Optical and structural properties of semipolar GaN on patterned Si substrates

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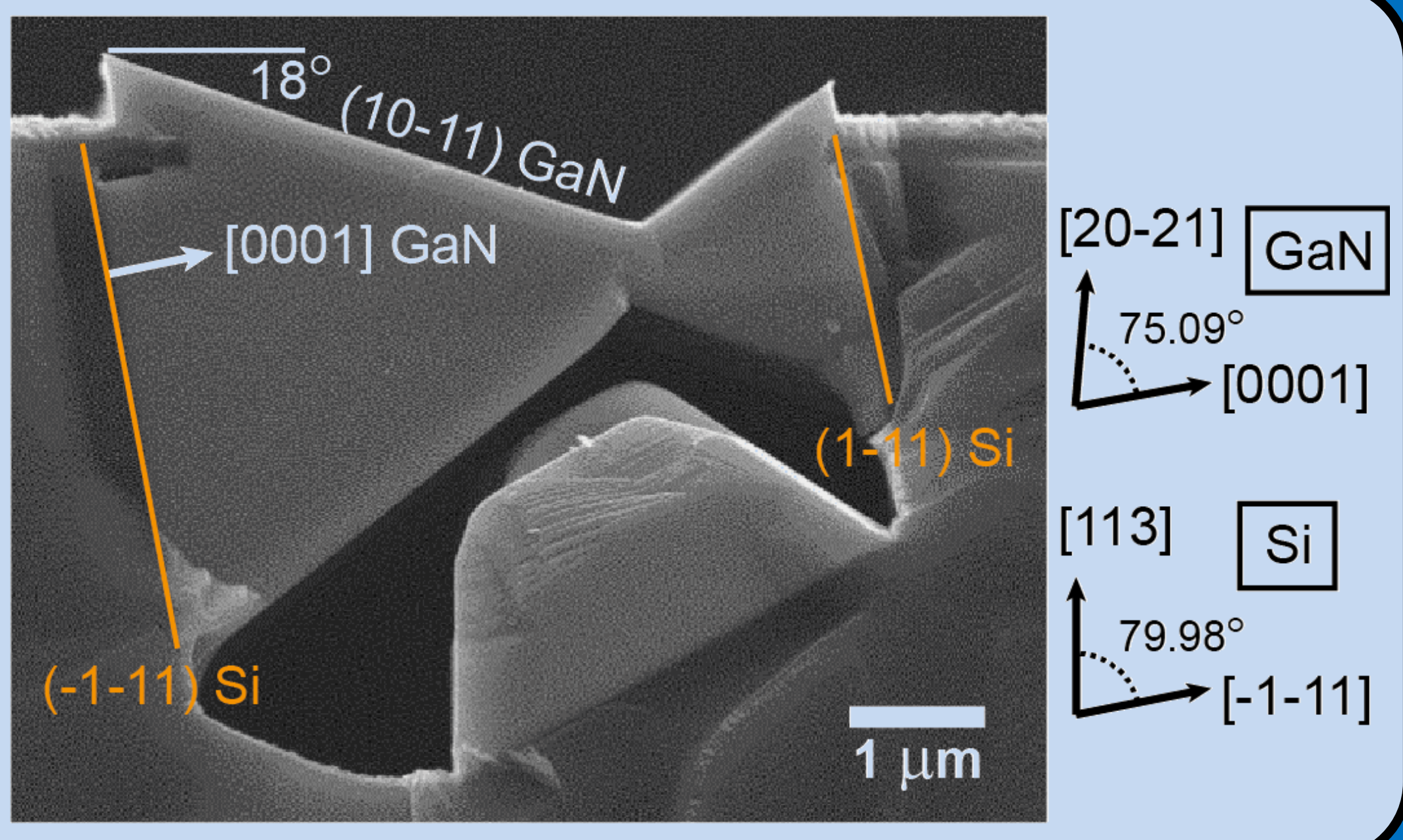
Introduction and motivation

