

The logo for nLIGHT, featuring a lowercase 'n' in a bold, italicized font followed by the word 'LIGHT' in a bold, uppercase, sans-serif font, all in white on a dark blue background.

***n* LIGHT**

Next-generation fiber laser pumps

R. Martinsen, K. Price, and S. Karlsen

Applications of High-Power Semiconductor Lasers

Advances in Technology & Pumping

San Diego, CA USA

October 6, 2008

- 1. Factors driving next-generation pumps**
- 2. Competing approaches to high-brightness**
- 3. High-power pumps for 100 to 400um fiber**
- 4. Summary & next steps**

Future Pump Requirements and Competing Technologies

Market Drivers Favor Multiple SE Architectures

Factors that influence high-power FL pump purchases	Competing Technologies			
	Microchannel-cooled bars	Conduction-cooled bars	SE FC	multiple SE
\$/Bright-Watt	●	●	●	● ●
Long-term Reliability	●	●	● ●	● ●
Brightness Scaling	●	●	●	● ●
Power Scaling	● ●	●	●	●
Efficiency	●	●	● ●	● ●
Cladding Light	●	●	●	● ●
High Op Temp	●	●	● ●	● ●

- = weakness
- = neutral
- = strength
- ● = best in-class



Pearl

Pearl and How it Addresses Next-Generation Requirements

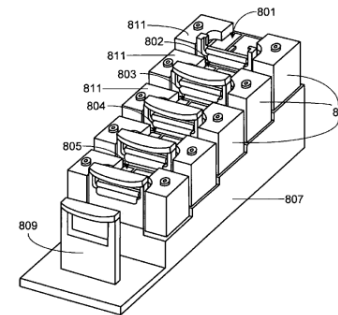
1. Power scaling architecture with SE reliability

- Series-connected single emitters
- Rugged optical design: FAC, SAC, focus
- MIL-spec environmental durability
- IBS-coated PowerCore™ fiber



2. Leverages efficiency to lower \$/W, enhance reliability

- HE device technology
- Extremely efficient optical design
- Up to 125W conduction-cooled
- Smallest package for >100W ,100-400um fiber



