# Spatial clustering of point defects in Si doped wide bandgap AlGaN

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## Motivation

One of the main limitations in using AlGaN layers with a high AlN content (x> 80%) for devices is inefficient doping. The conductivity of high band gap AlGaN layers suffers from an increase in the activation energy of the silicon (Si) donor (from 12-17 meV in GaN [1] up to 238-255 meV in AlN [2][3]) as well as a reduction of the formation energy of native and foreign point defects compensating active donors[4]. There are only a few reports of Si doping of large bandgap AlGaN layers and most of the studied samples were highly resistive. Due to this the influence of the compensating defect centres on the luminescence properties and conductivity are barely understood. To further the understanding of these effects we investigated wide bandgap AlGaN samples with different AlN concentrations and $SiH_4$/III ratios, which can be summarised as 4 different series.

## Overview

**Samples:**

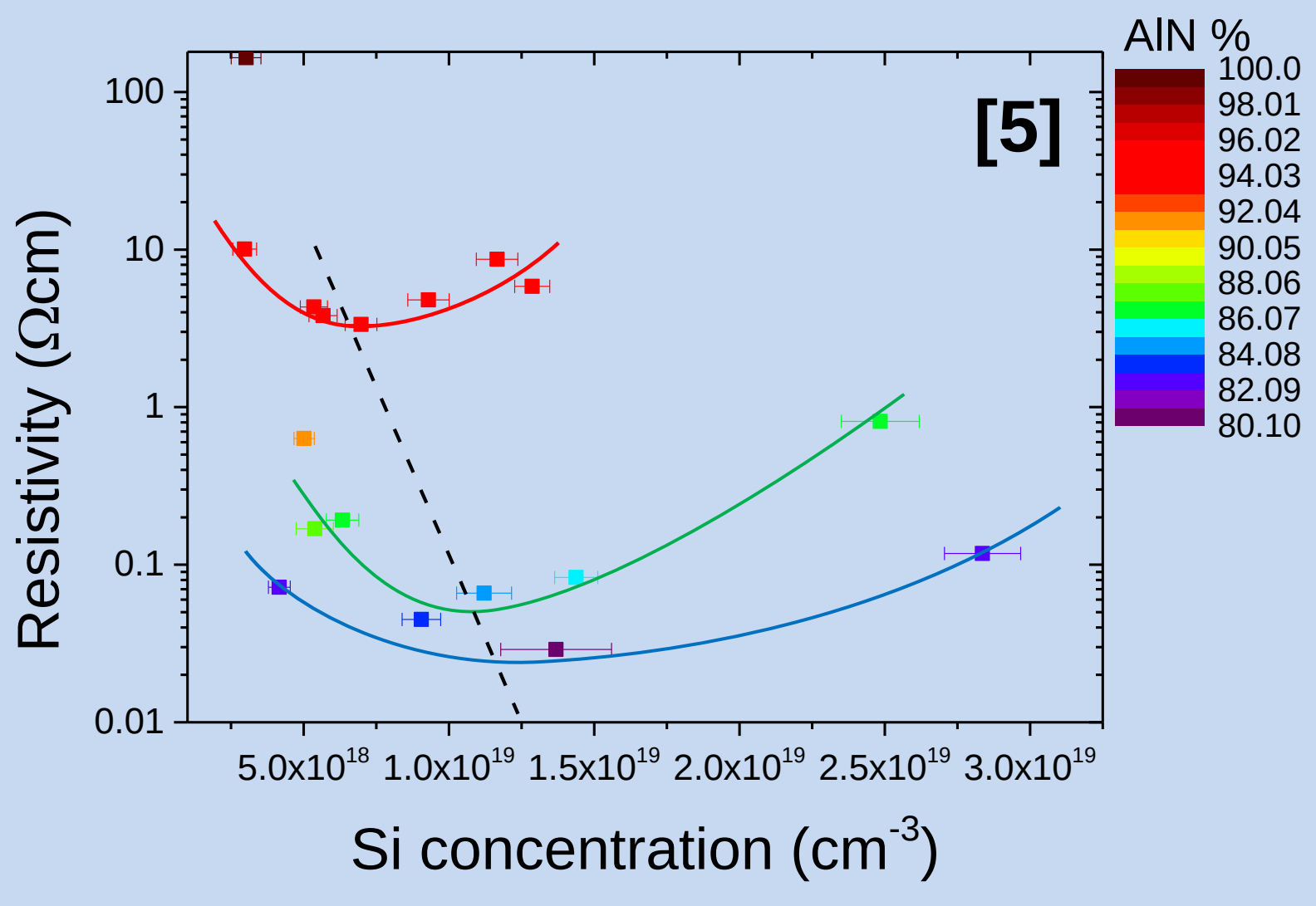
- Close coupled showerhead MOVPE reactor
- Substrate: Epitaxial lateral overgrown (ELO) AlN/$Al_2O_3$ (periodicity of 3.5 µm)
- Precursors: TMGa, TMAl, $NH_3$, $SiH_4$