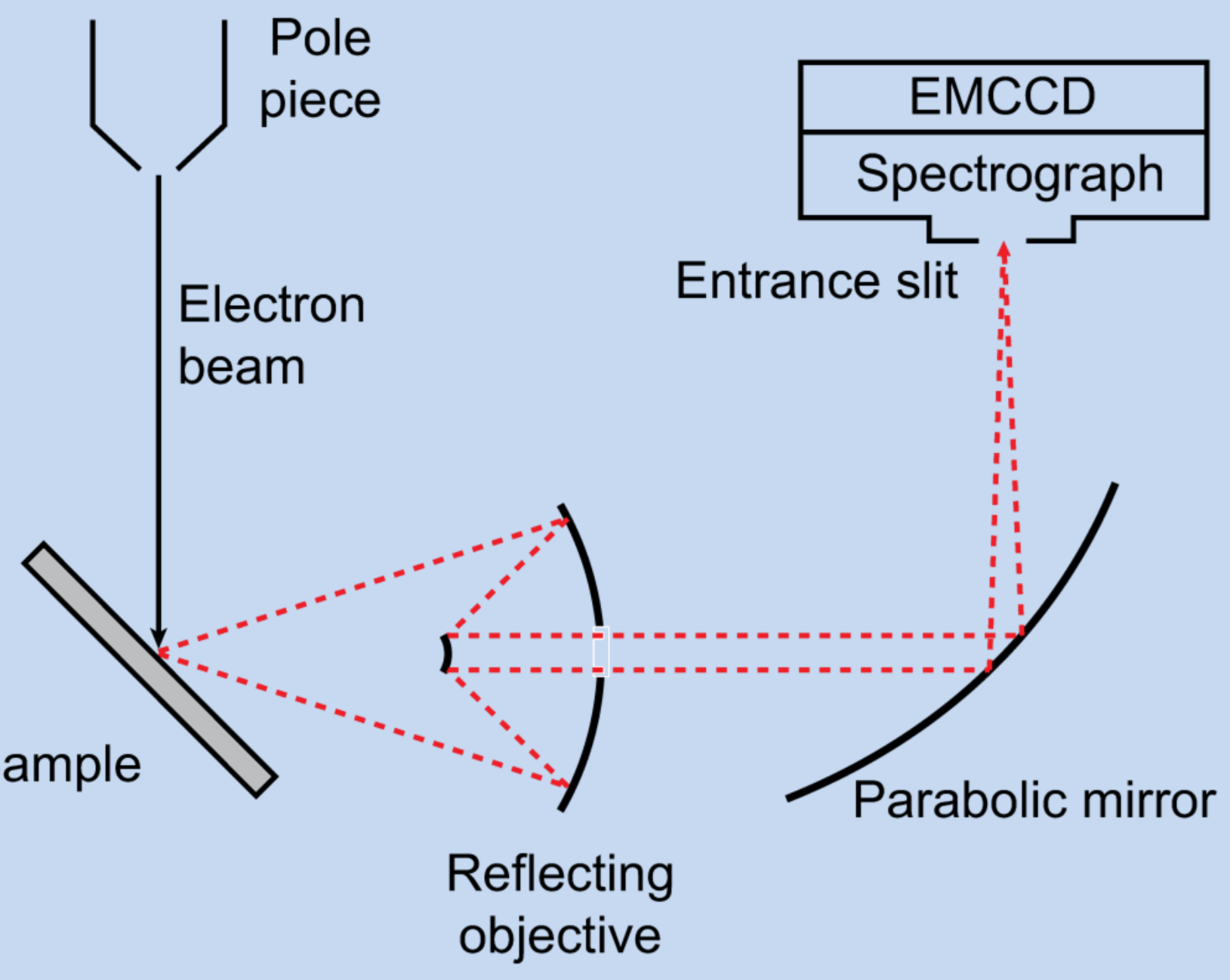
- Growth on Si offers low cost and integration into well-established Si-based integrated circuit technologies (CMOS drivers for LEDs)
- Patterning of Si substrates makes semi-polar planes accessible for reducing built-in electric fields for longer wavelength emitters
- Wafer scalability: availability of large Si wafers makes it possible to increase the usable area and reduce processing costs using Si fab lines
- However, several issues with Si as the substrate exist, such as substrate oxidation, Ga melt-back etching, wafer bowing and cracking due to large difference in thermal coefficients and high defect densities due to lattice mismatch between GaN and Si

Sample growth and fabrication

- (113) Si is patterned into stripes (width: 5.5 µm, depth: 4.5 µm) and anisotropically etched using KOH to reveal {111} Si facets
- MOCVD growth: (0001) GaN growth is initiated on the {111} Si facets until the growth fronts from opposing facets meet
- On the top surface a 5 period InGaN/GaN multiple quantum well structure is grown emitting at 470 nm
- Crystallographic orientations were determined using high resolution X-ray diffraction



Cathodoluminescence (CL) hyperspectral imaging



- CL imaging is a powerful technique to investigate the luminescence behaviour of sample features and defects
- The electron beam is scanned across the sample surface while simultaneously acquiring an entire room temperature CL spectrum at each pixel, resulting in a multi-dimensional (hyperspectral) data set
- Numerical peak fitting can be applied to each spectrum in order to extract 2D maps of parameters such as peak energy, peak intensity or line width

