Wide bandgap AlGaN semiconductors: doping and polarity

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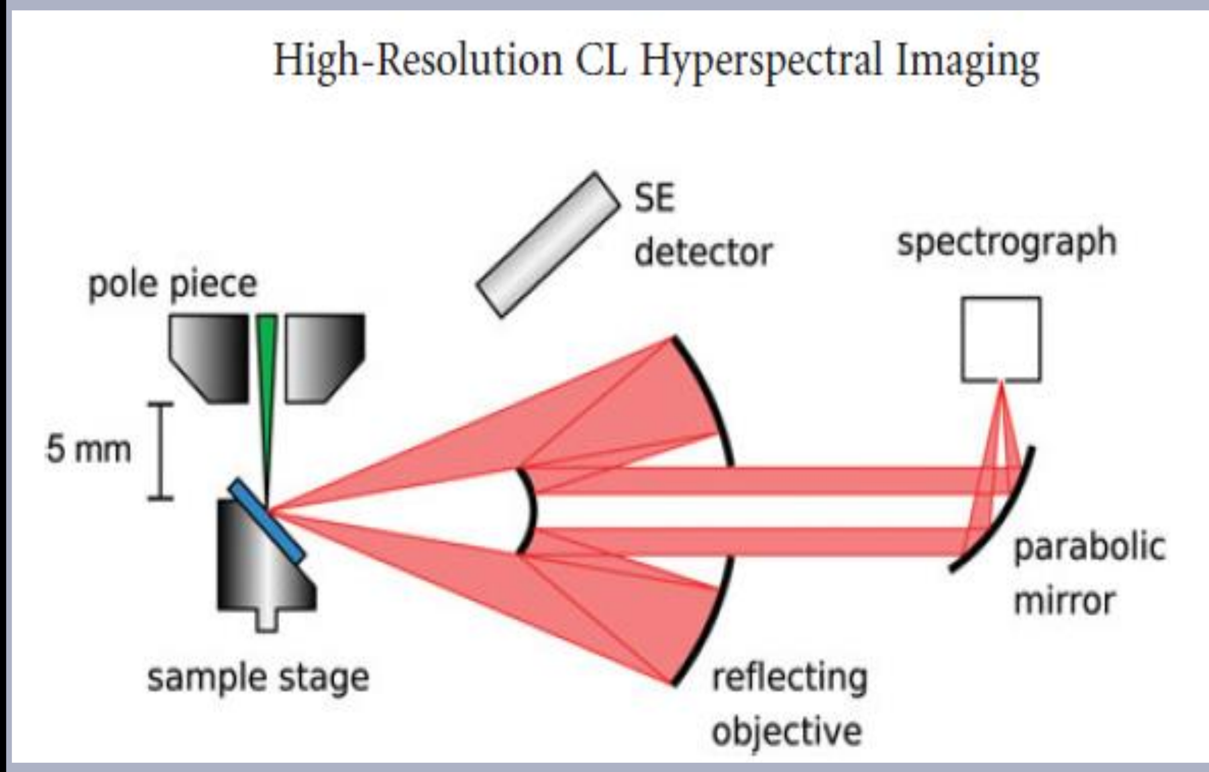
Introduction and motivation

- The AlGaN alloys are attractive material for optoelectronic devices, such as UV light emitting diodes (LEDs) and laser diodes (LDs) because of their direct and tunable wide band gap.
- Their employment requires certain crystal quality (sample morphology), defect density and doping concentration.
- Semipolar material has reduced polarisation fields along semipolar direction which results in an increase in radiative recombination probability
- N-type doping of AlGaN films with Si is difficult to achieve due to an increase in donor activation energy with an increase in AlN% content and the compensation of this donor by acceptor type defects such as oxygen, carbon and cation vacancies[1,2,3]
- Different scanning electron microscope techniques were employed to investigate the doping, and the impact of the crystal orientation

Sample details

- Grown by Metalorganic Chemical Vapour Deposition (MOVCD) in Tyndall Institute.
- 800-1100 nm thick Si-doped AlGaN layers, with reportedly 60 and 85 AlN% were grown on sapphire substrates (semi polar (11-22) or (0001) polar) orientation, covered with undoped AlN templates. The samples were grown with different Si_2H_6 /group III ratios (0 to 3.35 x 10^{-4}) and V/III ratios (23-600).
- Precursors: TMGa, TMAl, NH_3, Si_2H_6.

