Thermal performance of 1.3μm InGaAsN/GaAs laser diodes

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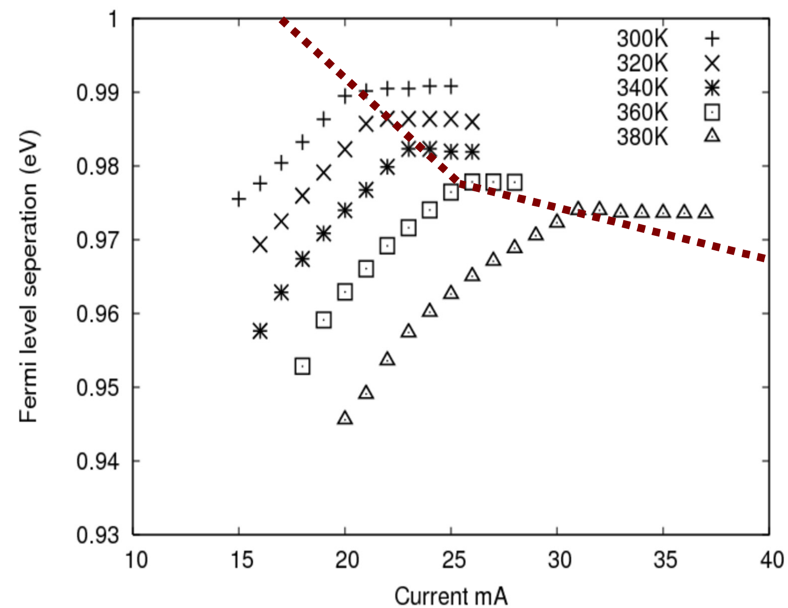
Presentation Outline

- Introduction
- Device Structure
- Thermal Imaging Technique
  - Calibration of Thermal Images
  - Operation at Elevated Temperatures
  - Device Temperature Variations
- Estimation of QW Temperature
  - Measurement of Spectral Shifts
  - Accuracy of Temperature Estimations
  - QW Temperatures during Operation
- Conclusions

Introduction

·1.3μm dilute nitride lasers are becoming feasible competitors to InP-based lasers

- Excellent high temperature performance
  - High T_0 values (up to 282K)
  - Low spectral shifts (up to 0.5nm/K)



R. MacKenzie *et al.*, Presented at EMRS 2007, Strasbourg, France)

·At high temperature in shorter cavities…

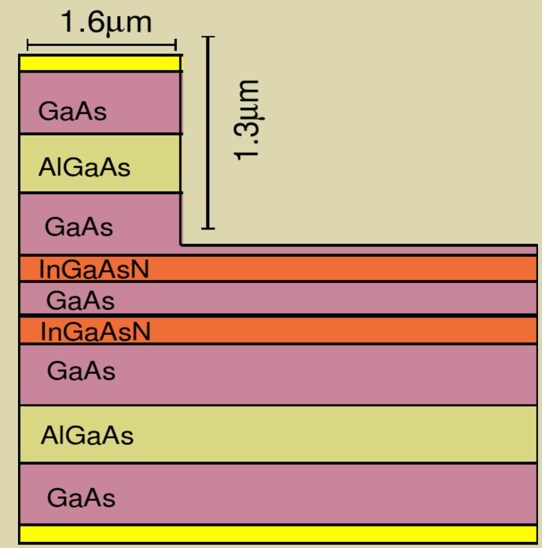
- Two distinctive characteristic temperatures
- Early onset of roll-over

·How is this linked to device heating?

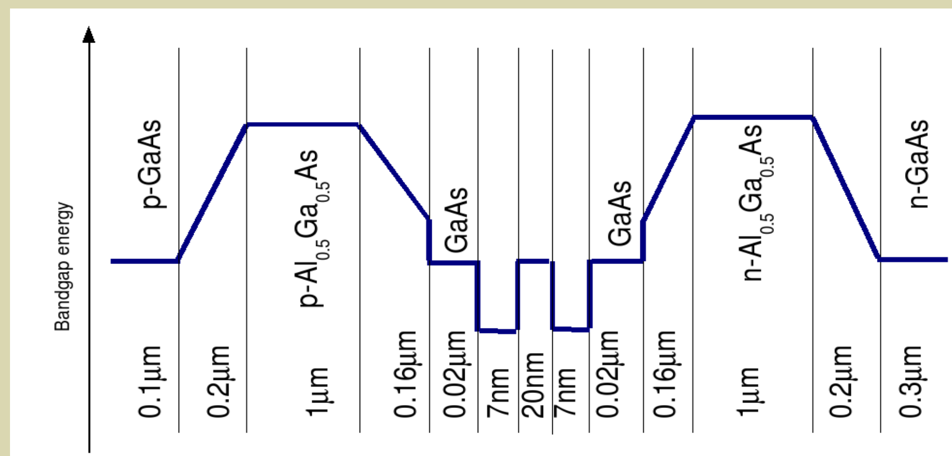
·Lack of experimental data on how much self heating raises device temperature!