Modular Diode Laser Assembly

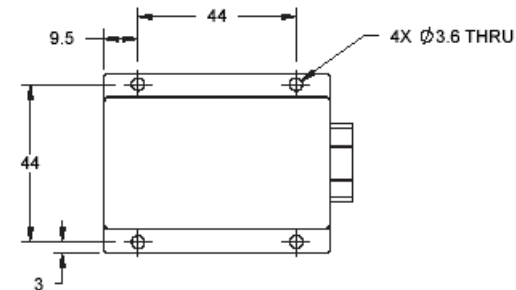
US Patent 7,420,996

6 more pending

Low-current 15-pin, micro-D connector for data & current

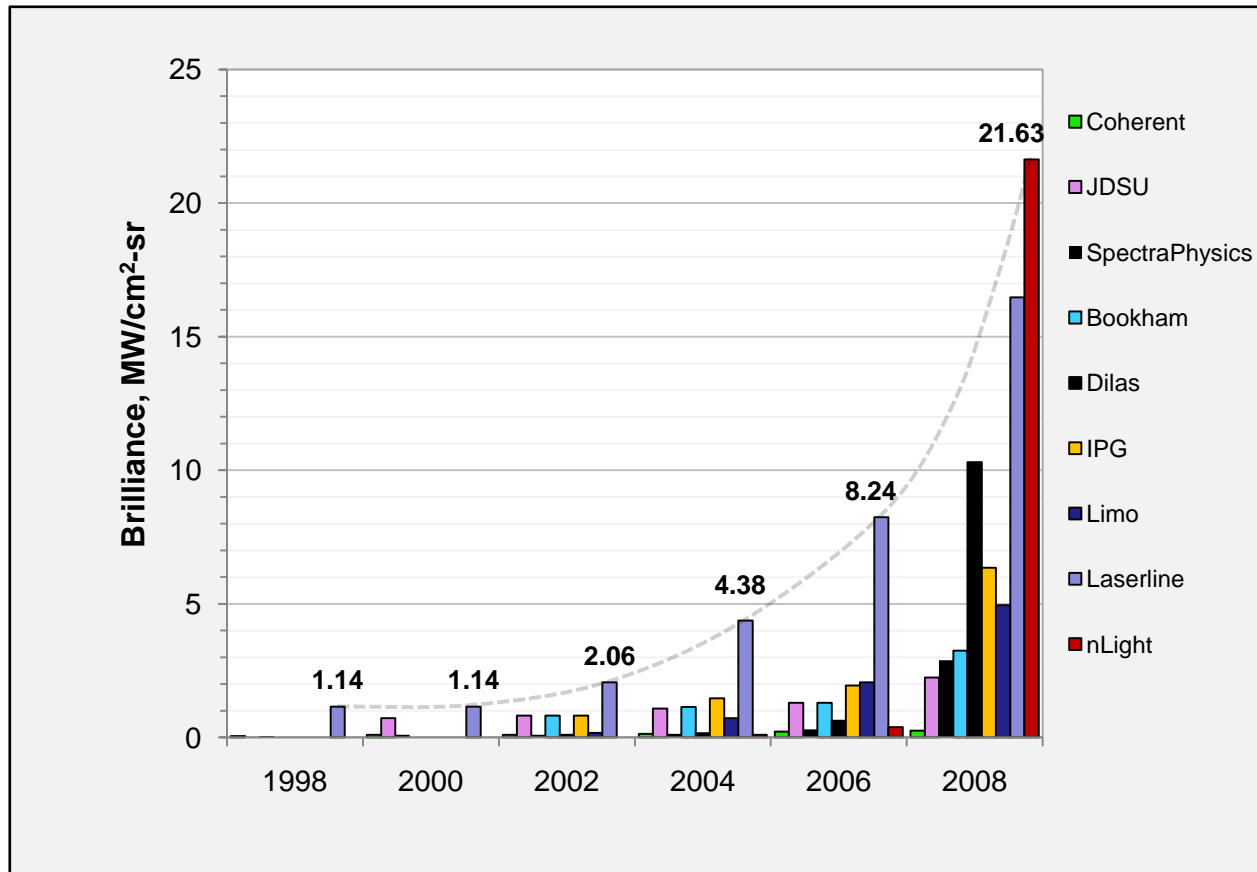


200um Pearl footprint for 20 – 75W



Industry Brightness Trend

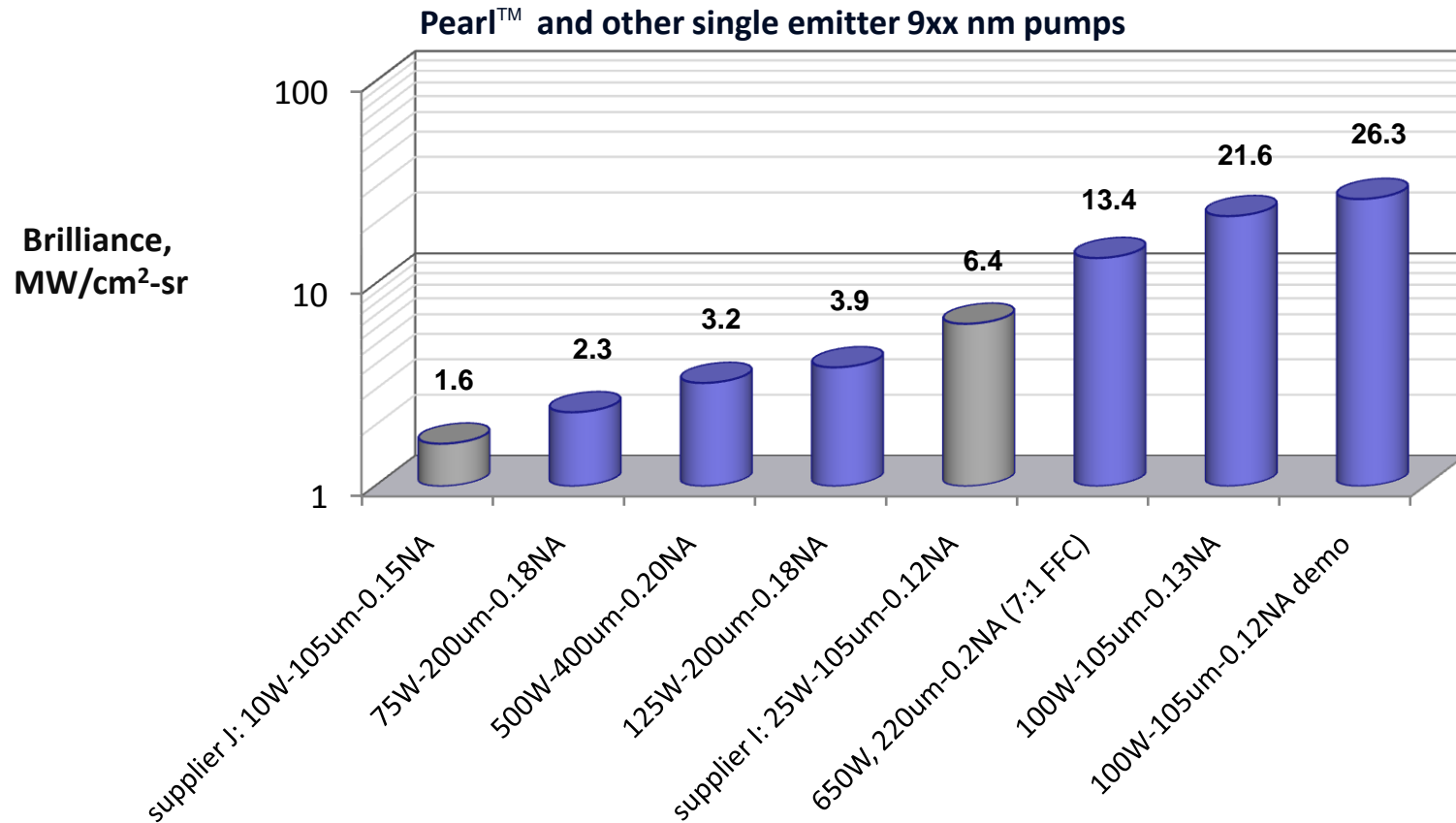
High-brightness, fiber-coupled diodes have proliferated recently due to advances in device and packaging technologies



*Sourced from respective web site data

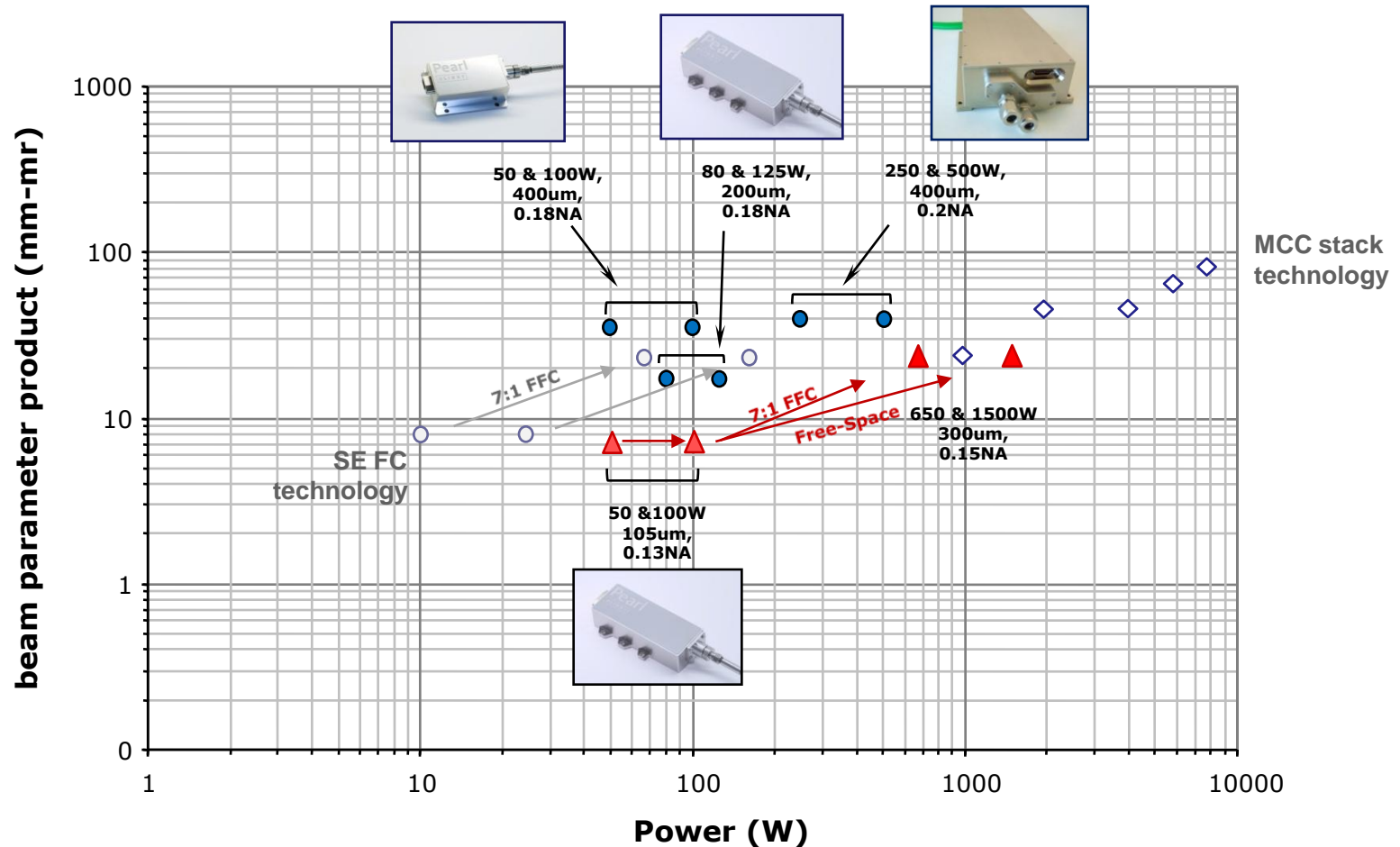
Fiber Laser Pump Options

A broad offering of high-brightness pumps are now available for 100, 200, and 400um fiber



