Effect of growth methodology on the localisation environment of InGaN/GaN quantum wells

UKNC Conference Bristol 7/1/14

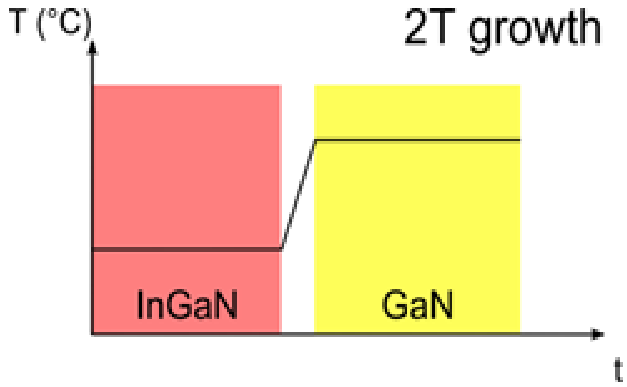
W.E. Blenkhorn[1], P. Dawson[1], F.C-P. Massabuau[2], M.J. Kappers[2], C.J. Humphreys[2] and R.A. Oliver[2]

william.blenkhorn@postgrad.manchester.ac.uk

[1]School of Physics and Astronomy, Photon Science Institute, University of Manchester, Manchester, M13 9PL, UK

[2]Department of Materials Science and Metallurgy, University of Cambridge, 27 Charles Babbage Road, Cambridge, CB3 0FS, UK

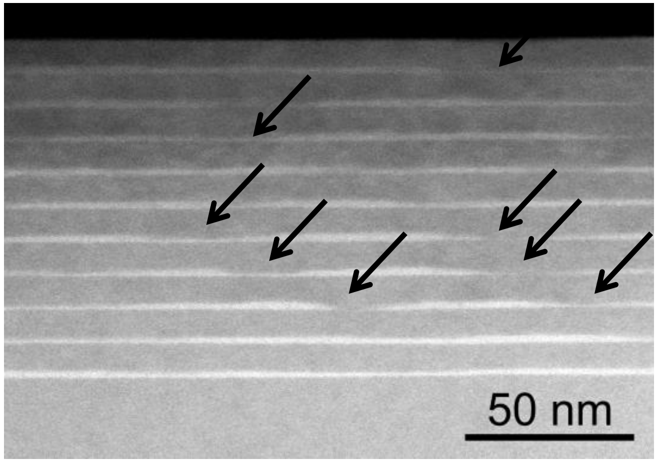
Two temperature (2T) growth



- The InGaN is grown at approximately 740°C (for Blue) followed by a temperature ramp for which ***no growth occurs*** up to 860°C for the GaN growth.

Consequences of growth: Exposure of InGaN to high temperatures during the temperature ramp leads to:

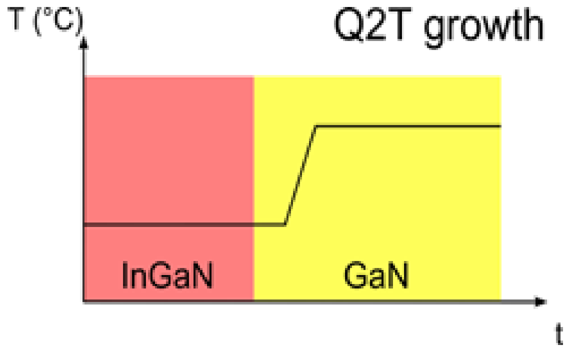
- Desorption of indium due to the weak In-N bond
  → Gross well width fluctuations (WWFs)



TEM Image of a typical 2T grown structure

Quasi-two temperature (Q2T) growth

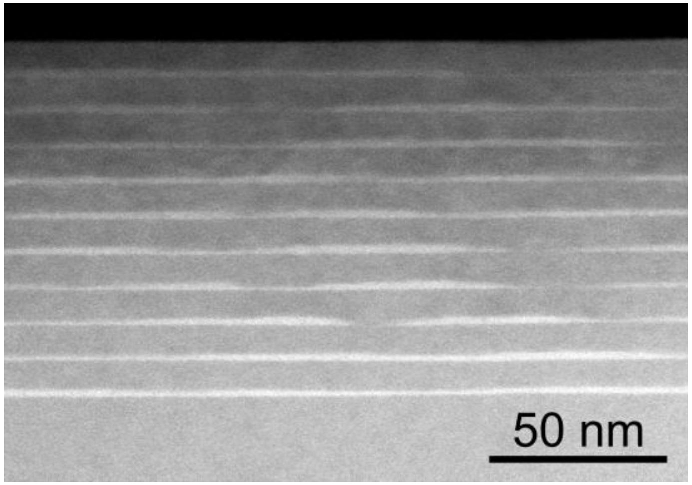
The InGaN layers are capped by a small GaN layer (~1nm) grown at the InGaN growth temperature.



