Hyperspectral cathodoluminescence imaging of InAlN/AlGaN quantum well/quantum barrier-structures

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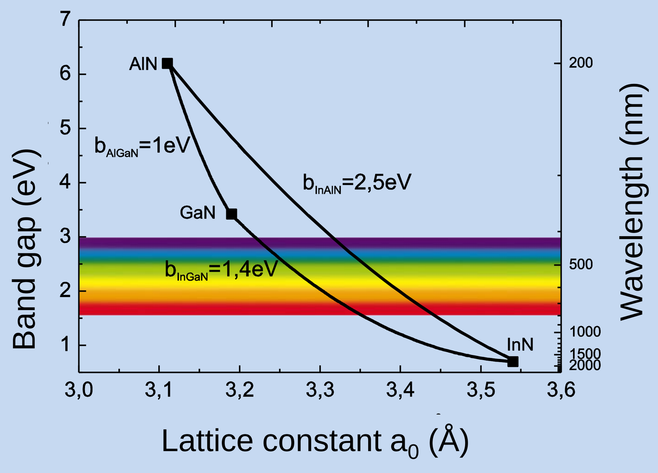
Motivation

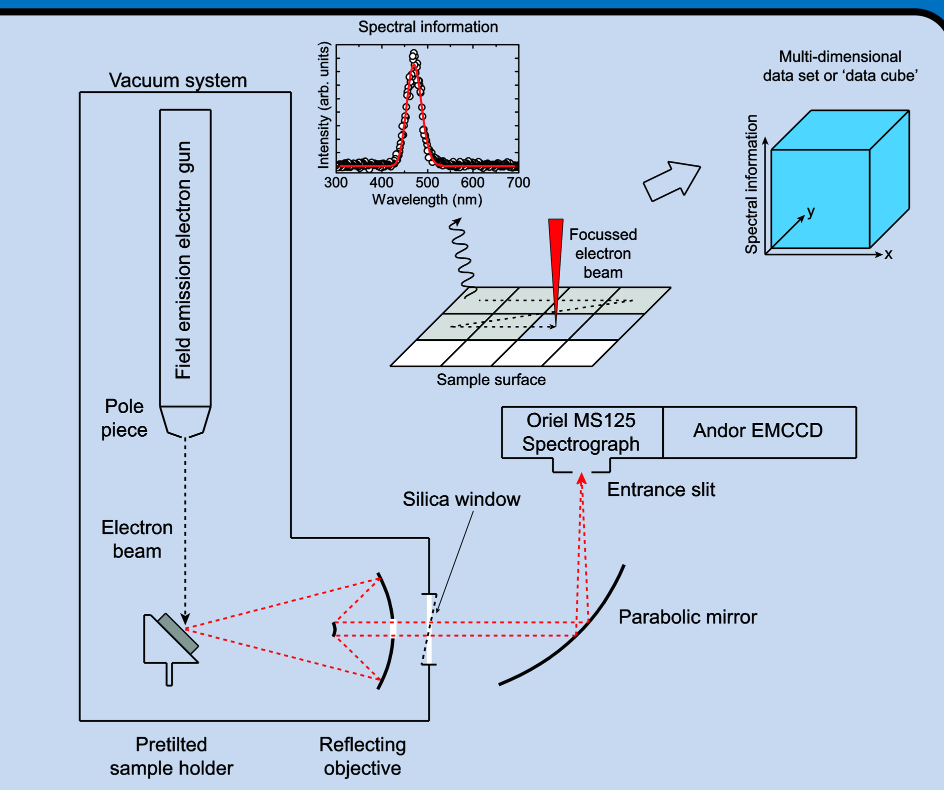
There are many interesting possibilities for the growth of high quality InAlN/AlGaN based semiconductor devices that have not been fully explored, and this remains one of the key challenges in the III-nitride material system. This is due to the complicated growth mechanics which potentially lead to phase separation and compositional inhomogeneity.



The large differences in growth temperature and lattice constant between InN and AlN present further challenges for the successful growth of InAlN/AlGaN based semiconductor devices.