Cathodoluminescence (CL) spectroscopy

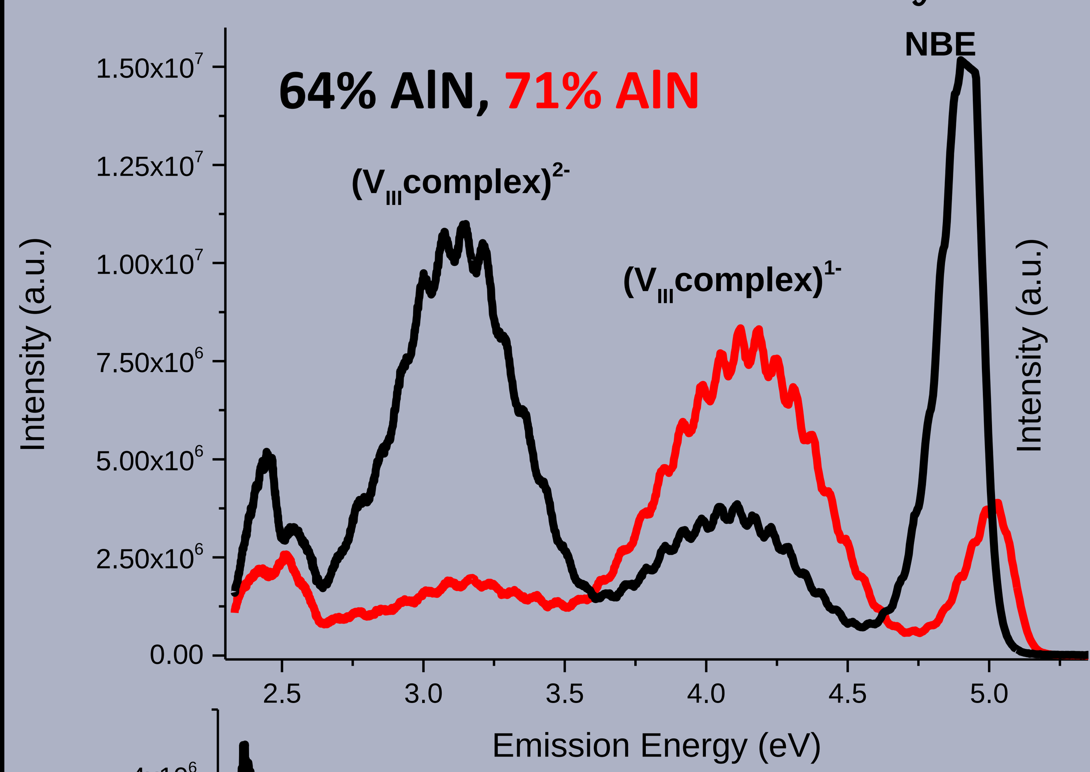


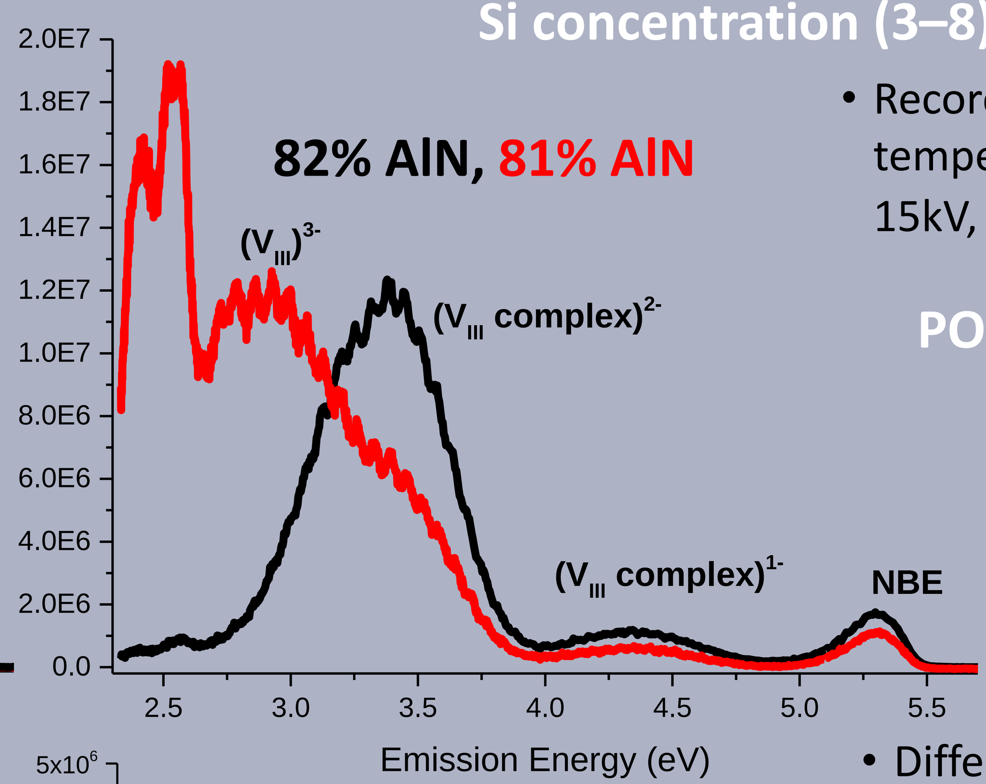
P. R. Edwards *et al.*, *Microsc. Microanal.* **18**, 1212 (2012)

