Hyperspectral Cathodoluminescence Imaging Of Low Resistivity Large Bandgap AlGaN Layers

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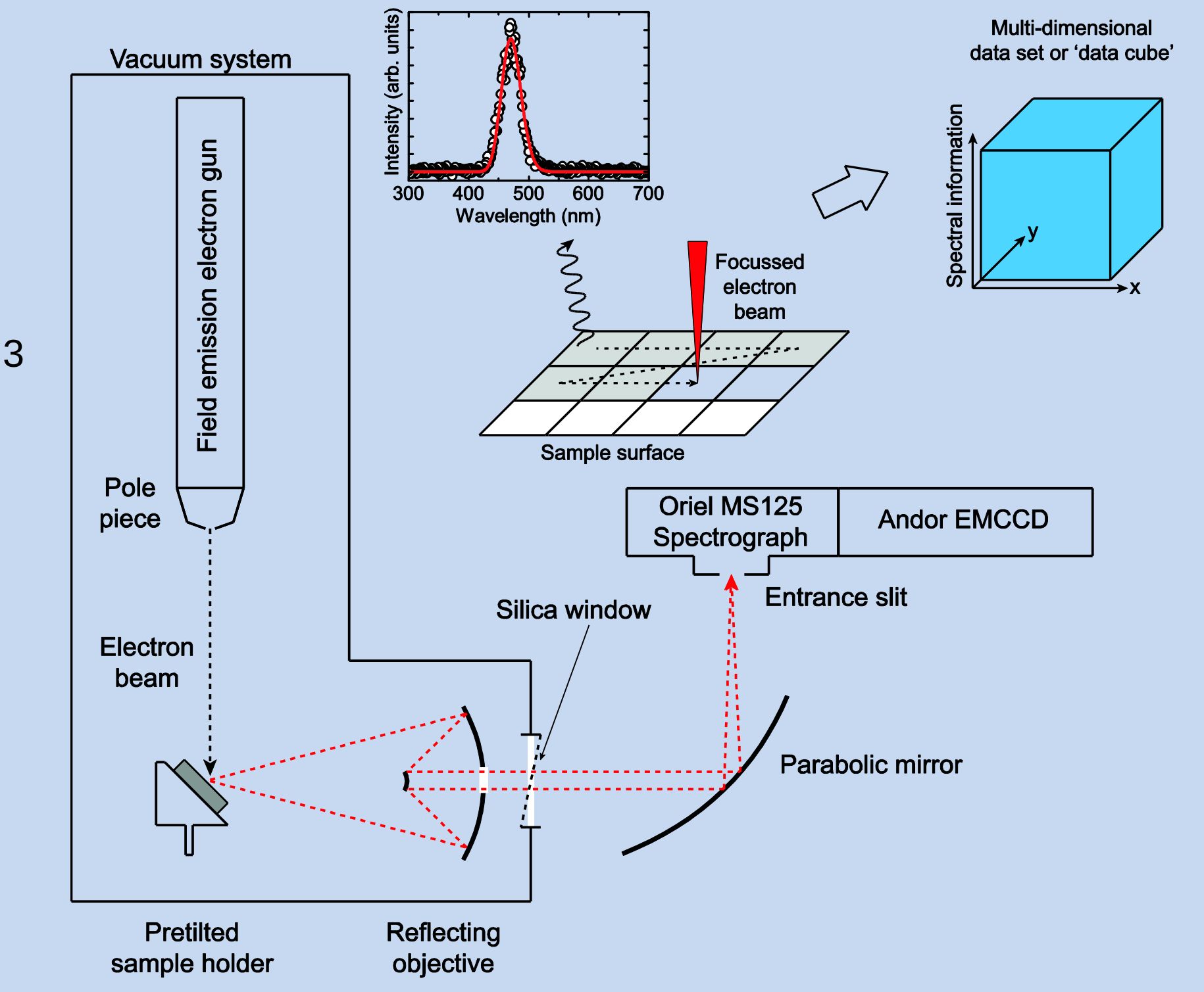
Motivation

There are many interesting applications for semiconductor devices emitting in the UV spectral region, which include: water purification, gas sensing and medical diagnostics. To realize these multi-quantum well based UV-light emitting devices, high quality AlGaN layers are required, for which challenges remain in their growth. One of the main limitations for the application of AlGaN layers with a high AlN content (x>80%) in devices is the inefficient doping. 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 the influence of the Si doping on the luminescence properties and the morphology of high AlN content AlGaN layers are barely understood.

