SHEDs Funding Enables Power Conversion Efficiency up to 85% at High Powers from 975-nm Broad Area Diode Lasers

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• *Our work to improve 9xx-nm device efficiency is supported by DARPA under the SHEDs contract number: MDA972-03-C-101.*
• *Work to improve performance at 1470-nm is supported by Army Research Office under contract number W911NF04C-0137*

Contents

- **Introduction to nLight**
- **Survey of single emitter performance**
- **How SHEDs Delivered Higher Efficiency**
- **Insights from cryogenic testing**
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- **Conclusions**

nLight Overview

- **History**
  - **Founded in 2000**
  - **Over 100 employees**

- **Technology**
  - **High power laser diodes from 630 to 1900 nm**
  - **Broad range of packages**

- **Production**
  - **60,000 sq ft vertically integrated manufacturing facility**
  - **Complete capabilities with MOCVD through packaging**

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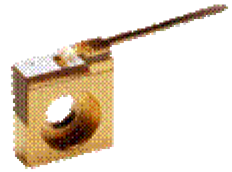
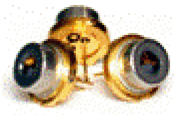
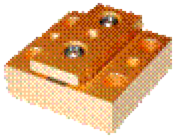
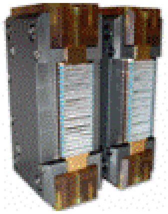
nLight's products range from several Watts to several tens of kW

Product category	nLight product examples
Single Emitter Up to 7W	  
Diode Arrays 40 to 100 Watts	 
Stacks of Arrays >100W to many kW	 
Fiber Bundled Arrays < 40 Watts	

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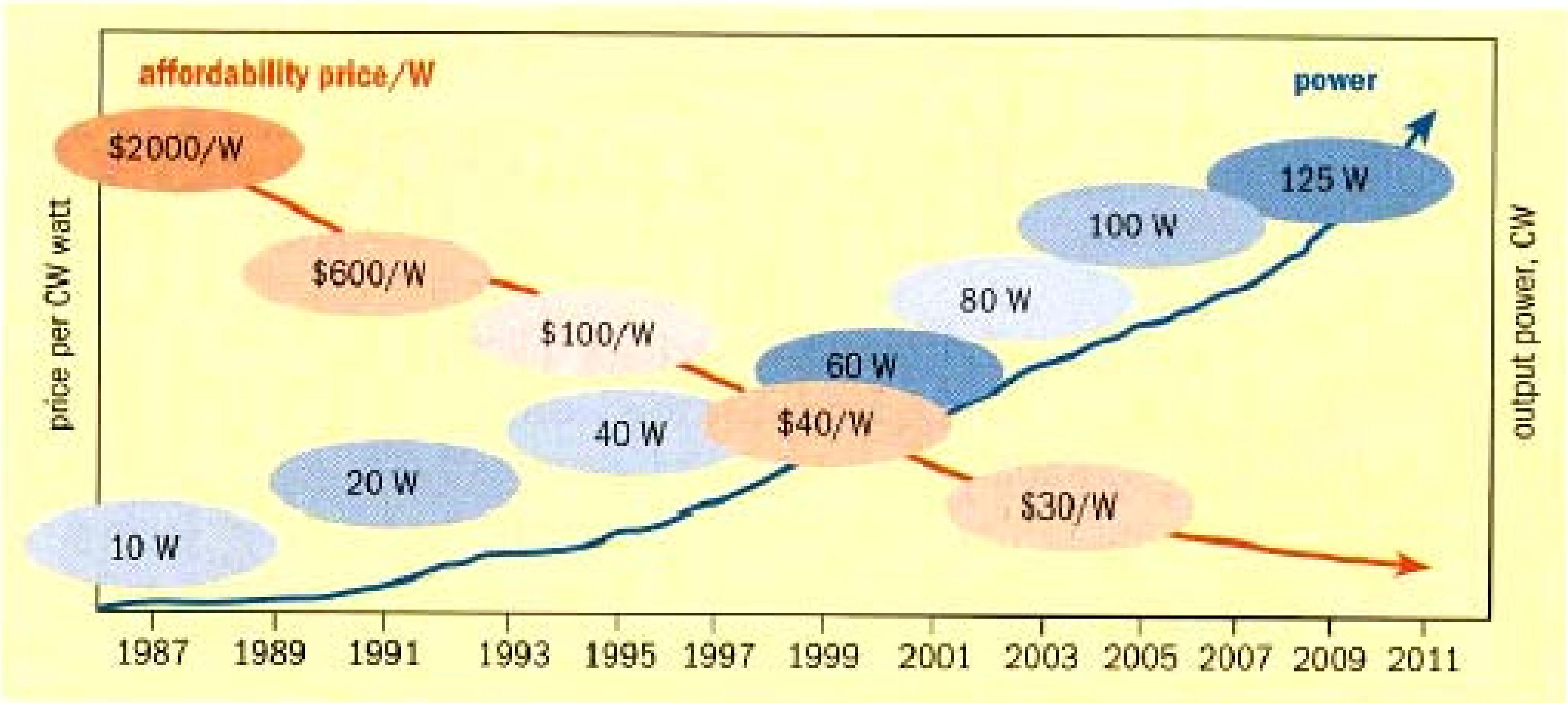
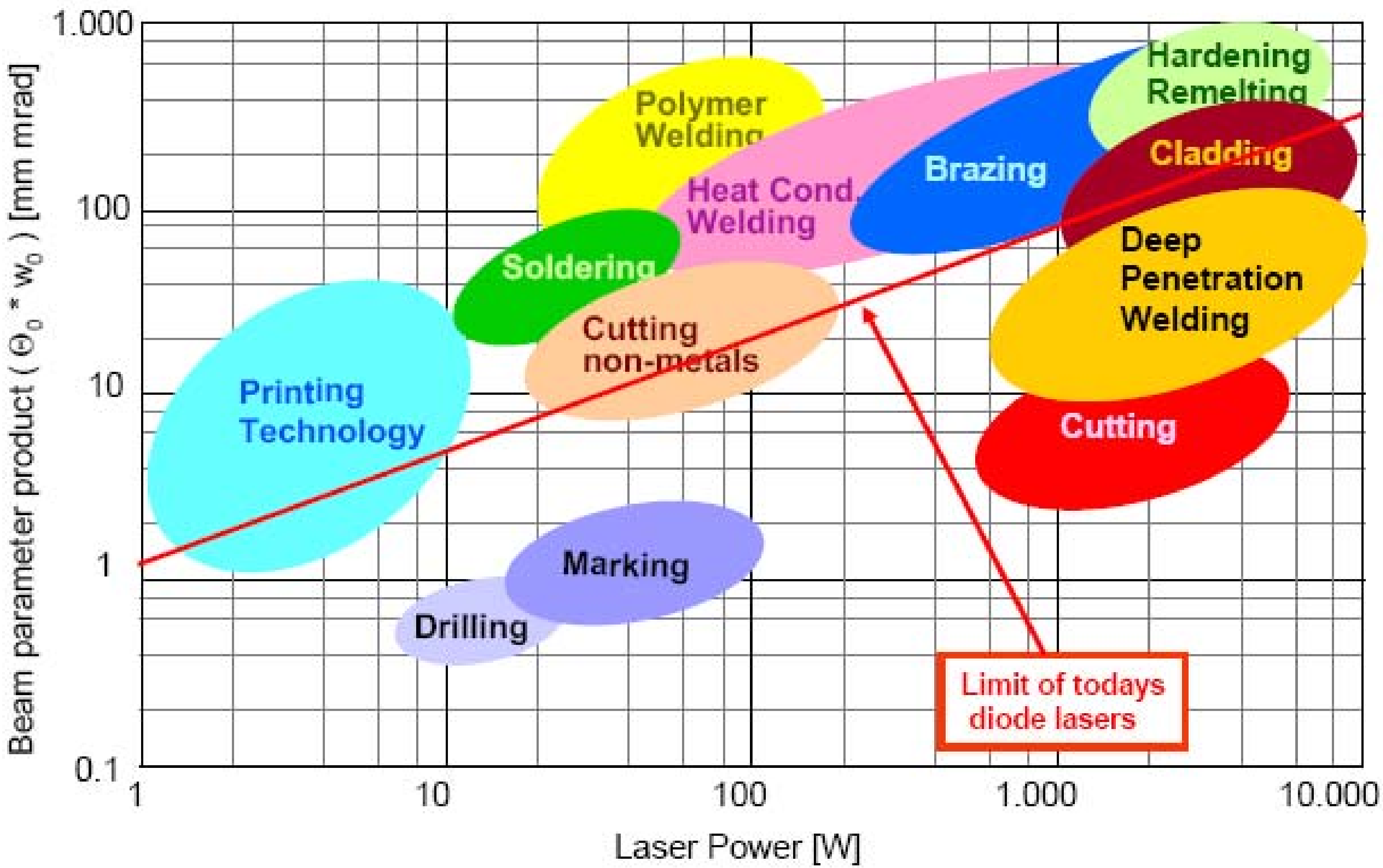
Diode Laser Bar Performance And Cost Rapidly Improving

