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Mitigating the “Green droop” effect of Nitride LEDs

EMRP JRP ENG05

Metrology for Solid State Lighting

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Metrology for Solid State Lighting

EURAMET European Association of National Metrology Institutes

Solid State Lighting Requirements

Societal Need:

- Energy savings
  - Traceable metrology
- Reduced carbon footprint
  - Longevity
  - Lower maintenance costs
- Energy efficient lighting for domestic, industrial and public spaces
  - Colour differentiation
  - Human factors
- Address fragmented EU metrology

"Green Droop" effect for Nitride LEDs

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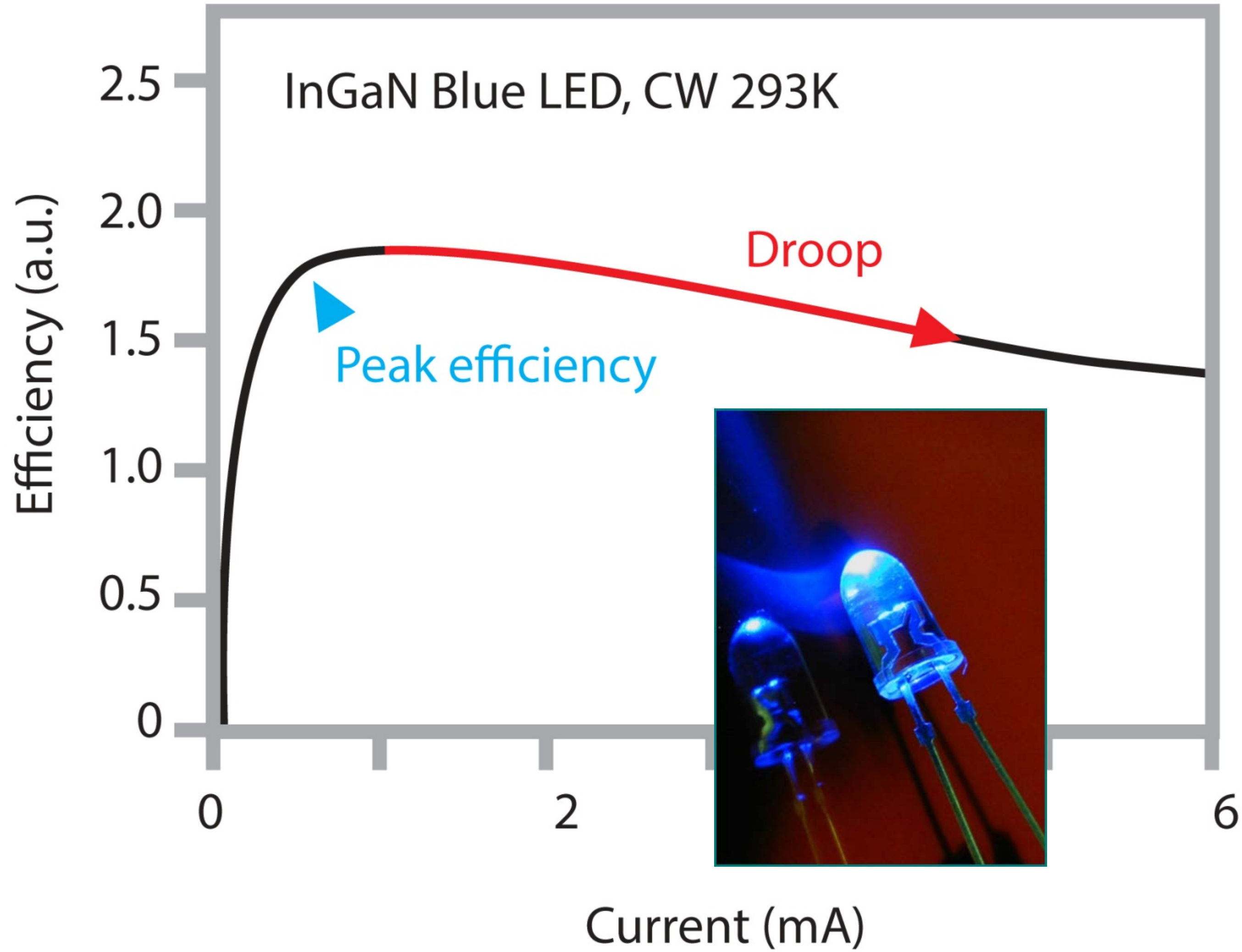

