Modal and Thermal Characteristics of 670nm VCSELs

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Vixar

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Overview

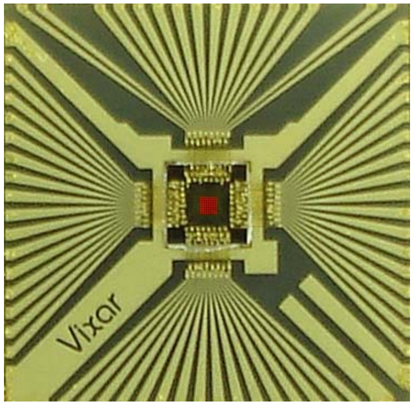
- Applications of red VCSELs
- Device performance / limitations
- Thermal management
- Improved oxide VCSEL mode control
- Results / Performance Data
- Summary

Who Is Vixar?

- Vixar founded in late 2004 (Maple Grove, Minnesota)
  - Focused on 660nm-800nm VCSELs
  - Biomedical, industrial, commercial and military sensors
  - Founding team has an extensive history in VCSEL R&D and productization
  - Outsource Model: “Fabless Opto”

Applications/Value Propositions

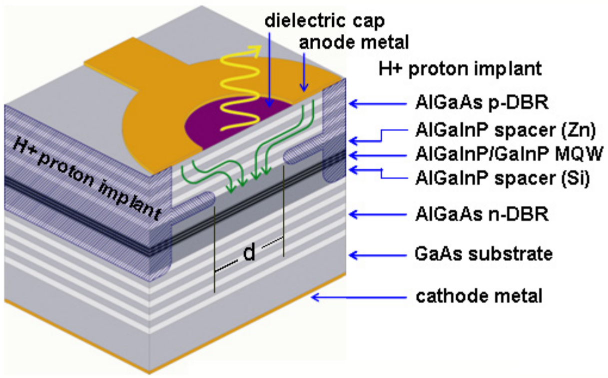
- Laser Printing
  - **2D arrays for speed enhancement**
  - **Preferred wavelength for photosensitive materials**



- Oximetry/BioSensors
  - **Low power for wireless sensors**
  - **High yields to wavelength specs; Low dλ/dT**
- Industrial Sensors
  - **Superior beam characteristics compared to LEDs**
  - **Reduced cost of optics and increased mechanical robustness**
  - **Arrays can eliminate mechanical scanning**
- Residential/Consumer POF
  - **High speed (>2Gb/sec) modulation**
  - **Low NA for efficient fiber coupling**

- Spectroscopy
  - **Narrow linewidth, polarization stable**
- Medical Diagnostics and Imaging
  - **Large scale linear arrays**
- MEMS Integration (beam scanners)
  - **Vertical emission simplifies packaging**

Typical Device Structure



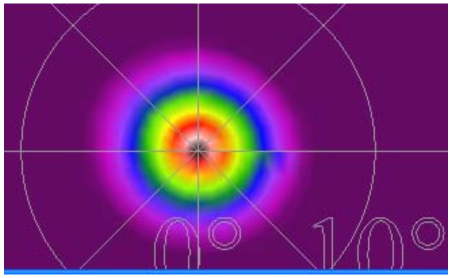
- $Al_{0.5}Ga_{0.5}As$ / $Al_xGa_{(1-x)}As$ DBRs: $x>0.92$
- 1-3λ cavity
- GaInP QW's (compressive strain)
- Tensile strained barriers and spacer transition
- 50%→70% graded AlGaInP SCH
- Zn doping in p-spacer
- Misoriented substrates

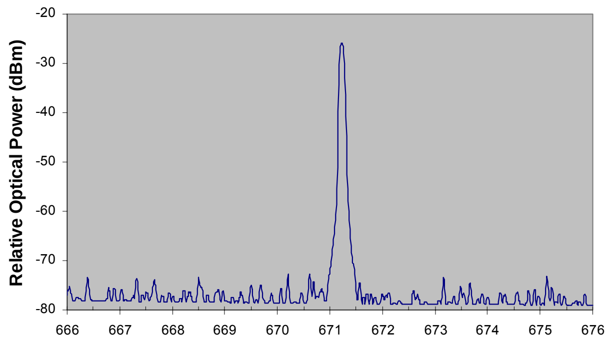
Well Known Technical Challenges

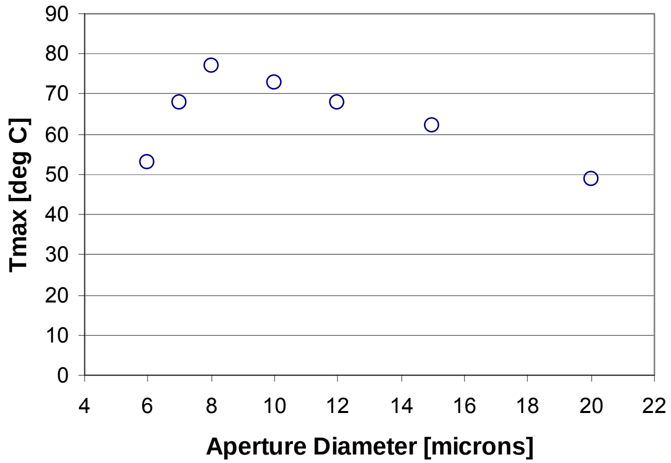
- Small conduction band offset AlGaInP
  →Thermal carrier overflow at high J,T
- Need for ~50% AlGaAs in DBRs
  Poor thermal conductivity (high thermal impedance)
  Low index contrast DBR (resistance, thermal impedance)
  Reduced mobility (increased resistance)
- Zn diffusion in active region
  Burn-in effects
  Reliability concerns
- Oxygen Incorporation
  Reduction in radiative efficiency

Demonstrated CW Performance (Proton)

- Single-mode
  - 2.8mW @ 671nm: 4.5mA, 20C
  - Divergence = 5.5 to 7.5 deg FWHM
  - SMSR > 45dB
- Multi-mode
  - 11.5mW @ 673nm, 20C
  - Peak WPE of 19.9% at 18mA.
- Temperature
  - 670nm Lasing to 79C
  - >1mW @ 60C
- Efficiency
  - Peak WPE 22.9%
- Polarization stability
  - PER 20-25dB typical







Proton VCSEL Limitations

For many applications, proton performance is fine

- Good single-mode power
- Adequate temperature performance

But…

Proton VCSELs don't modulate very well

- Severe DCD for low duty cycle, high ER applications
- Thermal lensing

Example: Laser Printing

Desire >20db (i.e. infinite) extinction ratio
Minimal turn-on delay
5-10ns pulse widths
Low duty cycles (<<1%)

