PHOTOLUMINESCENCE MAPPING OF InGaN/GaN QUANTUM WELL SAMPLES AND LEDS

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Motivation

Photoluminescence (PL) spectroscopy is a useful method for characterising semiconductors, in this case the group III-nitrides, which have high luminescence efficiency but are also rather inhomogeneous [1]. It can provide information on bandgap, structural properties, defects and internal quantum efficiencies (IQE) of the material under study. It has advantages over other techniques as it is non-destructive, requires no sample or environment preparations and allows for selective excitation. Combining PL spectroscopy with spatial resolution and mapping will give a deeper insight into the materials properties and behaviour. Our aim is to do micro-PL mapping with a near diffraction limited laser spot size to produce high resolution PL maps. By performing these maps at both room temperature and low temperature we aim to achieve mapping of the internal quantum efficiency (IQE) by taking the ratio of the maps peak intensities. This novel characterisation method will allow us to look at the homogeneity of the IQE over areas of varying dislocation densities and other features. In this work we present our PL mapping system design and our investigation, at both room and low temperature, of InGaN/GaN quantum well (QW) LED samples grown by two different methods. Progress towards IQE mapping is also presented.

System Set up

- With this custom system design (Fig 1) the main advantage is that we can look at the laser spot on the sample which gives us control over the areas we want to map.
- Having the positioners within the cryo-chamber allows low temperature mapping.

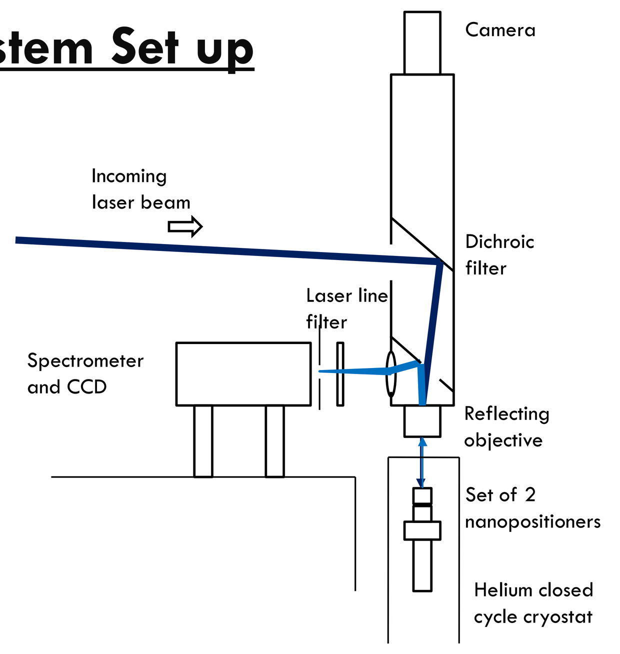

Figure 1: Schematic of set up

Nanopositioners Operation and Hyperspectral Imaging

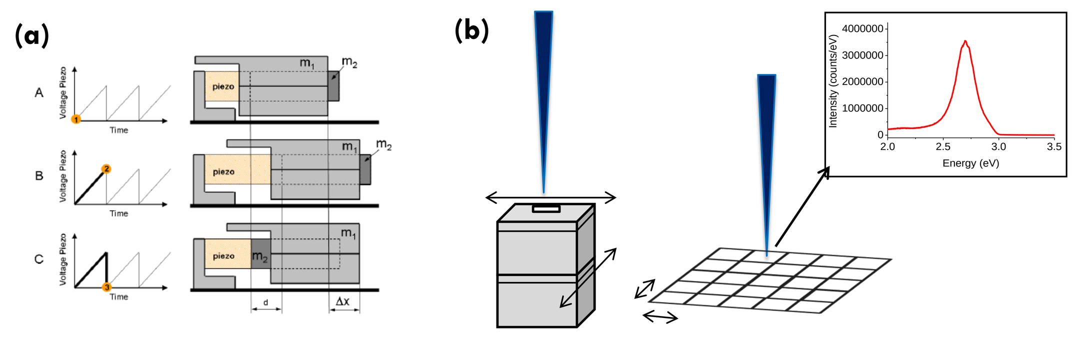

Figure 2: (a) Operation of piezoelectric "slip-stick-drive" designed nanopositioners. (b) Representation of hyperspectral imaging by collecting a spectrum at each step of the nanopositioners.

