Structural and optical characterisation of coreshell InGaN/GaN microtubes emitting in the green spectral range

G. Kusch[1*], P. R. Edwards[1], E. Le Boulbar[2], P.-M. Coulon[2], P. A. Shields[2], R. W. Martin[1]
[1] Department of Physics, SUPA, University of Strathclyde, 107 Rottenrow East, Glasgow G4 0NG, United Kingdom
[2] Department of Electronic and Electrical Engineering, University of Bath, Bath BA27AY, United Kingdom
*Gunnar.kusch@strath.ac.uk

University of Strathclyde Glasgow

UNIVERSITY OF BATH

Motivation

Micron and nanoscale structures based on the group-III nitrides have received significant attention due to a wide range of possible applications as photonic devices. Their high surface to volume ratio, their tunable bandgap, low defect density, strain free surface and chemical stability makes these structures particularly suited for biomedical sensing applications. Most of the recent research efforts focused on nanorods and more recently on core-shell nanorods due to their easy access on non-polar orientations. Another possible geometry for these nanoscale structures are nanorods with a hollow core (microtubes), which provide additional control over possible optical cavity modes, by prohibiting modes travelling through the core of the structure. This paper reports on the characterisation of microtubes fabricated by Talbot displacement Lithography to define the ring pattern, ICP etching to define the height of the structures and subsequent regrowth to deposit the core-shell quantum wells.

Overview

Sample details

Template:

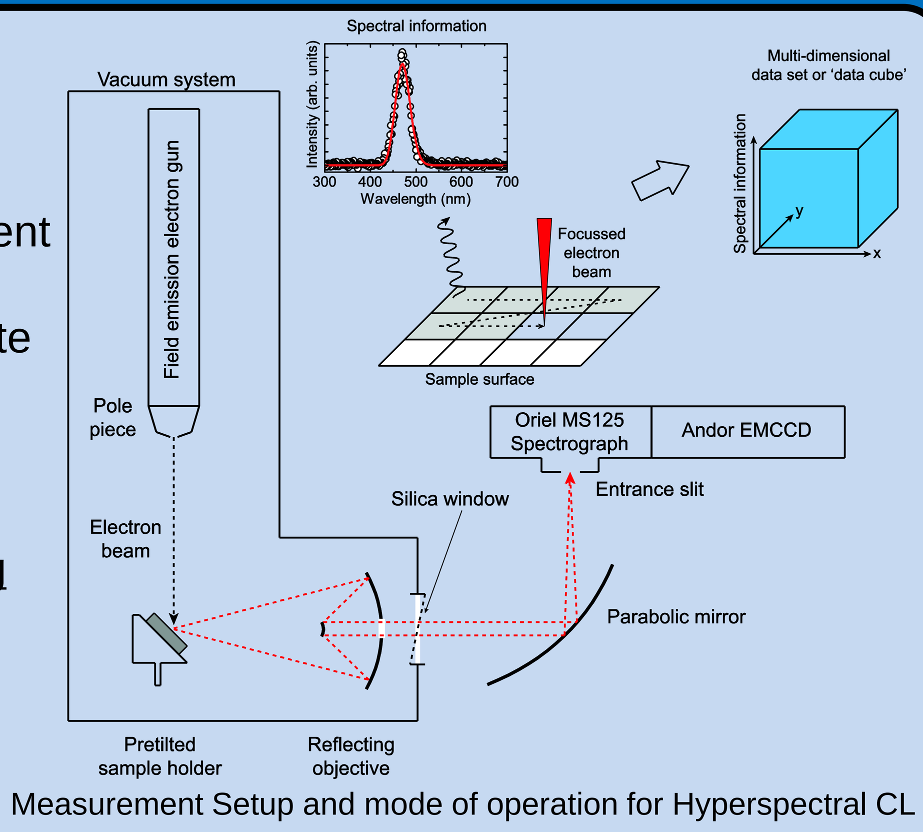
- GaN on Si patterned by Talbot Displacement Lithography (TDL)
- ICP etching to generate microtube template

Regrowth in MOVPE:

- 10 min GaN faceting at 920ºC
- Growth of InGaN/GaN shell

Cathodoluminescence hyperspectral imaging

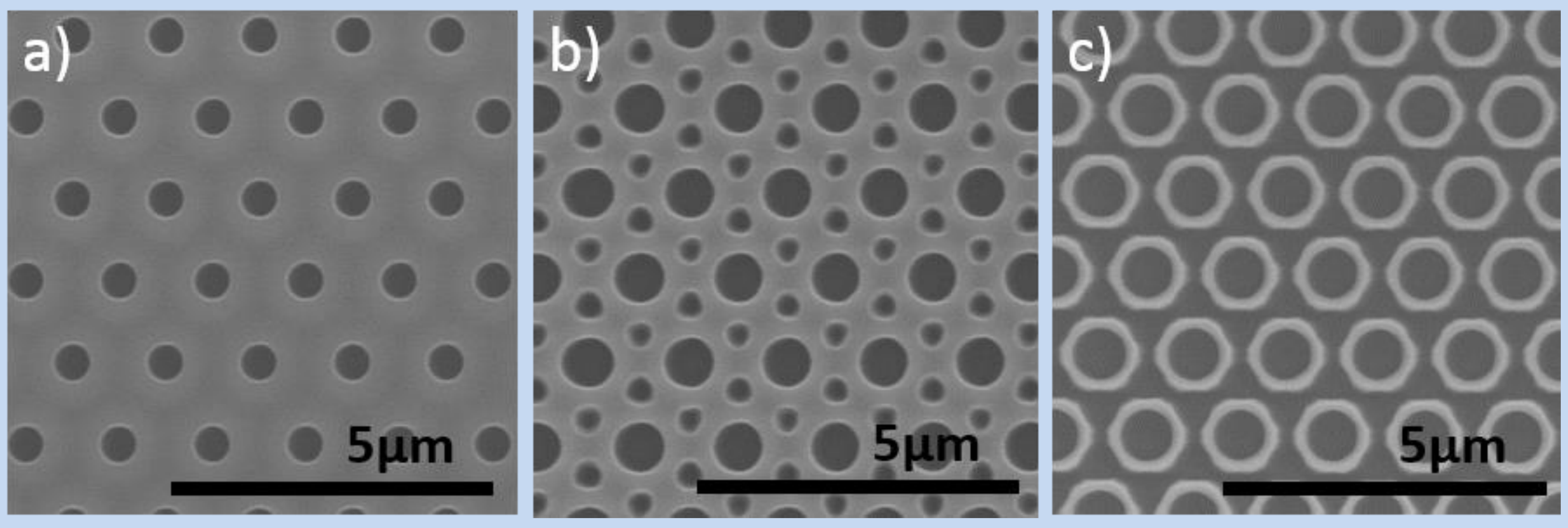
- All measurements at room temperature
- 5 kV acceleration voltage
- ~ 100 nm penetration depth according to Monte Carlo simulations



