Optoelectronics Industry Development Association Presentation of Pearl

San Jose, CA

April 16, 2008

The 1470-nm work was supported by the **Army Research Office** under contract number W911NF04C-0137
The 19xx-nm work is supported by **NASA** under contract number NNL06AA44P

nLIGHT

nLIGHT Corporate History

2000 **nLIGHT founded**

2003 **nLIGHT begins China operations**

2005 **Acquired Flextronics Photonics Division**

2007 **Acquired LIEKKI for fiber manufacturing**

State-of-the-art chip fab

High-volume, low cost packaging

State-of-the-art fiber mfg

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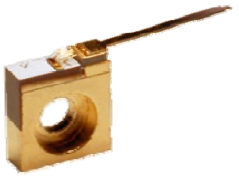
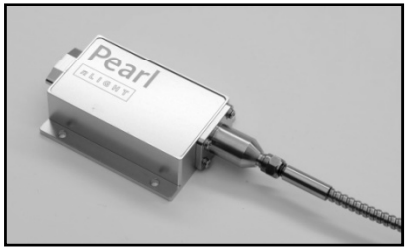
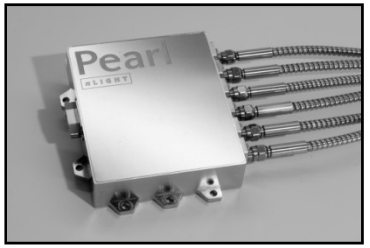
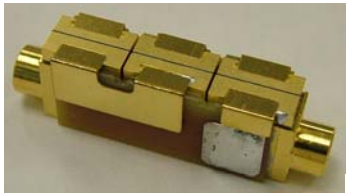
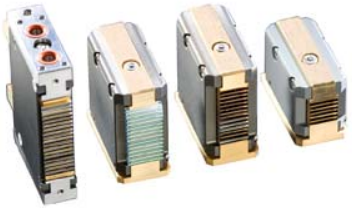
nLIGHT's broad capability in packaging

Product category	nLight product platforms
Single Emitter 0.5 to 7W	 
Diode Arrays 10 to 200 W	  
Fiber Coupled Package 2 to 300 W	 
Stacks of Arrays 100W to multi-KW	  

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nLIGHT focused on technology to support growing applications

Components → **Subsystems** → **OEM Systems**

Chips

Packaged Diodes

Fiber

Fiber Modules

- Medical
- Defense
- Industrial
- Consumer

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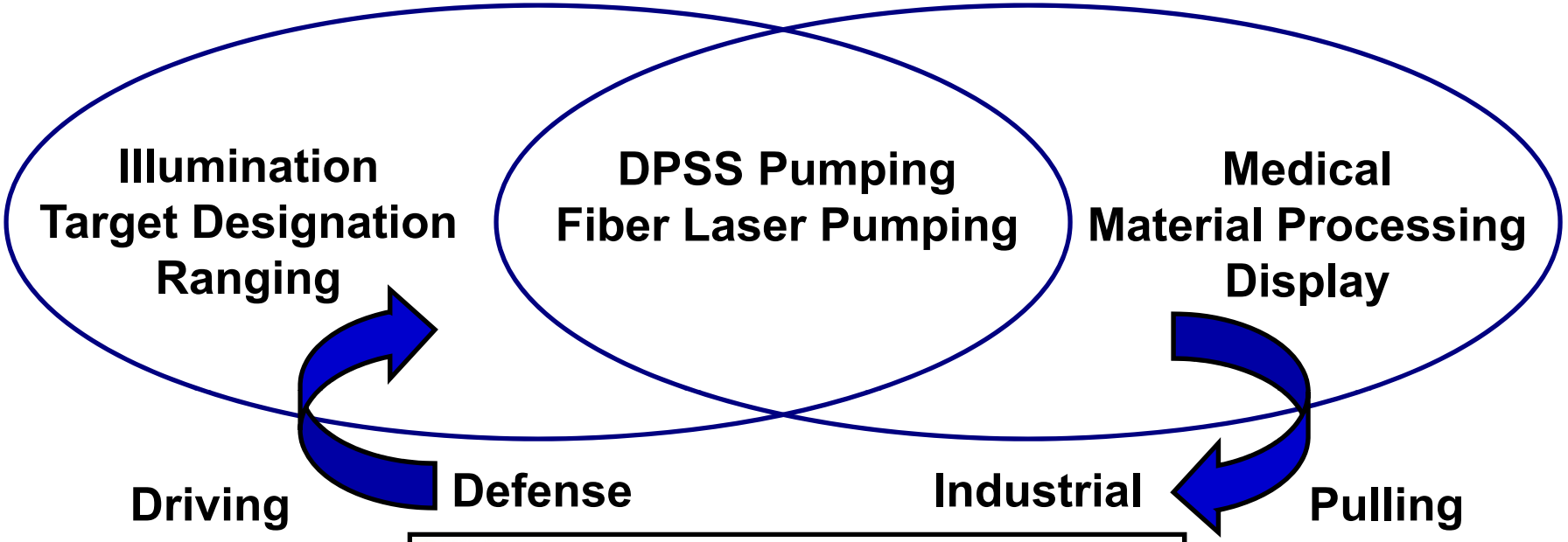
nLIGHT serving both Defense and Industrial Applications



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1. **Overview of Pearl**
2. Power Scaling
3. Brightness Scaling
4. Efficiency
5. Reliability/Temperature Performance
6. Wavelength Range
7. Wavelength Stabilized
8. Miscellaneous (Collimation, Pulsed Operation, Hermeticity)

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Pearl: Fiber Coupled Market Trends

The high-power fiber-coupled market shows the following observed key trends towards:

1) **Power Scaling**

   → **Driven by TEM_{oo} power scaling of Fiber, Disk, and DPSS Lasers as well as enabling new direct diode applications (Medical, Industrial)**

2) **Higher Brightness**

   → **Increased Rayleigh ranges for longer working distances or longer crystals**

3) **Increased Reliability/Lifetime**

   → **Maturing laser markets and competition with fiber lasers**

4) **Increased Efficiencies**

   → **Pump E-O as well as upper-state pumping of gain material (λ)**

5) **Lower Pricing**

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Pearl: Concept

"nLight's new architecture uses multiple facet-passivated high-power AuSn-bonded high-efficiency SEs in electrical series that are spatially combined into a single fiber core "

- **Facet-Passivation (leveraging *n*XLT)**
  - → **Ensures lasting high performance**
- **High-Power**
  - → **Enables high brightness**
- **AuSn-bonding**
  - → **On-Off reliability/lifetime**
- **High-Efficiency**
  - → **Minimizes waste heat (639 – 2050 nm)**
- **Single Emitter based**
  - → **Introduces new level of system flexibility and tremendous advantages over bar-based technologies including cost**

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Pearl: Scaling Power

- **100 W Modules @ 808, 88x nm**

WPE maintained at ~ 50% for efficient high power DPSSL pumping

PERFORMANCE SUMMARY

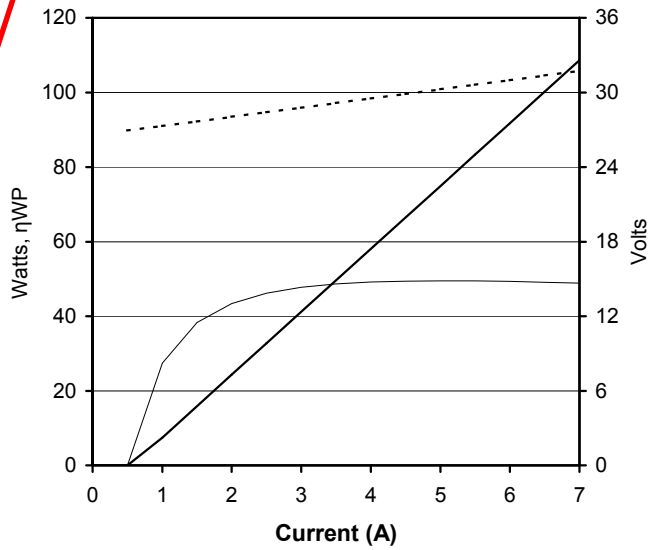
Pearl Model P4100-0808

S/N 29-05060-04-00003

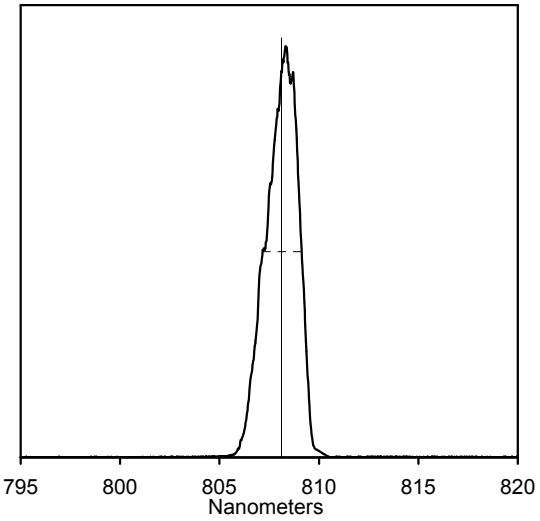
7 June 2007

OPTICAL	
Wavelength, nm	808.1
Output Power, watts	100
Spectral Width, FWHM	2.0
Slope Efficiency, W / A	16.9
Divergence, NA (90% power incl.)	NA
Wavelength Temp. Coeff., nm / °C	0.30
ELECTRICAL	
Total Conversion Efficiency (ηWP)	49%
Threshold Current, amps	0.56
Operating Current, amps	6.49
Operating Voltage, volts	31.35
Series Resistance, ohms	0.74
THERMAL	
Operational Temperature, °C	25.0
Thermal Resistance, °C / W_{heat}	NA

