Development of Semiconductor Disk Lasers for Sodium Guidestar Applications

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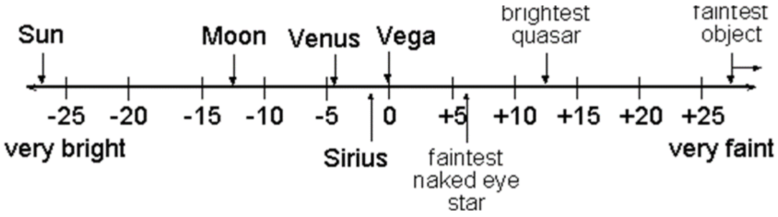
Outline

- Introduction
- Background of Laser Guidestar (LGS)
- Sodium Beacon Requirements
- History of Sodium Beacon Laser Sources
- Vertical External-Cavity Surface-Emitting Laser (VECSEL)
- Thermal Management and Power Scaling
    - Distributed Bragg Reflector Free (DBR free)
    - In Well Pumping/Multipass
    - Gain Embedded Meta Mirror (GEMM)
- Summary

Sodium Laser Beacon Background

- Guidestar Adaptive Optics on dim objects up to relative magnitude (RM) of 19
- Natural vs. Laser Guidestar (LGS)
- Sodium LGS
  - Excite mesospheric sodium atoms at 90km
  - RM of ~6 (depends on sodium layer)
  - Three current viable sodium guidestar sources
  - All sources are expensive and complex

Laser Guidestar Technology at the Starfire Optical Range

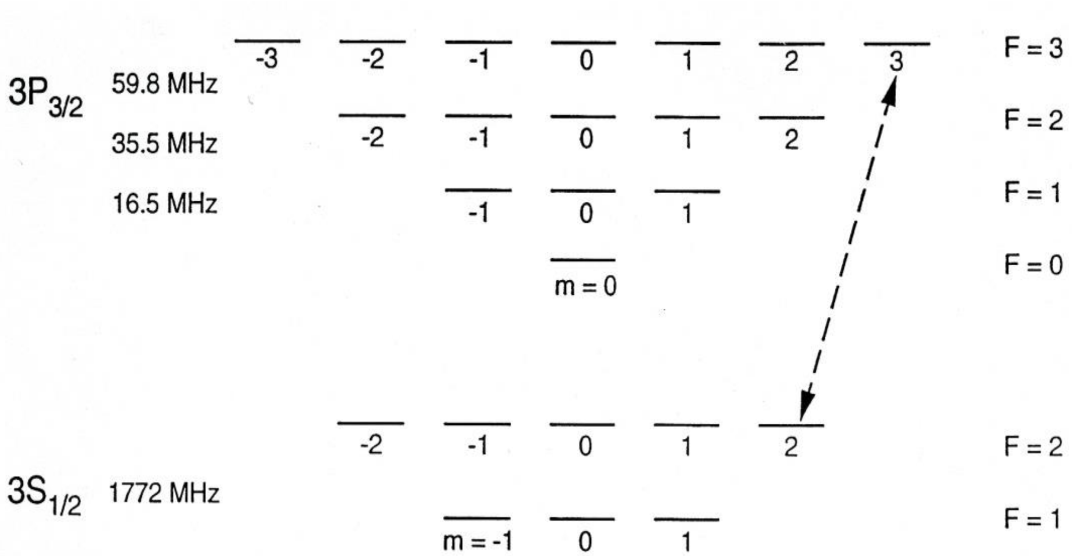


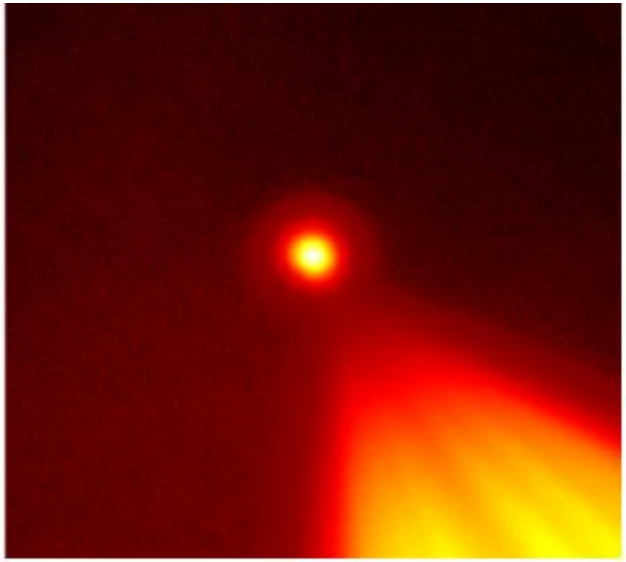
$$m_x - m_{x,0} = -2.5\log_{10}\left(\frac{F_x}{F_{x,0}}\right),$$

Max, C., American Astronomical Society, University of California at Santa Cruz, 2009.

Sodium Laser Beacon Requirements

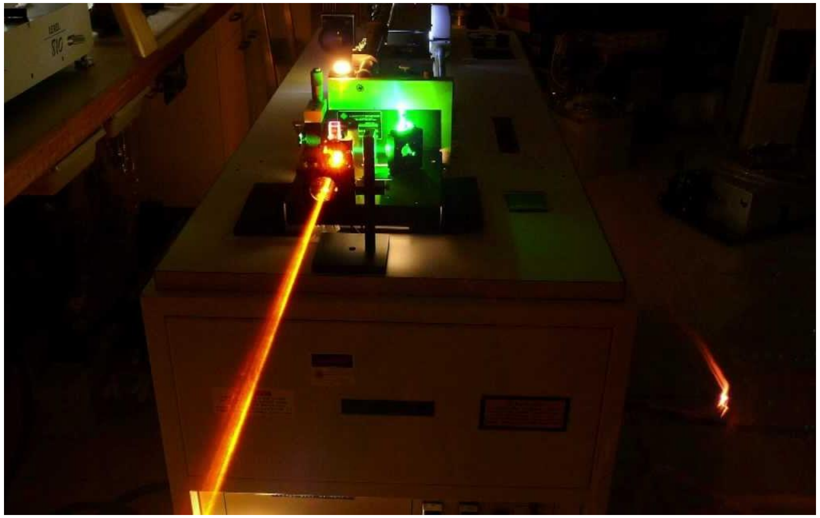
- Beam Quality $M^2 < 1.1$
- Linewidth < 3 GHz
- Power > 10 W
- Wavelength: 589 nm
  - Very hard to access
  - Non-linear optics often required
  - Second Harmonic Generation of 1178 nm
  - Sum Frequency Generation of 1319 nm, 1064 nm