MOVPE growth
- Close coupled showerhead reactor
- N_2 carrier gas was used for the quantum well structures
- Substrate: c-plane sapphire
- Precursors: TMGa, TMAl,TMIn, NH_3

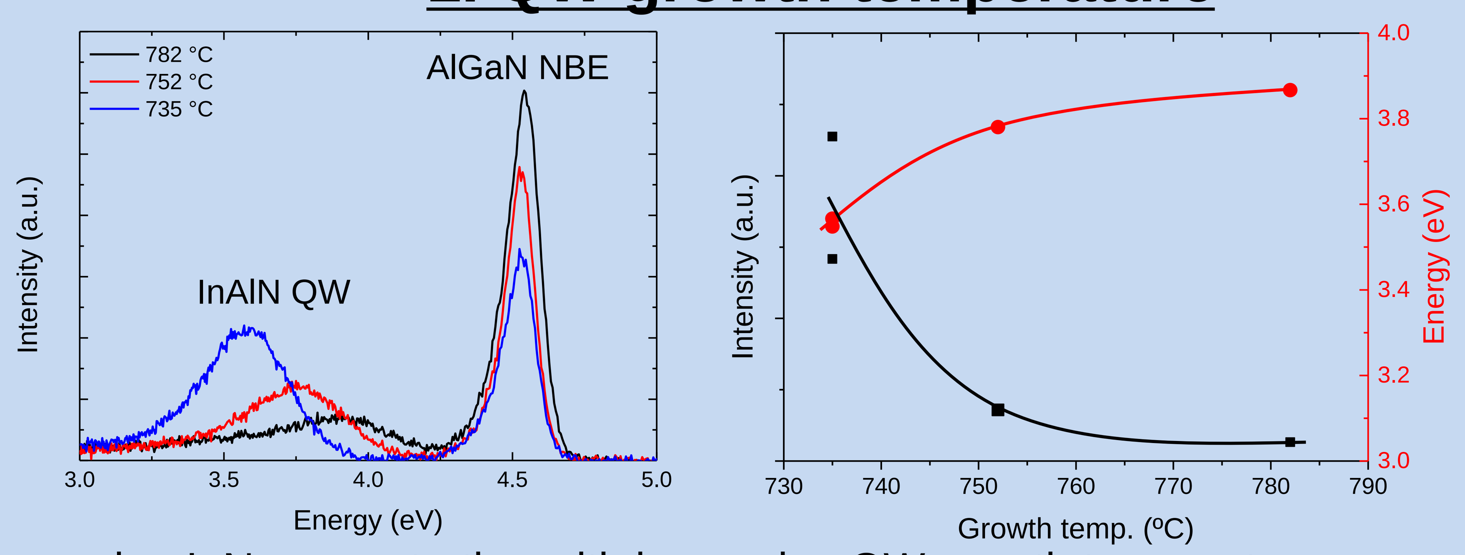
Hyperspectral Cathodoluminescence
- All measurements at room temperature
- 5 kV acceleration Voltage
- ~ 150 nm penetration depth according to Monte Carlo simulations
- Performed in a FEI Quanta 250 ESEM (allowing mapping of low conductivity samples)



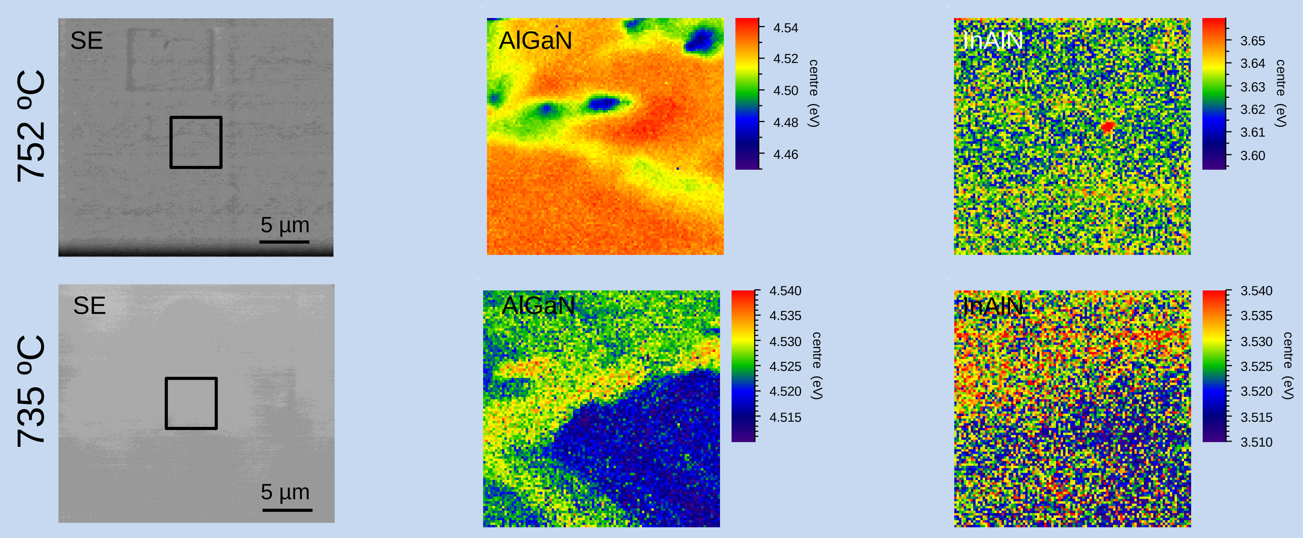
Measurement Setup and mode of operation for Hyperspectral CL