- Cathodoluminescence (CL) describes the emission of light from a material when it is excited by high energy electrons, for example originating from microscope beam. It is used to investigate luminescence properties of samples features and defects. While scanning the electron beam across the sample the entire room temperature CL spectrum is collected at each pixel thereby providing the multi-dimensional (hyperspectral) data set. Spatial resolution of the CL will depend on electron beam size, the size of the generation volume and upon the minority-carrier diffusion length.

CL emission from AlGaN:Si layers

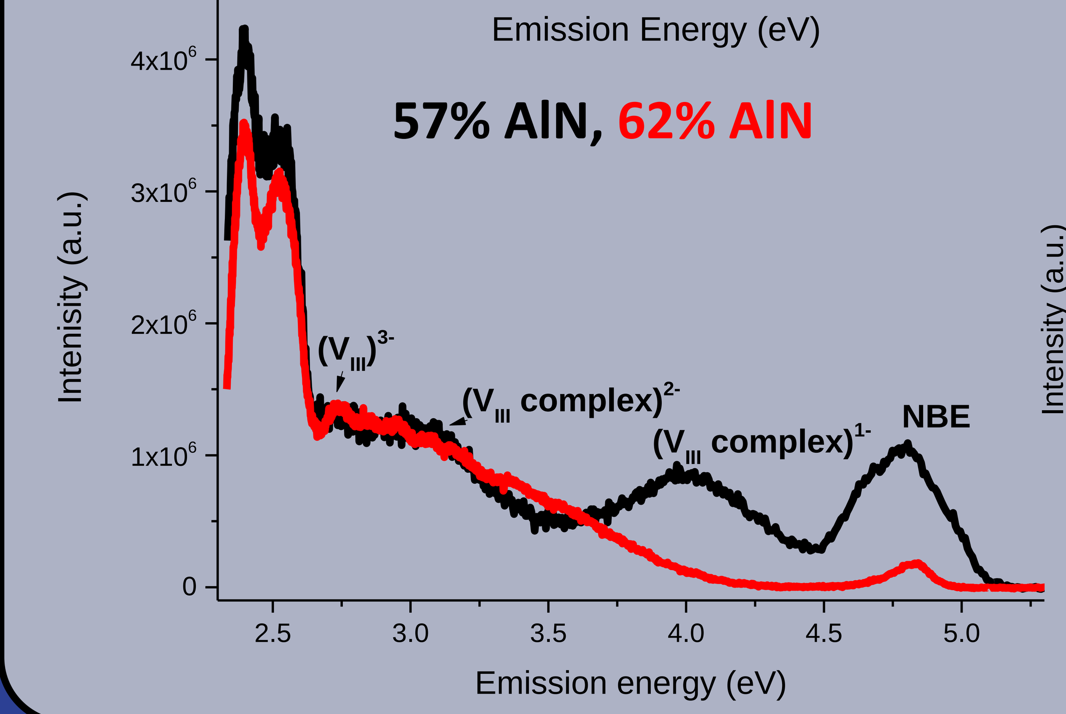
Si concentration (3–8) 10^{19} cm^{-3}

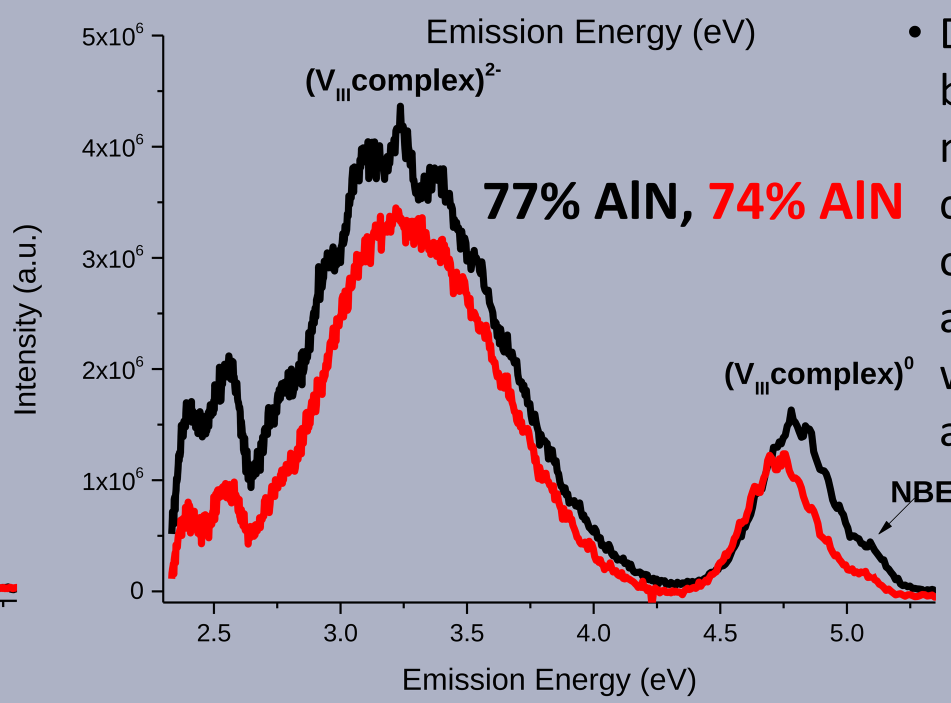




- Recorded at room temperature, 1 mbar, 15kV, ~ 19nA

POLAR



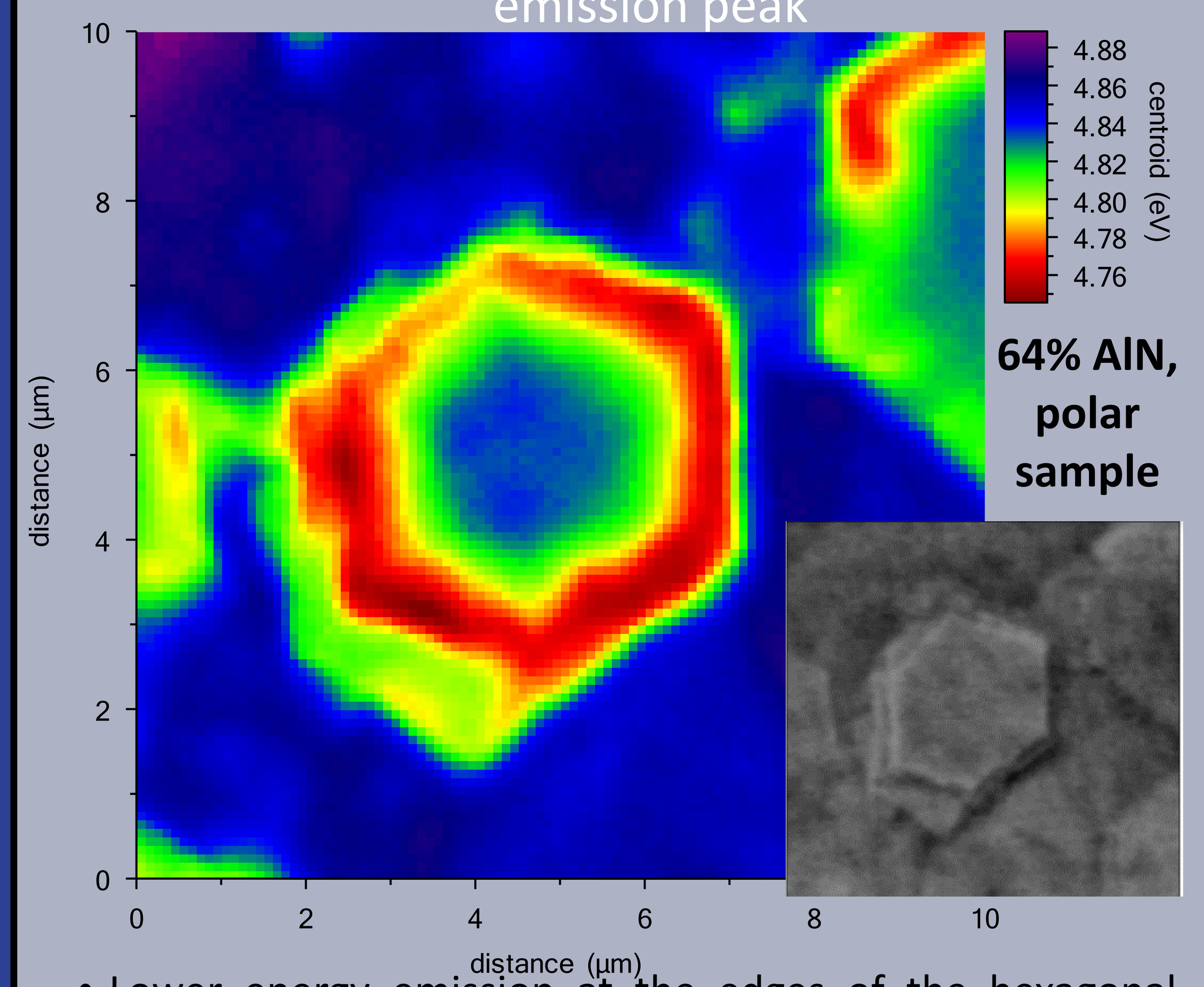


- Different peaks have been linked to negatively charged cation vacancies (Ga or Al vacancies V_{III}^{3-}) and their complexes with impurities such as (V_{III}–O_N or V_{III}–Si_{III})[4].

