Thermal performance characteristics of passively cooled 1.3μm InGaAsN/GaAs double quantum well lasers

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Presentation outline

- Generic device description
- Description of the laser model
- Numerical experiments
- Conclusions

Device details

Generic device structure:

QW material: InGaAsN

Number of QWs: 2

Bulk material: AlGaAs

Device length: $L = 250\ \mu m$

Device width: $W = 50\ \mu m$

Ridge width: $W_r = 2\ \mu m$

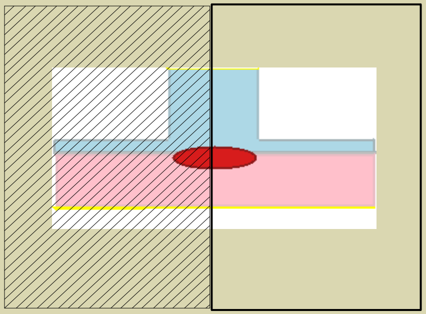
Front facet reflectivity: $R_f = 0.3$

Back facet reflectivity: $R_b = 0.7$

Heat sink resistance: $R_{hs} = 1.0$ K/W

Front facet output power: $P_{out} = 10 – 15$ mW

AlGaAs thermal conductivity: $k = 10 – 40\ Wm^{-1}K^{-1}$



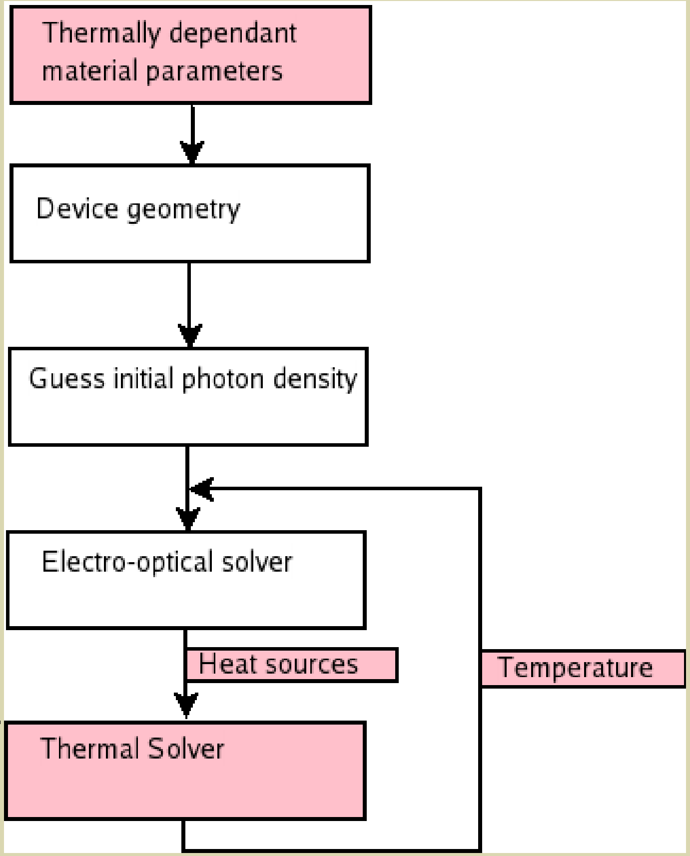
Simulation conditions:

- All simulations performed in 2D
- Half-space simulations used to reduce computation time
  - → Possible because of device symmetry

Device simulator

Electrical Model

- Bipolar 1D - 2D Drift Diffusion (DD) model (0^{th} and 1^{st} moments of the Boltzmann Transport Equation (BTE))
  - Includes thermal driving terms in current equation
- Poisson's equation
- QW capture/escape equations for each QW
- 2D lattice heat equation solved in external solver



Optical Model

- Photon rate equation interacting with all QWs
- Gain and spontaneous emission calculated using a 4x4 band ***k.p*** method

All equations solved using Newton's method

Thermal model

Thermally dependent parameters

- Electron and hole mobilities
- Band gap
- Electron affinity
- Gain (through look up table)
  - Fermi-Dirac statistics
- Spontaneous emission
- SRH recombination
- Auger recombination
- Effective densities of states
- Thermal lattice conductivity
- Maxwell-Boltzmann statistics
- Heat capacity