LI Performance



Spectral Performance



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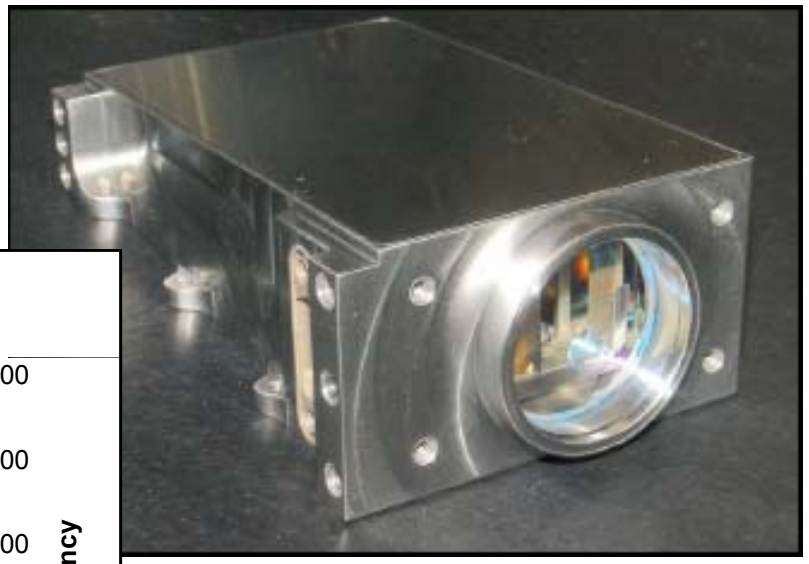
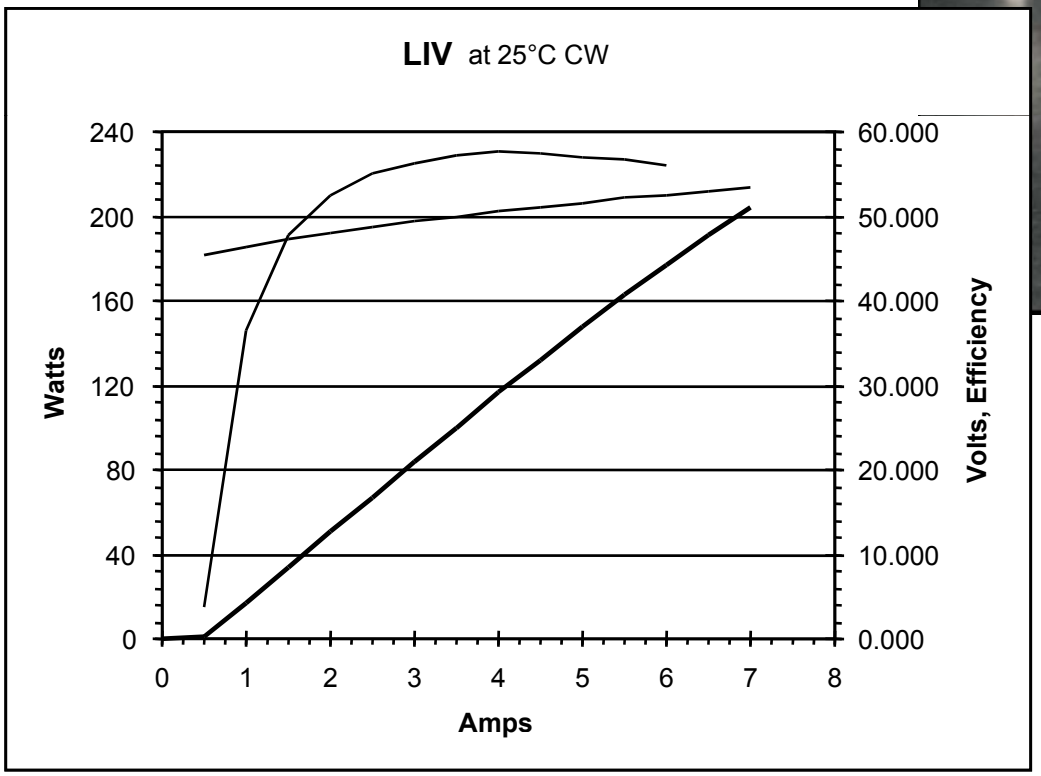
Pearl: Power Scaling

- **200 W Package (either Afocal [as shown] or coupled into a 600 um fiber)**





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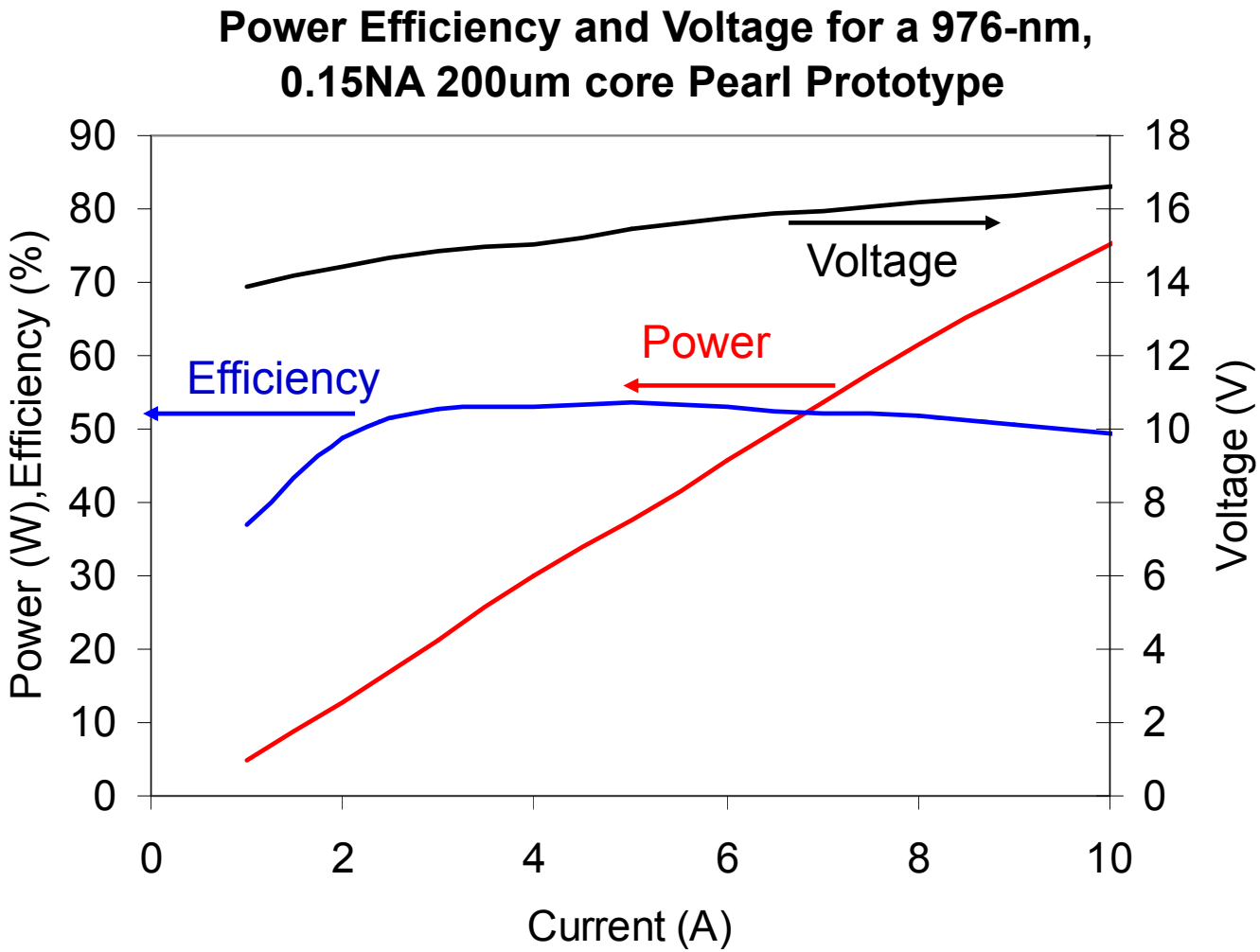
Pearl: Scaling Brightness



100W at 9xx from a 200-μm, 0.15 NA, core fiber in 3 months

60% E/O target

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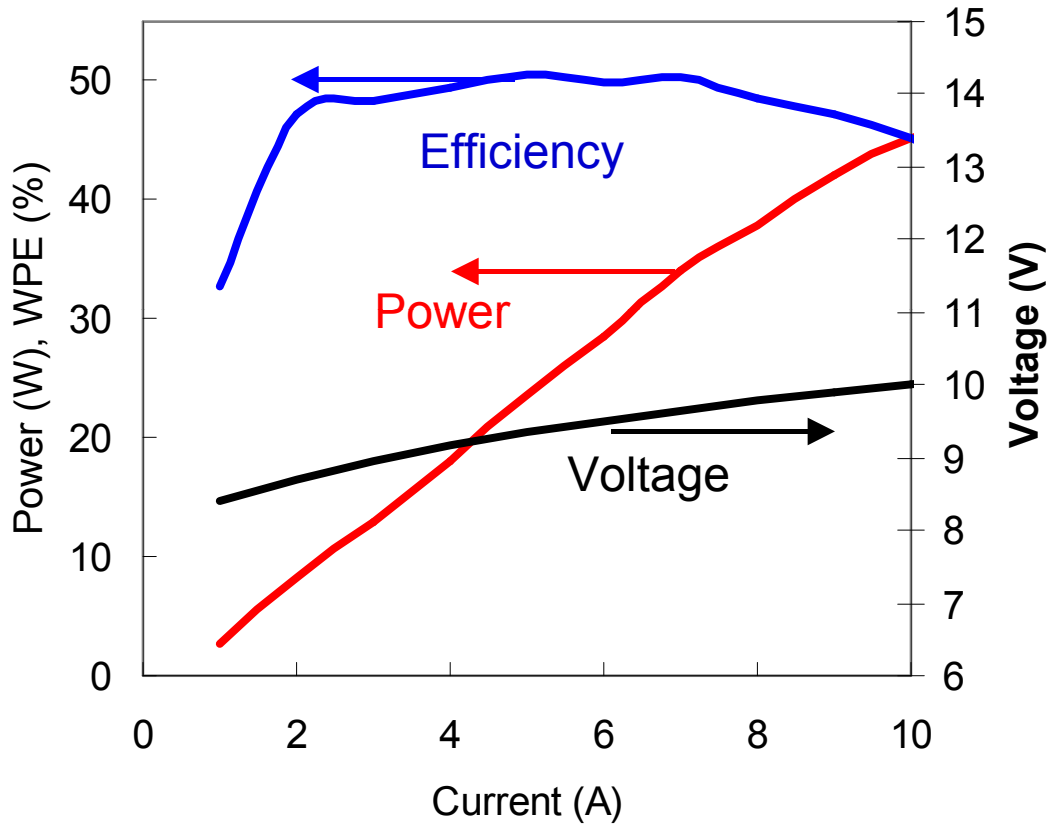
Pearl: Scaling Brightness