SEMI-POLAR

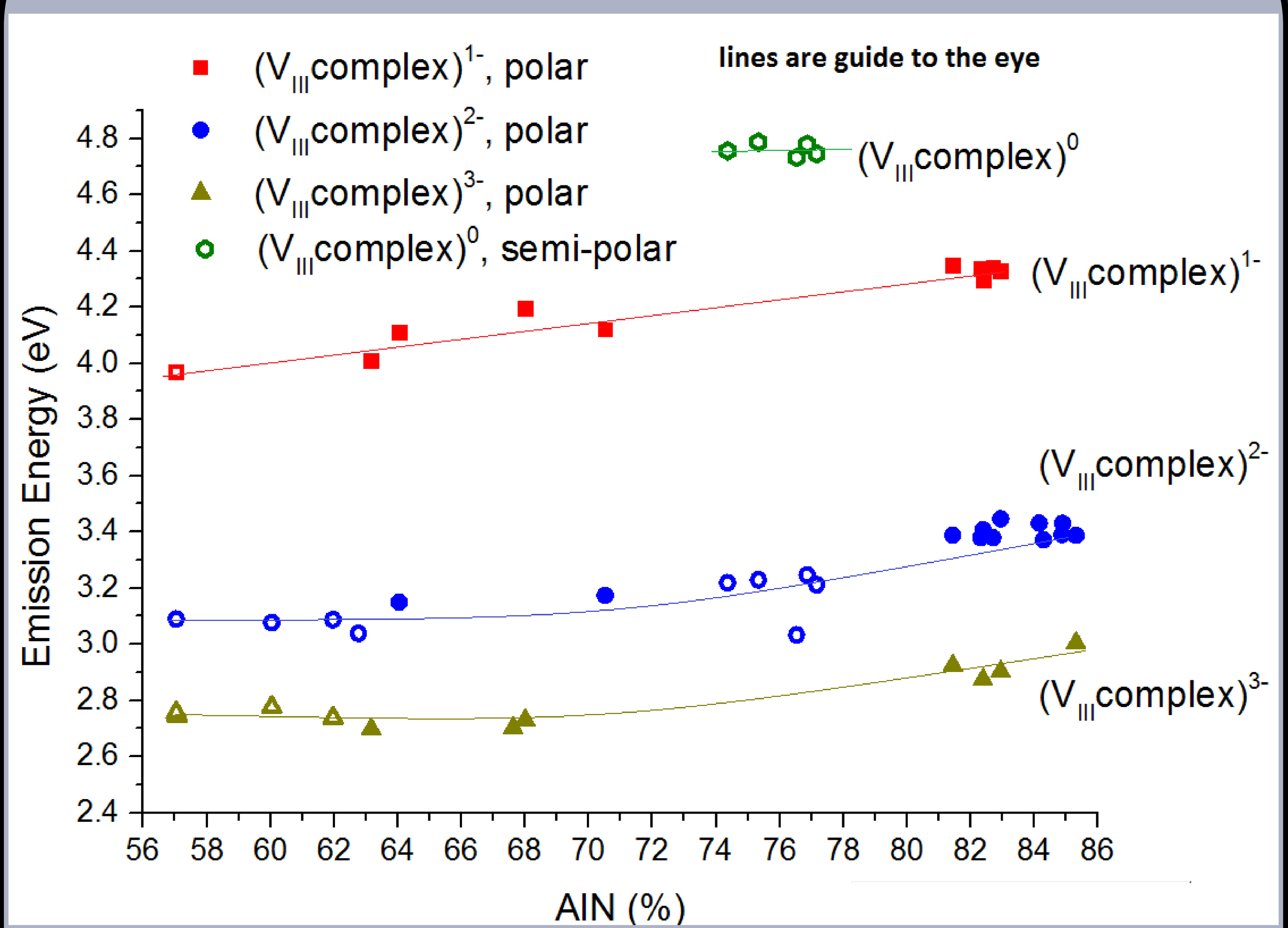
CL imaging

Centre energy map of NBE (near band edge) emission peak



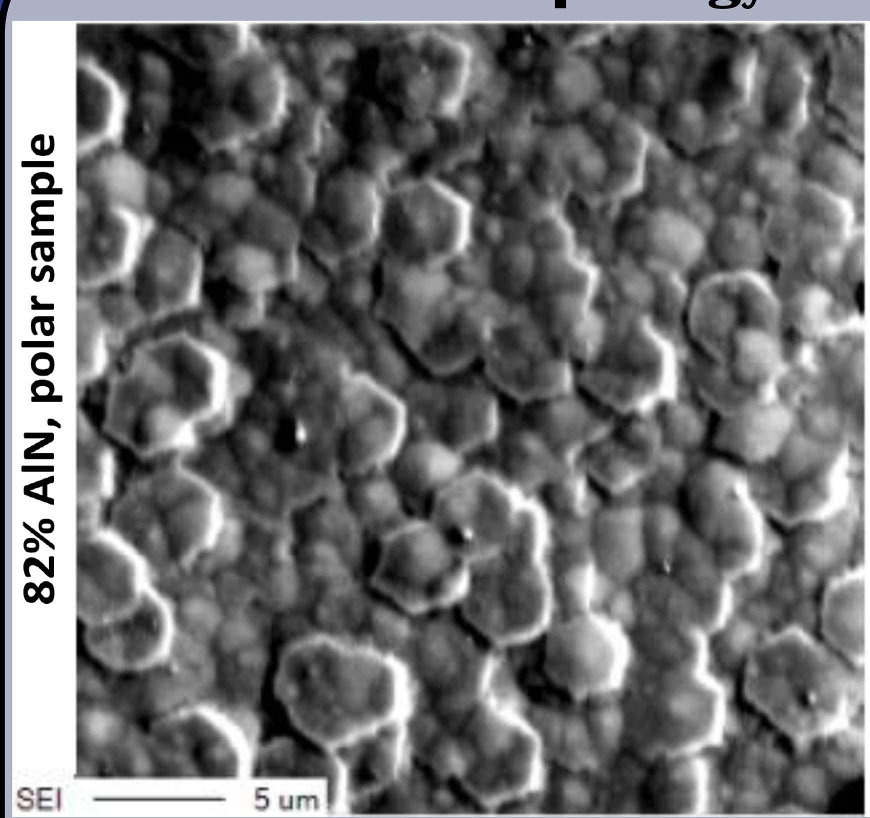
- Lower energy emission at the edges of the hexagonal features. The differences in the CL maps are caused by lower incorporation of Al atoms at the edges. The difference is more pronounced for lower AlN content samples.[5]