Measurement Setup and mode of operation for Hyperspectral CL

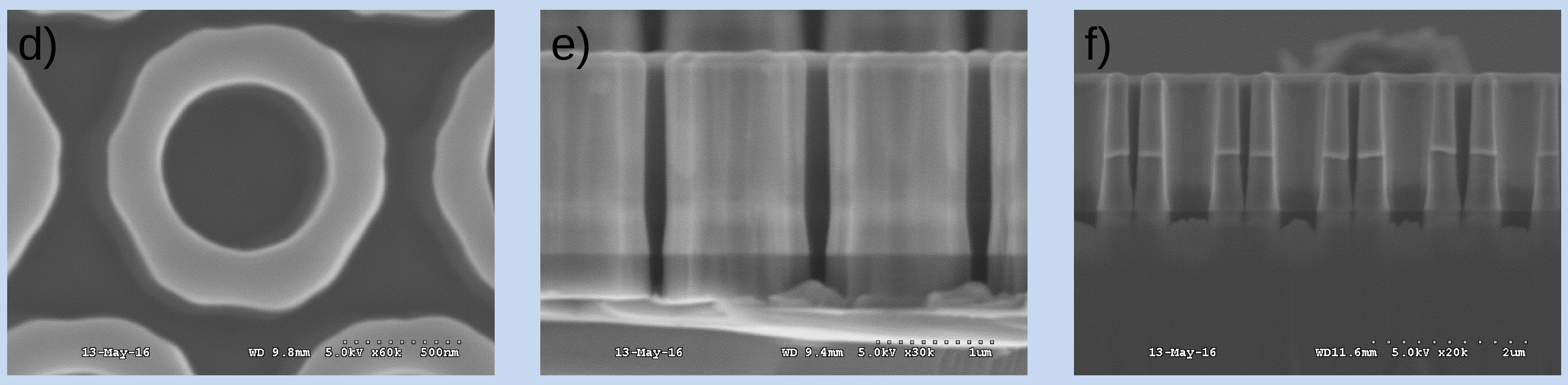
Template

Displacement Talbot Lithography



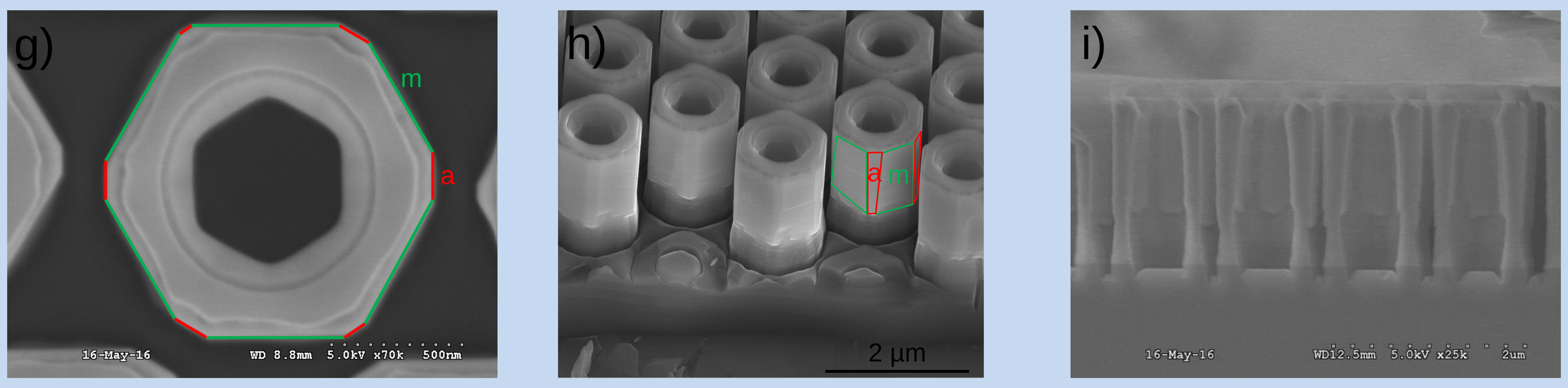
- Exposure of deposited resist by TDL system through 1.5µm hexagonal mask with 800nm diameter holes[2]
- Overexposure creates secondary pattern that eventually merges and creates rings
- Exposure dose: (a) 100mJ/cm^2; (b) 200mJ/cm^2; (c) 480mJ/cm^2