The Oxide Alternative

Red oxide VCSELs modulate well

But…

Low single-mode power

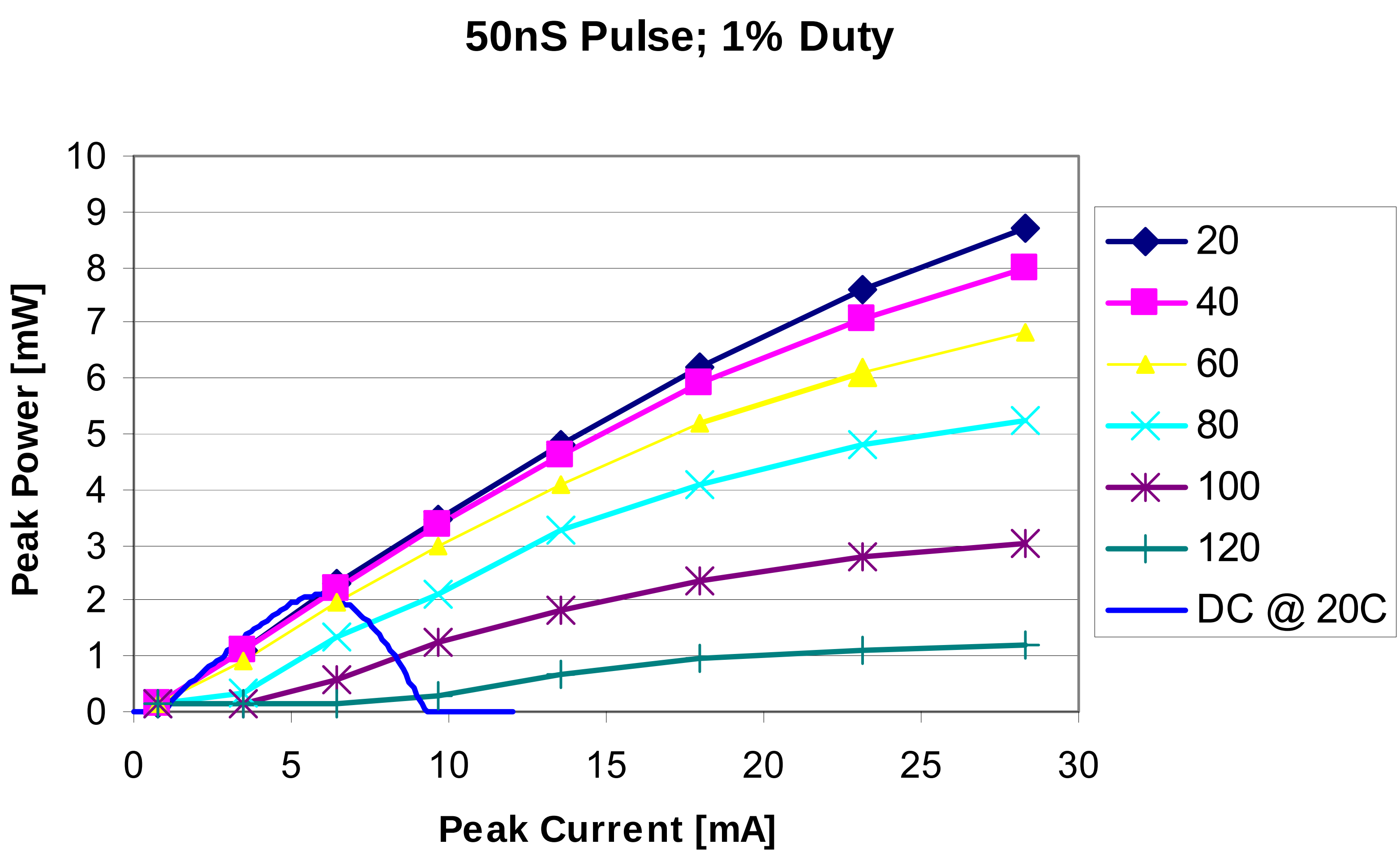
Exhibit poorer temp performance

Goal: Improve red oxide VCSEL performance through

1) Improved thermal management
2) Improved mode control

High Temp Pulsed Operation

Performance under pulsed conditions



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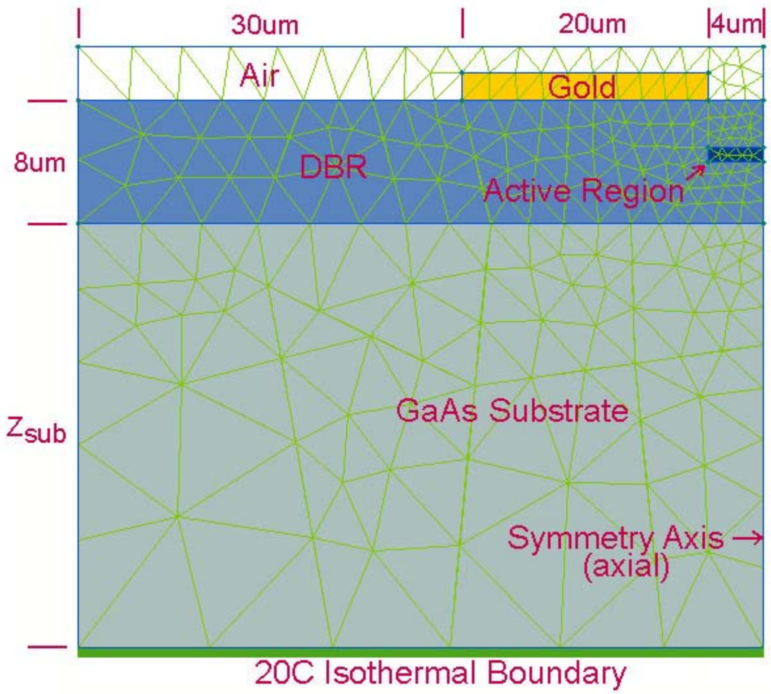
Thermal Model

- Planar and etched mesa device structures
- Extraction of thermal impedance

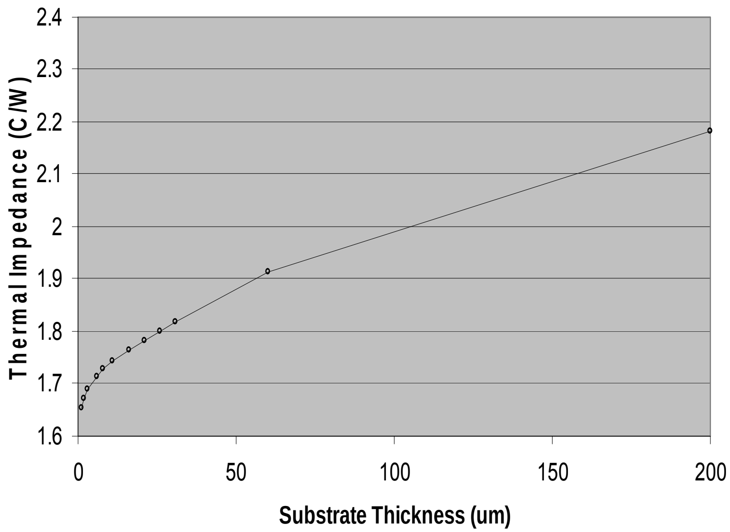


Anisotropic DBR thermal conductivity

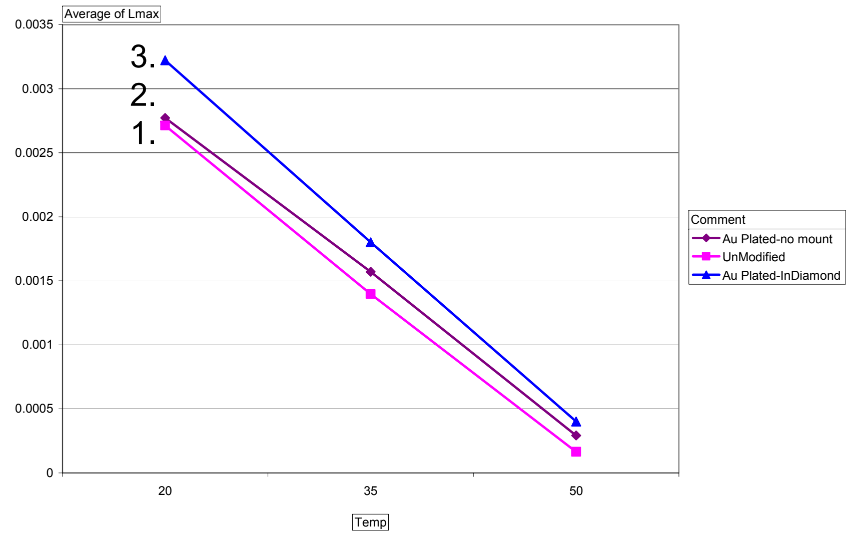
$$K_r = (K_{AlAs} + K_{AlGaAs})/2 = (90 + 10)/2 = 50\ W/mK$$
$$K_z = 2/(1/K_{AlAs} + 1/K_{AlGaAs}) = 2/(1/90+1/10) = 18\ W/mK$$

Substrate Removal

- Common practice in HB LEDs



Rth vs. Substrate Thickness (modeled)



Lmax vs. Temp (experimental)

- Not terribly effective for red VCSELs
- ~10% reduction in Rth reasonable
- Not attractive for processing