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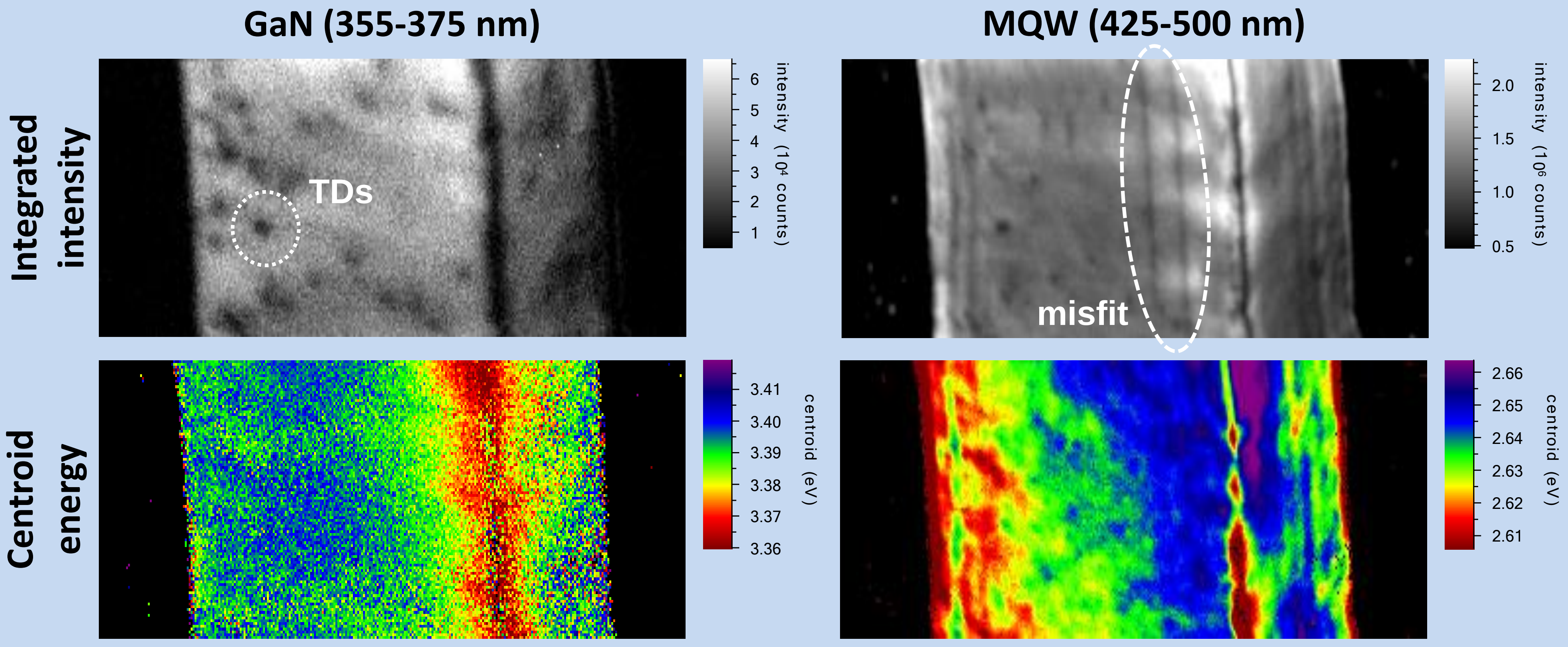