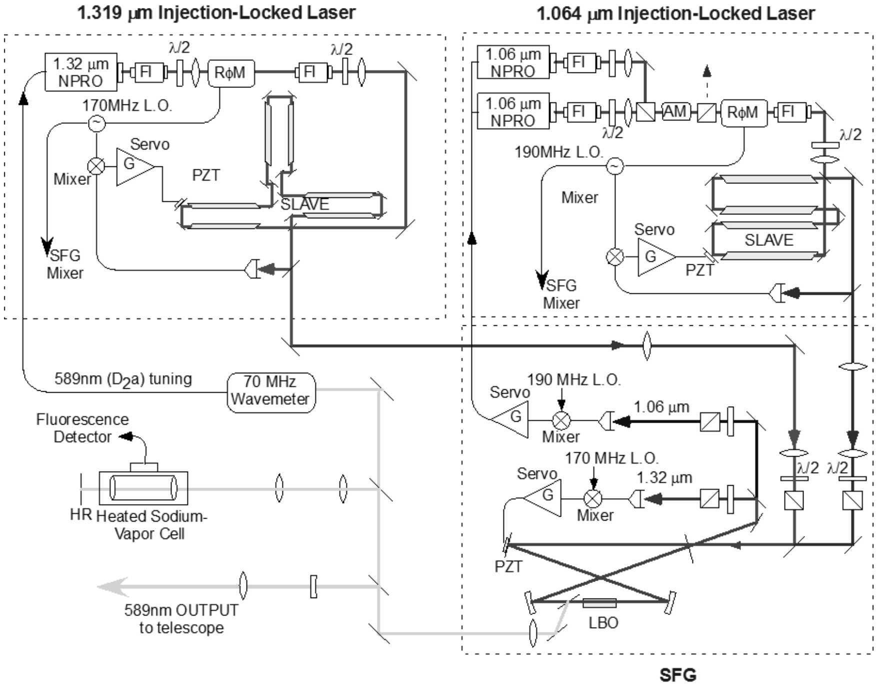


Laser Sources for Sodium Beacons

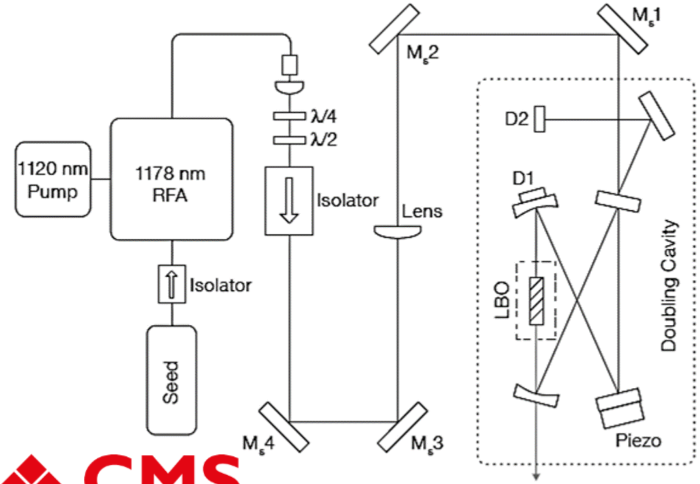
1st Generation Dye Laser



2nd Generation Sum Frequency Laser

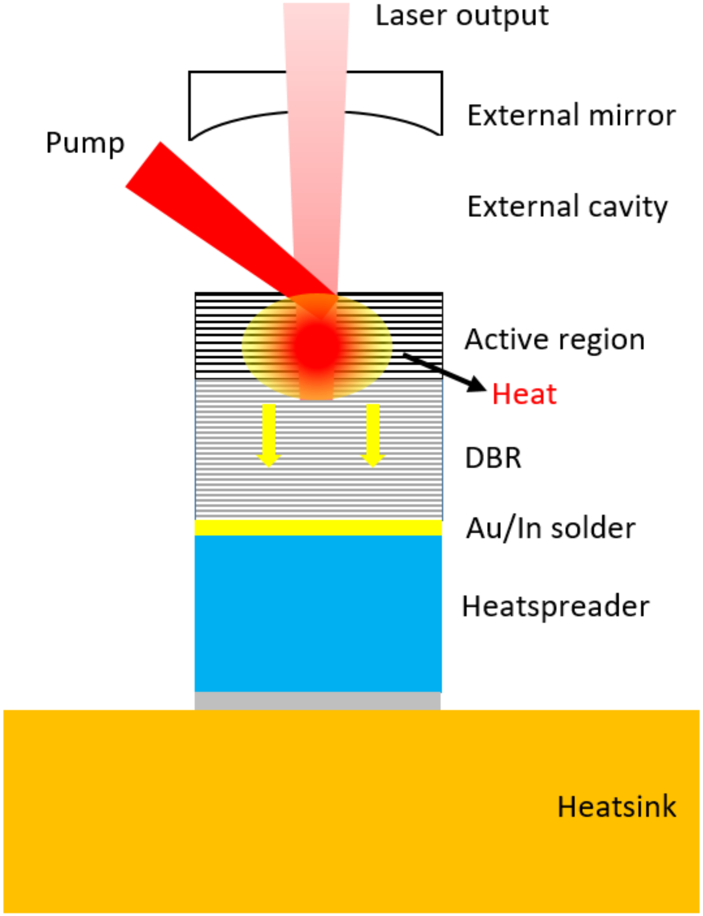


3rd Generation Raman Fiber Amplifier



- Denman et al., CfAO Conference Proceedings, November 2006.
- Bonaccini Calia D. et al., ESO Messenger Press Release, March 2010.
- Hackett, Shawn, UNM Digital Repository, November 2016

Optically Pumped Semiconductor Laser (OPSL)



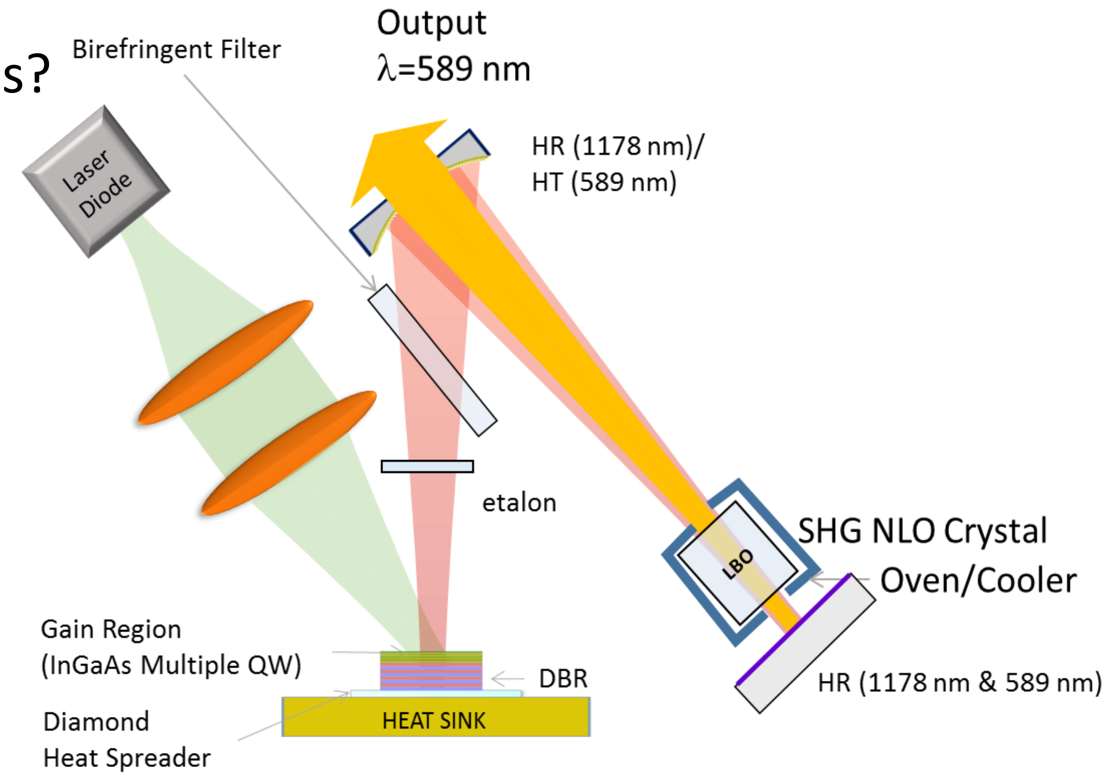
- Vertical External-Cavity Surface-Emitting Lasers
  - High quality mode (M^2~1)
  - Power scalability (106 W fundamental @ 1um)
  - Intracavity access (frequency conversion, cavity enhanced absorption,…)
  - Wavelength flexibility
  - Broadband gain