1. Substrate removed
2. Au plated
3. Diamond fused

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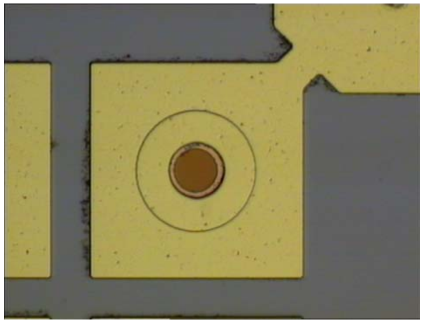
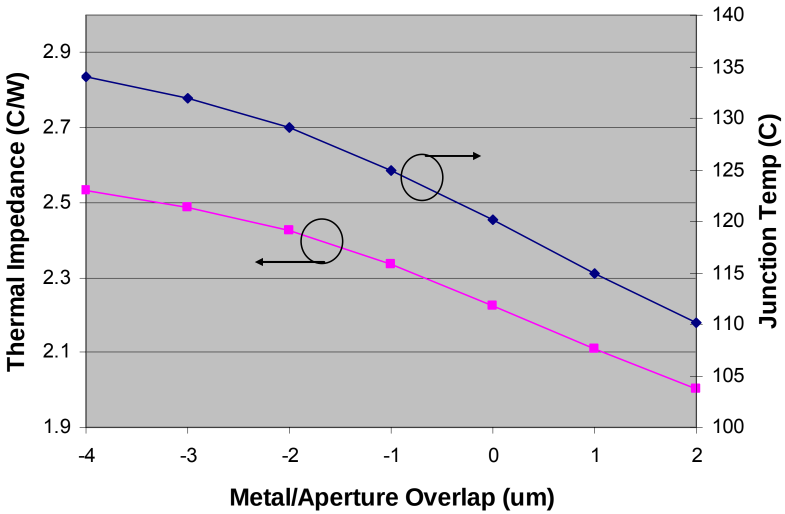
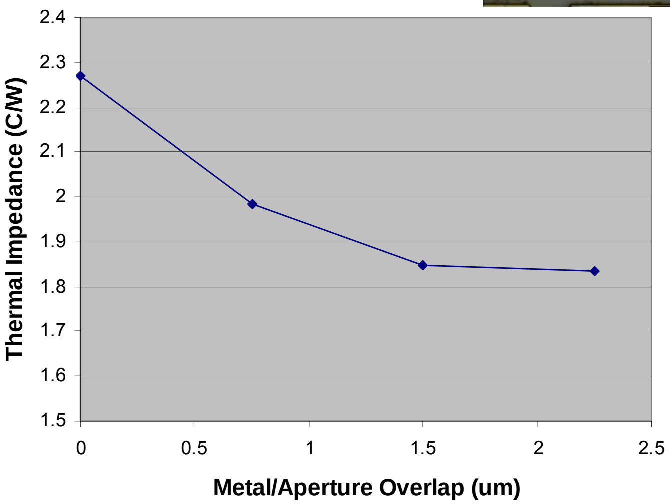
Aperture/Metal Overlap

- Strong effect on Rth





(modeled)

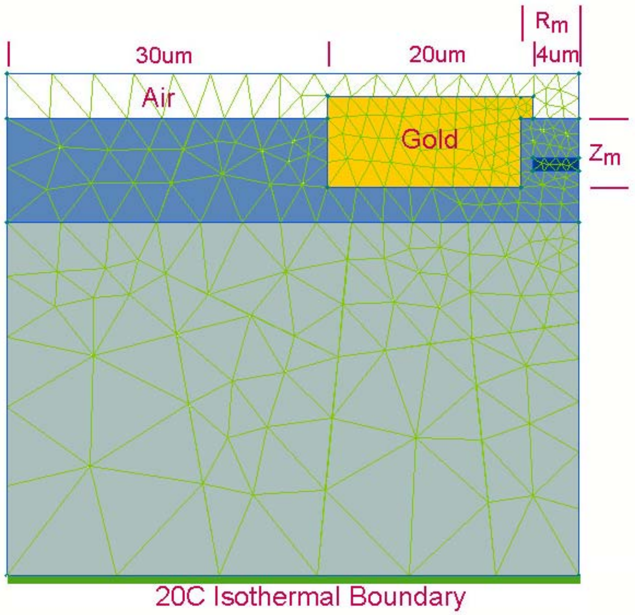


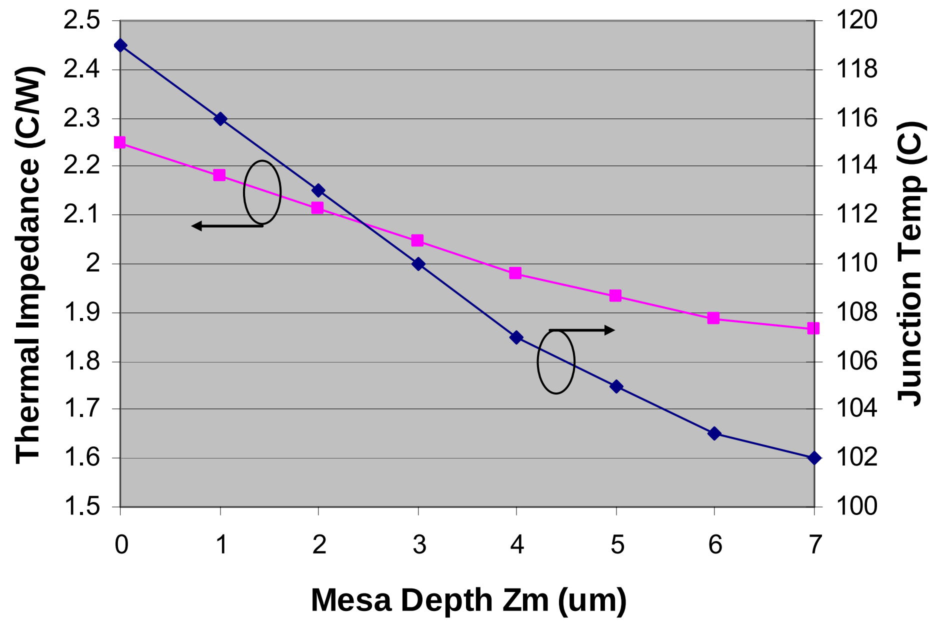
(experimental)

- Penalty in output power due to vignetting
- Alignment-related uniformity variation

Lateral Mesa Heatsinking

- Mesa etch with metal plating





- Potentially effective (~15% reduction in Rth)
- Increased process complexity
- Demonstration in process @CSU (Lear)

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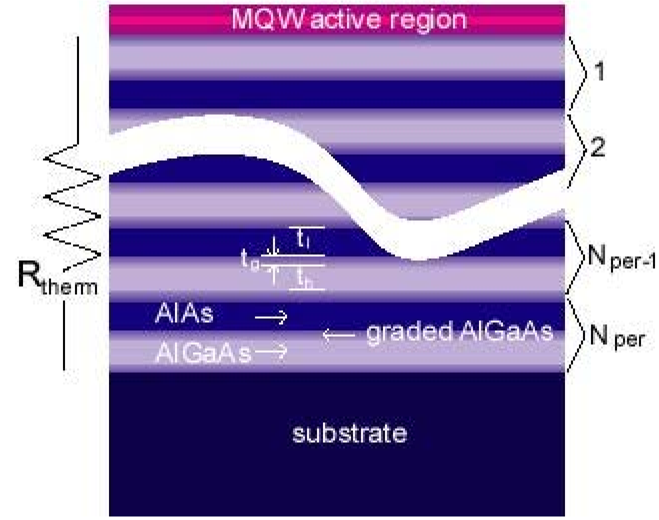
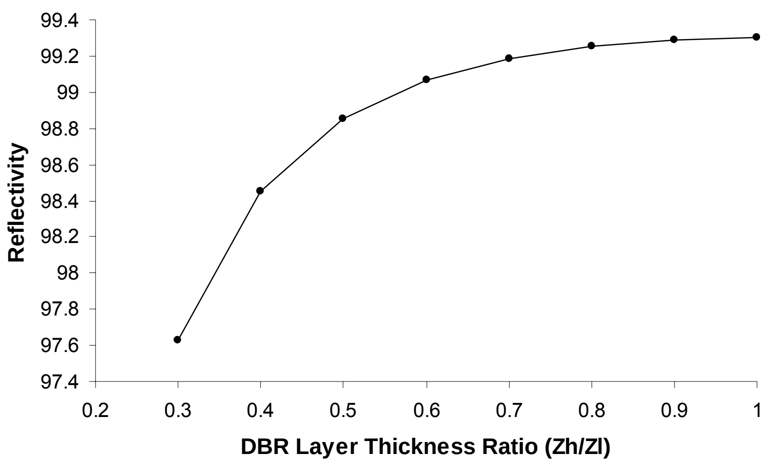
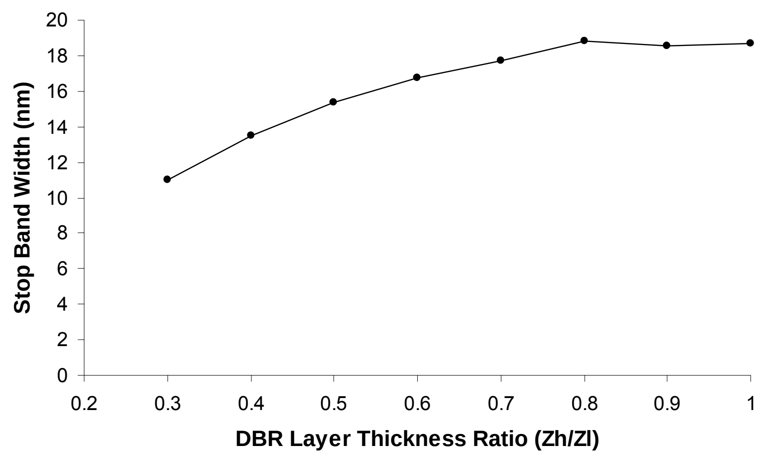
Improved Mirror Design