Power, Efficiency and Voltage for a 976-nm 100um core Pearl Prototype



80W at 9xx from a 100-μm, 0.15 NA, core fiber in 3 months
100W from a 100-μm, 0.15 NA core fiber in 4 months
55% E/O target

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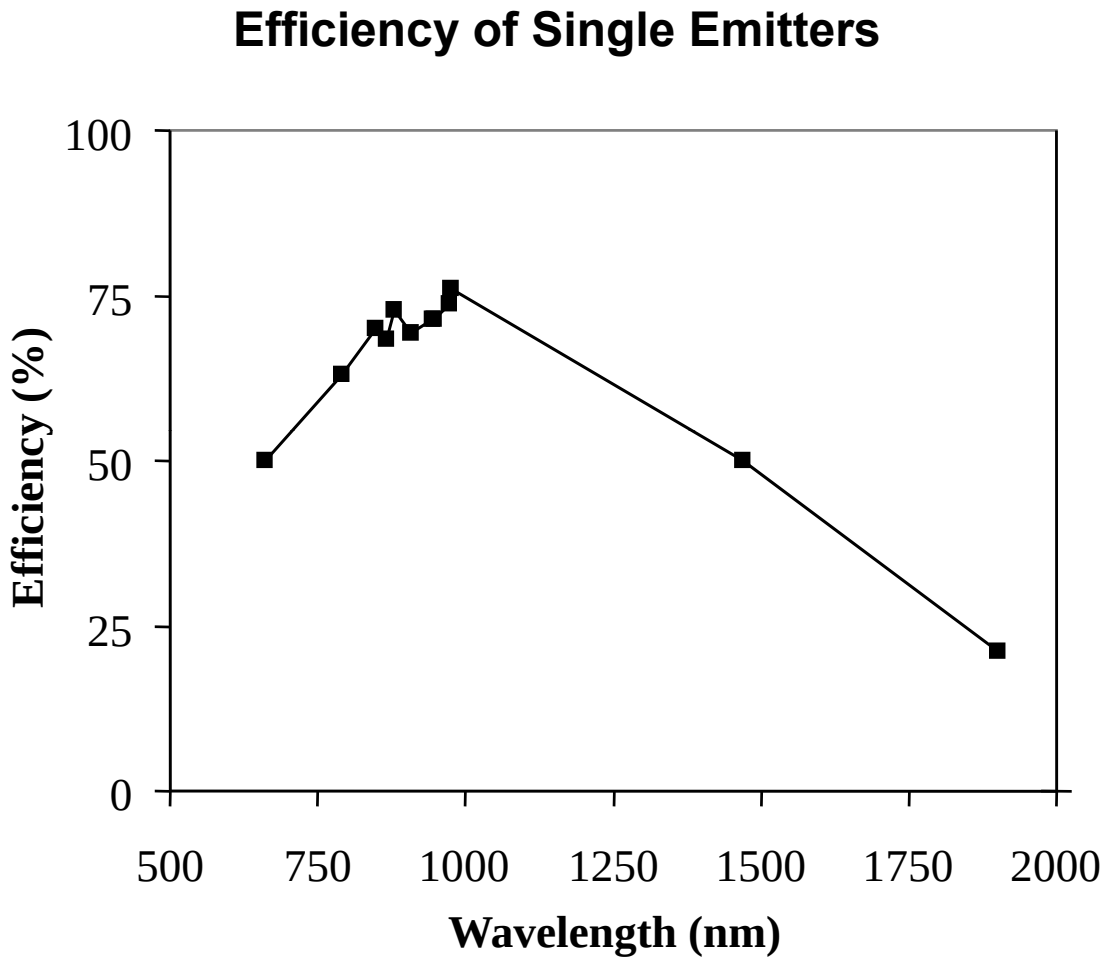
Pearl: Efficiency vs. Wavelength



Design challenges to achieving this end at longer wavelengths are different than 750nm to 1000nm

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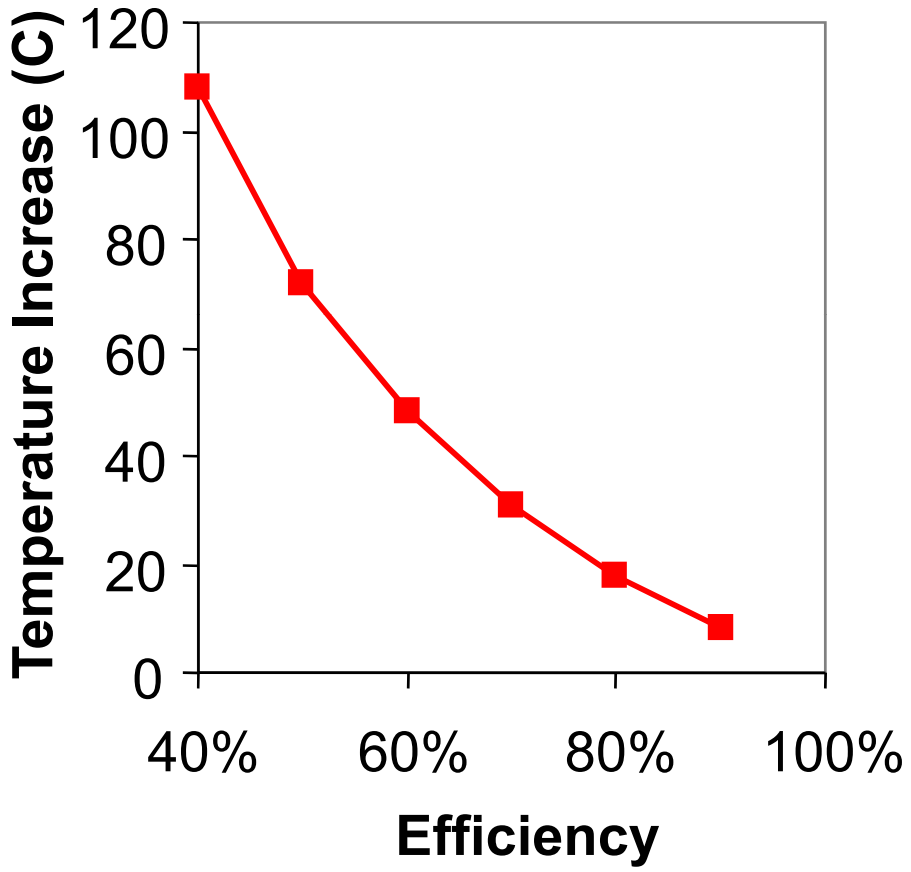
Pearl: Power of Efficiency

Efficiency reduces cooling demands/permits higher operating temp



Efficiency enhances lifetime by reducing active region temperature

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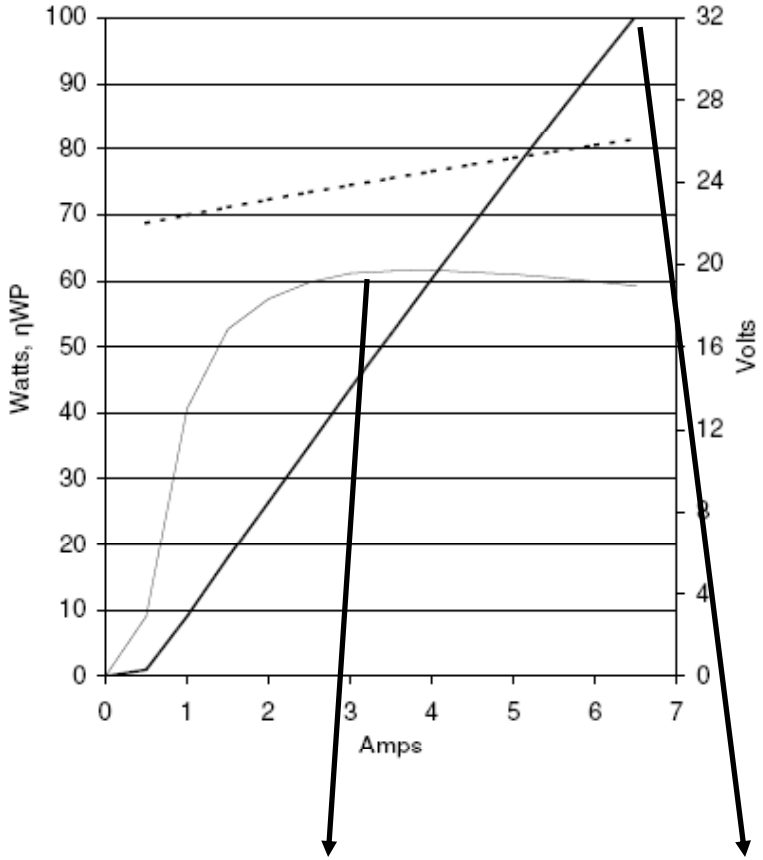
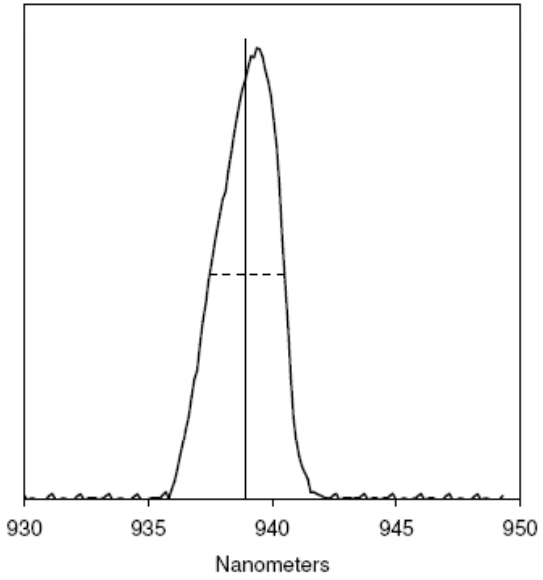
Pearl: Redefining High Efficiency