Photon absorption in a p-n homojunction

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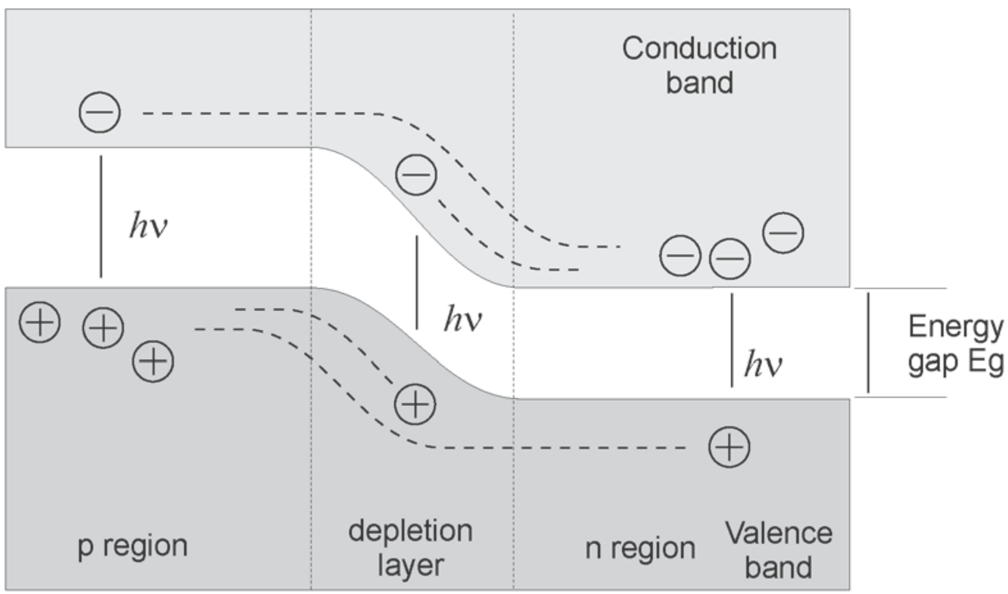
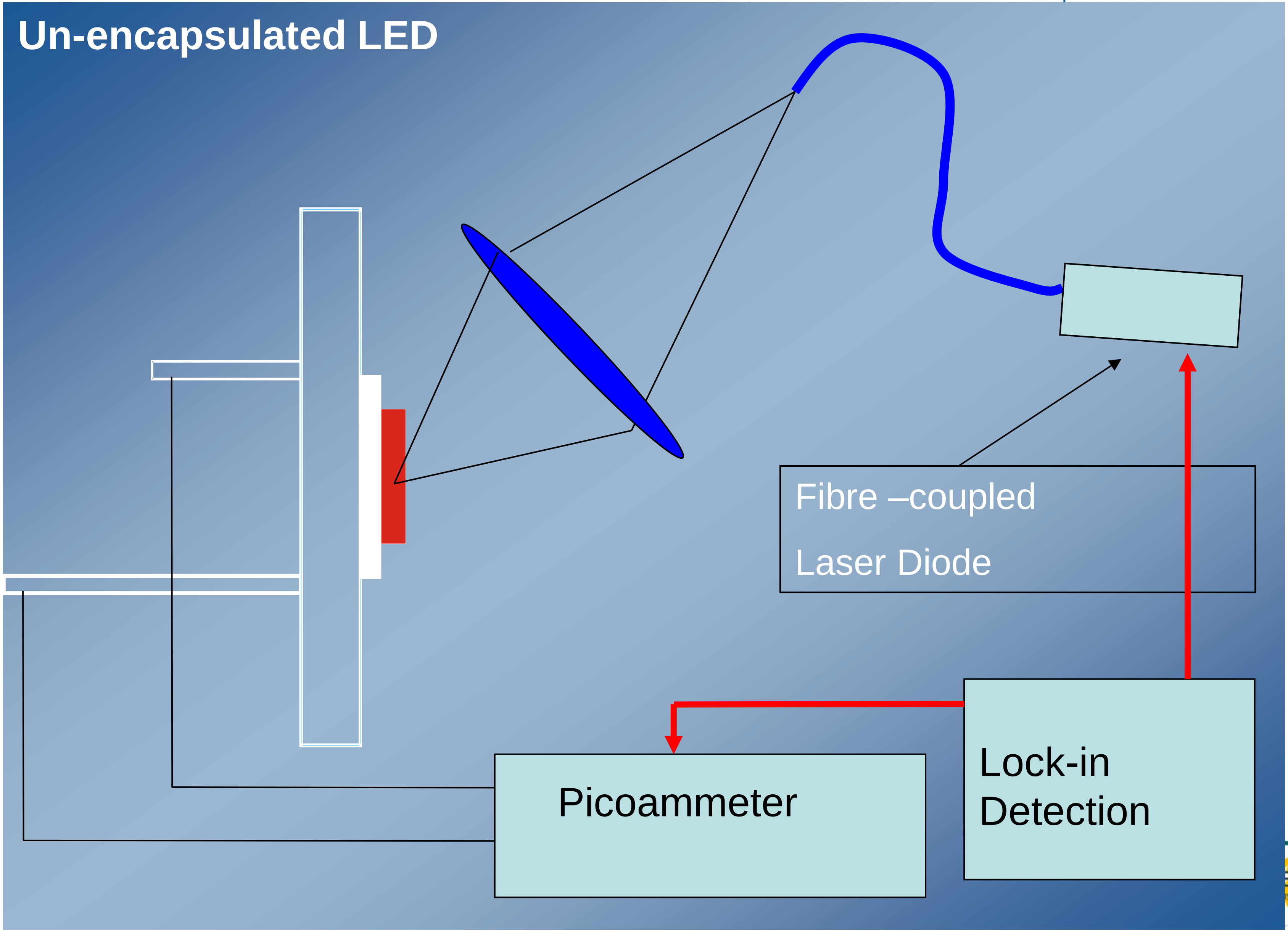


Resonant absorption technique for measuring band gap of Light Emitting Diodes (LEDs)



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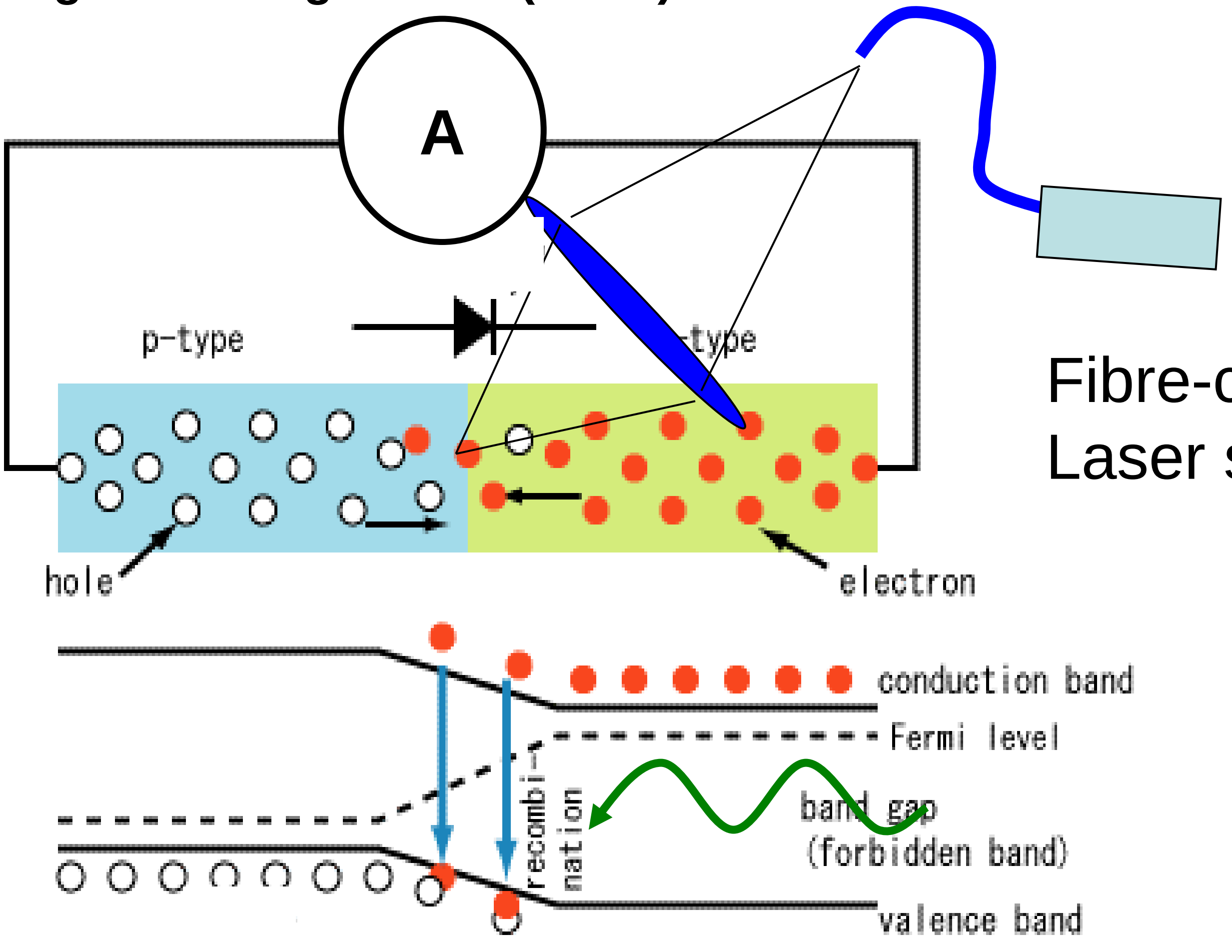
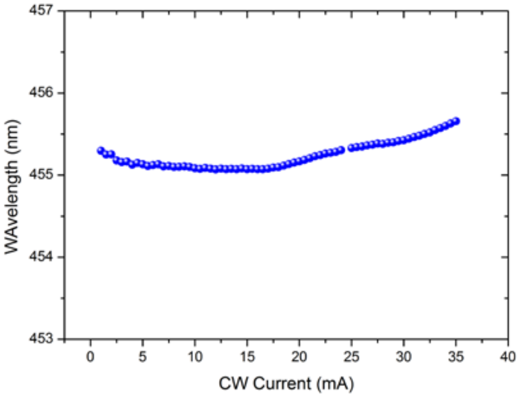