Power Scaling of High-Brightness Pumps

Pearl™ scales state-of-the-art reliability & brightness of single emitters to power levels previously associated with bars

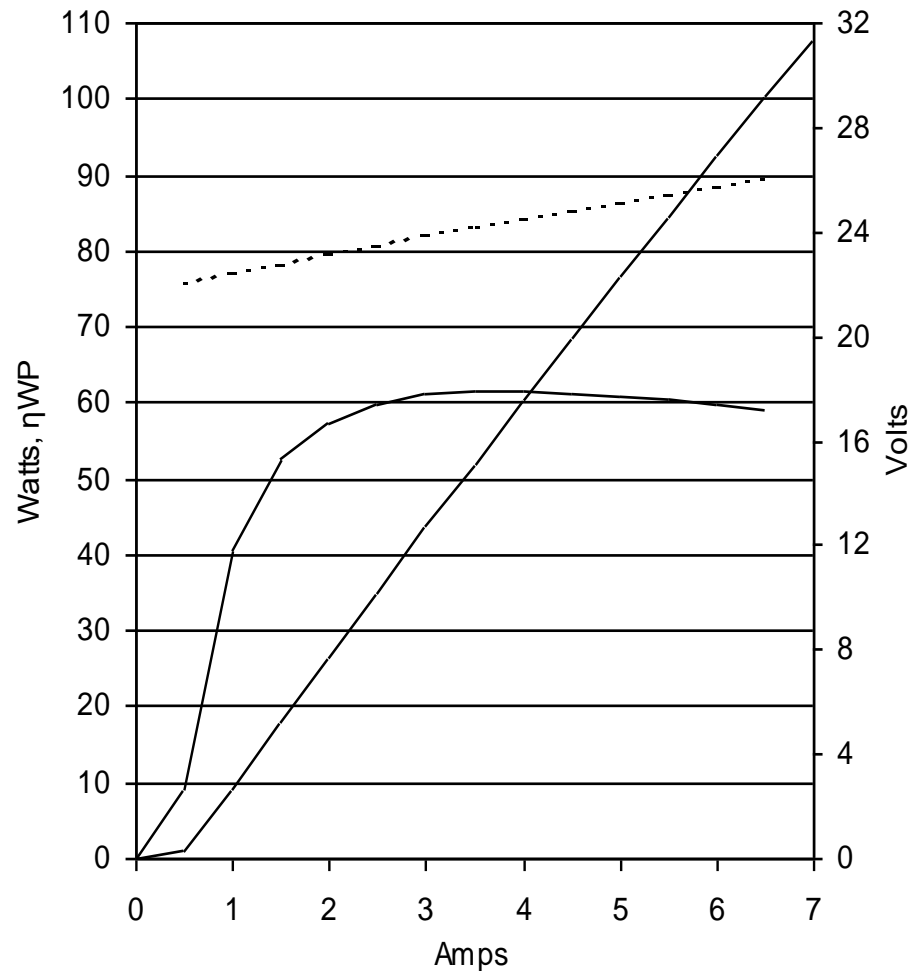


High-Power Fiber Laser Pumps for 200 & 400um Fiber

80 – 120W Pumps for 400um, 0.2NA



- 65% efficient diodes combined with 94% optical coupling in ***volume manufacturing***
- Up to 120W 9xx at 60% WPE from 400 μ m, 0.18 NA



25 – 75W Pumps for 200um, 0.22NA fiber

PERFORMANCE SUMMARY

Pearl Model P250-0976-AI
S/N 29-05109-02-00022
8-May-08

OPTICAL

Wavelength, nm	975.2
Output Power, watts	60
Spectral Width, FWHM	3.4
Slope Efficiency, W / A	9.4
Divergence, NA (90% power incl.)	0.16
Wavelength Temp. Coeff., nm / °C	0.32

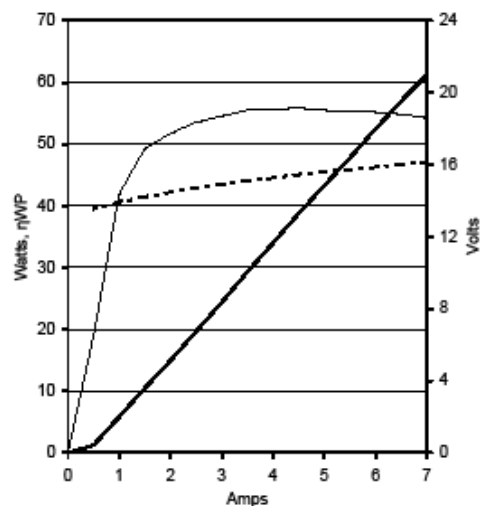
ELECTRICAL

Total Conversion Efficiency (η_{WP})	55%
Threshold Current, amps	0.39
Operating Current, amps	6.83
Operating Voltage, volts	16.10
Series Resistance, ohms	0.38

THERMAL

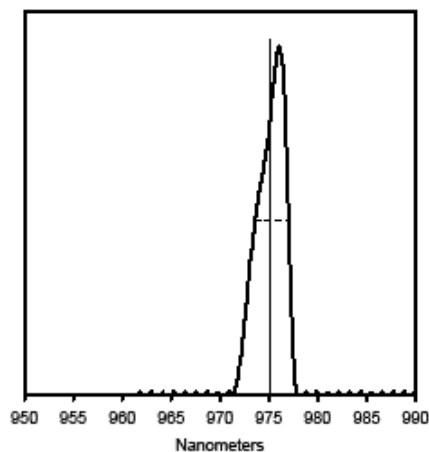
Operational Temperature, °C	25.0
Thermal Resistance, °C / W _{heat}	0.37