High-efficiency 9xx-nm – High efficiency diodes + high efficiency package





… have enabled 62% E/O and >100W
measured from the 400-μm fiber

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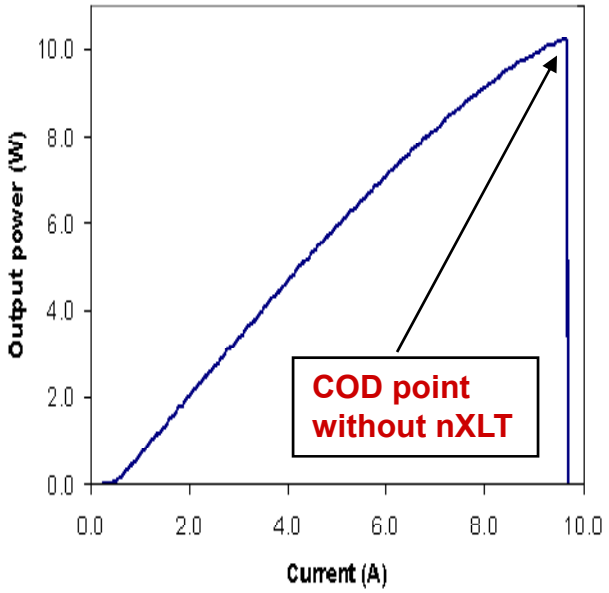
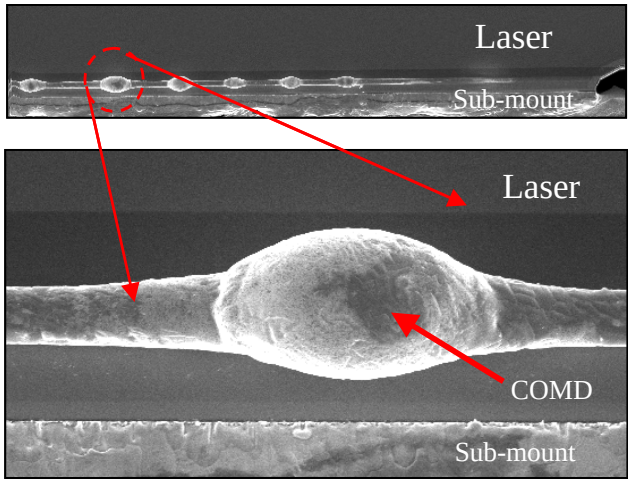
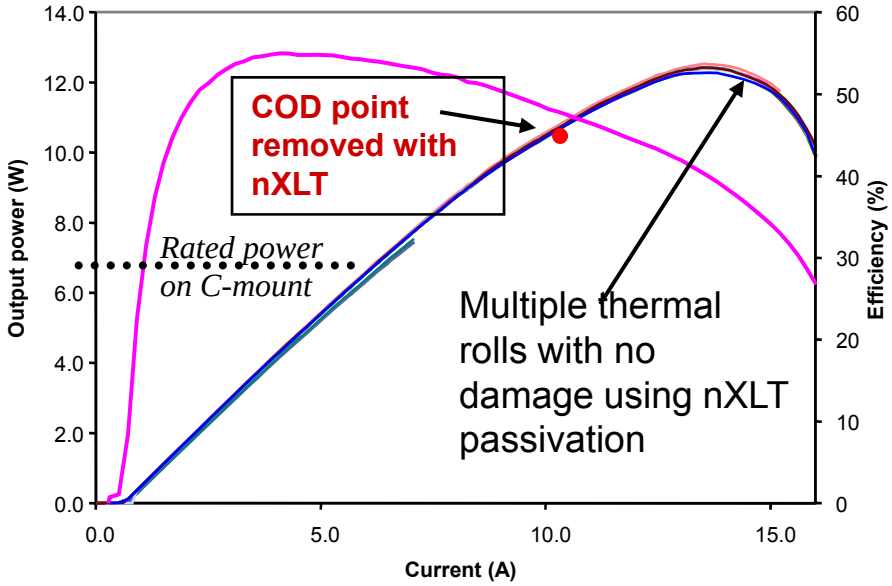
Pearl: COMD and Laser Performance





Catastrophic Optical Mirror Damage irreversibly destroys the device facets



- nXLT passivation technology removes COD in present nLIGHT laser designs
- Multiple thermal roll-overs are possible without COD and without part degradation.
- COD not much of a problem on wavelengths > ~1000-nm
- Effective from 639 – 2100nm

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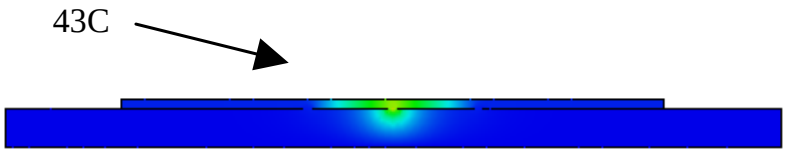
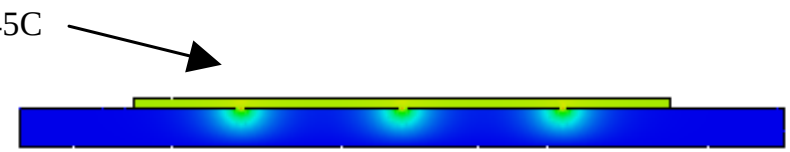
Pearl: Temperature Performance

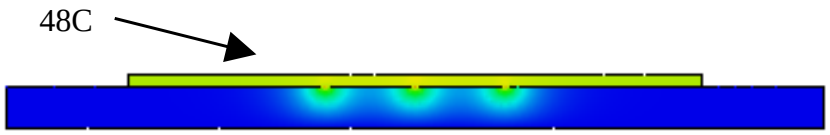
High fill factors also lead to thermal x-talk and unacceptably high operating temps-optimal fill factor is a trade



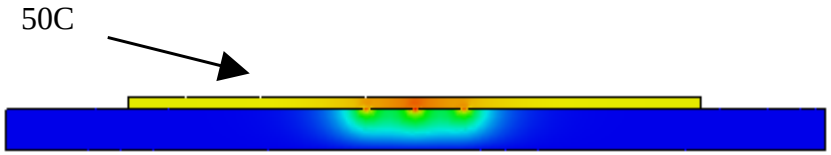
A. Single 6W 100µm emitter



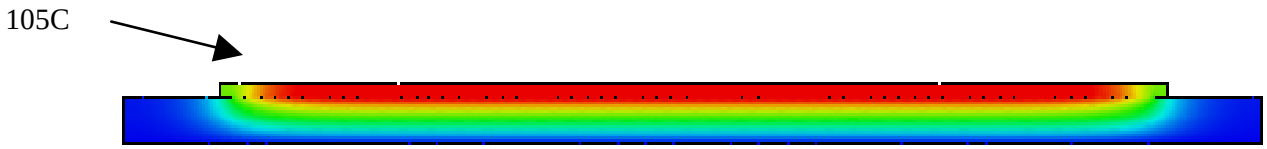
B. Three 6W 100µm emitters on 2mm centers



C. Three 6W 100µm emitters on 1mm centers



D. Three 6W 100µm emitters on 500µm centers



E. (64) 6W 100µm emitters on 125um centers (80% fill factor 10mm long laser bar)

Tightly packed bar creates thermal coupling
Compromises performance *and lifetime*

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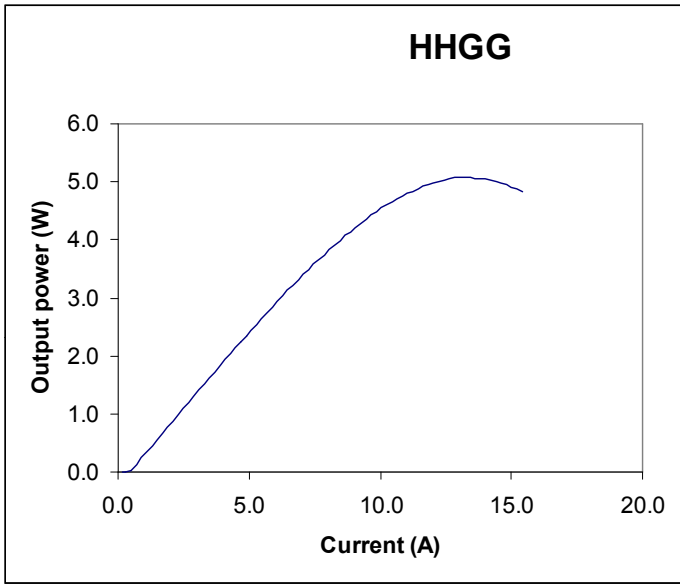
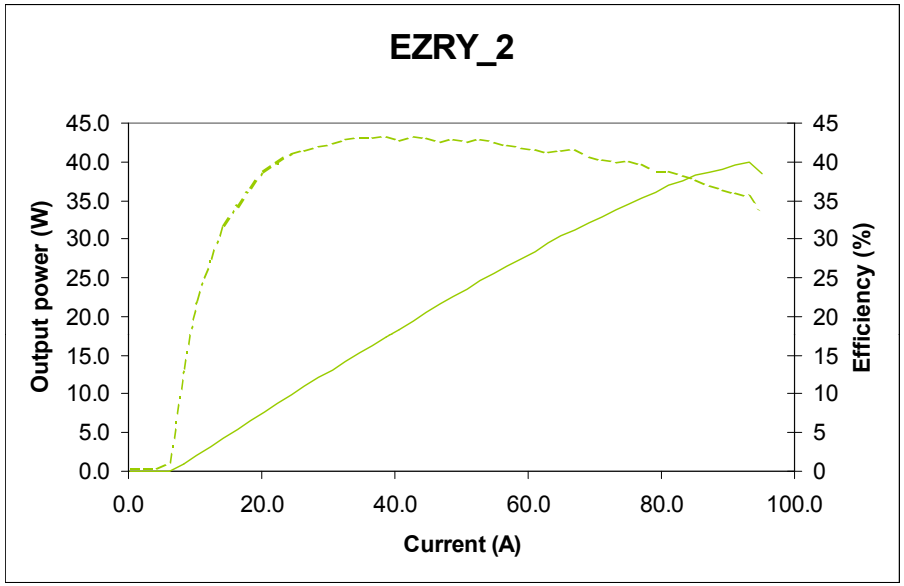
Pearl: Temperature Performance

5W single emitter is double the output power of same emitter on bar





- Left: A 5-W CW peak power from at stripe at 25C operation
- Right: A 40-W CW peak power bar on a Cu CS-mount with 19 emitters at 25C ⇒ power/emitter is 2.1-W, or less than half of the an isolated emitter