Fibre-coupled Laser source

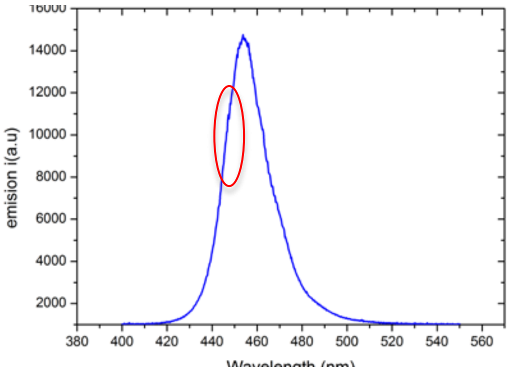
Existing methods

➢ Wavelength shift



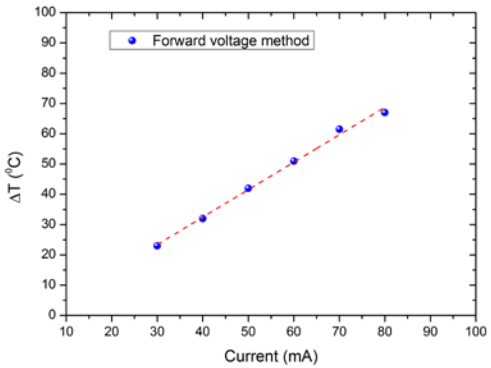
J. Senawiratne, A. Chatterjee, T. Detchprohm, W. Zhao, Y. Li, M. Zhu, Y. Xia, X. Li, J. Plawsky, C. Wetzel, "Junction temperature, spectral shift, and efficiency in GaInN-based blue and green light emitting diodes", Thin Solid Films 518, 1732 (2010).

➢ Spectral analysis



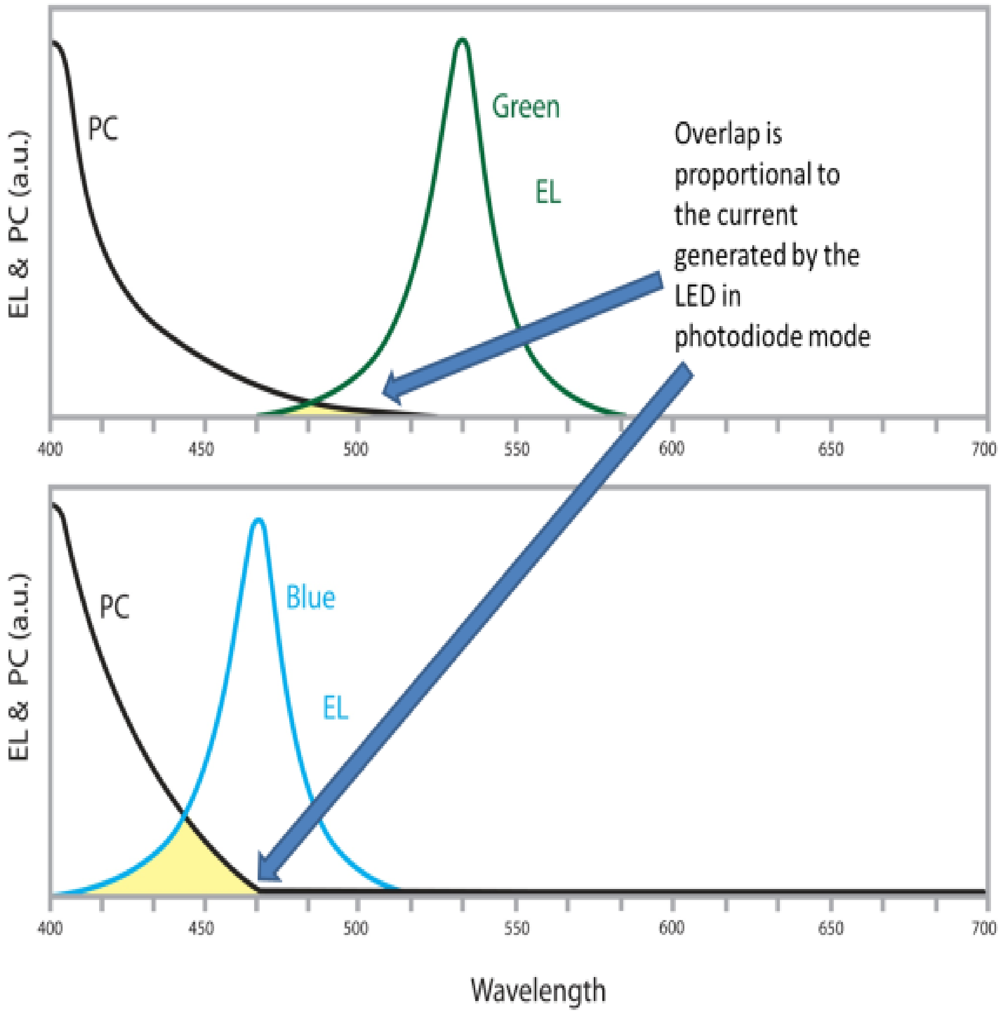
Z. Vaitonis, P. Vitta, and A. Žukauskas, "Measurement of the junction temperature in high-power light-emitting diodes from the high-energy wing of the electroluminescence band", J. Appl. Phys. 103, 093110 (2008)

➢ 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).