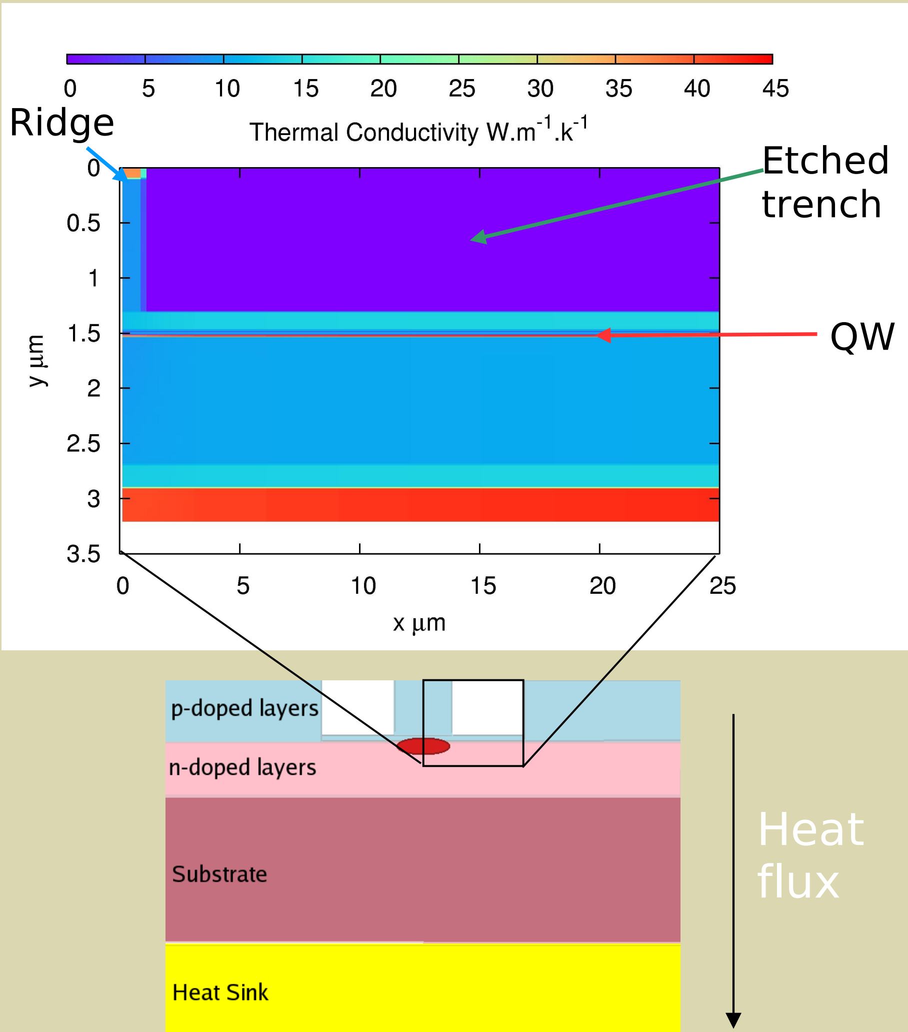
Heat sources

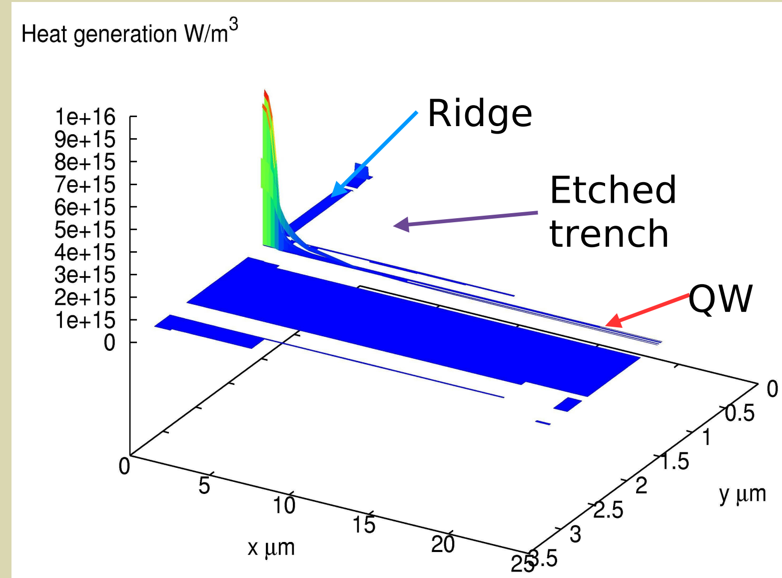
- Shockley-Read-Hall
- Auger recombination
- Free carrier absorption
- Spontaneous emission
- Joule heating
- Peltier cooling/heating

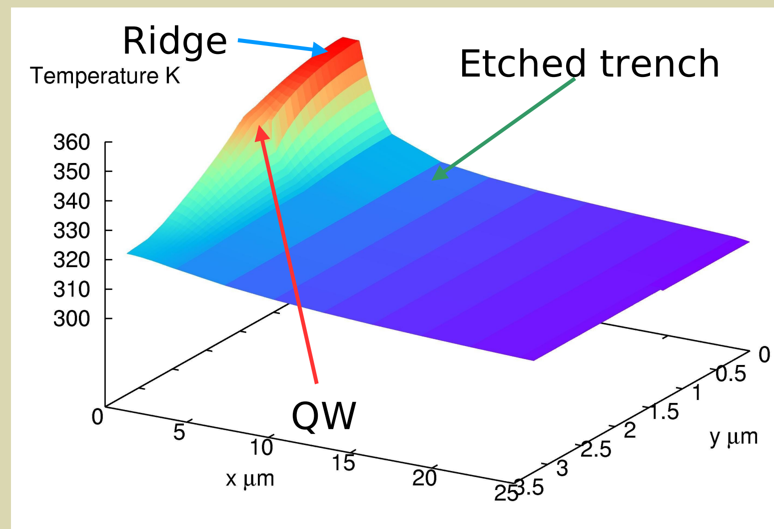
Meshing

- Separate electrical and thermal meshes
  - Mesh same over electrical region (avoids interpolation)
  - Electrical problem area small compared to thermal problem area
- Software updated to simulate p-side up/down mounting

Typical thermal simulation – p-side up mounting







Can this be improved upon?