Device Structure

- Dilute nitride 1.3µm RW lasers
  - Designed for 10-15mW operation
  - Capable of 10Gb/s modulation at 110ºC



- Double InGaAsN QW with [N] = 1.2%
- Ridge width = 3.2µm
- Cavity lengths = 300-750µm
- Facets: R_f = 0.30, R_b = 0.70

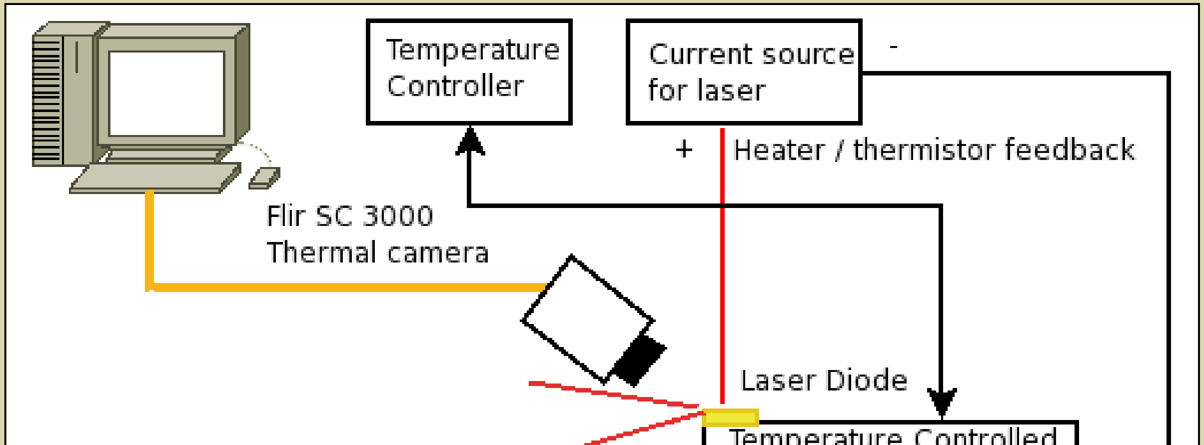


J.S. Gustavsson et al. Electron. Lett. Vol. 42, No. 16, pp. 925-926, 2006.

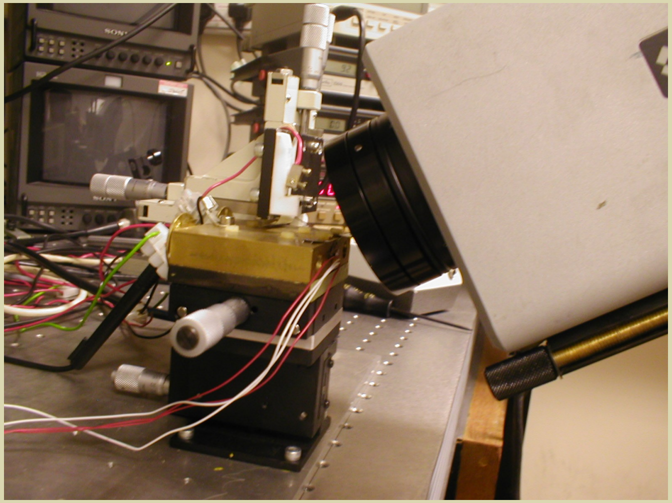
Thermal Imaging Technique

Flir SC3000 Thermal Camera

- Detection wavelengths: 7-9μm
- Thermal sensitivity : 20mK
- Spatial resolution: 30μm x 30μm



