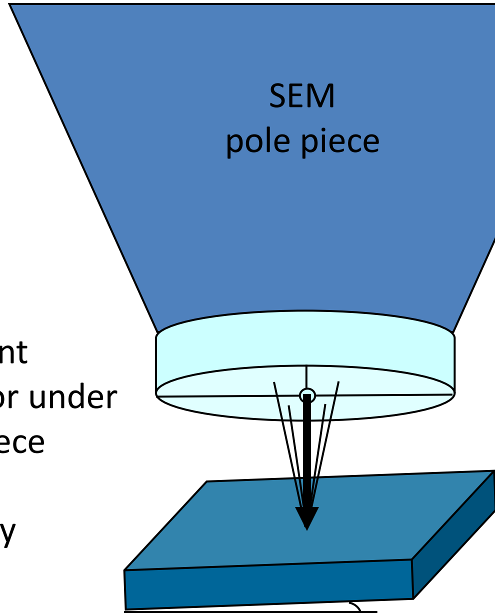




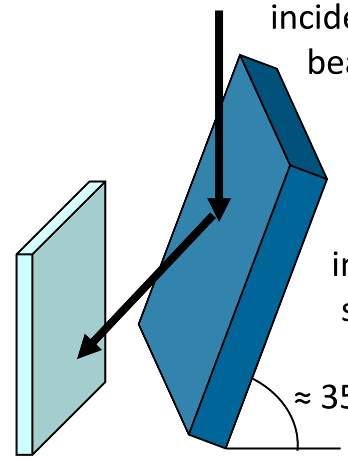
Carol Trager-Cowan *et al.,* Phys. Rev. B **75**, 085301 (2007)