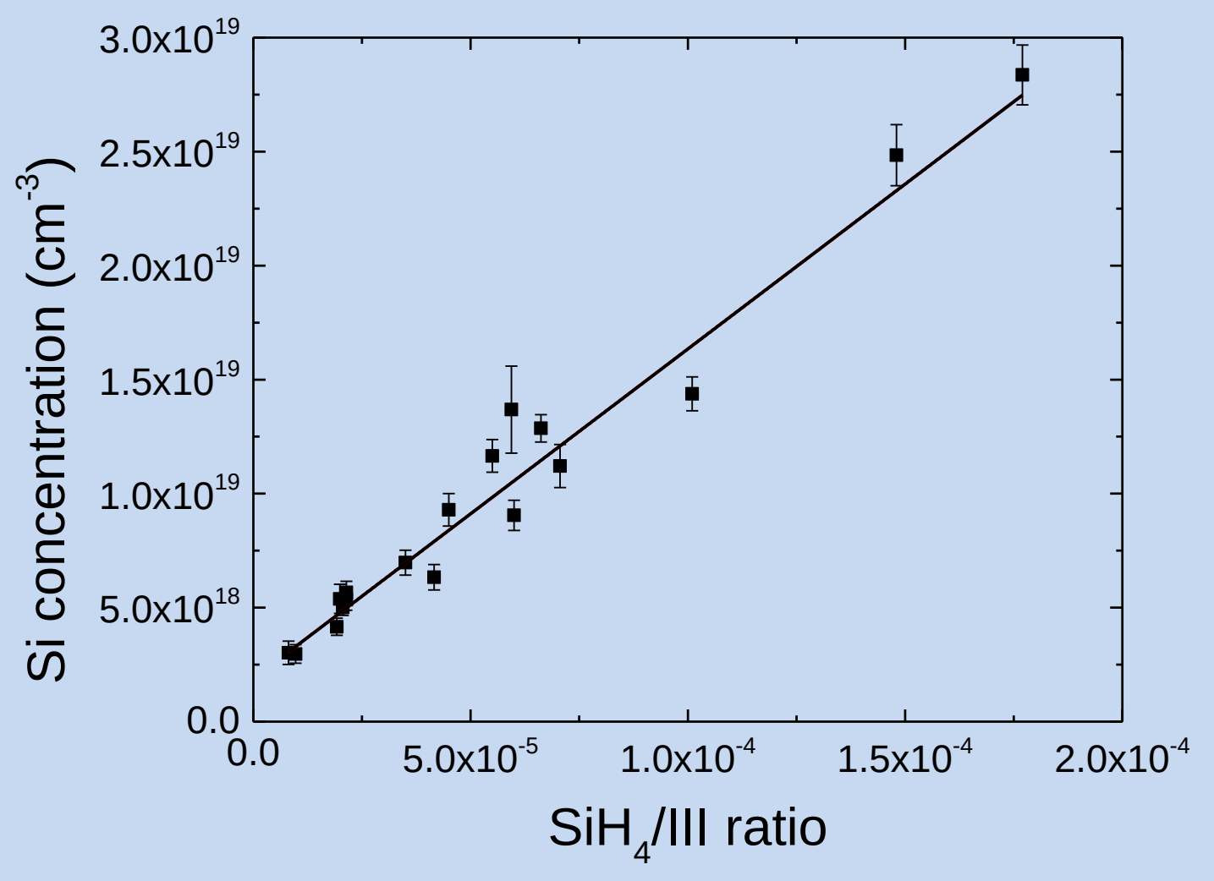
| | AlN% | $SiH_4$/III ratio |
|---|---|---|
| Series 1 | 82 | $1.9*10^{-5}$-$1.8*10^{-4}$ |
| Series 2 | 86 | $4.2*10^{-5}$-$1.5*10^{-4}$ |
| Series 3 | 96 | $9.7*10^{-6}$-$6.6*10^{-5}$ |
| Series 4 | 82-95 | $2*10^{-5}$ |