Overview of parameters investigated

1. Ridge width
   - How does ridge width affect the thermal performance?

2. Trench width
   - How does etch trench width affect thermal performance?

3. Trench filling
   - Can we improve device performance by filling the trenches?

4. Investigation of poor thermal environments
   - How do external temperature variations affect device performance?

5. Mounting p-side up/down
   - How does substrate thickness affect p-side up mounted devices?

6. Meshing
   - How far does the thermal mesh need to extend beyond the electrical mesh?

Thermal simulation window & boundary conditions

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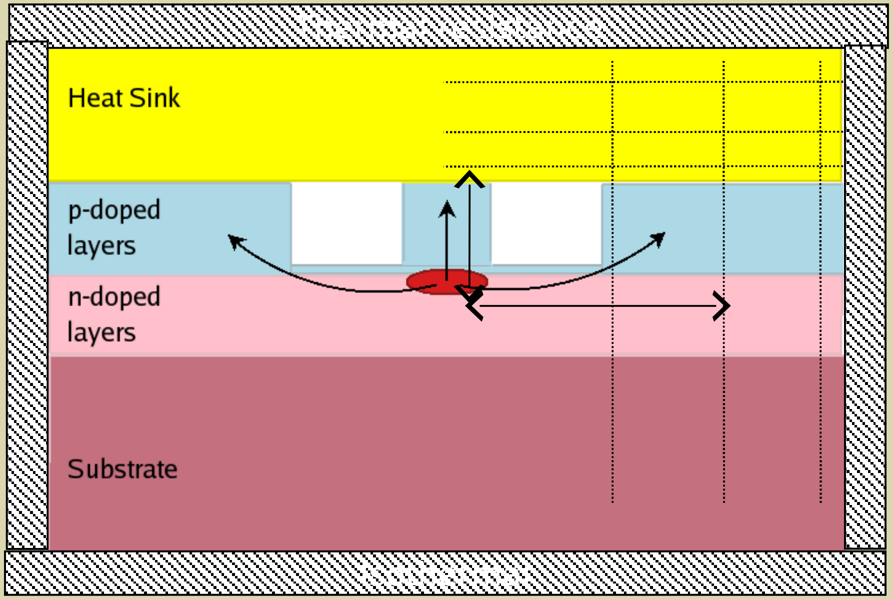
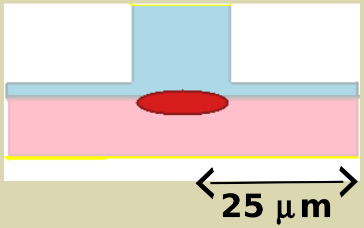
Thermal mesh



