Bridging the Gap

Daren Lock and Benjamin Crutchley

LED Devices

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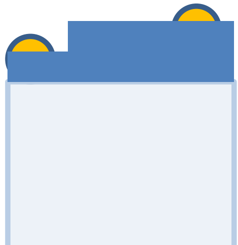
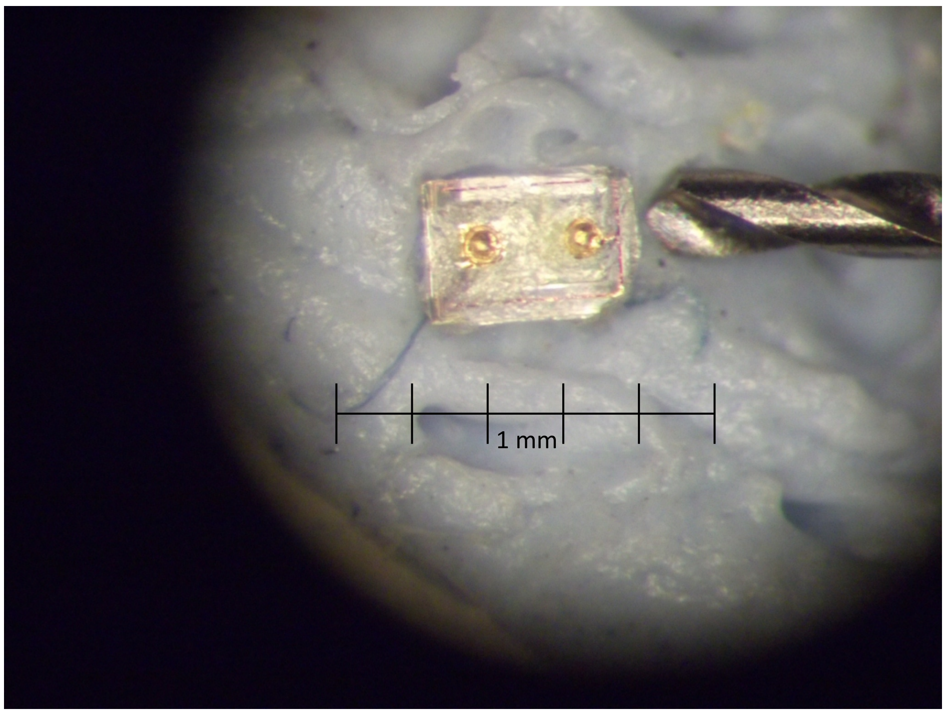
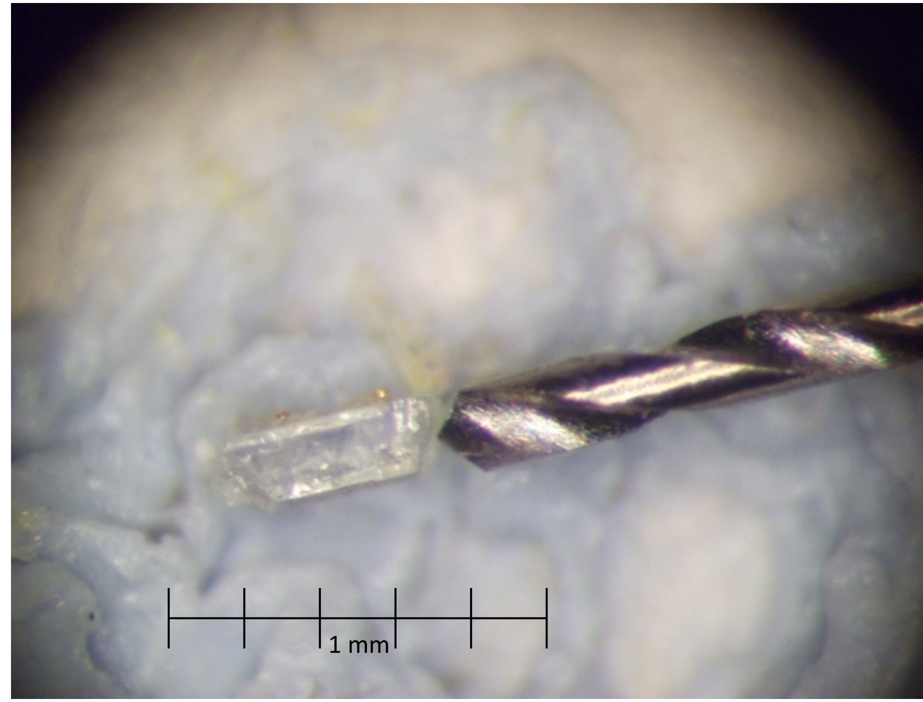
InGaN structure



Substrate





Predominantly Sapphire

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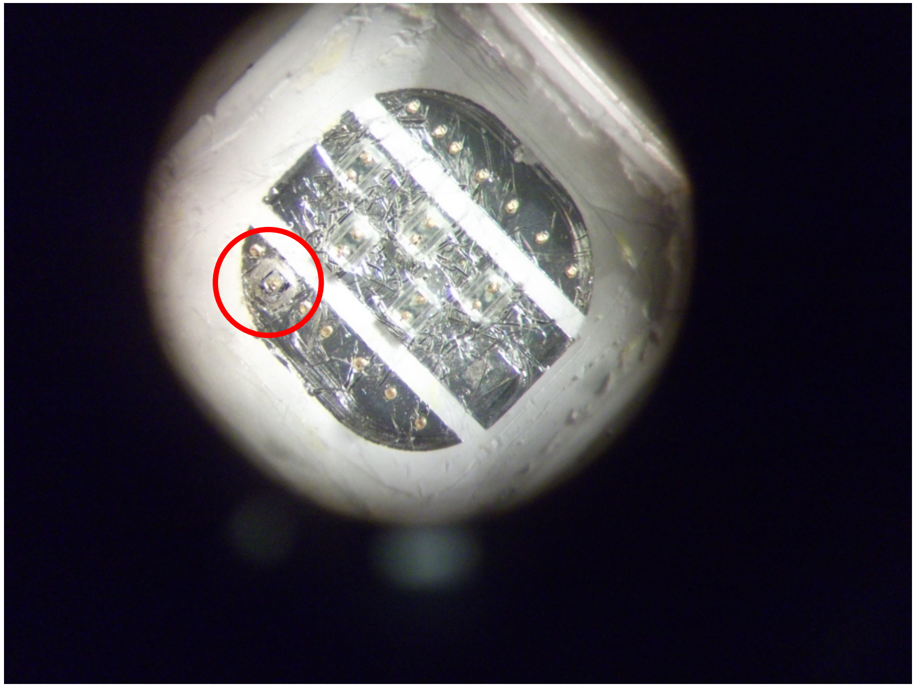

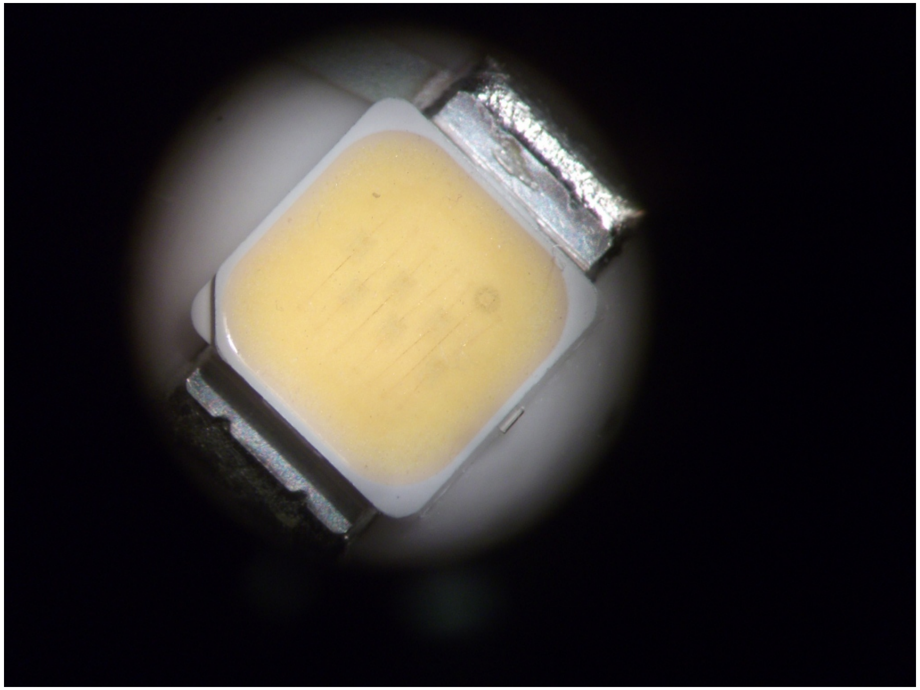

Red LED for warmer colour rendition

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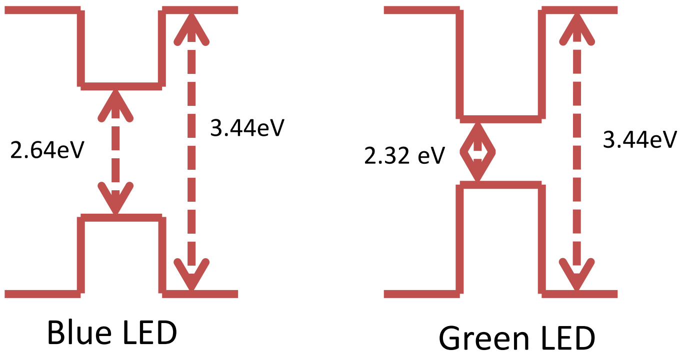
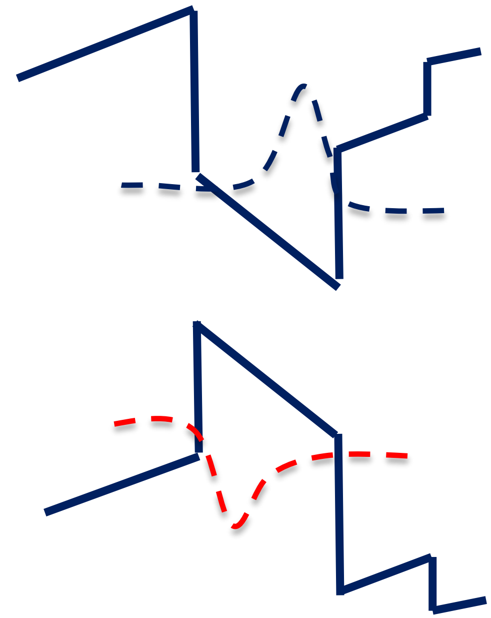
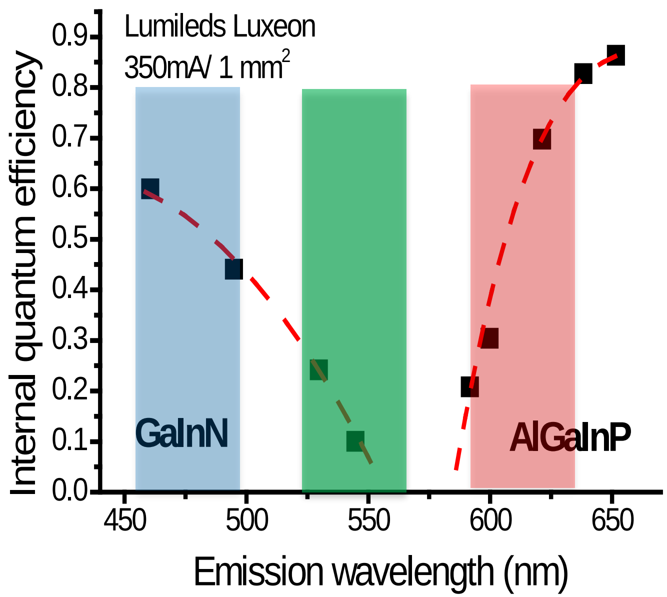
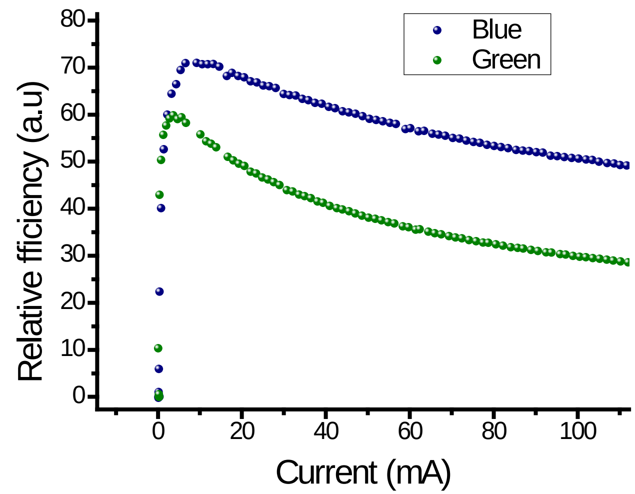
Band Gap dependence









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Recombination losses

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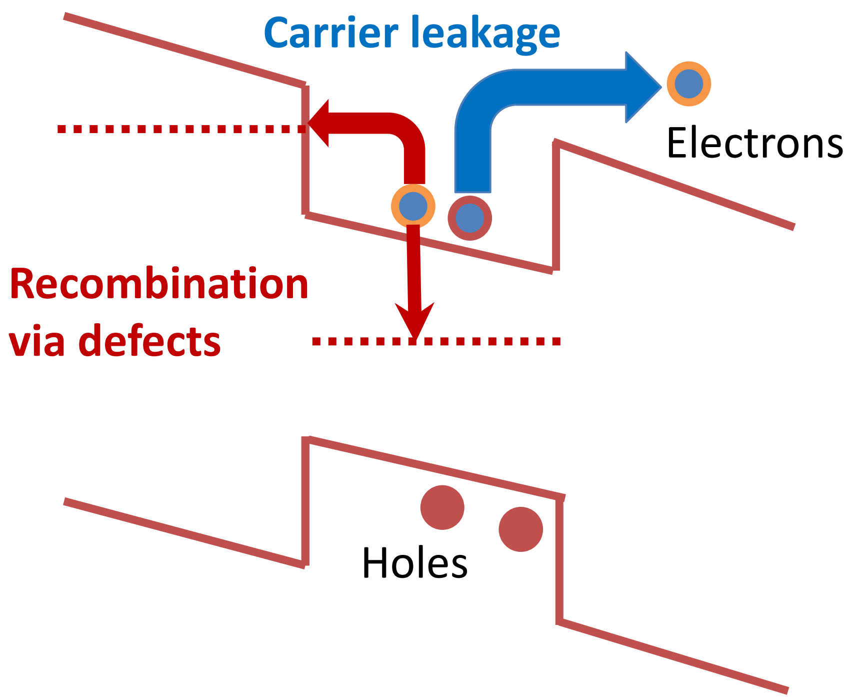
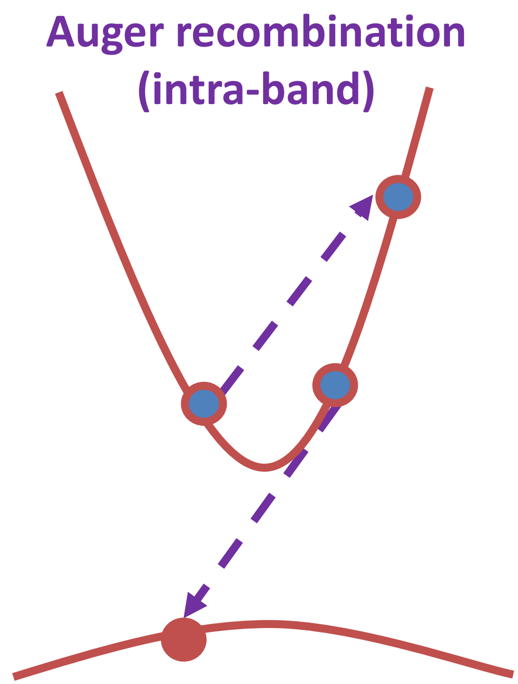
$$I = eV(An + Bn^2 + Cn^3) + I_{leak}$$