A series of samples with different SiH_4/group-III ratios (1.9, 5.9 and 18·10^{-5}) in the top $Al_{0.82}Ga_{0.18}N$ layer was grown by metalorganic vapour phase epitaxy (MOVPE) on defect reduced AlN buffers. Using cathodoluminescence (CL) hyperspectral imaging we have investigated the influence of the Si doping on the luminescence properties and morphology of the samples.

MOVPE growth
- Close coupled showerhead reactor
- Substrate:
  Epitaxial lateral overgrown (ELO) AlN/Al_2O_3
- Precursors: TMGa, TMAl, NH_3, SiH_4

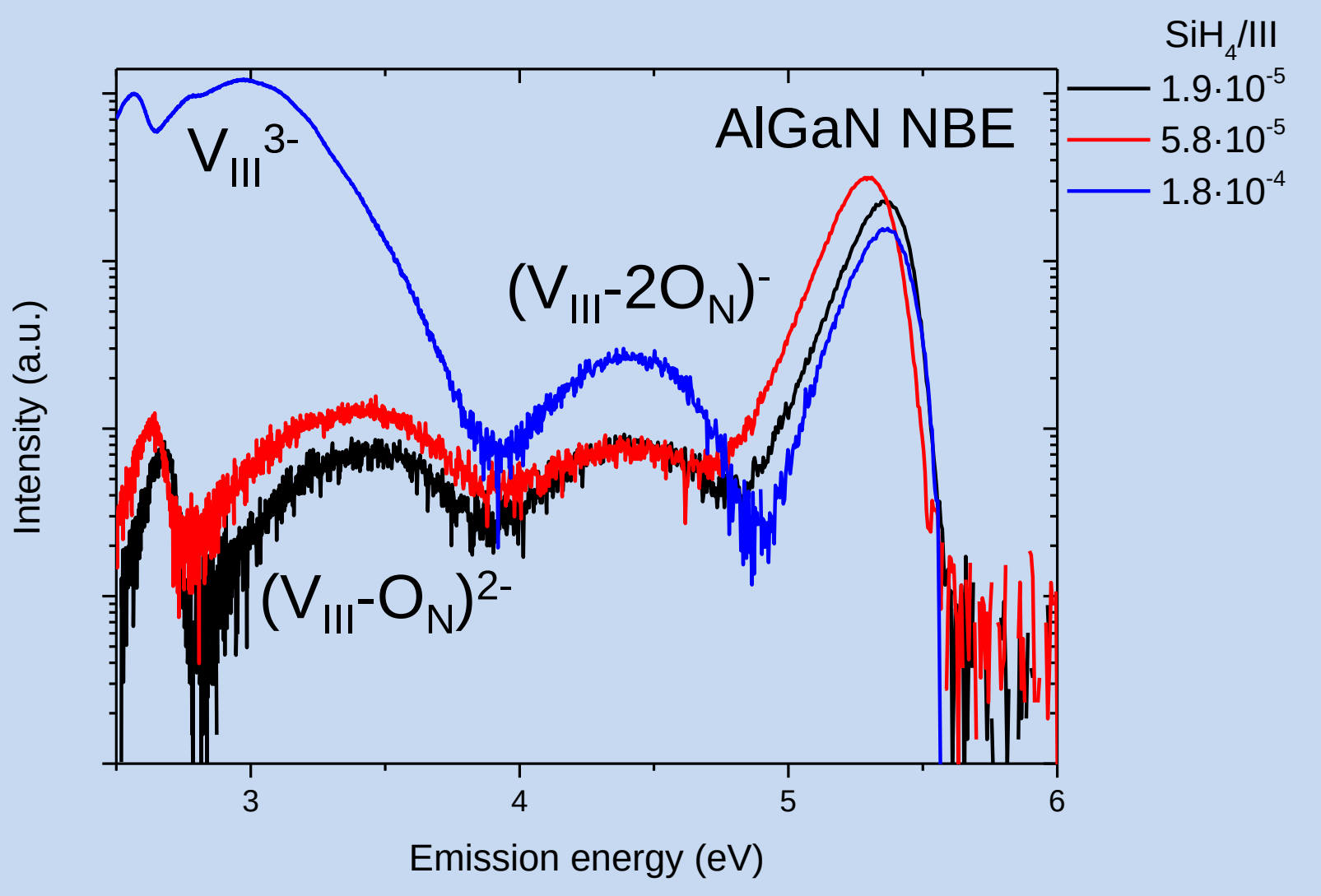
Cathodoluminescence hyperspectral imaging
- All measurements at room temperature
- 5 kV acceleration Voltage
- ~ 100 nm penetration depth according to Monte Carlo simulations
- Performed in a FEI Quanta 250 ESEM