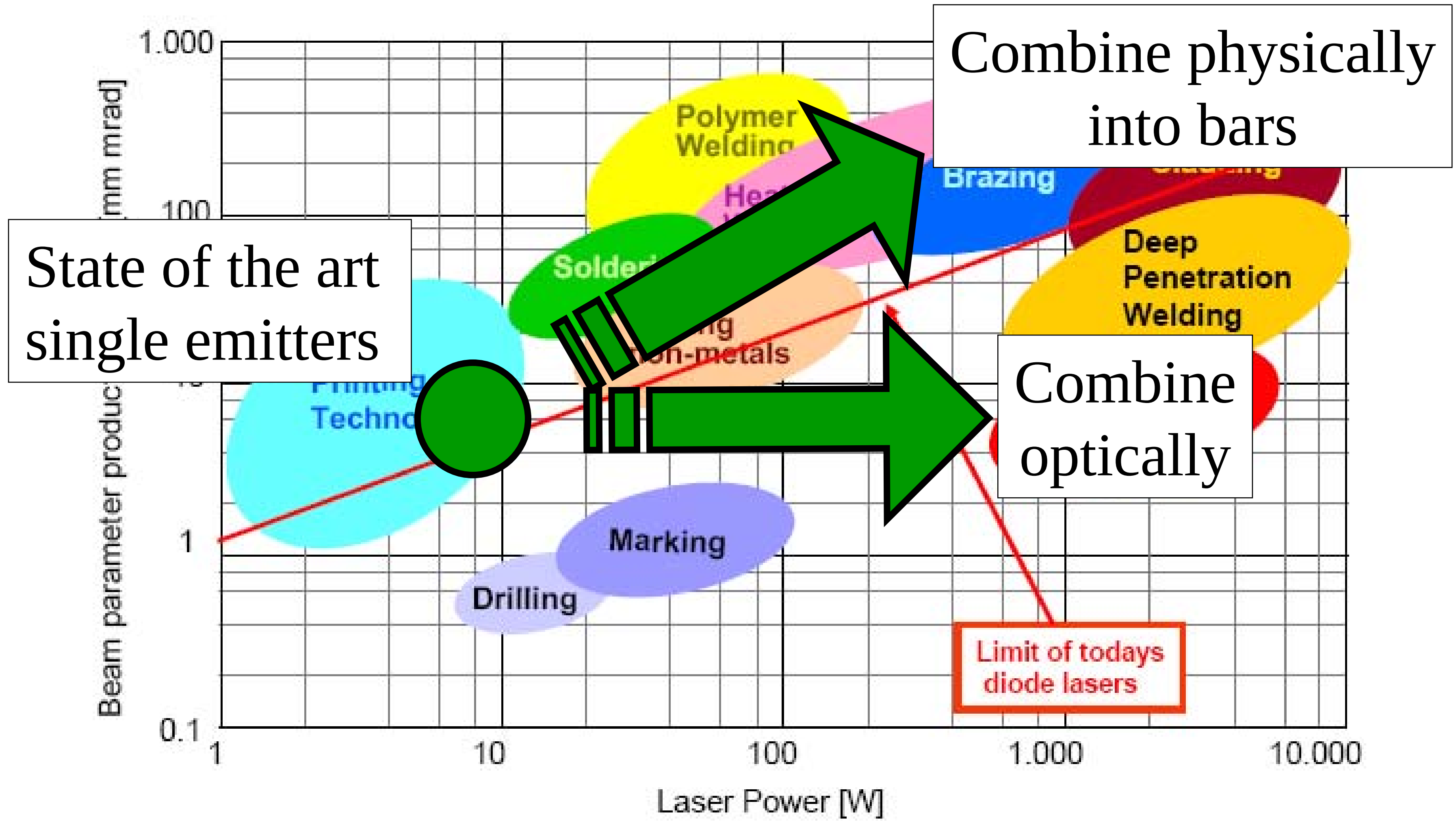


Reliant on key building block – the single emitter

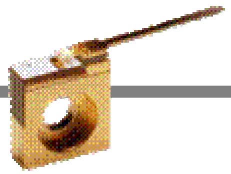
Segmentation of Market for Laser Material Processing



Single Emitters Allow Access to All These Markets

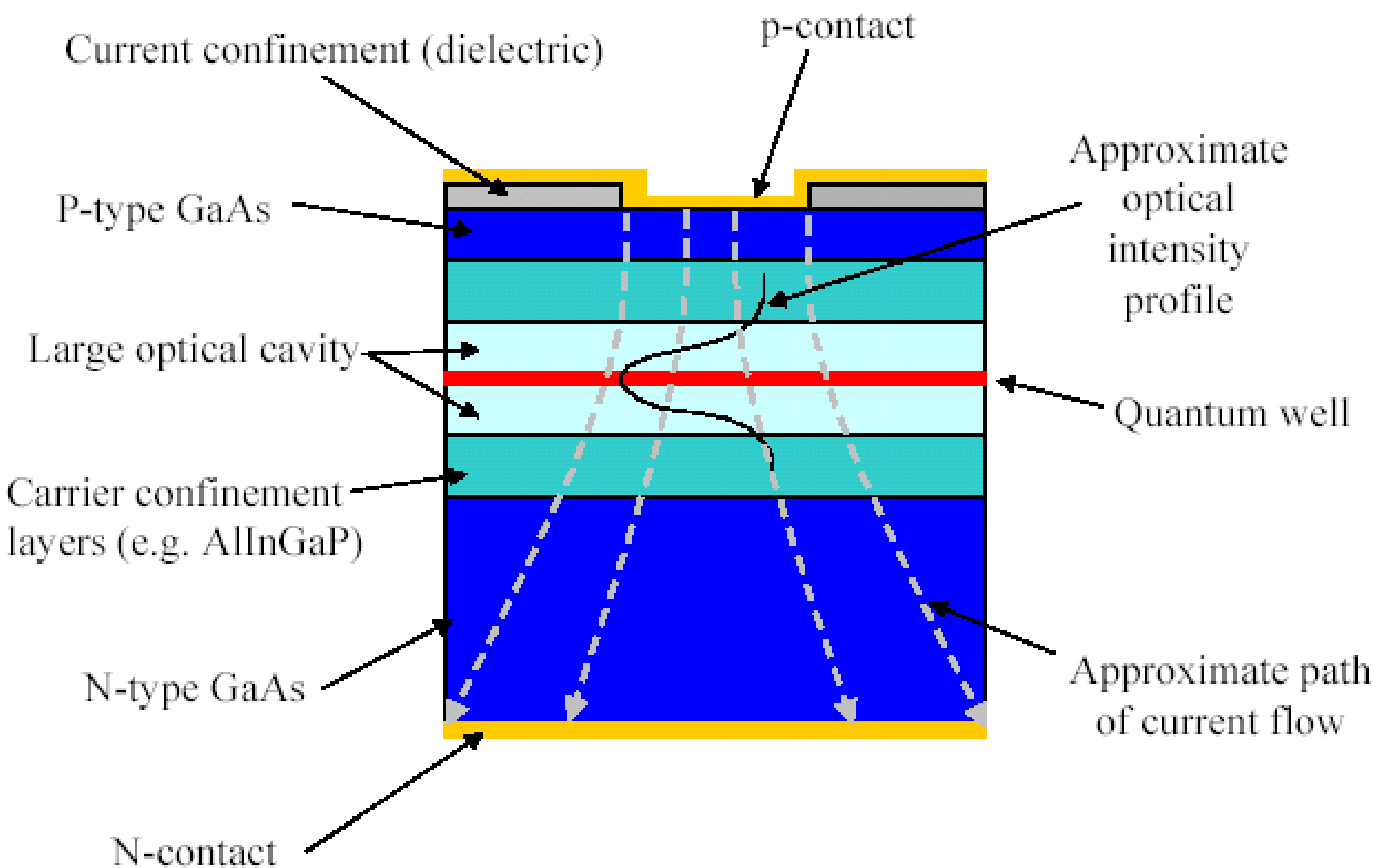


Product Line Depends on High Performance Single Emitters



- **Single emitter critical technology**
- **High power, high brightness source**
  - Up to 7W at 808-nm from 50-um by 1-um aperture
- **Wide range of wavelengths**
  - From < 660-nm to > 1700-nm
- **Leading edge performance**
  - 76% Power Conversion Efficiency at 980-nm (85% at –50C)
  - 45% Power Conversion Efficiency at 1470-nm
- **Building block for many different products**
  - Integrated into 1-cm bars for high power stacked arrays

Construction of High Power Diode Lasers



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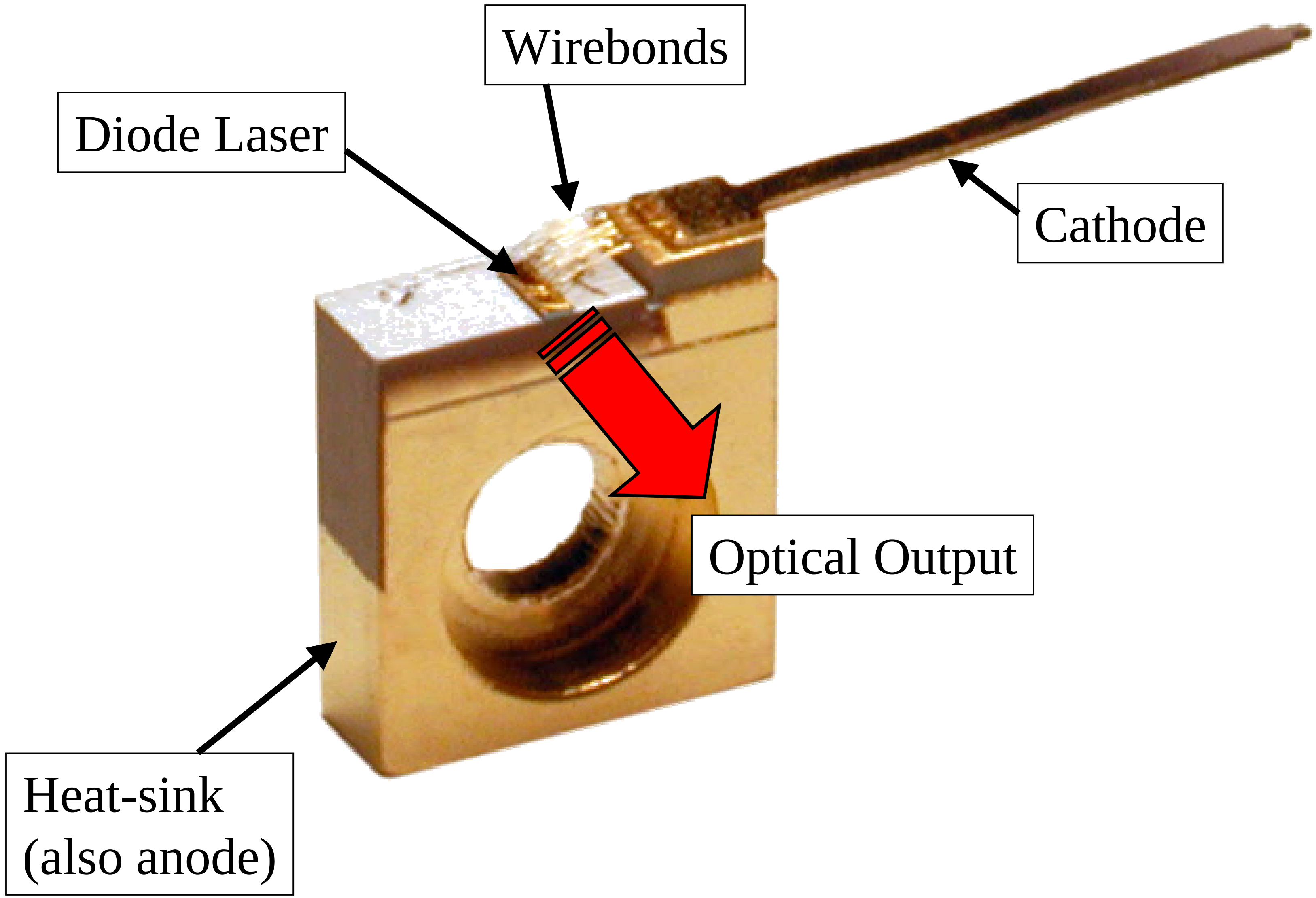
Soldered to C-Mount