M. Kuznetsov, et al., *IEEE Photon. Technol. Lett.* 9, 1997
B. Heinen, et al., *Electron. Lett.,* 2012
U. Keller and A. C. Tropper, *Phys. Rep.,* 2006
A. Garnache, et al., *J. Opt. Soc. Amer. B*, 2000
M. Scheller, et al., *Opt. Express,* 2010
A. Quarterman, et al., *Nat. Photonics,* 2009
A. Albrecht et al., *Opt. Express,* 2013

OPSL for Sodium Beacons

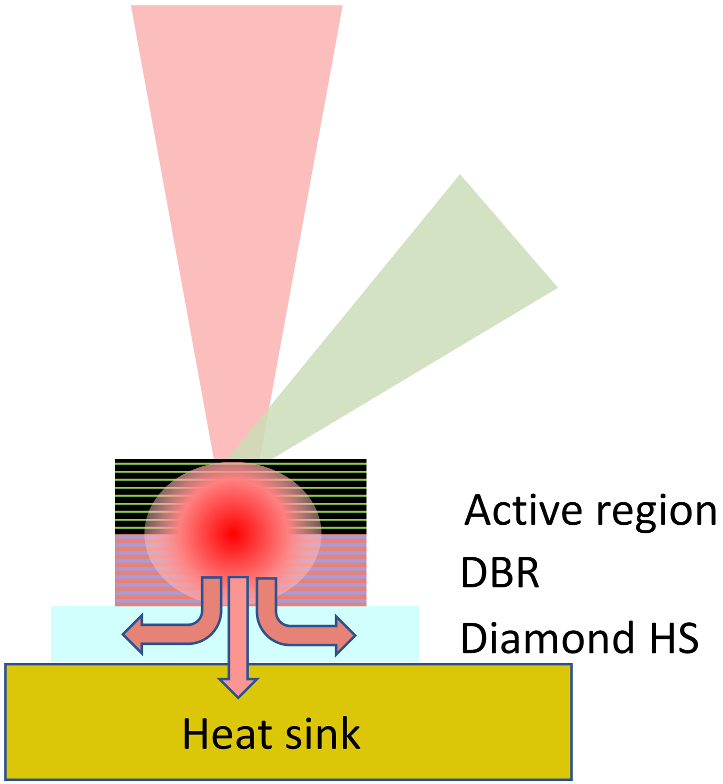
- 4th generation of LGS sources?
  - Few Optical Elements
  - Inexpensive
  - Compact
  - Light weight

- First demonstrated by University of Arizona
- Power > 20 W Yellow broadband at Tampere University of Technology



Hackett, S., et al. *SPIE Photonics West Proceedings*, 2016
Fallahi, M., et al. *IEEE Photonics Technol. Lett.*, 2008.
Kantola, E., et al. *Opt. Express*, March 2014.

Thermal Management and Power Scaling



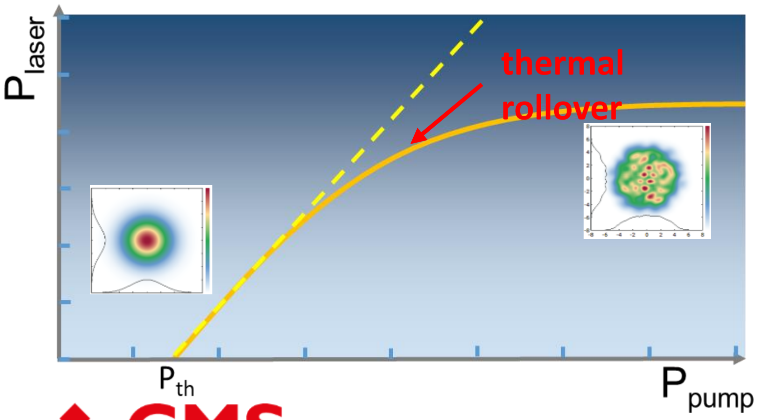
Quantum Defect: Laser= 1178 nm , Pump=808 nm

$$\delta_{quantum} = 1 - \frac{P_{laser}}{P_{pump}} \approx 32\%$$

Heat Loads:

Gain region: Quantum defect and non-radiative recombination losses

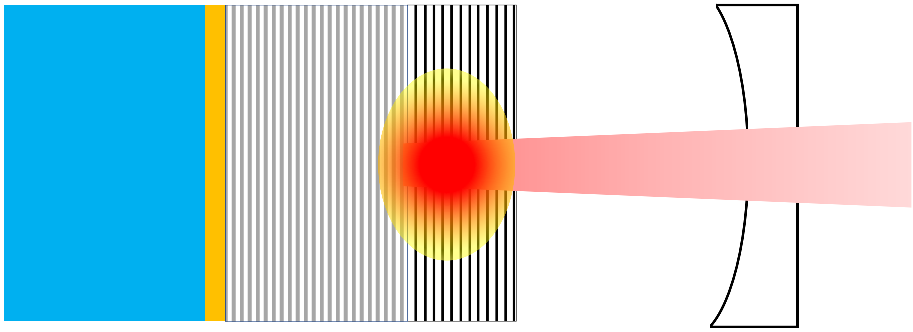
DBR region: pump absorption (~ 11% of the incident pump power for 12 QWs)



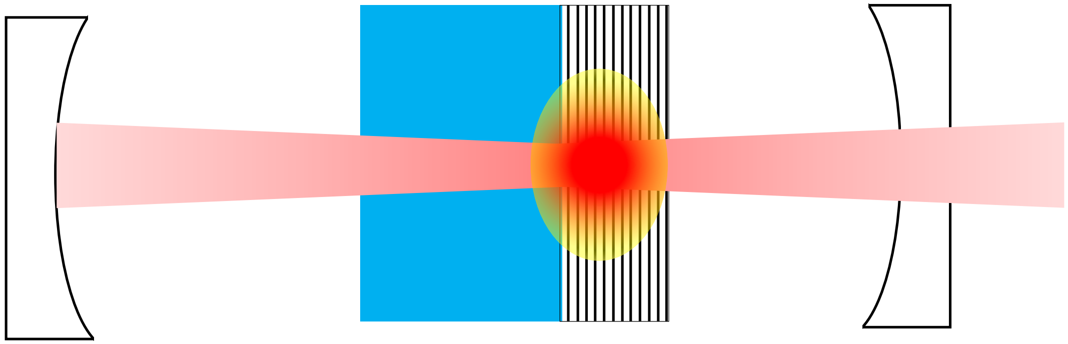
Thermal conductivity coefficients:

- DBRs: ~ 20 W/(m·K) : thermal bottleneck
- Diamond heat spreader: ~ 2000 W/(m·K) (ideal)
- SiC heat spreader: ~ 400 W/(m·K) (the next best thing)