- Voltage and frequency selection drives the positioners movement to a desired distance (Fig 2(a)).
- Using this movement for both positioners (x and y) we can scan the sample using the laser.
- For each step of the positioners a spectrum is acquired (Fig 2(b)).
- This builds up a hyperspectral image or PL map [2].

Limiting Factors

- Laser quality – single mode 17mW 325nm HeCd TEM_{00} laser.
- Lens - 0.5NA reflecting objective aids spot size reduction and chromatic aberration.
- Beam expander - expands beam to fill reflecting objective to help obtain small spot size but can cause loss of power and scatter.
- Helium cold stage - causes vibration and drift.
- Nanopositioners - errors in reproducibility and variability.

Sample Details

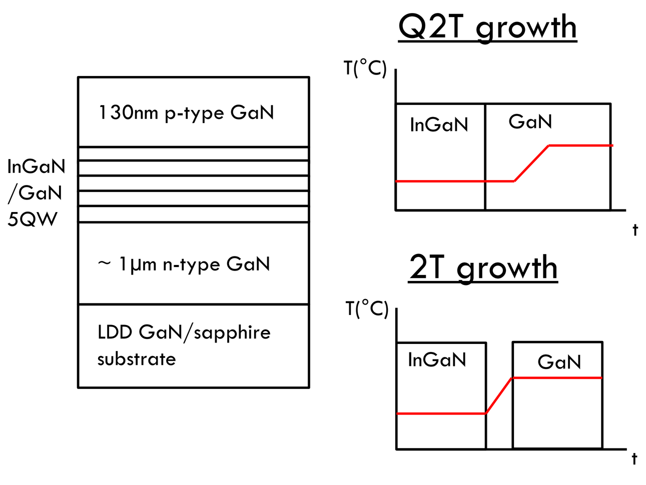

Figure 3: LED design with growth method shown for each of the two samples.

- These LED samples were grown by at University of Cambridge using the design shown in Fig 3 and fabricated at University of Bath.
- Q2T growth - The quasi-two temperature growth method starts the growth of the GaN barrier before the temperature is raised.
- 2T growth - The two temperature growth method has a break between the InGaN quantum well (QW) and the GaN barrier growth where the temperature is allowed to rise.

Spot Size Measurements

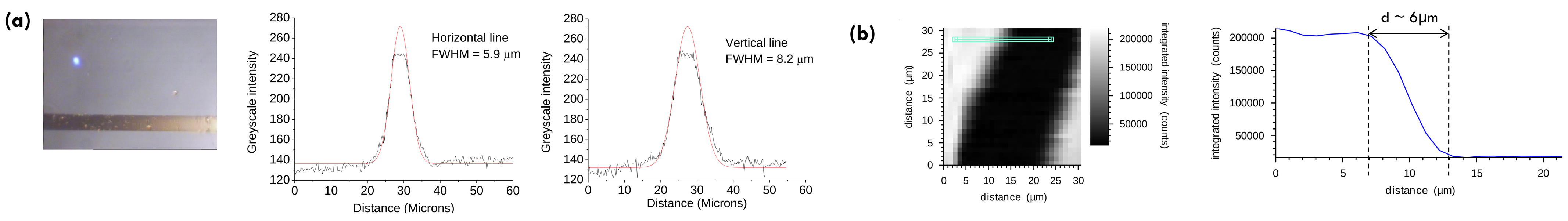

Figure 4: (a) Image technique - laser spot on an LED with spectra corresponding to intensity linescans over spot . (b) Knife-edge technique - PL map linescan over LED contact (used as knife-edge) showing map and intensity spectrum.

- These measurements were performed without a beam expander.
- Spot size measured to be ~6μm which was confirmed by both techniques (Fig 4).