Defect
(Shockley Read Hall)

Radiative

Auger





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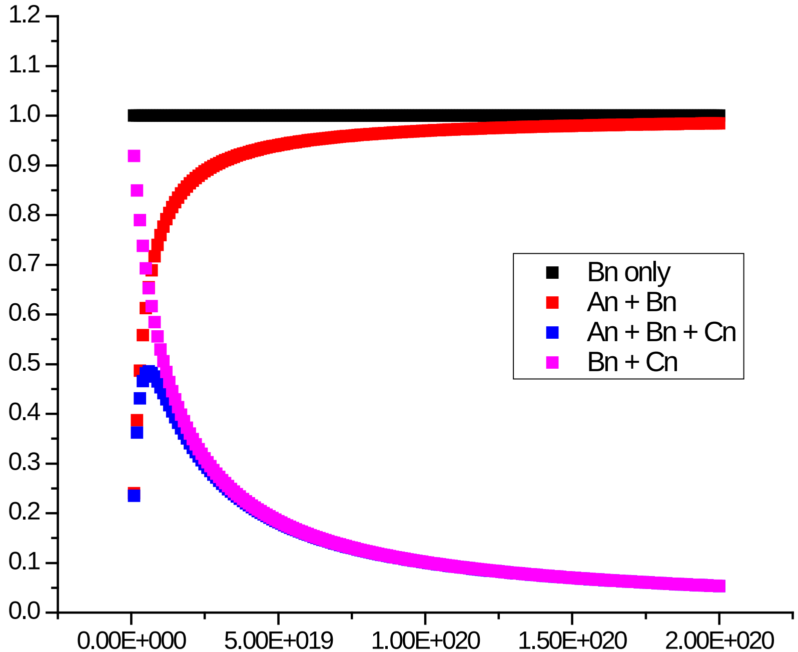
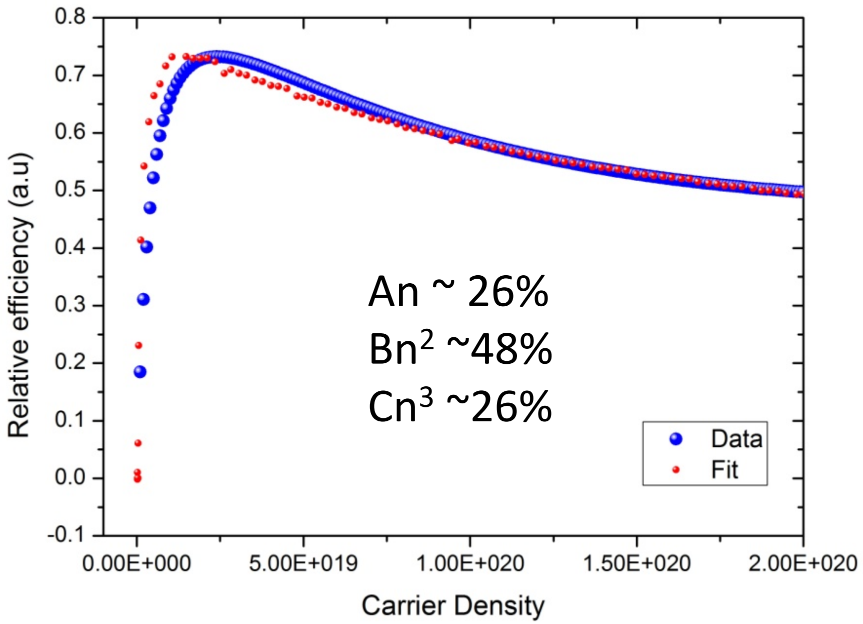
Modelling

$$Efficiency = \frac{\text{radiative recombination rate}}{\text{total recombination rate}}$$

$$I = An + Bn^2 + Cn^3$$

$$\text{Efficiency} = \frac{Bn^2}{An + Bn^2 + Cn^3}$$

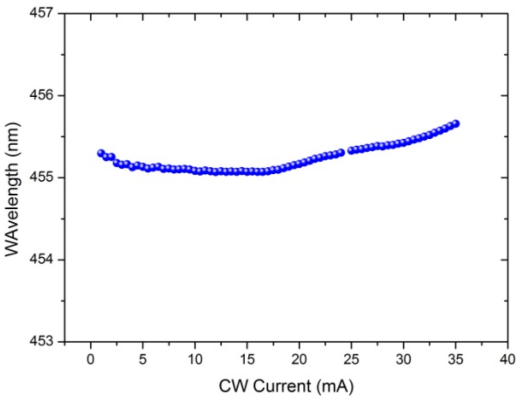




Junction temperature methods

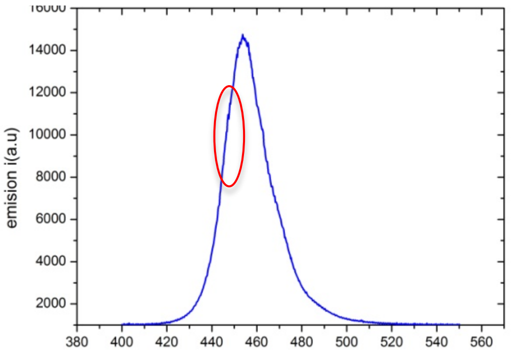
- Wavelength shift

J. Senawiratne, A. Chatterjee, T. Detchprohm, W. Zhao, Y. Li, M. Zhu, Y. Xia, X. Li, J. Plawsky, C. Wetzel, “Junction temperature, spectral shift, and efficiency in GaInN-based blue and green light emitting diodes”, Thin Solid Films 518, 1732 (2010).



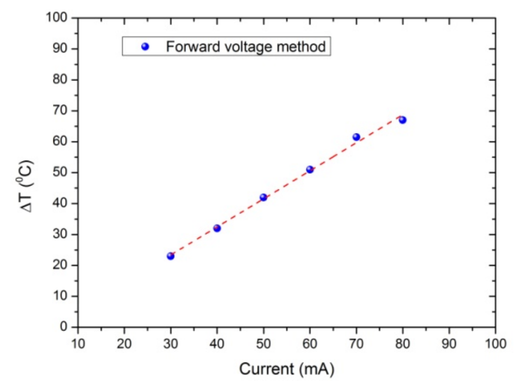
- Spectral analysis

Z. Vaitonis, P. Vitta, and A. Žukauskas, "Measurement of the junction temperature in high-power light-emitting diodes from the high-energy wing of the electroluminescence band", J. Appl. Phys. 103, 093110 (2008)



- Forward voltage technique

Xi and E. F. Schubert, "Junction–temperature measurement in GaN ultraviolet light-emitting diodes using diode forward voltage method", Appl. Phys. Lett. 85, 2163 (2004).



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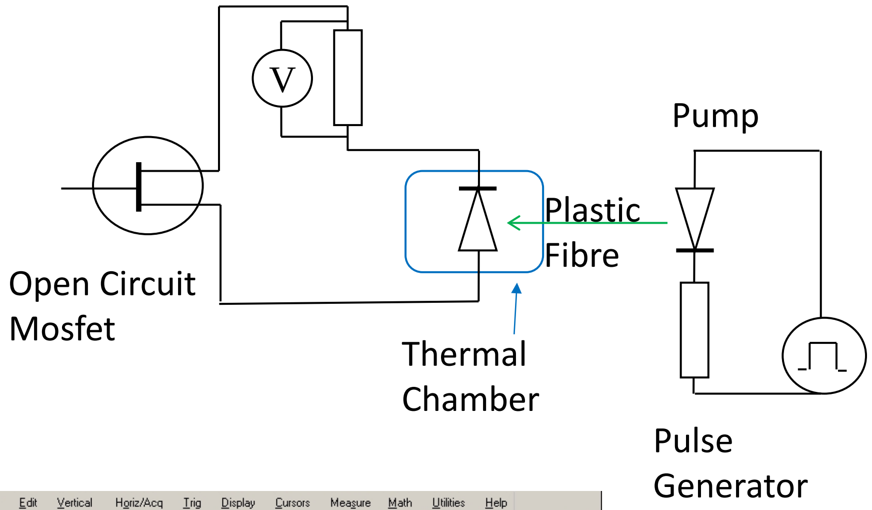
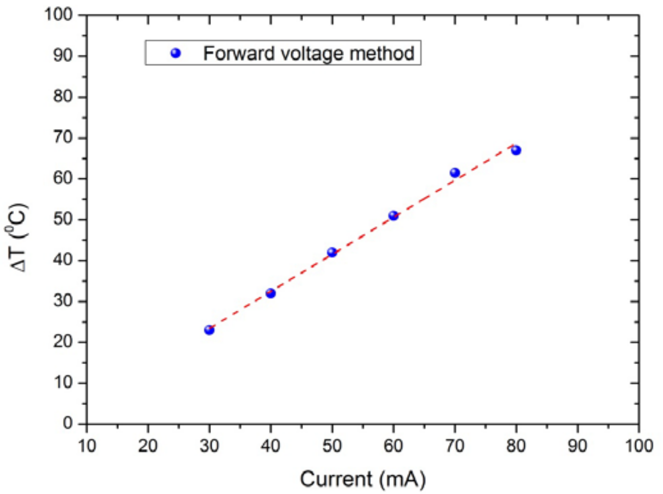
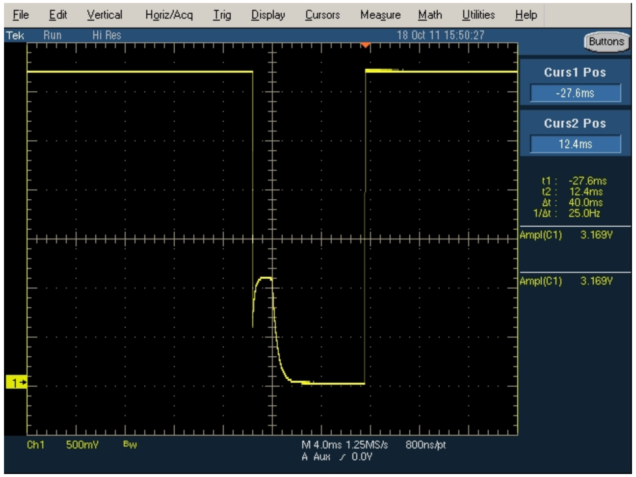
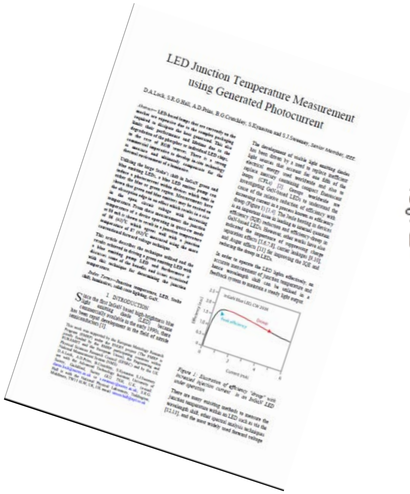
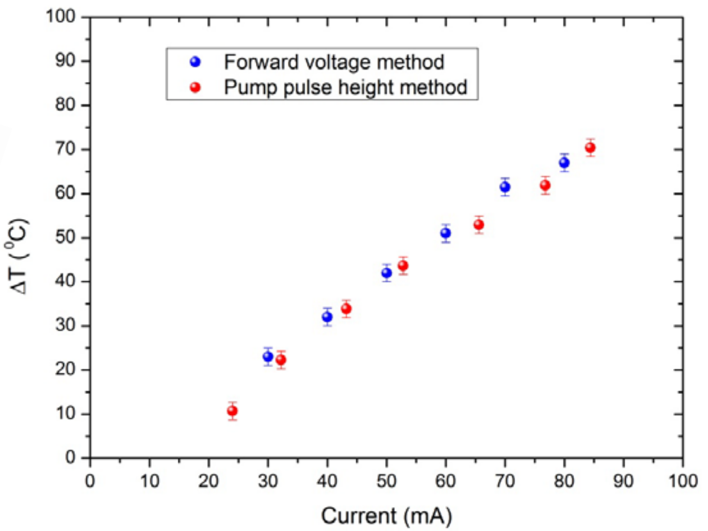
New Technique











[LED Junction Temperature Measurement Using Generated Photocurrent]

DA Lock, SRG Hall, AD Prins, BG Crutchley, S Kynaston, SJ Sweeney

Journal of Display Technology 9 (5), 396-401

Thermal effects

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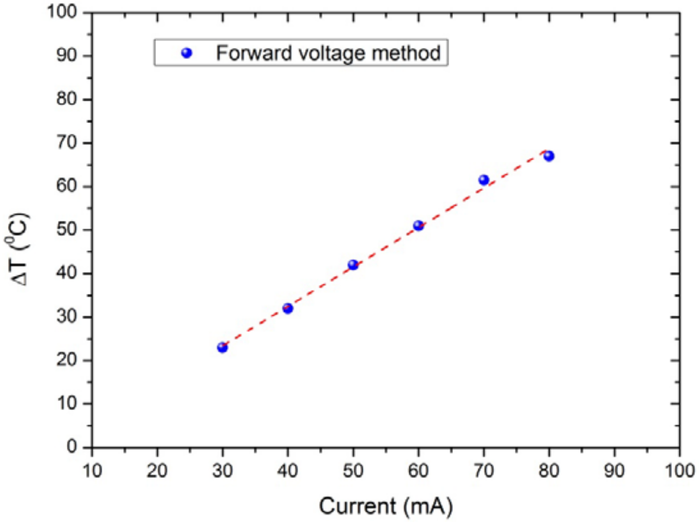