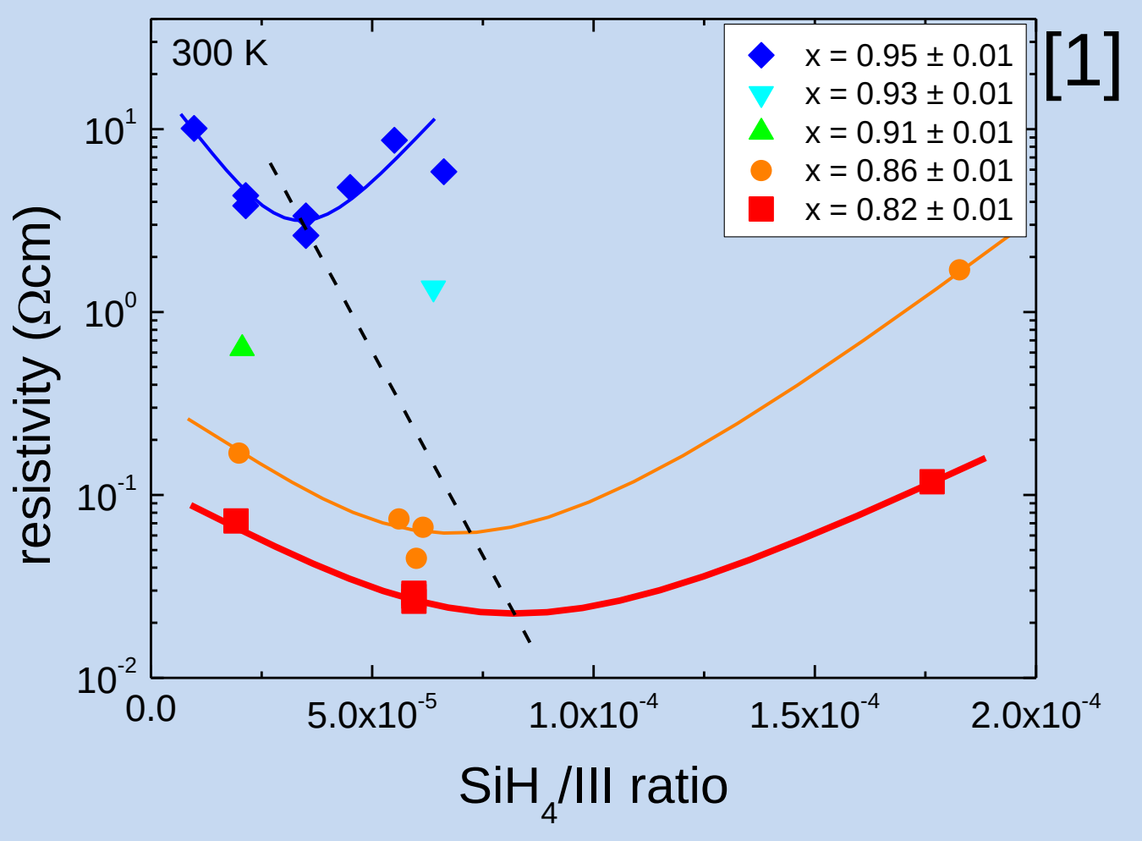


Measurement Setup and mode of operation for Hyperspectral CL

Morphology and luminescence properties of $Al_{0.82}Ga_{0.18}N$:Si

1. Overview

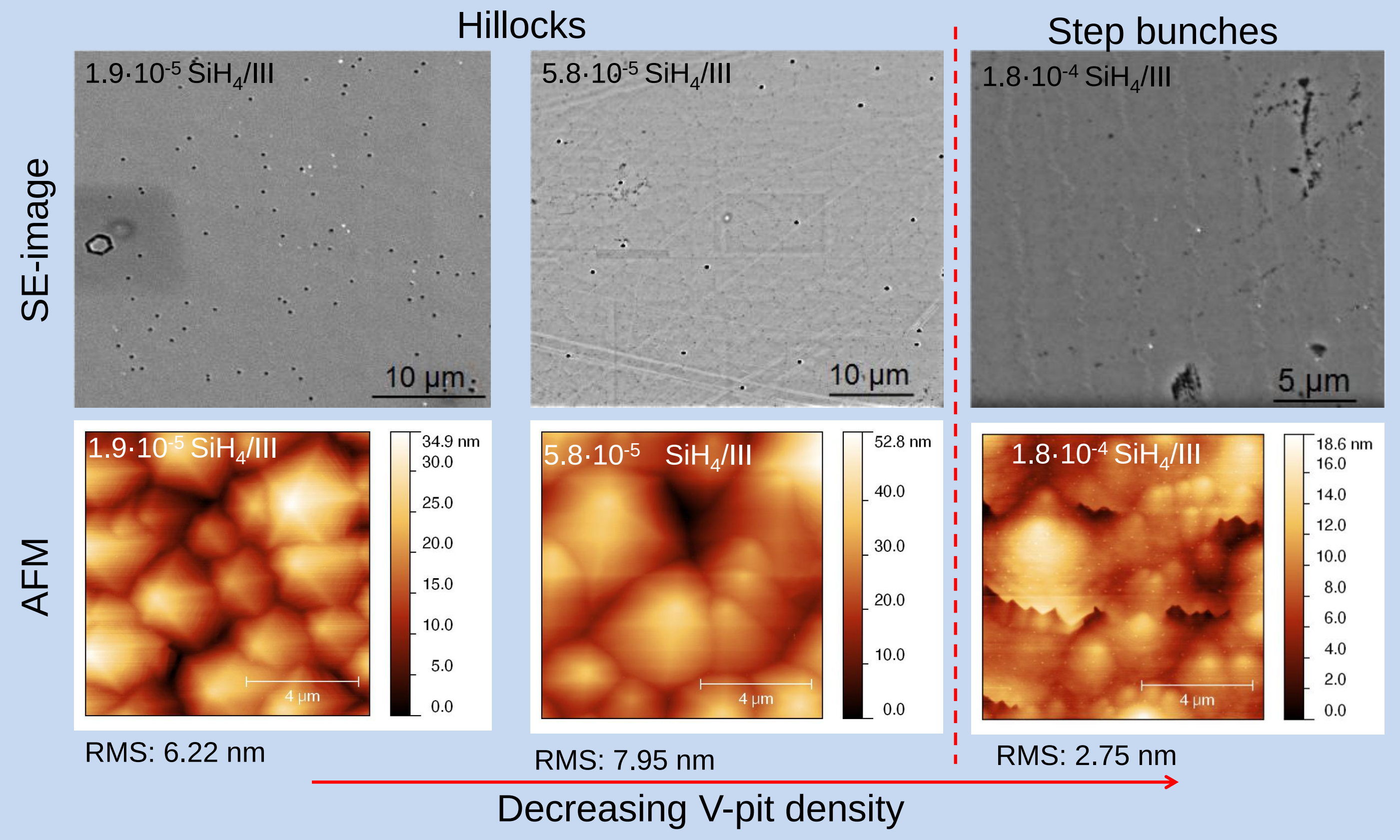




- 1.9·10^{-5} → 5.8·10^{-5} SiH_4/III, decreasing resisitivity → three peaks
- AlGaN NBE (5.36 eV), Two DAP peaks: $(V_{III}\text{-}2O_N)^{-}$ and $(V_{III}\text{-}O_N)^{2-}$ (4.35 eV, 3.39 eV) [2]
- 5.8·10^{-5} → 1.8·10^{-4} SiH_4/III increasing resistivity, additional Peak: V_{III}^{3-} (2.95 eV) [2,3]