Room Temperature Mapping

Q2T sample

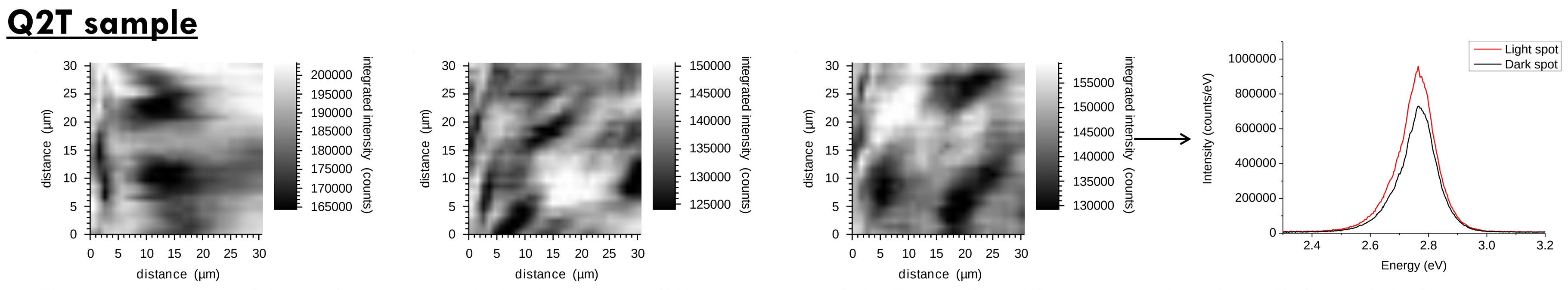

Figure 5: Integrated intensity maps of InGaN peak on different areas of Q2T sample with spectra taken from light and dark areas.

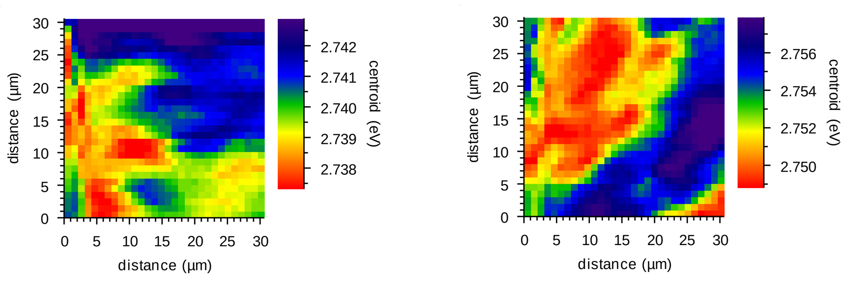

Figure 6: Centroid energy maps of the InGaN peak corresponding to integrated intensity maps directly above.

- Excitation power density for room temperature maps is ~ 2.4×10^{4}Wcm^{-2}.
- Mapping the integrated intensity resolved features of 5-10μm on different areas of the Q2T sample (Fig 5).
- The first energy map shows a clear red shift for the dark "spots" in the integrated intensity map and blue shift for the light "spots".
- This positive correlation is not as evident within the second energy map.

2T sample

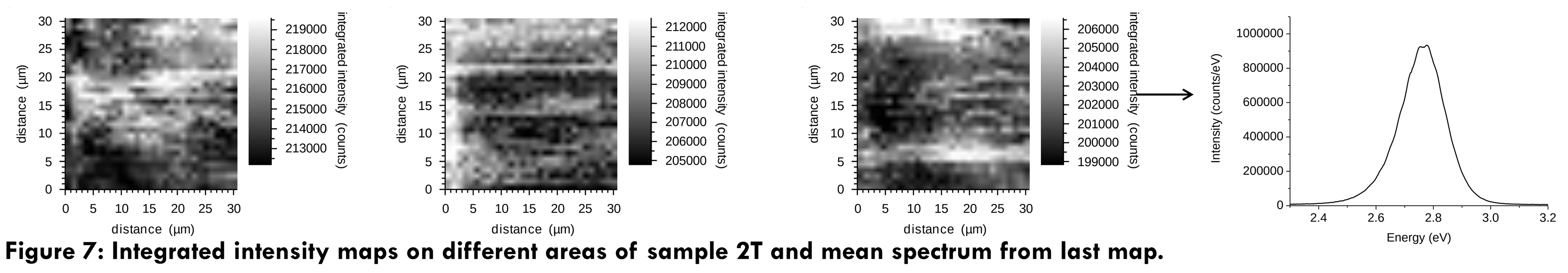

Figure 7: Integrated intensity maps on different areas of sample 2T and mean spectrum from last map.

Table 1: Comparing mean integrated intensity and standard deviation of the above maps.