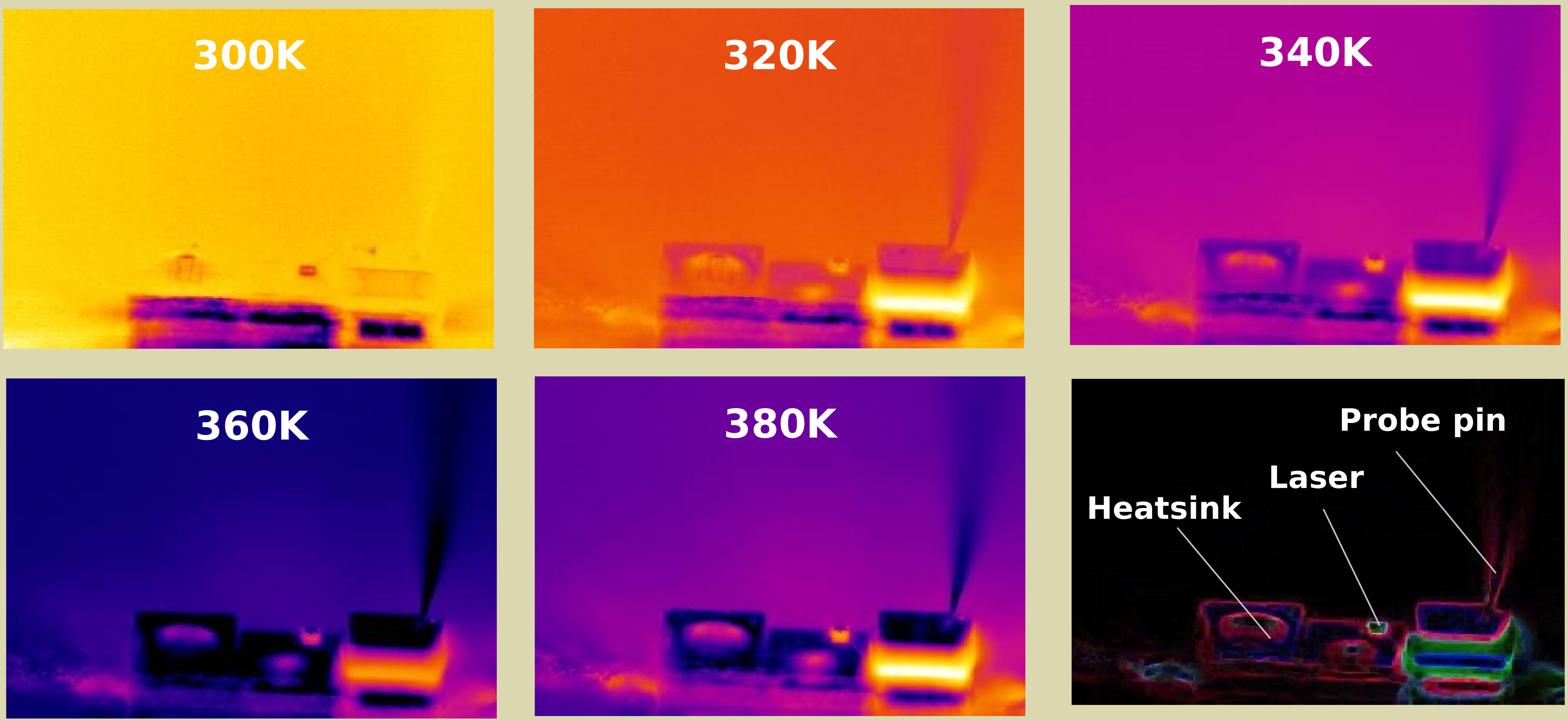
Block diagram of the experimental setup



View of the thermal camera looking down on the laser diode which is mounted on a temperature stabilised block

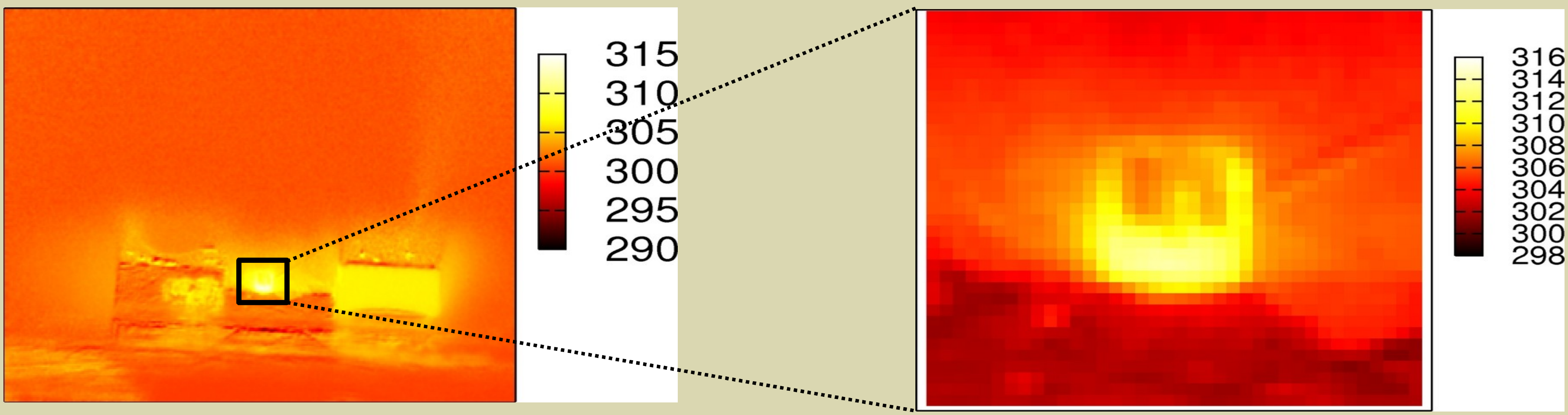
Calibration of Thermal Images

- Images taken of unbiased laser at stabilised heatsink temperatures
- Provides a calibration of each pixel within the thermal images