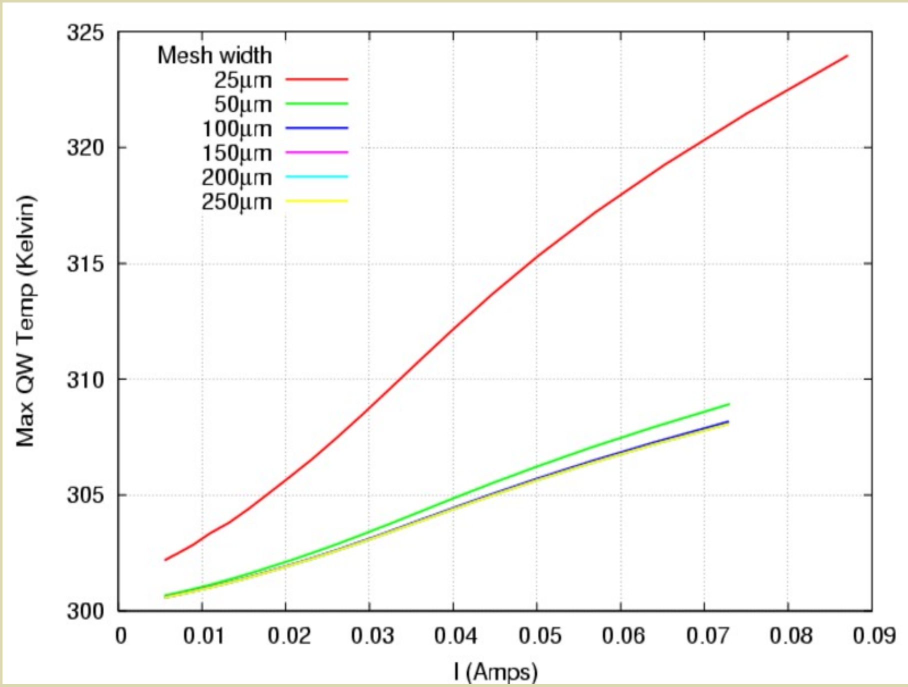
Electrical mesh



Q. How wide does the thermal mesh need to be?

A. About 4 times wider than the electrical mesh

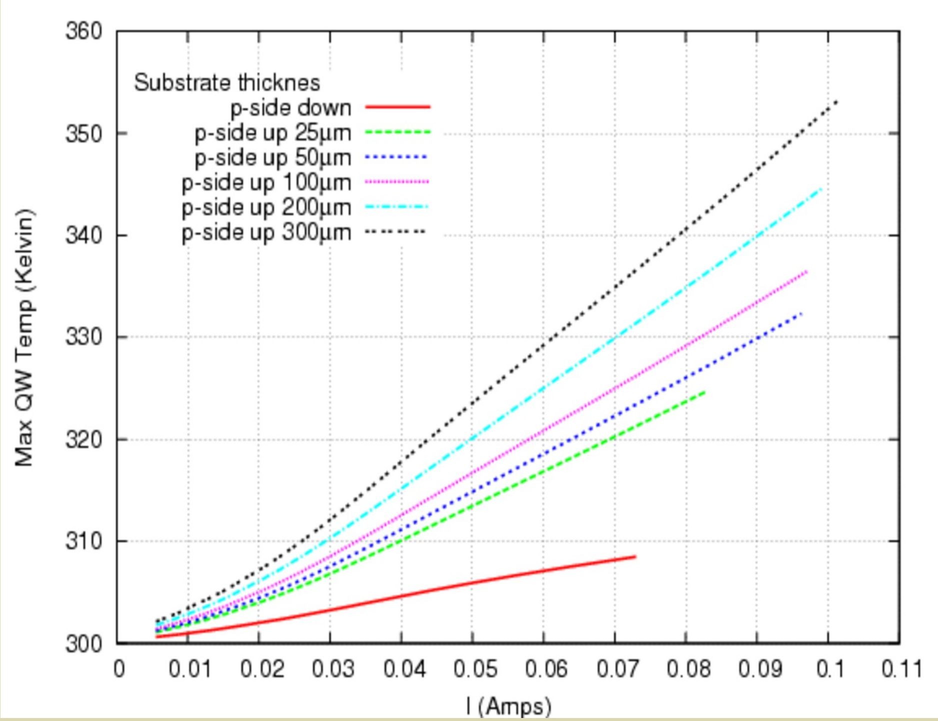
Most important for p-side down mounting

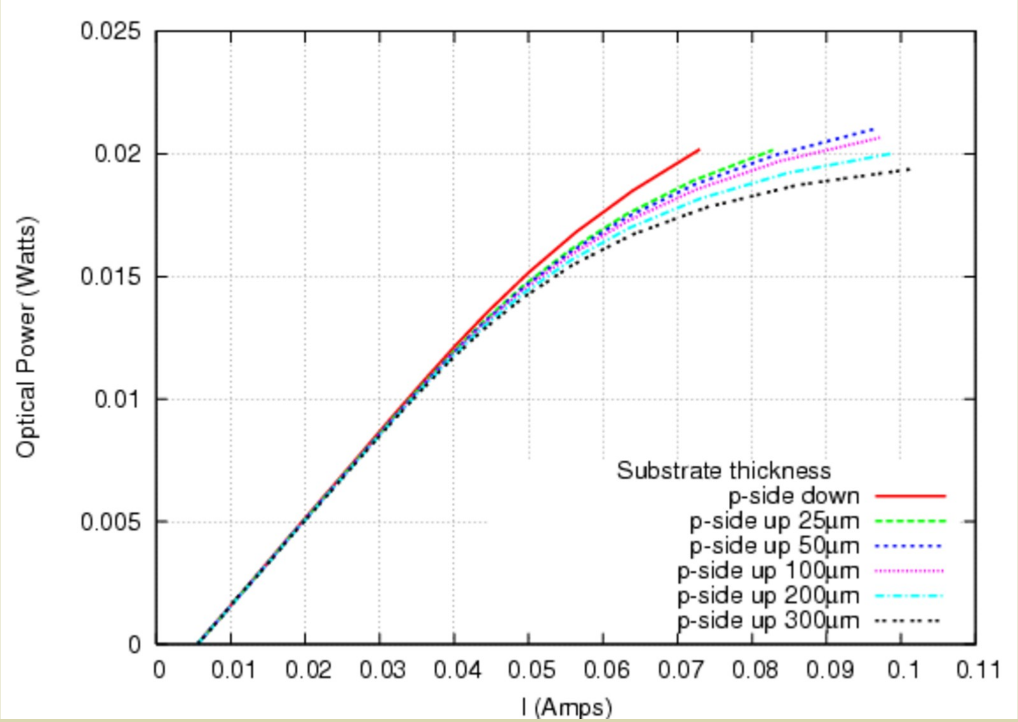


Q. How far does the vertical mesh need to extend into the heat sink to model thermal spreading?

A. 100µm

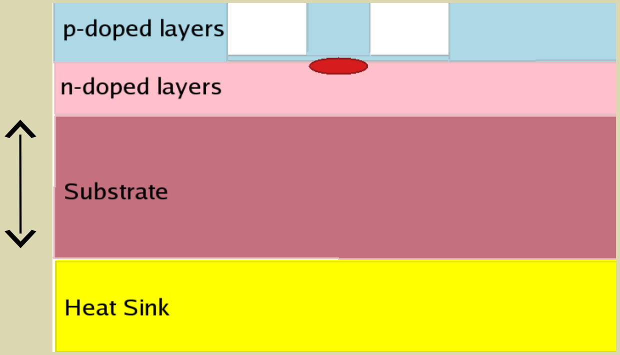
Impact of substrate height on maximum temperature



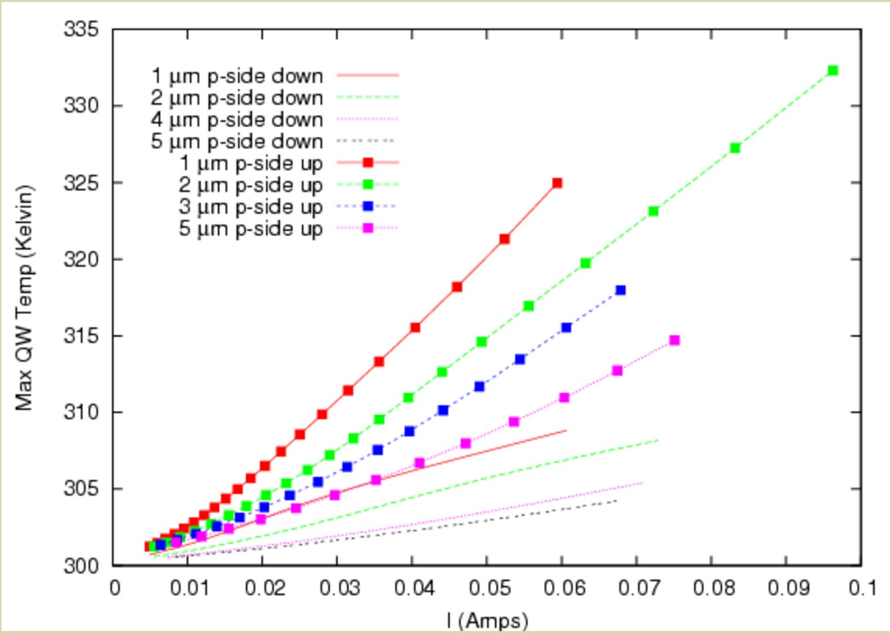


- Better high frequency response for p-side up mounts
  - What is the thermal penalty?