→ Self compensation, caused by formation of V_{III}^{3-}

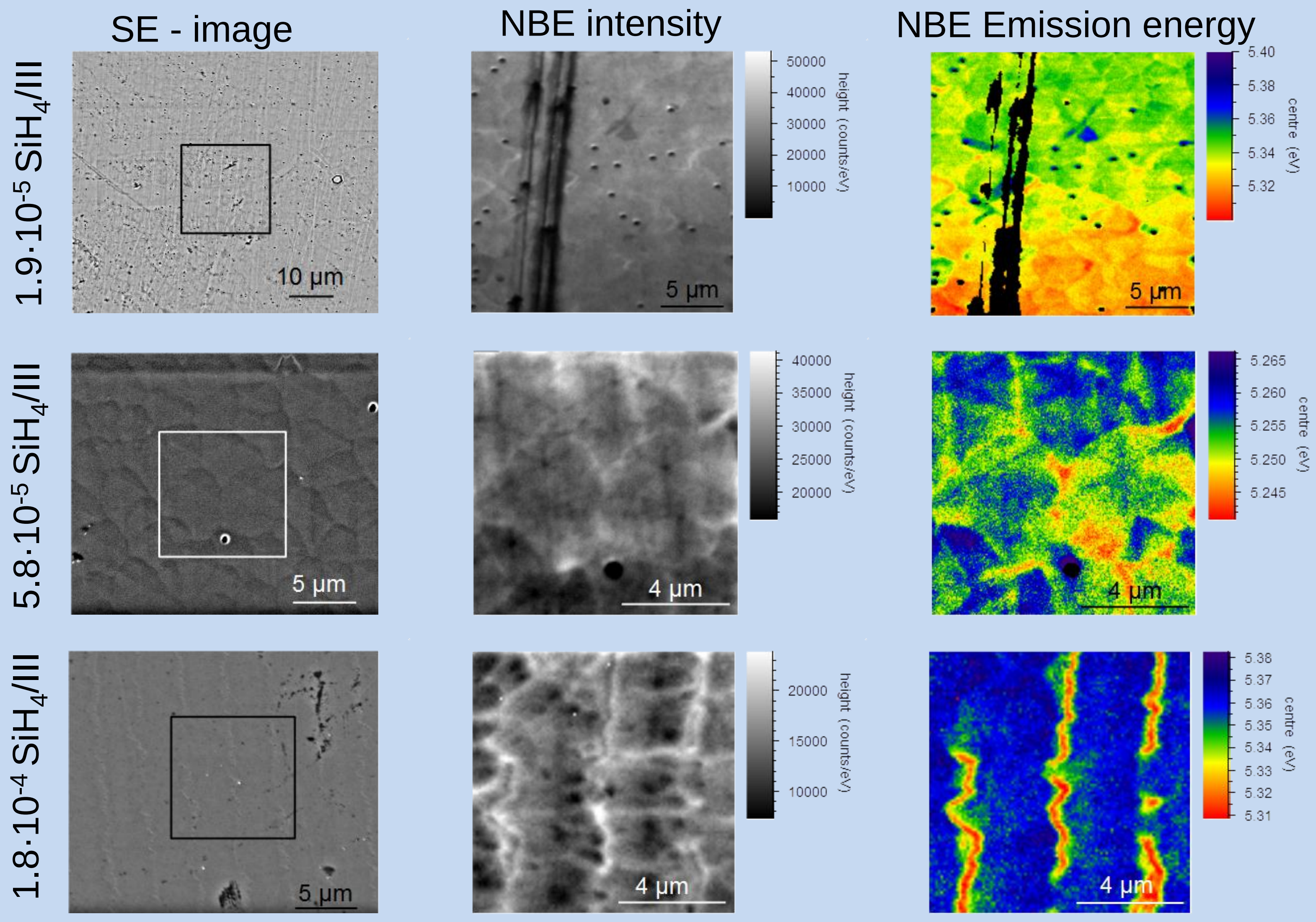
2. Morphology



- 1.9·10^{-5} SiH_4/III, surface governed by hillocks, high V-pit density
- 5.8·10^{-5} SiH_4/III, increasing hillock height and surface roughness, reduced V-pit density
- 1.8·10^{-4} SiH_4/III, step bunches with a periodicity of 3.5 µm, hillocks on terraces

→ Change in surface morphology due to different substrate miscut