Variation of specific growth parameters for InAlN/AlGaN structures

1. QW growth temperature

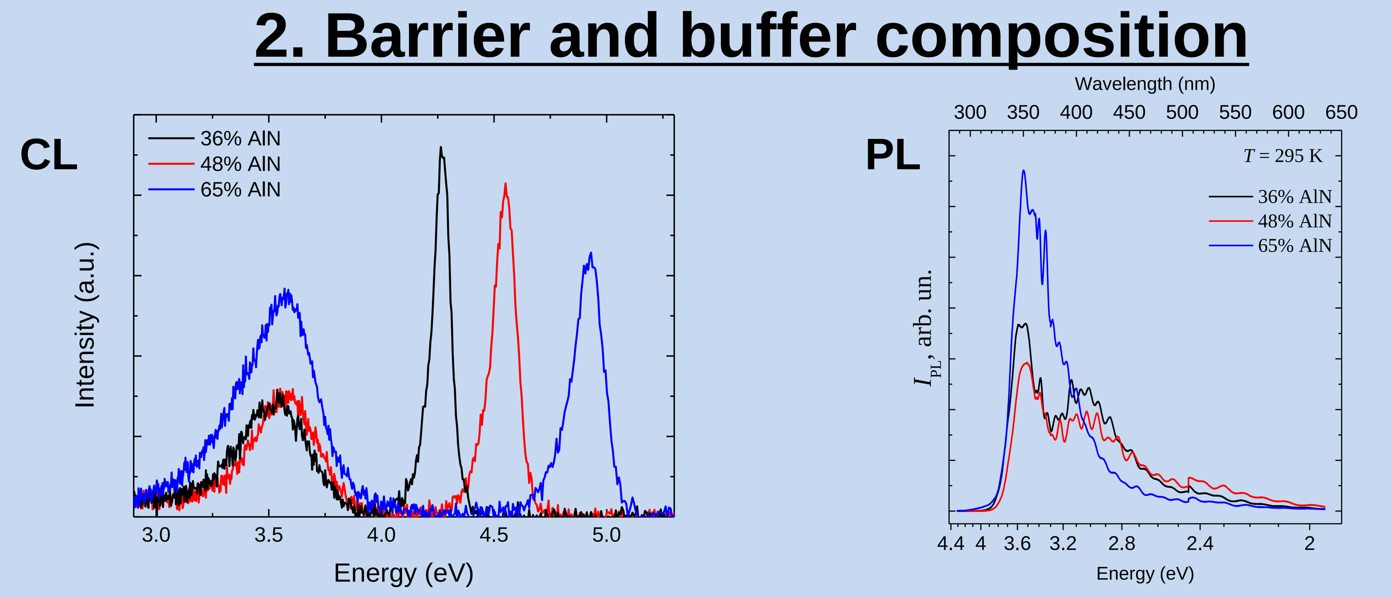


- Decreasing InN concentration with increasing QW growth temperature
- Emission energy between 3.55 eV (735 ºC) and 3.85 eV (782 ºC)
- Strong decrease in QW intensity with increasing QW growth temperature
  ⟶ Strong influence on intensity and wavelength