Theory of measurement



- Blue emitting devices have the ability to generate photocurrent in another blue device due to overlapping emission and absorption edges
- The large Stoke's shift of the green devices, show that a blue device should also be able to generate a photocurrent in a green device
- The emission of the Blue LED sits on the Urbach tail of both Green and Blue
- Urbach tail is $\propto$ T and is a material property

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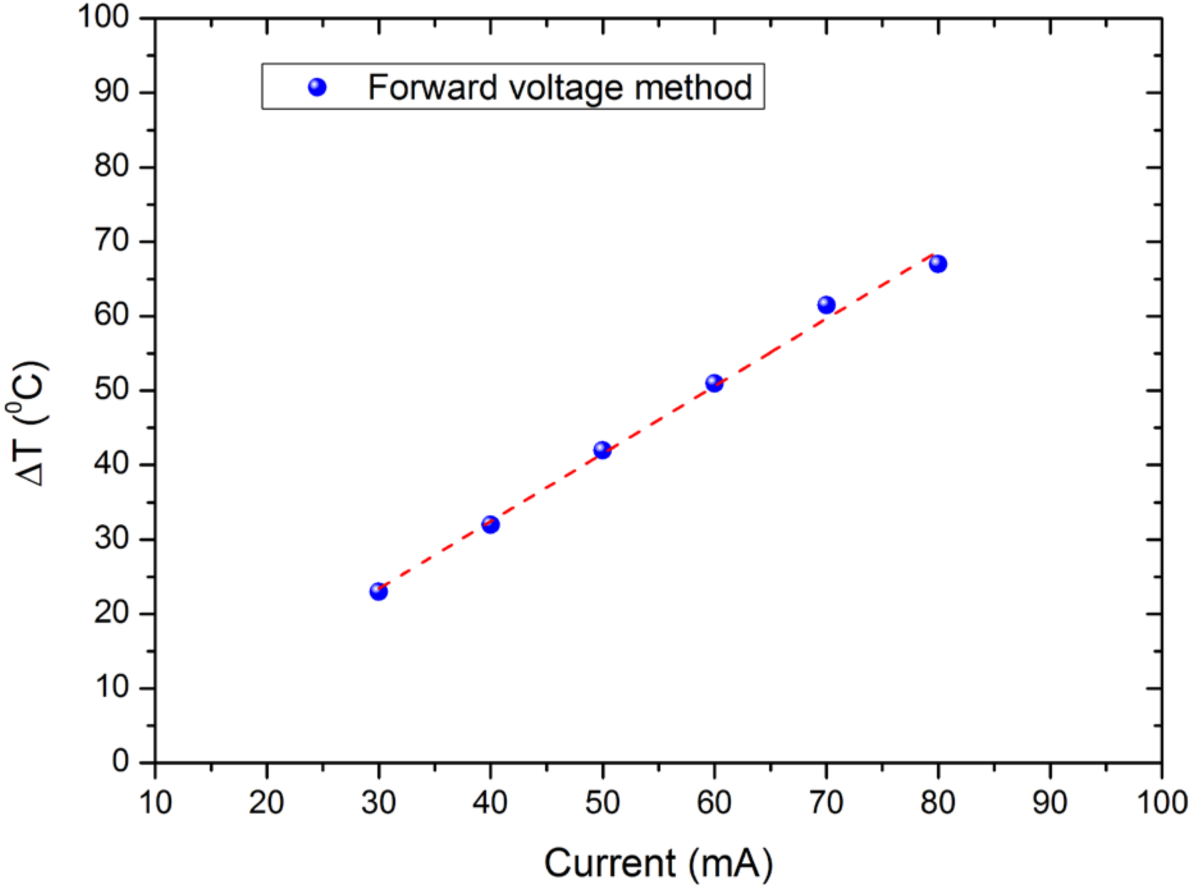
Forward voltage measurement

green (NSPG510S)
Nichia InGaN LED

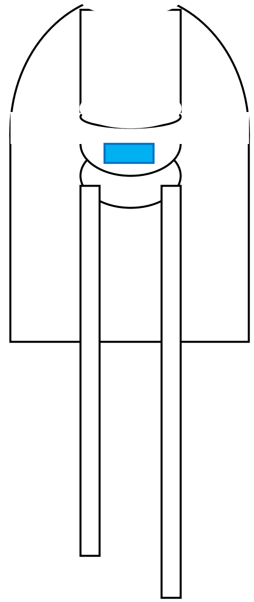
ΔT is the measured J_t – Bulk T

Pulsed duty cycle < 0.1 %



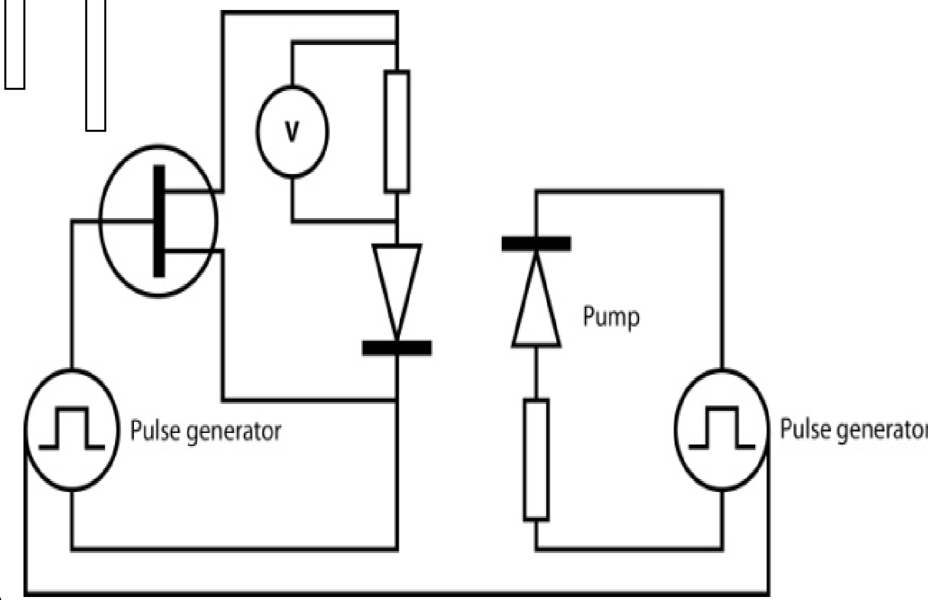
F_v = 87 ^{0}C (ΔT is 67 ^{0}C + 20^{0}C bulk) at 80mA