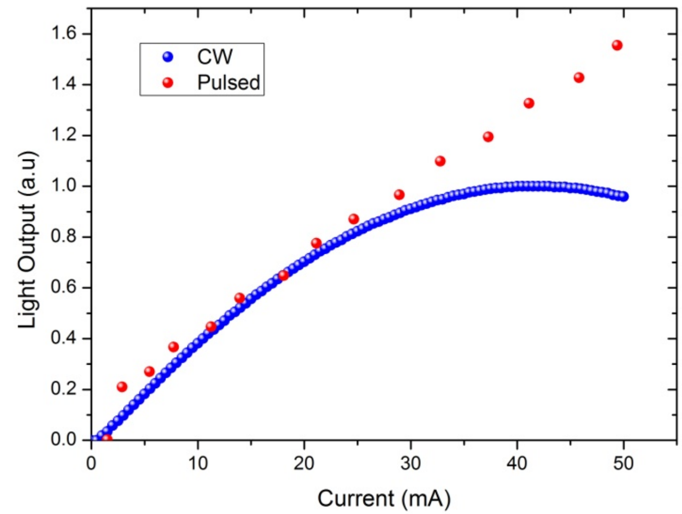

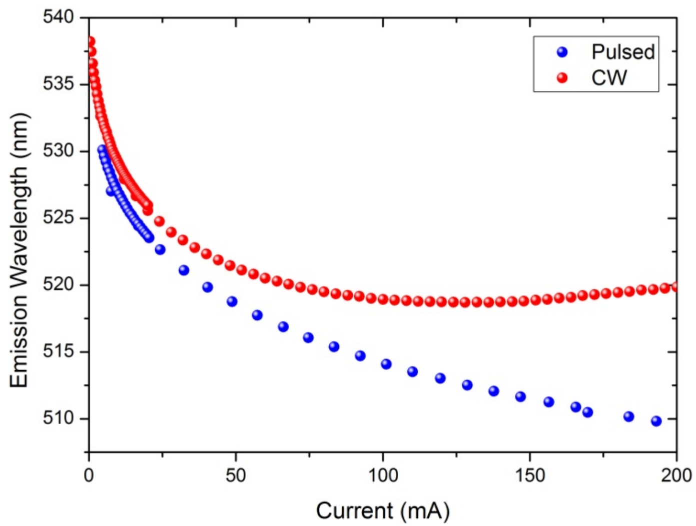

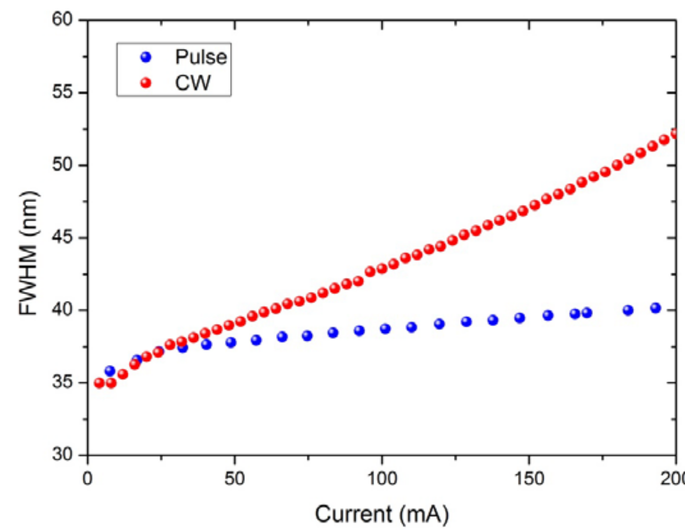

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Thermal effects

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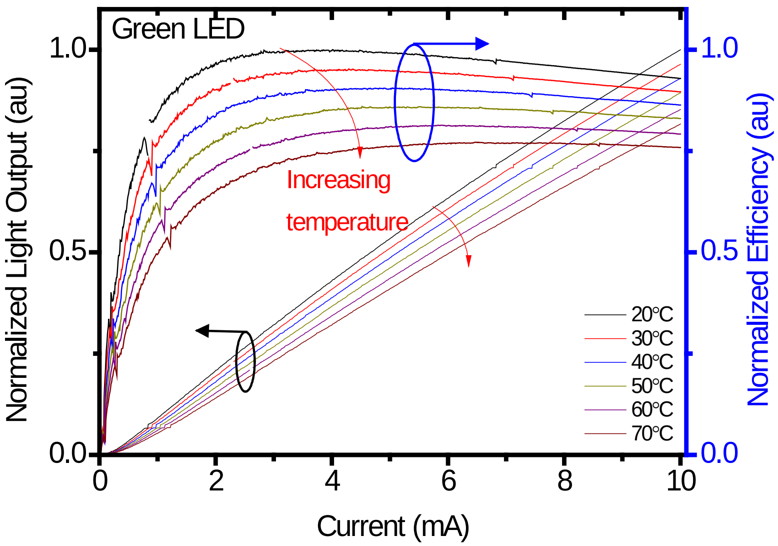

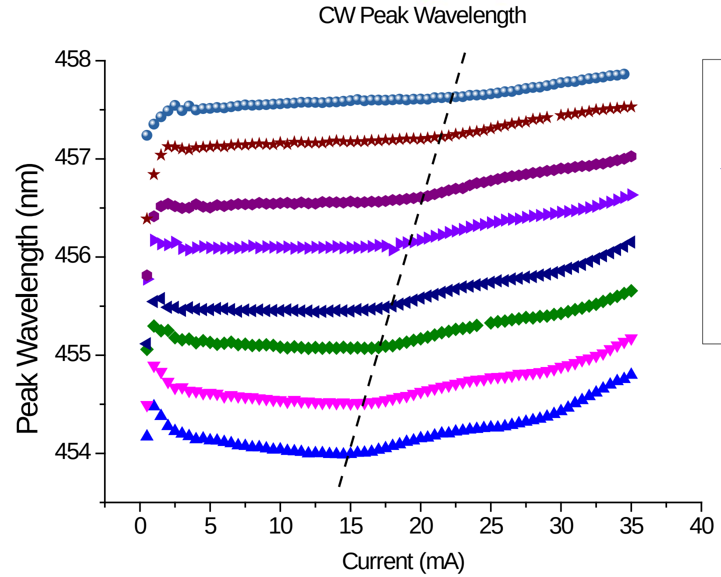

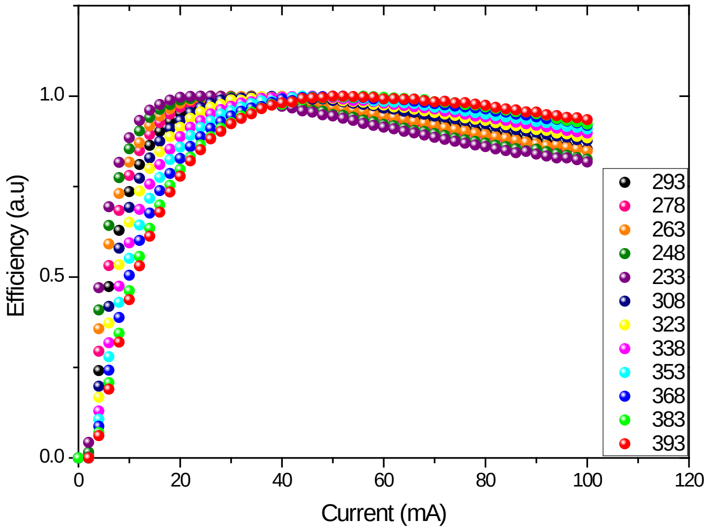

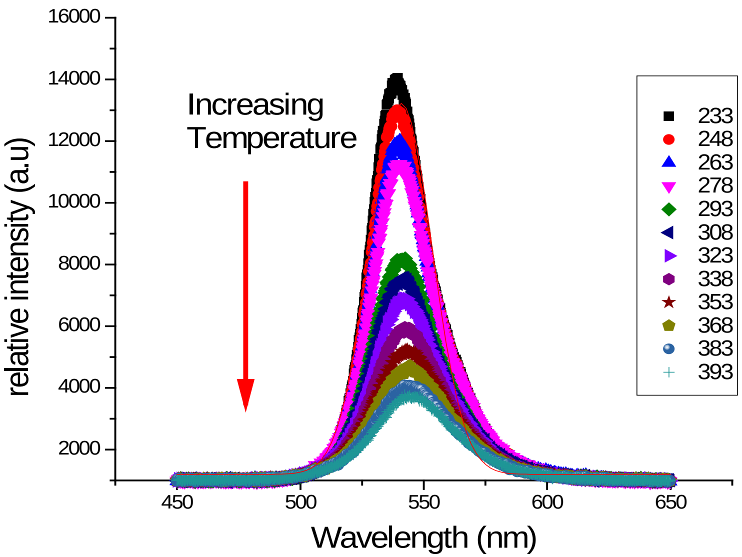

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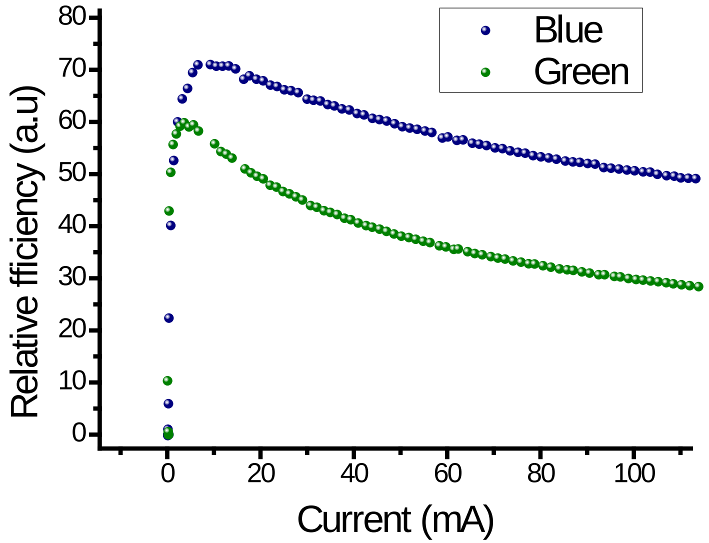
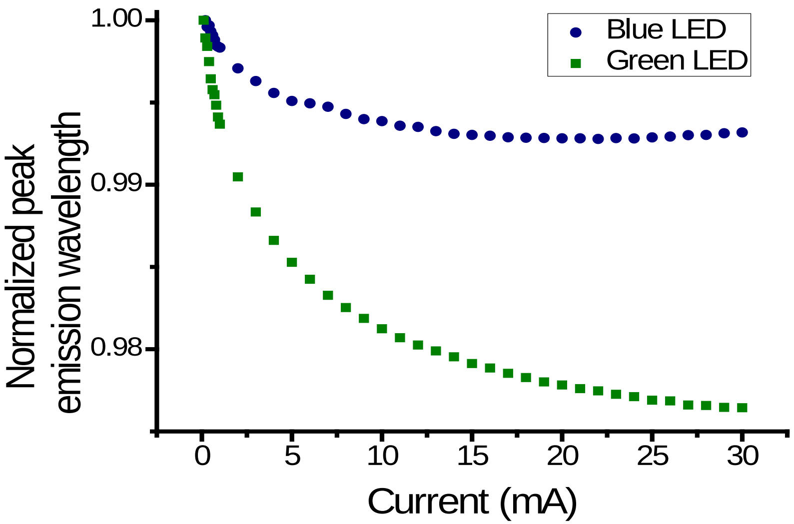
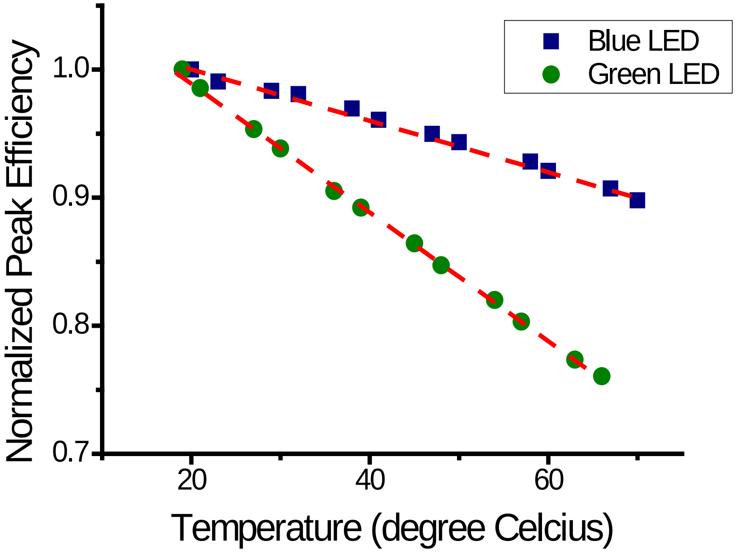
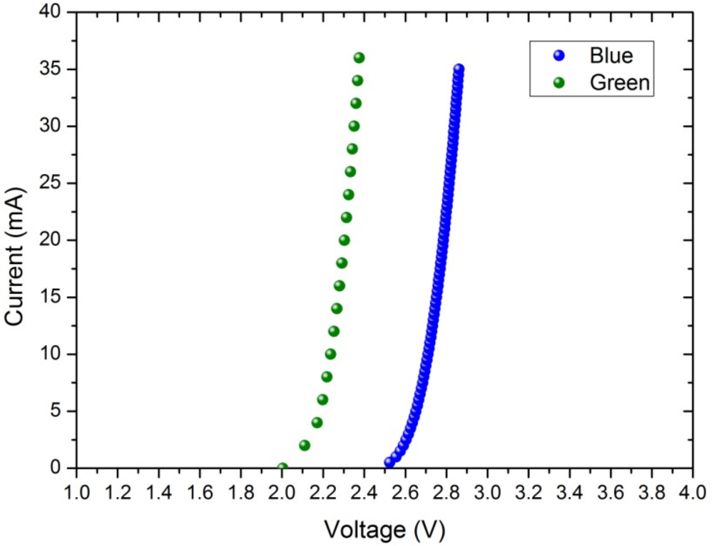
Blue vs Green