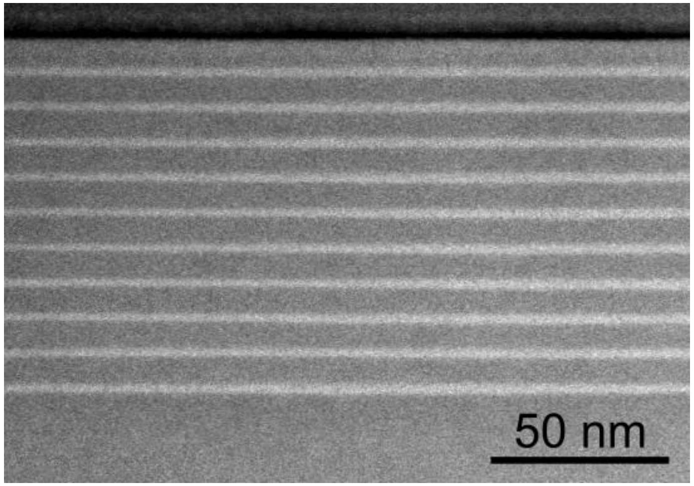
Consequences of growth:

- Less indium desorption
  → Reduction in gross well width fluctuations

Two temperature (2T)



Quasi-two temperature (Q2T)

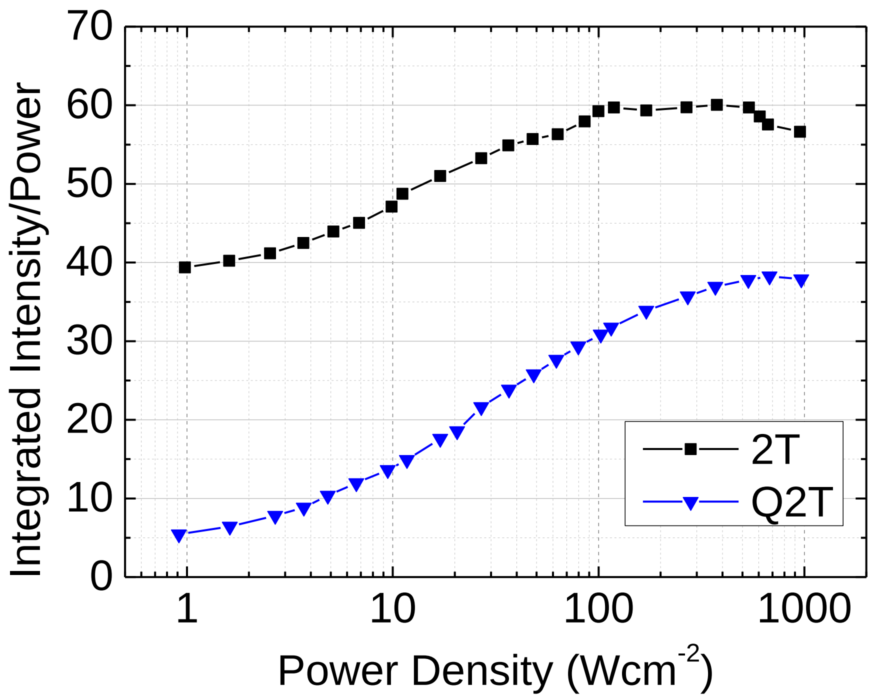


Optical performance comparison

Sample Details:

InGaN/GaN 10 QW structures deposited on GaN buffer layers which had been deposited on c-plane sapphire.