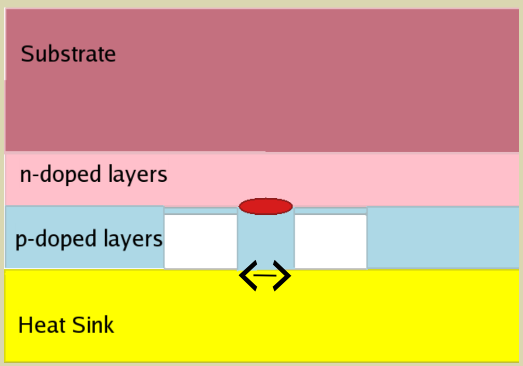
- Reducing substrate thickness reduces:
  - QW temperature
  - The onset of thermal rollover



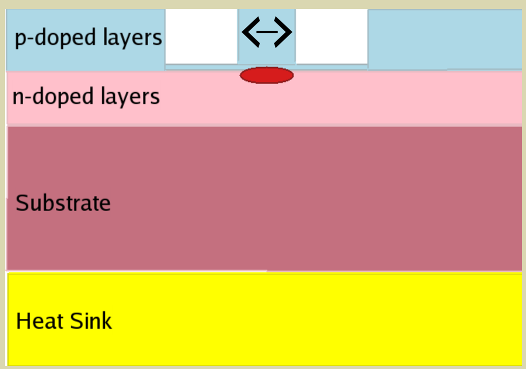
Variation of ridge width



- How does the ridge width affect the QW temperature?
- What is the impact of p-side up mounting on this?
- Wider ridge → higher electrical conductivity → less Joule heating
- Wider ridge → bigger area → lower heat flux density → lower temperature
- P-side up mounting → no route for heat to escape up the ridge → higher QW temperature
- The ridge forms a *thermal island* that gets very hot