WDX and CL measurements combined



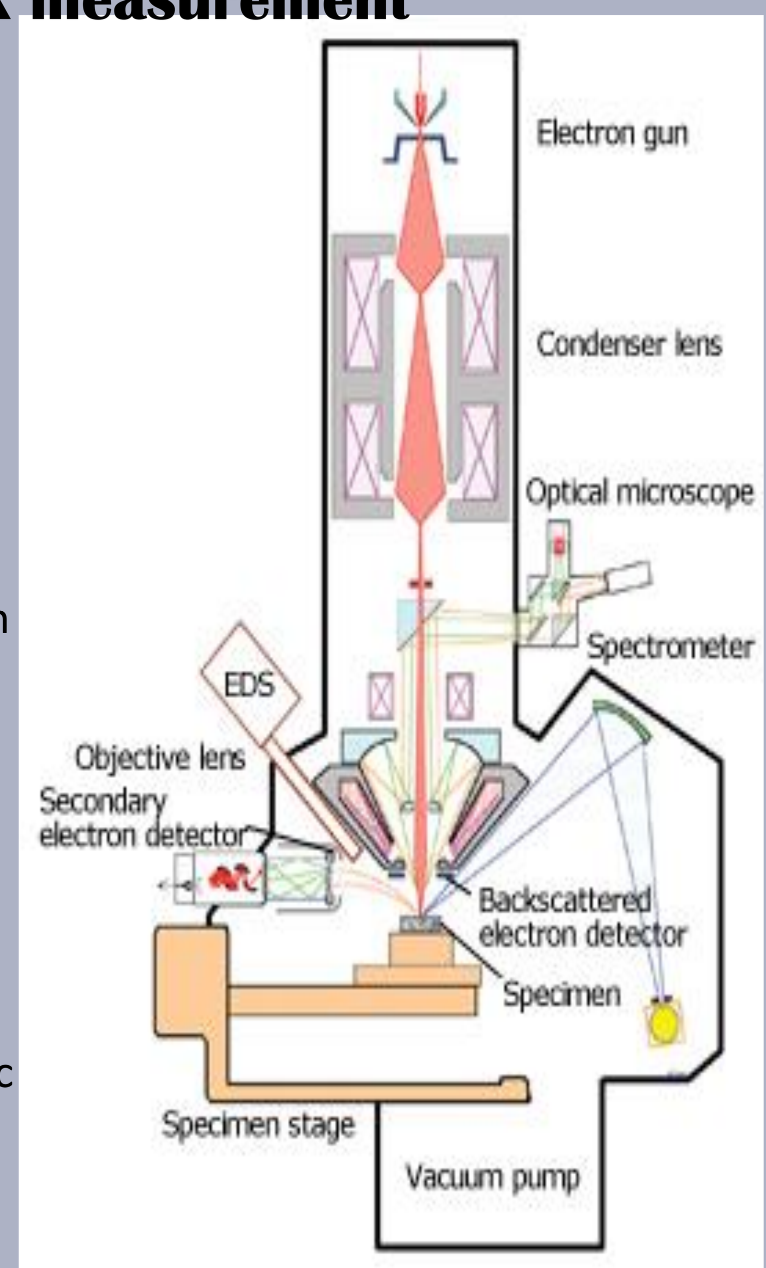
- RT-CL and WDX (Wavelength-dispersive X-ray spectroscopy) data for the experimental observed impurity-related complexes. Semi-polar and polar samples show the same trends for their emission, because of their similar nature

Surface morphology



Typical surface morphology of the polar samples. All of the polar samples showed hexagonal features of about 2-4 μm in diameter. These features cause surface roughening and the compositional variation at the edges. They can be formed by spiral growth around screw or mixed type dislocations.[5] Semi-polar surface was much flatter with no hexagons.

WDX measurement



- In the EPMA technique elements can be identified according to their characteristic X-ray emission.
- Quantitative analysis is performed by comparing the intensities measured for all the elements in the sample against standards of known composition.
- The elemental composition is calculated after applying matrix corrections for atomic number, absorption and fluorescence effects (ZAF).

Summary

- In order to improve the IQE of UV LEDs it is crucial to reduce the density of point defects and dislocations in these alloys. 3D structures seen on polar samples cause surface roughening and the compositional variation at the edges. Effects of Si doping are not fully understood yet, but it seems that Si doping has little impact on the occurrence of surface features in the investigated sample series. CL spectra of the samples, confirmed the existence of impurity related complex associated with Si doping. The samples surface quality was improved by growth in semi-polar direction. NBE (near band edge) peaks were visible in all samples, and their emission was shifting according to AlN content.

Acknowledgements

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Citations

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