DBR-Free SDL Configurations



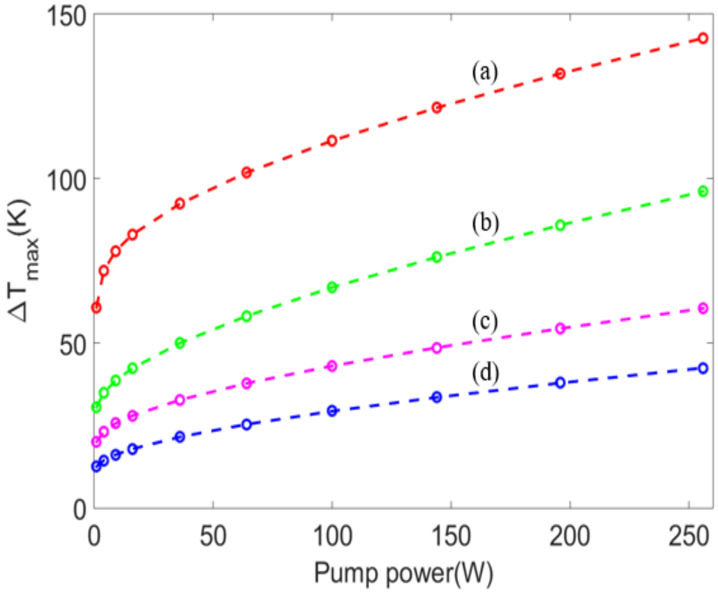
DBR-Free SDL Configurations

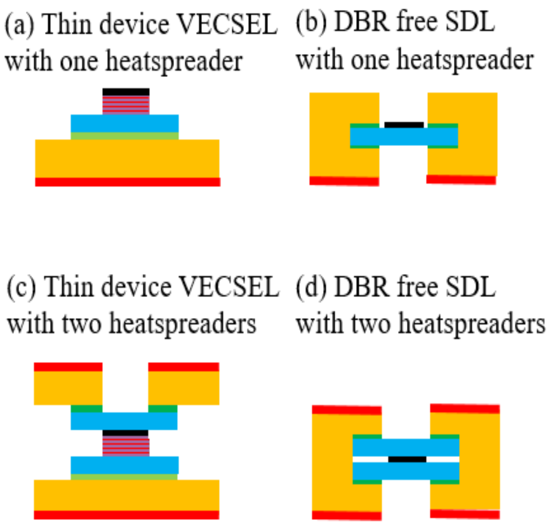


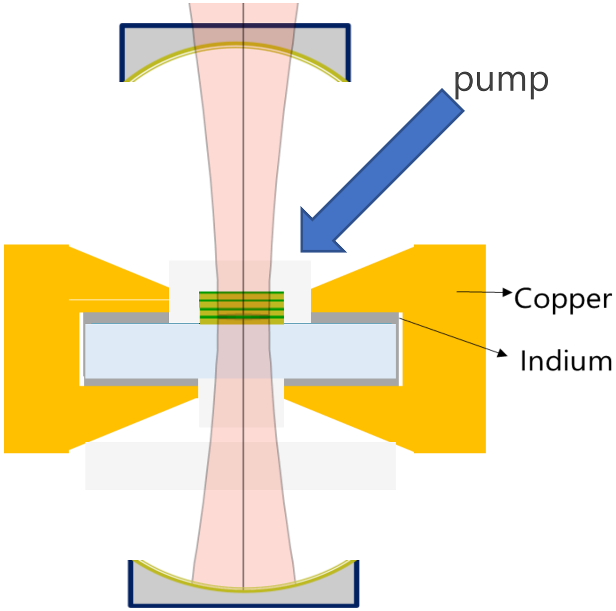
[Z. Yang, et al., Proc. SPIE 9349, 934905 (2015)]

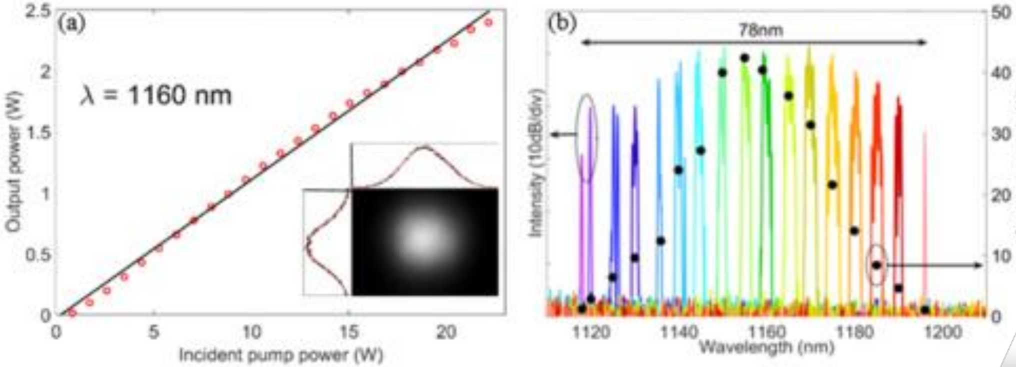
DBR-Free Architecture

- M. Sheik-Bahae, U.S. Patent # 11/845,367 (2009)
- Z. Yang, et al.,, Opt. Express, 23 (26), 33164 (2015)
- H. Kahle *et al.*, *Optica*, vol. 3, no. 12, pp. 1506–1512 (2016)
- S. Mirkhanov *et al.*, *Electron. Lett.*, vol. 53, no. 23, pp. 1537–1539, (2017)