- Two ways to go with single emitter:
  - Operate at higher power but equal active region temperature as an emitter on a bar
  - Operate at same power but lower active region temperature as an emitter on a bar

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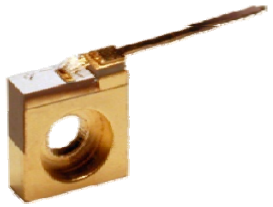
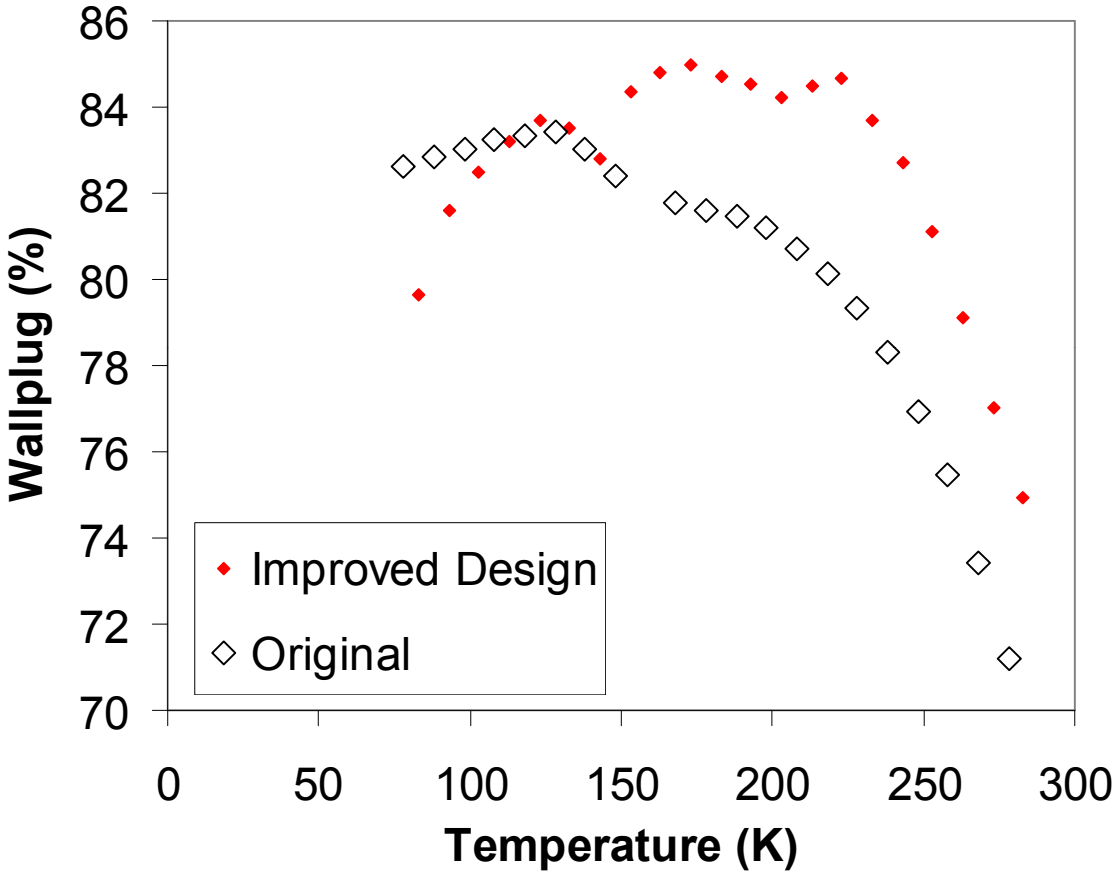
Pearl: Temperature Performance

nLight design for performance at a specific temperature



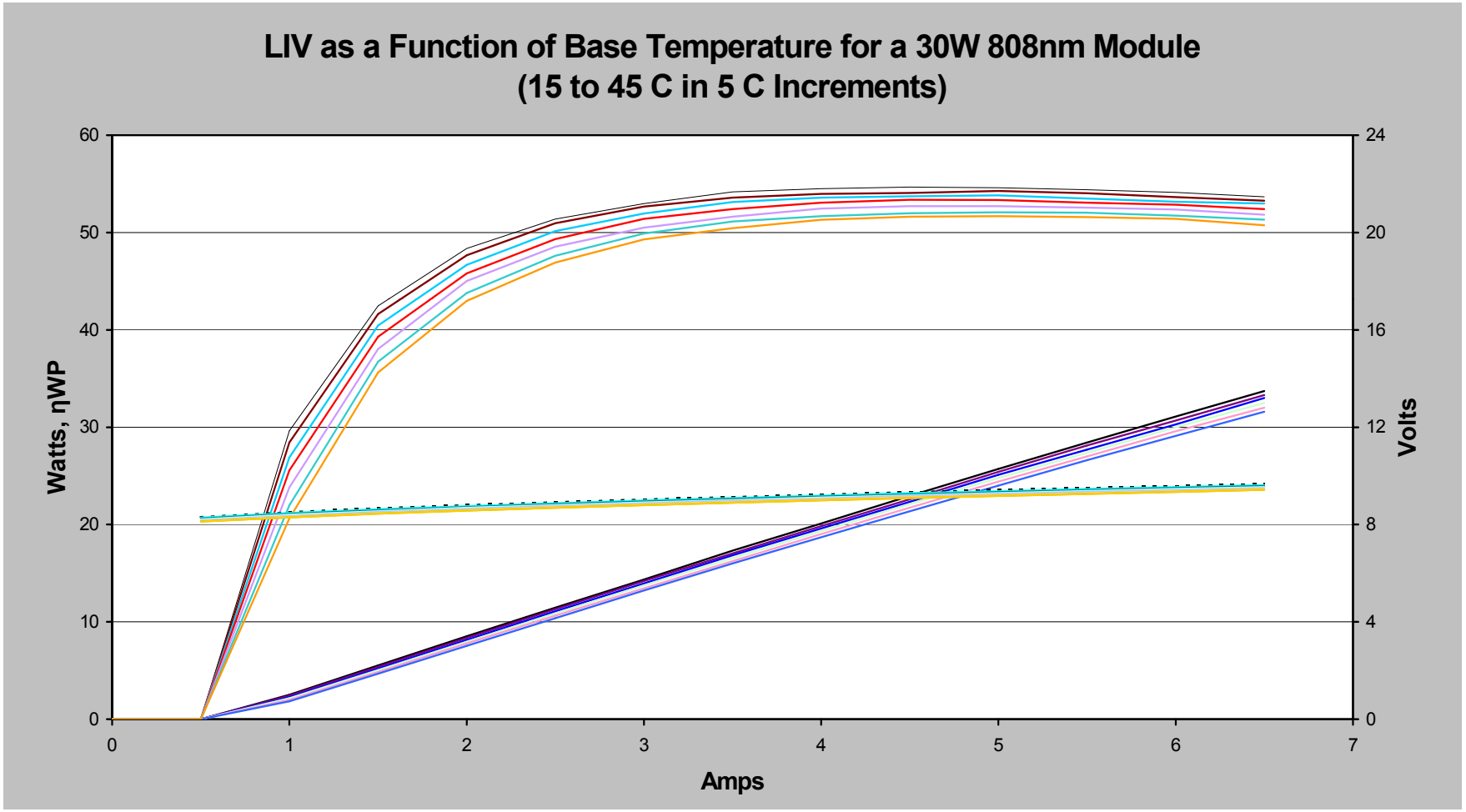


Demonstrates that a device efficient a a strong function of temperature

Measurement courtesy of Directed Energy Solutions, CO

Pearl: High Temperature Performance

- **Exceeding 50% Efficiency even at 45C**



Data from a 30W 808nm Pearl

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Pearl: Broadening Wavelength Availability

- **4 W 400 um Module @ 639 nm**
- **Also available in Afocal configurations or with 600um fiber**

PERFORMANCE SUMMARY

Pearl Model P404-0639

S/N 29-05013-06-05108

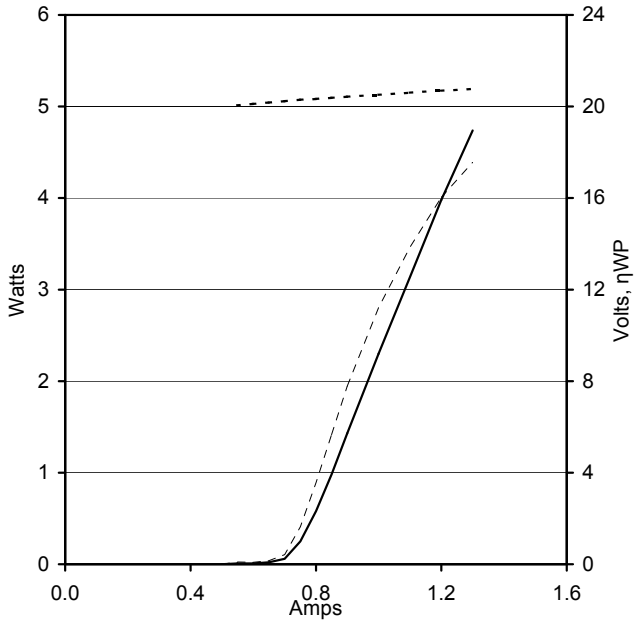
21 September 2007

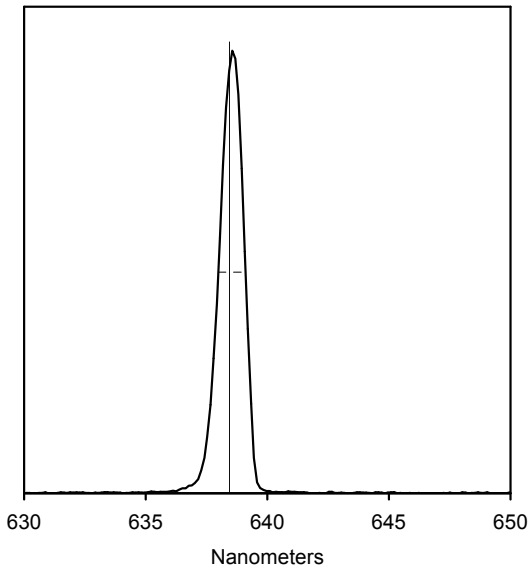
Ideal for Display applications

OPTICAL	
Wavelength, nm	638.4
Output Power, watts	4
Spectral Width, FWHM	1.1
Slope Efficiency, W / A	8.1
Divergence, NA (90% power incl.)	0.17
Wavelength Temp. Coeff., nm / °C	0.15