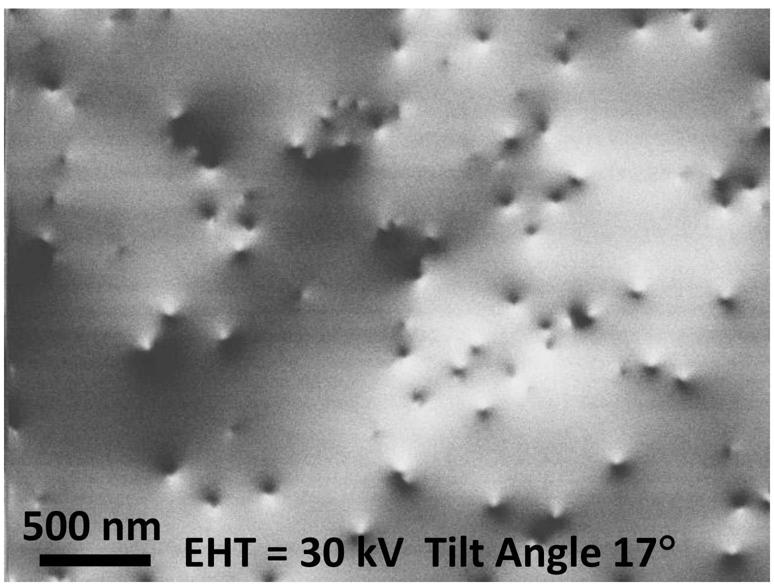
ECCI at different geometries

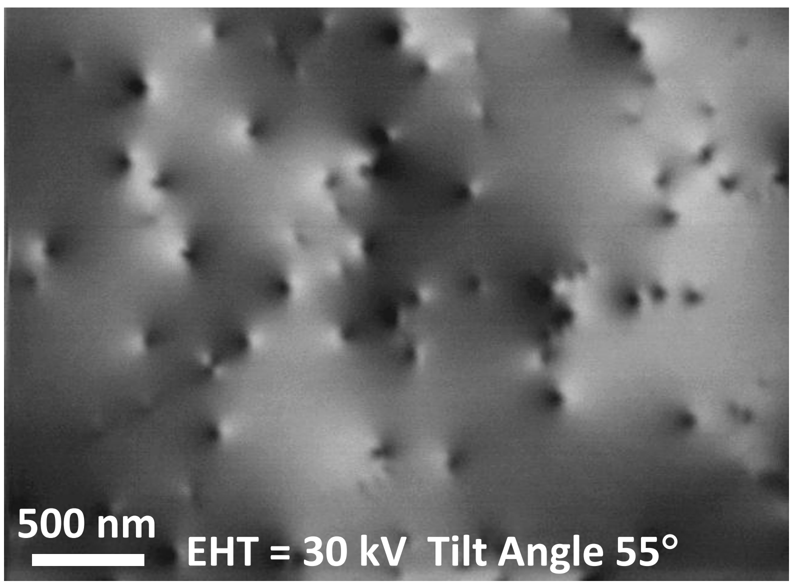
Backscatter diffraction geometry



Forescatter diffraction geometry



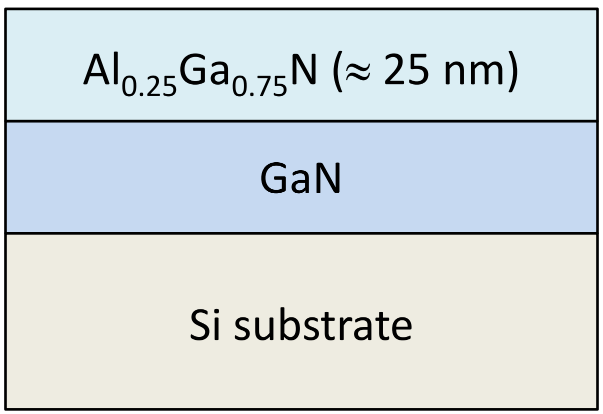




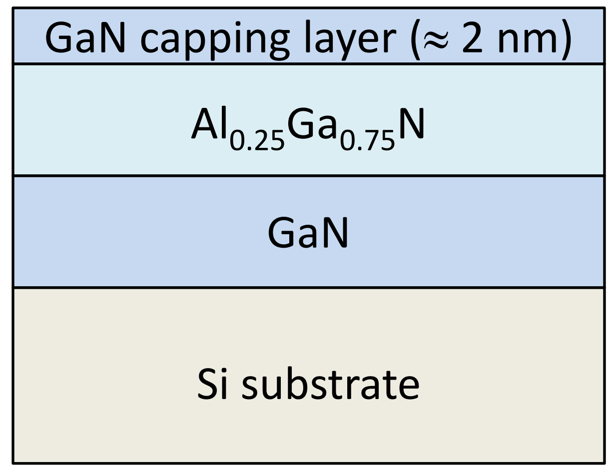
Electron channelling contrast images from a 900 nm thick GaN thin film

Sample Structure & Growth

- 2 AlGaN/GaN Samples grown on a 6” Si wafer
  - Both samples grown using the same procedure
  - Sample A is uncapped
  - Sample B has a GaN capping layer