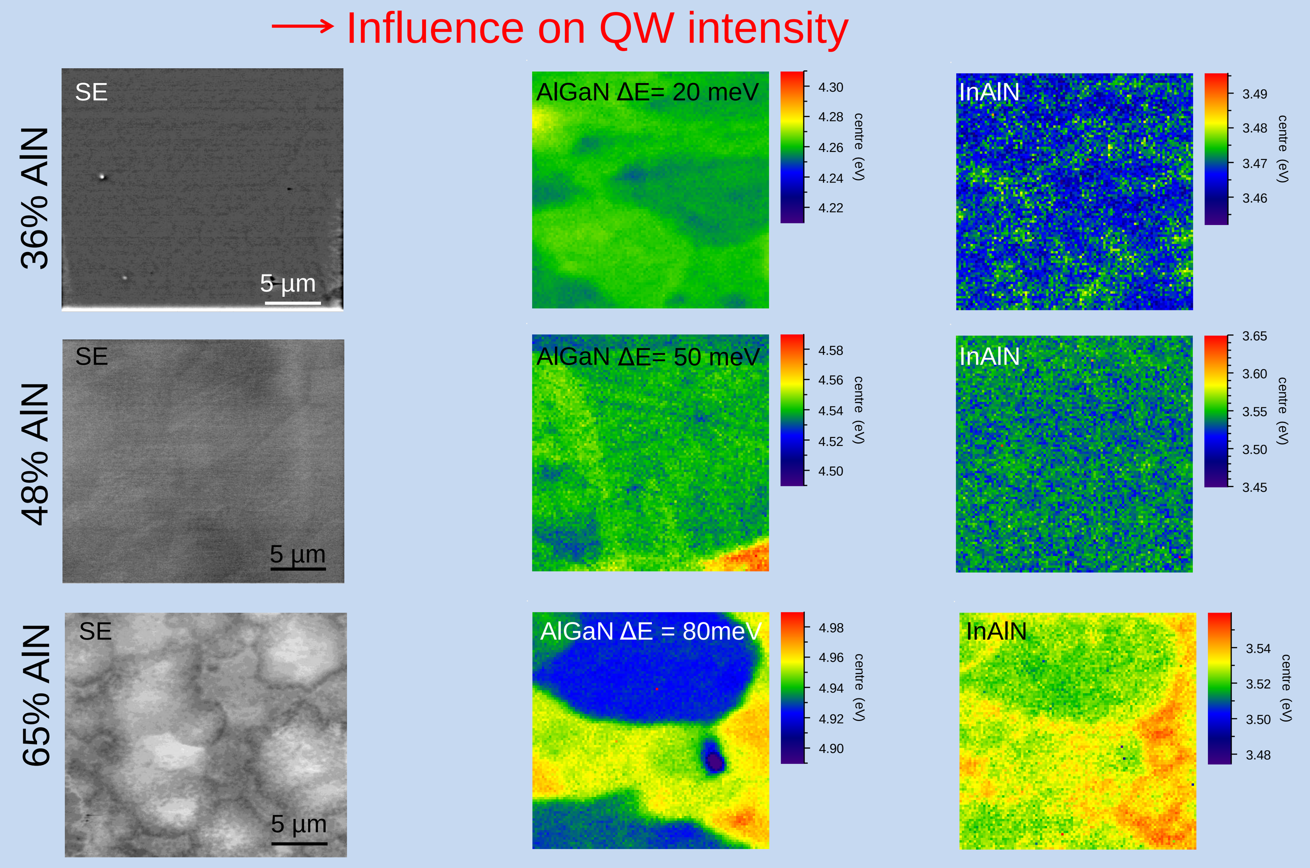


- SE-image (mag x12000) and CL maps (5x5 µm) of 752 ºC and 735 ºC sample
- There are few surface features/defects
- AlGaN domains with different emission energies, small variation in QW emission
  ⟶ Weak influence on spatial homogeneity

2. Barrier and buffer composition



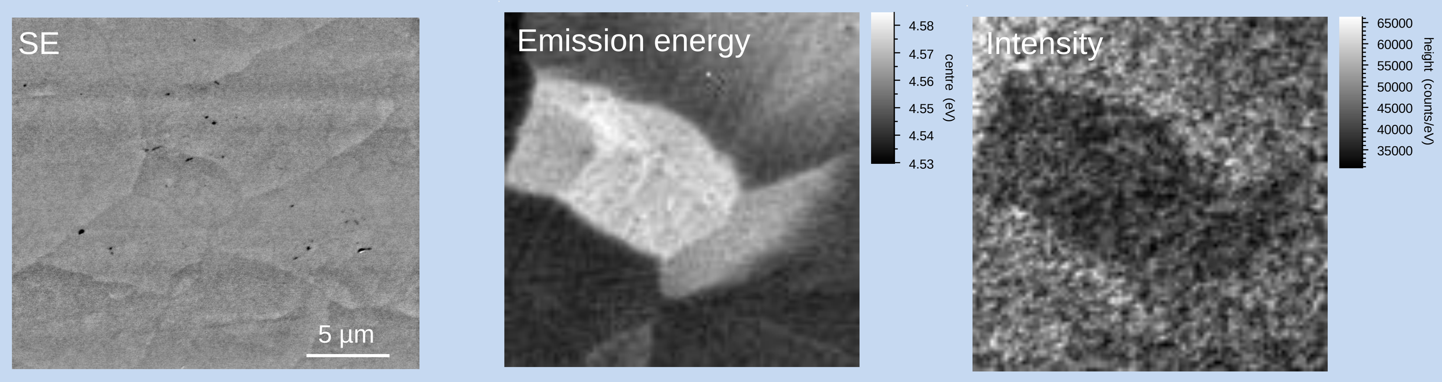
- AlGaN NBE emission energy between 4.27 eV (36% AlN) and 4.92 eV (65% AlN)
- Increasing QW intensity with increasing AlN concentration
  ⟶ Better confinement
  ⟶ Influence on QW intensity