Calibrated Thermal Images

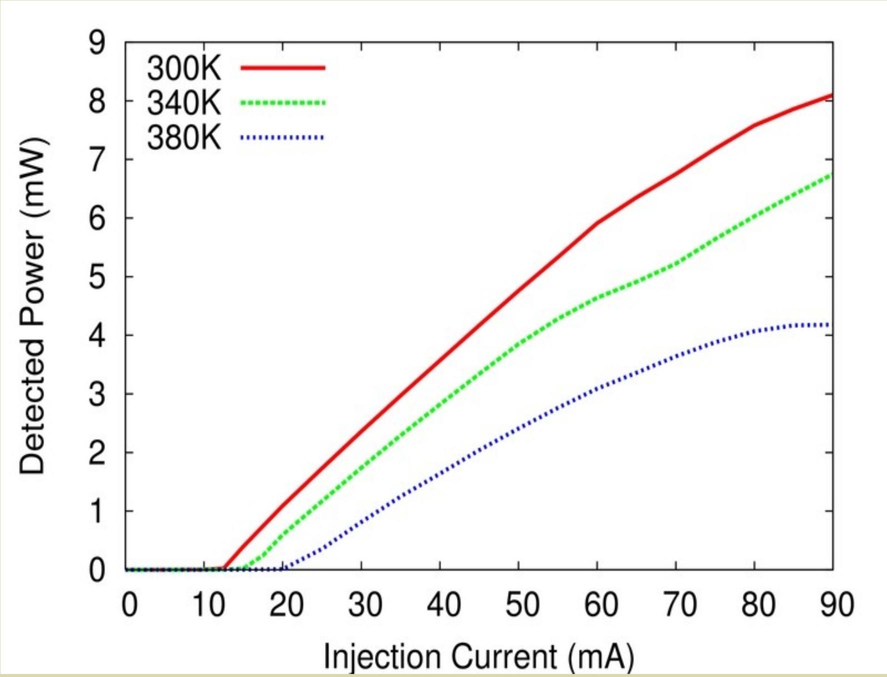
- Images of each device taken as a function of current and temperature
- Using the calibration, the true temperature of each pixel can be found
- Investigations of temperature variations at different positions can be made
- An example of a calibrated thermal profile (500μm device, 300K, 90mA):