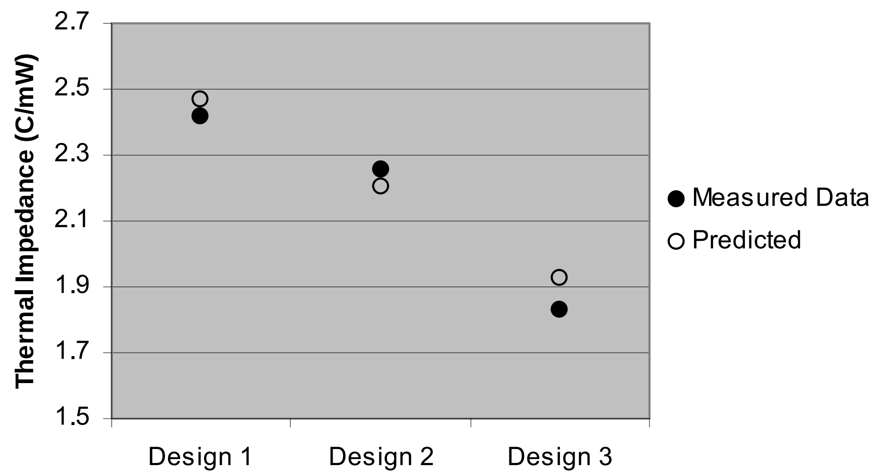
- Depart from quarter wave stack
- ~30% reduction in Rth
- Minimal observable increase in Ith



Design	Zh/Zl	Grade
1	0.90	12nm
2	0.88	20nm
3	0.58	12nm







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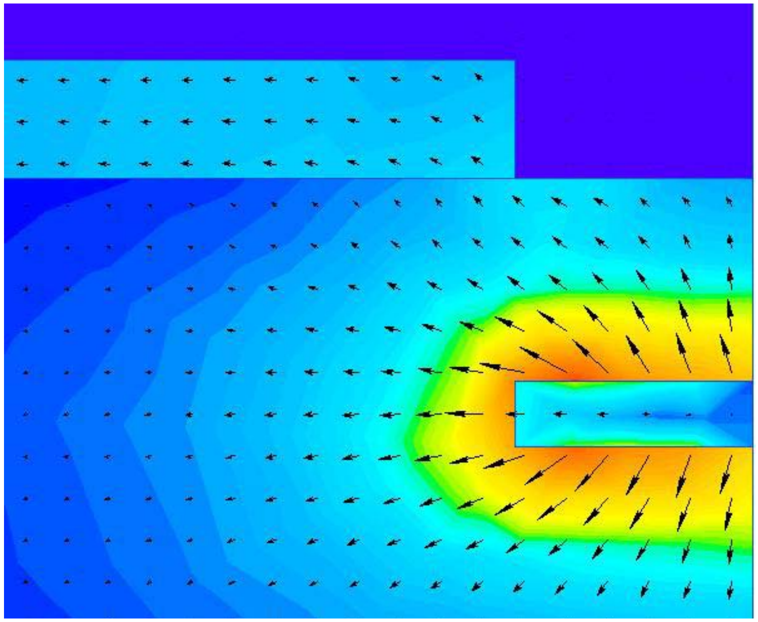
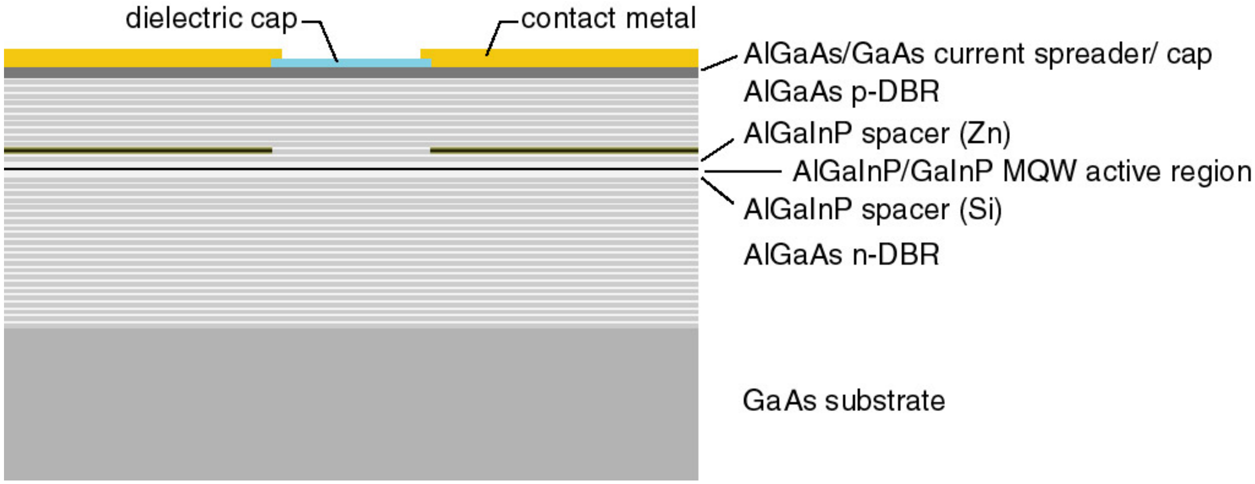
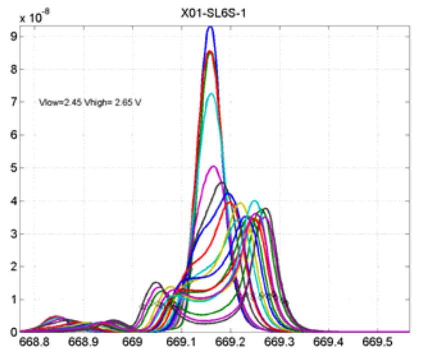
Junction Heating