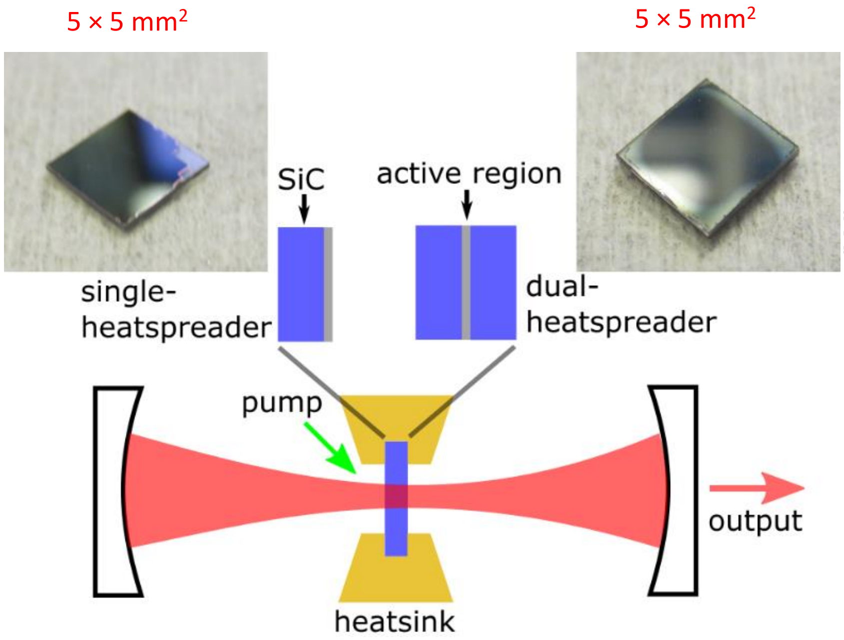


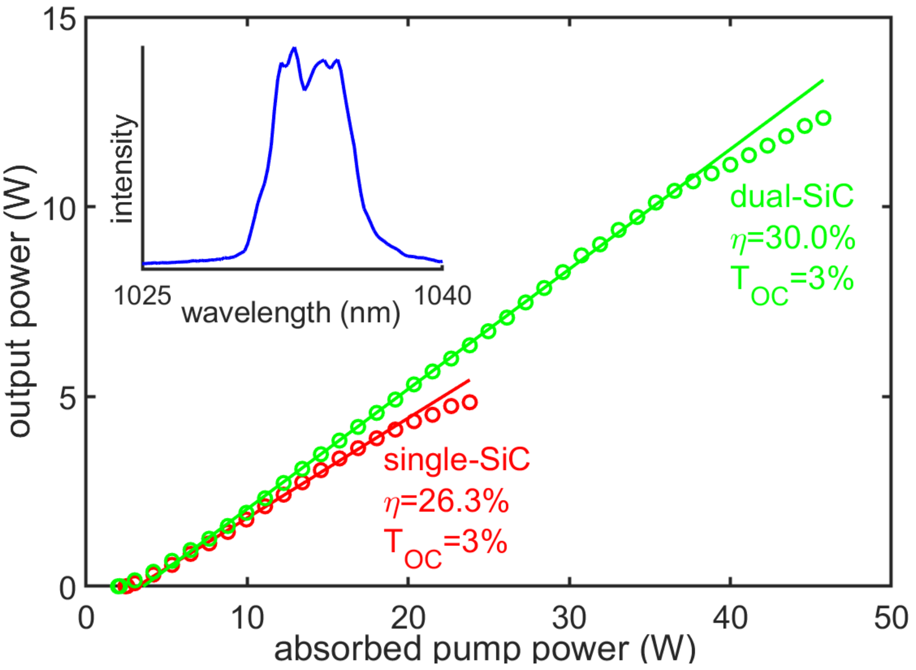




- Broadband tunability (>80 nm)
- Suitable for wavelengths for which epi DBR's not available

Dual-SiC Heat Spreader DBR-Free



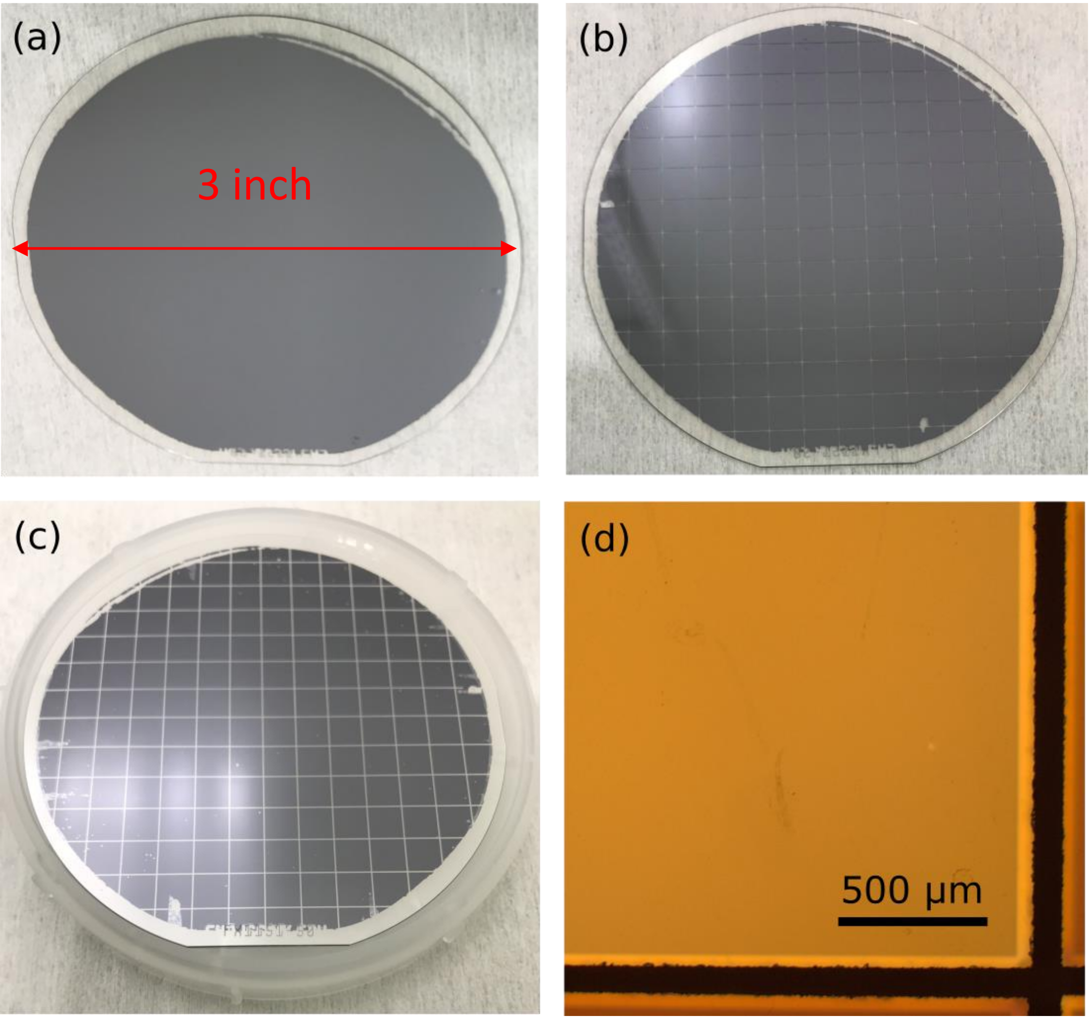


16 W DBR-free semiconductor disk laser using dual-SiC-heatspreader

Yang, et al. Electronics Letters (Volume: 54 , Issue: 7 , 4 5 2018)

Also see: S. Mirkhanov *et al.*, *Electron. Lett.*, vol. 53, no. 23, pp. 1537–1539, 2017 (Univ. Dundee)

Wafer-Scale Fabrication



Cost-efficient manufacturing of high-power SDLs

Wafer-scale manufacturing process for a dual-SiC-heatspreader structure:

(a) direct bonding of epitaxial GaAs to SiC

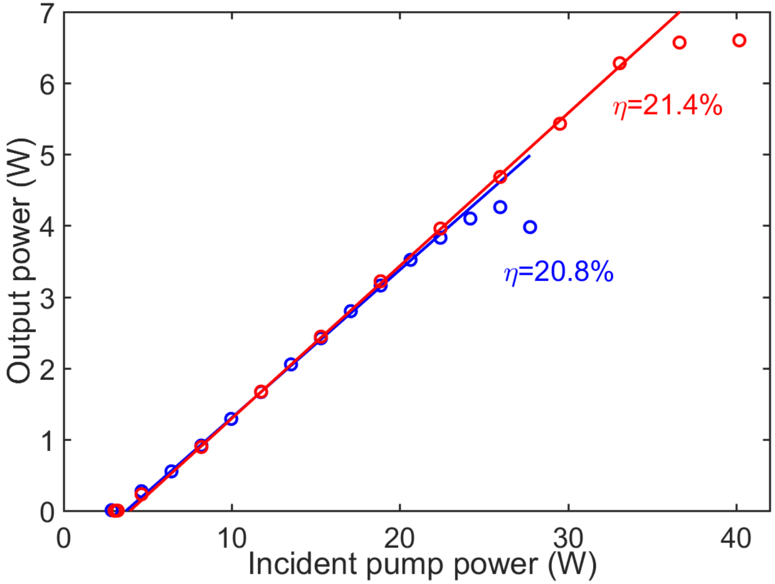
(b) lithography and wet etching of dicing lanes