ELECTRICAL	
Total Conversion Efficiency (ηWP)	16%
Threshold Current, amps	0.68
Operating Current, amps	1.21
Operating Voltage, volts	20.69
Series Resistance, ohms	0.92

THERMAL	
Operational Temperature, °C	25.0
Thermal Resistance, °C / W_{heat}	0.29





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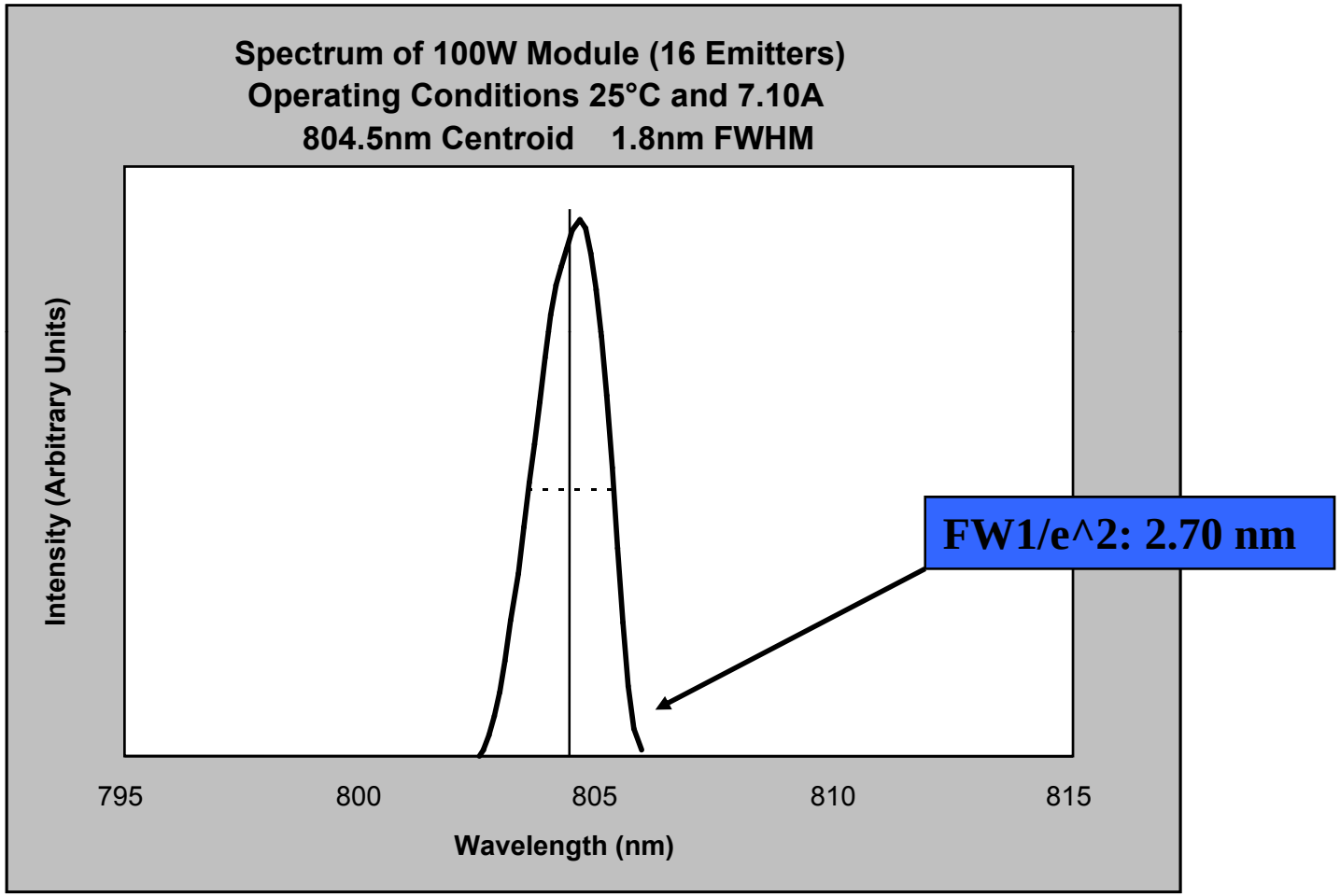
Pearl: Spectral Performance

- **Outperforming bar based solutions with typical spectral width of 1.85 nm**



Approaching FWHM of individual constituent single emitters: 1.74 nm

Pear: InP Wavelengths

- **25 W Modules @ 1470 nm**
- **15 W Modules @ 1530 nm**

PERFORMANCE SUMMARY

Pearl Model P425-1470

S/N 29-05013-05-00065

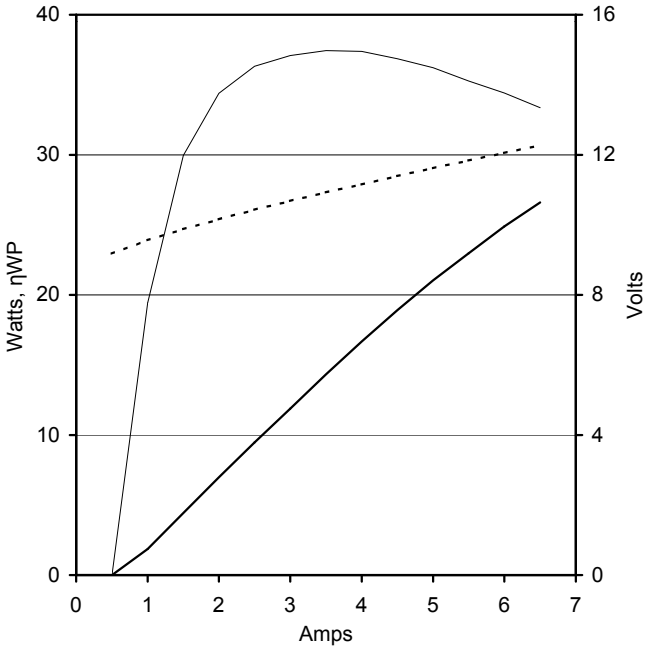
0 January 1900

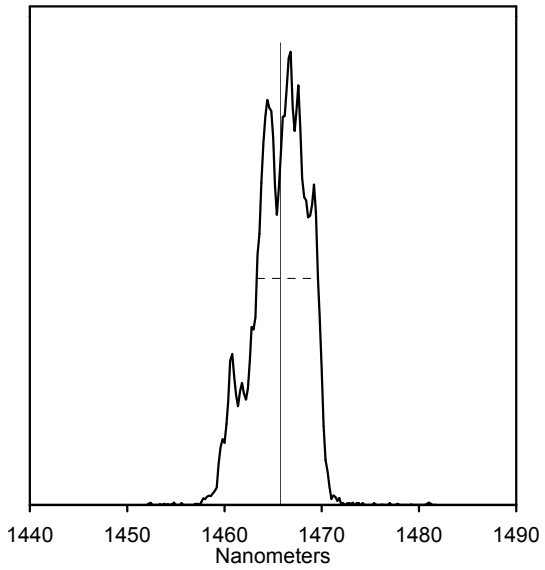
Ideal for Illumination Applications

OPTICAL	
Wavelength, nm	1465.8
Output Power, watts	25
Spectral Width, FWHM	6.3
Slope Efficiency, W / A	4.6
Divergence, NA (90% power incl.)	0.16
Wavelength Temp. Coeff., nm / °C	0.28

ELECTRICAL	
Total Conversion Efficiency (ηWP)	34%
Threshold Current, amps	0.50
Operating Current, amps	6.01
Operating Voltage, volts	12.07
Series Resistance, ohms	0.49

THERMAL	
Operational Temperature, °C	25.0





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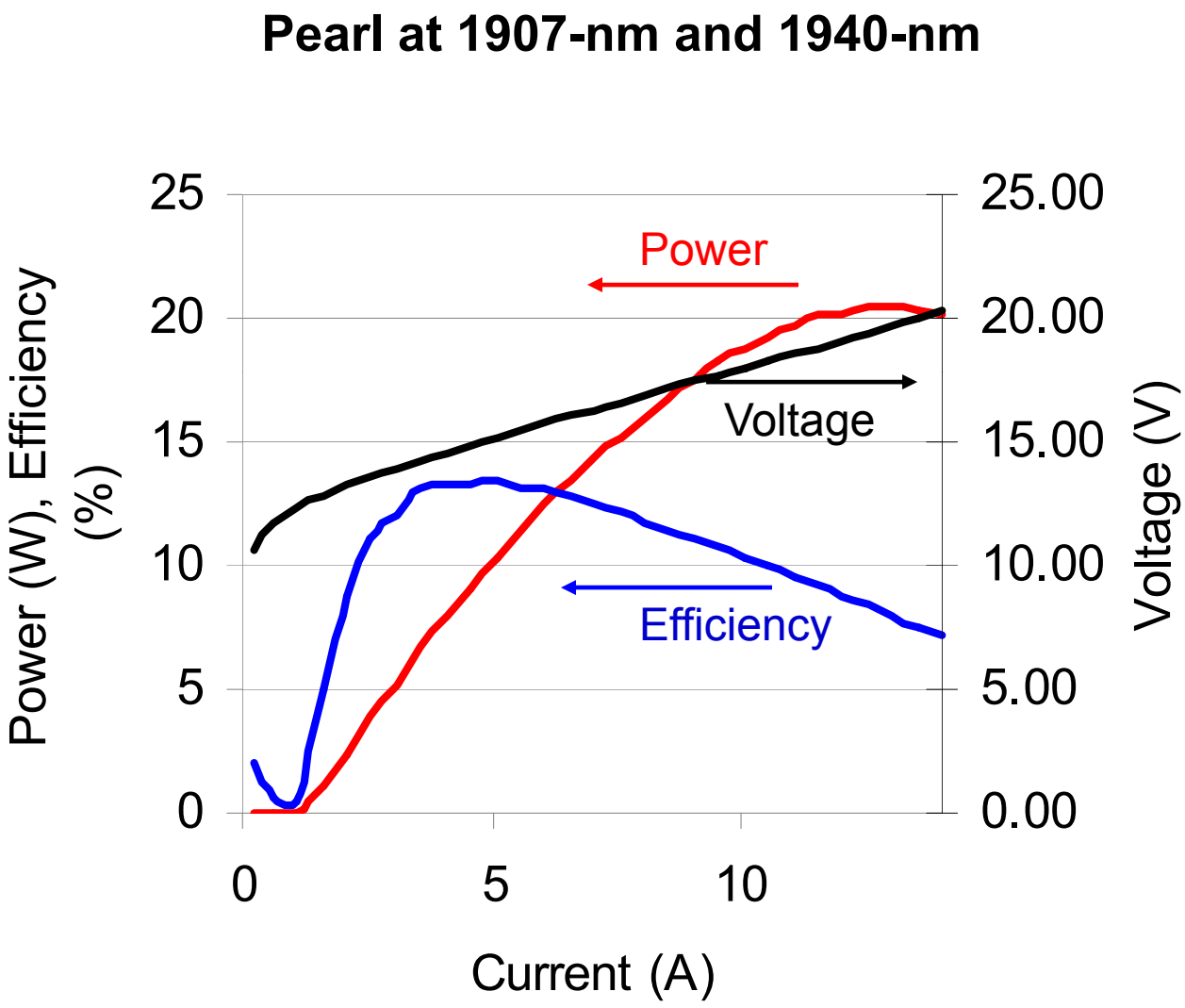
Pearl: InP Wavelengths