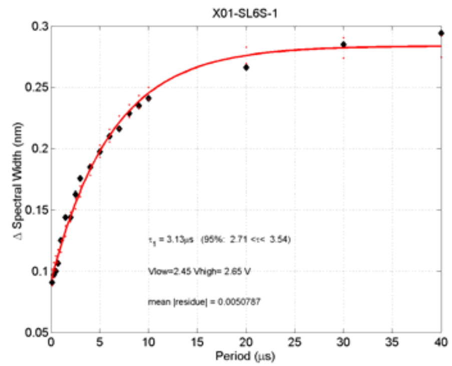


Color map of heat flux

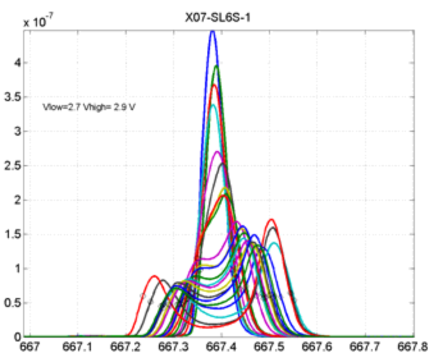


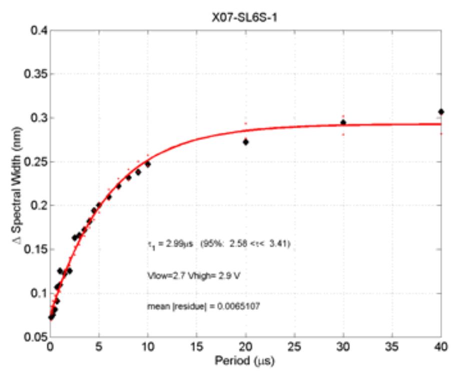
Junction Heating Time Constant



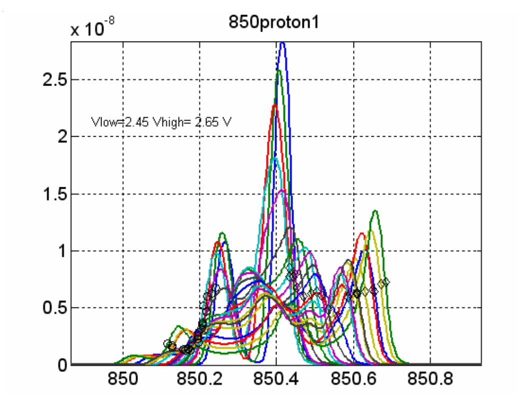


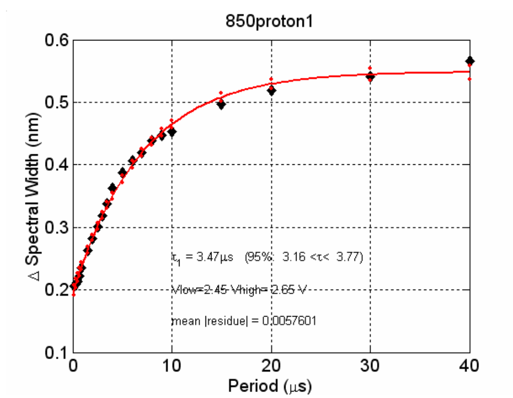
1λ AlAs Cavity: τ=3.13uS





2λ AlAs Cavity: τ=2.99uS

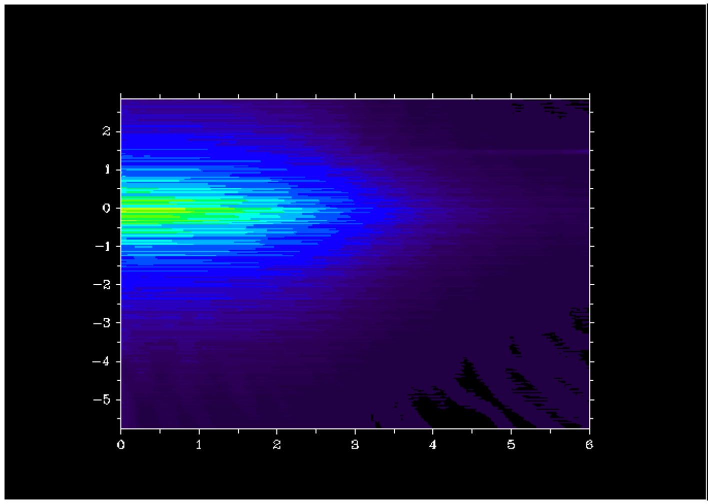




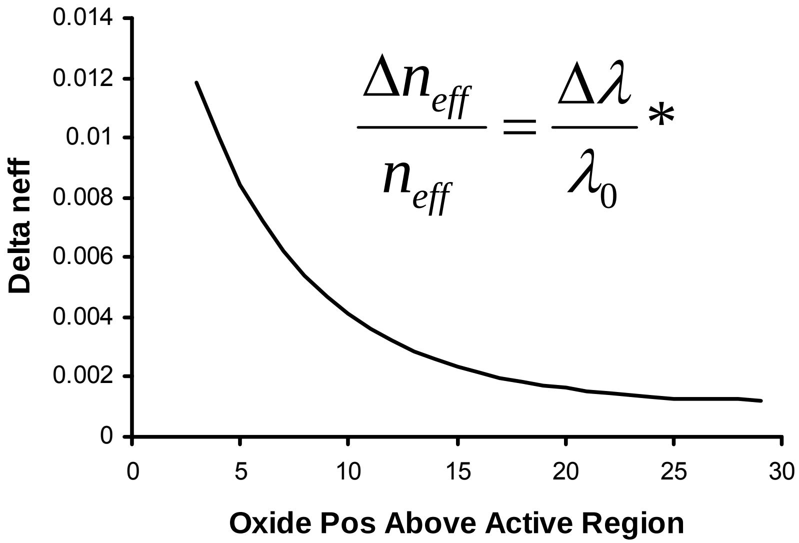
850nm: τ=3.47uS

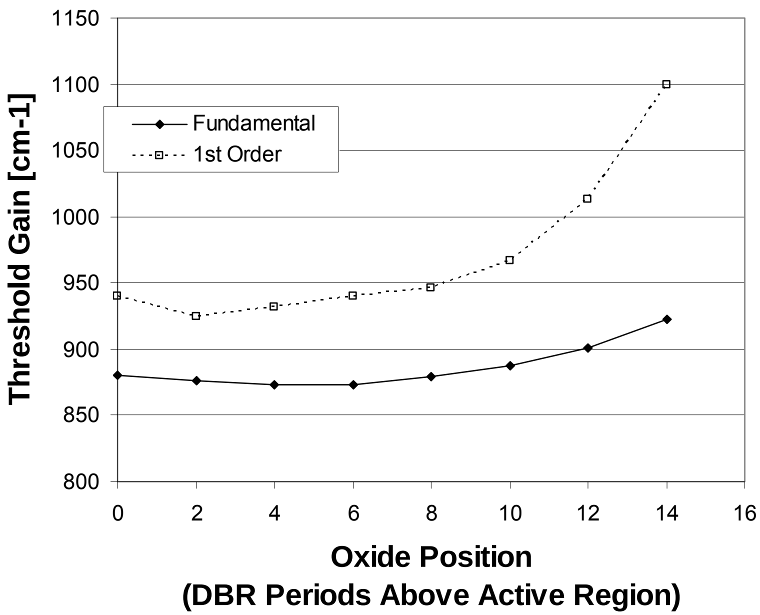
Oxide VCSEL Mode Control

- Displace oxide layer in P-DBR
- Reduced index confinement
- Increased scattering loss
- High order mode suppression