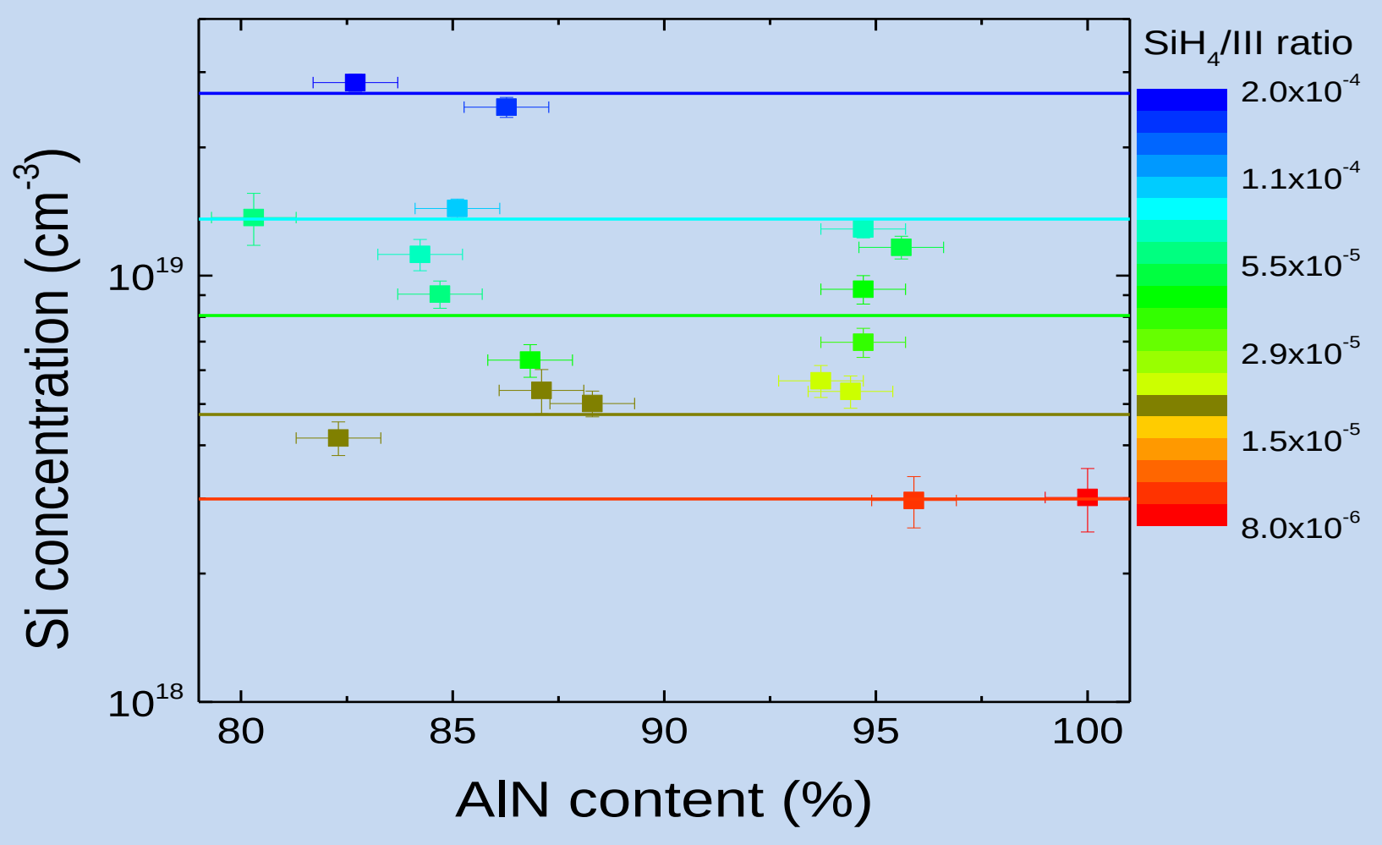
**Techniques:**

- Composition and Si concentration: Wavelength dispersive X-ray spectroscopy (WDX) Standards: AlN (Al,N), GaN (Ga,N), Si
- Luminescence Properties: Cathodoluminescence hyperspectral imaging (CL) at room temperature
- Structural Analysis: Electron channelling contrast imaging (ECCI)