Microtube template

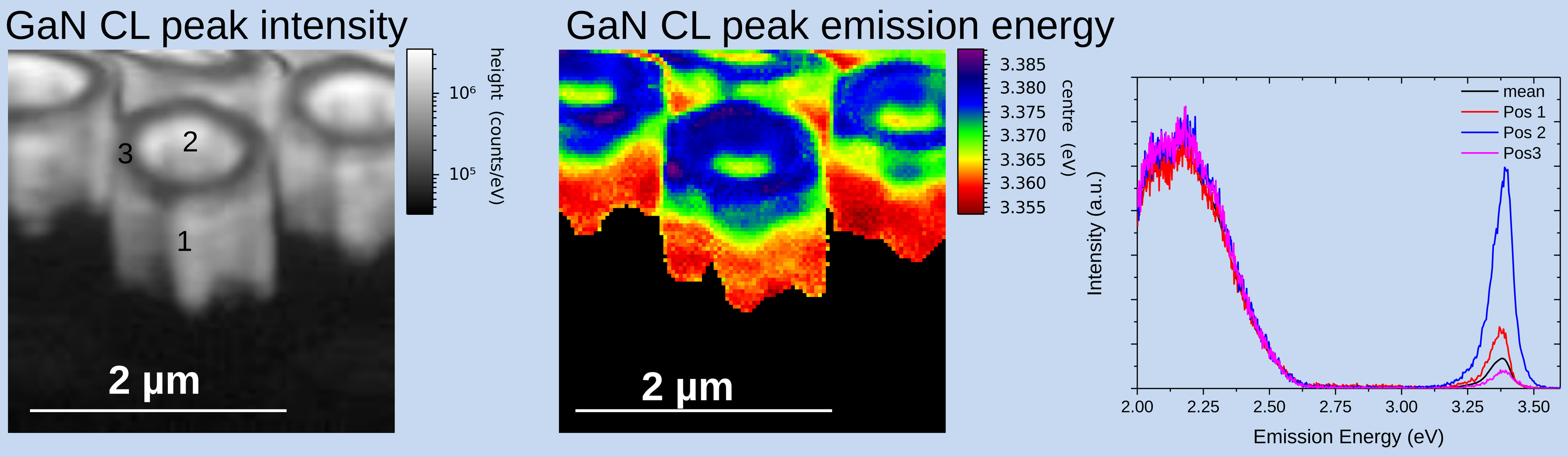


- ICP Cl_2/Ar etching through mask generated by DTL to create GaN microtubes
- Smooth circular inner sidewalls with a diameter of about 850nm
- Faceted outer sidewalls, facets are due to merging of secondary DTL pattern

GaN regrowth

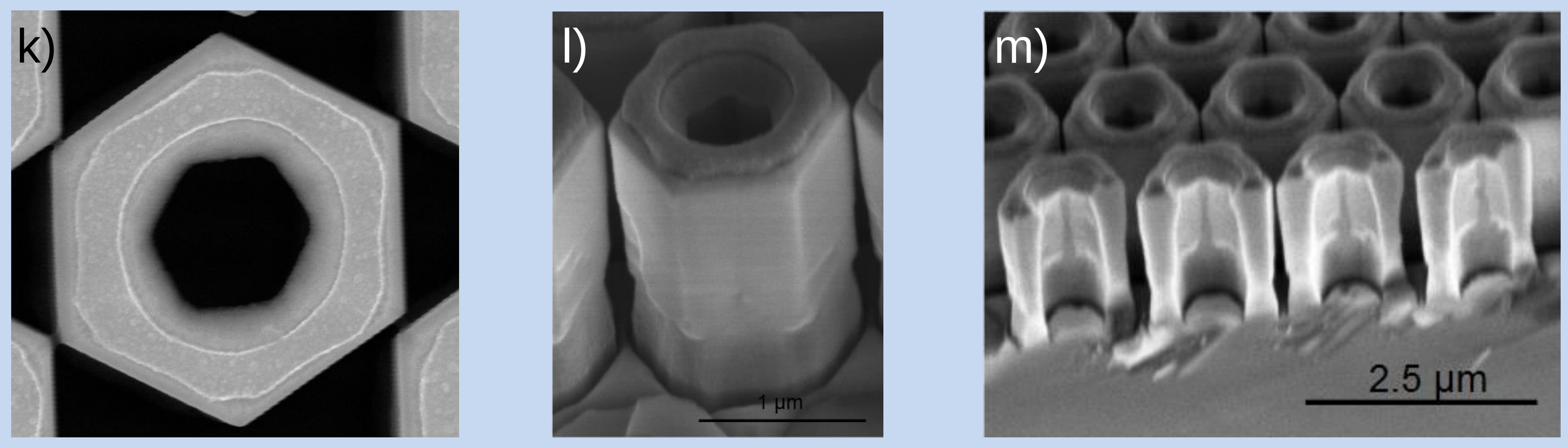


- GaN regrowth by MOVPE, 10min at 920ºC, with SiN_x cap to prevent vertical growth
- Formation of clear *a* and *m*-plane facets on the outer microtube sidewalls
- Faceting on inner sidewalls, emerging *a*-plane and {11-22} facets



