Electroluminescence studies of InGaN blue LEDs

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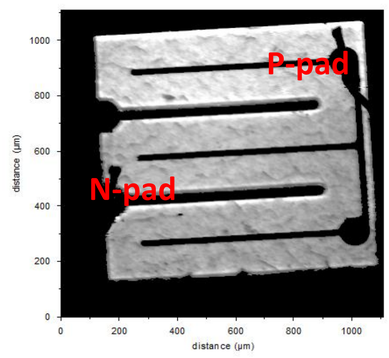
Motivation

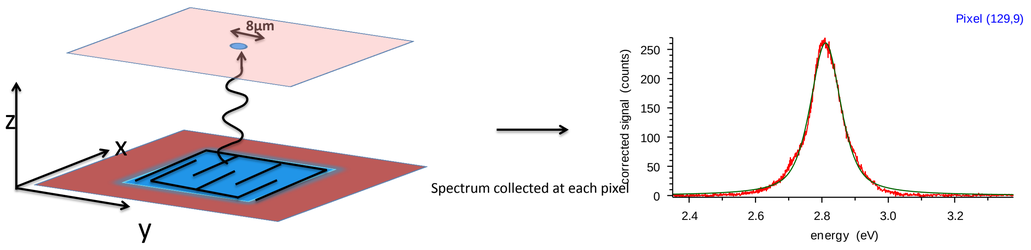
- Lighting is currently responsible for ~ 20% of global electricity use
- Light emitting diodes (LEDs) offer a solution to this problem
- GaN/InGaN based blue LEDs are combined with yellow emitting phosphors to produce a white light source.
- However, GaN based LEDs suffer from so called efficiency droop – whereby their efficiency drops as the drive current is increased
- The ability to image and map correlations between current, intensity, wavelength and line width across an entire LED die can show the homogeneity and current response of LED emission
- In this study a blue LED was studied using Electroluminescence Hyperspectral Imaging

LED Specifications

- C-plane GaN on sapphire grown by MOCVD
- Six period $In_{16}Ga_{84}N$ MQW active region emitting at 440nm at 10mA
- 2.5nm/10nm well/barrier structure
  Stack is topped by an AlGaN electron blocking layer and a large 800nm p-GaN region –
- 1mm² LED die with an interdigitated contact structure as shown on right
- In this study the LED die used was mounted to a T05 can and wedge bonds were made to diagonally opposite p and n contact pads

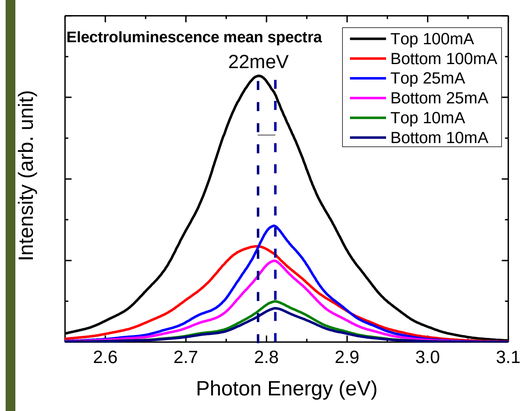


Electroluminescence Hyperspectral Imaging



Scanning stage of a modified Electron Probe Multi-Analyser (EPMA) used to collect maps.
Can fixed to scanning stage of EMPA and driven by a constant current source.
Emitted light is collected and focused to a 8µm pinhole at the entrance of the spectrometer
The stage is scanned under the pinhole and the LED emission is collect pixel by pixel to build the image
Due to the magnification of the optics a spatial resolution of 3µm was obtained.