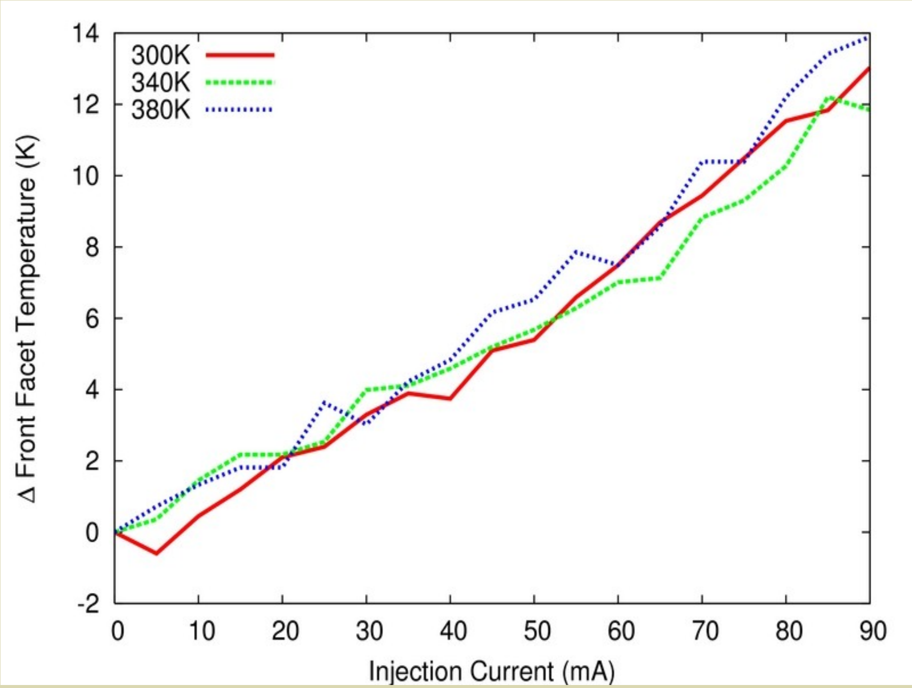
Operation at Elevated Temperatures

The University of Nottingham

LI-curves for 300µm long device



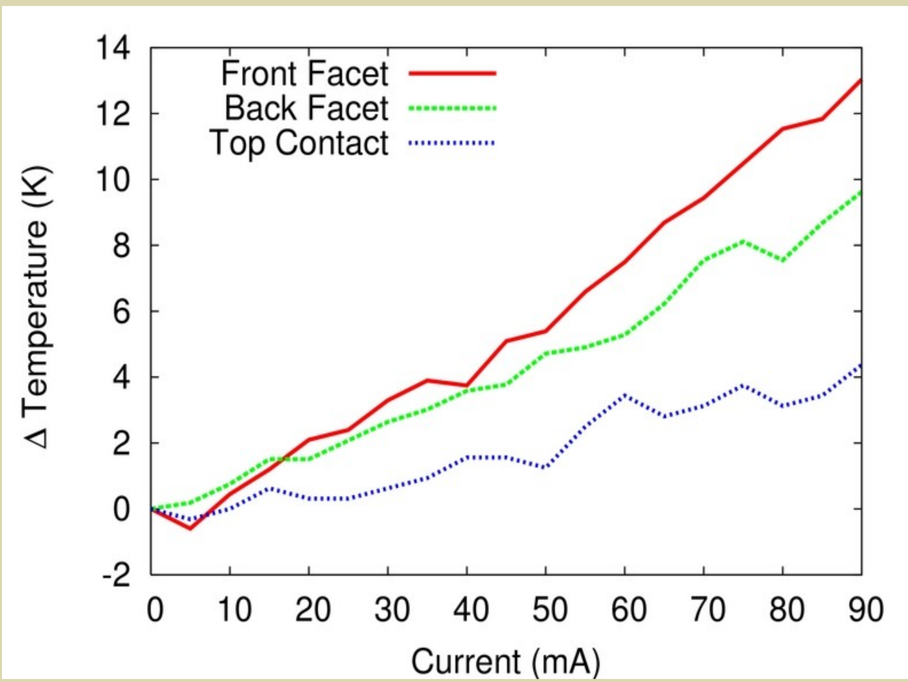
Change in front facet temperature



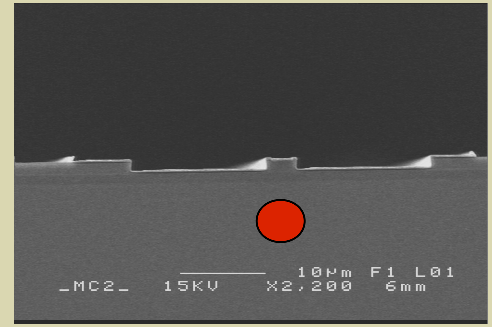
- The rise in front facet temperature is not strongly dependent upon the heatsink temperature.
  - Suggesting that heat generation near the front facet is not a strong function of the heatsink temperature

Device Temperature Variations

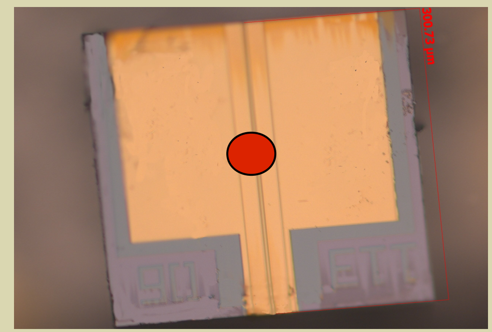
- Top contact cooler than front facet by up to 10K
  - Air cooling
  - Wire bond
- Back facet cooler than front facet by up to 2K