Experimental set-up



Devices drilled to accept POF then polished

Nichia blue (NSPB510s)
Nichia green (NSPG510S)

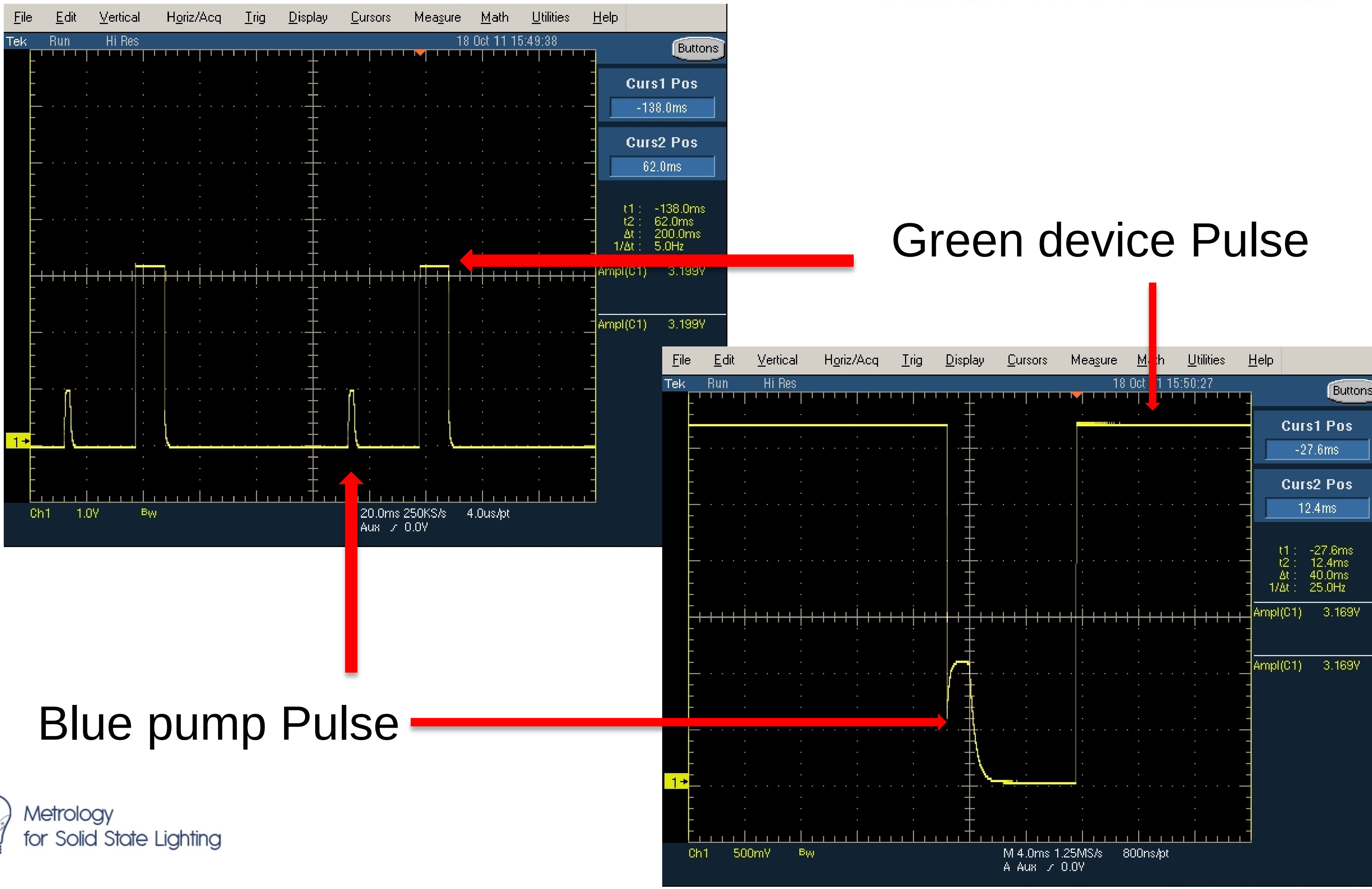


Two pulse generators with a linked trigger

Voltage measurement is across a 47Ω resistor

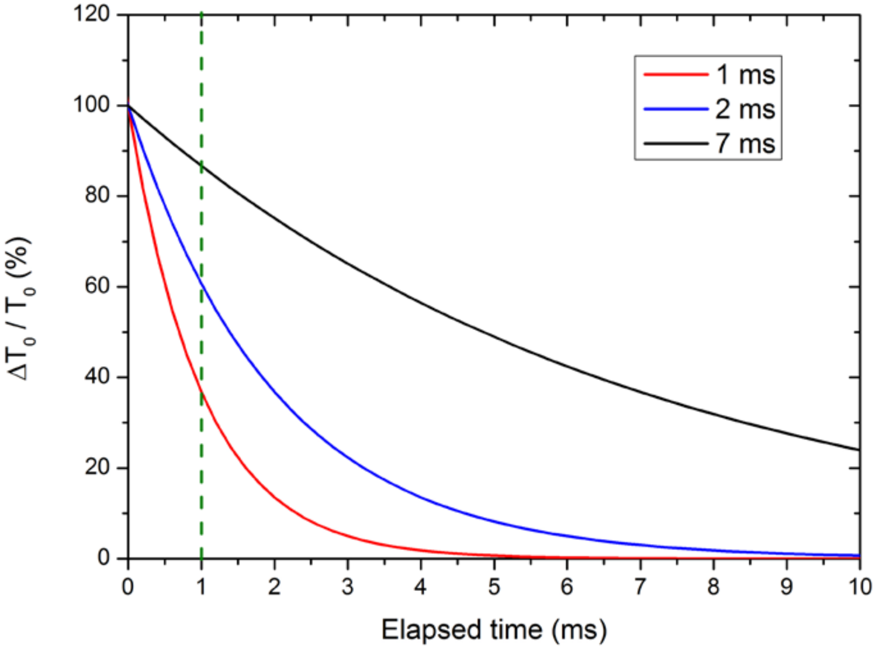
Pump fixed at 100 mA for all measurements

Pulse Regimes



Thermal Co-efficients

$$T(t) = T_0 + \Delta T_0 e^{-t/\tau}$$



where T(t) is the time (t) dependence of the absolute device temperature, T_0 is the ambient temperature and ΔT_0 is the initial temperature above ambient.