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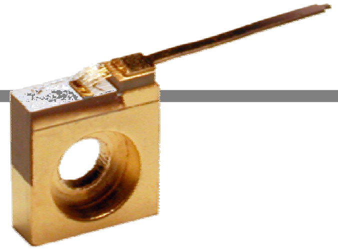
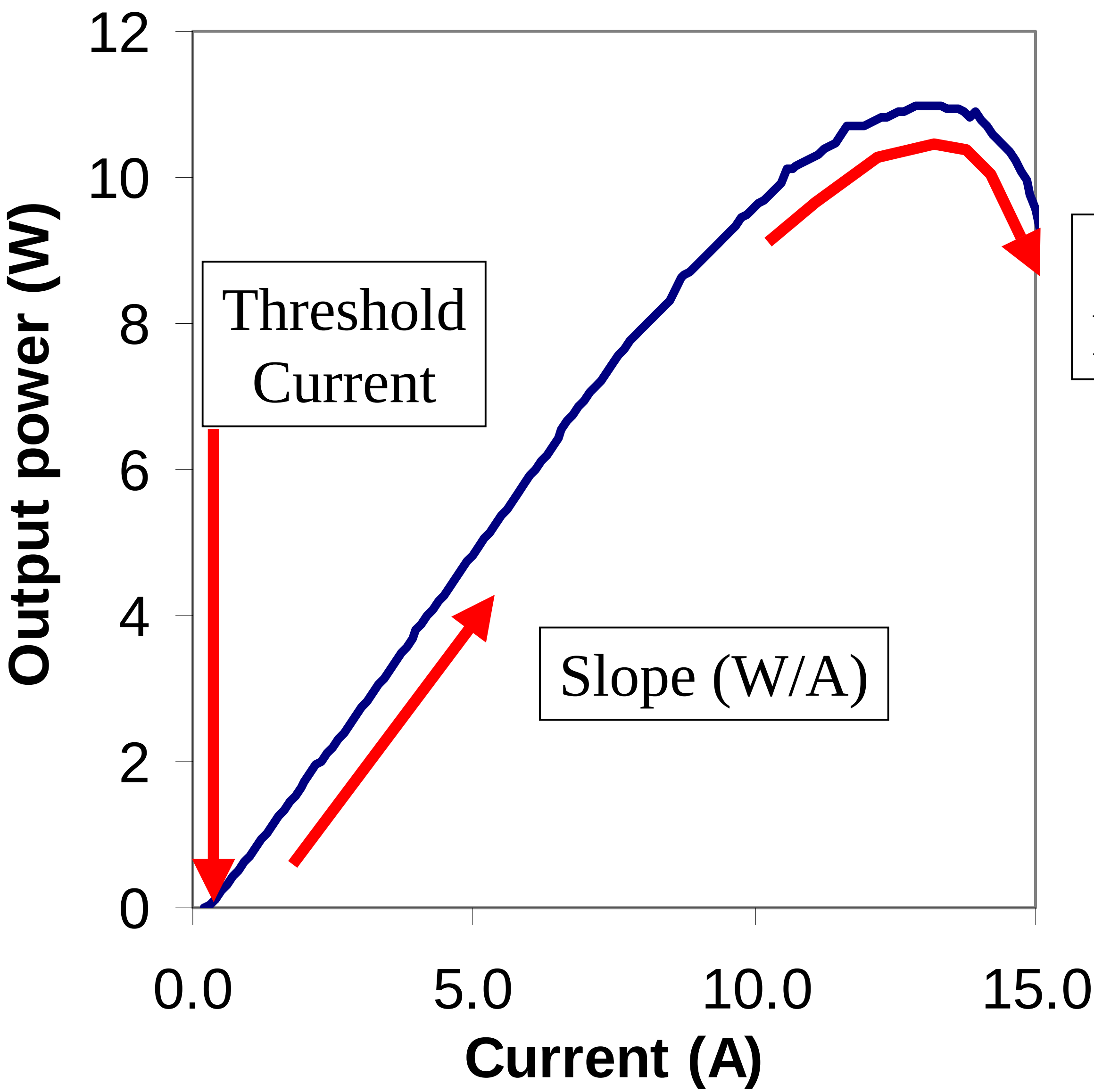
Limits to Peak Power





High Power Conversion Efficiency Means Higher Peak Power

- **Higher efficiency means more power out for same current**
  - Lower threshold
  - Higher slope
- **Higher efficiency means less heat deposited**
  - Device does not heat up so severely
  - Higher powers before performance degrades
- **Lower temperatures mean longer lifetimes**
  - Most degradation in diode lasers is thermally activated

Catastrophic Optical Damage (COD) also limits power and reliability

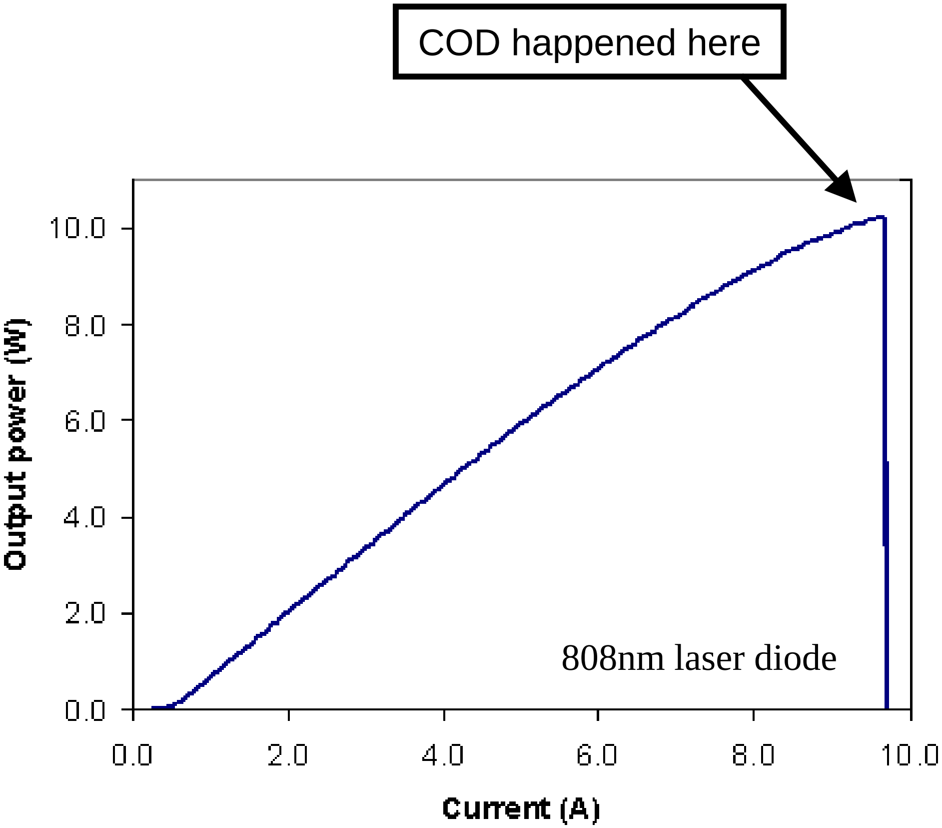


Image of a COD event (top view)

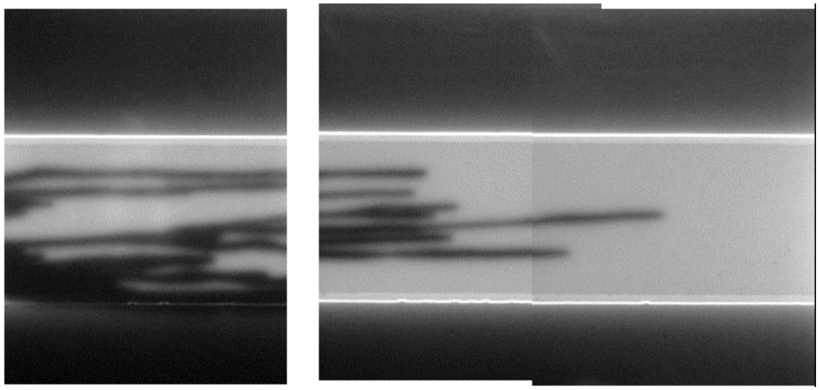
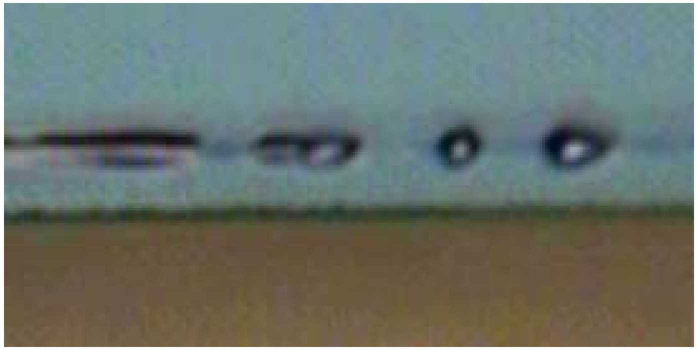


Image of a COD event (front view)



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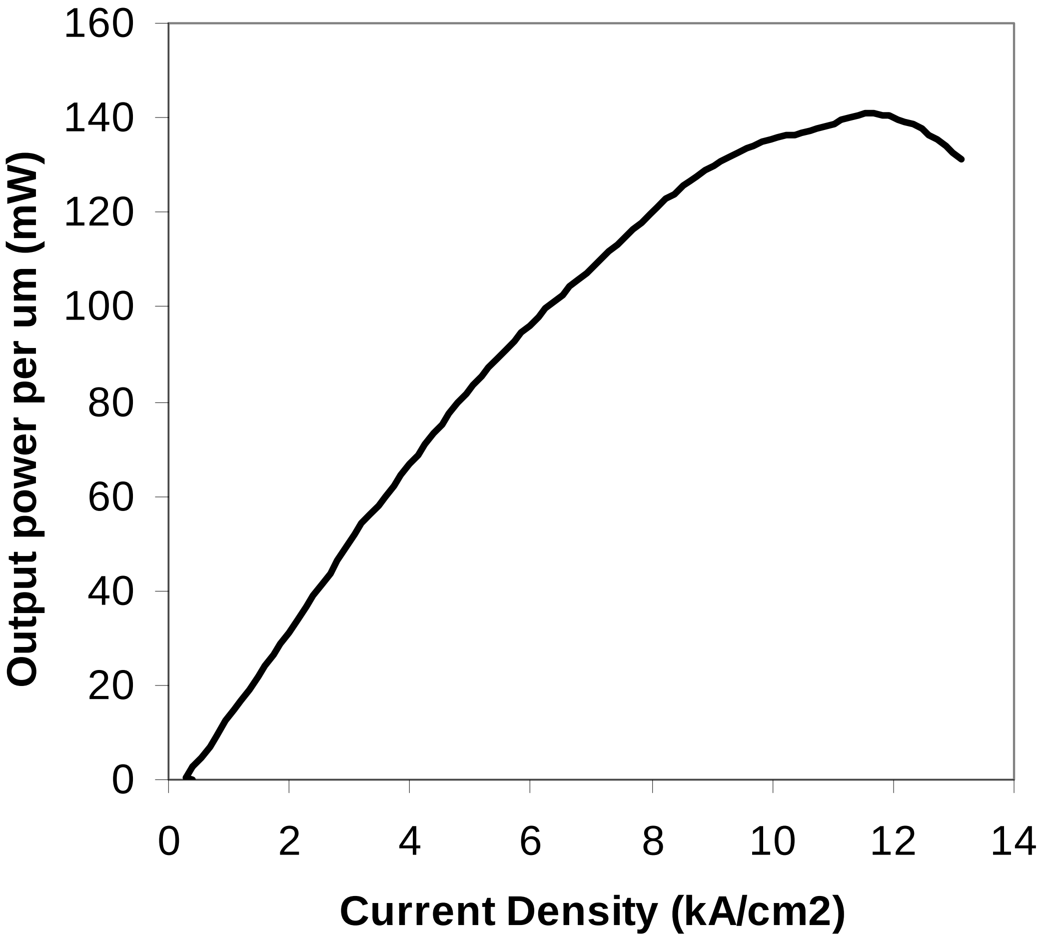
808-nm Passivated Facet Rolls Thermally at 140mW/um