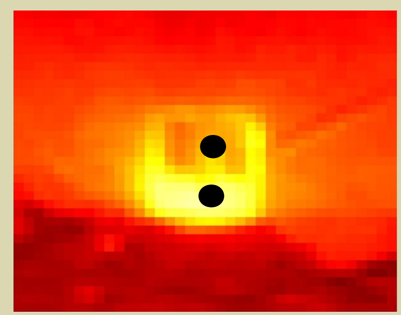
300μm coated device at 300K



Front / back facet



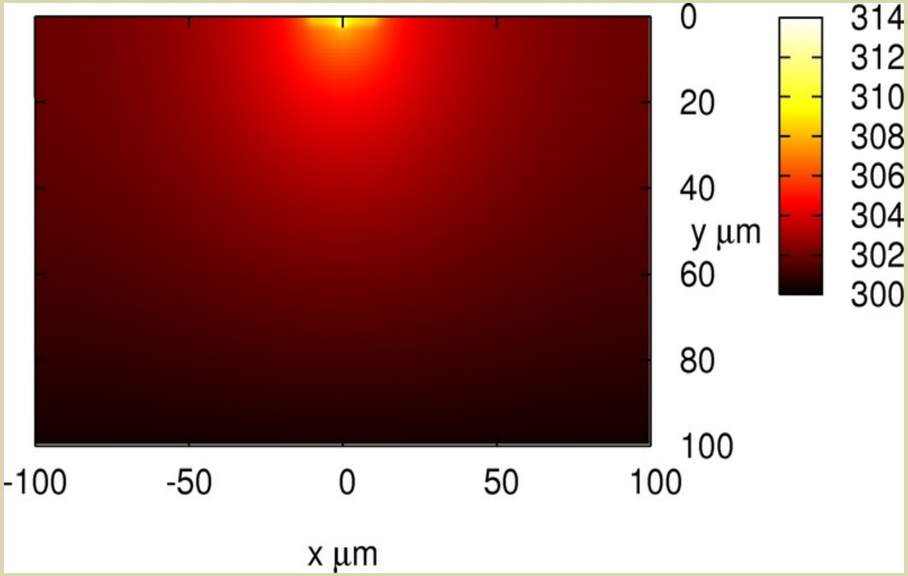
Top contact



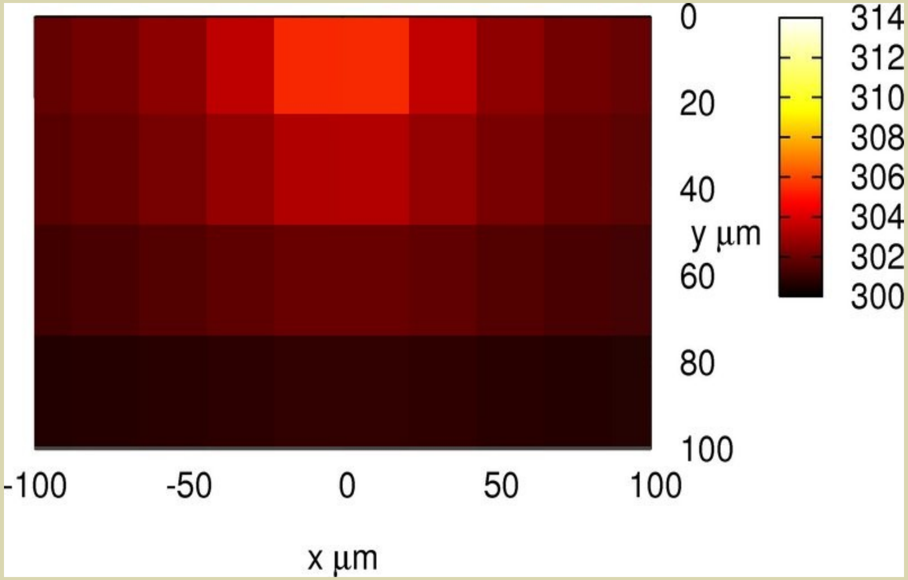
Thermal image

Camera Resolution

- The thermal imaging technique is limited by the spatial resolution of the camera (~30μm x 30μm)



Simulated thermal profile of a vertical slice through the device and epitaxial layers

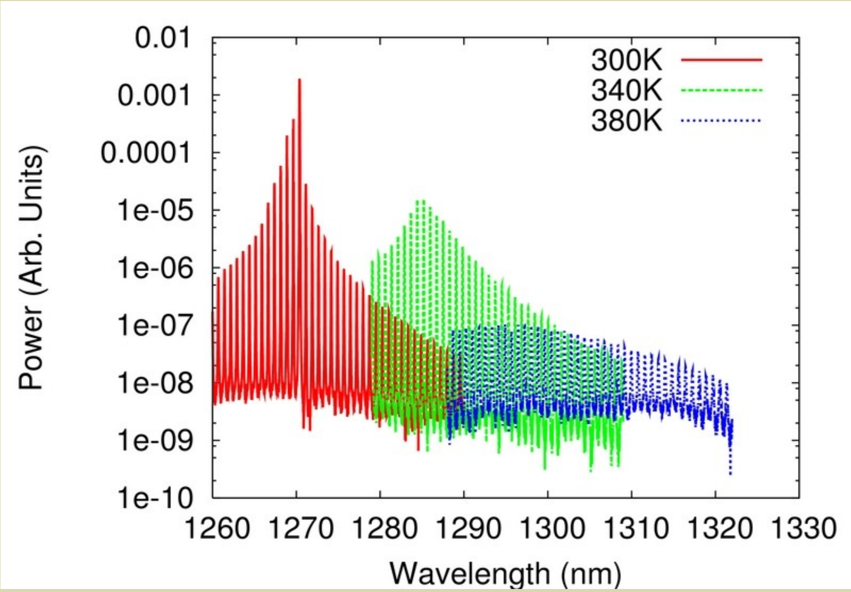


Pixalated squares show a representation of the averaging the camera would see

- This is acceptable for looking at large regions (e.g. substrate), but another technique must be used to investigate the temperature of the QW

Determining QW Temperatures

- Red shifts in the lasing spectra with increased temperature are well known
- However, can we estimate the QW temperature by measuring this red shift?
- Firstly, consider the factors that affect the lasing wavelength:
- Bandgap renormalisation red shifts the lasing spectra as the carrier density increases
- The lasing wavelength blue shifts with increased carrier density – band filling
- The QW band gap shrinks (red shift) with increasing temperature