References indicate our LED type will have a 1-2 ms time co-efficient

A measurement within 1 ms of the device switching off will be between ~ 30% and 60% of the device temperature at switch off

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Q. Shan, Q. Dai, S. Chhajed, J. Cho, and E. F. Schubert “Analysis of thermal properties of GaInN light-emitting diodes and laser diodes”, J. Appl. Phys. 108, 084504, 2010.

P. Vitta and A. Žukauskas "Thermal characterization of light-emitting diodes in the frequency domain" Phys. Status Solidi C 6, S877 (2009).

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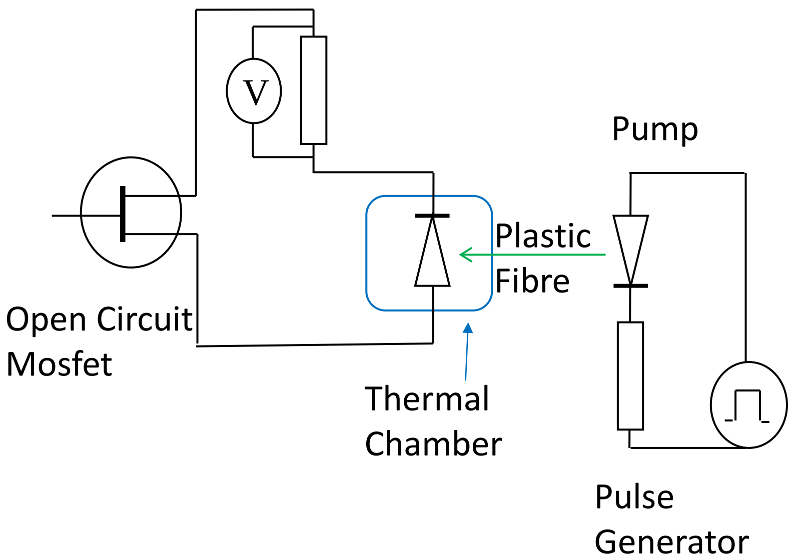
Calibration

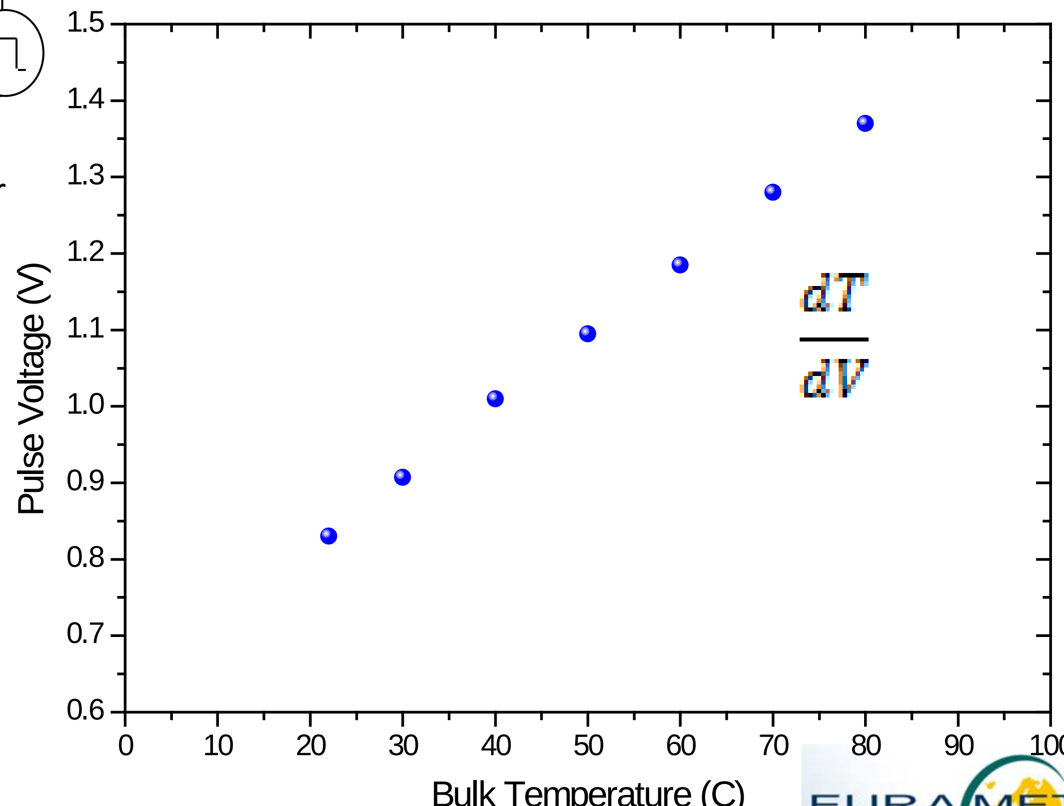


Green device held open circuit

Blue pump set at 100 mA

Bulk temperature set by thermal chamber

Calibration Graph



Junction Temperature

Bulk Temperature $\alpha = V_1 - V_0$

Where V_1 is the measured voltage under zero device drive current
And V_0 the voltage at 0 ^{0}C