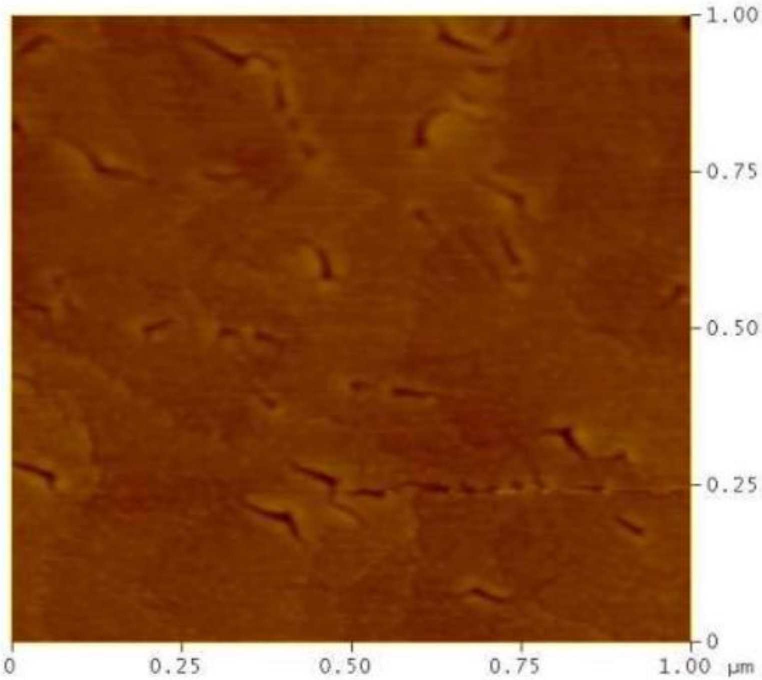
Sample A



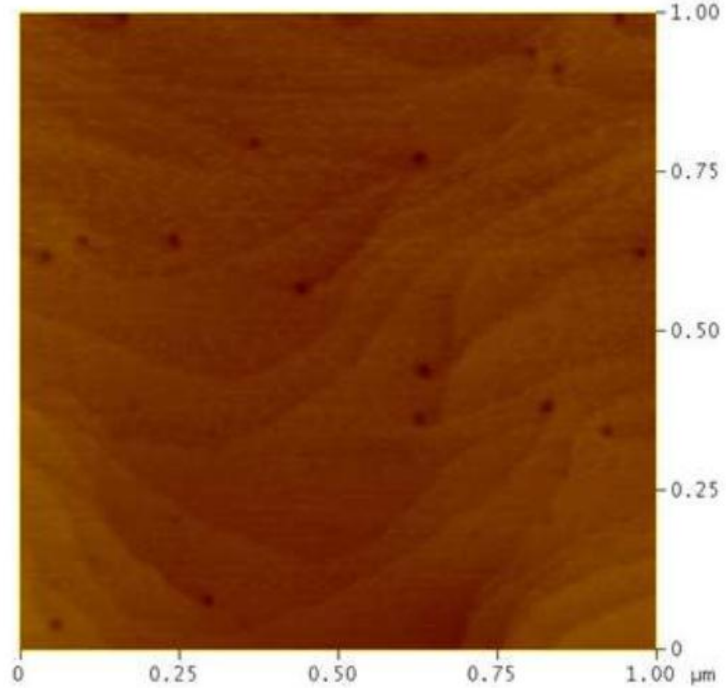
Sample B

AFM of AlGaN/GaN samples

- Atomic force microscopy (AFM) measurements of similar capped & uncapped AlGaN/GaN samples