	Mean Integrated Intensity (counts)	Mean Standard Deviation (counts)
Q2T sample – light spots	1.7×10^{5}	8.0×10^{3}
Q2T sample – dark spots	1.3×10^{5}	
2T sample	2.1×10^{5}	2.0×10^{3}

- The 2T sample integrated intensity maps (Fig 7) are more uniform than Q2T.
- This is evident from the maps lower mean standard deviation (Table 1).
- The pixelated maps are due to a scanning artefact.

Low Temperature Mapping

Cooler On: T~19K

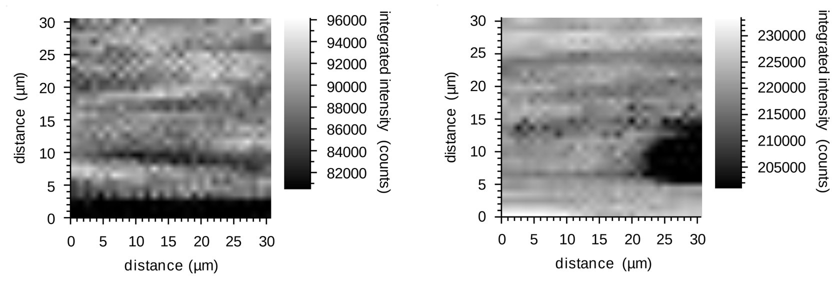

Figure 8: Integrated intensity maps of both samples with the cold head left on and T~19K. The dark areas within these maps are LED contacts.

- Excitation power density for low temperature maps is reduced to ~ 2.0×10^{4}Wcm^{-2} due to loss of power through the cold head cover.
- With the cooler on the influence of the vibrations are evident within each of the maps (Fig 8).

Cooler Off: T~ 19K - 40K

Q2T sample

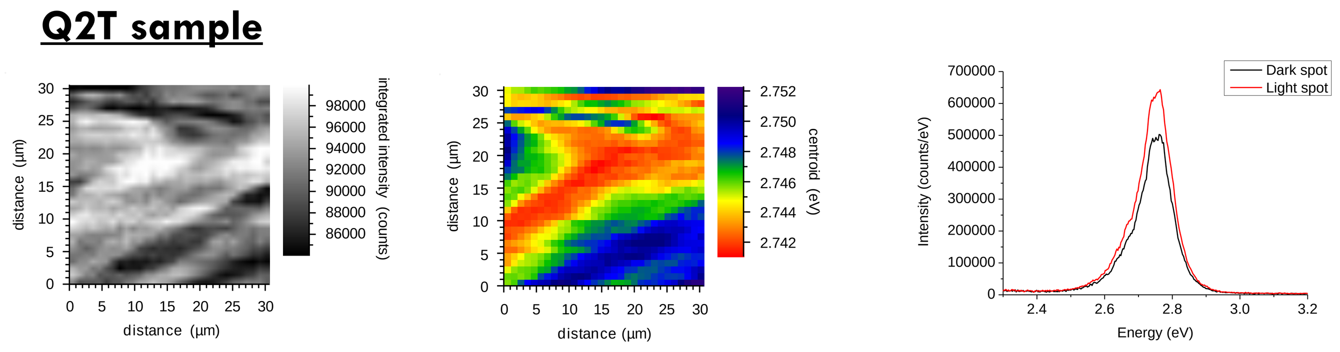

Figure 9: Integrated intensity and centroid energy map of sample Q2T at low temperature with spectra taken from light and dark areas.

2T sample

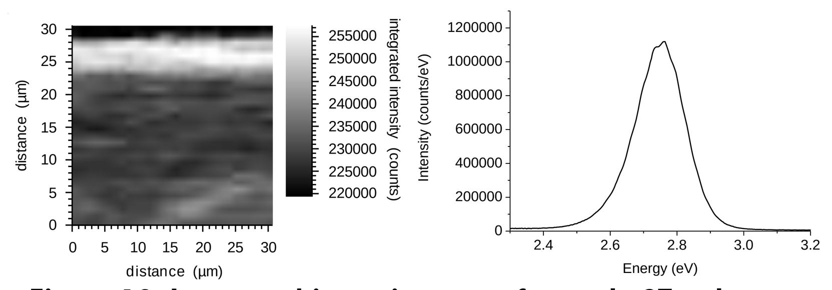

Figure 10: Integrated intensity map of sample 2T at low temperature with corresponding mean spectrum.