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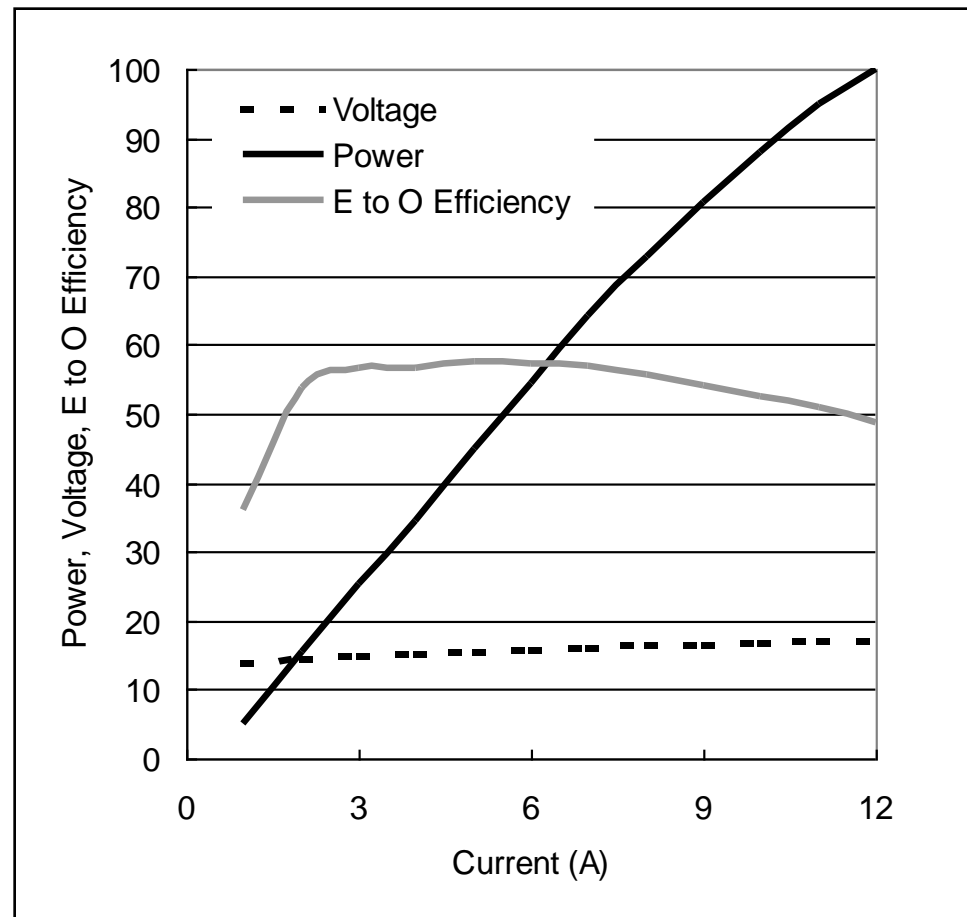
DANGER
AVOID EYE OR SKIN EXPOSURE
TO DIRECT OR SCATTERED
RADIATION.

WARNING
THIS IS A CLASS IV LASER PRODUCT. CW
POWERS IN EXCESS OF 100 WATTS COULD BE
ACCESSIBLE. ALWAYS WEAR PROPER EYE
PROTECTION WHEN OPERATING.



75W Pump for 200um, 0.22 NA Fiber

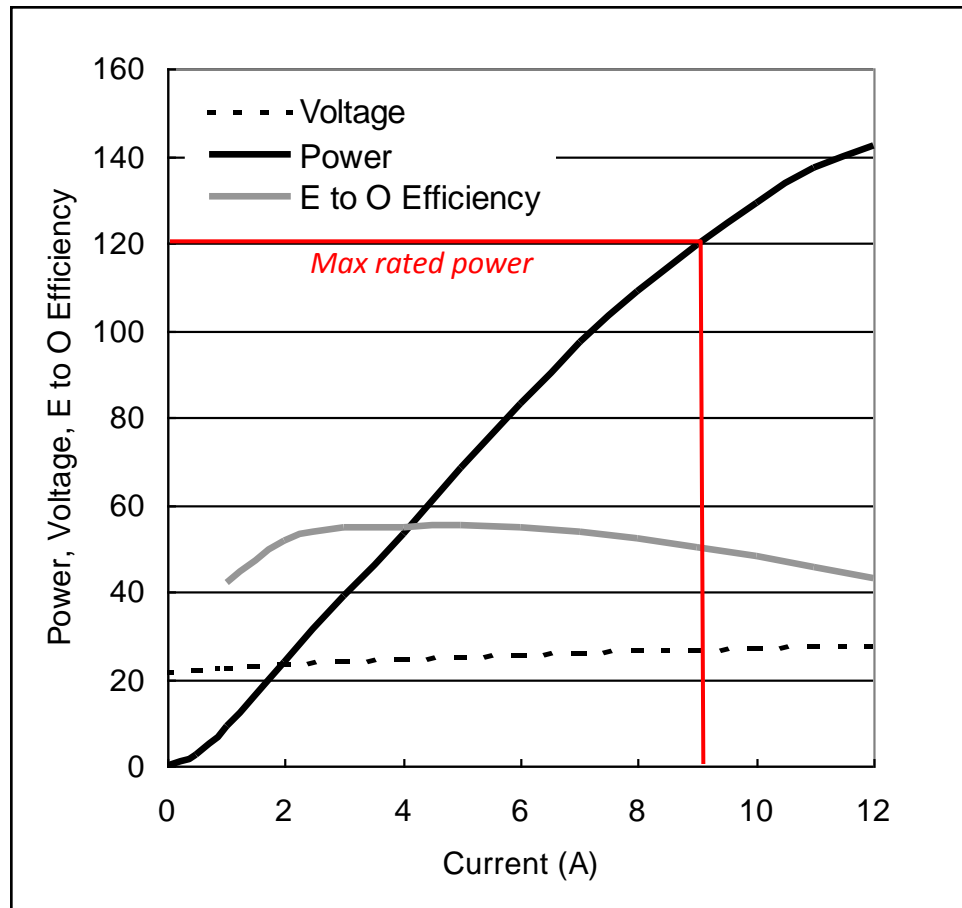
- More than 75 W from a package the size of a business card
- $\gg 50\%$ WPE over entire operating range
- $< 1\%$ cladding light



120W Pump for 200um, 0.22NA Fiber



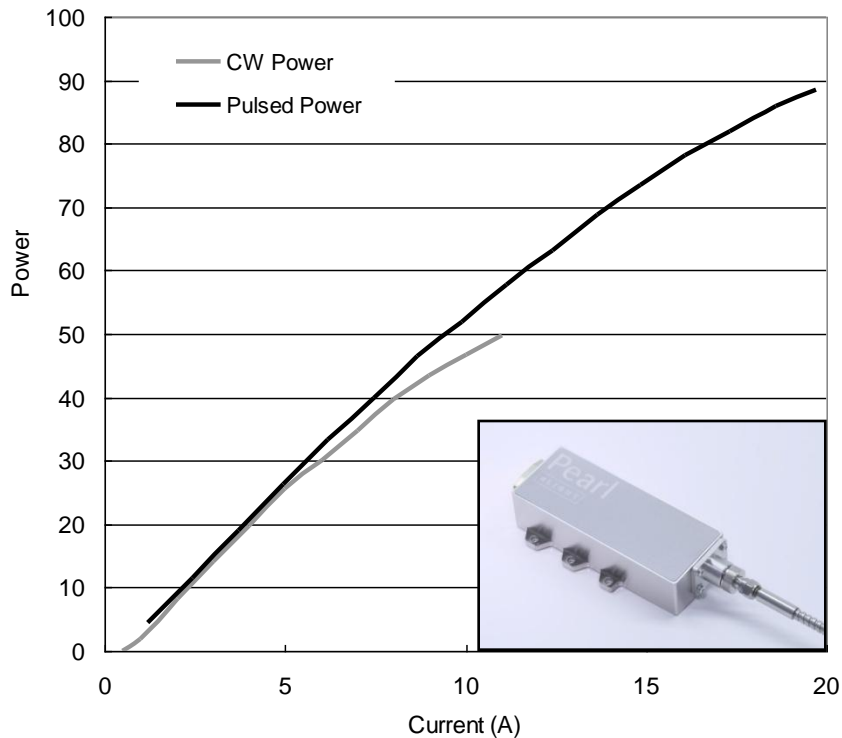
- 9A, 26V typical for 120W out
- >50% WPE over operating range
- <1% cladding light