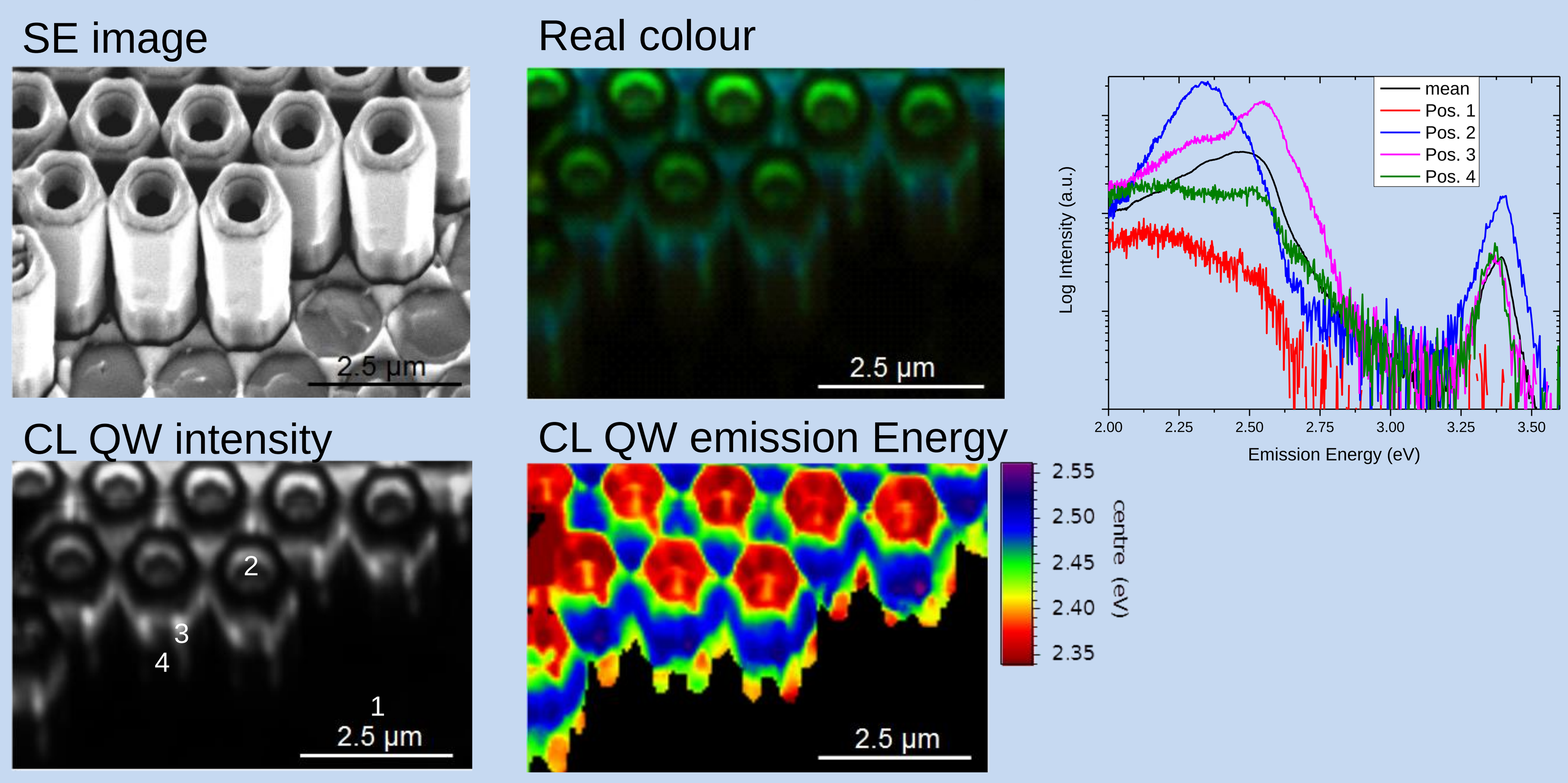
- CL hyperspectral imaging on centre of image (h)
- High CL GaN NBE peak intensity and best GaN/YL ratio on inner *a*-plane facets
- Low CL signal on microtube top due to SiN_x mask
- Low GaN intensity variation on outer sidewalls with slight increase on *a*-plane facets
- Increase in emission energy of about 30meV from bottom to top of microtube