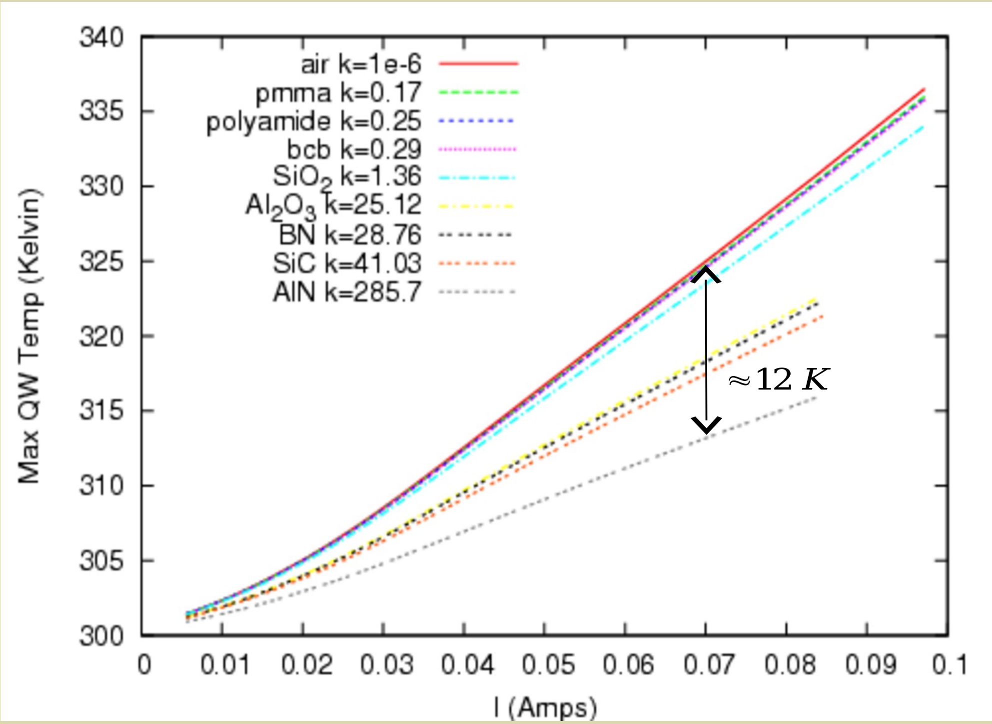
P-side down



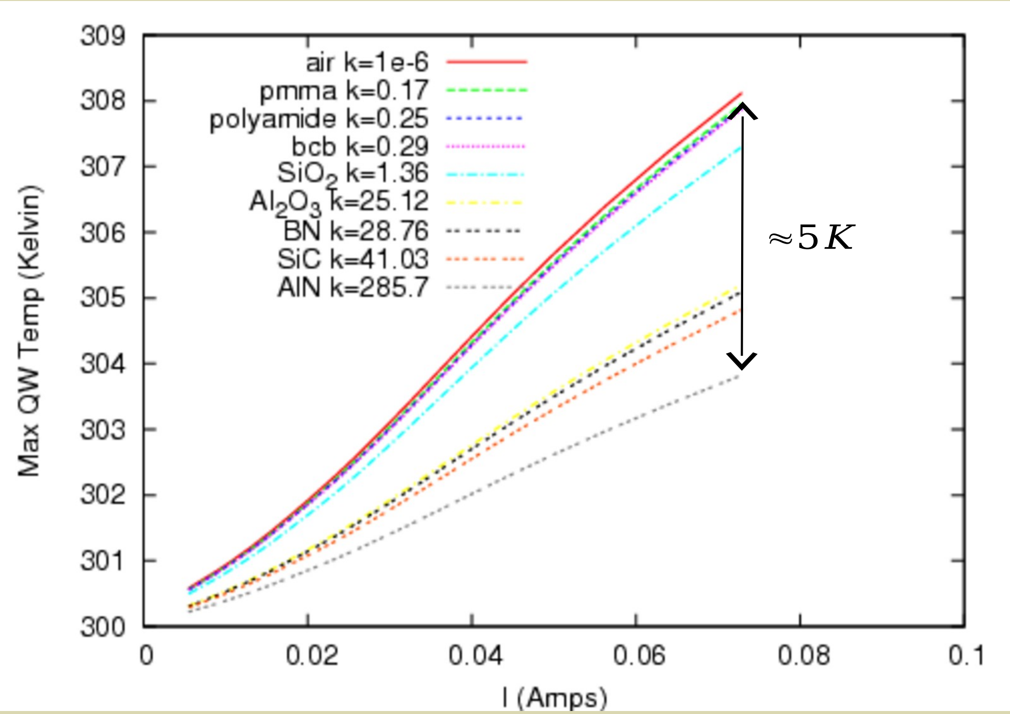
P-side up

Thermal conductivity of the etched trench

P-side up



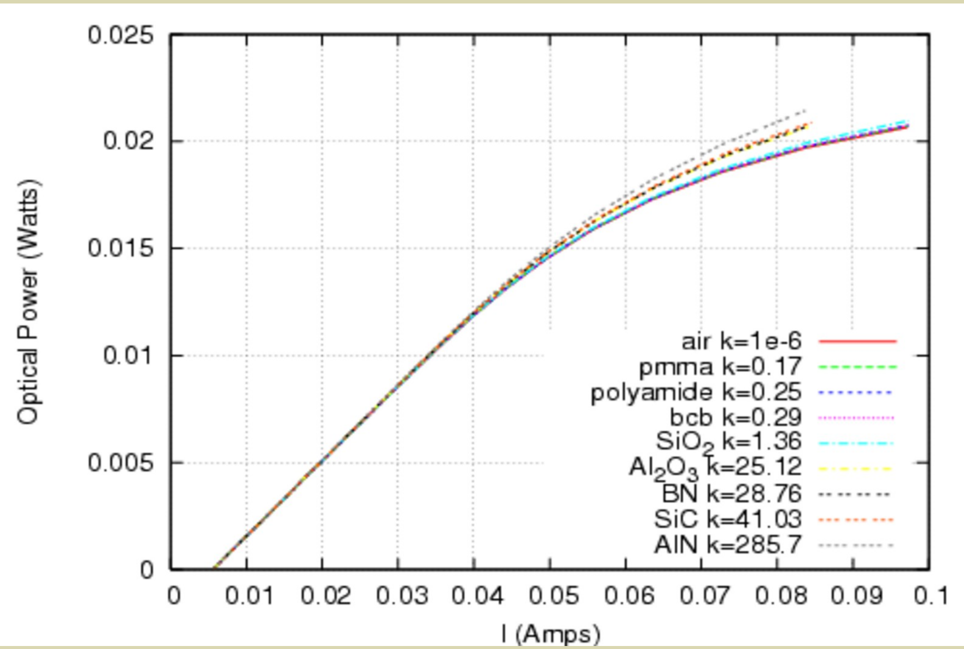
P-side down



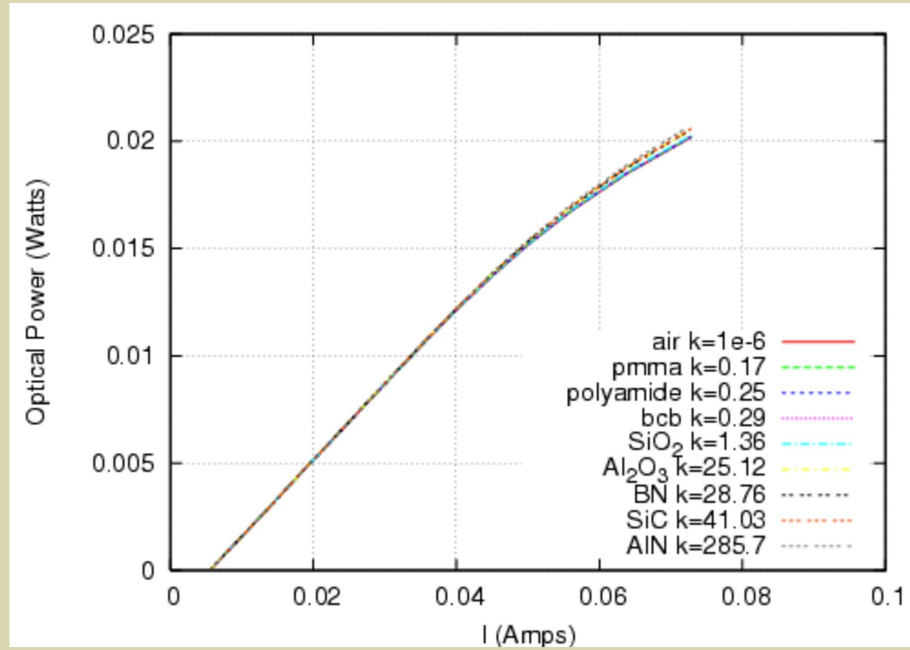
- Material system makes a *large* impact for p-side up mounted devices
- Less impact for p-side down mounting