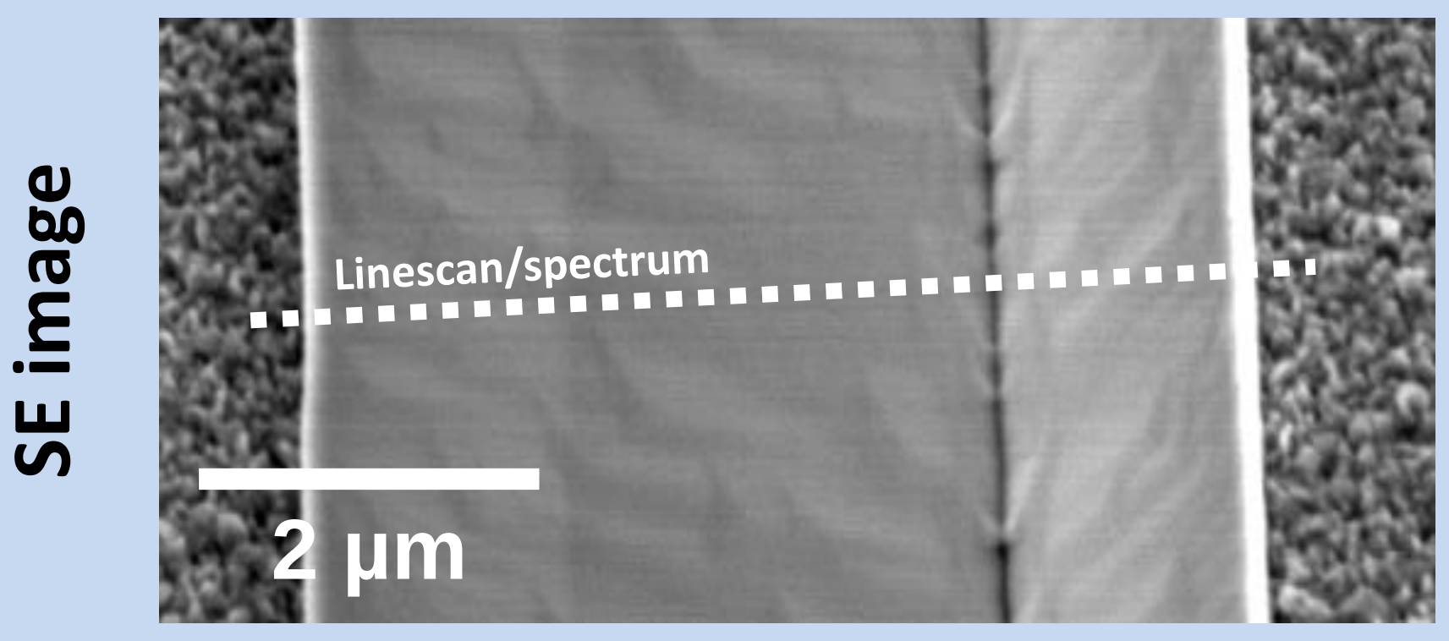
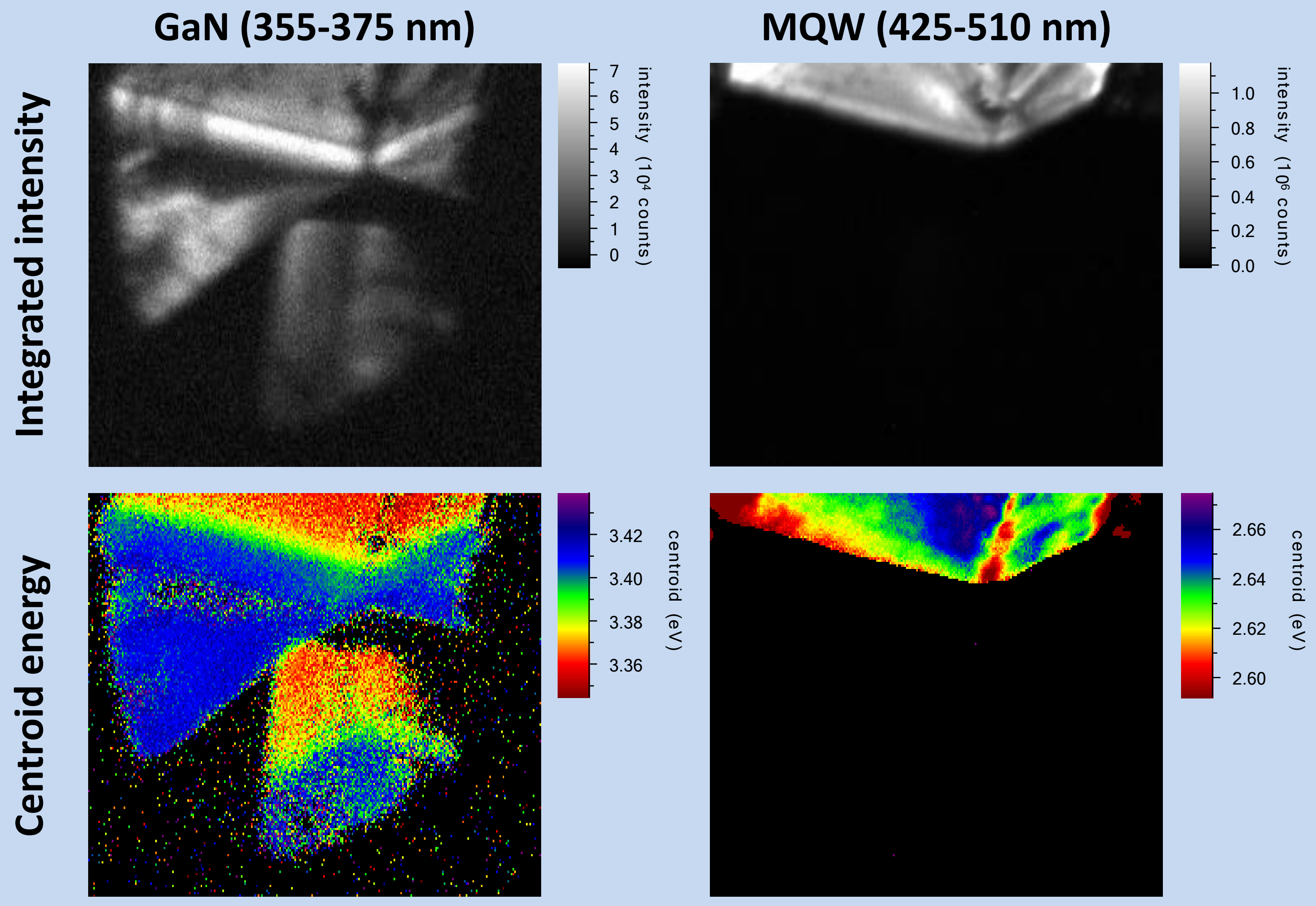
Plan-view CL imaging