$$\frac{\Delta n_{eff}}{n_{eff}} = \frac{\Delta \lambda}{\lambda_0} *$$

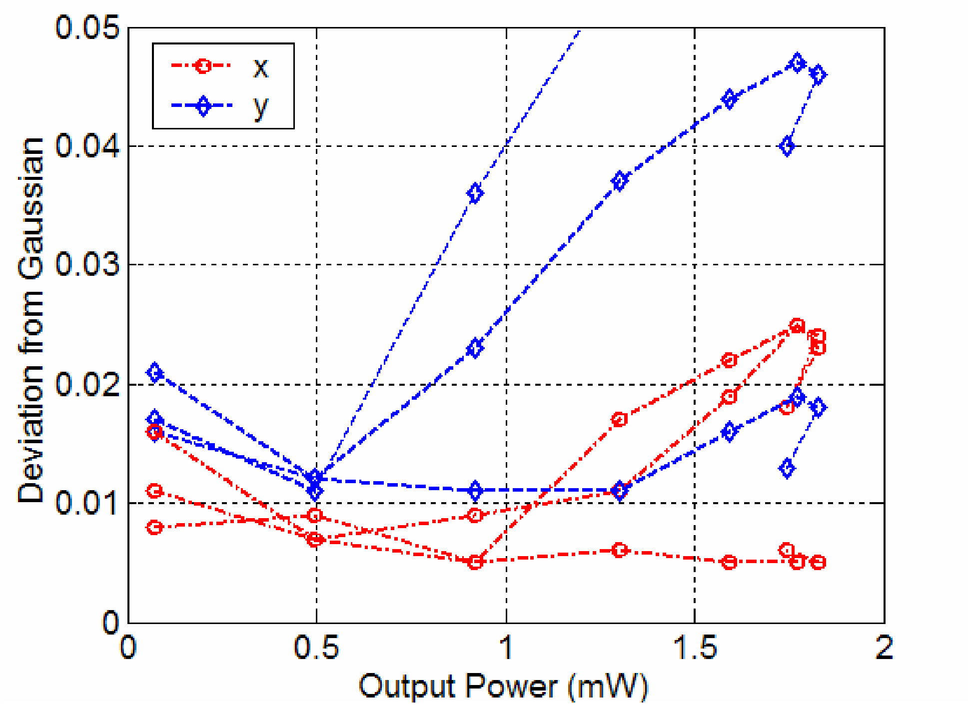


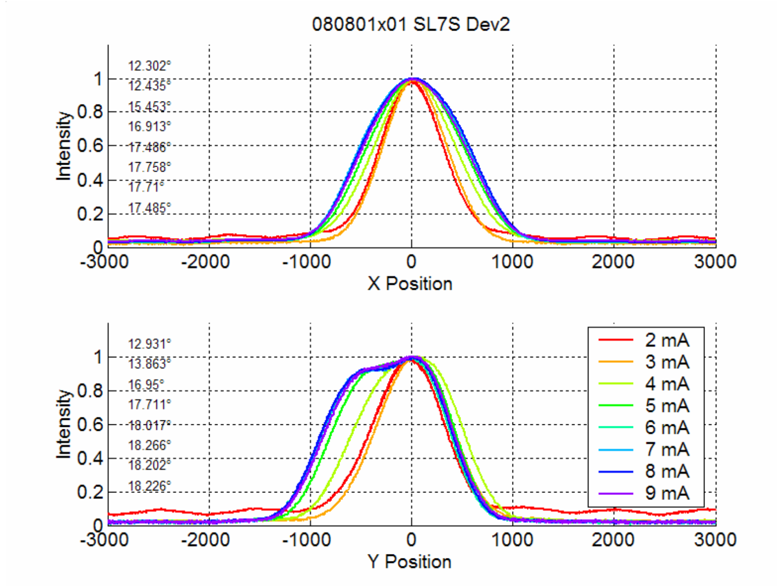


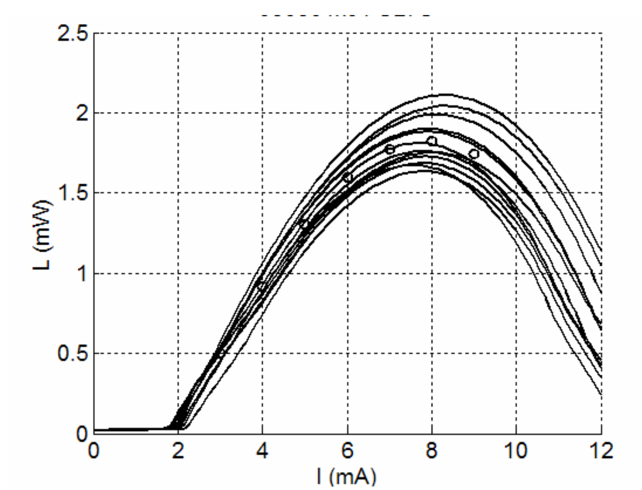
*Hadley, JQE, v32, n4, p607, 1996.

Mode Control Results

- 8^{th} period oxide
- 7um aperture







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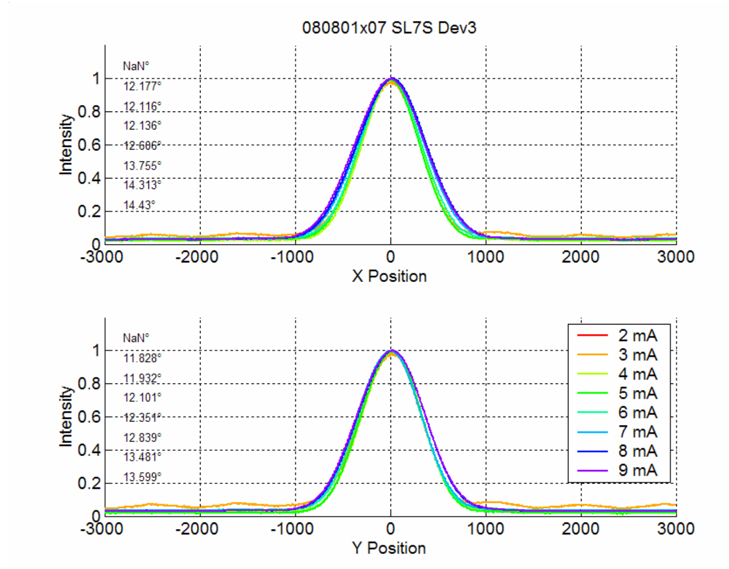
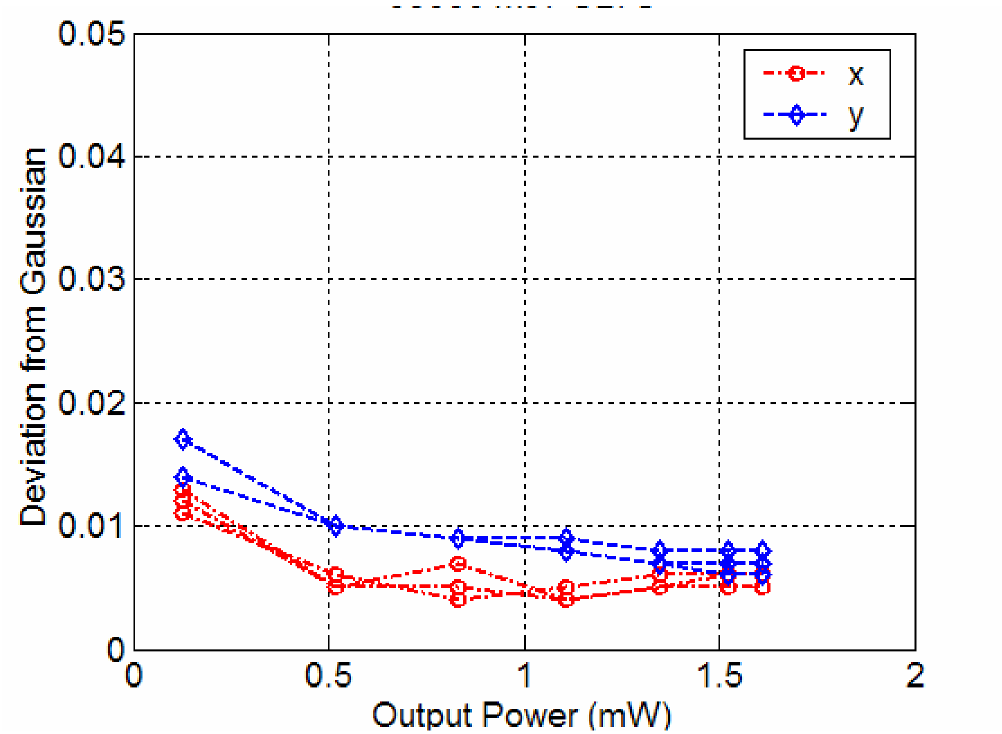
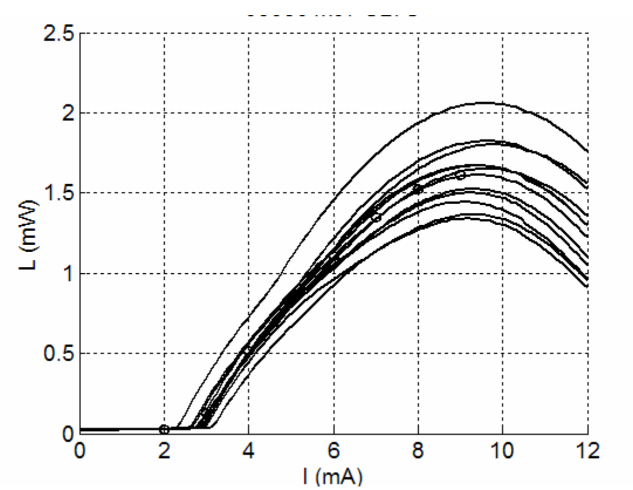
Mode Control Results