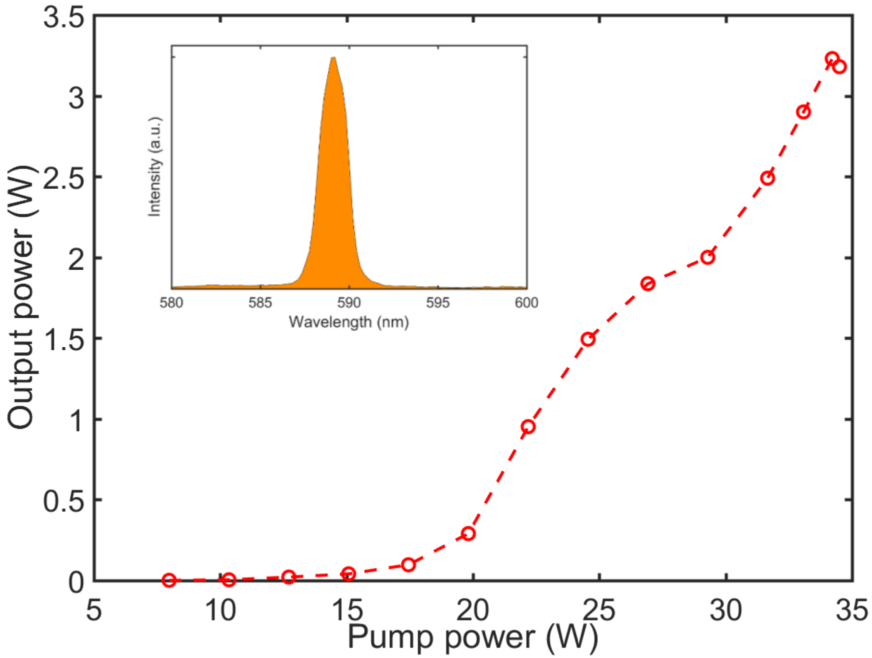
(c) second bonding step for SiC/epi/SiC

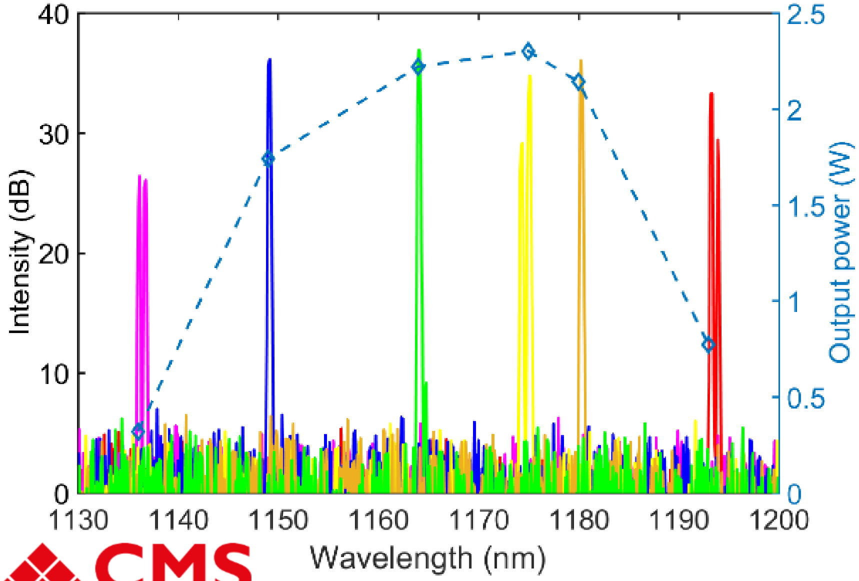
(d) Close up of a dicing lane for a 5x5 mm^2 chip

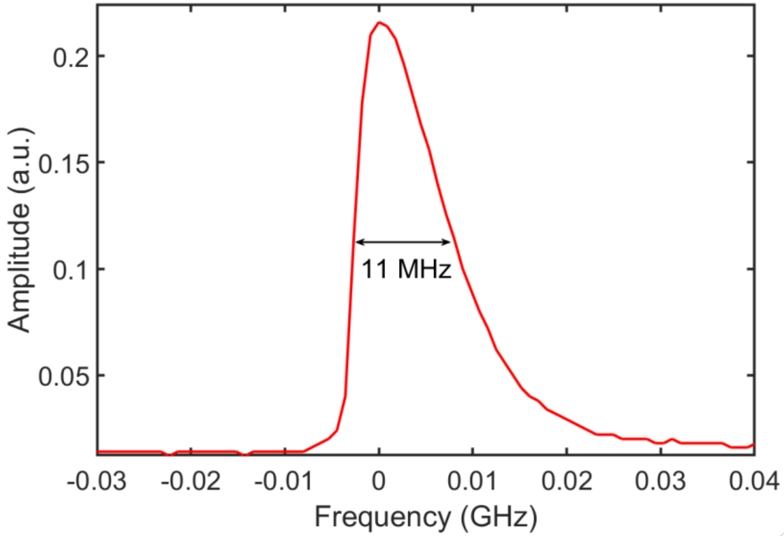
118 die @ 5 × 5 mm^2 from a single fab run