Voltage rise due to extra heating $(V_2 - \alpha)\,\gamma$

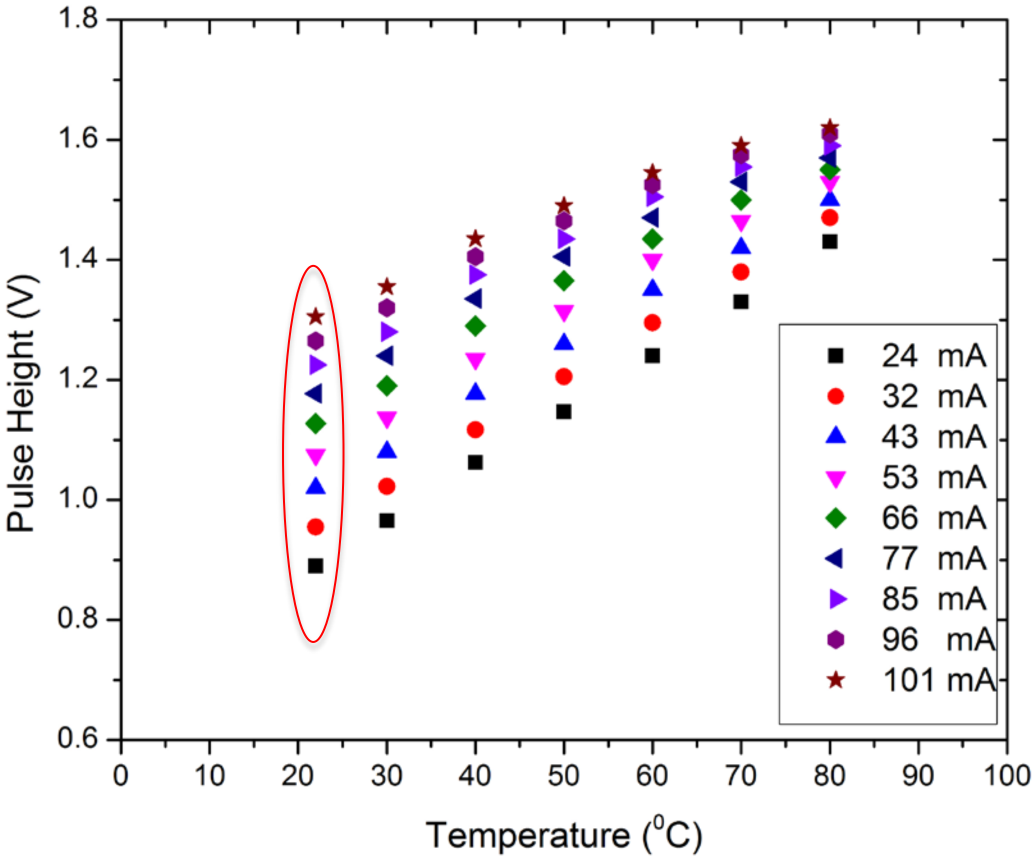
Where V_2 is the measured voltage under operation
And **γ** is the adjustment for temperature decrease

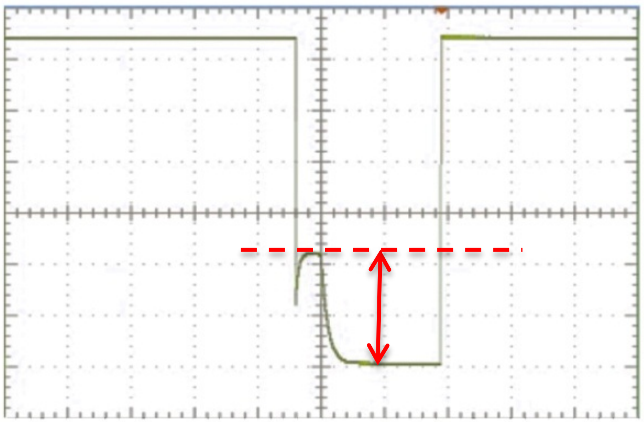
Junction Temperature, $T_j = (V_2 - \alpha)\,\gamma\,\frac{dT}{dV}$

Where $\frac{dT}{dV}$ is the gradient from the calibration graph

Initial measurements

Measurements of the Blue pump pulse height with increasing Green device drive current

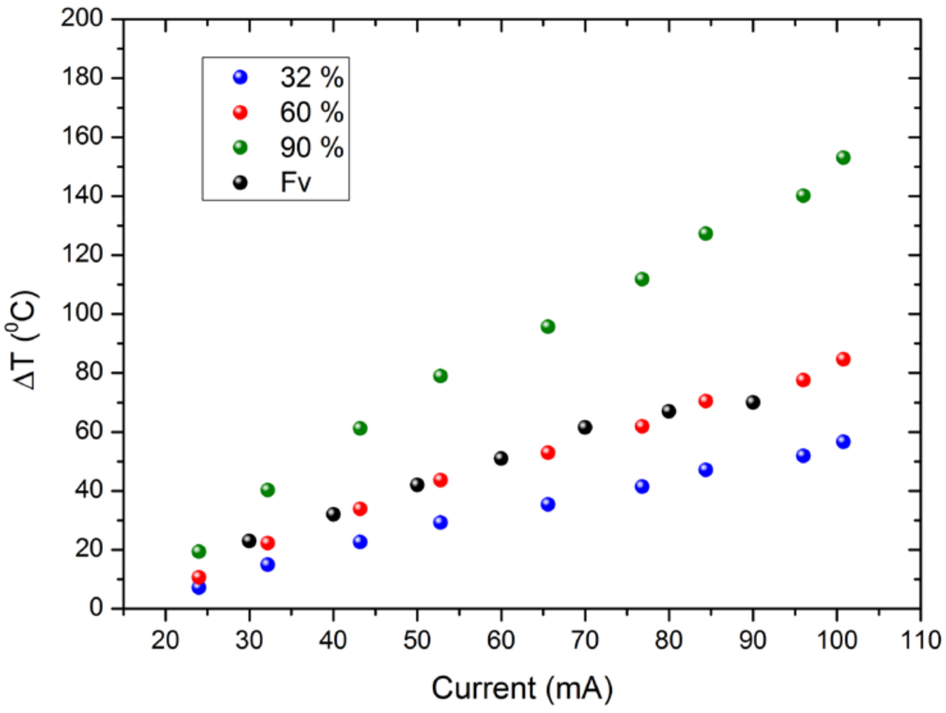




Blue pump pulse height

Temperature co-efficient

With a 1 ms Blue pulse delay, the temperature co-efficient (γ) is between 30 to 90 % of the device temperature



We can plot 30%,60% and 90% values of γ.
From references we expect these devices to have ~ 60 % due to their construction and packaging style