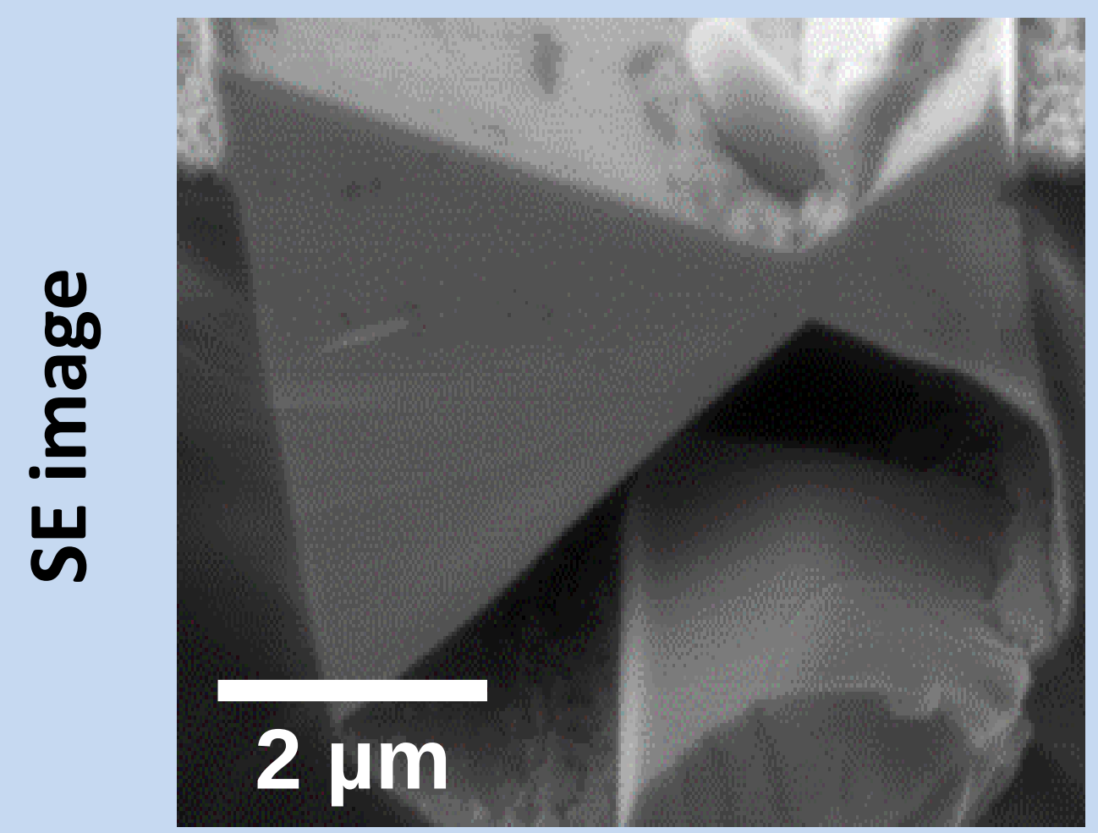




- GaN intensity image shows dark spots associated with non-radiative recombination at threading dislocations (TDs)
- The join of the bow-tie where the two +c-growth front meet also appears darker
- GaN energy is redshifted at the join, possibly related to a change in strain when the growth fronts meet
- MQW intensity is fairly uniform except at the join
- MQW intensity map also shows faint dark lines which can be associated with non-radiative recombination at misfit dislocations introduced during the growth of the MQW structure
- The MQW emission also exhibits modes superimposed on the emission peak, which are interrupted by the misfit dislocations as shown in the spectrum and line spectrum on the right