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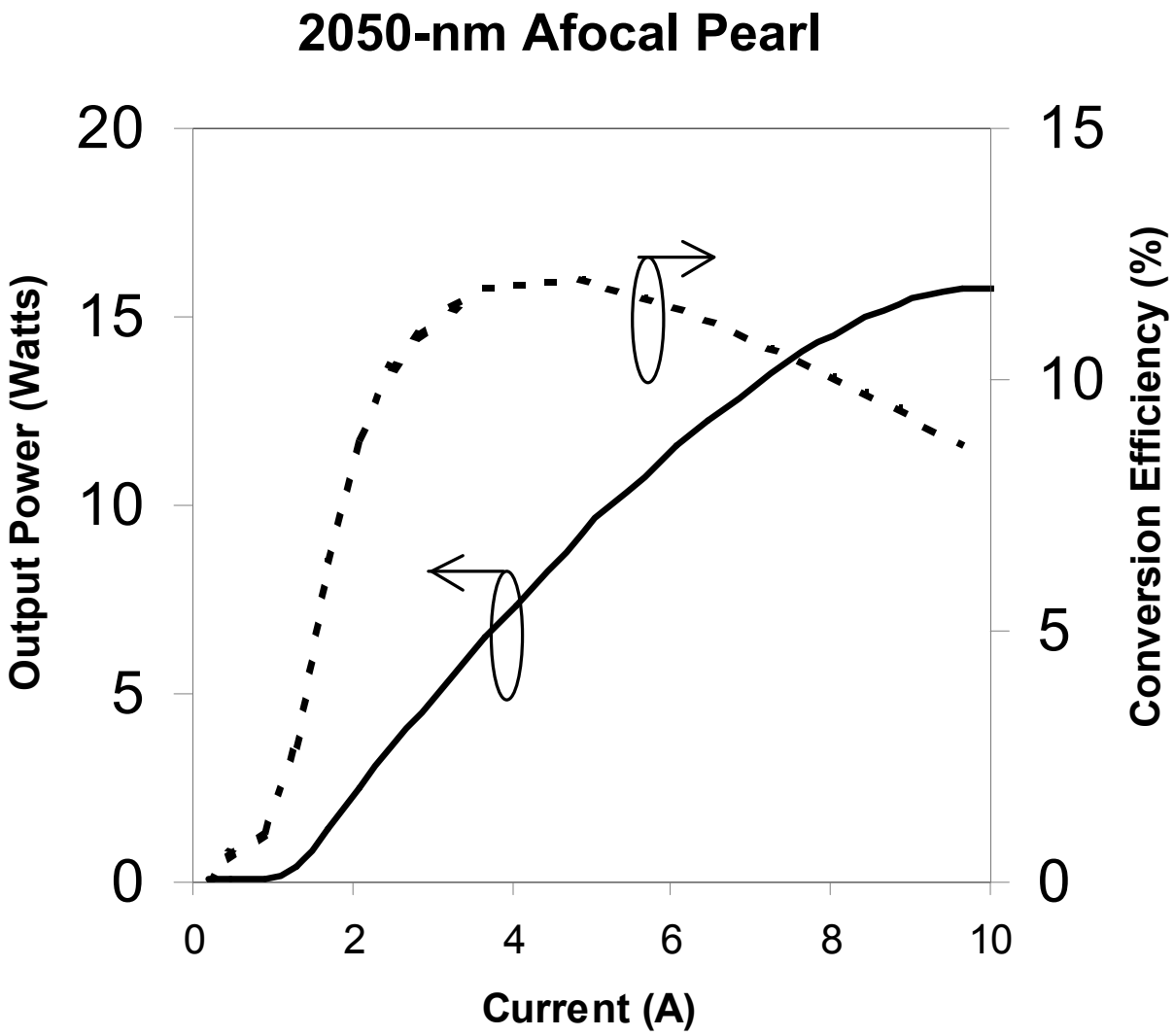
Pearl: InP Wavelengths



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Pearl: Spectrally Locking

- **Spectrally Locked Modules @ 879 or 976 nm**

PERFORMANCE SUMMARY

Pearl Model P442-0880-VBG

S/N 29-05013-05-00058

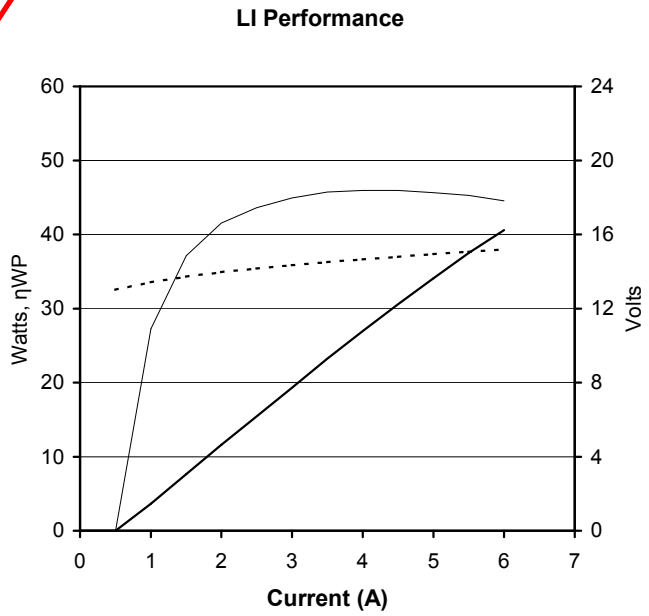
7 June 2007

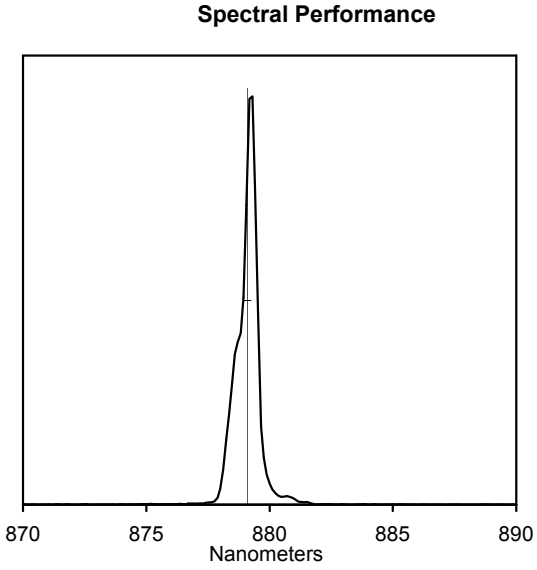
OPTICAL	
Wavelength, nm	879.1
Output Power, watts	42
Spectral Width, FWHM	0.6
Slope Efficiency, W / A	7.4
Divergence, NA (90% power incl.)	0.15
Wavelength Temp. Coeff., nm / °C	0.10 *

ELECTRICAL	
Total Conversion Efficiency (ηWP)	45%
Threshold Current, amps	0.44
Operating Current, amps	6.19
Operating Voltage, volts	15.24
Series Resistance, ohms	0.34