Thermal conductivity of the etched trench

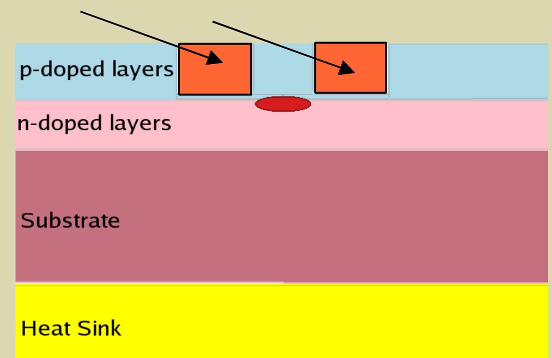
P-side up



P-side down



- The change in temperature can be seen in the L-I curves
- Thermal roll-over in L-I curve due to temperature dependence of gain



Variation of etch trench width

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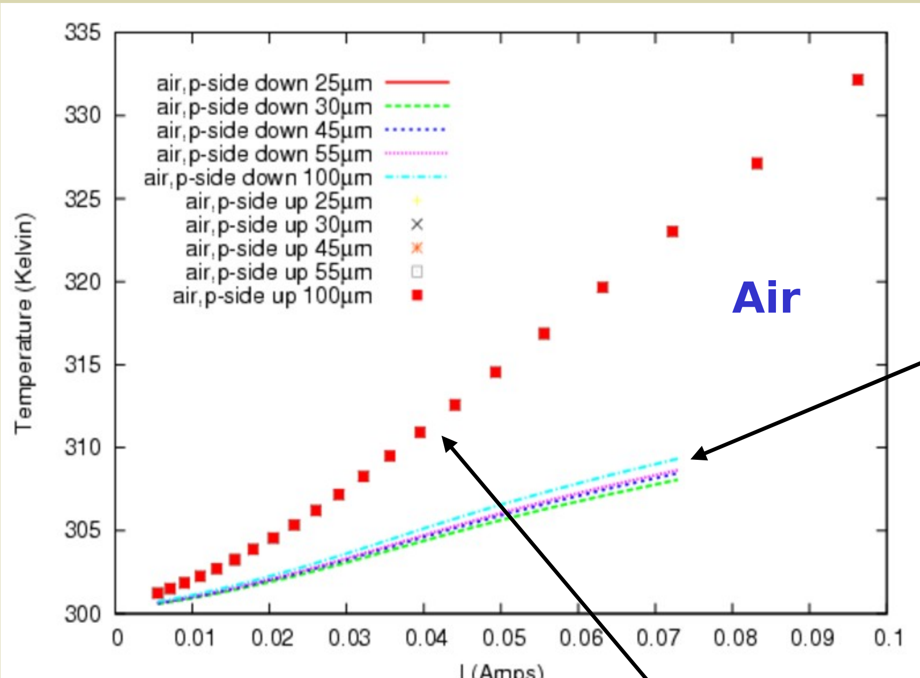
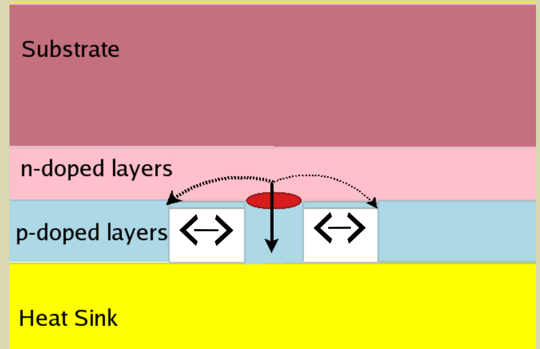