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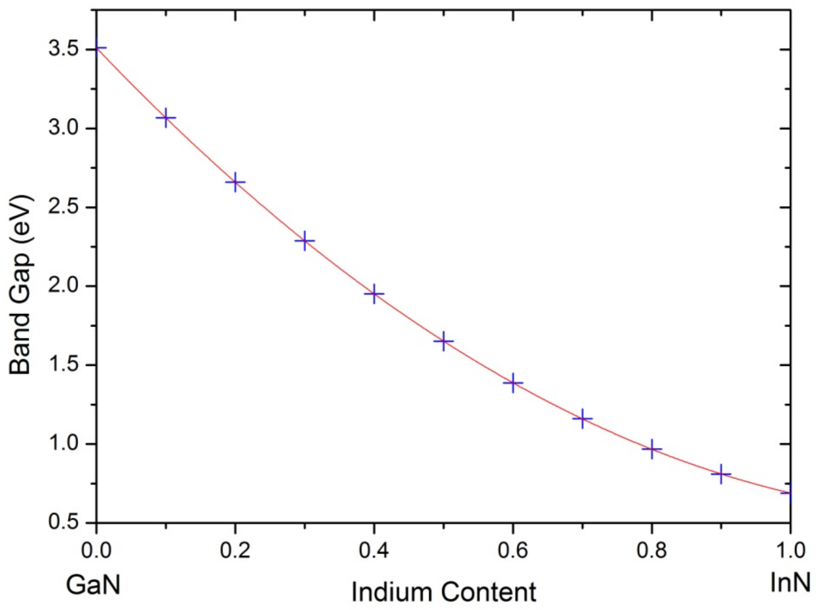
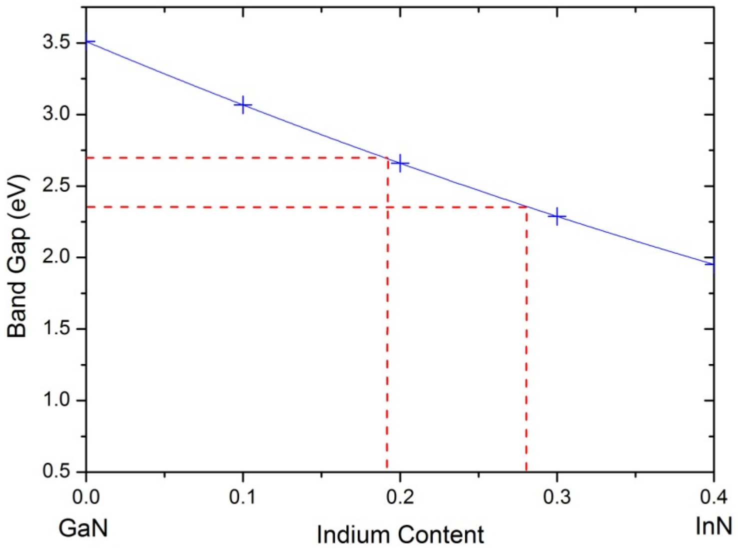
Indium Content

$E_g(In_xGa_{1-x}N)=(1-x)E_g^{GaN} + xE_g^{InN} - bx(1-x)$

Where x is the Indium content, and the values for the bands taken from [1]





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[1] P.G.Moses and C.G.Van de Walle, "Band bowing and band alignment in InGaN alloys" App. Phys. Lett 96, 021908 (2010)

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TEM

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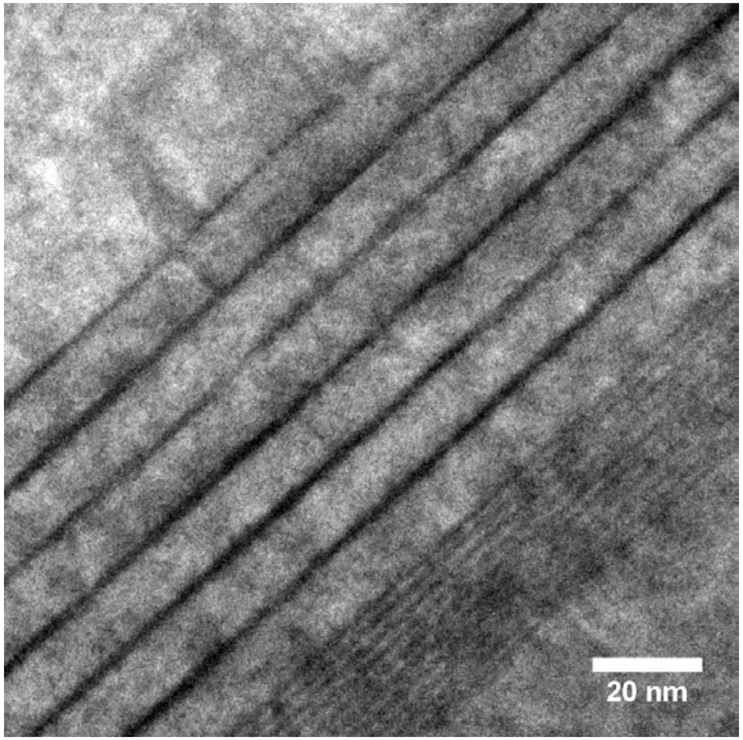
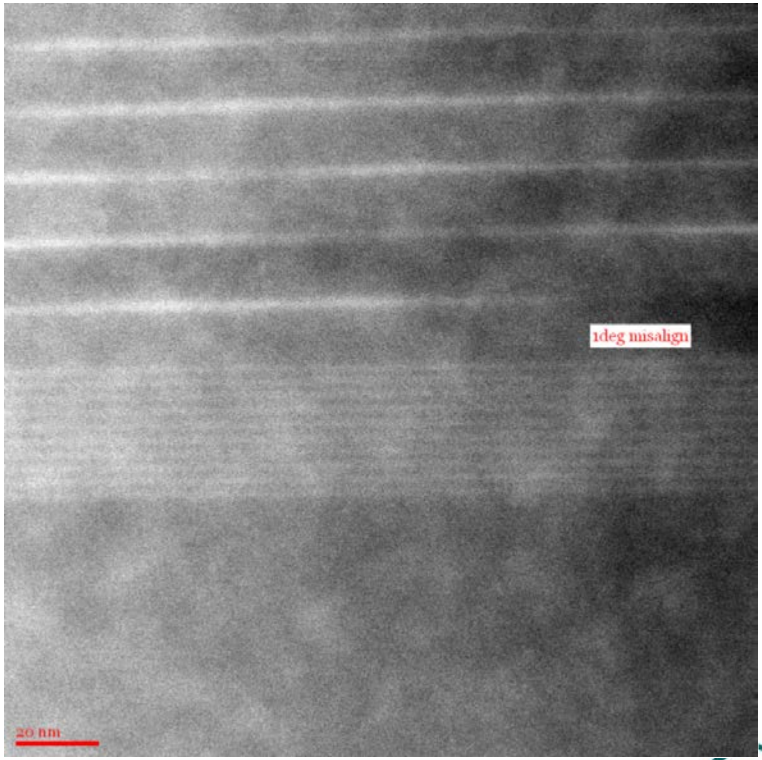
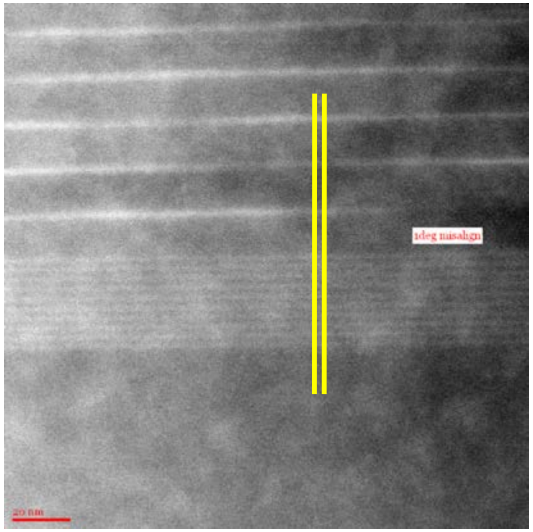
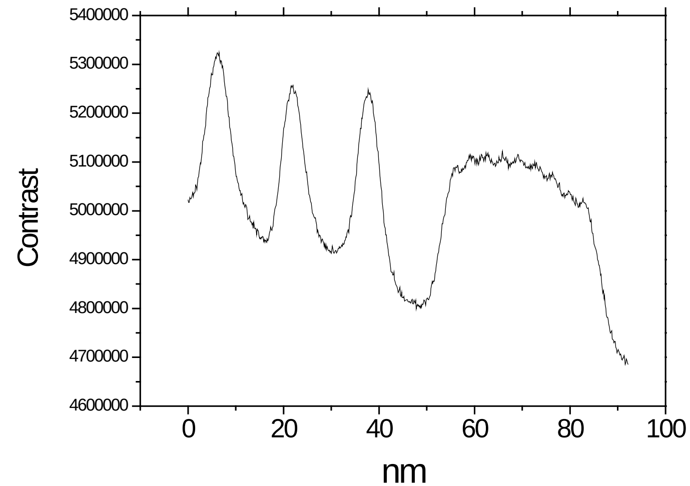
Utilising TEM Images of the samples it is possible to calculate the Indium content of the Quantum Wells

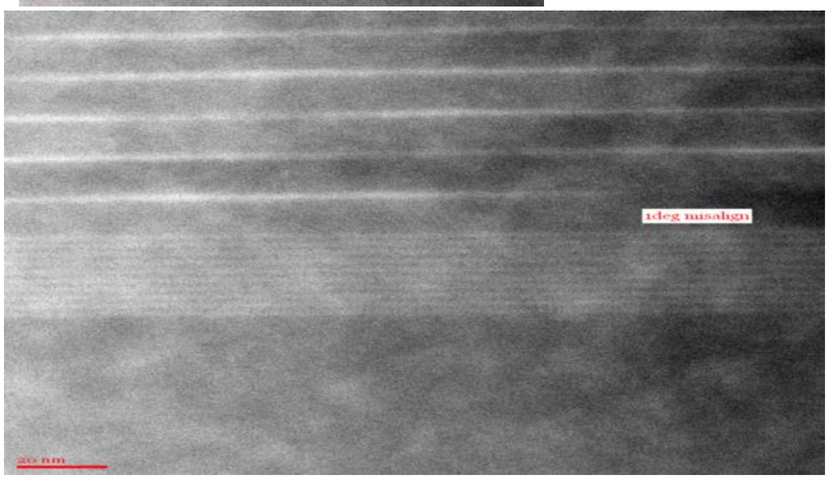


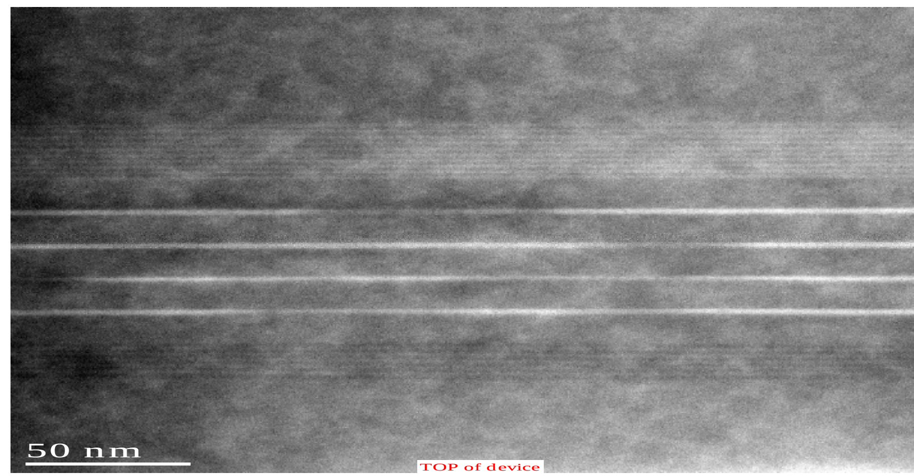


Z contrast









6 QW, 6 nm width ~ 26 % In

4 QW, 3 nm Width ~20 % In

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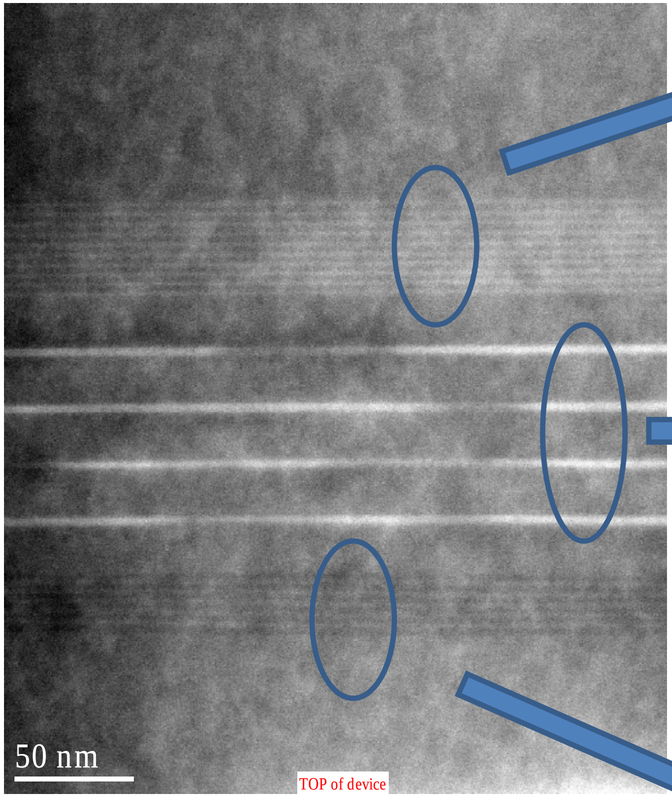
LED Devices

Sapphire Substrate



InGaN SSL to block lattice dislocations

Four InGaN QWs

AlGaN SSL electron reflector

Top Contact

High hydrostatic pressure studies on visible LEDs

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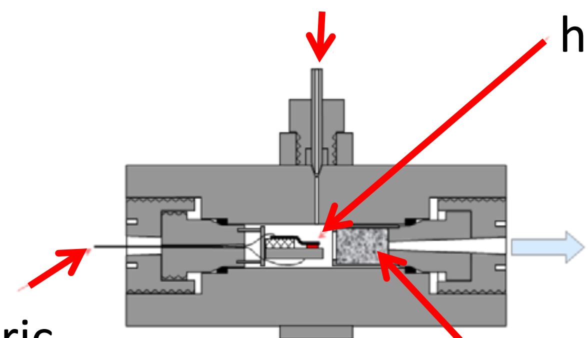
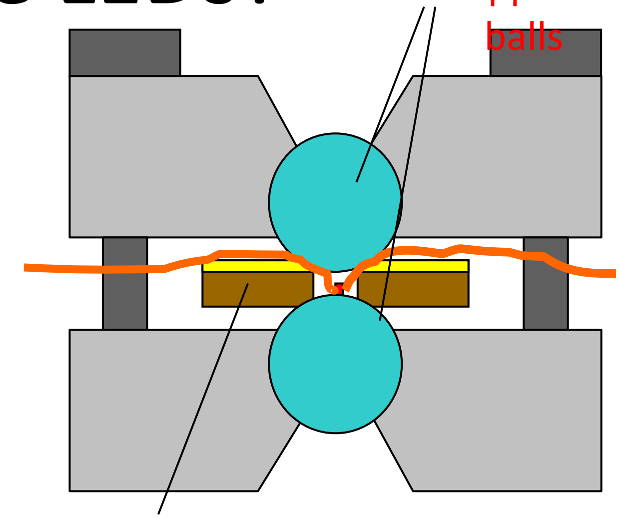
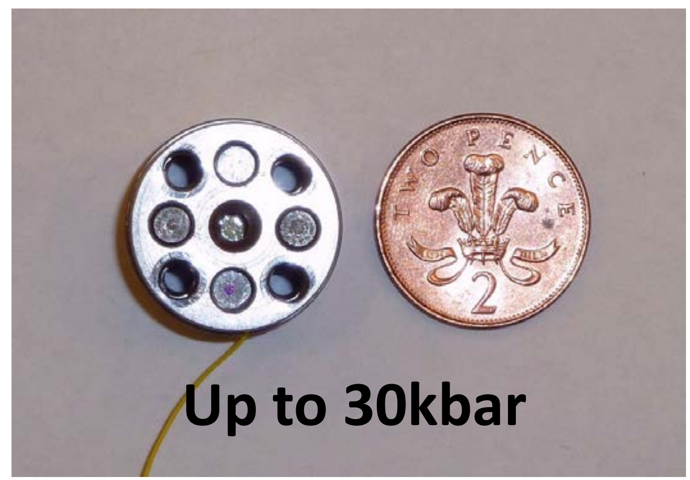
How do we apply high hydrostatic pressure to the LEDs?