3. CL hyperspectral imaging



- 1.9·10^{-5} SiH_4/III, small spatial variations in intensity and emission energy
- 5.8·10^{-5} SiH_4/III, spatial variations in intensity and emission energy

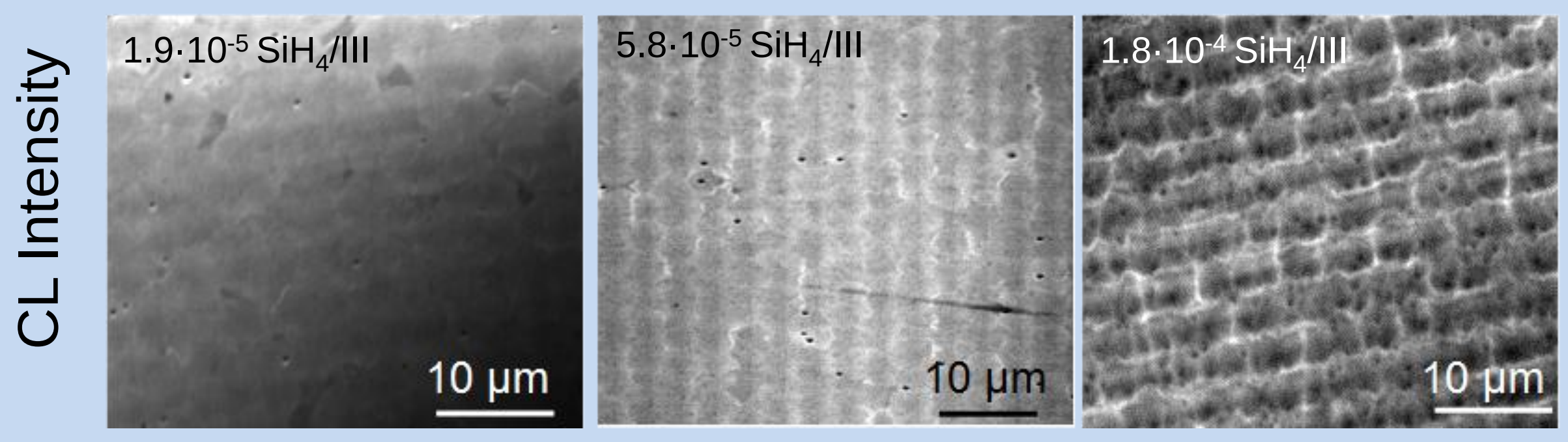
→ Spatial variation caused by hillocks

- 1.8·10^{-4} SiH_4/III, increasing intensity, decreasing emission energy due to higher GaN incorporation along steps