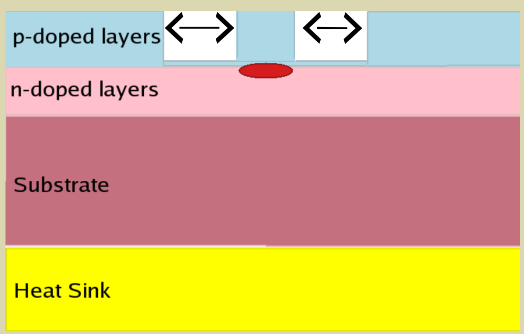


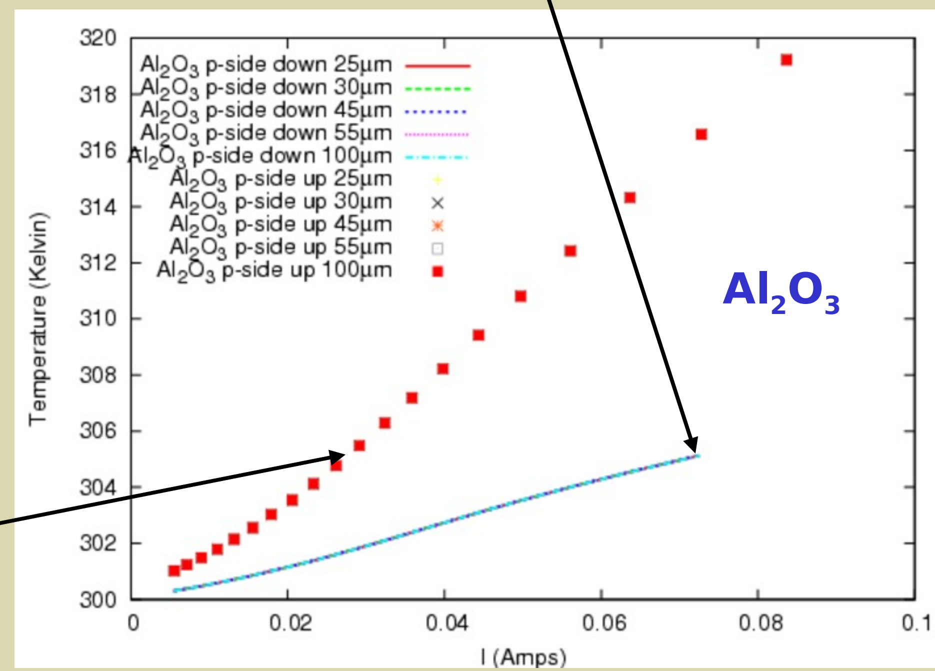
P-side down

- Cooler
- Etched trenches block heat flow out of device

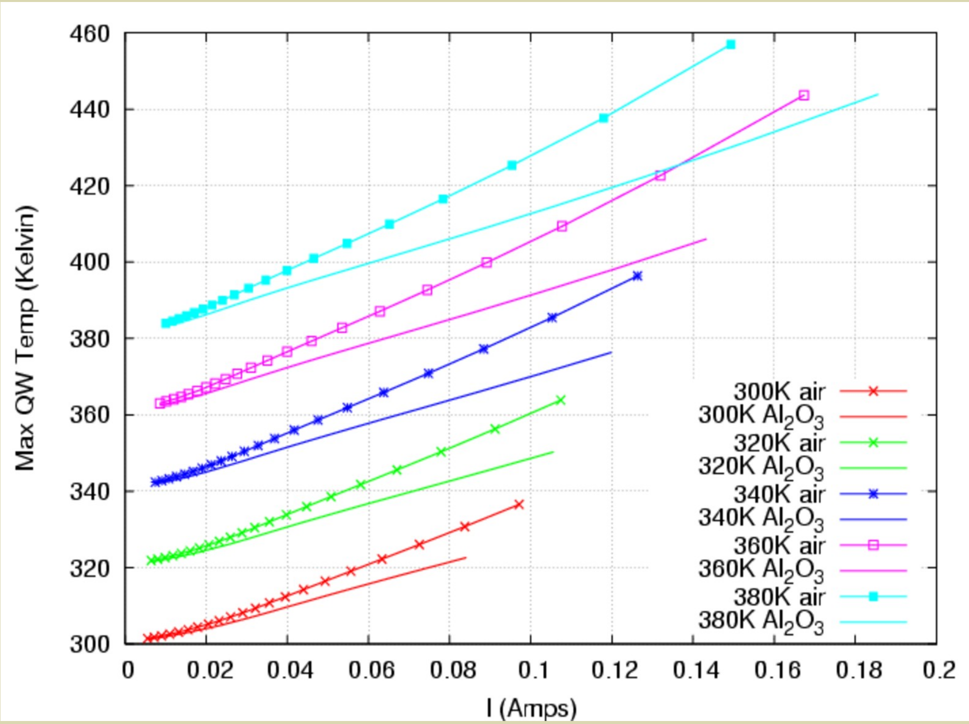
P-side up

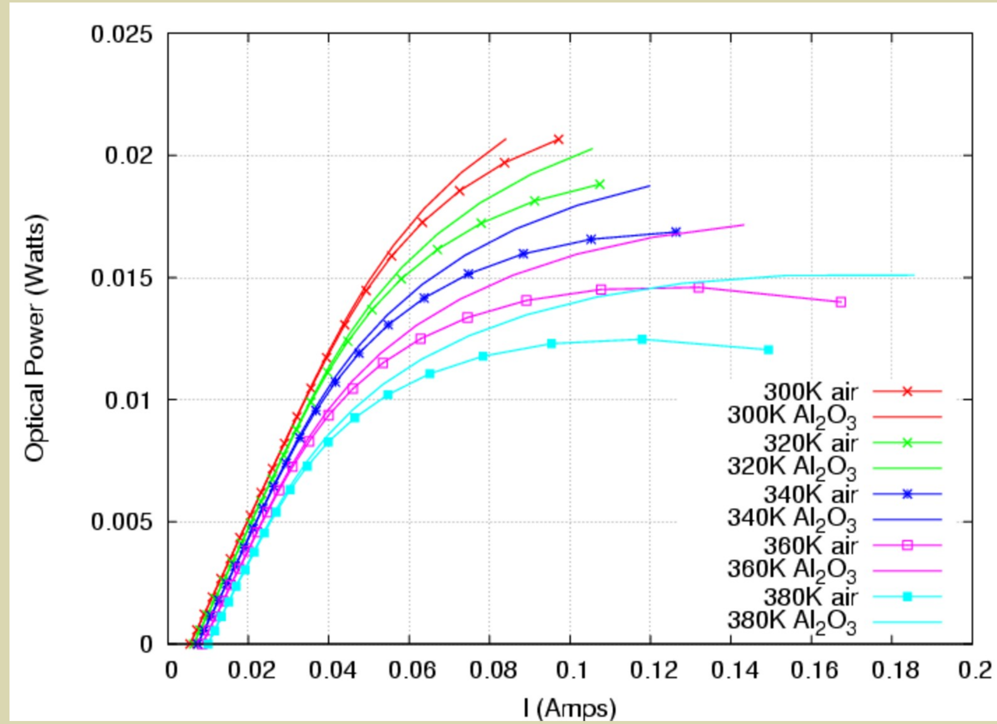
- Hotter
- Etched trenches block/help heat flow from ridge





Operation at elevated temperature





- Devices often operate in a poor thermal environment → increased heat sink temperatures
- Filled etched trenches at high temperatures → significant performance improvements
- Operating temperature strongly affects device reliability and life time

Conclusions

- The thermal mesh should extend 100μm laterally beyond the etched trenches and 100μm vertically into the heat sink

- There is a significant thermal penalty for p-side up mounting

- A thinner substrate results in a lower QW temperature

- Refilling the trenches with a thermally conductive material significantly reduces the QW temperature.

- A wider ridge reduces electrical resistance
  - Reduces Joule heating and decreases the thermal series resistance of the ridge
  - For a single-mode device, there is a limit to how wide the ridge can be

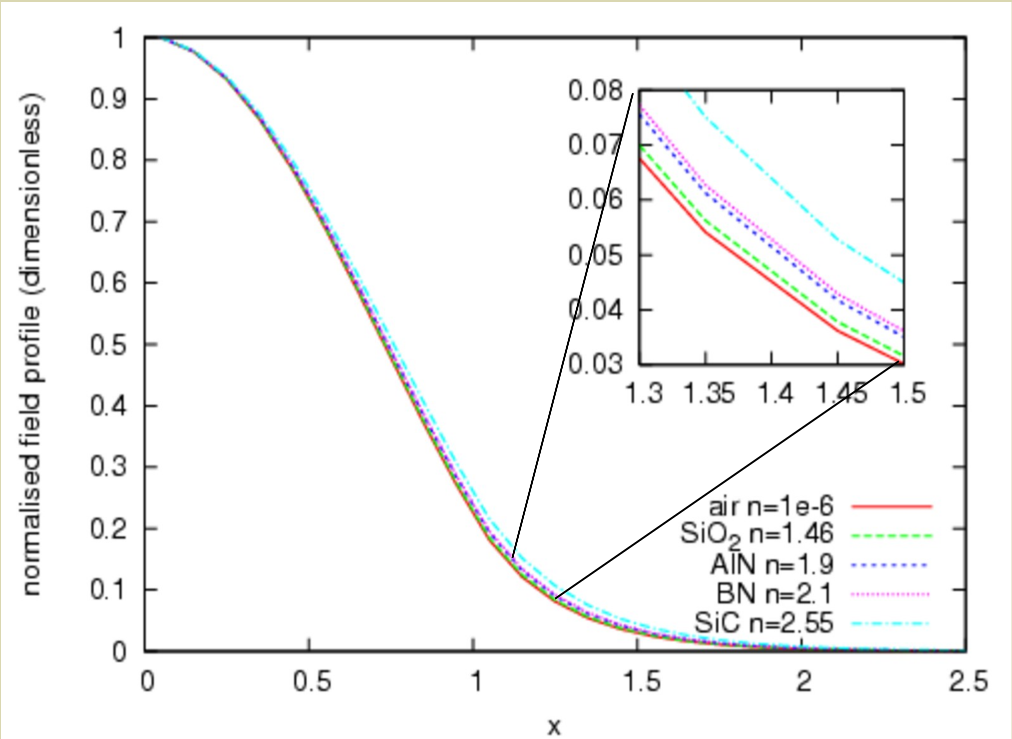
- The design of uncooled lasers requires the global optimisation of their thermal, electrical and optical performance (usually requiring a trade-off).

Thank you for your attention

What are the optical penalties of filling the trenches?

- More poorly confined lateral mode
  - Slightly worse confinement factor (minimal)
  - However this loss is more than compensated for by improved thermal performance

Ridge width = 2μm



Trend: The larger the refractive index of the trench, the worse the guiding

With decrease in index step and width of etch leaky modes are more likely to cause problems