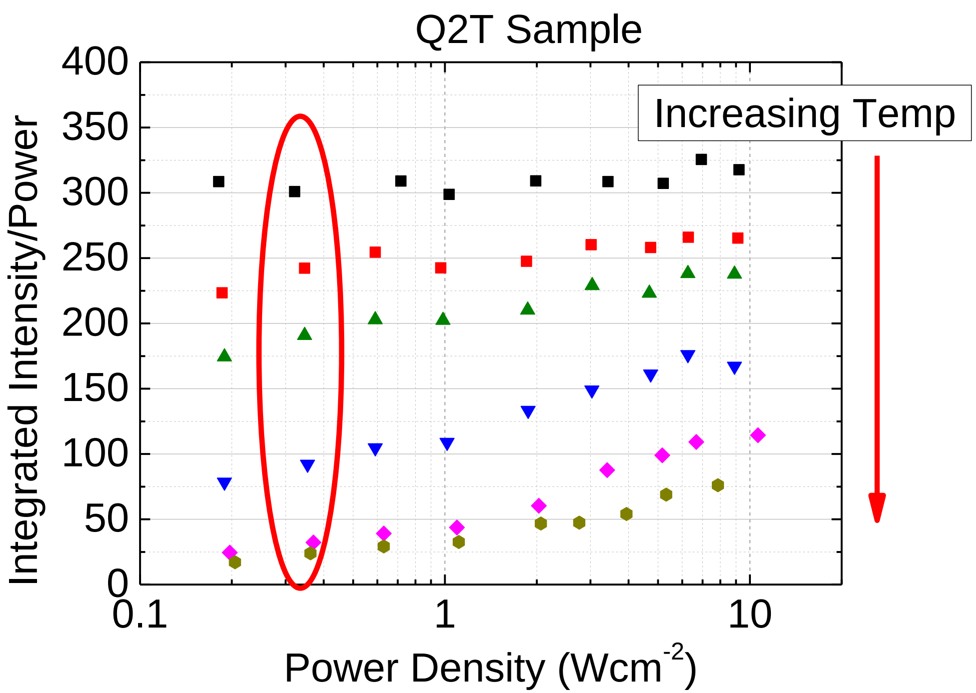
Dimensions: Nominally 2.5/7.5 nm well/barrier thickness   Indium Content: ~ 18%

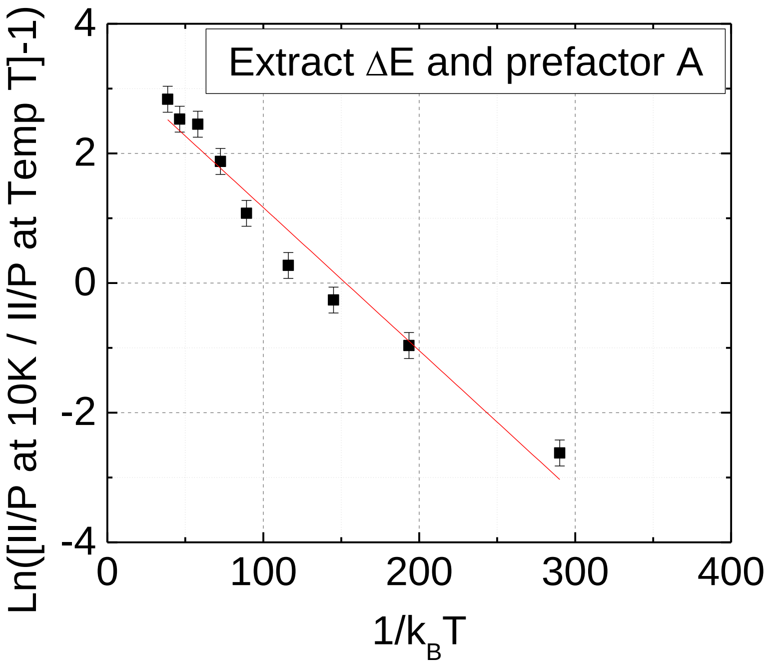


Typically 2T grown samples outperform Quasi-2T grown samples. **WHY?**

Thermal activation of non-radiative recombination

- Could this difference be due to defect density?