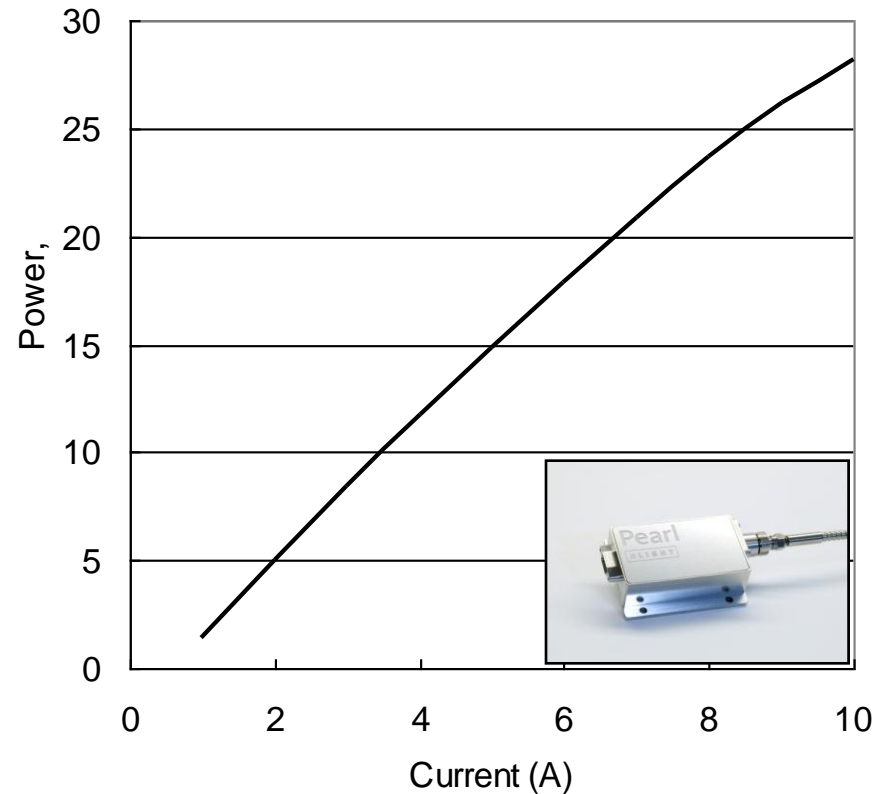
Low quantum defect pumps for Er-doped fiber lasers

1470nm Pumps for 200 and 400um fiber


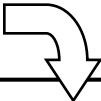



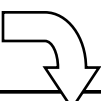


50W CW or 90 W pulsed at 1% duty,
1ms pulse width from 400um fiber



25W - 200 μ m Pearl



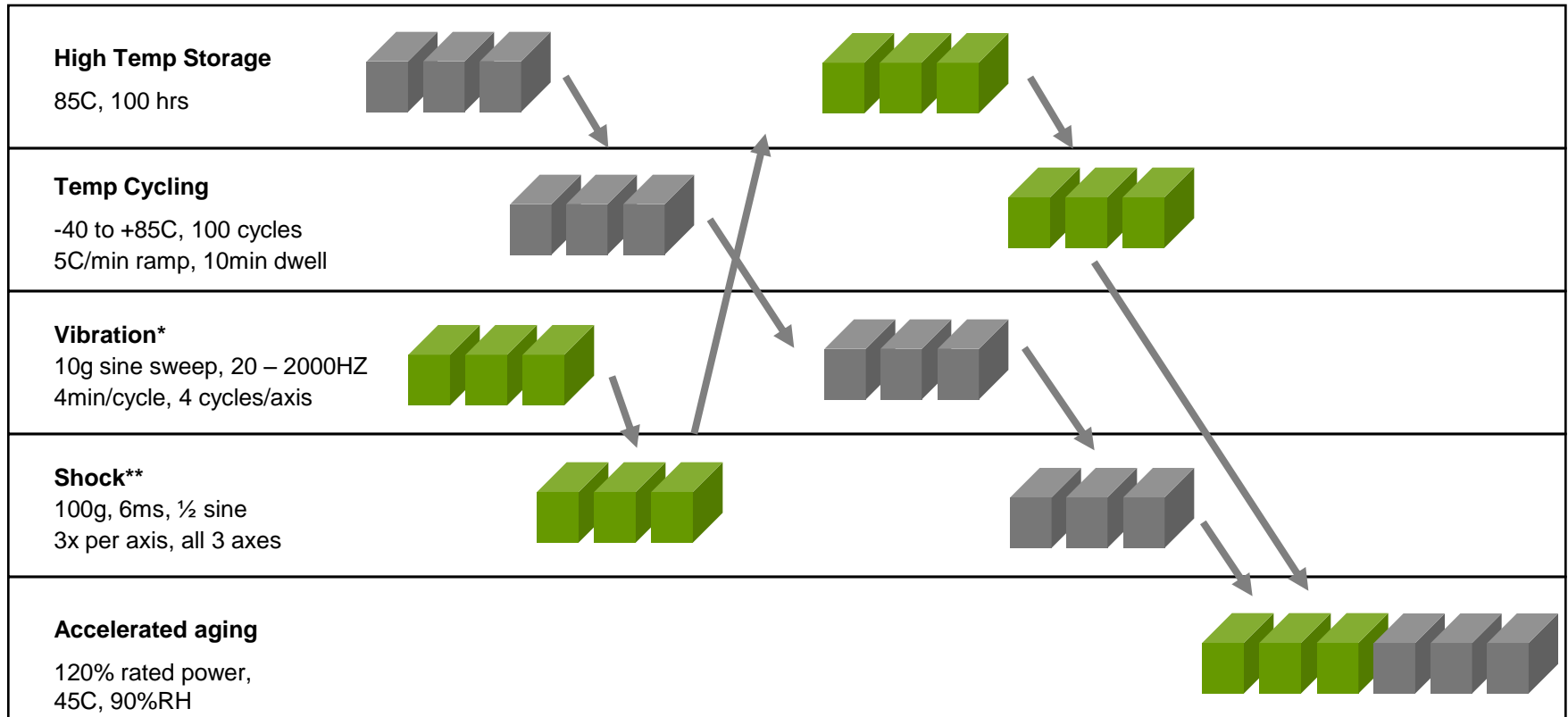
Pearl Environmental Qual for Industrial Deployment

Environmental Stress Test	Procedure & Pass/Fail Criteria	% Power Change for 200um Pump Lasers
High Temp Storage 85C, 100 hrs	 	
Temp Cycling -40 to +85C, 100 cycles 5C/min ramp, 10min dwell	 <p><5% power loss</p> 	00009 : -2.3% 00014 : -2.6% 00015 : -2.5%
Vibration* 10g sine sweep, 20 – 2000HZ 4min/cycle, 4 cycles/axis	 	
Shock** 100g, 6ms, ½ sine 3x per axis, all 3 axes	 <p><5% power loss</p> 	00022 : 0.5% 00023 : -0.4% 00025 : -0.1%