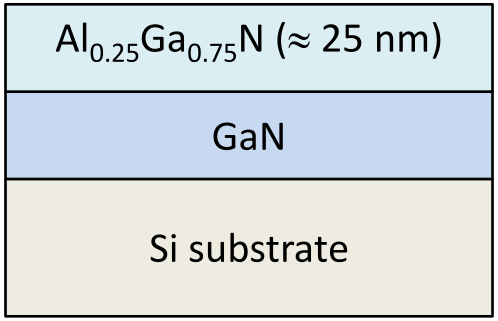
AlGaN surface

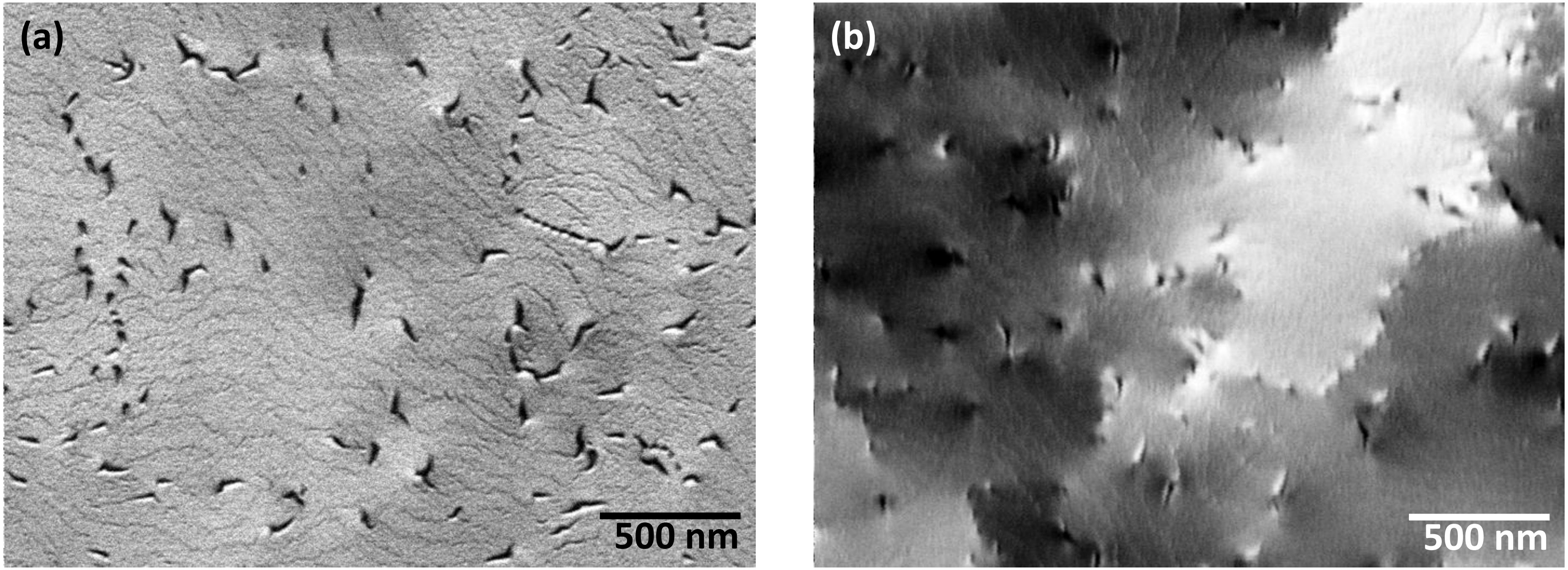


GaN surface

ECCI of AlGaN/GaN grown on Si

- Sample A
- Uncapped AlGaN/GaN
- Fissure density ≈ 2×10^{9} cm^{-2}



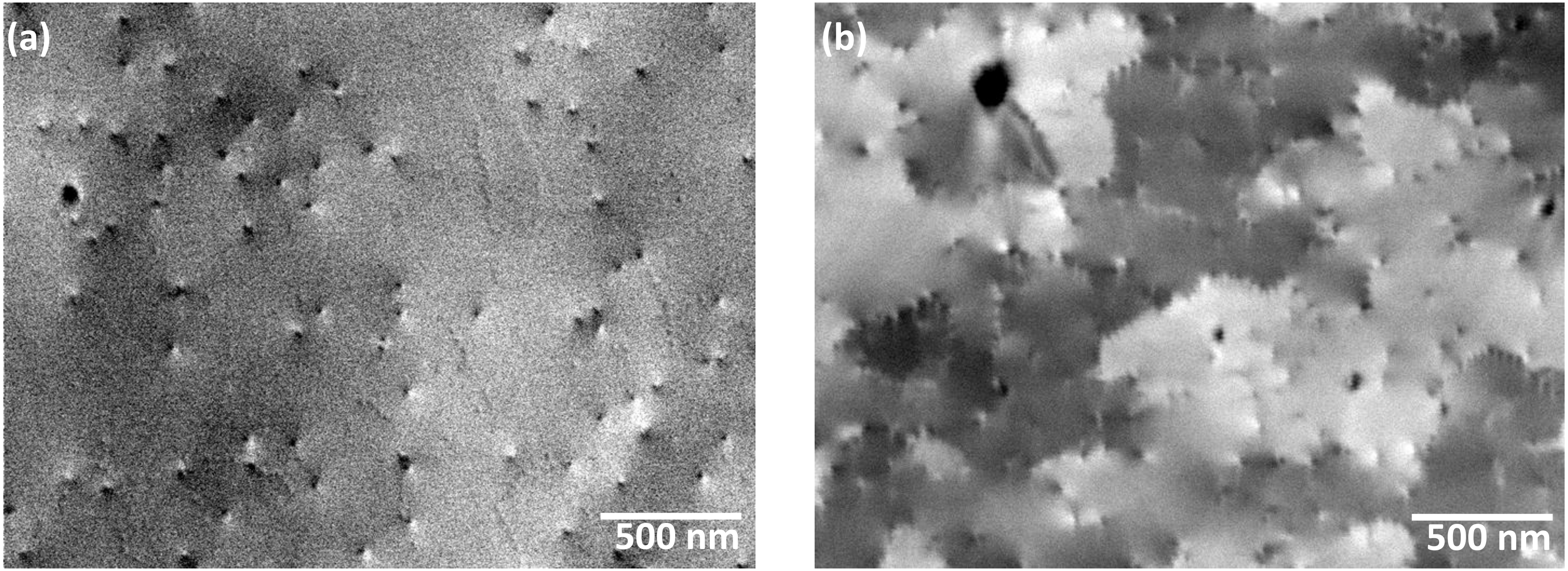


ECCI of AlGaN surface from sample A in (a) backscatter and (b) forescatter detector geometries