Single-SiC Heat Spreader DBR-Free



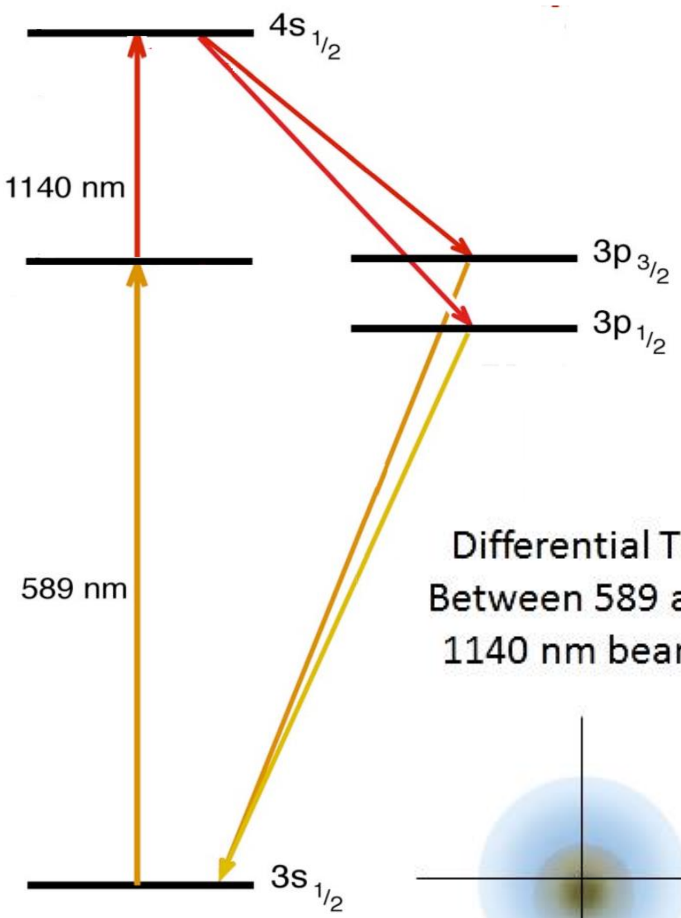




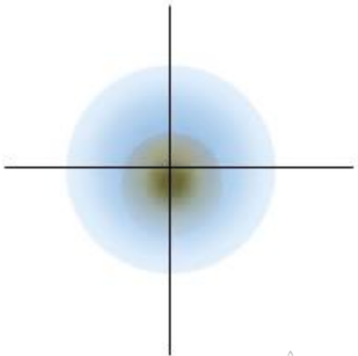


Tip Tilt LGS

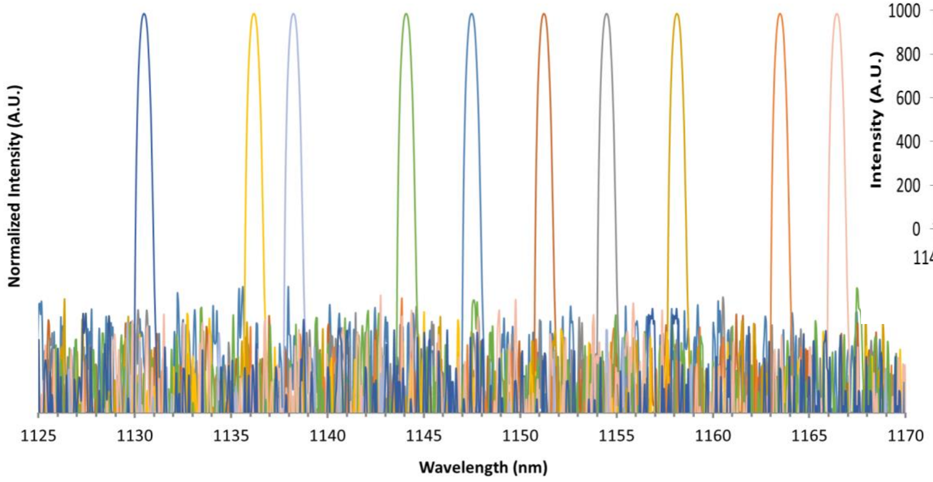
- Pumping two transitions simultaneously
  - Known as a Polychromatic LGS (PLGS)
- Tip/Tilt correction via Δn (dispersion)
- Greater Δn increases TTLGS performance
- Atmospheric transmission is poor for many transitions such as 330 nm
- Best candidate transition is 1140 nm
  - Large absorption cross section
  - OPSL able to be grown at 1140 nm
  - High atmospheric transmission (approximately 70%)

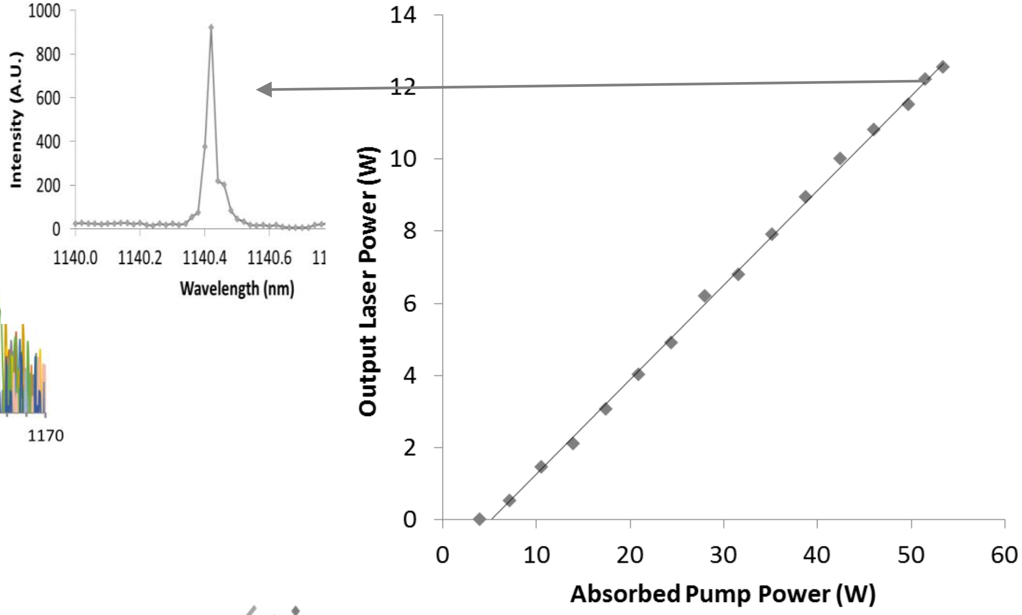


Differential Tilt Between 589 and 1140 nm beams

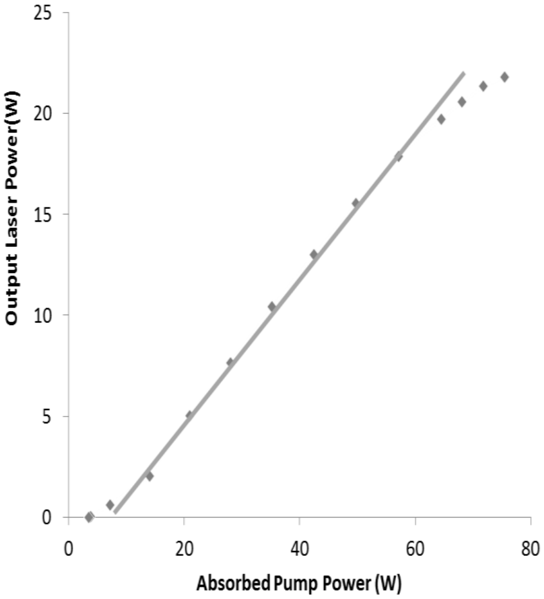


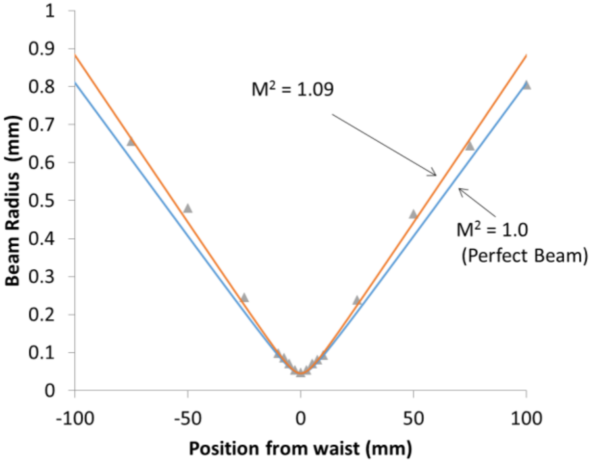
1140 nm OPSL Performance





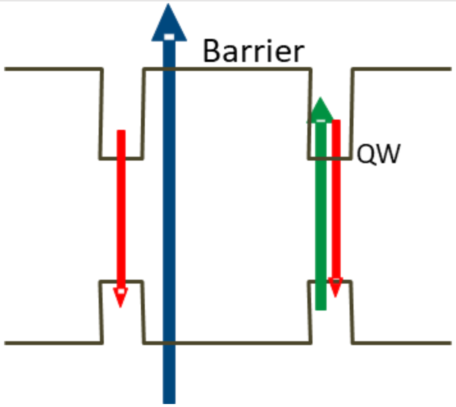
- High power at 1131 nm - 1167 nm with BRF
  - Narrowband power at 1140 nm > 12.5 W
- 22.5 W max power with slope efficiency of 32%
- Slope Efficiency of 26%
- Bandwidth less than ~7.5 GHz (OSA limit)
- M^2 at 5 W