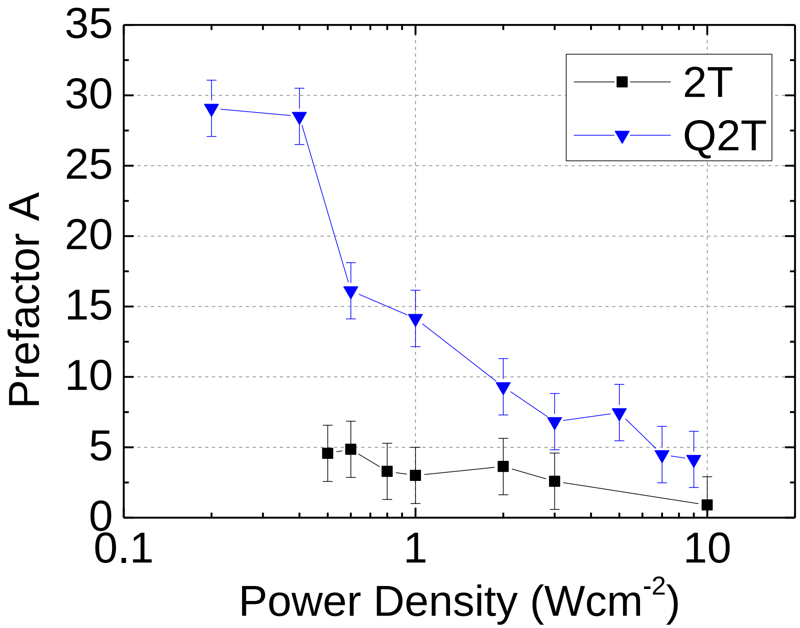
A simple Arrhenius model was used:

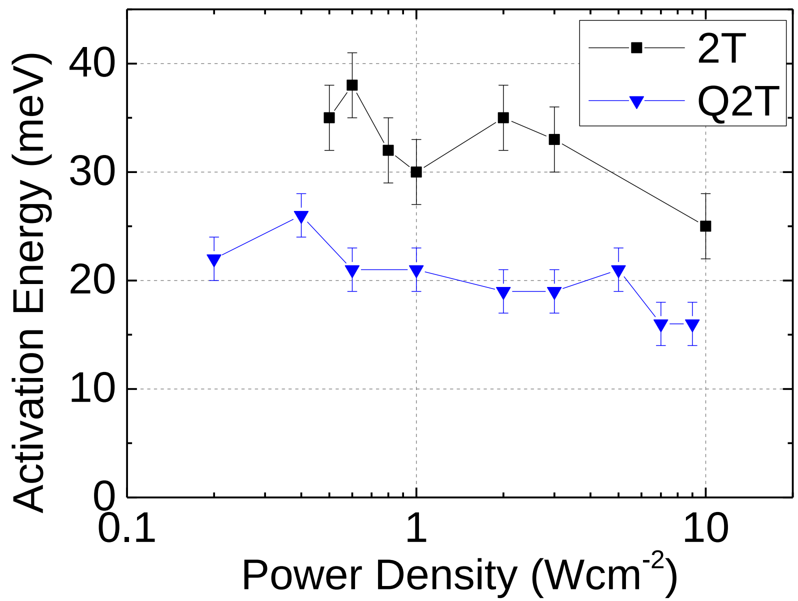
$$II/P(T) = \frac{II/P(10\ K)}{1 + Ae^{\frac{-\Delta E}{k_B T}}}$$

ΔE: Activation Energy

Prefactor A: Proportional to the defect density

2T vs Q2T





- Prefactor A larger in the Q2T samples.
  → Suggests that the defect density is higher.

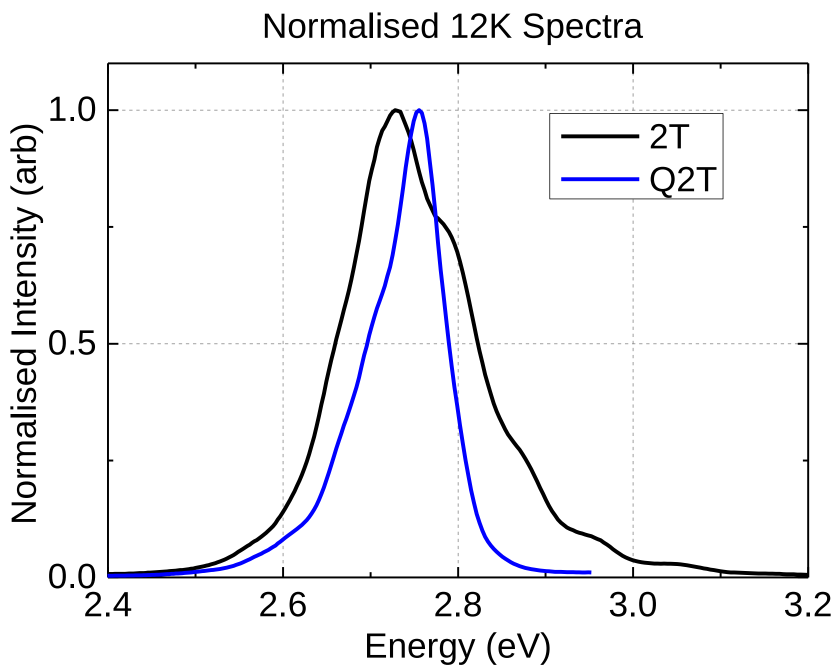
- 2T samples have a larger activation energy for non-radiative recombination compared to Q2T samples.