ECCI of AlGaN/GaN grown on Si

- Sample B
- GaN capped AlGaN/GaN
- Dislocation density ≈ 5×10^{9} cm^{-2}

GaN capping layer (2 nm)
$Al_{0.25}Ga_{0.75}N$
GaN
Si substrate

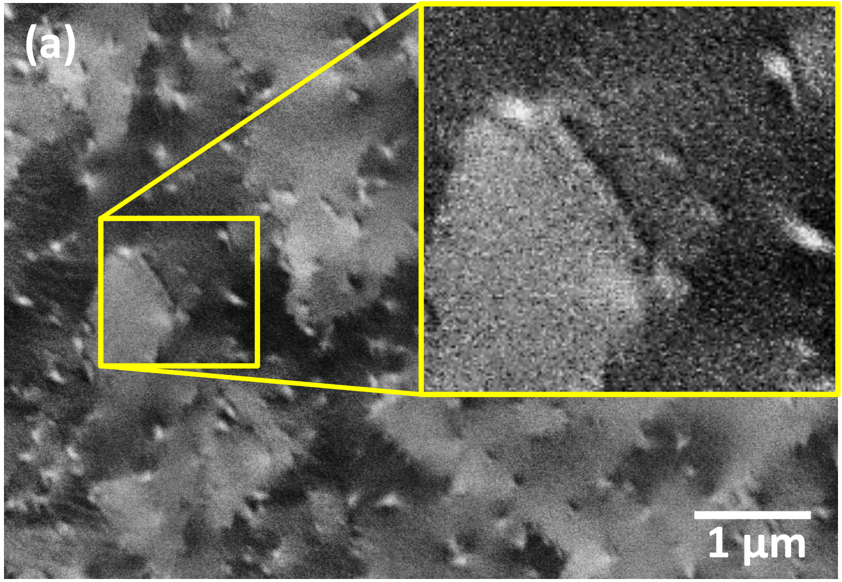


ECCI of GaN cap from sample B in (a) backscatter and (b) forescatter detector geometries