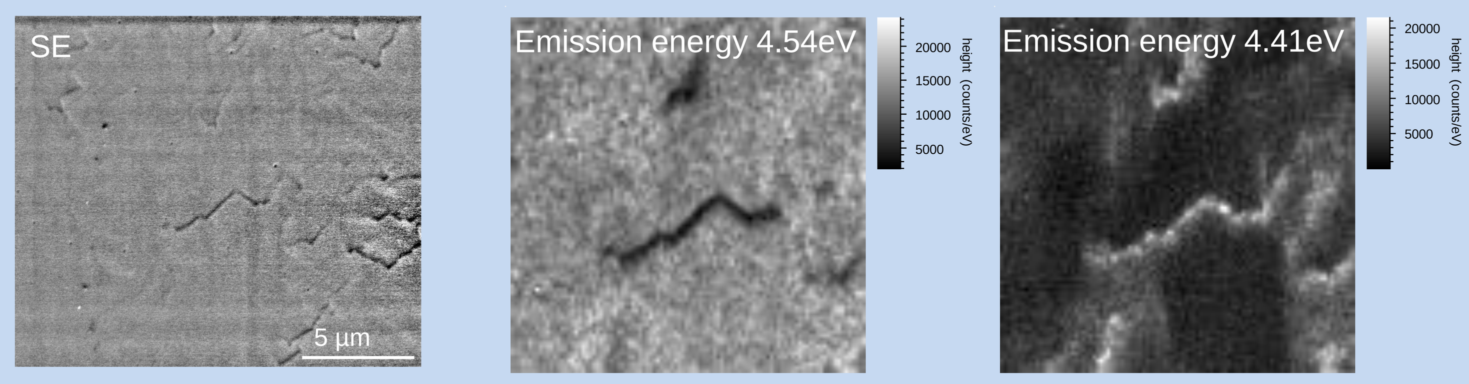
- Increasing AlN% ⟶ deteriorating morphology, increasing strain ⟶ increasing ΔE_{AlGaN}
- Increasing AlN% ⟶ increasing strain ⟶ decreasing InAlN spatial homogeneity
  ⟶ Strong influence on morphology and homogeneity

Effect of substrate miscut on $Al_{0.5}Ga_{0.5}N$ morphology

- AFM measurements on samples with a substrate miscut of 0.1º(a) and 0.4º(b)
- RMS roughness is 4 nm (a) and 5 nm (b)
- Two different morphologies
  a) Small hillocks separated by valleys
  b) Large surface steps



- SE-image and CL-map for emission energy and intensity of sample a)
- AlGaN domains with varying emission energy
- Emission energy fairly constant in each domain
- Formation of domains is a possible process to reduce strain



- SE-image and CL-maps for emission energies of sample b)
- 4.54 eV peak constant over area except in regions with surface steps
- No AlGaN domains
- Surface steps correlate to 4.41 eV peak

⟶ Two AlGaN peaks
⟶ Reduced AlN incorporation along step edges
⟶ High miscut promotes formation of stress relieving step bunches
⟶ Strong influence of substrate miscut on stress relief and surface morphology

Conclusion

Growth Parameters
- Strong influence of QW growth temperature on intensity and wavelength of QW emission
- Weak influence of growth temperature on spatial homogeneity
- AlN composition in barrier influences QW intensity
- Increase in AlN composition of buffer reduces surface morphology and spatial homogeneity

Substrate miscut
- Different miscut leads to different strain relaxation processes and thus to different morphologies

Acknowledgements

SUPA

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