Understanding Thermal Management and Reliability in Packaged Cascade Lasers

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Motivation

- Type II interband cascade lasers are useful in electronic countermeasures
- Lasers are low power compound semiconductor chips
- At the operating wavelength of 3.4μ, CW operation is possible only at very low temperatures
- If a technology could be found to allow operation in normal ambient environment, these lasers could be deployed in combat aircraft

Objectives

- For a bar of 8 lasers operating one at a time in CW mode:
  - Maintain chip base temperature at 180 K or lower
  - Electrical design need not accommodate high speed operation
  - Optical design to collimate the beam from any laser through the package wall allowing relative power and wavelength measurement
  - Design λ=3.4μm
- Develop a compact package that can be re-used on the lab bench
- Eliminate the cold finger in favor of a thermoelectric cooler

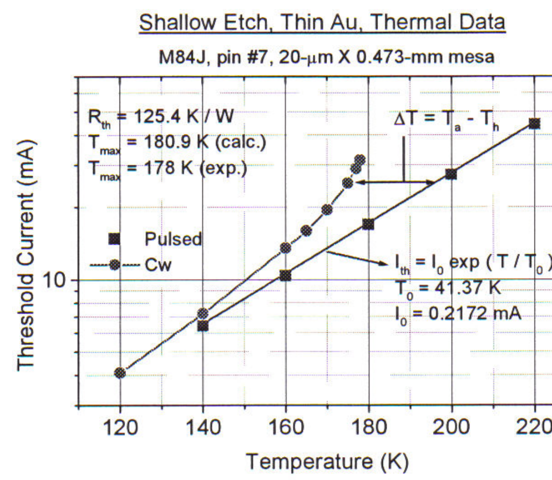
Approach

- Model chip thermal performance and determine operating temperature for laser submount.
- Investigate thermoelectric coolers and identify a model with sufficient capacity to meet the design objectives.
- Model and quantify parasitic heat sources and develop a package design to minimize unwanted heat transfer to the laser submount.
- Design a package to meet the thermal optical and mechanical performance objectives allowing the compact demonstration of the laser.
- Build an experimental prototype and measure operation on the bench.
- Identify future work to allow deployment of the laser prior to the availability of a chip capable of room temperature operation

Background

Type II Interband Cascade Laser Operating Characteristics

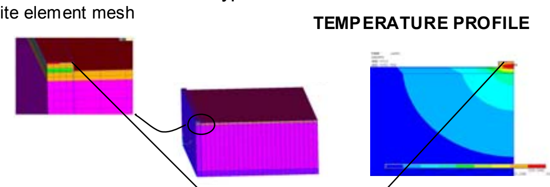
- The CW threshold current departs significantly from pulsed performance for temperatures above about 180 K.
- Laser was tested at both CW and pulsed operating conditions.
- This indicates that thermal dissipation causes significant heating at higher threshold currents.
- Laboratory operation of the laser is on a "cold finger" maintained at low temperatures.
- The cold finger is a large and complex apparatus suitable for laboratory use only.
- Laser thermal dissipation at 180K is ~ 315mW.
- Temperature rise at active region is made up of ΔT (chip base to active region) + ΔT (ambient to chip base).
- Research and development is ongoing to create a chip that is capable of room temperature operation.



Chip Thermal Performance Modeling

- To understand the required temperature of the laser submount, modeling of the chip active region is needed.
- Thermal modeling of the laser cavity subjected to uniform heat generation in the laser active region.
- The analysis is steady state.
- Heat generation ~315 mW over 1 mm cavity length.
- Two structures modeled for chip thermal performance – thin gold contact, thick gold contact.
- Results show minimum 13 °C rise from base of chip to active region.
- An improvement of ~ 7°C was gained by use of thick Au

Thermal Analysis of Type II Interband Cascade Laser

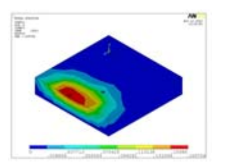


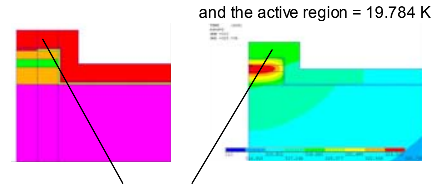
Thin Au contact

Thermal resistance = 62.84 K/W Max difference between the heat sink and the active region = 19.784 K