*MIL-STD-883F Method 2007.3

**MIL-STD-883 Method 2002

Design Margins Confirmed by “Cross-Over” Stress Tests & Testing-to-Failure



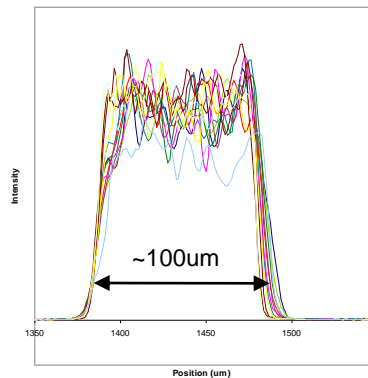
*MIL-STD-883F Method 2007.3

**MIL-STD-883 Method 2002

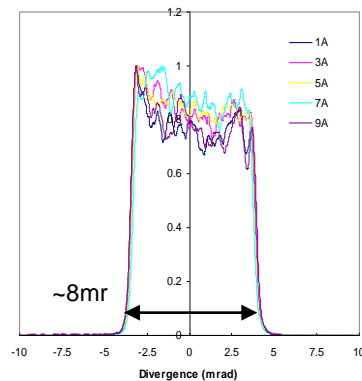
High-Power Pumps for 100um Fiber

High-Brightness Coupling Fundamentals

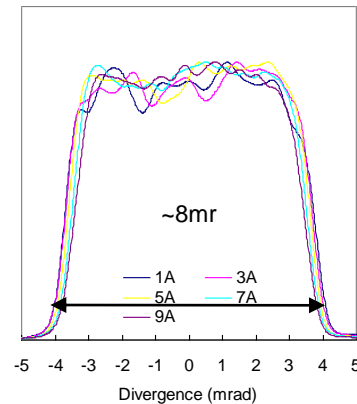
Coupling multiple 95 μ m-stripe devices into 105 μ m fiber require stable near-/far-fields over current and design tolerance to environmental factors.



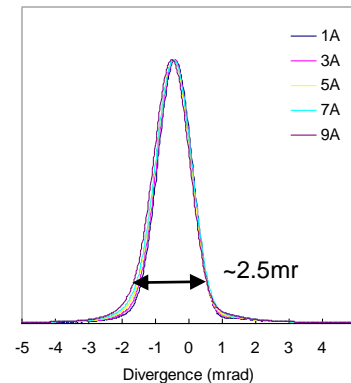
SA near-field



SA far-field,
individual emitter



SA far-field,
14-emitter package

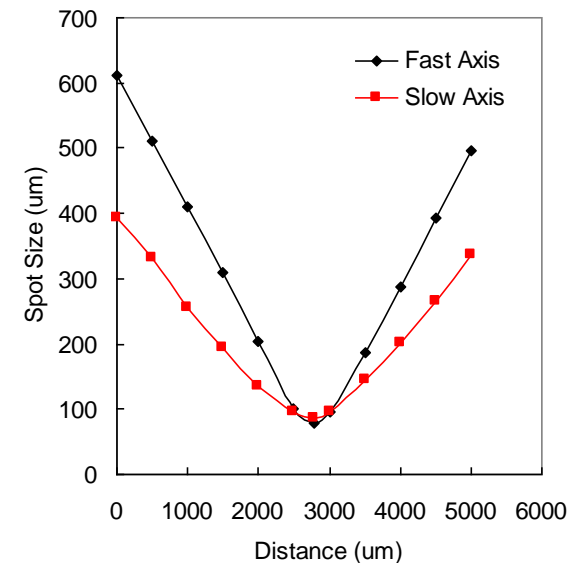


FA far-field,
14-emitter package

Focused spot size = 79 x 86 μ m

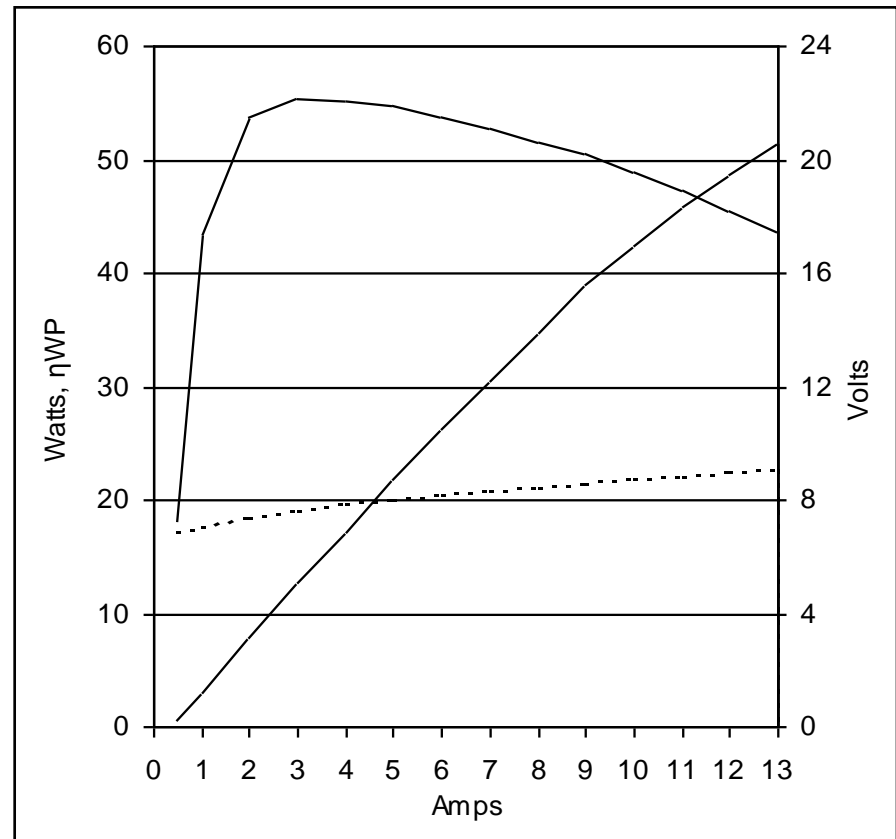
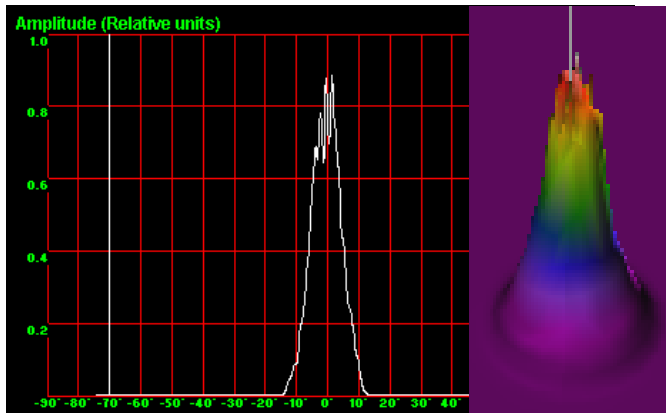
Excitation NA = 0.118

>26 MW/cm²-steradian (@ 100W)