- Gas compressor system to apply pressure which increases E_g.

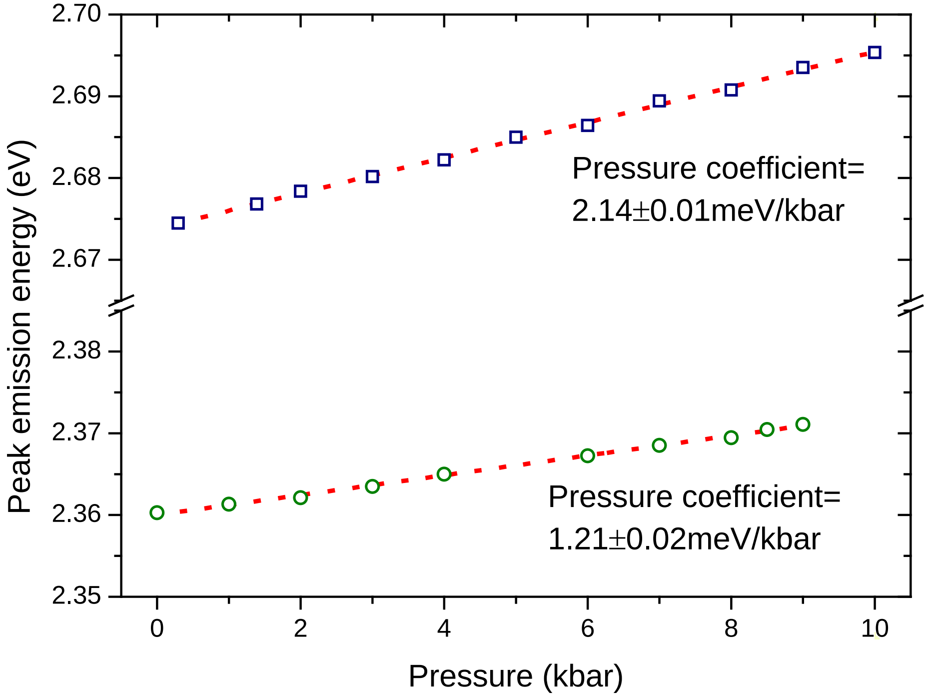


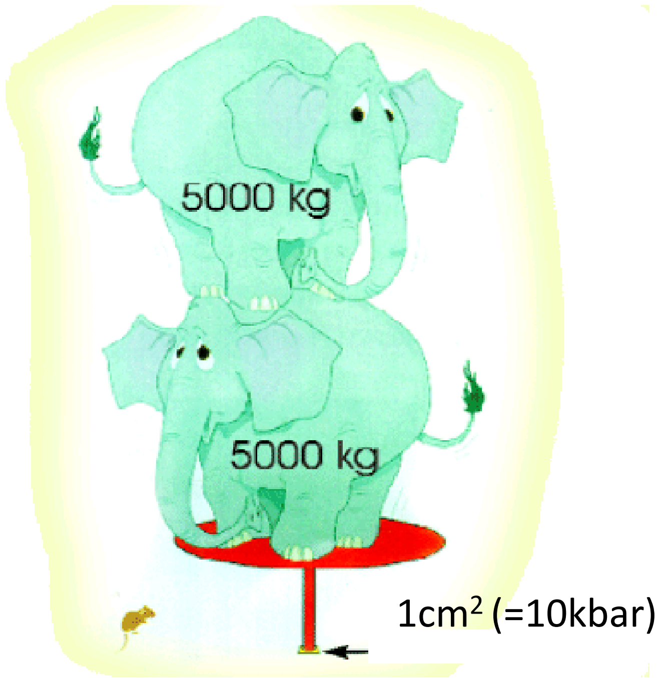
Up to 10kbar





Why use high hydrostatic pressure?





- Use hydrostatic pressure to increase the bandgap of III-V semiconductors
- Investigate bandgap dependent properties without the need to grow multiple LED devices

Hydrostatic pressure alters the emission wavelength of the LEDs

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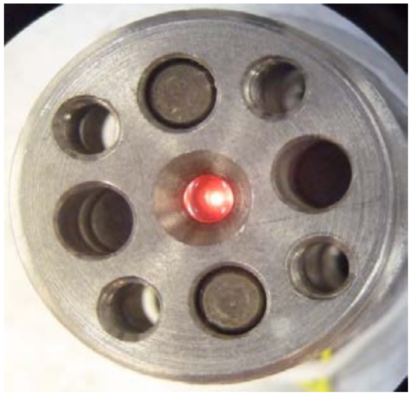
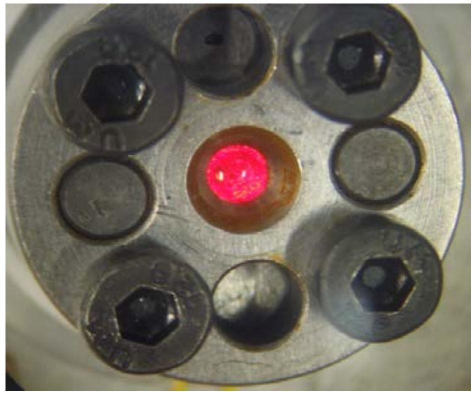
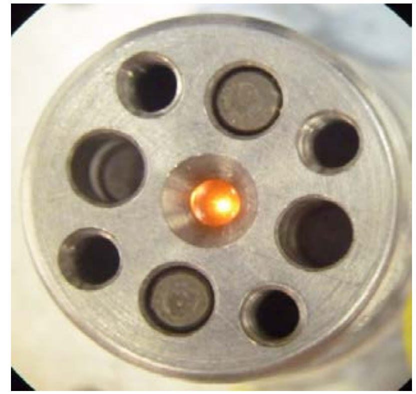


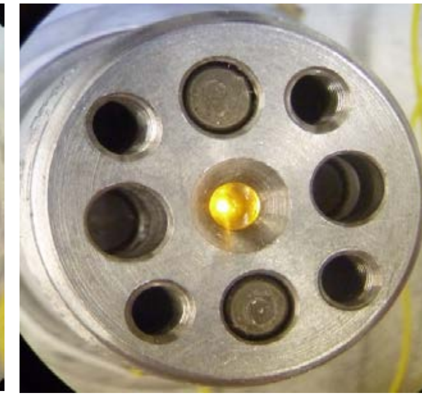
0 kbar



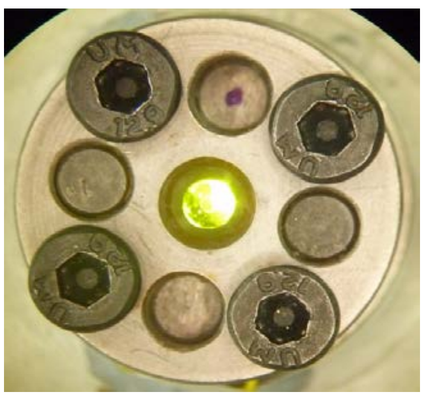
4 kbar



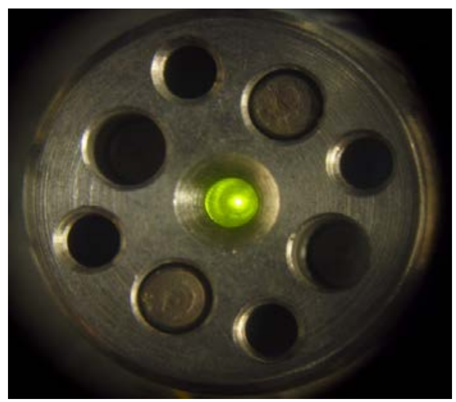
9 kbar



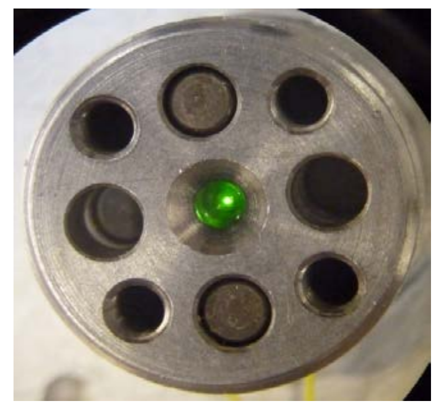
11 kbar



20 kbar



21 kbar



26 kbar

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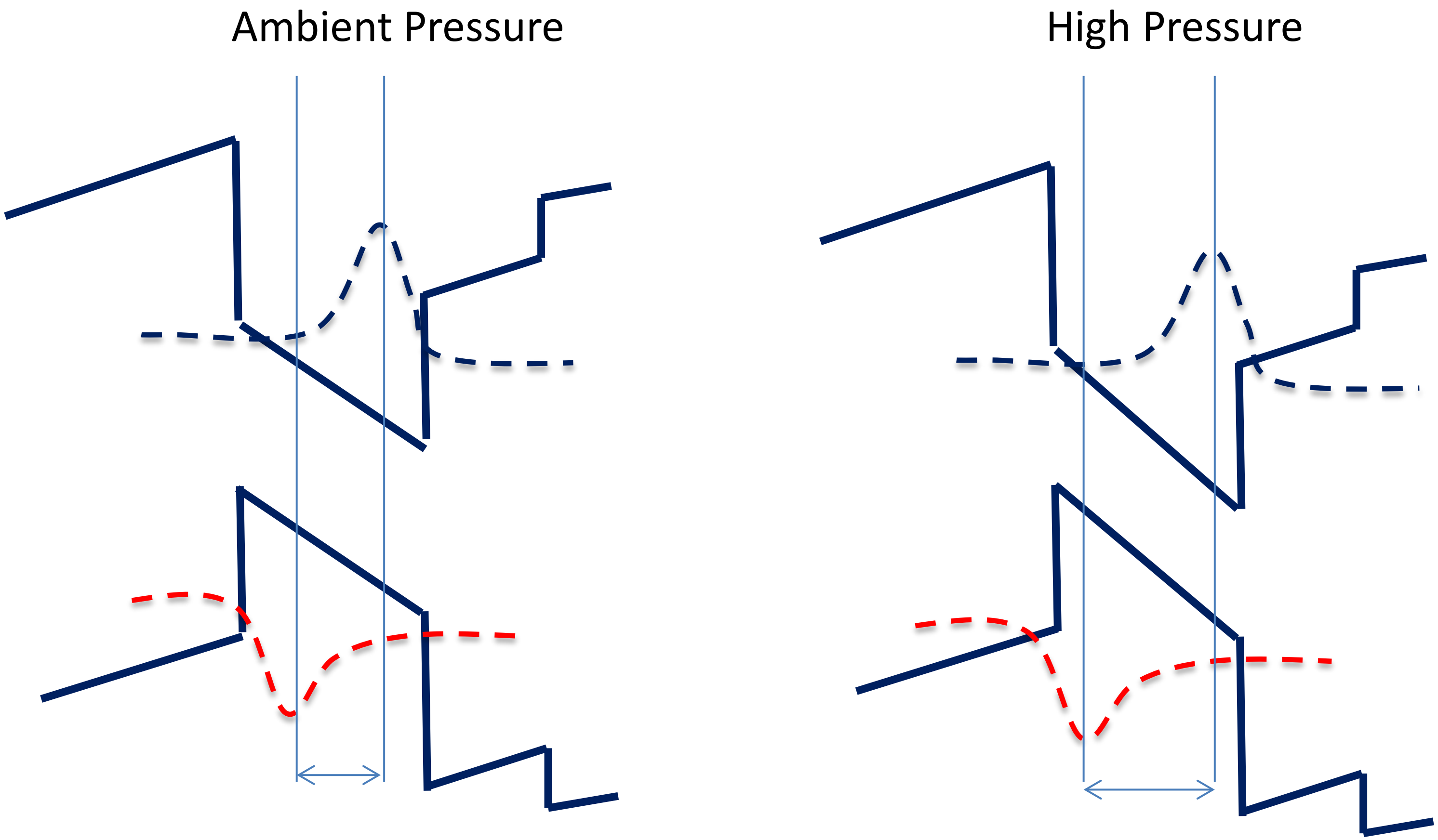
High hydrostatic pressure also increases the piezoelectric field in nitride III-V