- To insure no hot spots beneath the 8 chip bar, a diamond submount heat spreader is used
- FEM modeling of the spreader shows < 0.2 °C rise beneath the laser chips

Diamond Submount Thermal Performance



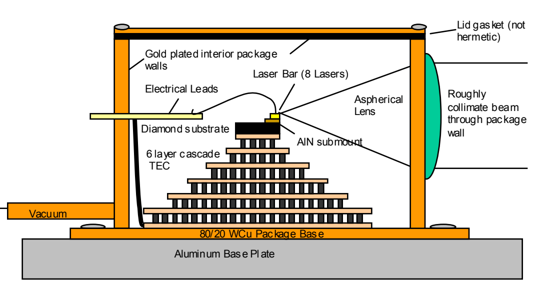


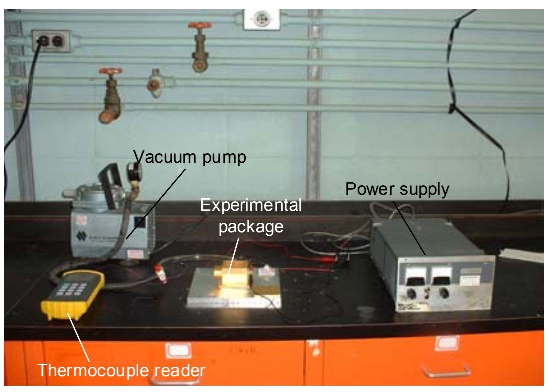
Thick Au contact

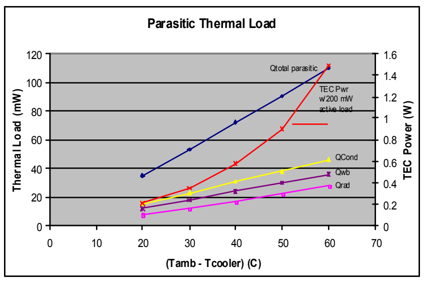
Thermal resistance = 40.46 K/W Max difference between the heat sink and the active region = 12.74 K

Package Development

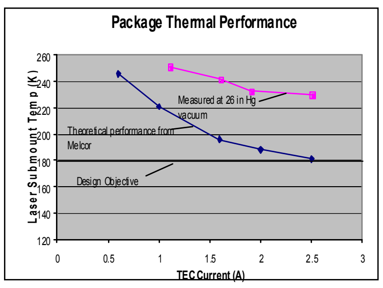
Experimental Architecture for ARL Cascade Laser Package







- Estimate of parasitic heat transfer to laser submount shows:
  - -Conduction through electrical leads
  - -Conduction through the internal gas
  - -Radiation from package walls and lid
- Note that the parasitic thermal load is of order the thermal load of the laser.



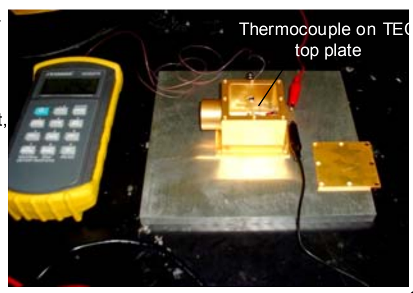
Submount minimum temperature = 230K

Reasons for difference between objective and experiment:

vacuum (frost on submount)

Rth TEC to pkg base

- A package has been developed that employs a Melcor 6 stage cascade thermoelectric cooler to reach design objective temperatures of 180K – 200K
- Package walls and lid are Kovar, base is 80/20 WCu, CaF aspheric collimating lens for 3.4μ wavelength light, AlN laser submount and interconnect ceramic
- Parasitic thermal load minimized by:
  - Operation in vacuum
  - Low thermal k constantan interconnect wires
  - Gold plating on package internal walls and lid



Conclusions

- Chip temperatures of 230K are possible with a 6 stage thermoelectric cooler
- Diamond submount heat spreader minimizes local hot spot at chip mounting location
- Much better vacuum and improved thermal conductivity between the package base and TEC bottom plate is needed to obtain the design objective performance

Future Work

- Improvements to the experimental apparatus are needed to achieve the target operating conditions of 180K-200K
  - Higher vacuum operation
  - Lower Rth TEC base - pkg base
- A more efficient cooling system is needed.
- Development of a MEMS vapor compression refrigeration system would improve the coefficient of performance by roughly an order of magnitude while maintaining the small size of the TEC

Acknowledgement

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