- 12th period oxide
- 7um aperture







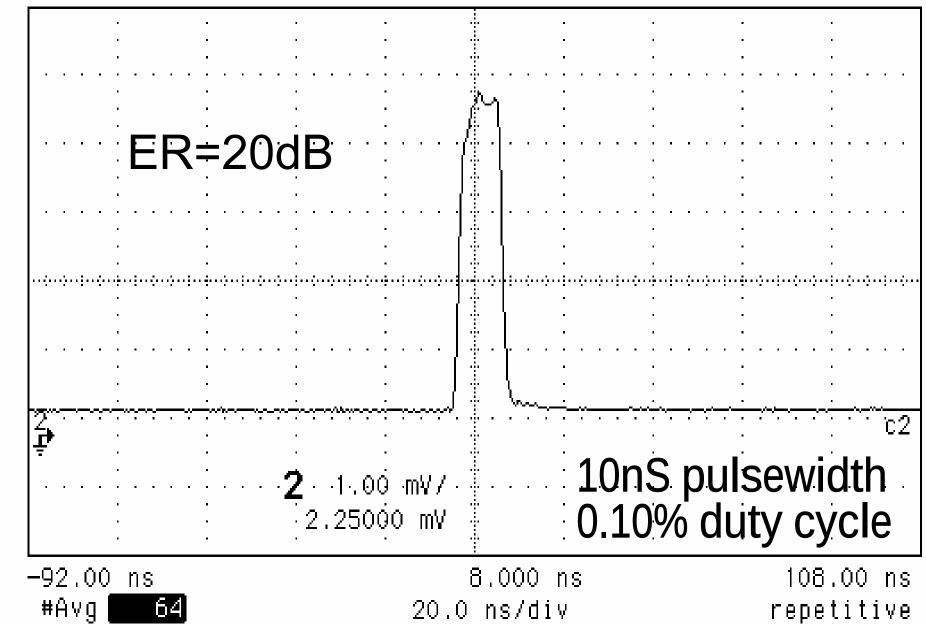
- Excessive current leakage

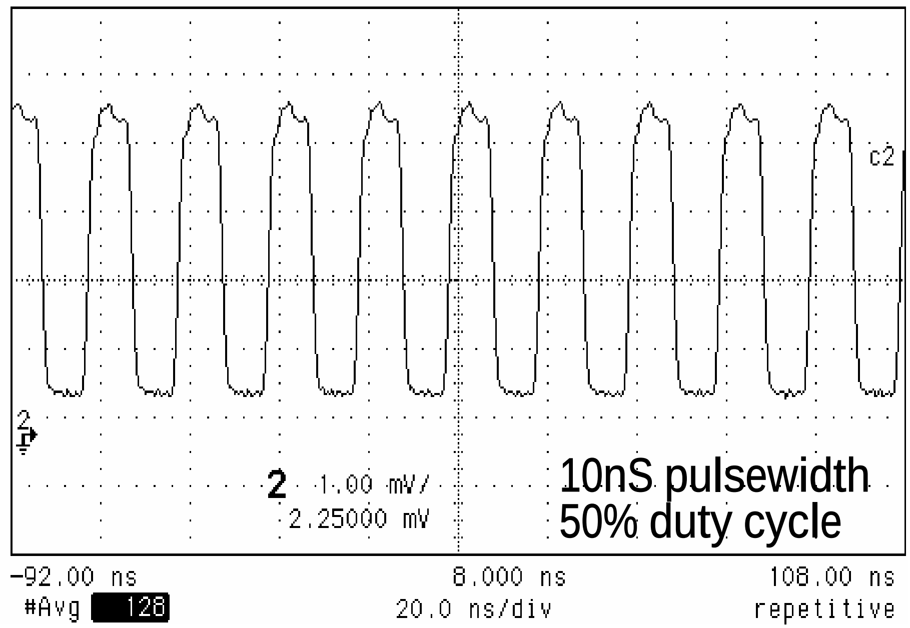
DCD Results

Duty Cycle Disortion

- DCD is a dependence of peak pulse power on duty cycle
- Proton VCSELs have issues with DCD due to thermal effects

12th period oxide





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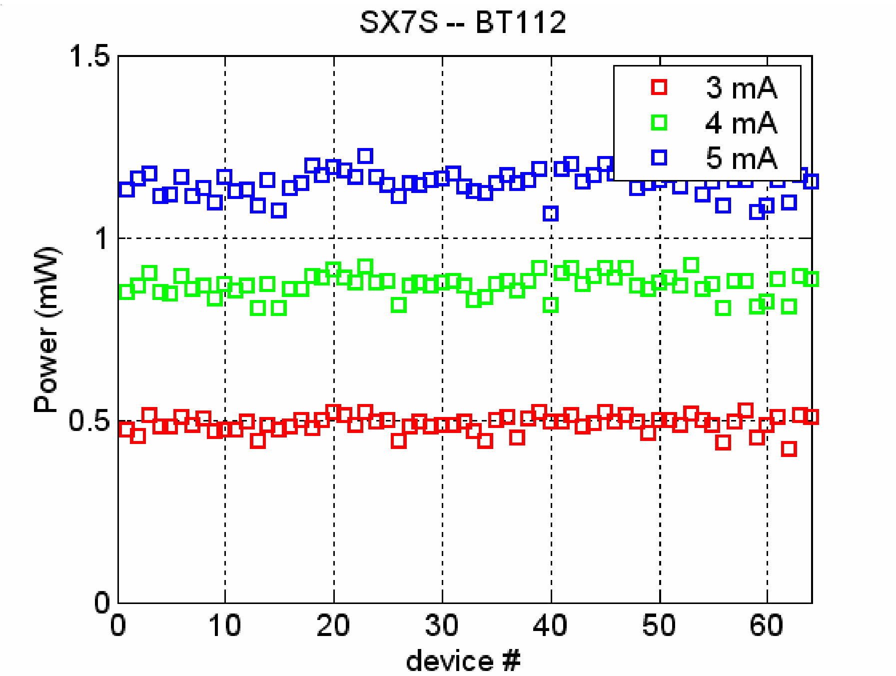
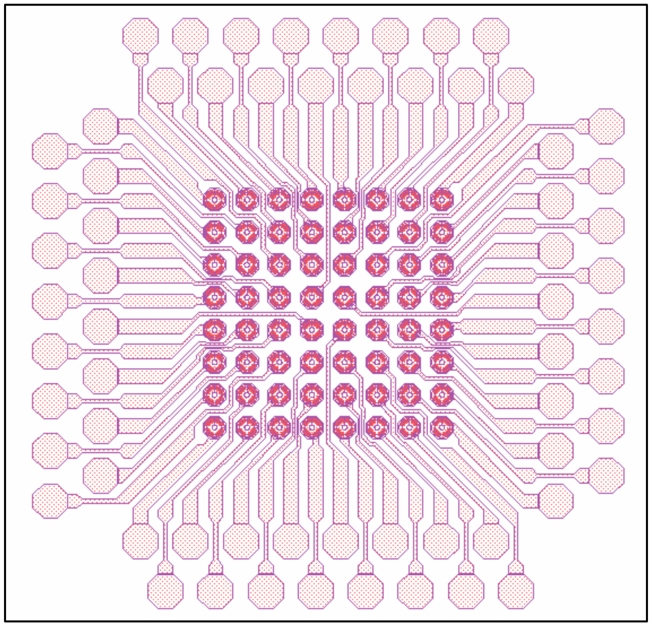
Uniformity