50um stripe, 7W roll-over at 25C, 7mm-mRad

Equivalent to 28W from 200um stripe

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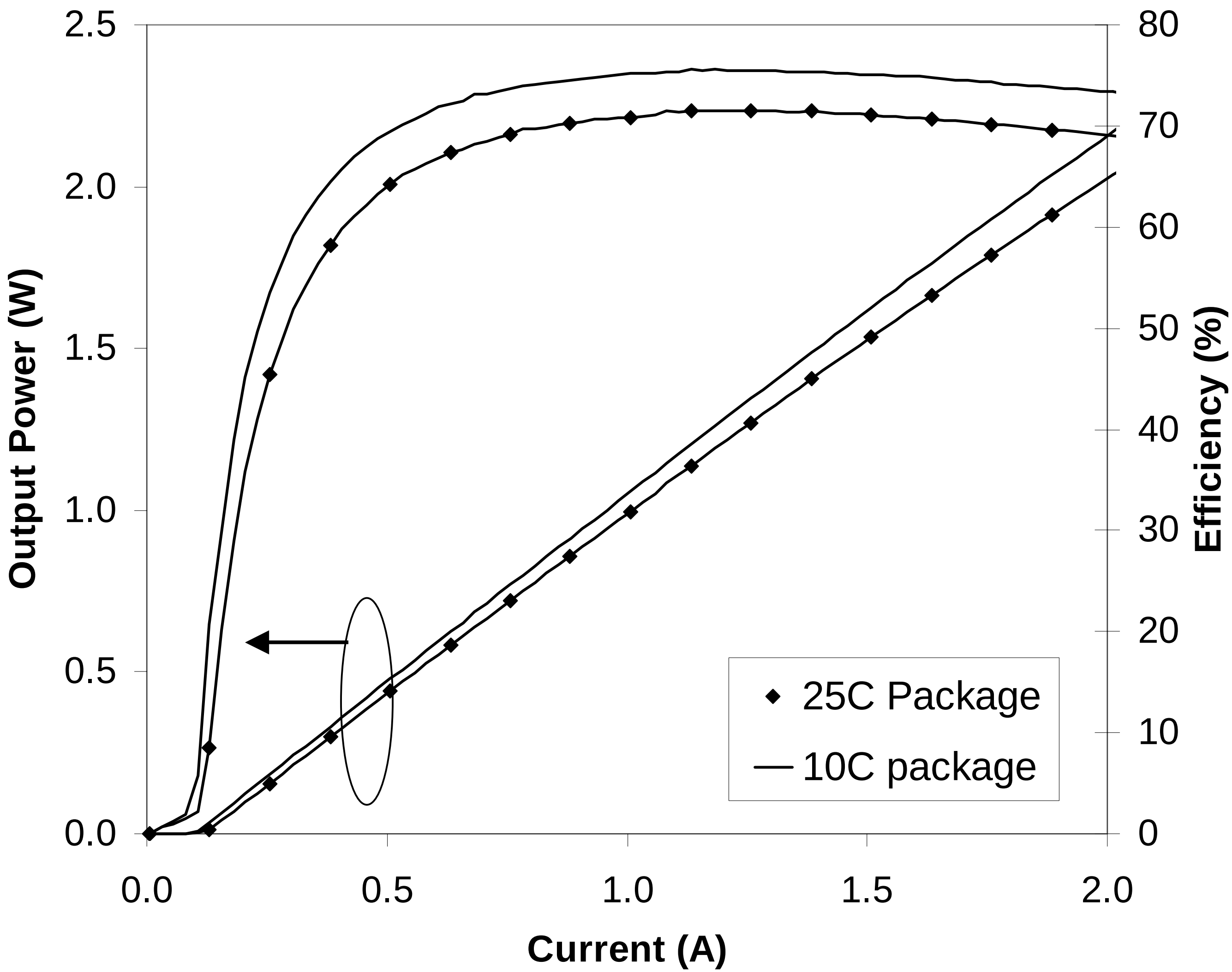
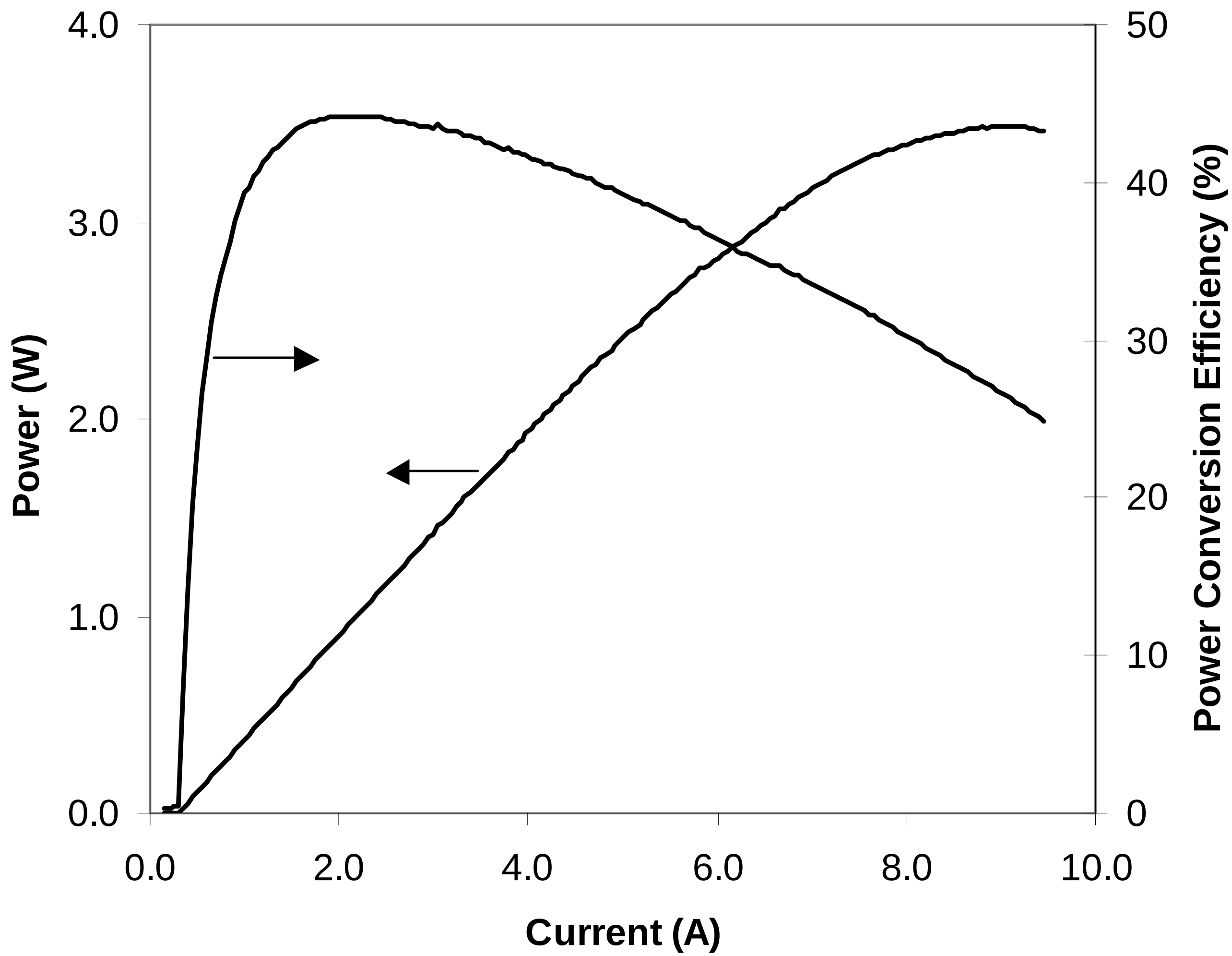
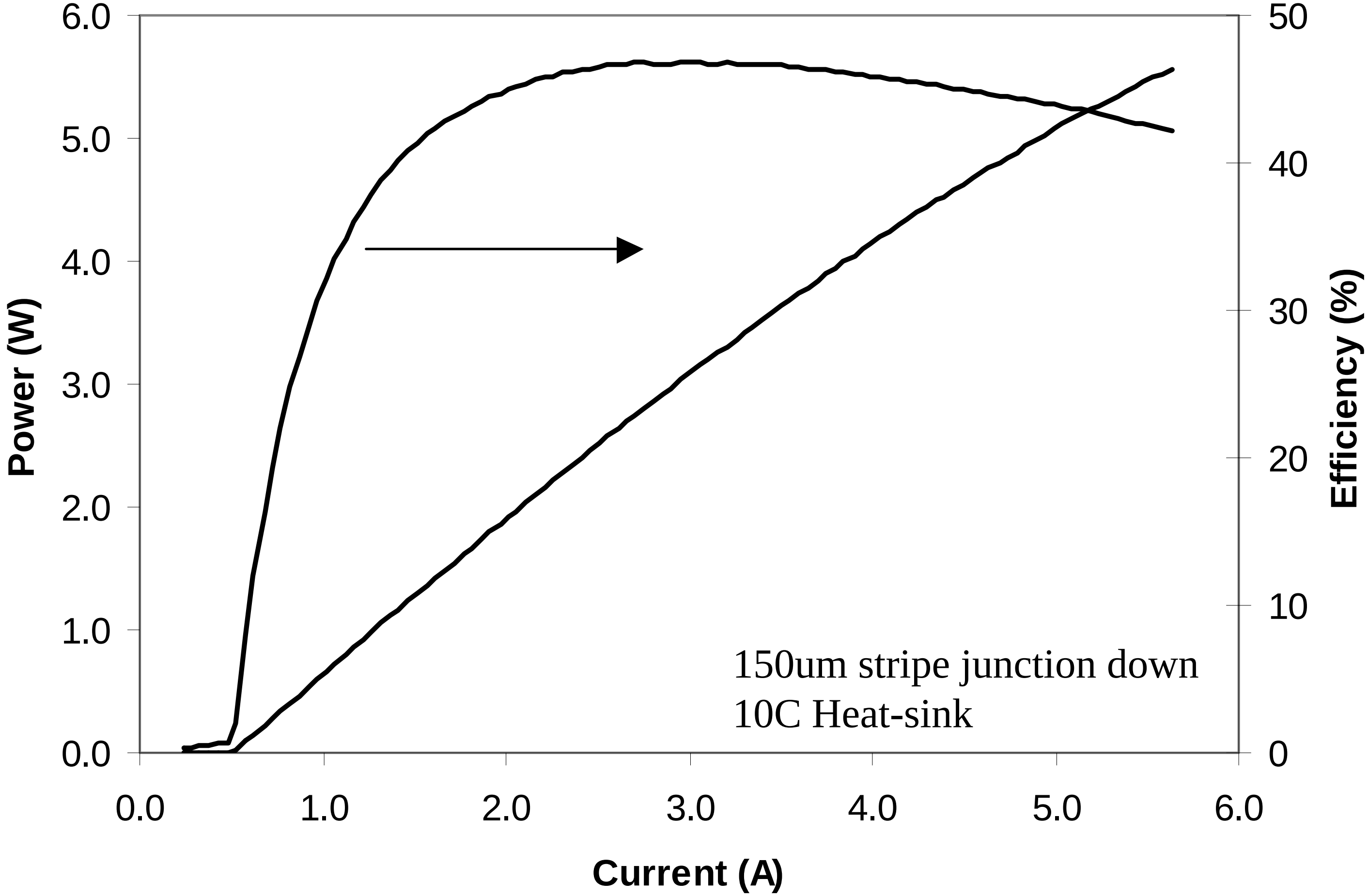
975-nm Diodes Achieve 76% Power Conversion