## Resistivity and Si incorporation



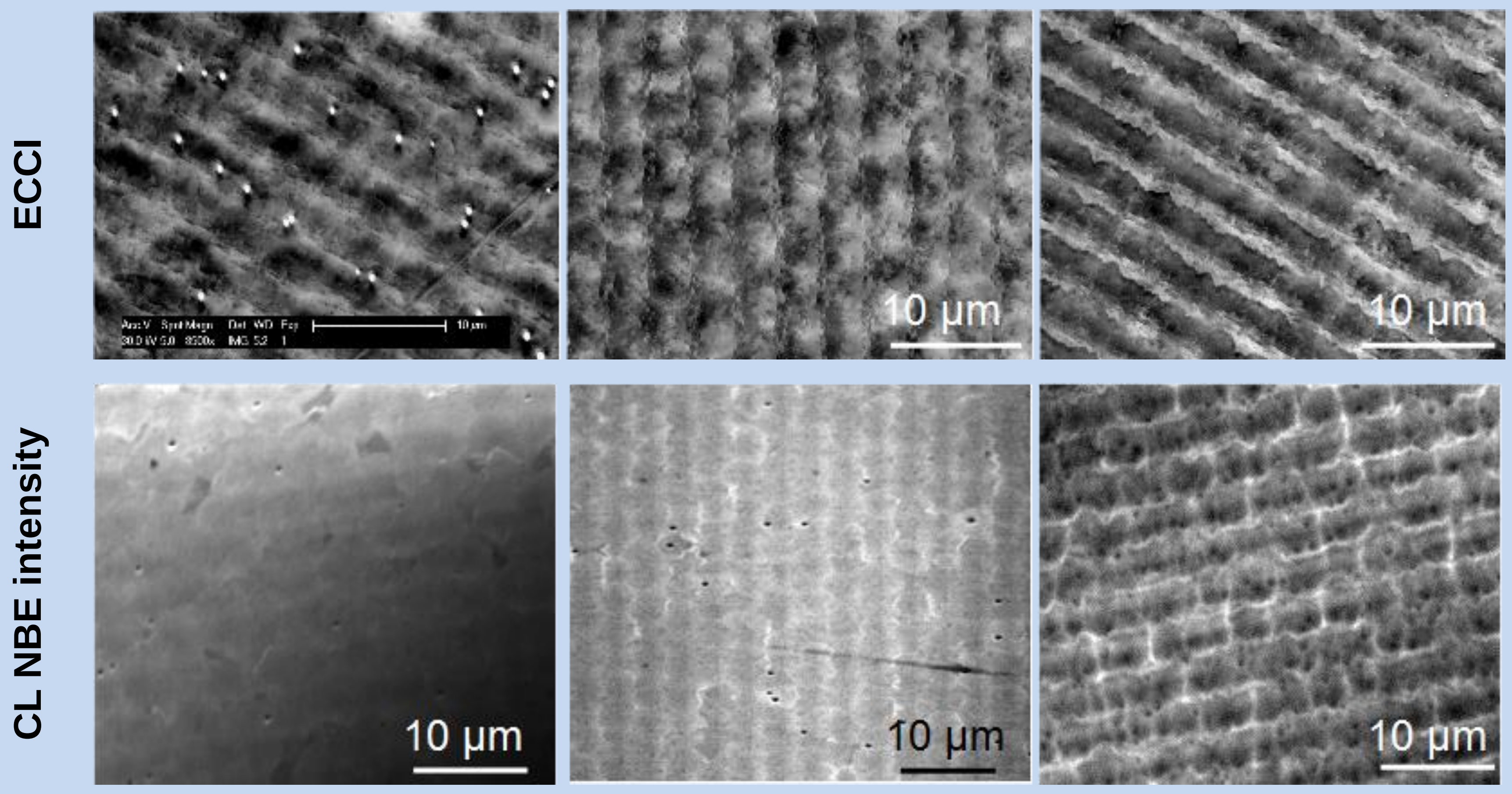




- Optimal point of resistivity
- Optimal point shifts with AlN%
- Si incorporation is linear and independent of AlN% thus optimal point not affected by variations in Si incorporation
- Point defects responsible for observed resistivity behaviour