InGaN/GaN coreshell microtubes

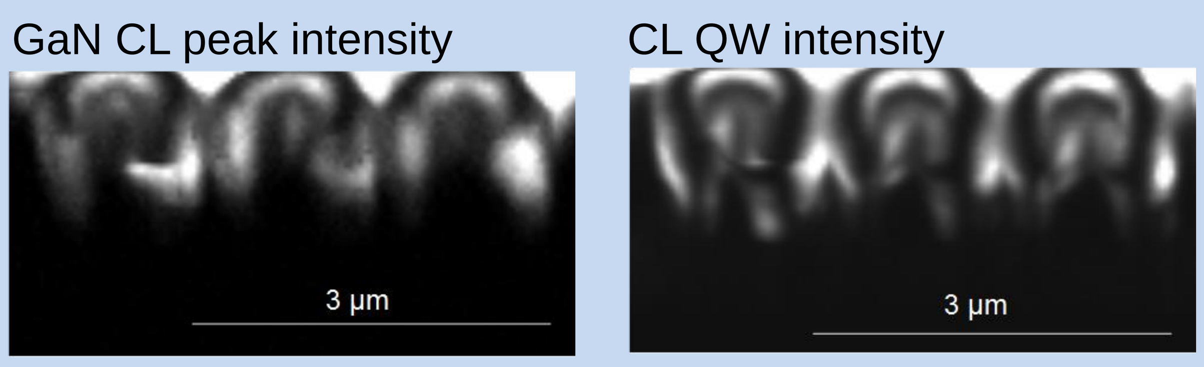


- Smooth outer *m*-plane sidewall morphology, no a-plane facets on outer sidewall
- Inner sidewall *a*-plane facets not coalesced, enhanced growth of {11-22} facets

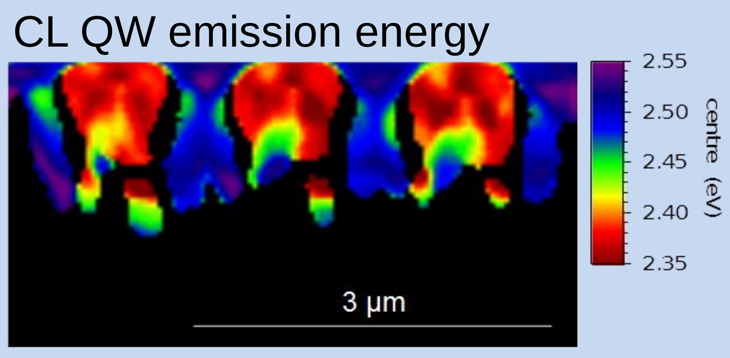
→ Morphology determined by growth speed of facets on concave and convex growth fronts; convex: low speed dominant, concave high speed dominant[3]



- QW peak emission in the turquoise to green spectral range
- Inhomogenous InN composition in QWs on outer shell (Pos. 3&4), higher emission energy on ridges between *m*-plane facets indicating higher InN% on *a*-plane facets
- Emission enertgy shift of ~150meV from bottom to top of microtube
- Inner QW (Pos. 2) redshifted compared to outer QWs, indicating enhanced InN%



- CL hyperspectral image on centre of image (m)
- GaN NBE shows similar behaviour to regrowth sample



- QW peak intensity shows clear distinction between outer and inner QW
- QW emission energy shows strong variation (~200meV) for inner QW
- *a*-plane facets show lower InN incorporation, caused by shadowing effect of {11-22} facets

Conclusion

- Produced microtube template by DTL and ICP etching
- Merging of secondary DTL pattern causes formation of *a* and *m*-plane facets
- *a*-plane facets on outer sidewall influence InN incorporation during InGaN/GaN overgrowth
- Successful deposition of QW on inner and outer facets
- Inner QWs show strong emission energy variation due to morphology induced InN variation

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