Radiative rate ↓

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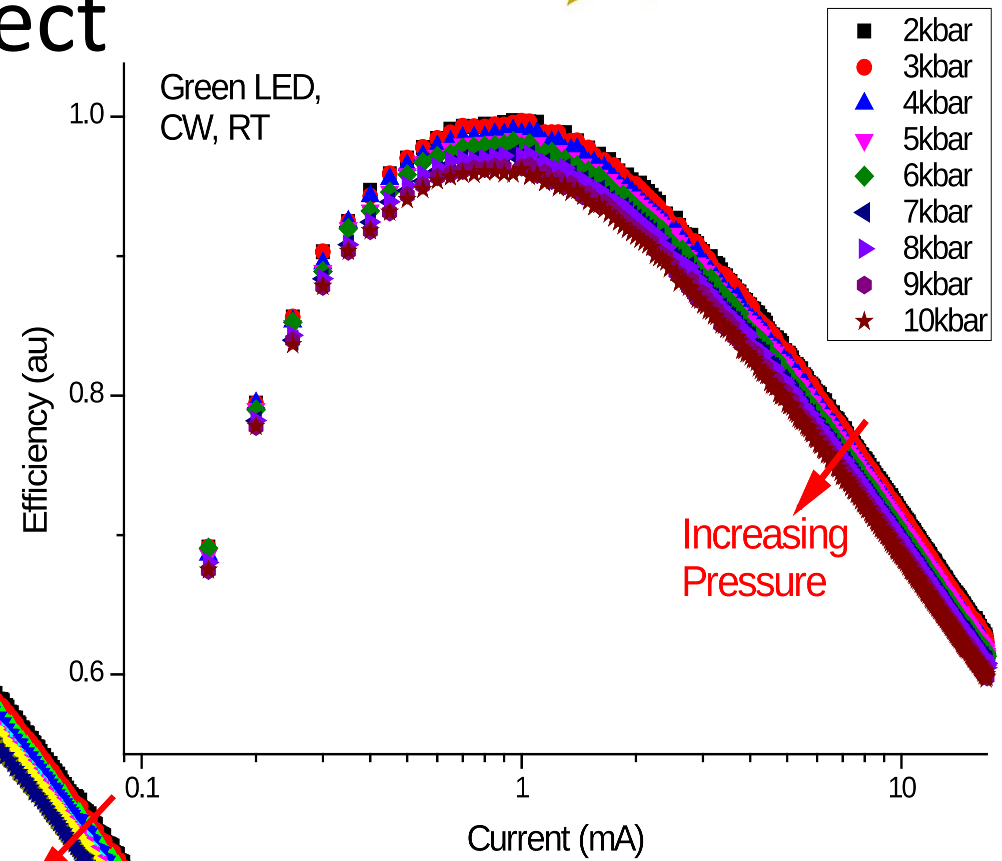
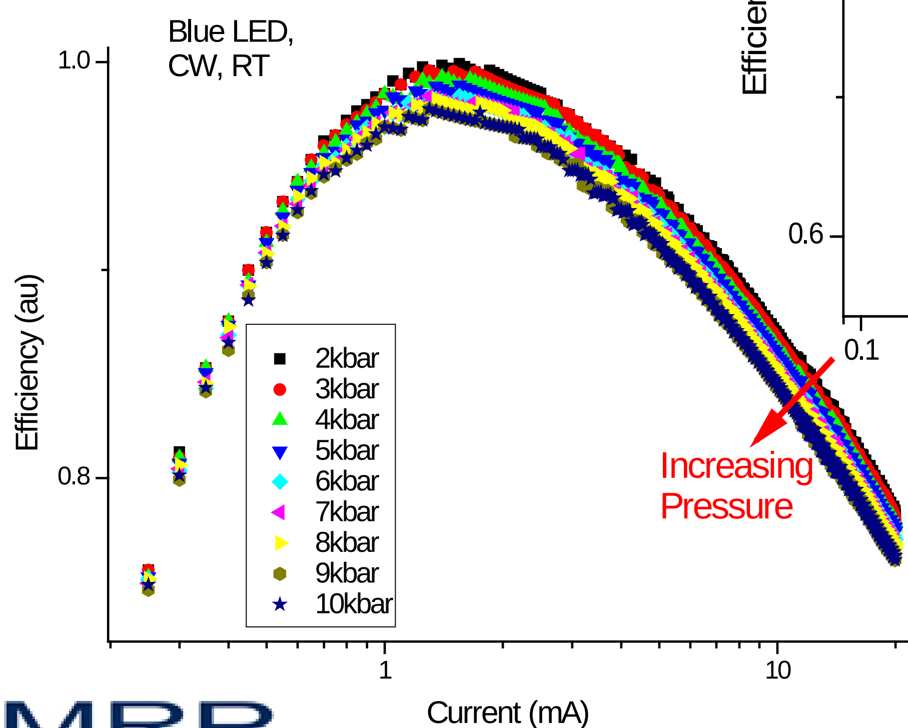
Influence of pressure on the efficiency droop effect

Pressure ↑
Peak efficiency↓
Droop effect≈ pressure insensitive

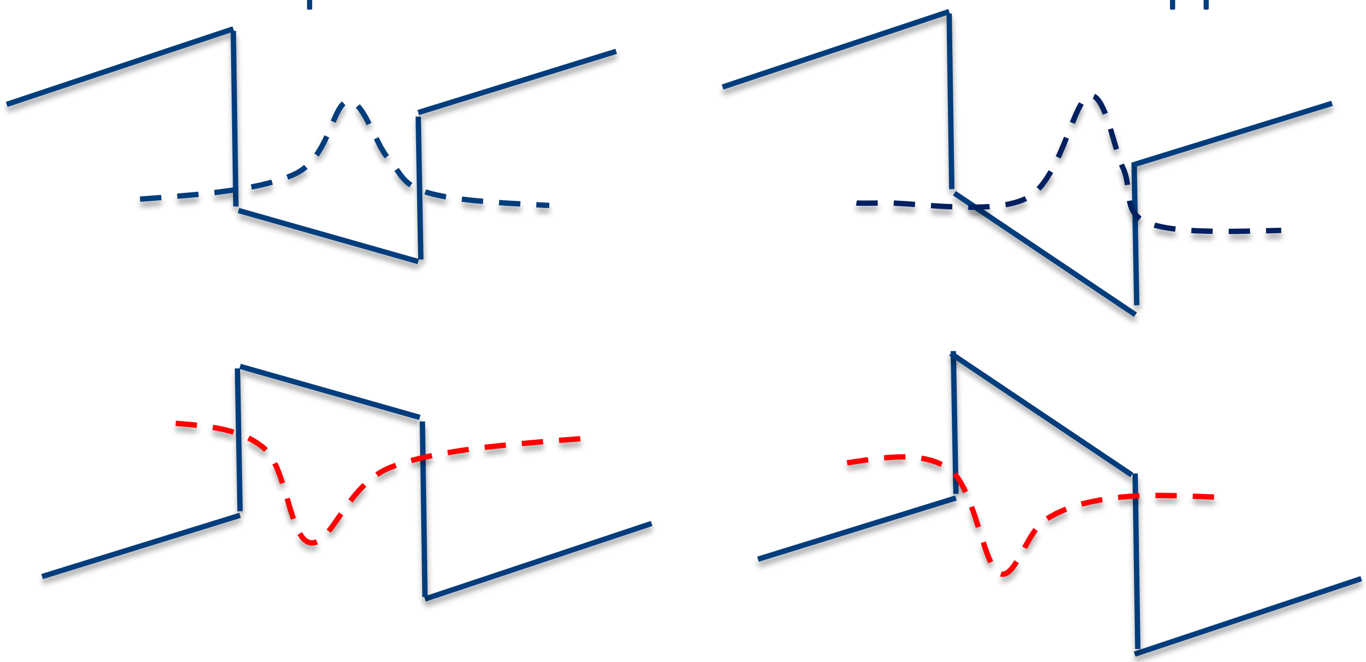




Can carrier leakage explain this?

Ambient pressure

Pressure applied



•Fields increase

•If carrier leakage is dominant, Droop ↑

Not observed

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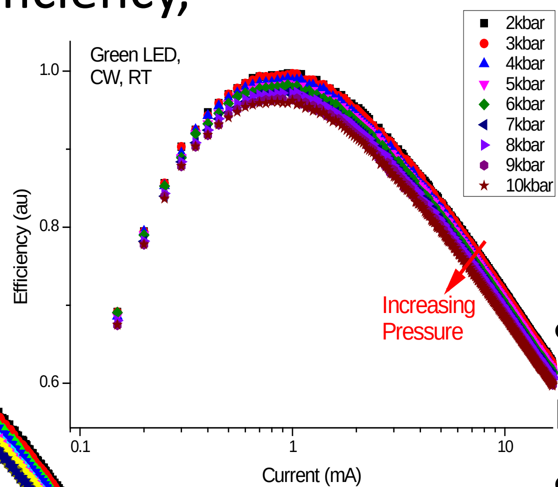
Can Auger recombination explain this?

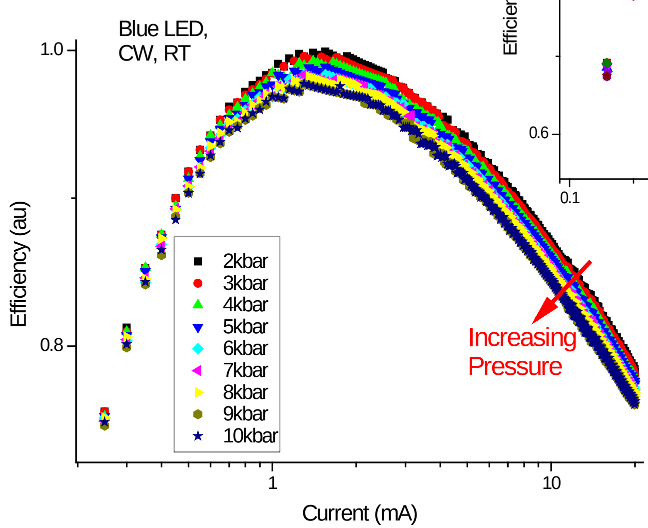
Pressure↑ ,
Auger recombination↓
(in other III-V materials)
Not consistent with reduced peak efficiency and earlier onset of efficiency droop

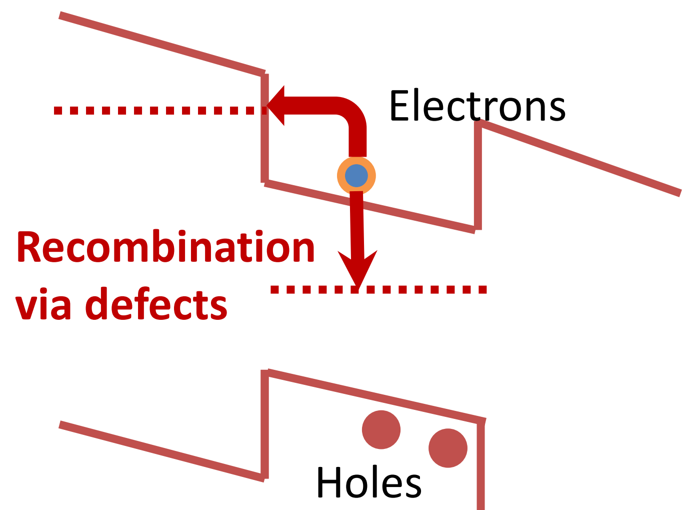
Additionally, pressure↑ , fields↑ ,
→Further reduction of the Auger recombination rate

Can defects explain this?

Fixed current, carrier concentration↑,
Carriers fill potential minima at lower currents,
→Earlier onset of efficiency droop,
→Reduction of peak efficiency,
→Similar droop effect







Findings shows:
- More investigation into the nature of the defect states
- Reduce dislocation density
- Design LED structure to reduce internal field strength