Comparison with Forward voltage techniques is consistent with 60%

ΔT is the measured J_t – Bulk T

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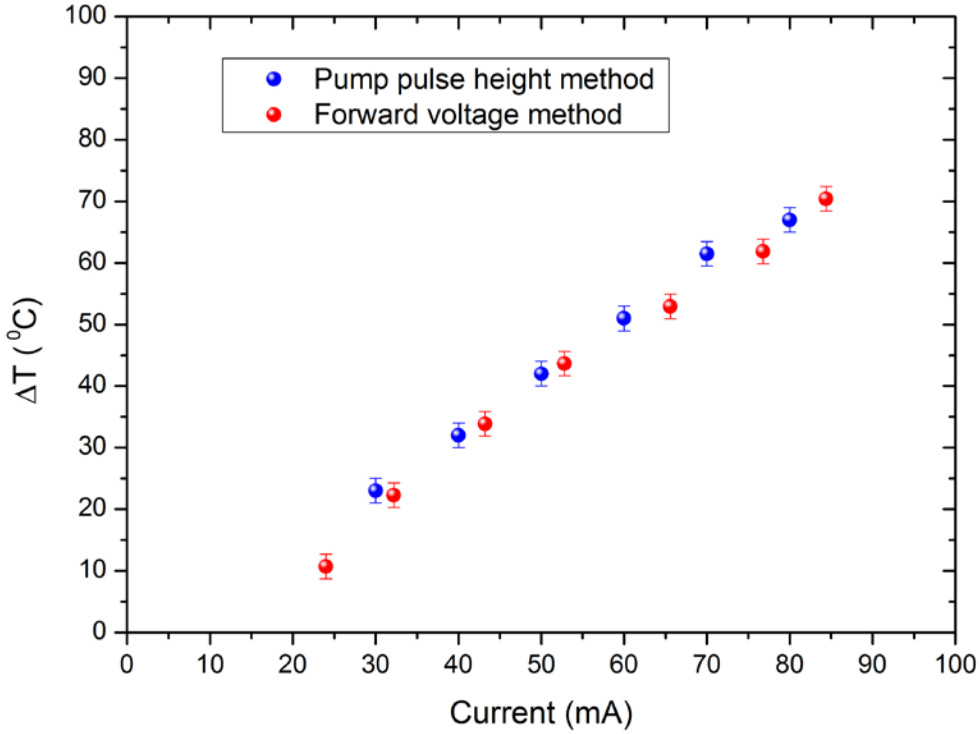
Results



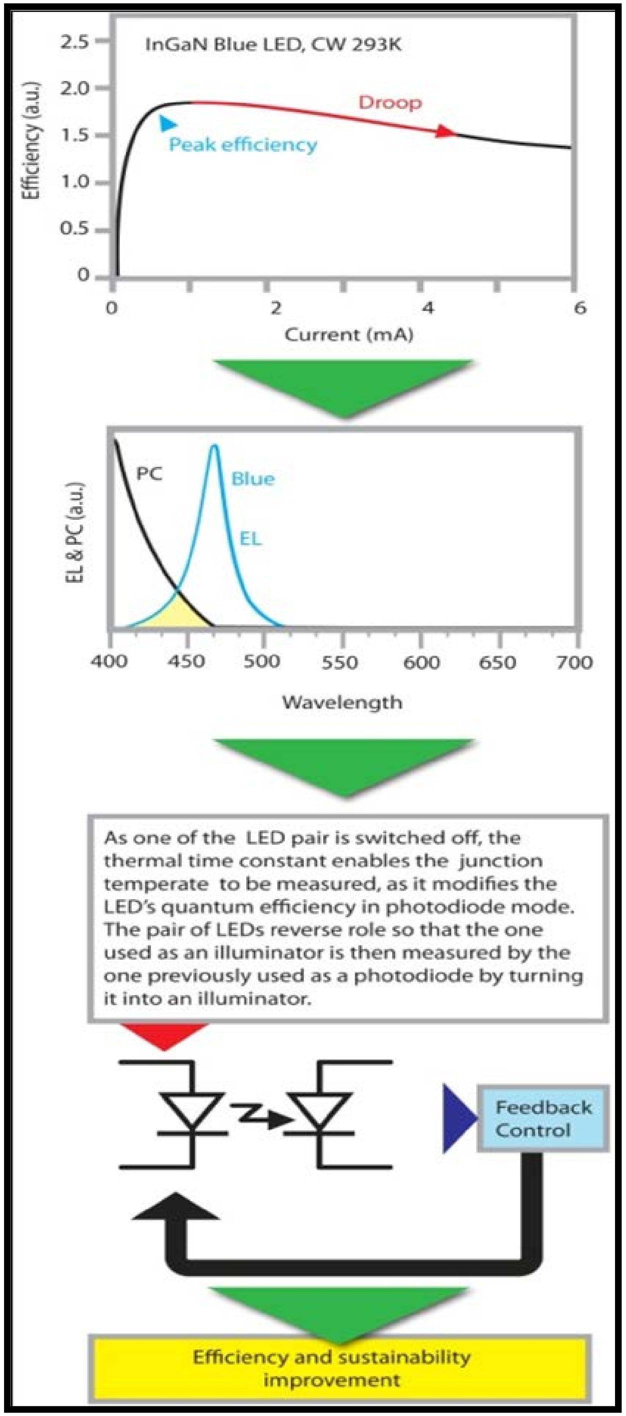
Utilising a temperature co-efficient of 60% we can see that there is good agreement with our measured forward voltage technique

J_T = 86 ^{0}C (ΔT is 66 ^{0}C + 20^{0}C bulk) at 80mA

F_v = 87 ^{0}C (ΔT is 67 ^{0}C + 20^{0}C bulk) at 80mA

Further work

- Measurements of Urbach tail shift with temperature
- Application of this technique to blue devices
- Investigate the technique with the two devices close coupled
- Investigate the technique at raised temperatures
- Increase the Technology Readiness Level of the technique so that it can be exploited commercially



InGaN Blue LED, CW 293K
Efficiency (a.u.)
2.5
2.0
1.5
1.0
0.5
0
Droop
Peak efficiency
0
2
4
6
Current (mA)
EL & PC (a.u.)
PC
Blue
EL
400
450
500
550
600
650
700
Wavelength
As one of the LED pair is switched off, the thermal time constant enables the junction temperate to be measured, as it modifies the LED's quantum efficiency in photodiode mode. The pair of LEDs reverse role so that the one used as an illuminator is then measured by the one previously used as a photodiode by turning it into an illuminator.
Feedback Control
Efficiency and sustainability improvement

Conclusions

- We have demonstrated a novel technique for measuring junction temperature.
- Measurements of the junction temperature of a Green LED device has been shown. The technique should also work for Blue emitting devices.
- Comparison with the forward voltage technique shows good agreement.
- Technique is dependent upon Urbach tail and is therefore a material property.

GB Patent Application No. 1207503.2 – Apparatus and method for monitoring LED efficiency

GB Patent Application No.1207505.7 – Apparatus and method for monitoring LED colour mix

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Conclusions (2)

- Development of a measurement of junction temperature, independent of electrical behaviour
- Ability to measure in-situ within a luminaire without additional architecture
- Ability to measure both blue and green devices in RGB system to provide stability control for colour rendition

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Thank you for your attention

With acknowledgement to EMRP