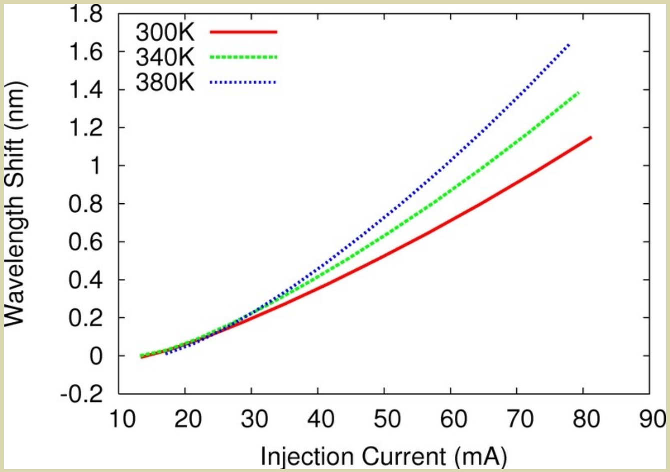


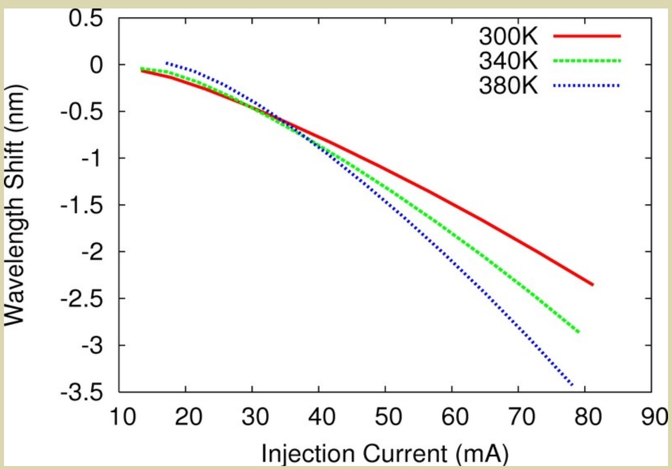
Spectra at 15mA for a 300μm device

Accuracy of Temperature Estimations

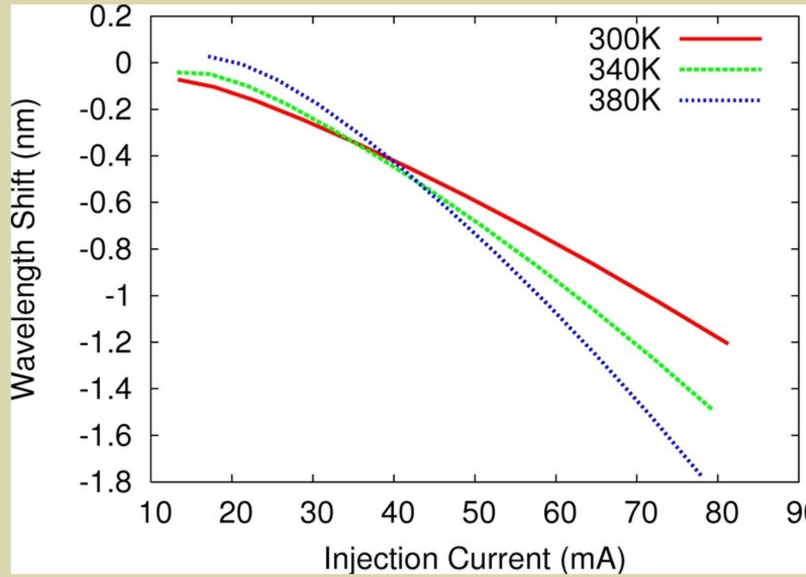
- Results from our calibrated in-house 2D electro-optical-thermal simulation tool

Red shift due to band gap re-normalisation





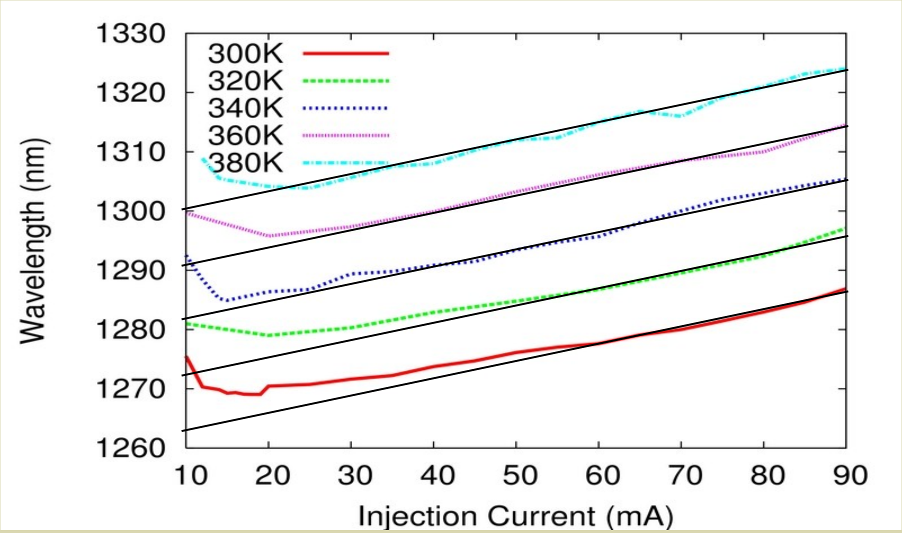
Blue shift due to increased electron density