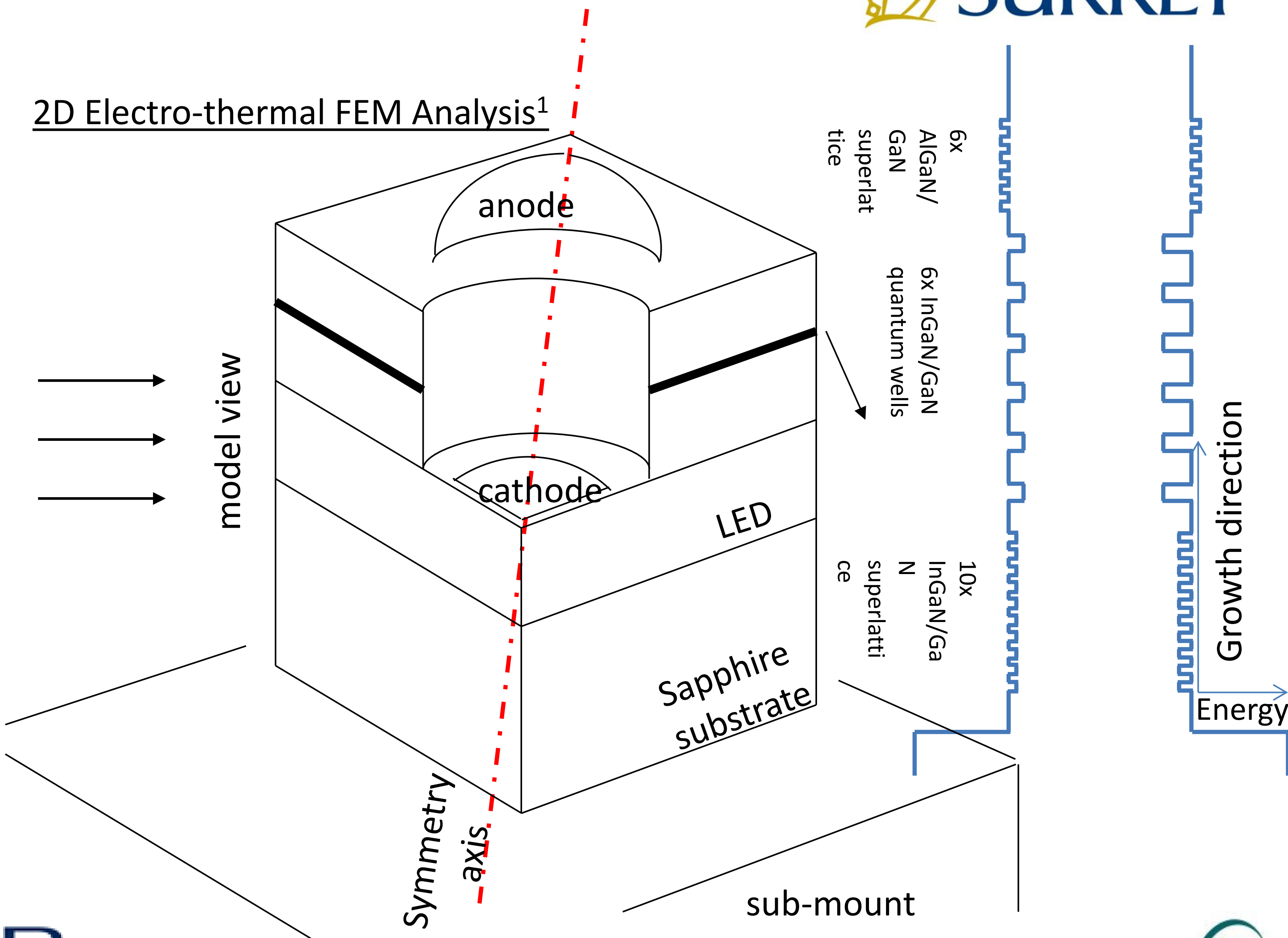
→ Increase efficiency of LEDs

Thermal modelling of visible LEDs

Thermal modelling of operational LEDs

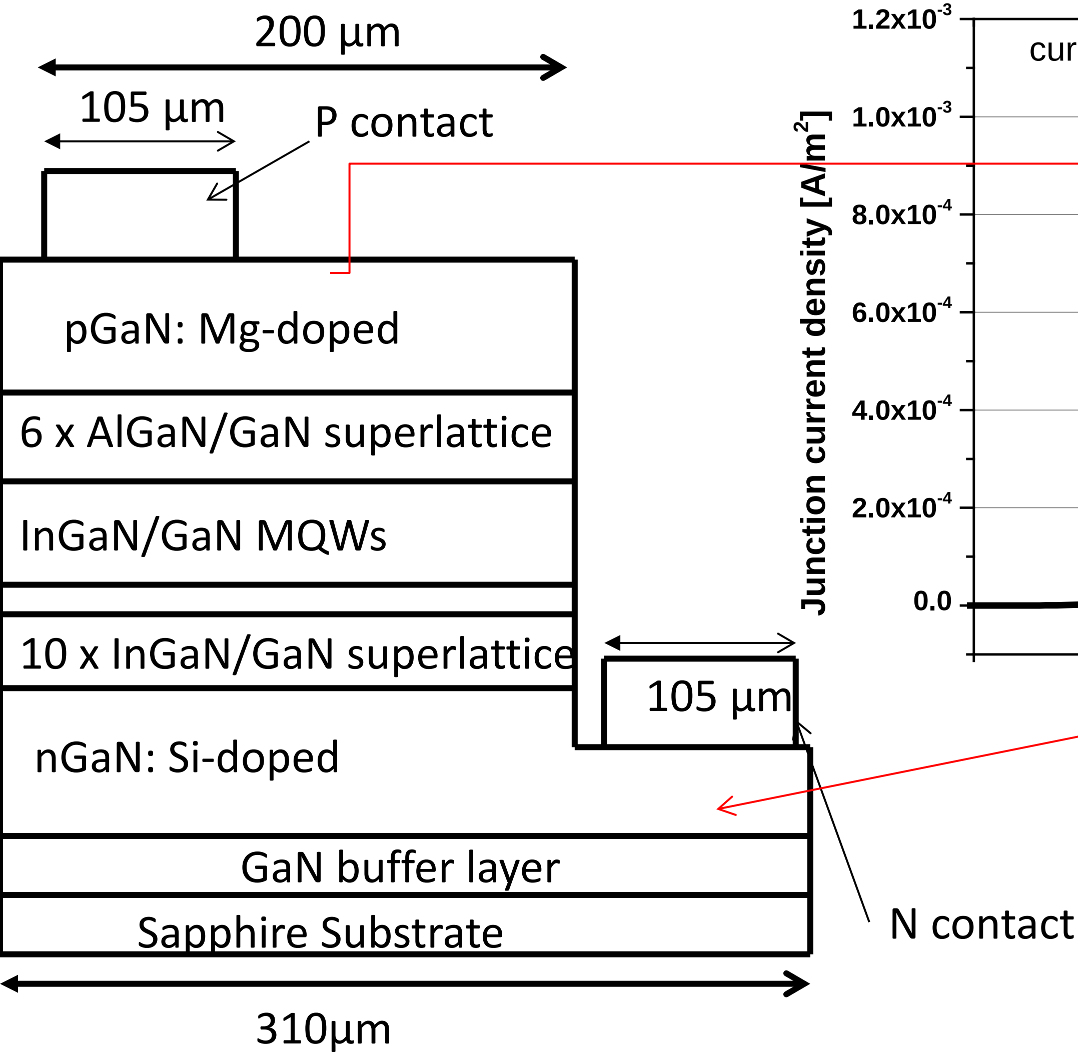
- To carry out the thermal model using COMSOL the dimensions: electrical resistivity and thermal properties of each material layer are needed.

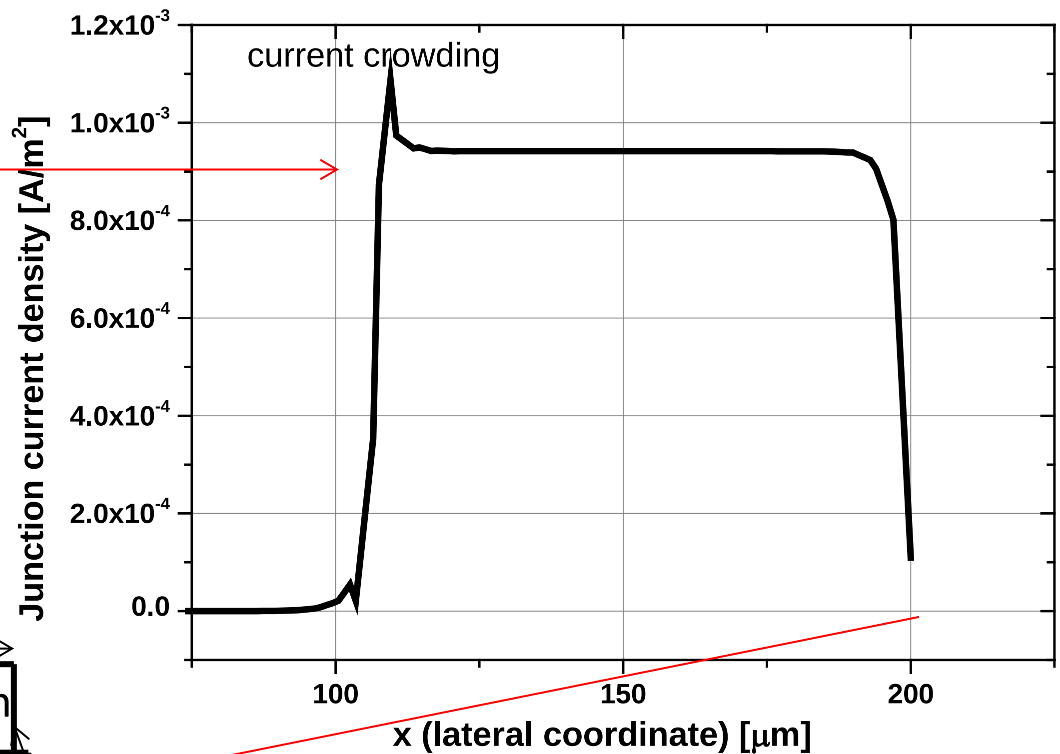
2D Electro-thermal FEM Analysis[1]



[1]J.Mukherjee et.al. IEEE JSTQ. 13, 1180 (2007)

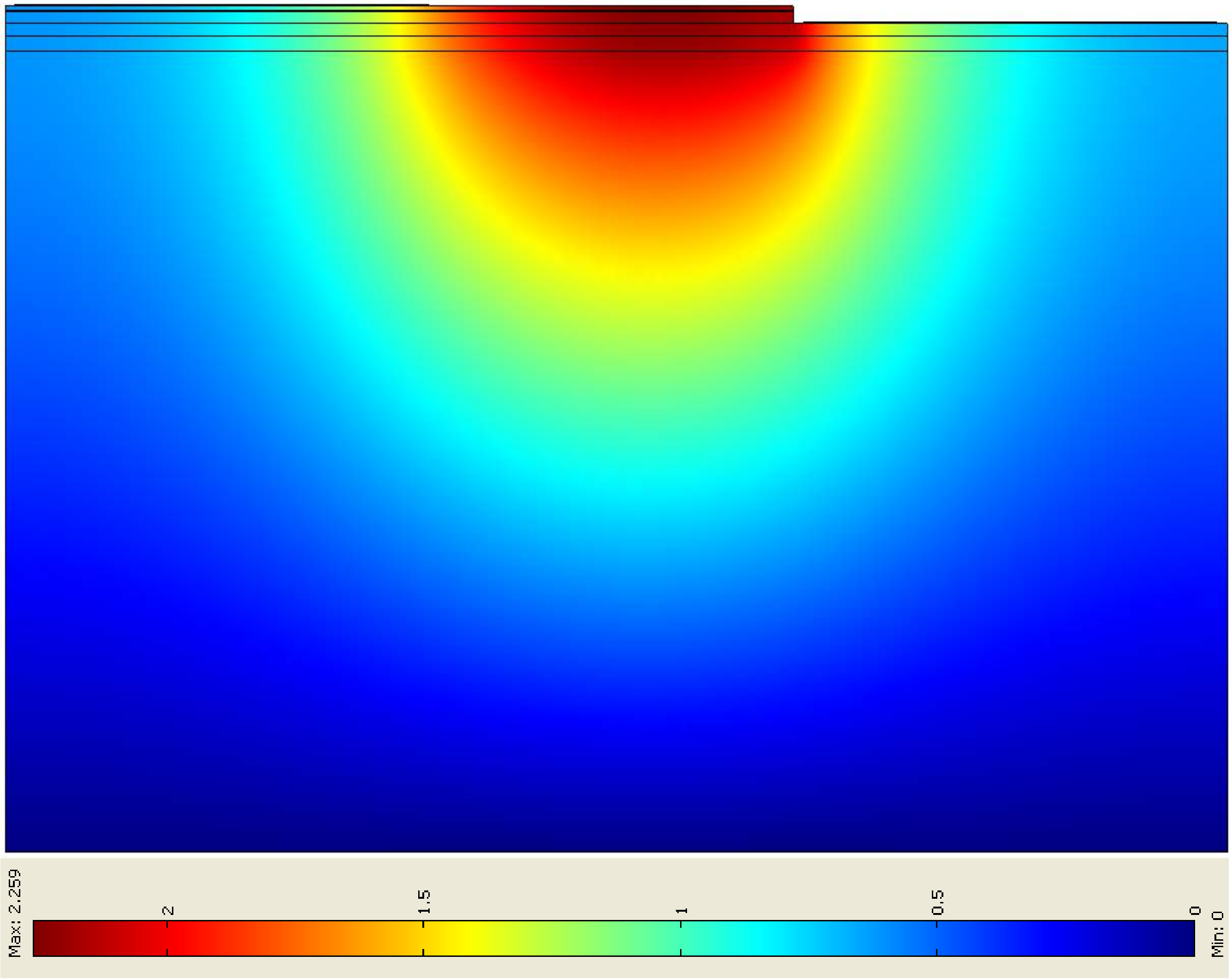
Lateral current spreading





- COMSOL solves the Laplace's equation and the Heat equation in order to determine the current spreading

Thermal mapping



ΔT above ambient (sub-mount temperature) at **2.5 V (~ 10 mA)**

- The software may also be used to obtain a thermal map of the LED.
- It is observed that there Joule heating in the resistive layers.
- The heating of the junction is linked to the current crowding
- May also carry out the modelling at different bias levels to determine whether the model is consistent with experimental observations

Conclusion

- COMSOL used to thermally model operational devices
- This is carried out by solving the Laplace's equation and the Heat equation
- Leads to the current spreading in the device
- A thermal map of the operational device may be achieved at different bias levels

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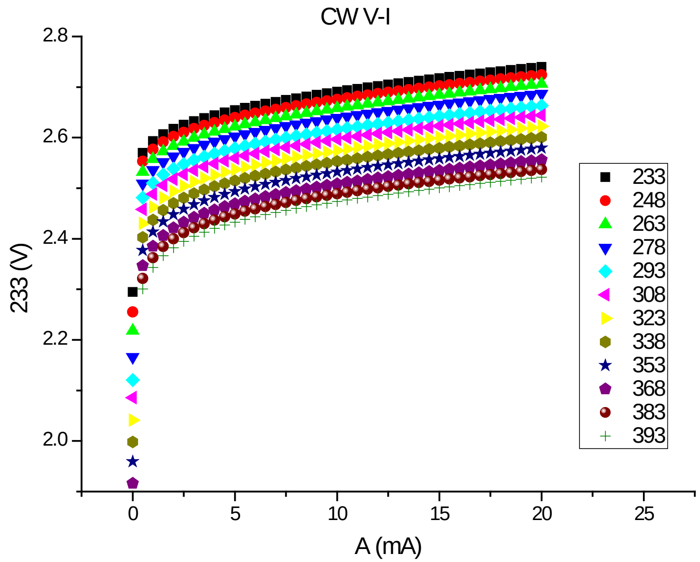
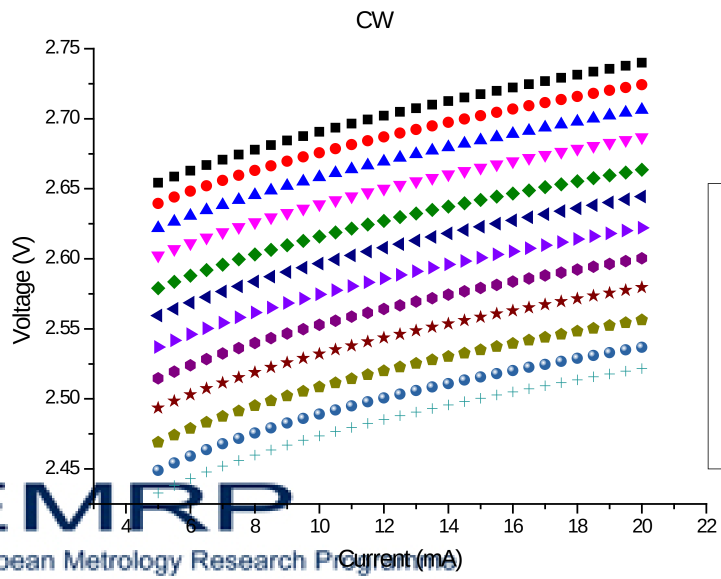
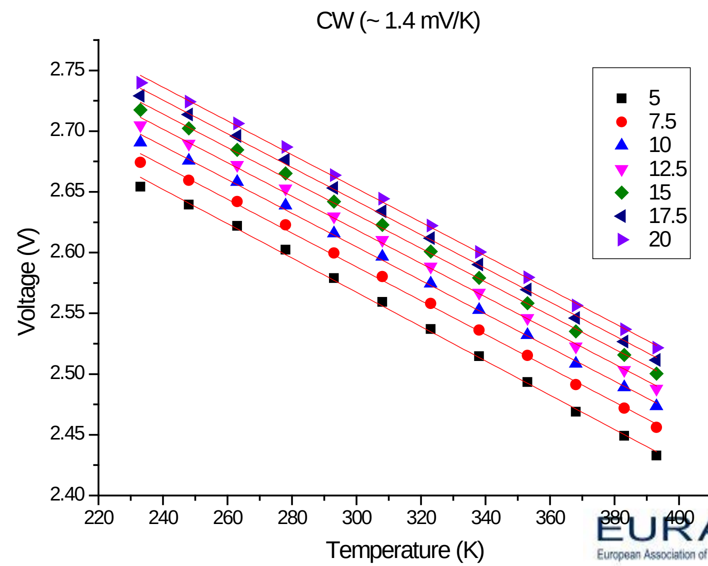
Task 1, Temperature and current dependence of SSL Pump LED Characteristics