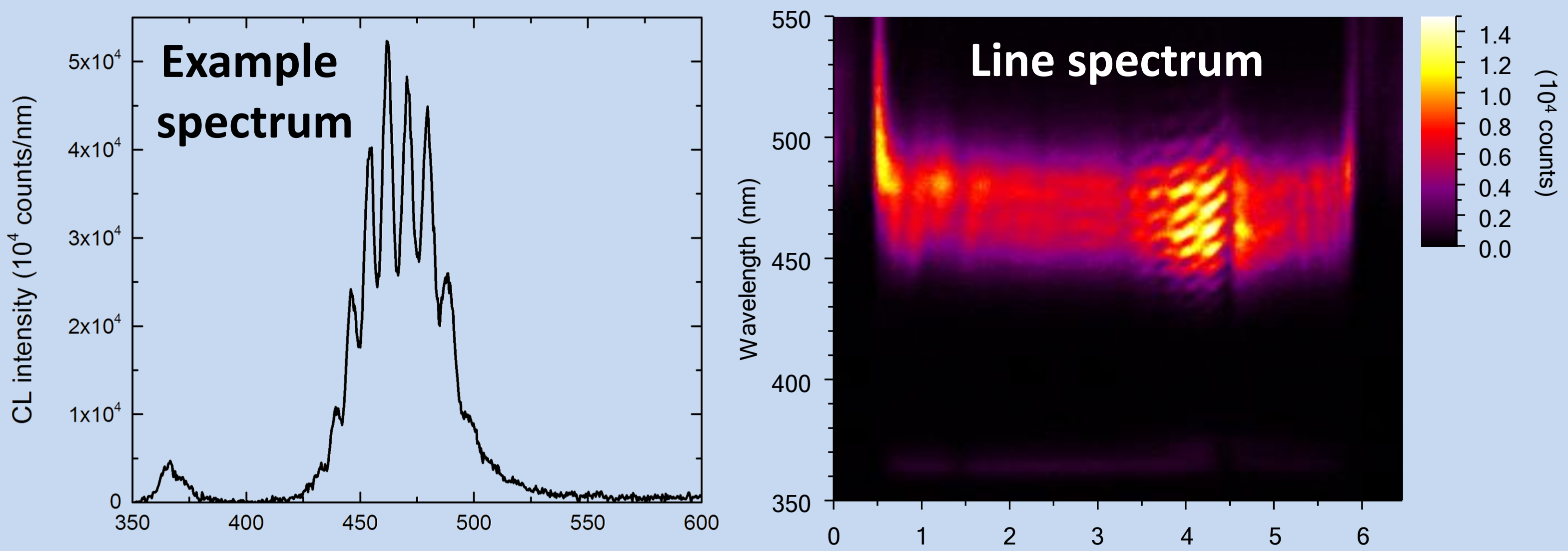
Cross-section CL imaging



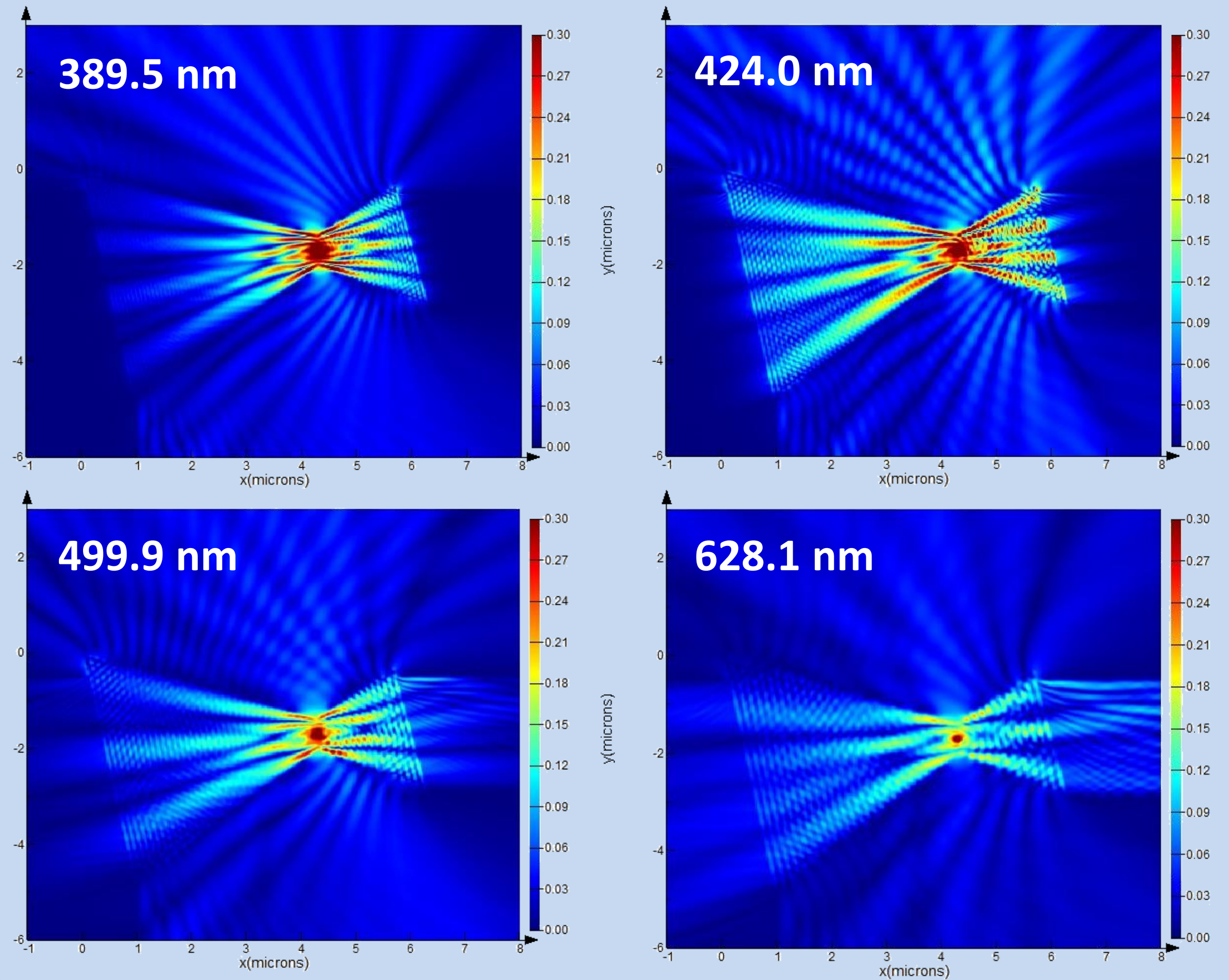


- GaN intensity image shows TDs coming up to surface through the structure
- GaN energy is redshifted at the top due to self-absorption of the emission at the surface due to measurement geometry
- MQW peak only present at the surface of the structure since the MQW is grown after the GaN structure has coalesced