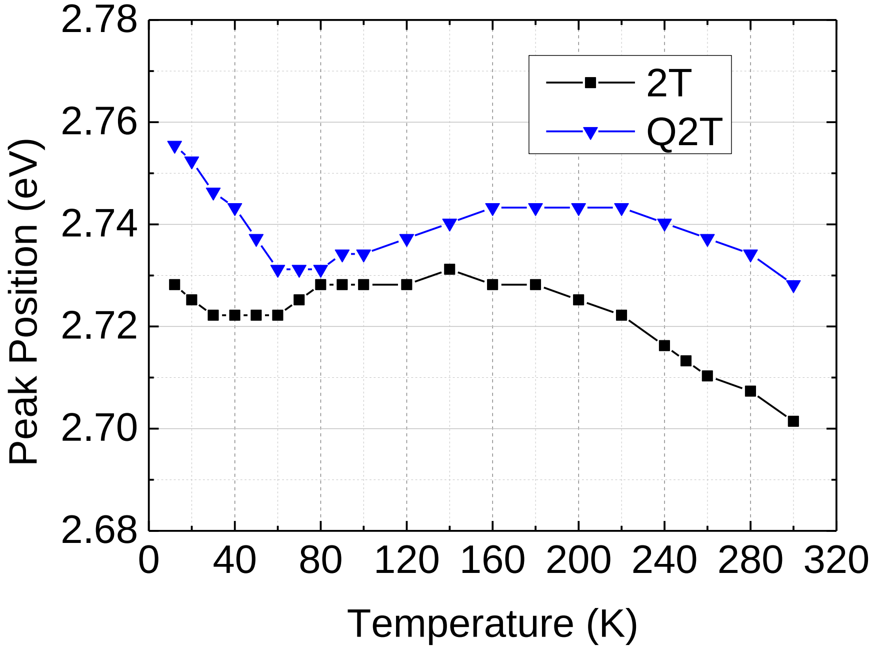
- Difference in activation energy could be due to:

1. Nanoscale localisation environment (nanostructure)
2. Gross well width fluctuations acting as an extra means of carrier localisation [1]

[1] N.K. van der Laak, *et al*, Appl. Phys. Lett. **90**, 121911 (2007).