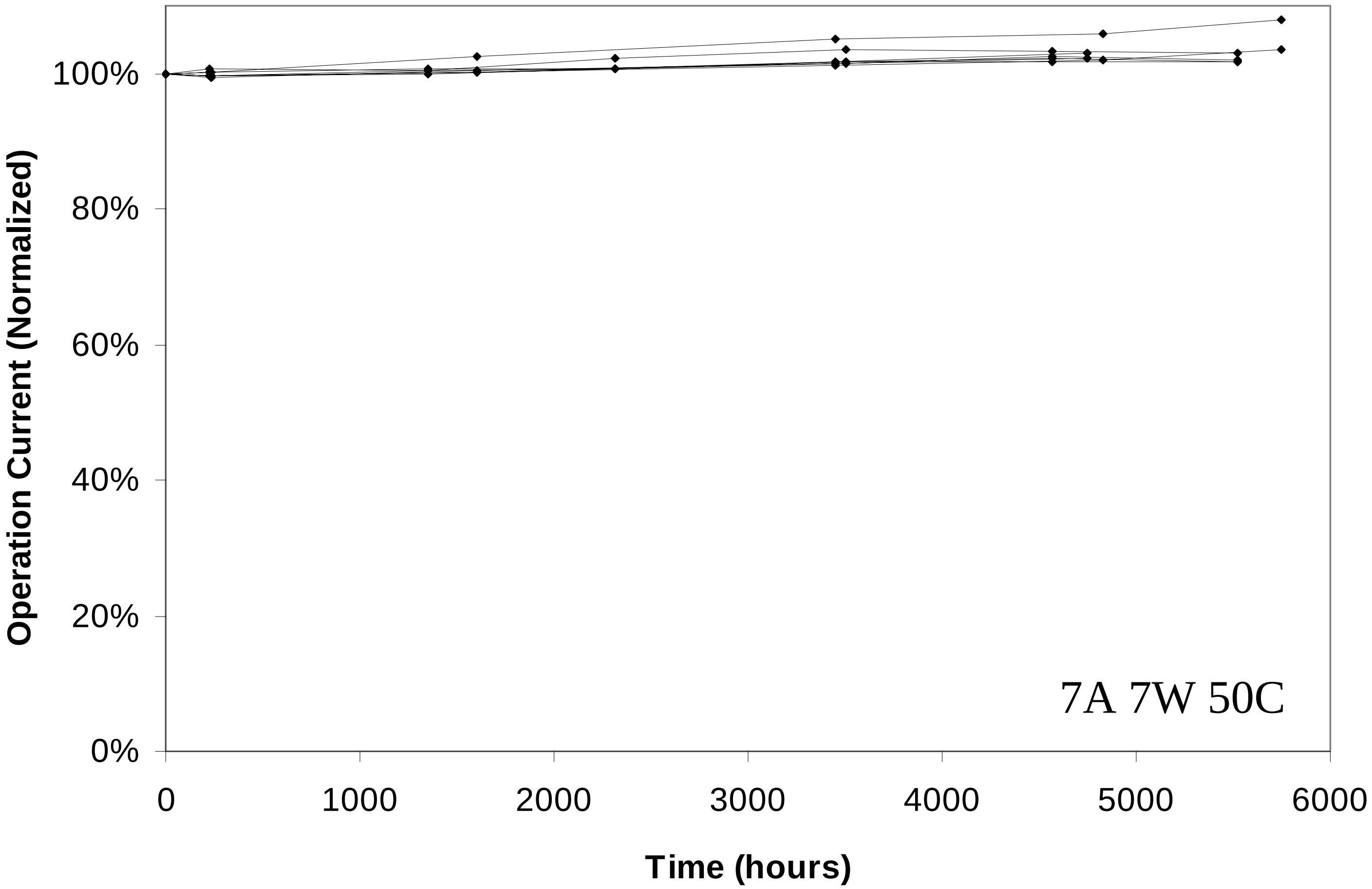
1470-nm Diodes Achieve 45% Efficiency and 3.5W Peak Power



660-nm 47% Efficiency at 3W Output



808-nm Diodes Project No Failures in > 30 Years



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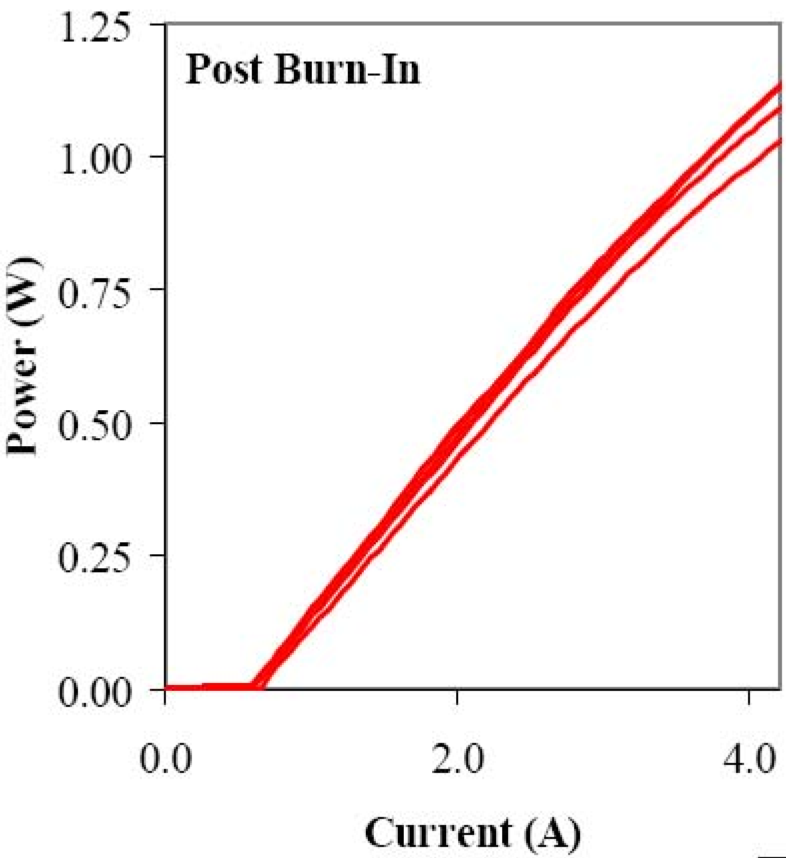
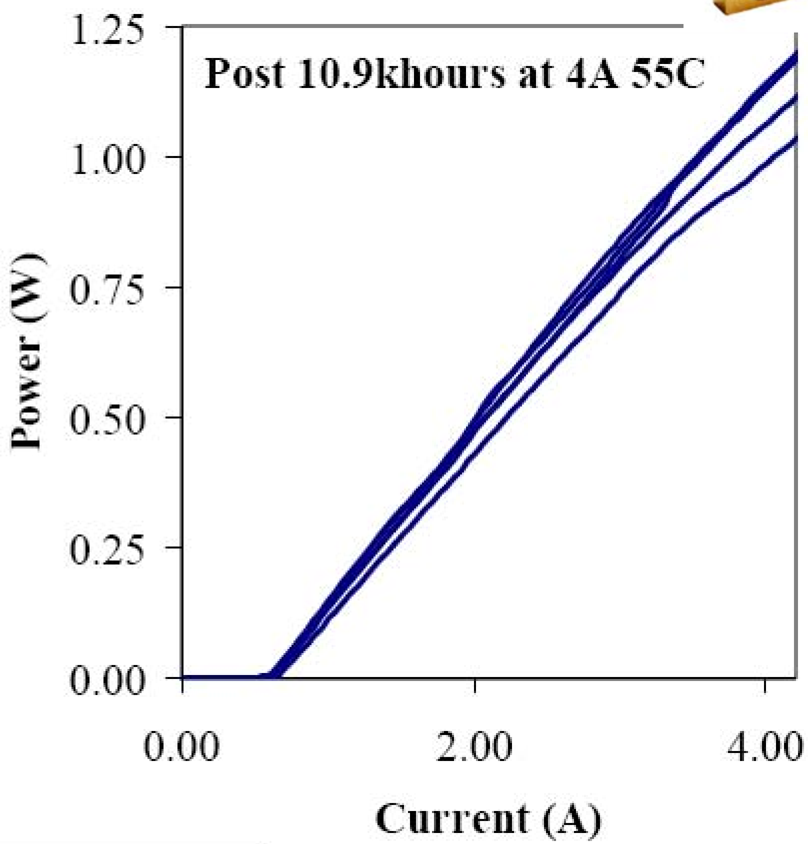
1470nm Diodes Show no Measurable Degradation