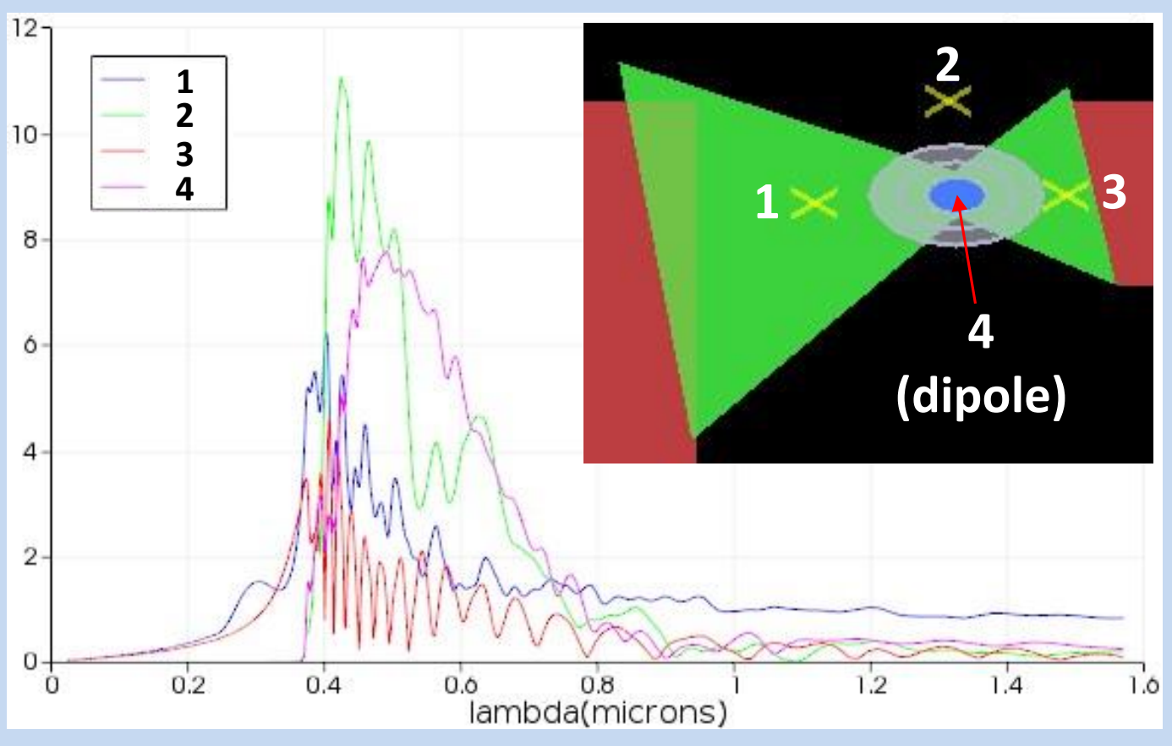
Optical modes



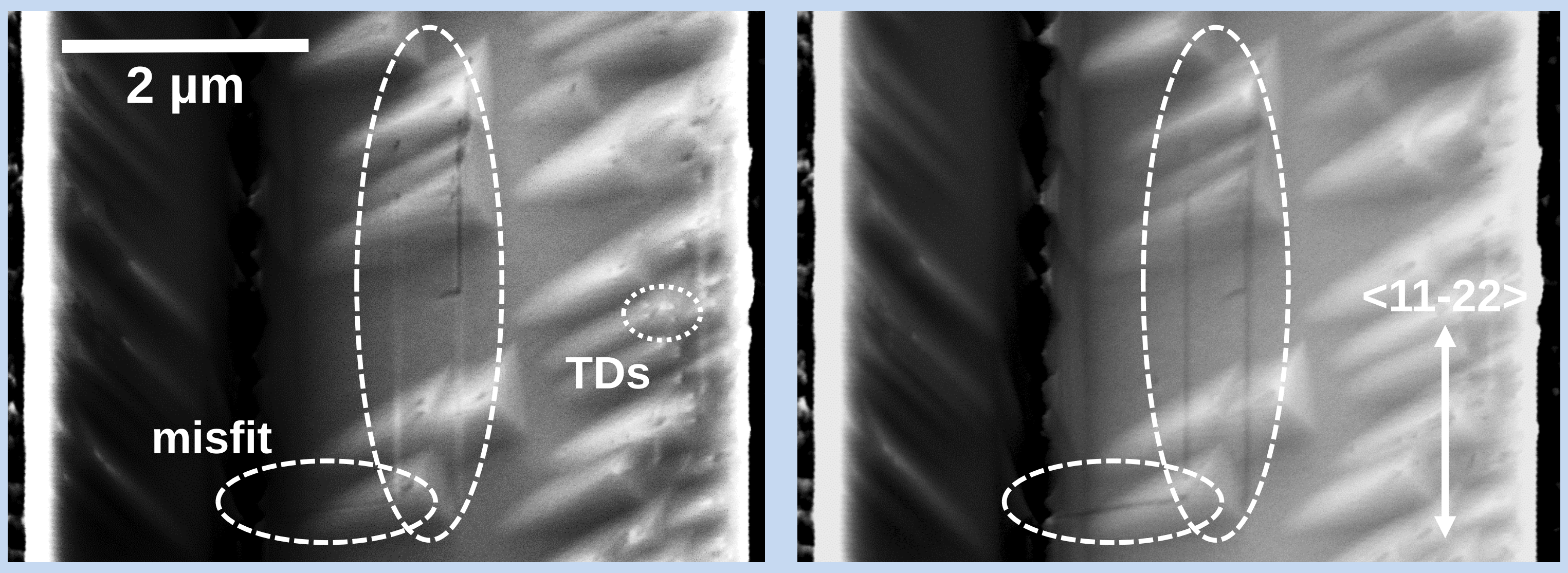
Finite-difference time-domain (FDTD) simulations



- 2D FDTD simulations with dipole at the join of the bow-tie structure
- Fabry-Perot type resonances are observed from the sidewalls of the grooves of the patterned Si
- The calculated cavity length is approximately 5 µm matching well with the width of the Si groove



Electron channelling contrast imaging (ECCI)



- In ECCI, crystal imperfections and changes in local strain are revealed by variation in the intensity of the backscattered electrons of a suitable-orientated sample with respect to the incident electron beam
- In addition to TDs, misfit dislocations running parallel to the sample surface can be seen in ECC images; the misfit dislocations appear to be located at the MQW interfaces as they are only observed in the MQW CL intensity images

Summary

- Semi-polar InGaN/GaN MQWs on GaN on Si substrates show emission at about 470 nm
- MQW emission exhibits optical modes originating from Fabry-Perot resonances from the Si sidewalls
- Threading and misfit dislocations are revealed in ECCI and correlate to dark spots and lines in CL intensity images where non-radiative recombination occurs at these extended defects

Acknowledgements

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