LED mean spectra



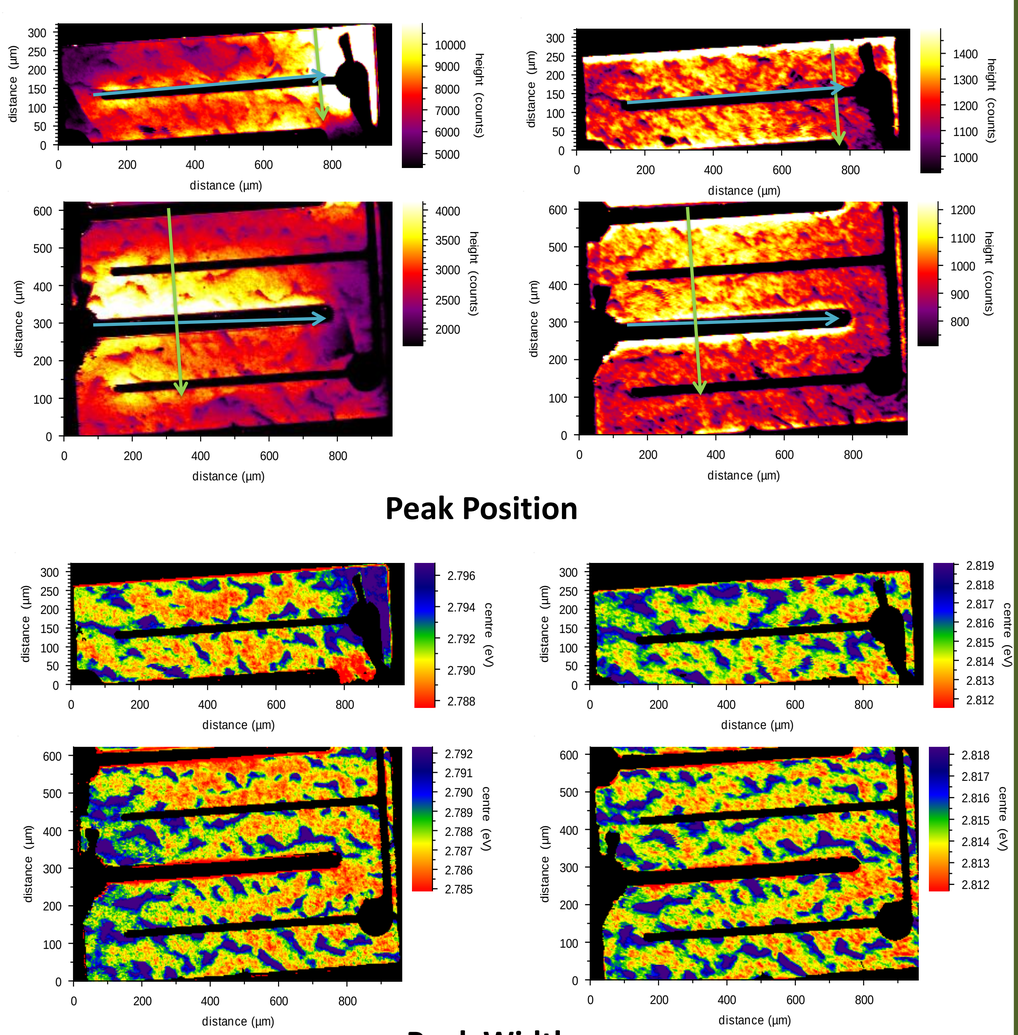
Mean spectra taken from top (top, addressed p-contact) and bottom (lower, unaddressed, p-contacts) region of maps of 10mA, 25mA and 100mA.

No shift from 10mA to 25mA, but 22meV redshift at 100mA and large broadening indicate heating effect

Increased ratio between top and bottom area intensity shows increased current crowding around addressed p-contact pad

Electroluminescence Maps

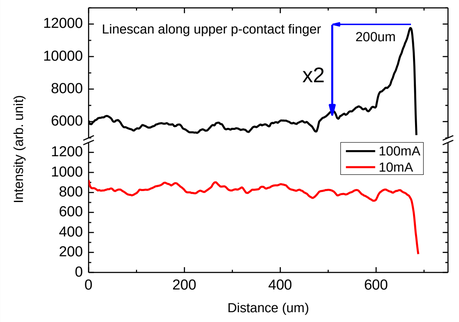
100mA **Intensity** 10mA



Peak Position

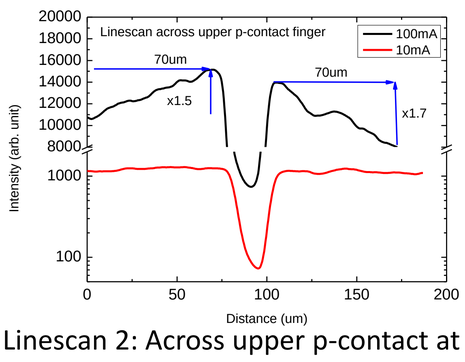
Peak Width

Intensity Linescans
Top – across and along p-finger



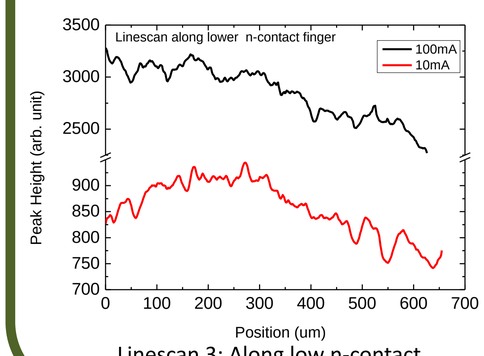
Linescan 1: Along upper p-contact

- At 10mA there is no change in the intensity along the p-finger or across it.
- At 100mA, a two fold increase in intensity occurs within the last 200µm toward the finger and there is a 1.6 factor change with 70µm either side