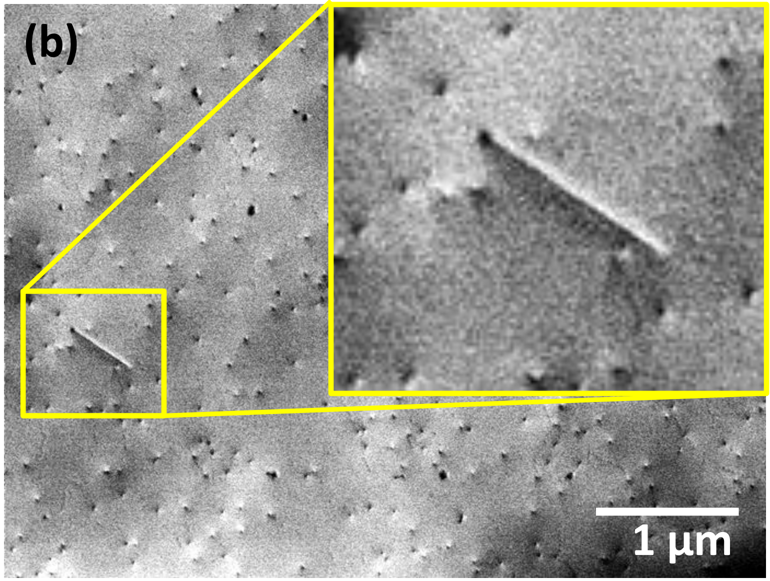
ECCI of AlGaN/GaN grown on Si

- Extended defects parallel to sample surface present in both samples

Sample A



Sample B

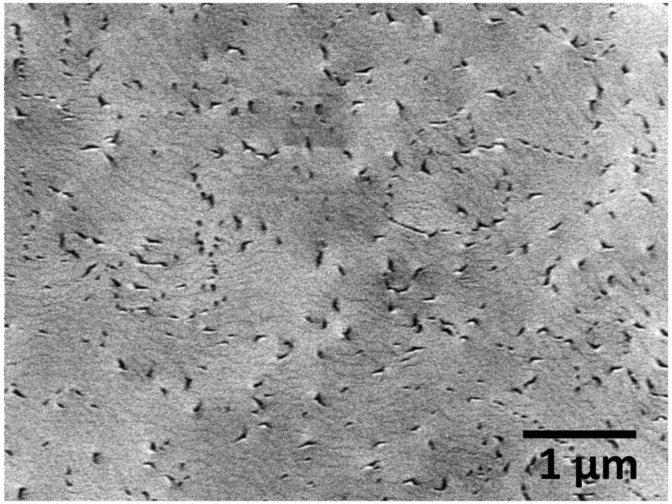


ECCI images of (a) sample A and (b) sample B showing extended defects parallel to the sample surface

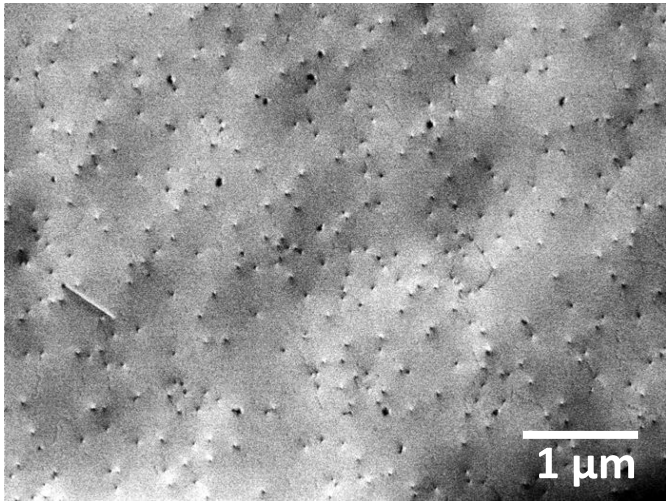
Results

- Formation of fissures on sample A most likely occurs during cooling after growth
- GaN capping layer on Sample B prevents fissures from forming
- Fissure density of similar number to dislocation density in capped sample
- Backscatter ECCI detector geometry provides good topographic images
- Forescatter ECCI detector geometry provides good dislocation & grain boundary contrast
- Fewer dislocations visible in the BS geometry in the capped sample – possibly due to diffraction conditions
- Extended defects parallel to the sample surface are seen in both samples – possible misfit dislocations or stacking faults

Sample A



Sample B



Summary

- Nanoscale fissures are observed on the AlGaN surface
- No fissures are observed on the GaN capped surface
- GaN capping layer prevents formation of fissures in the AlGaN
- Fissure density was estimated to be 2×10^9 cm^{-2}
- Fissures are associated with threading dislocations(TDs) and they are possibly due to all three types of dislocations
- Dislocation density for the GaN capped sample was estimated to be 5×10^9 cm^{-2}
- Difference in TD density between the samples is within the expected variance across a 6 inch wafer
- Extended defects parallel to the surface have been observed in both samples
- Further investigation is required to identify the types of dislocations in the samples

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