Part #	Power (4A) Post burn-in	Power (4A) Post 10.9khours	Change in power
ACKN	1.08	1.14	106%
ACKL	1.09	1.13	104%
ACKY	1.06	1.05	99%
ACKX	0.99	0.99	100%
ACKM	1.13	1.08	96%

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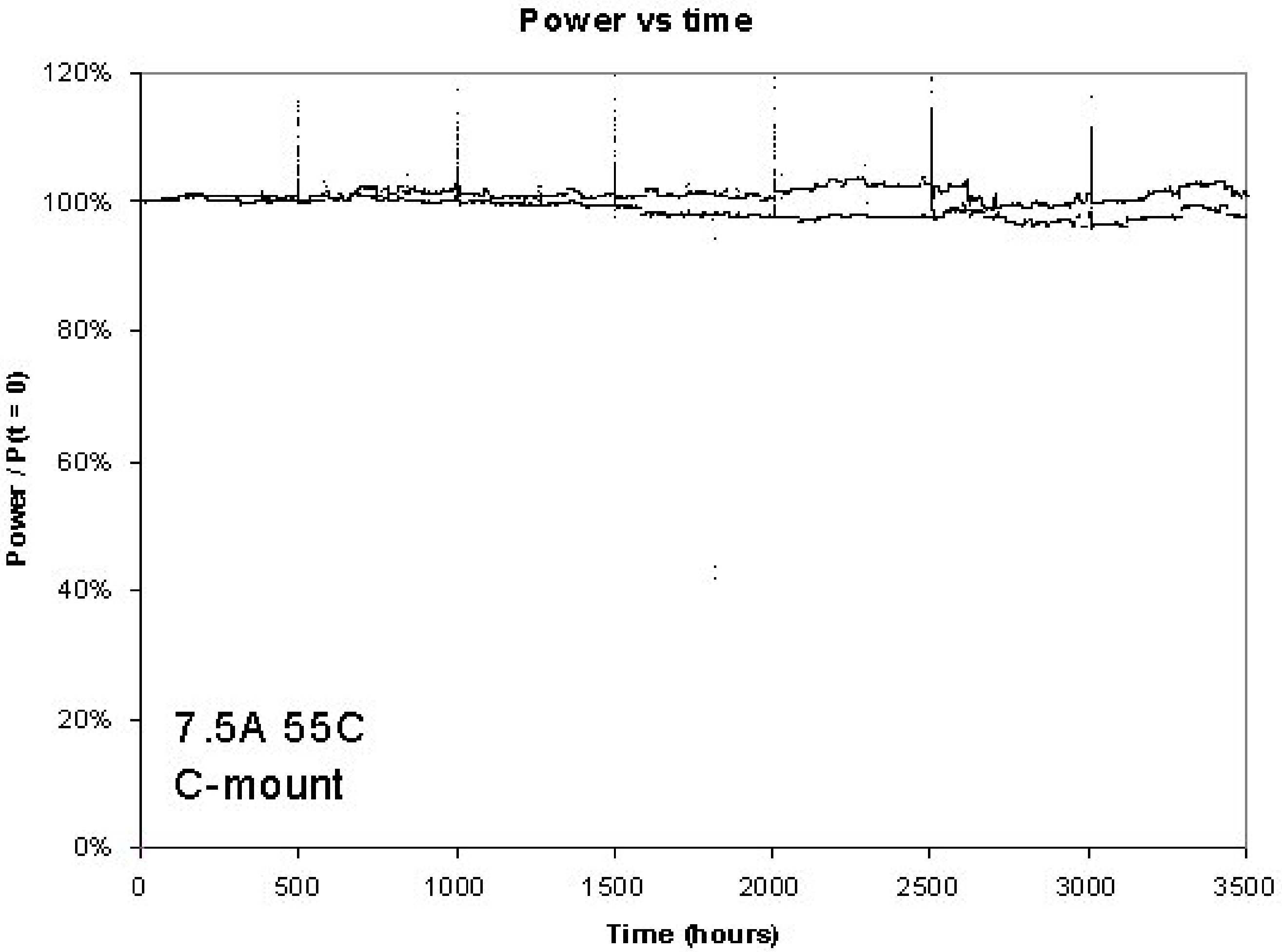
980-nm Diodes Show No Measurable Degradation



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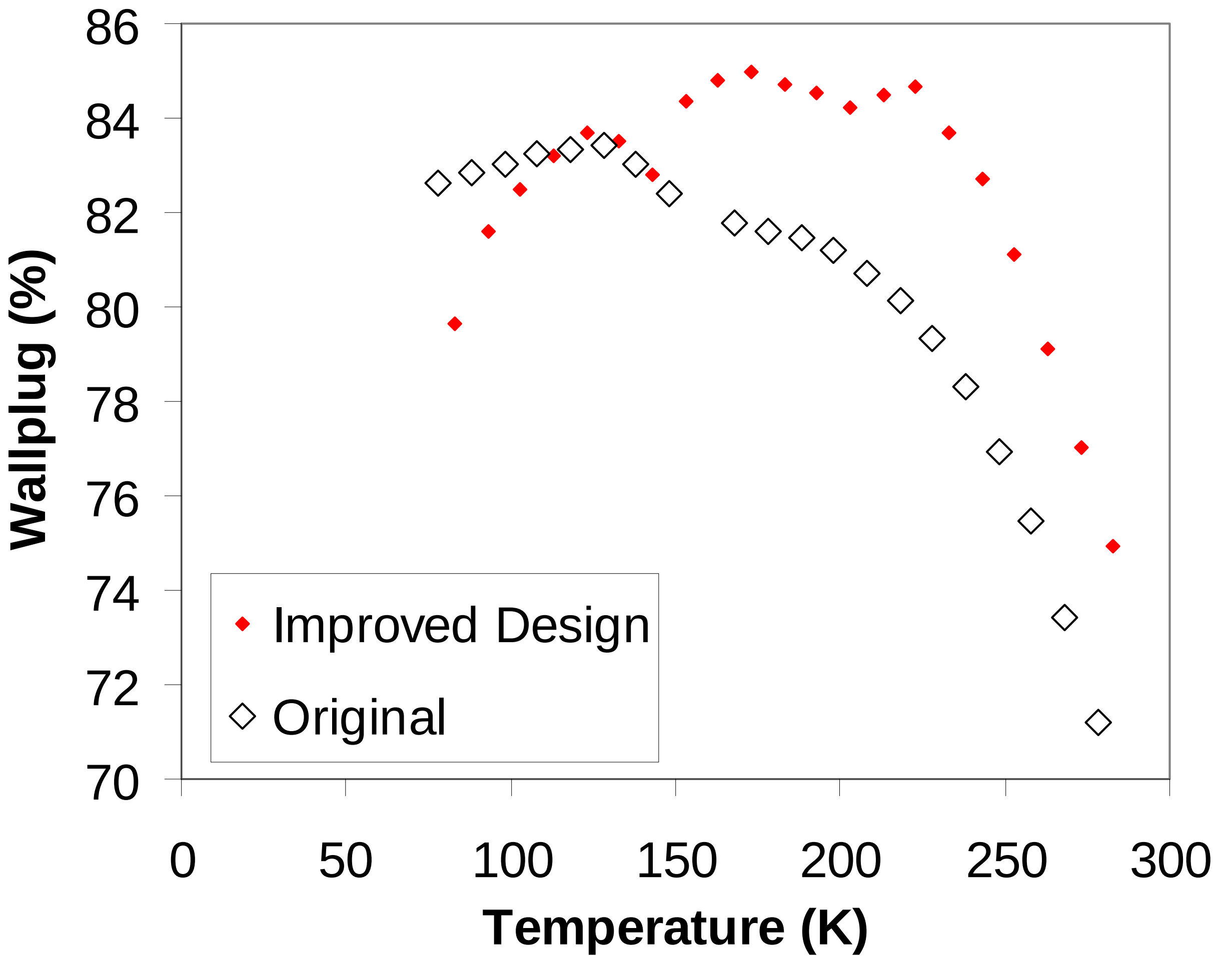
85% Power Conversion at –50C at 980-nm



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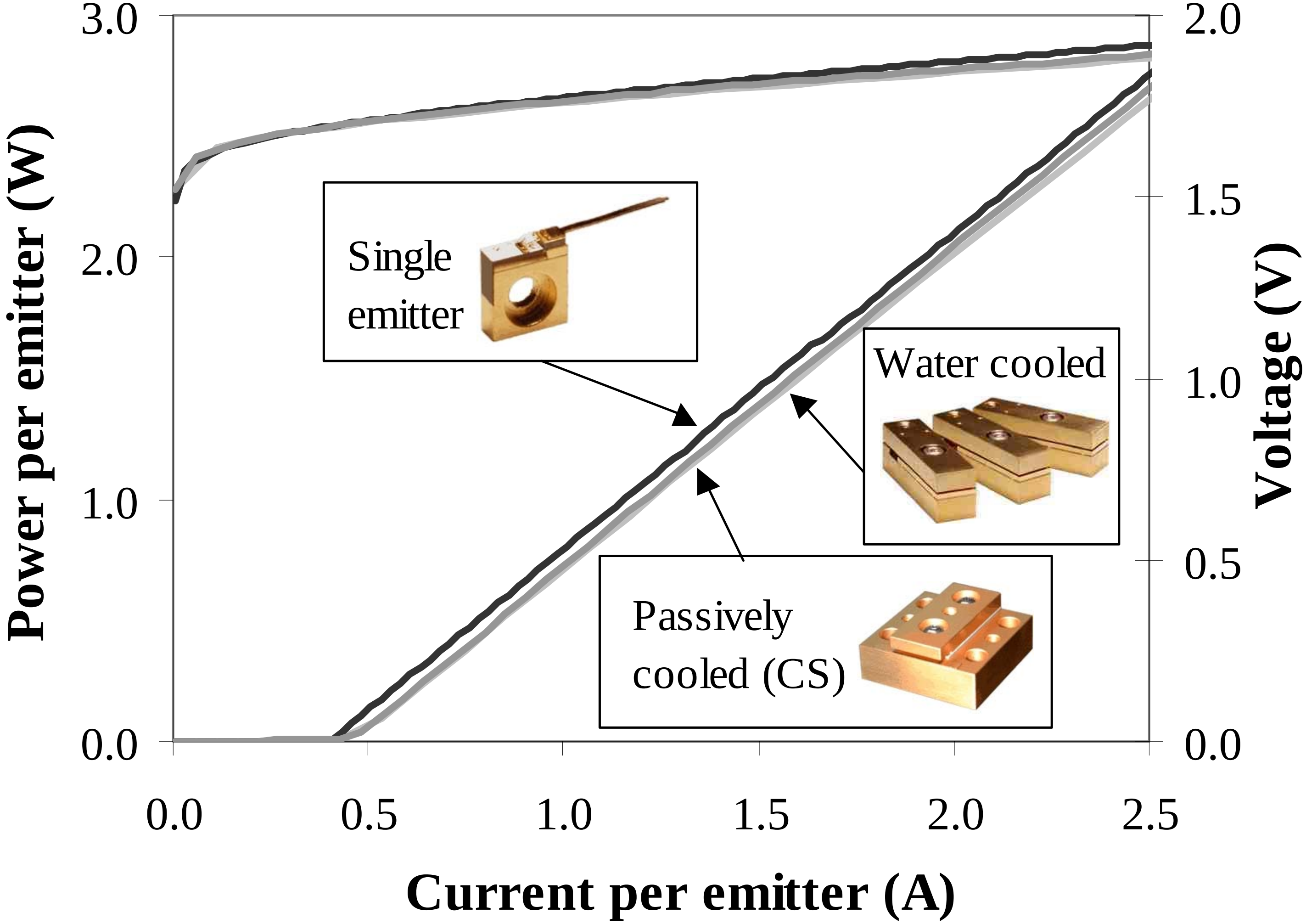
No Drop In Performance from Single Emitters to Bars