50W Pump for 105um, 0.22NA fiber

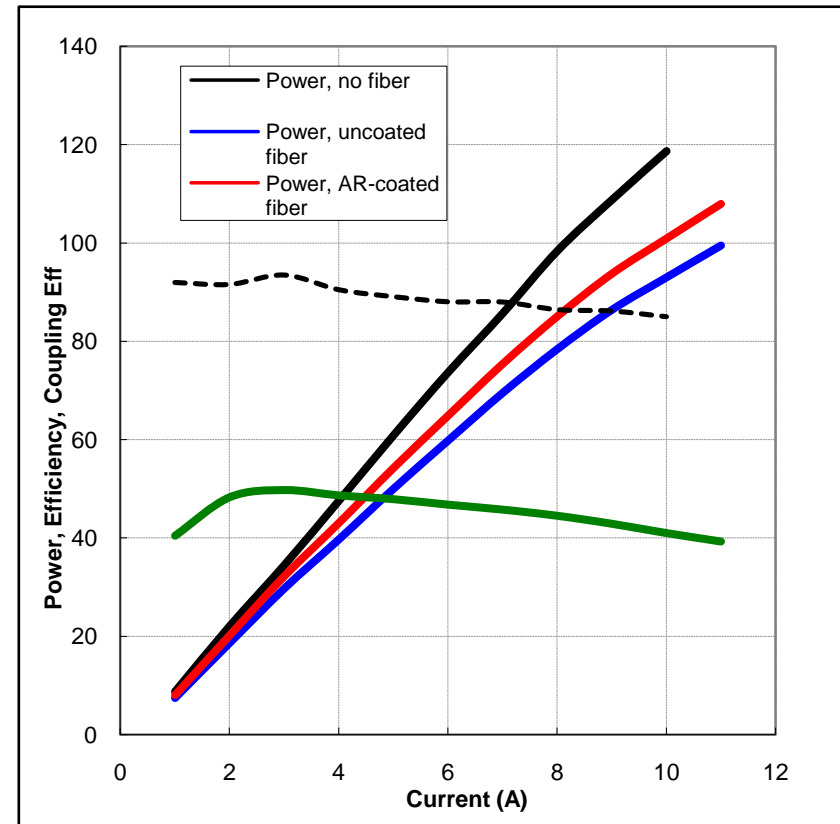
- **>93% fiber coupling efficiency at 0.167NA excitation**
- **<1% cladding light in 0.22NA fiber**
- **>45% wall-plug**



100W Pump for 105um, 0.13NA

High coupling efficiency essential for package reliability and minimizing \$/W

- **100W of 976nm power of cladding-free light from mode-stripping fiber**
- **>40% wall-plug efficiency**
- **85 – 90% fiber coupling efficiencies over entire operating range**
- **Ongoing developments:**
 1. Qualify 50% WPE from 0.22NA fiber
 2. Reduce polarization-related losses
 3. Reduce aberrations for focused spot size



Multiple SE Architectures Meet OEM-*specific* Requirements with Lowest \$/W

An OEM application requiring only 40W of power from 105um fiber did not have to purchase a 50 or 60W product and de-rate

PERFORMANCE SUMMARY

Pearl Model P1-050-0976

S/N 29-05044-01-00166

15-Aug-08

OPTICAL

Wavelength, nm	971.6
Output Power, watts	40
Spectral Width, FWHM	3.7
Spectral Width, $1/e^2$	5.3
Slope Efficiency, W / A	4.2
NA (90% power)	0.17
Wavelength Temp. coeff., nm/°C	0.32

ELECTRICAL

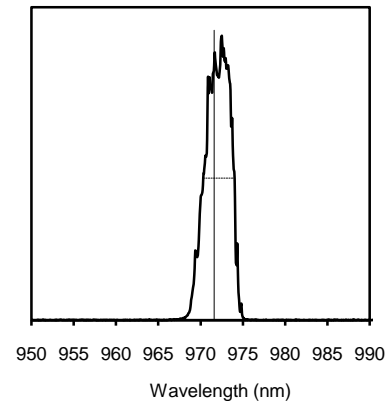
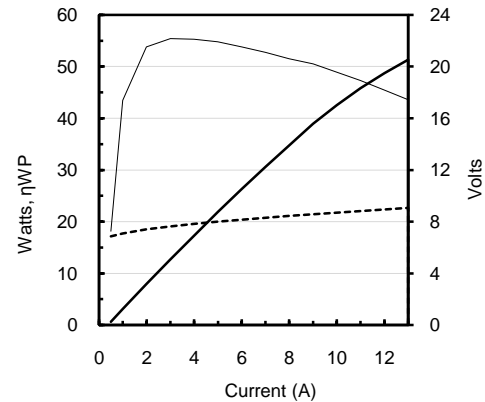
Power Conversion Efficiency (η_{wp})	50%
Threshold Current, amps	0.50
Operating Current, amps	9.37
Operating Voltage, volts	8.61
Series Resistance, ohms	0.17

THERMAL

Operational Temperature, °C	25.0
Thermal Resistance, °C/W _{heat}	0.58

DANGER
AVOID EYE OR SKIN EXPOSURE
TO DIRECT OR SCATTERED
RADIATION.

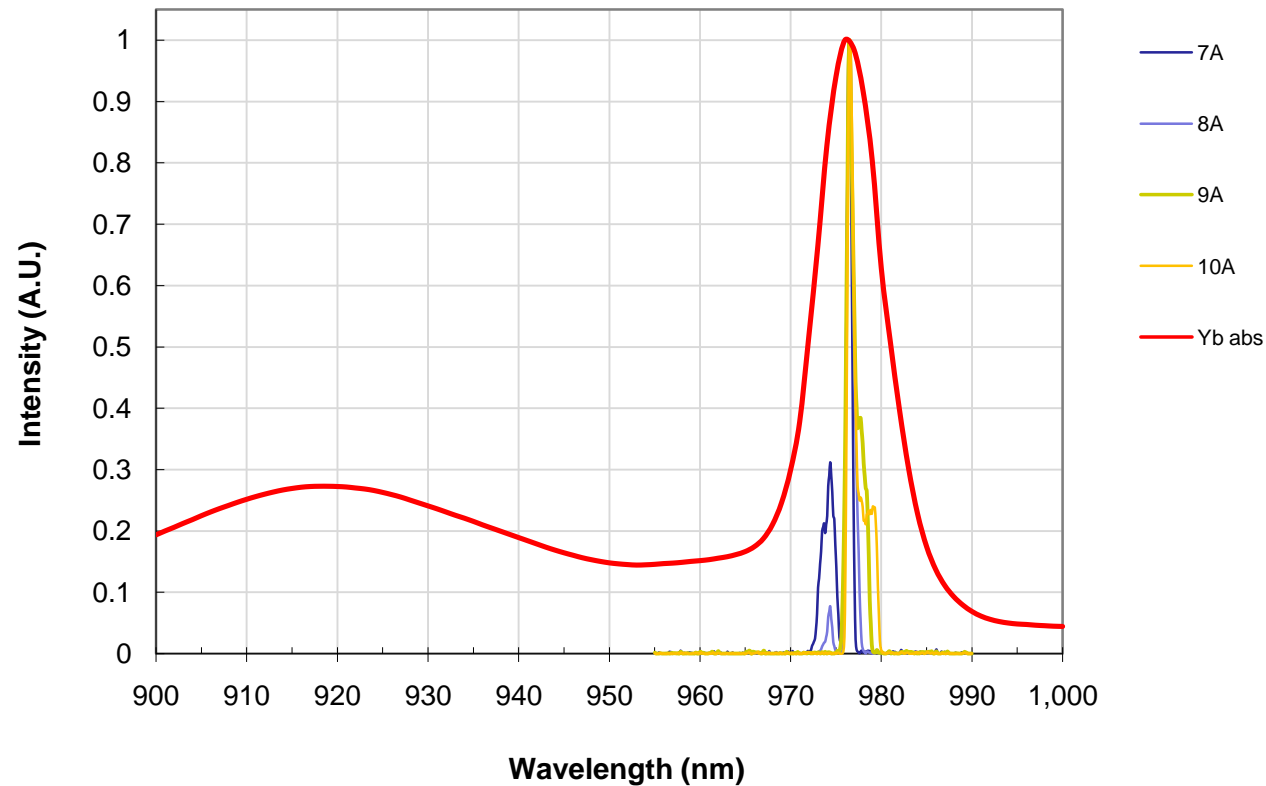
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Wavelength Stabilized 976nm