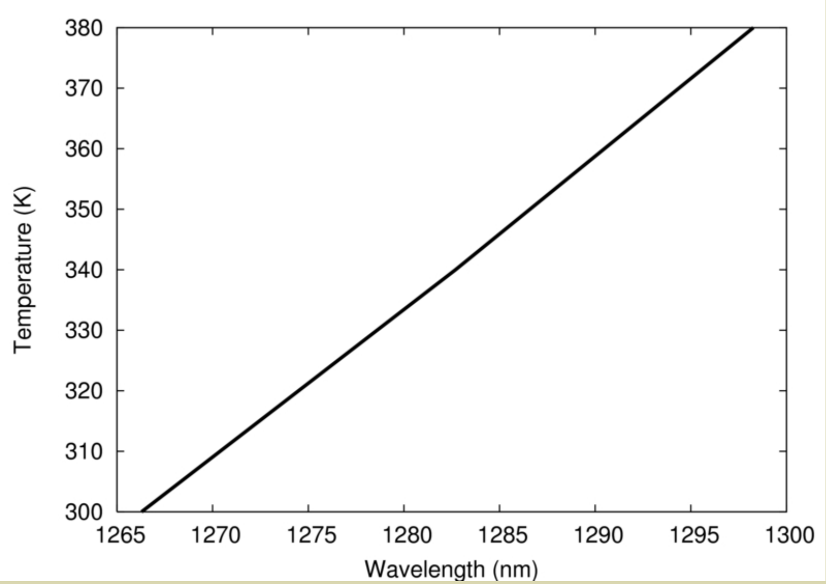
Combination of blue shift and band gap renormalisation shift is small

Measurement of Spectral Shifts

- Spectra measured as a function of injection current and temperature



Spectra as a function of injection current



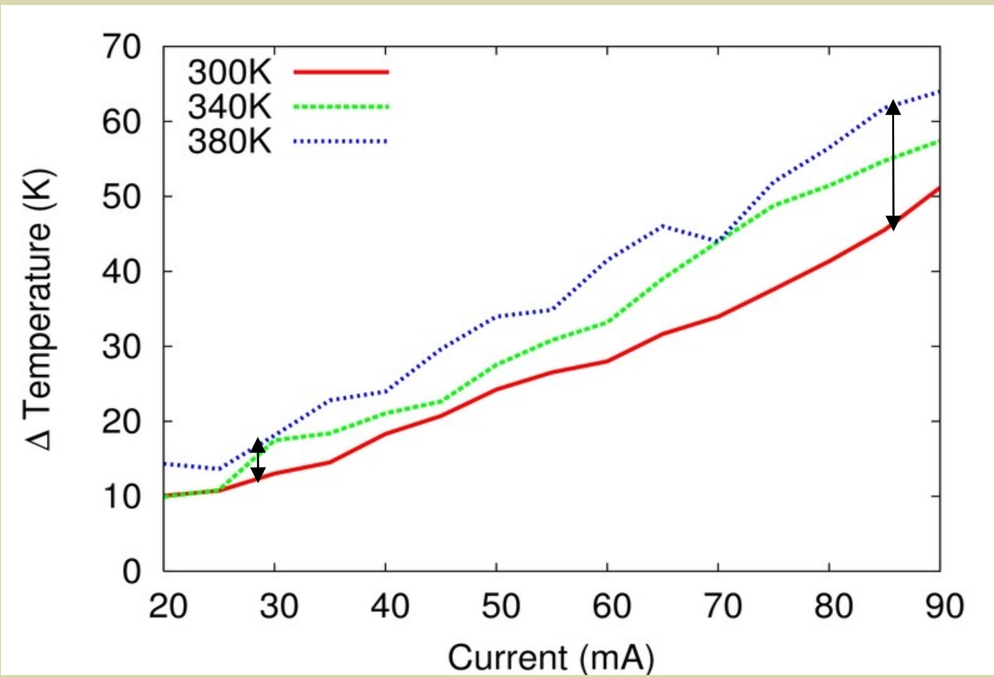
Calibration curve converting wavelength to temperature

- By extrapolating the wavelength back to 0mA, a calibration curve relating lasing wavelength and temperature can be generated

QW Temperatures during Operation

- At higher heatsink temperatures, self heating raises the QW temperature more than it does at low heatsink temperatures because of:

Estimated shifts in QW temperature



- Increased Joule heating (lower mobility)
- Higher Auger recombination rates
- Higher carrier escape rates
- Higher free carrier absorption

Conclusions

- The thermal imaging technique is suitable for large areas and overview temperature profiles (particularly contacts)
- The top contact temperature increases slower than that of the facets
- Bandgap shrinkage shown by simulation to be the dominant effect on lasing wavelength in these devices
- Possible to use spectral shifts to estimate QW temperatures
- QW temperatures of up to 60K greater than the heatsink determined
- Devices operated with an internal QW temperature of up to 440K