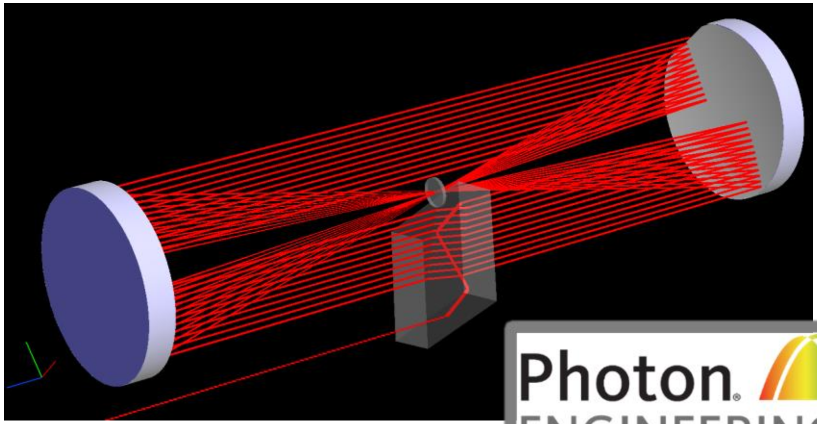


Hackett, Shawn, UNM Digital Repository, November 2016

In-Well Pumping



No DBR : No parasitic absorption of the pump



Quantum defect:

$$\delta_{quantum} = 1 - {}^{h\nu_{laser}}\!/_{h\nu_{pump}}$$

Pumped @ 808 nm

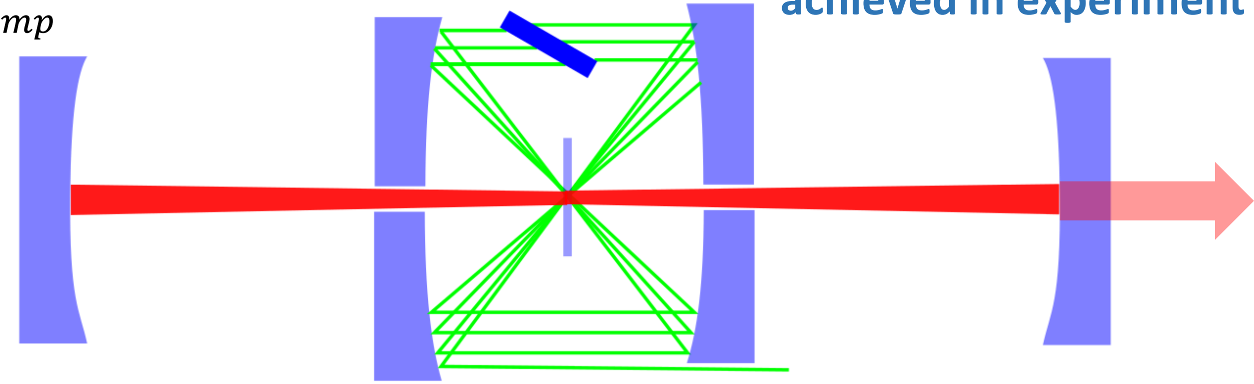
$$\delta_{quantum} = 31.4\%$$

Pumped @ 1070 nm

$$\delta_{quantum} = 9.2\%$$

Shifter: window @ Brewster's angle

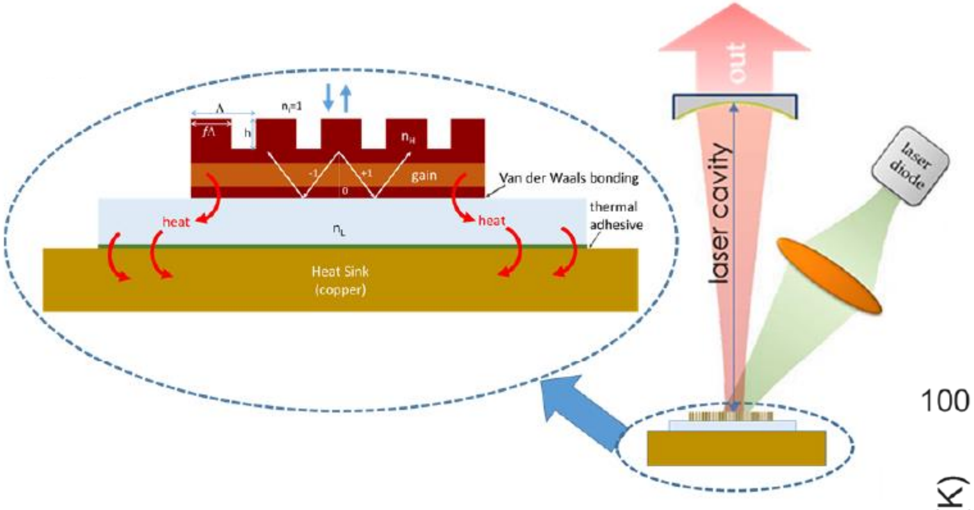
22 passes have been achieved in experiment



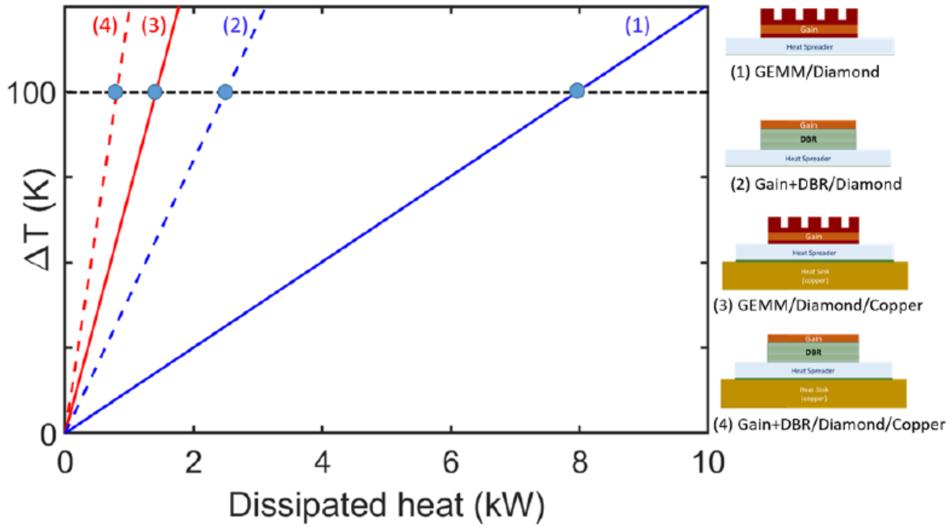
1070nm

Yang, et al. SPIE Conference Proceedings, March 2019

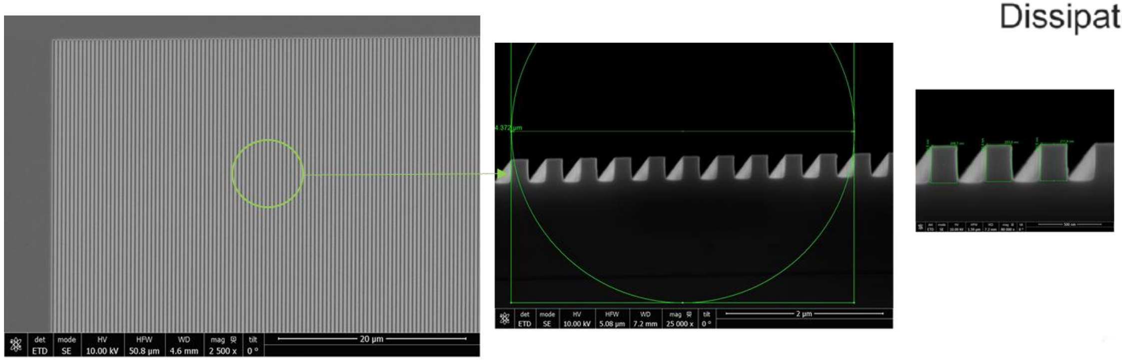
GEMM Modeling Results



kW power dissipation capability



Ongoing Fabrication
at CINT



Conclusion

- Laser power, linewidth, and beam quality for 1140 nm and 1178 nm OPSL devices were shown

- Multiple methods for thermal management of OPSL devices were discussed
  - DBR free OPSL with SiC heat spreader has been compared with traditional VECSEL

  - Multipass scheme has been demonstrated and can be used for In-Well Pumping

  - A GaAs-based GEMM-on-diamond structure can theoretically outperform traditional VECSELs by more than a factor of 3