- Turning the cooler off removes the vibration but incurs drifting (Fig 9) and temperature increases from ~20K to 40K.
- In this case the dark intensity "spots" show a strong blue shift in centroid energy of the InGaN peak.

IQE Mapping1

- IQE is determined by eq(1) where I_{RT} is the peak intensity at room temperature and I_{LT} is the peak intensity at low temperature, this is with the assumption that at low temperature the IQE is approximately 100% [3].

$$IQE = I_{RT}/I_{LT} \quad (1)$$

- Using 60um square grids as a guide and repeating maps at RT andLT on the same grid an attempt at IQEmapping was performed on sample Q2T (Fig 11).
- The room temperature maps were taken with the cold head cover on.

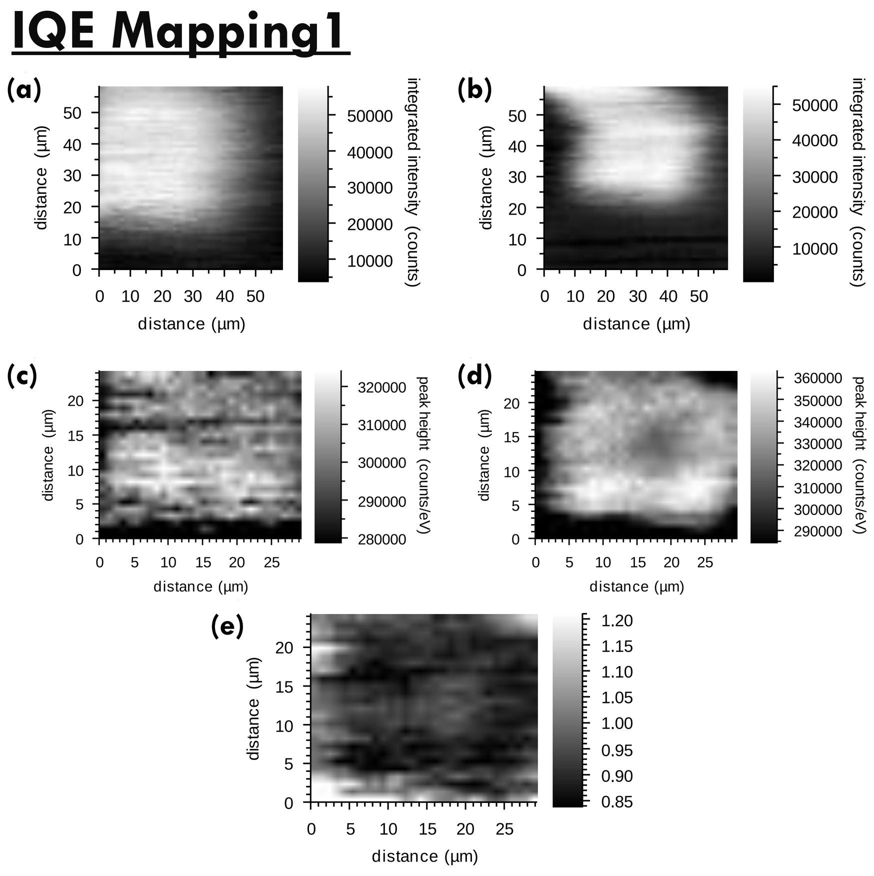

Figure 11: Integrated peak intensity maps at (a) RT and (b) LT- T~24K-56K . Cropped peak intensity maps on approximately the same area at (c) RT and (d) LT. (e) IQE map of the ratio of maps c and d.

Image portraying PL mapping with LED sample mounted on to movable nanopositioners.

Summary and Future Work

- We have designed a system to allow PL mapping at both room and low temperature. This is evident in the study of the Q2T and 2T InGaN/GaN LEDs where variations over the mapped area were seen and features of 5-10μm were resolved.
- Progress towards mapping of IQE was presented.
- We know the limiting factors of our set up and know how to correct for these.
- Our next step is to install a beam expander in order to achieve a smaller spot size and therefore better resolution.
- This will allow study of the IQE of samples with areas of varying dislocation densities to see how this compares.

References

[1] E.Taylor et al, Semicond. Sci. Tech, **28** 065011 (2013)
[2] P. R. Edwards et al, Phys. Stat. Sol (c), **0** 2474 (2003)
[3] J. Danhof et al, Phys. Stat. Sol (b), **249** 600 (2012)

Acknowledgements

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