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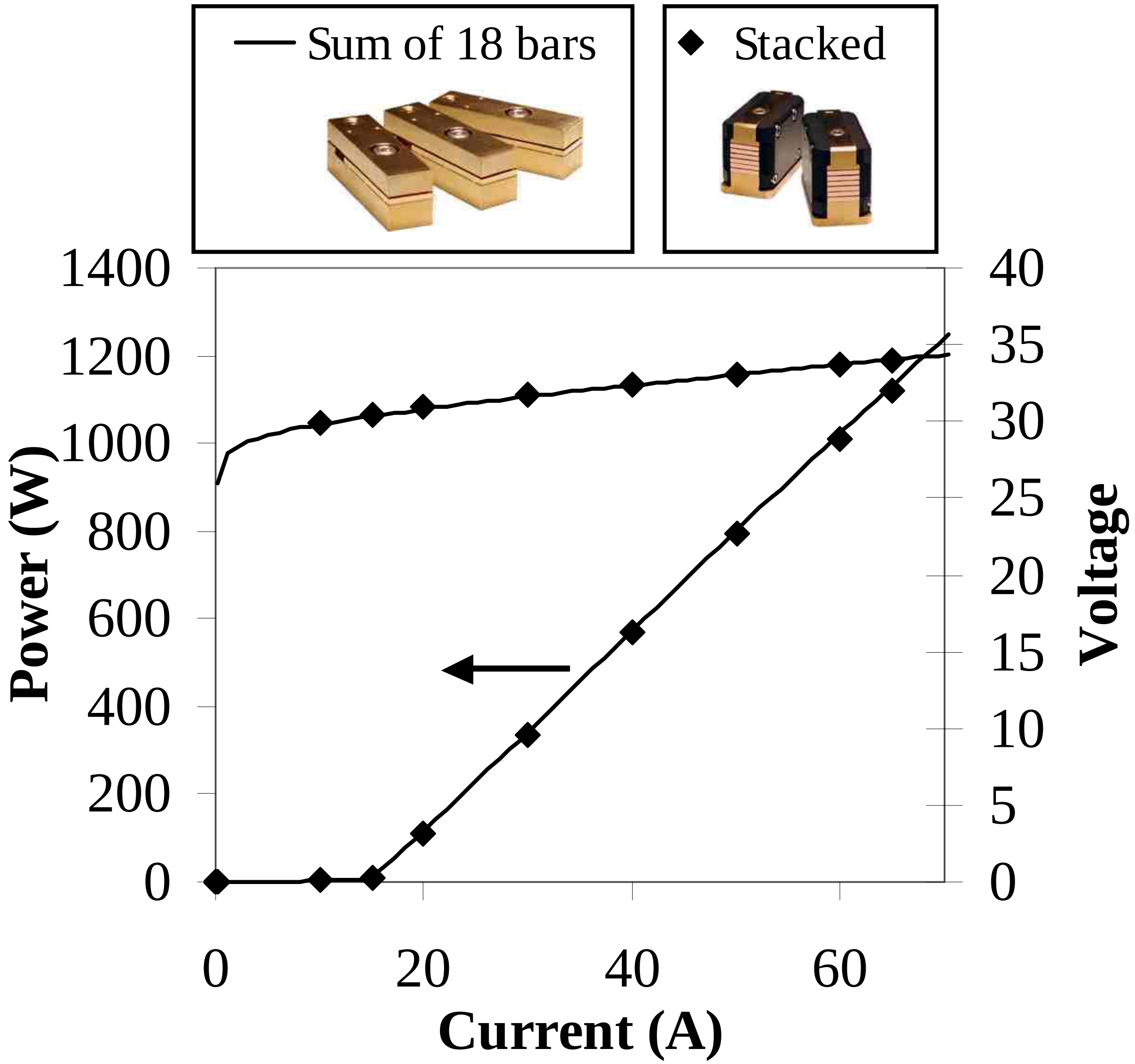
No Drop In Performance from Bars to Stacked Array



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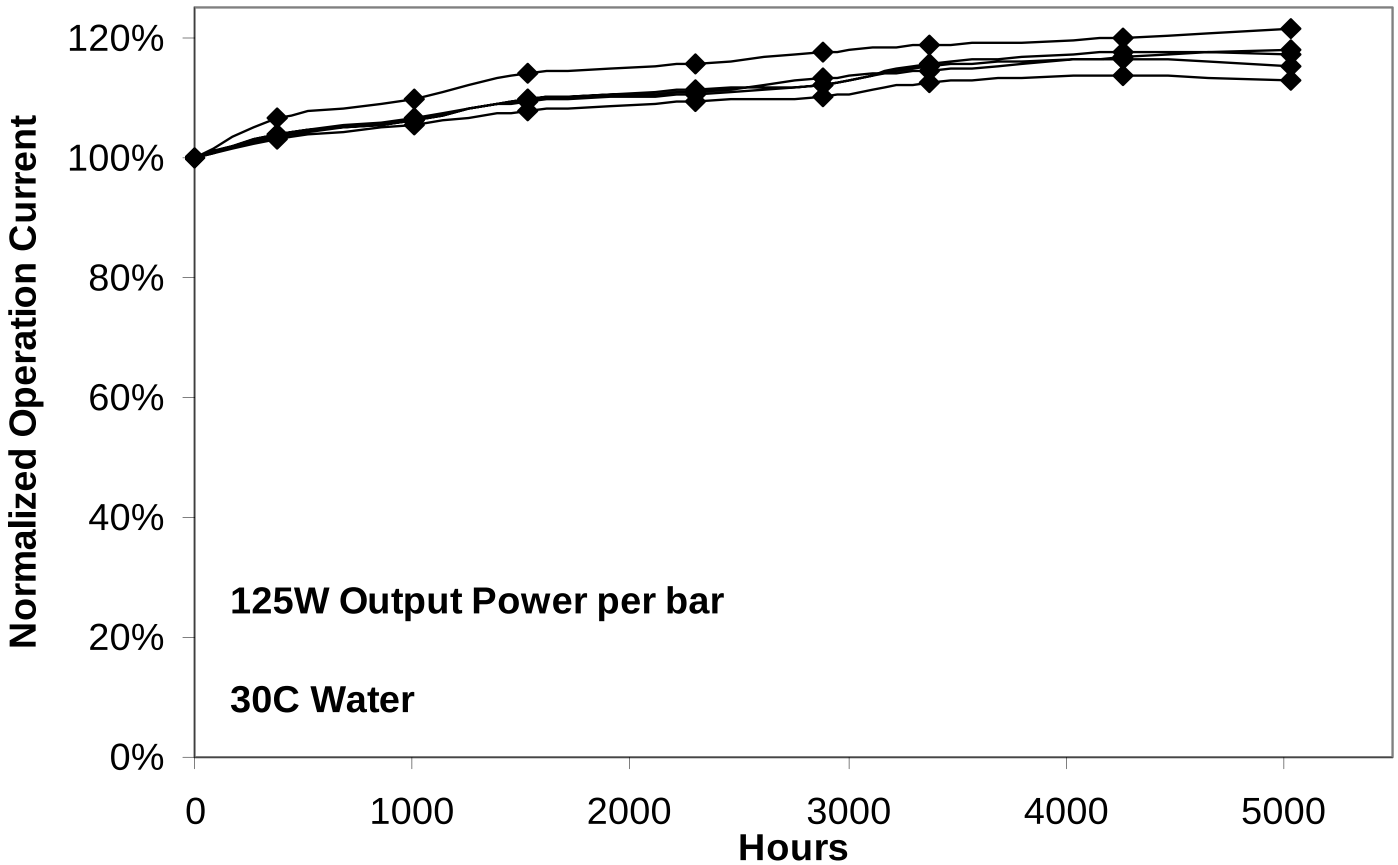
125W Bars Show Highly Reliability



Overall SHEDs Program Goals

Attribute	Oct 2003 Program Start	36 Mo.
Bar Power Conversion Efficiency	45%	--
Bar Power Output	80 W	
Spectral Width	5 - 10 nm	3 ± 1.5 nm
Junction Temperature		50°C
Stack PCE	45%	80%
Stack Power	480 W	480 W

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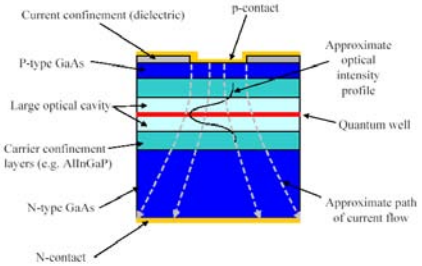
Overall Design Approach



- **Break down all contributors to laser efficiency**
  - Characterize, model, optimize
- **Optimize materials and interfaces by experiment**
  - Contact / interface resistance
  - Bulk mobility
  - Low temperature photoluminescence
- **Systematic approach**
  - Rigorous physics-based modeling
  - Detailed root cause materials analysis
- **Use high performance facet passivation**
  - Open up design space

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Improvement Approach Taken

Parameter	Approach
Threshold	Optimize Strain in quantum well
Slope	Minimize overlap of light with lossy regions
Voltage	Optimize hetero-junctions