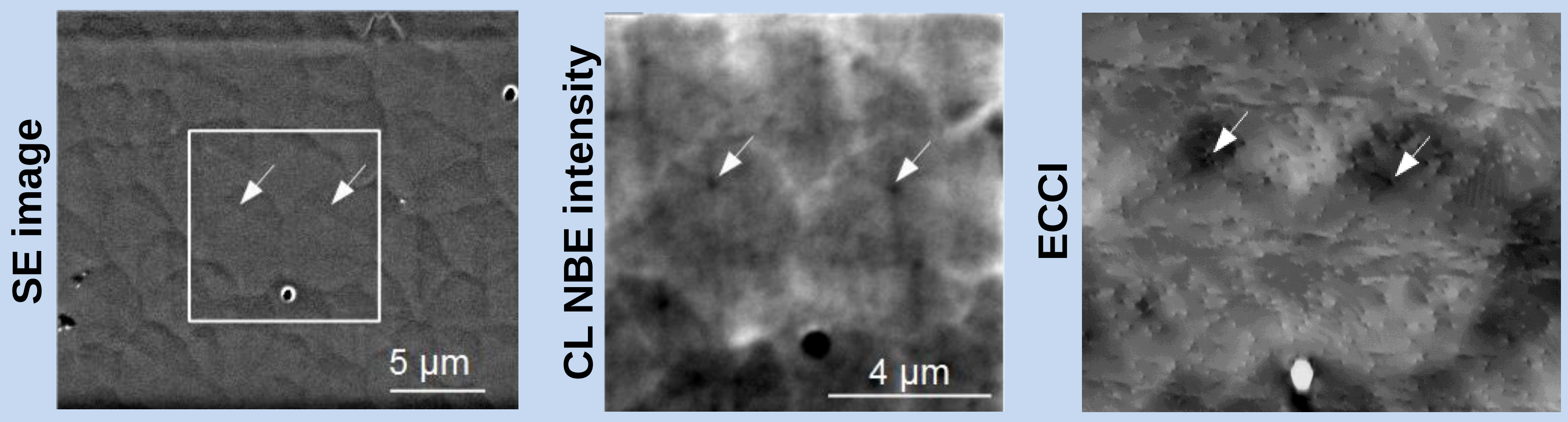
## Extended defects

**Si: $4.2*10^{18}$ cm$^{-3}$** **Si: $1.4*10^{19}$ cm$^{-3}$** **Si: $2.8*10^{19}$ cm$^{-3}$**



- Threading dislocation (TD) density of $1.2*10^9$ cm$^{-2}$ ±$0.2*10^9$ cm$^{-2}$ ( TDs with screw component $3.7*10^7$ cm$^{-2}$ ±$0.2*10^7$ cm$^{-2}$)
- Strong increase in defect density and reduction in emission intensity with a periodicity of 3.5 µm (same as ELO pattern)
- Threading dislocations (TD) acting as non-radiative recombination centres for NBE emission
- Clustering and ordering of TD density due to underlying ELO pattern [6]