S-Shape temperature dependence





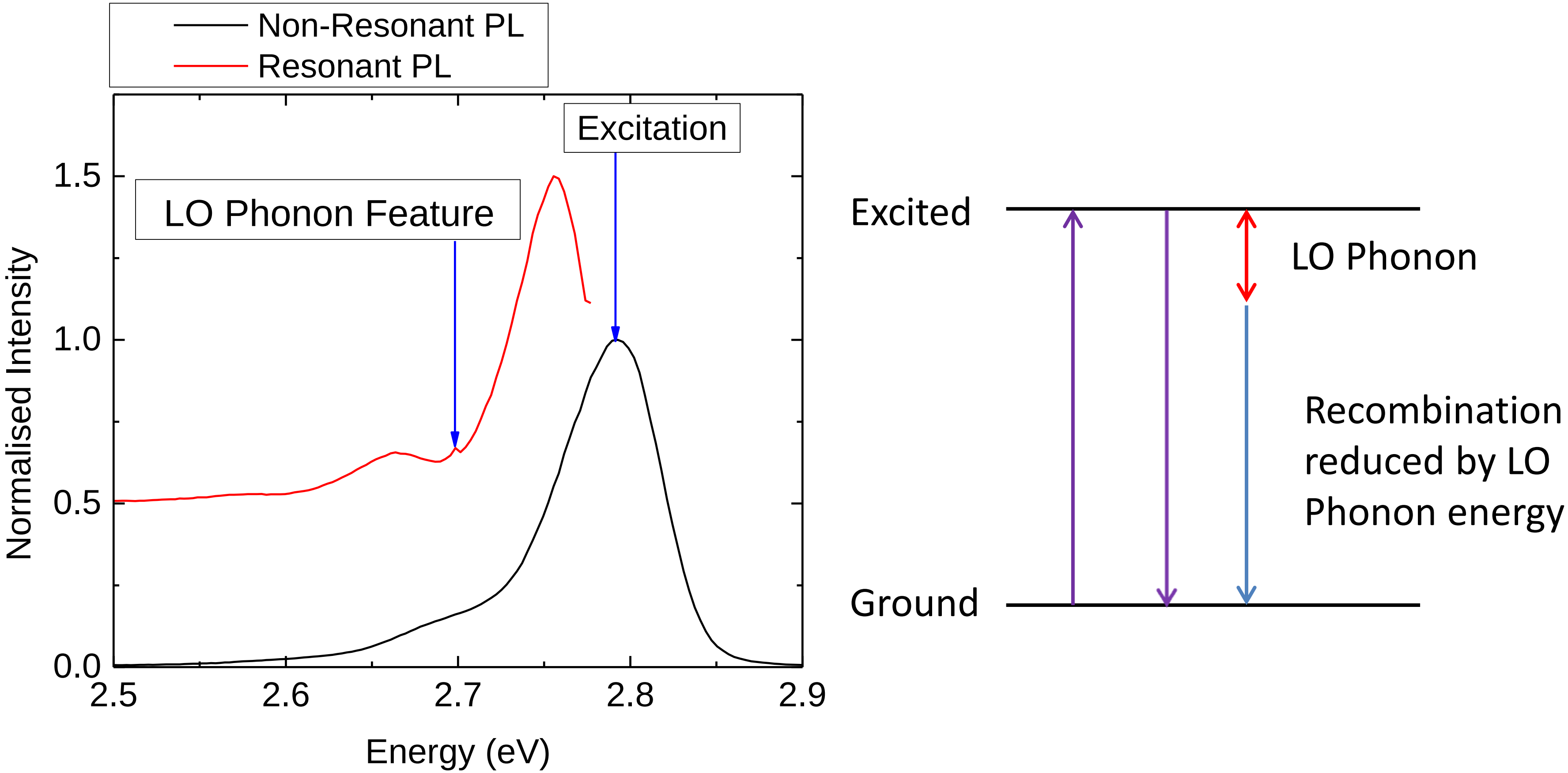
- S-shape of peak position with temperature is a key fingerprint of carrier localisation.
- Average localisation energies have been extracted previously from the S-shape temperature dependence of the peak position [2].
- No information could be extracted from our data due to the S-Shape being masked by the broadness of the spectra of the 2T samples.

[2] S. Hammersley, *et al*, J. Appl. Phys. **111**, 083512 (2012).