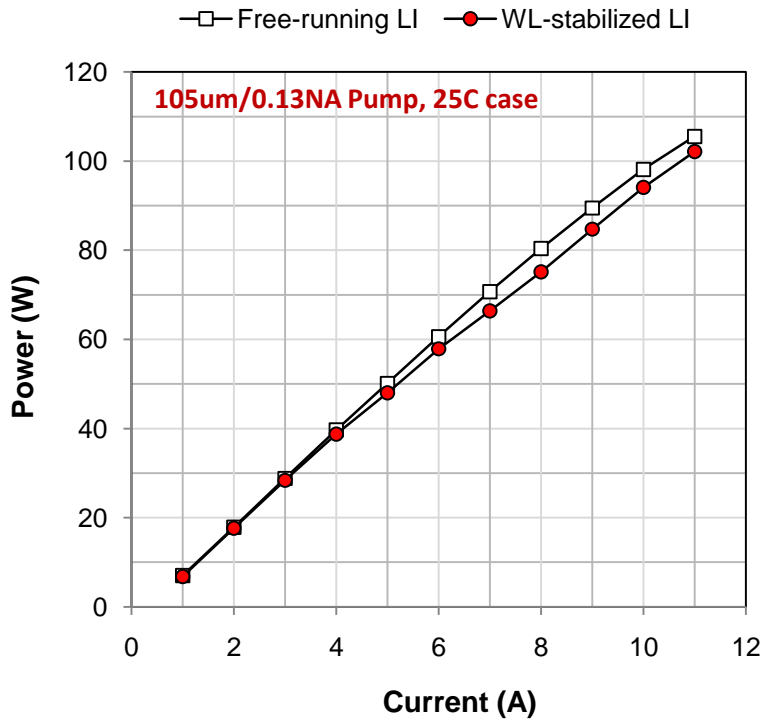
Spectrally-Stabilized Pumps for Scaling PFL Peak Power

- Reduced absorption length at 976nm increases threshold for nonlinearities
- Lower quantum defect & temperature sensitivity improves efficiency

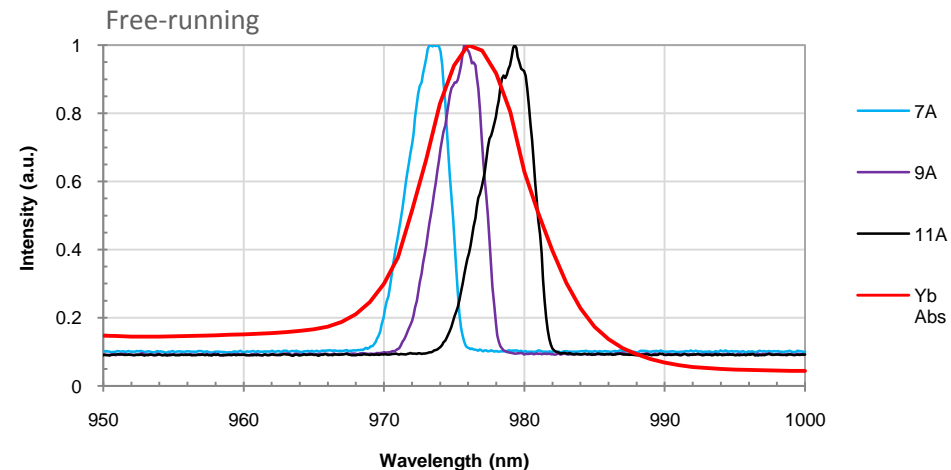
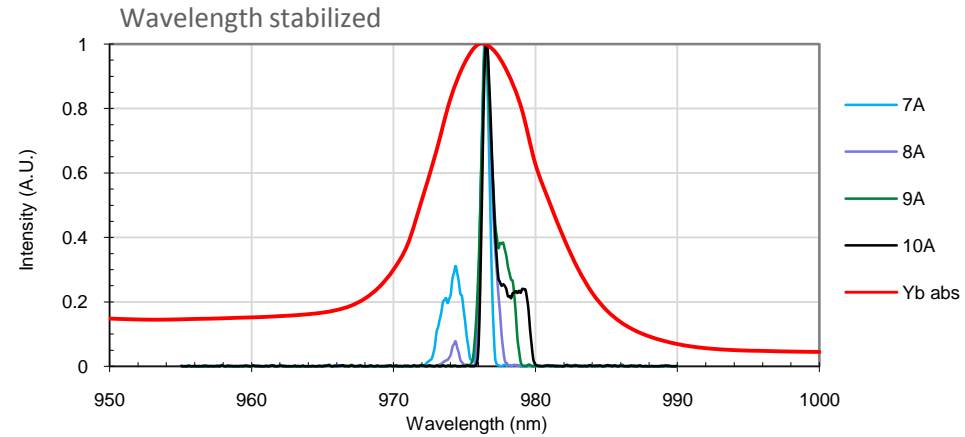


Efficient spectral stabilization

Spectral locking range over temperature and current are in balance with overall efficiency objectives



- ~44% peak $\eta_{\text{wall-plug}}$ demonstrated to date
- >50% peak $\eta_{\text{wall-plug}}$ expected by '09 release



Pearl pumps offer fiber laser OEMs distinct advantages:

- 1. Power scaling with state-of-the-art single emitter reliability**
 - Series-connected, AuSn packaging, facet passivation
- 2. Highest efficiency, cladding-free light**
 - >60% WPE for 100W-400 μ m/0.22NA fiber
 - >50% WPE for 100W-200 μ m/0.22NA fiber
 - >40% WPE for 100W-100 μ m/0.15NA fiber (~50% expected for 0.22NA fiber)
- 3. Highest brightness**
 - 100W from 105 μ m, 0.12NA, >20 MW/cm²-sr
- 4. Granularity minimizes app-specific \$/Bright-Watt**

Next-generation feature set strengthens imbedded value:

- Durability (Robust package & fiber qualified to MIL-STD-883E)
- Efficient spectral control
- Compactness (highest power/volume for products \geq 75W)