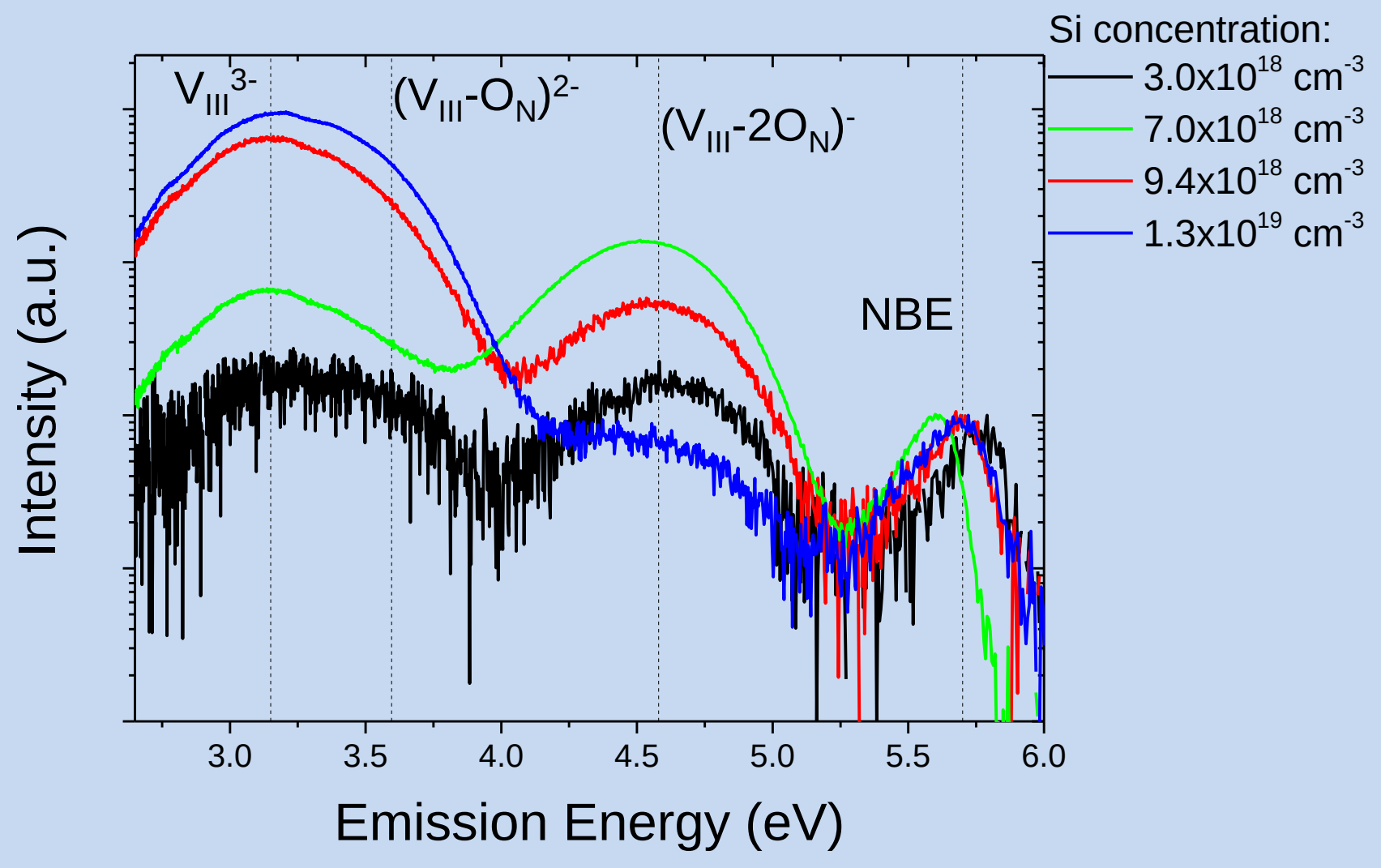
**Correlative SE, CL and ECC imaging**



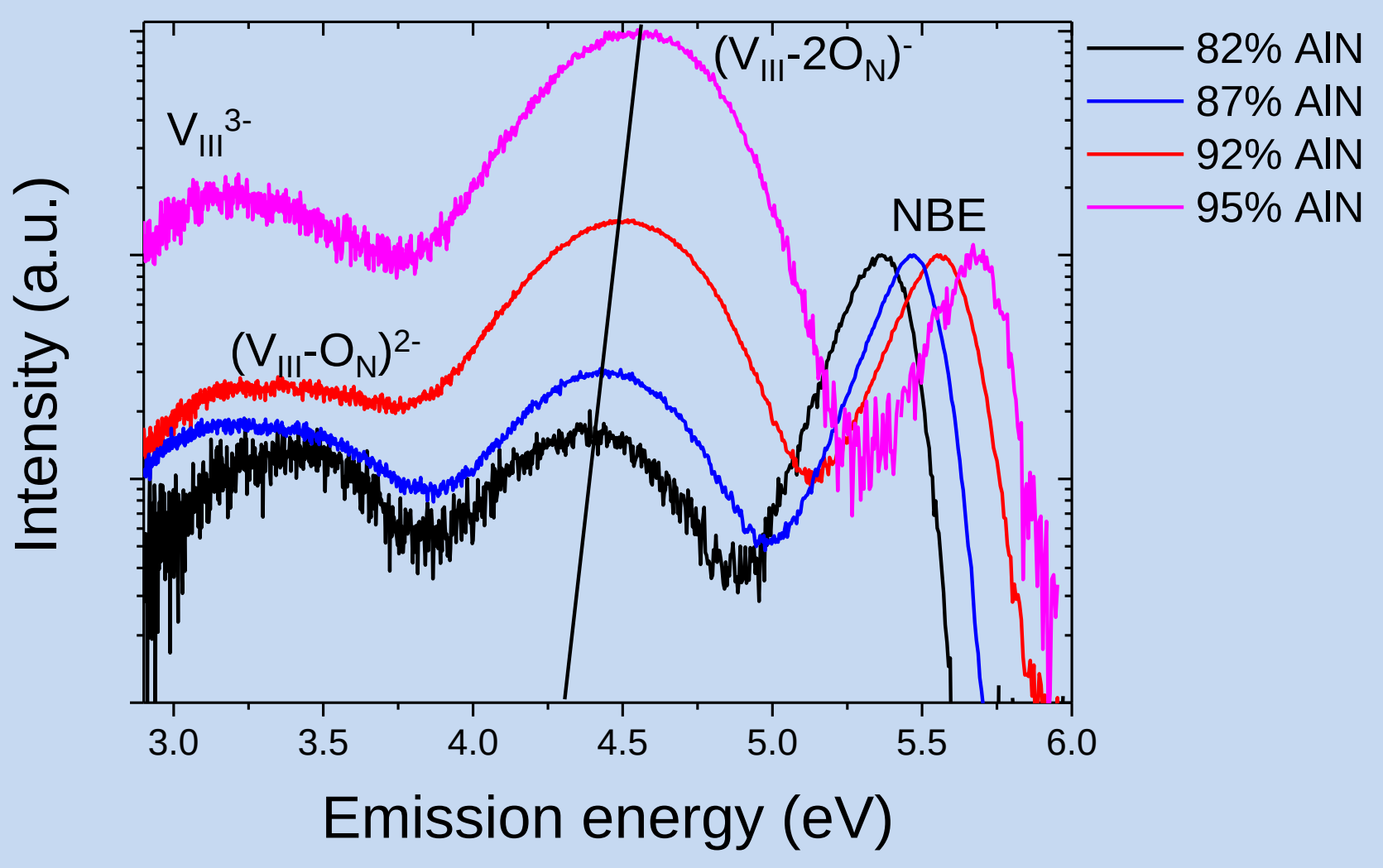
- Secondary electron (SE), CL and ECC image taken from the same area
- ECC imaging allows to identify TD with screw component in apex of hillock which acts as a centre of non-radiative recombination for the NBE emission
- Hillocks contain screw component TDs and are caused by spiral growth