Under CW conditions, the device voltage increases by ~ 1.4 mV / K





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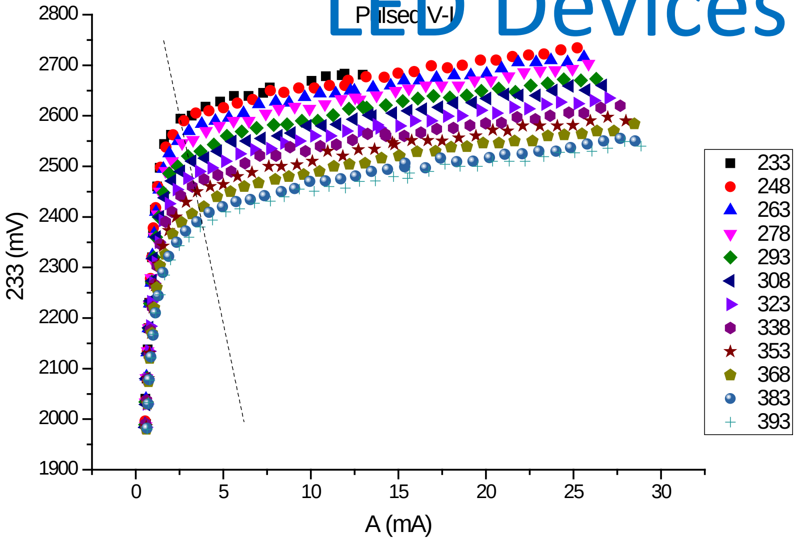
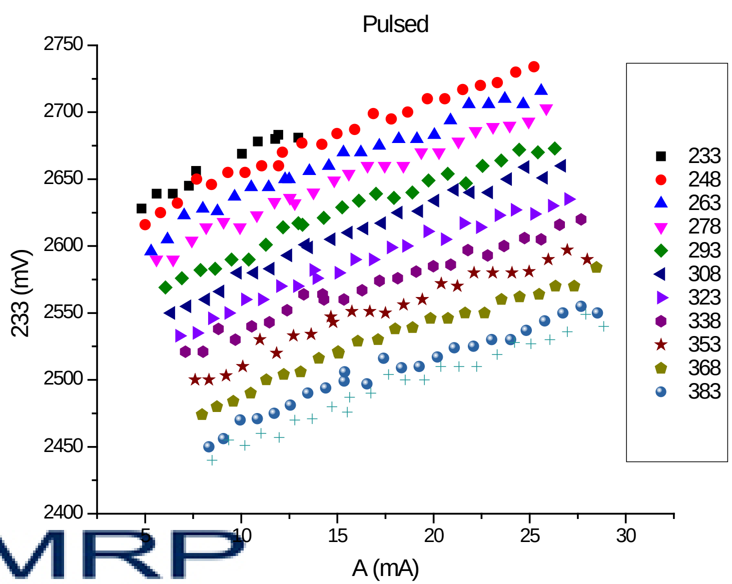
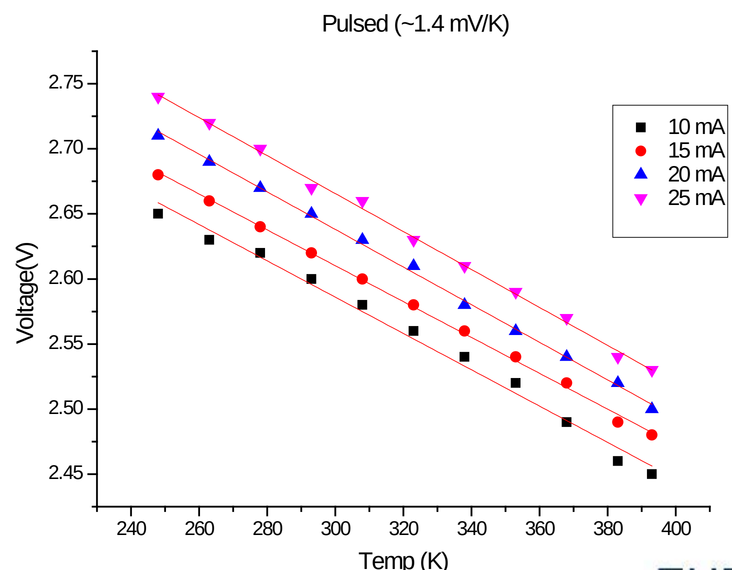
LED Devices



Under Pulsed conditions (10 KHz, 500 ns) the data is more scattered due to lower light output, and the device voltage increases at ~ 1.4 mV / K





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CW Spectra

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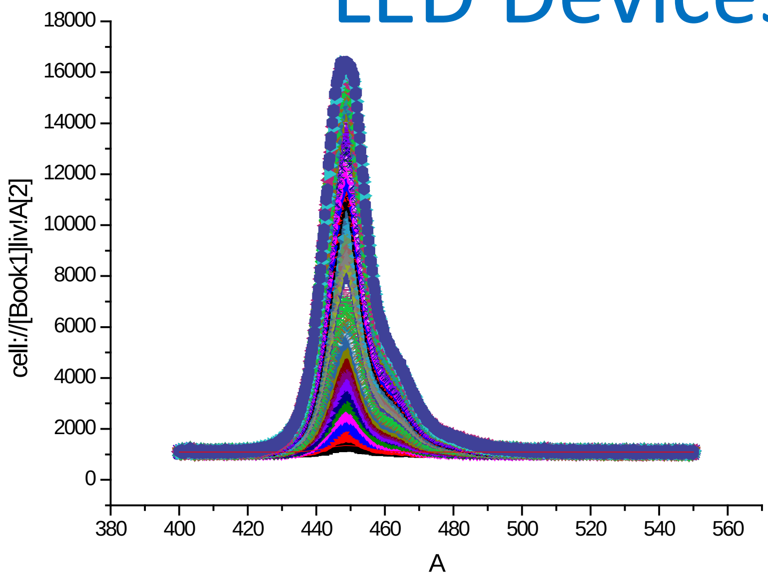
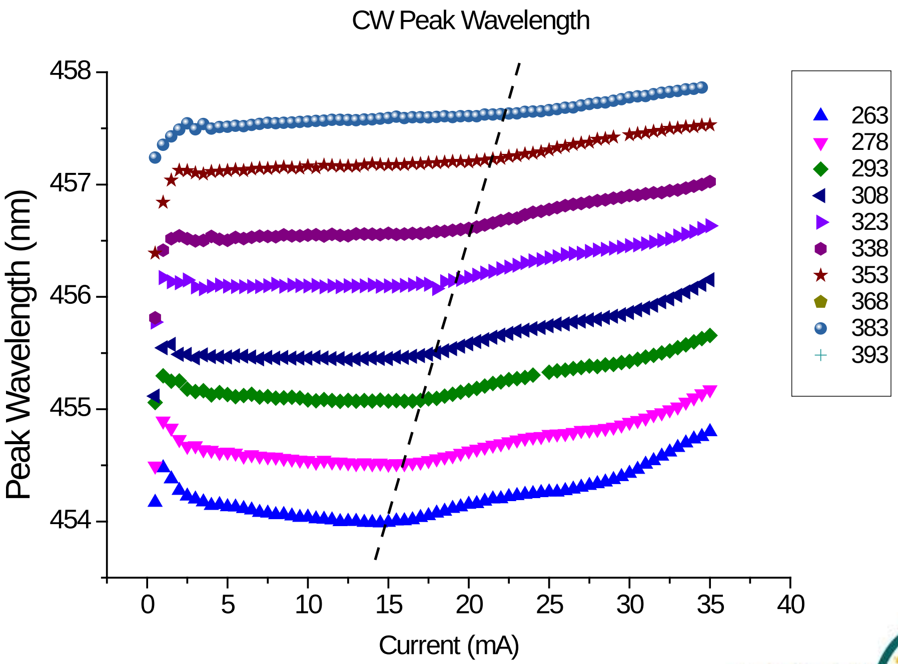


With increasing current the peak wavelength shift is small over this current range < 1nm

However, we do observe an initial decrease with current before the wavelength then starts to increase

The point at which the wavelength starts to increase is observed to increase with increasing temperature and is due to heating effects



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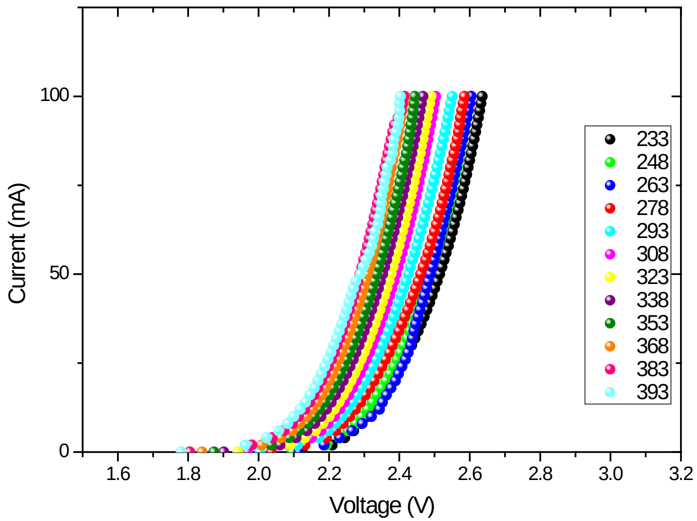

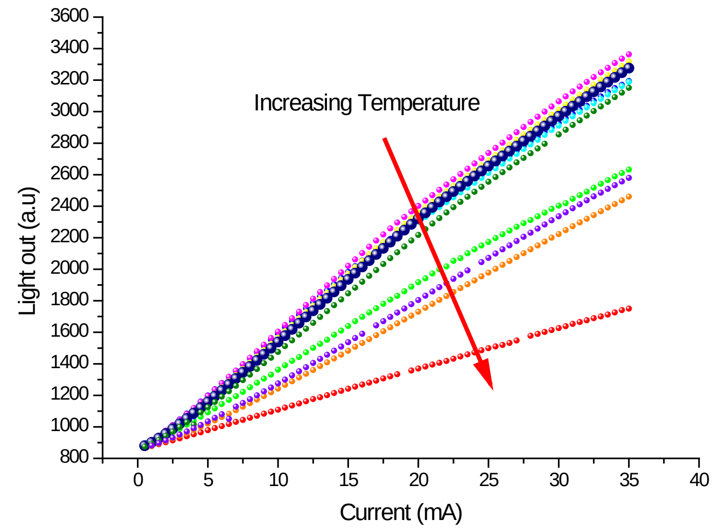

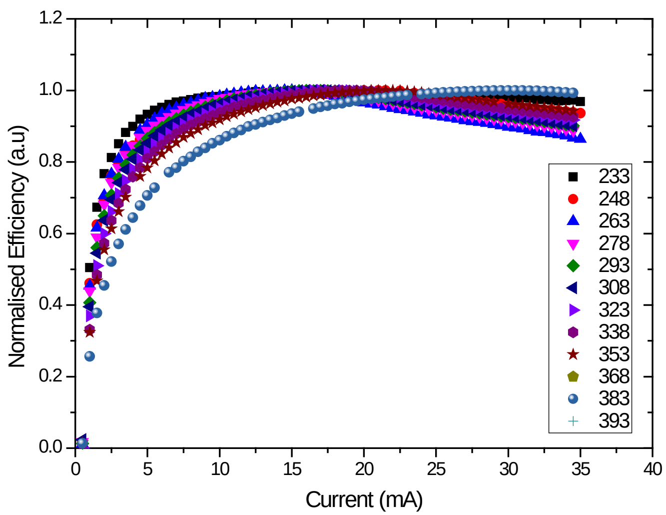

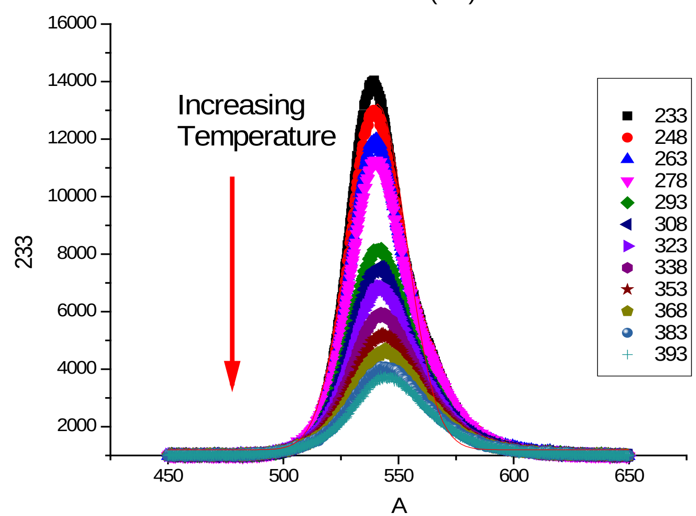

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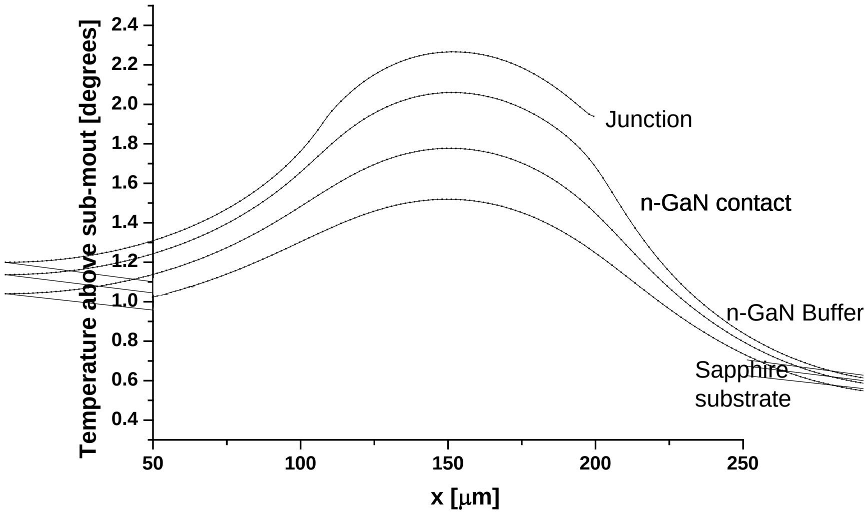

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