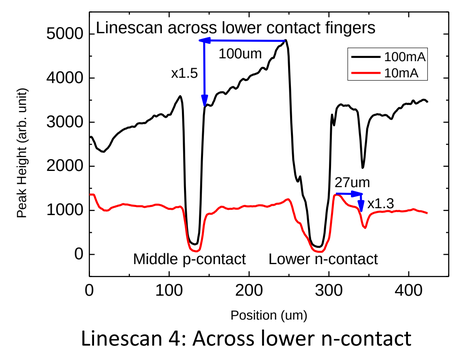
Linescan 2: Across upper p-contact at pad

Bottom – across and along n-finger



Linescan 3: Along low n-contact

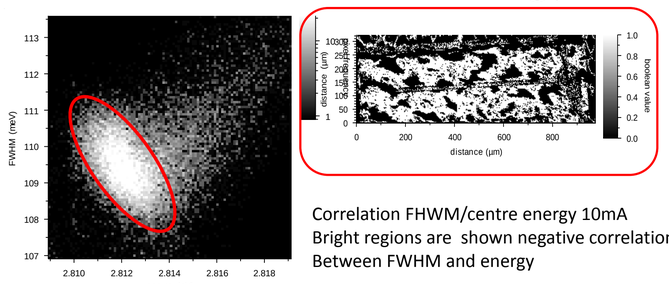
- At 100mA an 1.5x increase in intensity on the 'top' side of n-contact.
- At 10mA large increase is on the 'bottom' side of the n-contact, away from the p-contact pad
- Both currents show similar drops along finger axis



Linescan 4: Across lower n-contact

Correlation plots

10mA FHWM vs. Energy



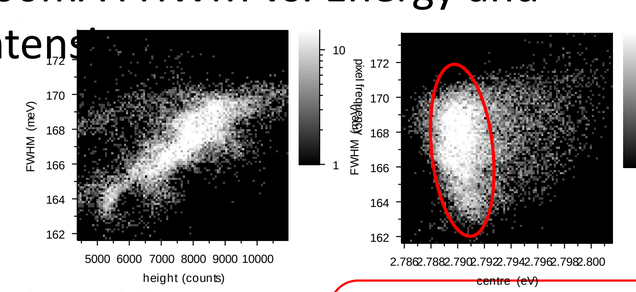
Correlation FHWM/centre energy 10mA
Bright regions are shown negative correlation
Between FWHM and energy

Pearson r value: 0.3452

At **10mA** Back correlation plot displays positional source of selected pixels on the correlation plot. Two relationships between FHWM and centre energy;

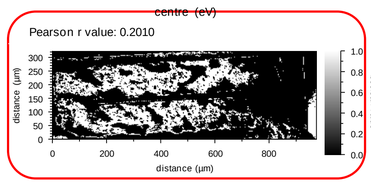
- In domains of highest energy, the correlation is positive. – May be due to local junction field variations – i.e. higher field cause screening of the quantum confined Stark effect and band tail filling
- Other regions show negative correlation- due to indium composition fluctuations

100mA FHWM vs. Energy and Intens



Pearson r value: 0.4409

Pearson r value: 0.2010



- At **100mA**, a clear positive correlation exists between FWHM and intensity – due to thermal broadening
- Similarly to 10mA a double correlation exists between FHWM and centre energy- the effect does not appear random as similar areas are dark in both back correlation plots

Acknowledgments

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Conclusions

- 1mm² InGaN blue LED was mapped with electroluminescence imaging at a resolution of 3µm at 10mA and 100mA
- At 100mA current crowding and heating redshifts emission and localises it strongly around p-contact pad
- At 10mA emission around n-contact fingers is relatively increased and more homogenous but around p-contact is reduced possible due to improved current spreading of both electrons and holes
- Correlation between FHWM and emission energy shows to domains, a positive correlation at high energies due local variations in junction field and a negative correlation else where due to Indium composition fluctuations