## Luminescence Properties of AlGaN:Si

**Constant AlN% (96%)**



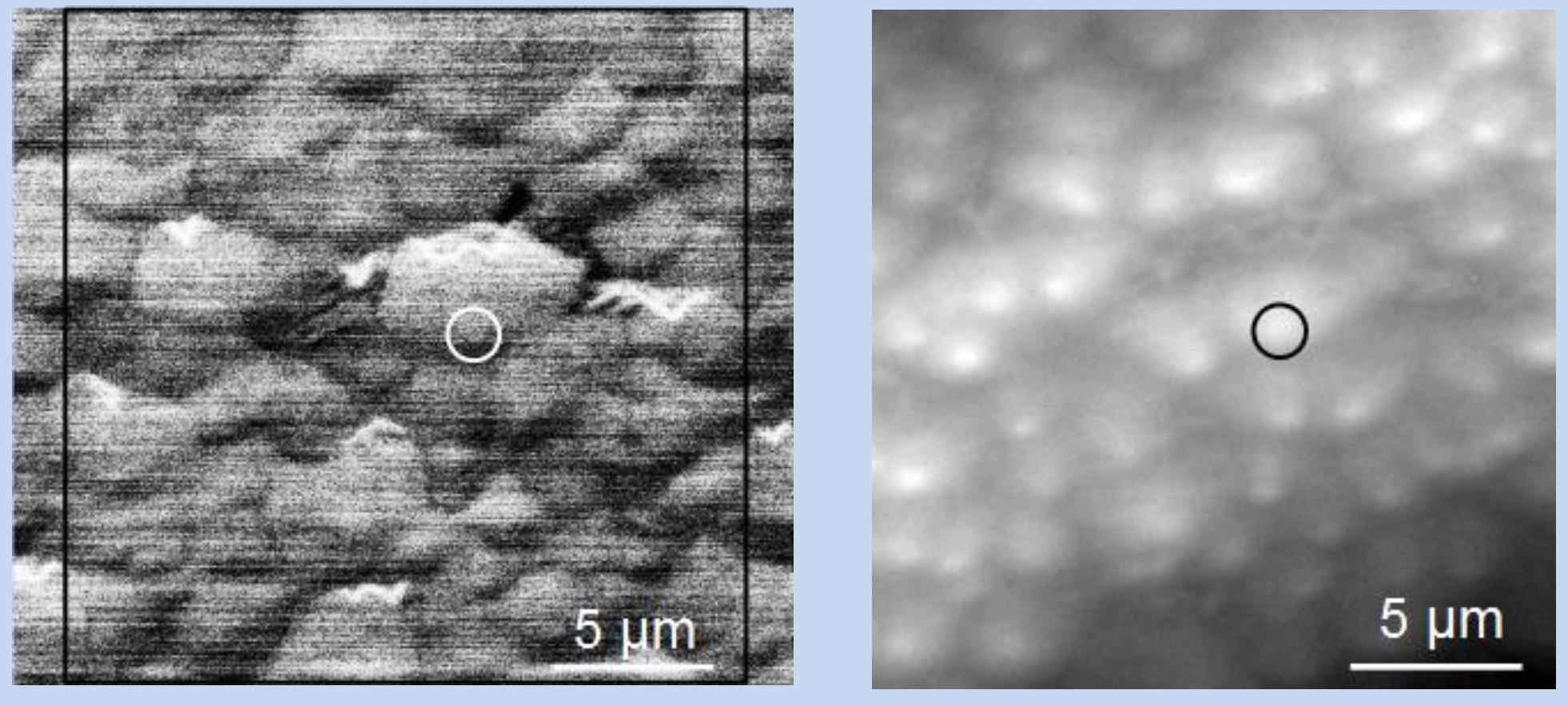
**Constant Si concentration**



- Multiple peaks in all spectra: near band edge (NBE) and three defect peaks with the 82% AlN sample only showing two defect peaks
- Defect peaks have DAP character and are associated with different point defect complexes $(V_{III}\text{-}2O_N)^-$, $(V_{III}\text{-}O_N)^{2-}$ and $V_{III}^{3-}$ [7],[8]
- Constant AlN%:
  - Si: $3*10^{18}$ cm$^{-3}$ to $9.4*10^{18}$cm$^{-3}$: decreasing resistivity; $(V_{III}\text{-}2O_N)^-$ dominant defect peak
  - Si: $9.4*10^{18}$cm$^{-3}$ to $1.3*10^{19}$cm$^{-3}$: increasing resistivity $V_{III}^{3-}$ dominant defect peak, causes selfcompensation
- Constant Si concentration:
  - $(V_{III}\text{-}2O_N)^-$ always dominant defect peak, Si concentration below optimal point, $V_{III}^{3-}$ present only for higher AlN concentrations
  - Blue shift of defect centres with increasing AlN%
- Formation energy of point defects depends on AlN% and Si concentration

**Spatial clustering of defect luminescence**

**SE image** **CL defect intensity**



- SE image and CL defect intensity from within the marked area
- Increased defect intensity in apex of hillocks
- Incorporation of defect centres increased around TD with screw component

- Formation of a Cottrell atmosphere is unlikely as there is no correlation between defect luminescence and pure edge TD
- Enhanced O incorporation in dislocation core or non c-plane growth facets most likely cause
- Reduction of screw component dislocations paramount for enhancing resistivity

## Conclusion

Extended defects:

- Dislocation density and type identified by ECCI, clustering due to template
- Screw component TDs cause formation of hillocks

Luminescence Properties:

- Three defect complexes identified: $(V_{III}\text{-}2O_N)^-$, $(V_{III}\text{-}O_N)^{2-}$ and $V_{III}^{3-}$
- Incorporation of defect centres strongly depends on Si concentration and AlN%,
- Cause for self compensation identified by $V_{III}^{3-}$ peak

Increased incorporation of point defects around screw component TDs

## Citations

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## Acknowledgements

SUPA

EPSRC
Engineering and Physical Sciences Research Council

This work was partly supported by the Federal Ministry of Education and Research of Germany, under contract 13N12588 (UltraSens).