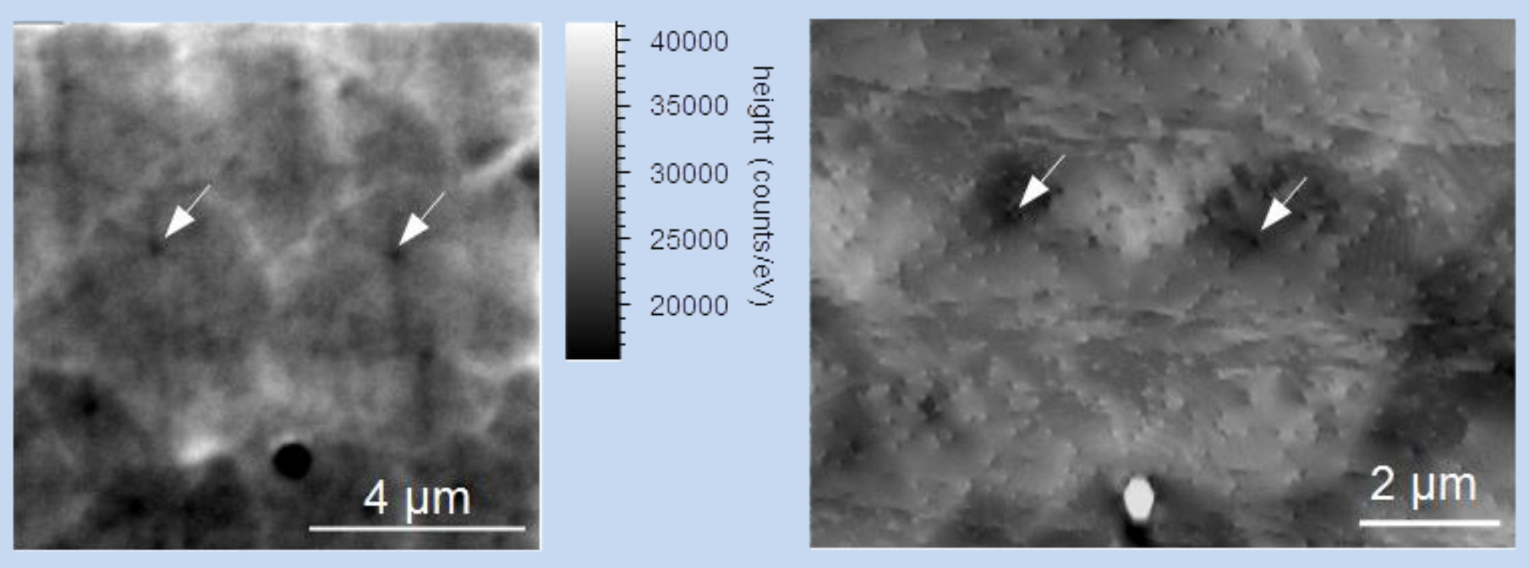
→ Strong influence of morphology on luminescence properties