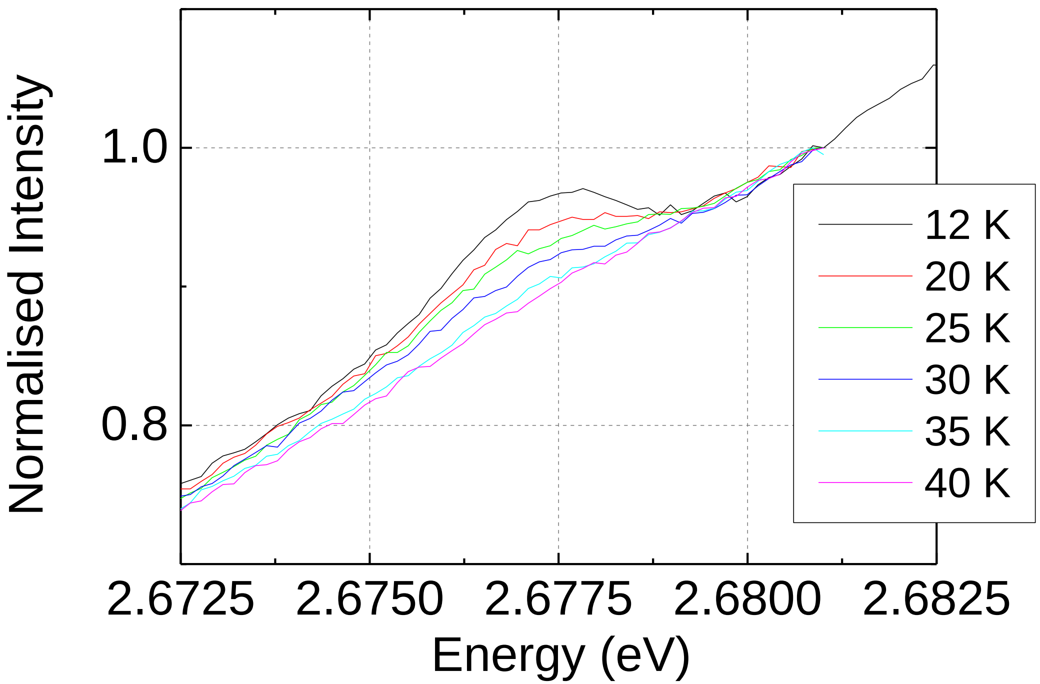
Resonant Photoluminescence Spectroscopy

- Can be used to look at the localisation environment of carriers inside the quantum well.

- Involves the direct excitation of ***subsets*** of the localised electron and hole states of the quantum well.

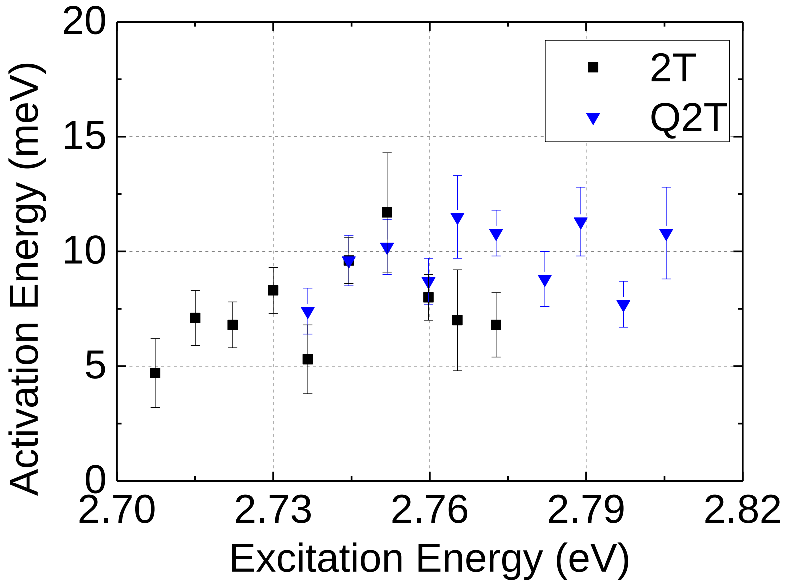


Resonant PL continued



- Arrhenius model used to extract an activation energy.
- Activation energy relates to the removal of the most weakly localised carrier from the resonant state, in the simple picture of ***independently*** localised electrons and holes.
- Excite across the QW lineshape to extract spectrally resolved activation energies.

Activation energies



- Activation energy is roughly a constant across the lineshape for both Q2T and 2T around 8 meV, which is much less than the FWHM of the spectrum.
- No difference in the nanoscale localisation environment between Q2T and 2T grown samples.
- Activation energy correlates with localisation energy of electrons due to alloy and well width fluctuations ~10 meV calculated by Watson-Parris [3].

[3] D. Watson-Parris, Carrier Localization in InGaN/GaN Quantum Wells, University of Manchester, 2011.

Conclusions

- 2T samples have a lower defect density compared to Q2T samples.
  → Based on the prefactor A calculated.

- 2T samples have a larger activation energy of non-radiative recombination pathways compared to Q2T samples.

- No observable difference in nanoscale localisation environment between Q2T and 2T growth methodologies.

  → Therefore gross WWFs may act to localise carriers away from non-radiative pathways on a larger length scale.

Acknowledgements

The University of Manchester
Photon Science Institute

UNIVERSITY OF CAMBRIDGE

Thanks to my colleagues at the University of Manchester and Cambridge for their help and input.

EPSRC
Pioneering research and skills

Thanks to the EPSRC for funding our research.

Thanks for listening