THERMAL	
Operational Temperature, °C	25.0
Thermal Resistance, °C / W_{heat}	0.38

0.6 nm Spectral Width
vs. 2.0 – 2.5 unlocked





Narrowed Spectral Width, Improved Temperature Performance

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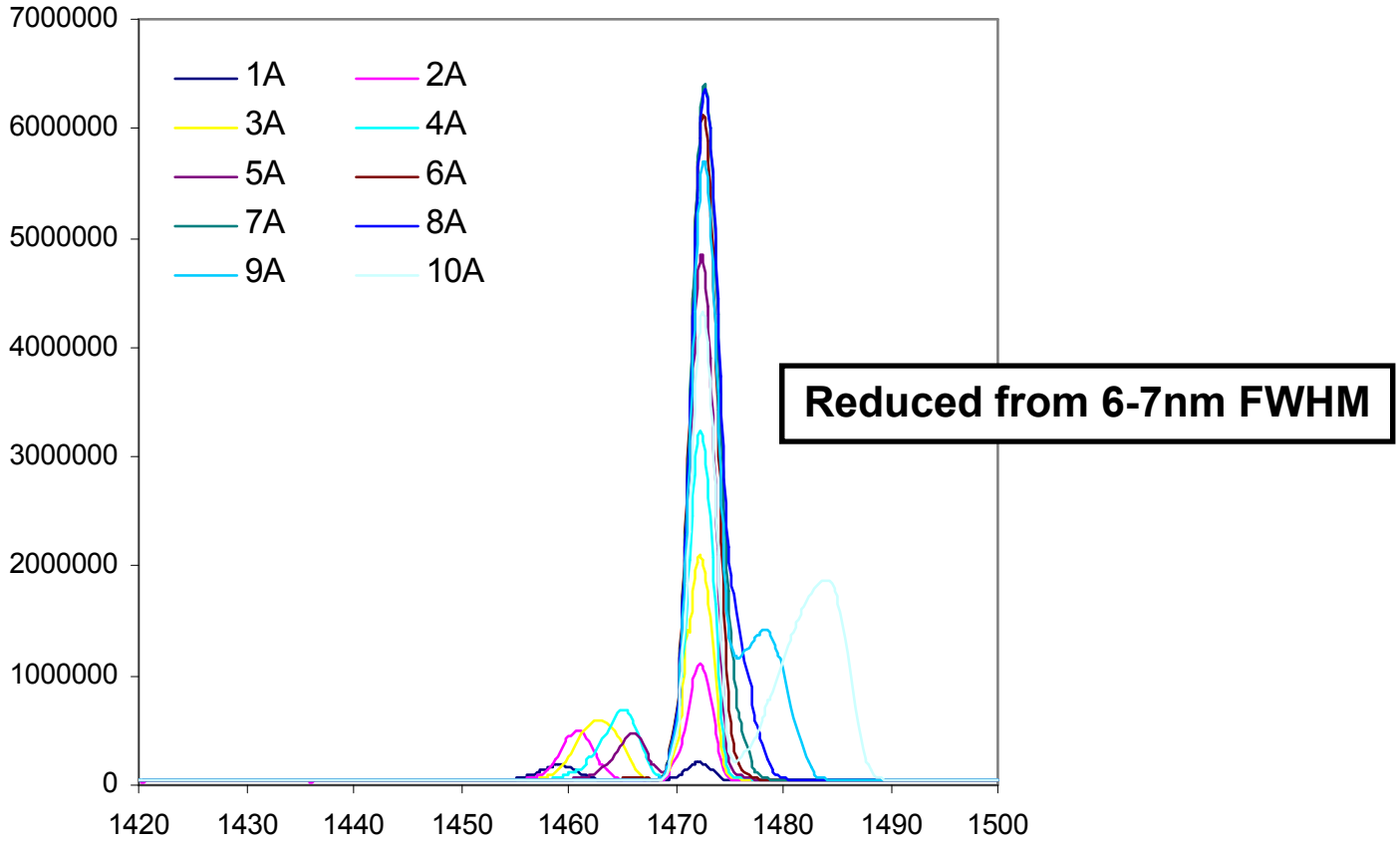
Pearl: Spectrally Locking

Preliminary result - External grating-locked 1473nm diode laser



Line locked at 1473-nm over 10A range at 25C
Line width ~3-nm and secondary peaks due to coating reflectivity of front facet
Also experimenting at 19xxnm

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Contents

1. Overview of Pearl
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6. Wavelength Range
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8. **Miscellaneous (Collimation, Pulsed Operation, Hermeticity)**

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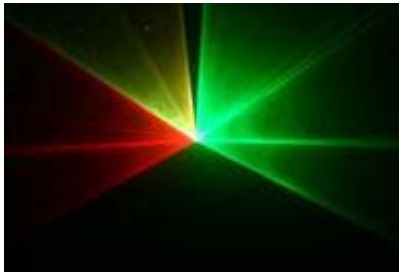
Pearl: Collimating Light

- **Collimated Units**
  - **8 mm x 5 mrad beam**



PERFORMANCE SUMMARY

Pearl Model PA03-0635

S/N 29-05044-01-00196

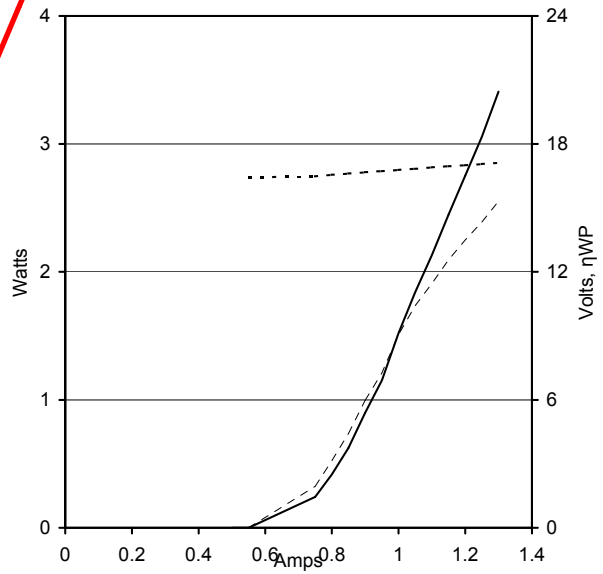
26 June 2007

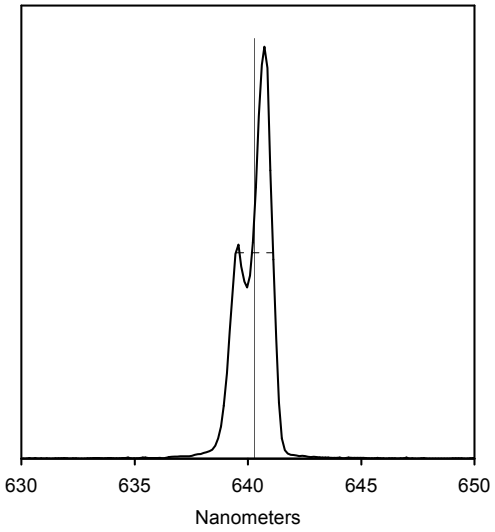
OPTICAL	
Wavelength, nm	640.3
Output Power, watts	2
Spectral Width, FWHM	1.6
Slope Efficiency, W / A	5.8
Divergence, (90% power incl.) mrac	4.20
Wavelength Temp. Coeff., nm / °C	0.15
Fast Axis Divergence, mrad	5.13
Slow Axis Divergence, mrad	5.25

ELECTRICAL	
Total Conversion Efficiency (ηWP)	11%
Threshold Current, amps	0.73
Operating Current, amps	1.08
Operating Voltage, volts	16.87
Series Resistance, ohms	1.13

THERMAL	
Operational Temperature, °C	25.0
Thermal Resistance, °C / W_{heat}	0.62

Superior collimated





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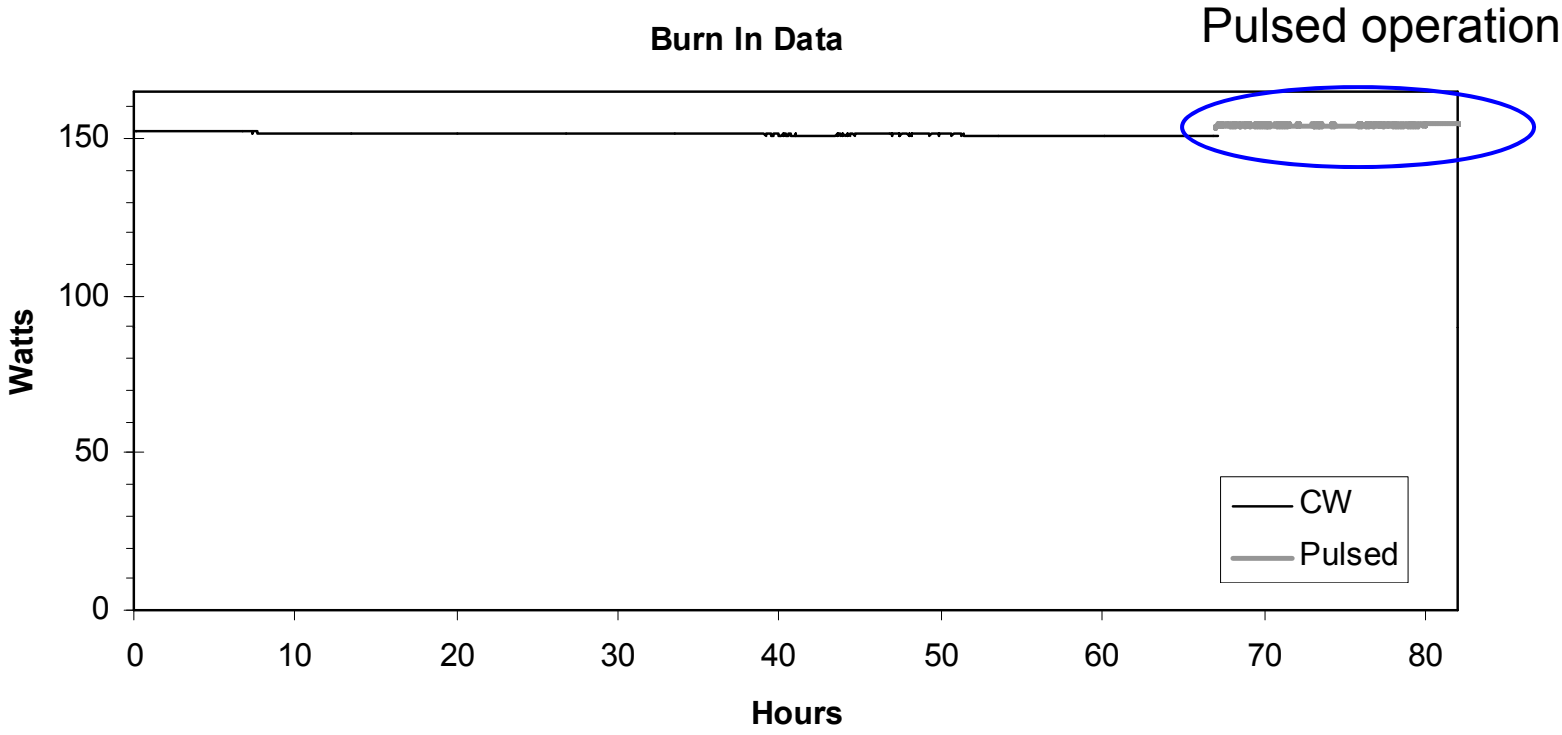
Pearl: Operational Flexibility

Pulsed data for 150W 791-nm Pearl unit



- 150W, 79x-nm custom Pearl box
- Run at 25C, 150W for 66hrs CW to ensure box and chiplets were stable
- 15hrs of pulsing at 20msec pulse width (< 10Hz) for 378, 000 cycles
  - Hard pulsed (full on/off power), rapid rise/fall
  - Very demanding pulse scheme for any bar configuration, especially non-water cooled

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Pearl: Optional Hermeticity

- Seam Sealed Lids
- Brazed Cu/SS Construction
- Sapphire Window
  - → Laser Welded

- 15-Pin Micro-D connector
  - → Laser Welded
  - → Provides easy of use

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