Influence of defects and Cross-section analysis

4. Defects



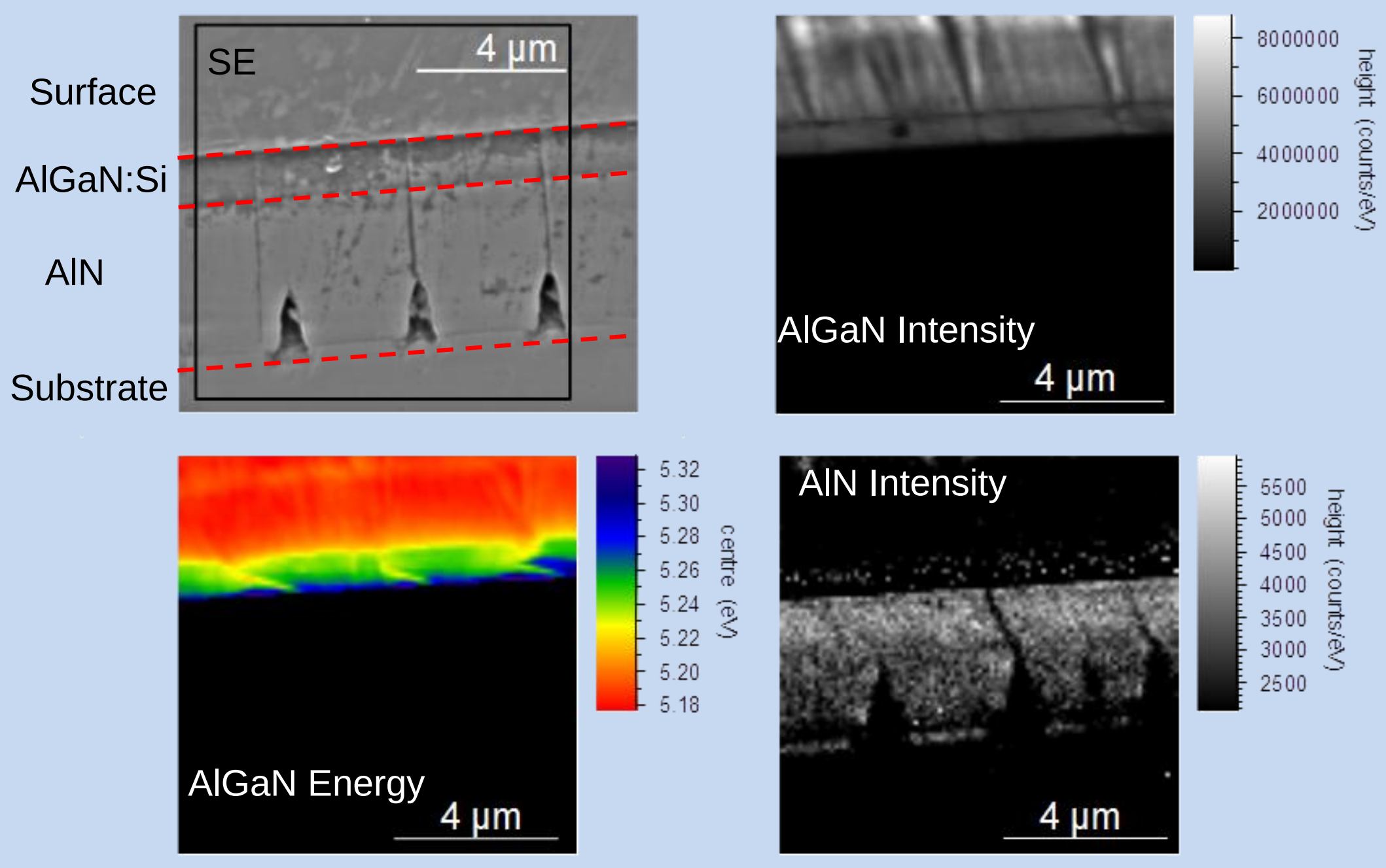
- Strong periodic reduction in emission intensity with a periodicity of 3.5 µm
- Threading dislocations (TD) acting as non radiative recombination centers
- Clustering and ordering of TD density due to underlying ELO pattern [4]



- Electron Channeling Contrast Imaging (ECCI) [5] and CL performed on same area
- Correlation of both techniques → identification of threading dislocations with screw component in apex of hillocks(white arrows) → hillocks form due to spiral growth different terrace width of hillocks → different GaN incorporation

→ cause of the observed variation in NBE intensity and emission energy

5. Cross-section



- Small increase in AlGaN NBE intensity along growth direction
- Triangular shaped variation of emission energy → higher GaN% → caused by step bunches of AlN template [6]
- Increase in AlN intensity after coalescence → increased crystalline quality

Conclusion

Morphology:
- Change in morphology (spiral growth to step bunches) is due to variation of substrate miscut

Luminescence Properties:
- Defect luminescence changes with doping, self compensation identified by V_{III}^{3-} peak
- Morphology strongly influences luminescence properties due to compositional inhomogenities

Defects:
- Dislocation clustering is caused by the template, Strong effect on luminescence properties
- Hillocks are caused by threading dislocations with screw component

Citations

[1] F. Mehnke et. al. Appl. Phys. Lett.103, 212109 (2013)
[2] K. Nam et. al. Appl. Phys. Lett. 86, 222108 (2005)
[3] D. Hevia et. al. Phys. Rev. B 88, 085202 (2013)
[4] A. Mogilatenko et. al. Journal of Crystal Growth 402 (2014) 222
[5] C. Trager-Cowan. et al., Phys. Rev. B 75, 085301 (2007)
[6] U. Zeimer et. al. Journal of Crystal Growth 377 (2013)

Acknowledgements

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