- 670nm oxide VCSEL 8x8 array uniformity
- 12th period oxide





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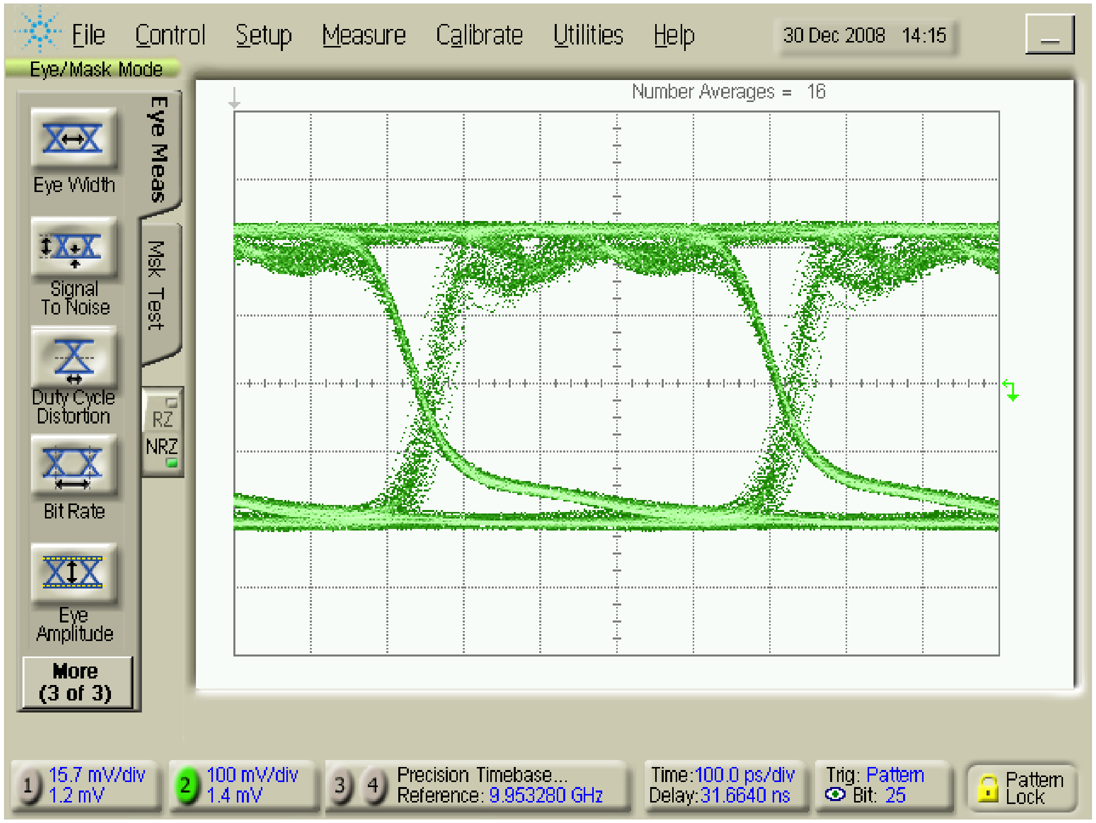
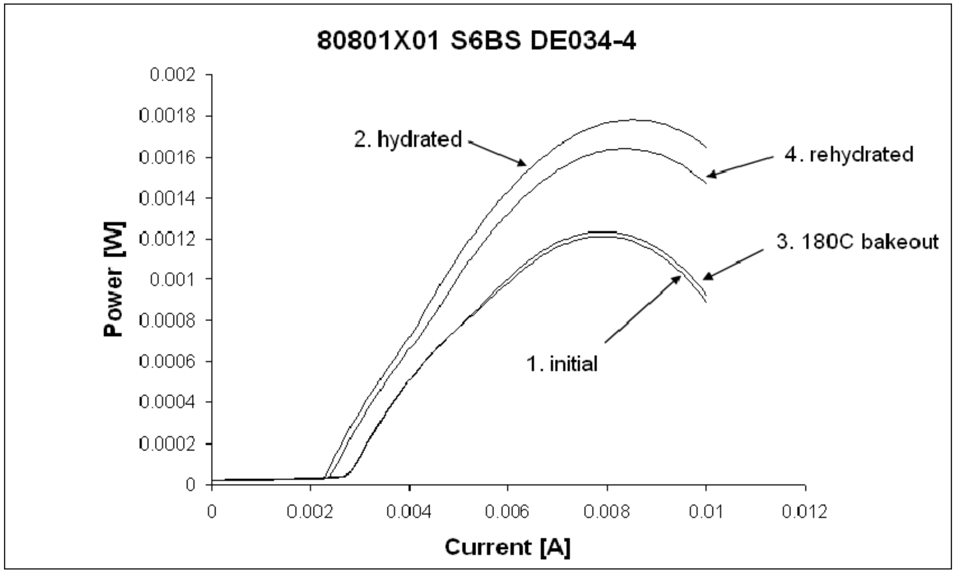
High Speed Modulation

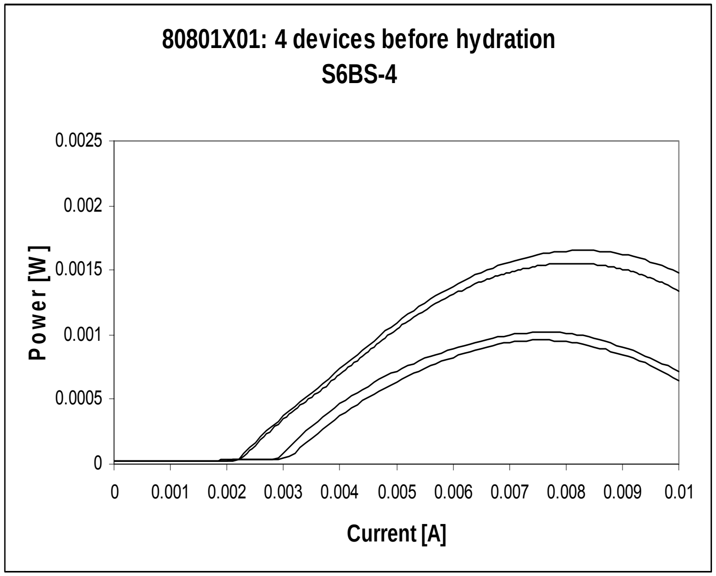
- 2.125GB/s PRBS 2^7
- ~10dB ER

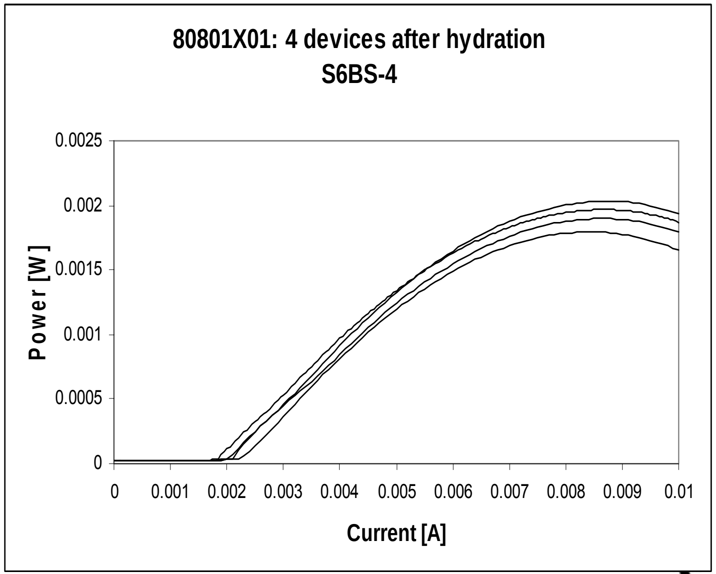


670nm Unfiltered Eye @ 2.125G

Nitride Hydration Surprise







Summary

- Investigated multiple thermal management techniques
  - Surface and lateral mesa heatsinking promising
  - Substrate removal cost/benefit not compelling
  - Improved DBR design is highly effective
  - Direct heatsining of active region inconclusive
- Raised oxide highly effective for mode control
  - 2mW, 7um aperture, full operating range
  - Minimal DCD
  - Need to reduce leakage