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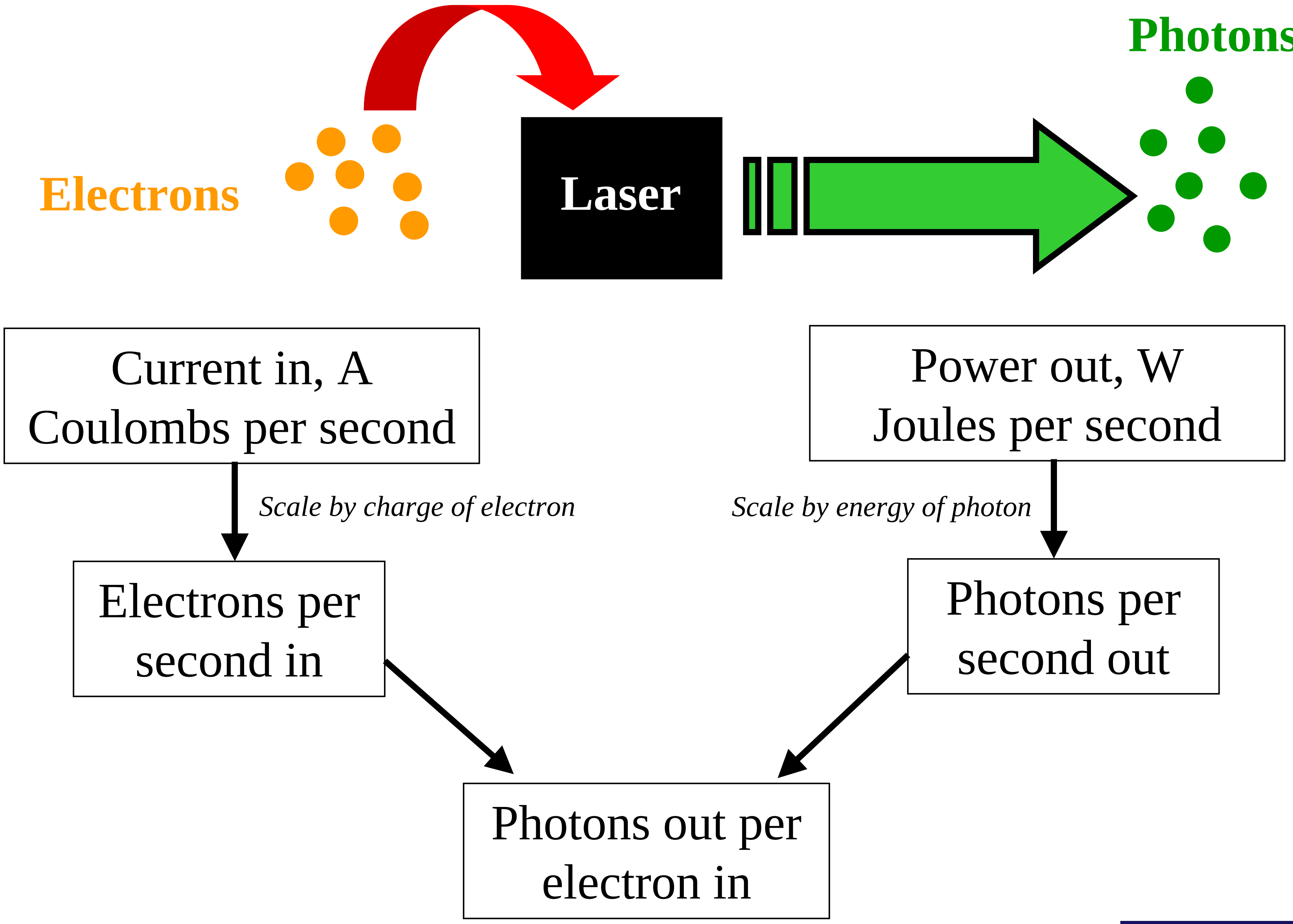
Key Term 1: Photons per Electron (DQE)



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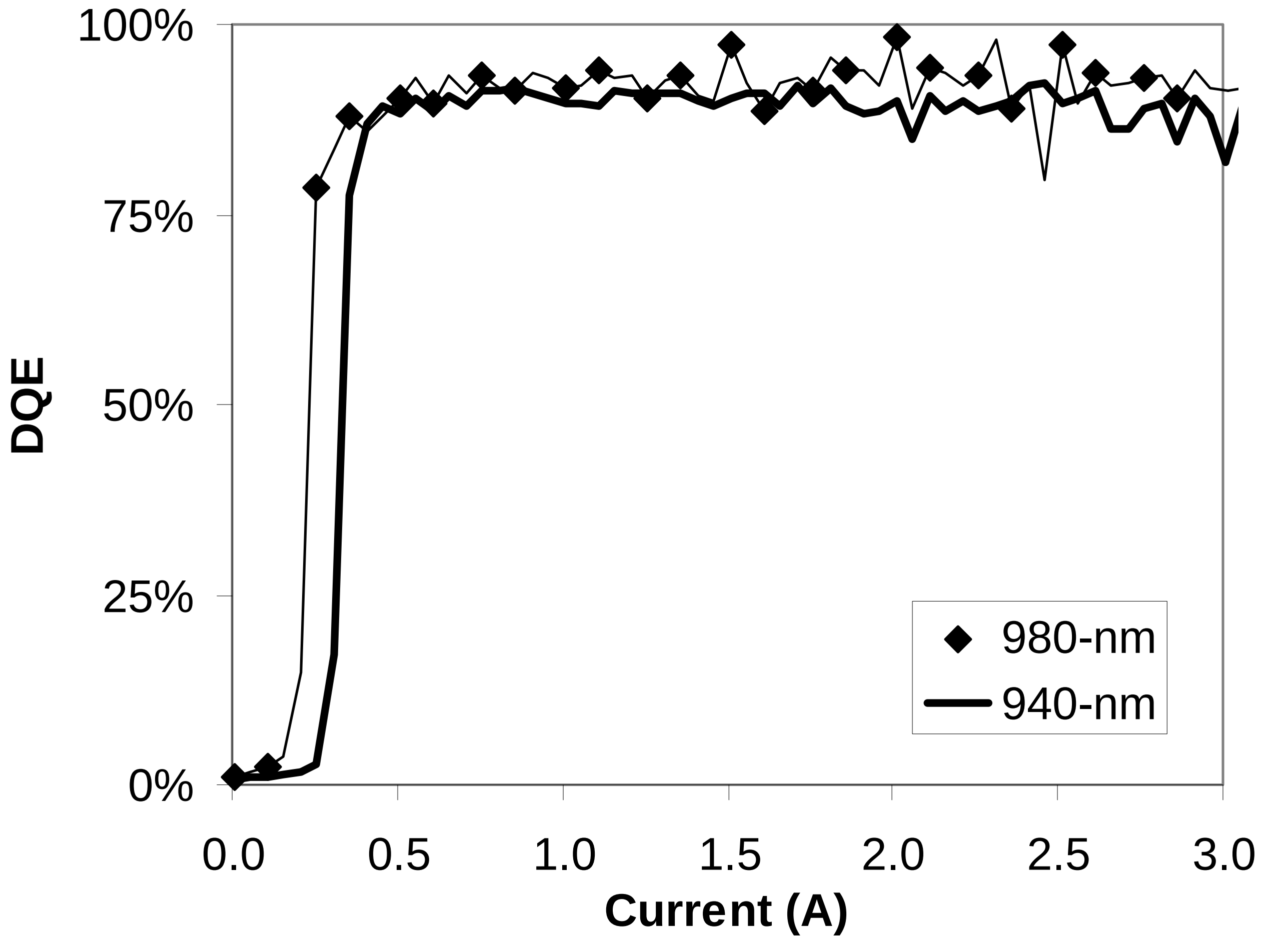
DQE ~ 90% Across Wavelength



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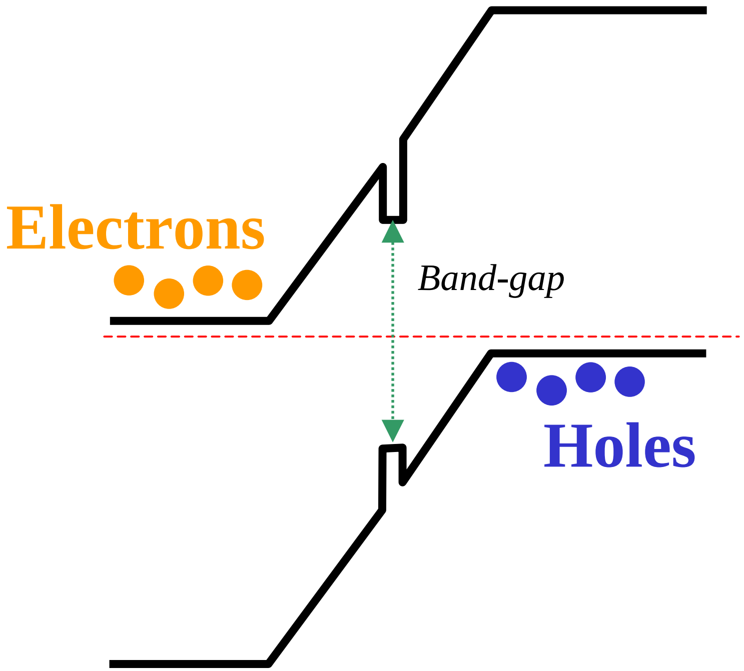
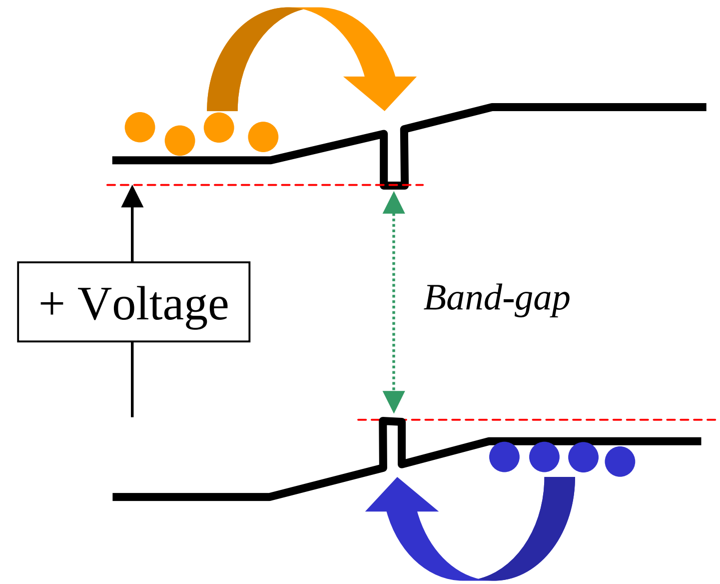
No voltage

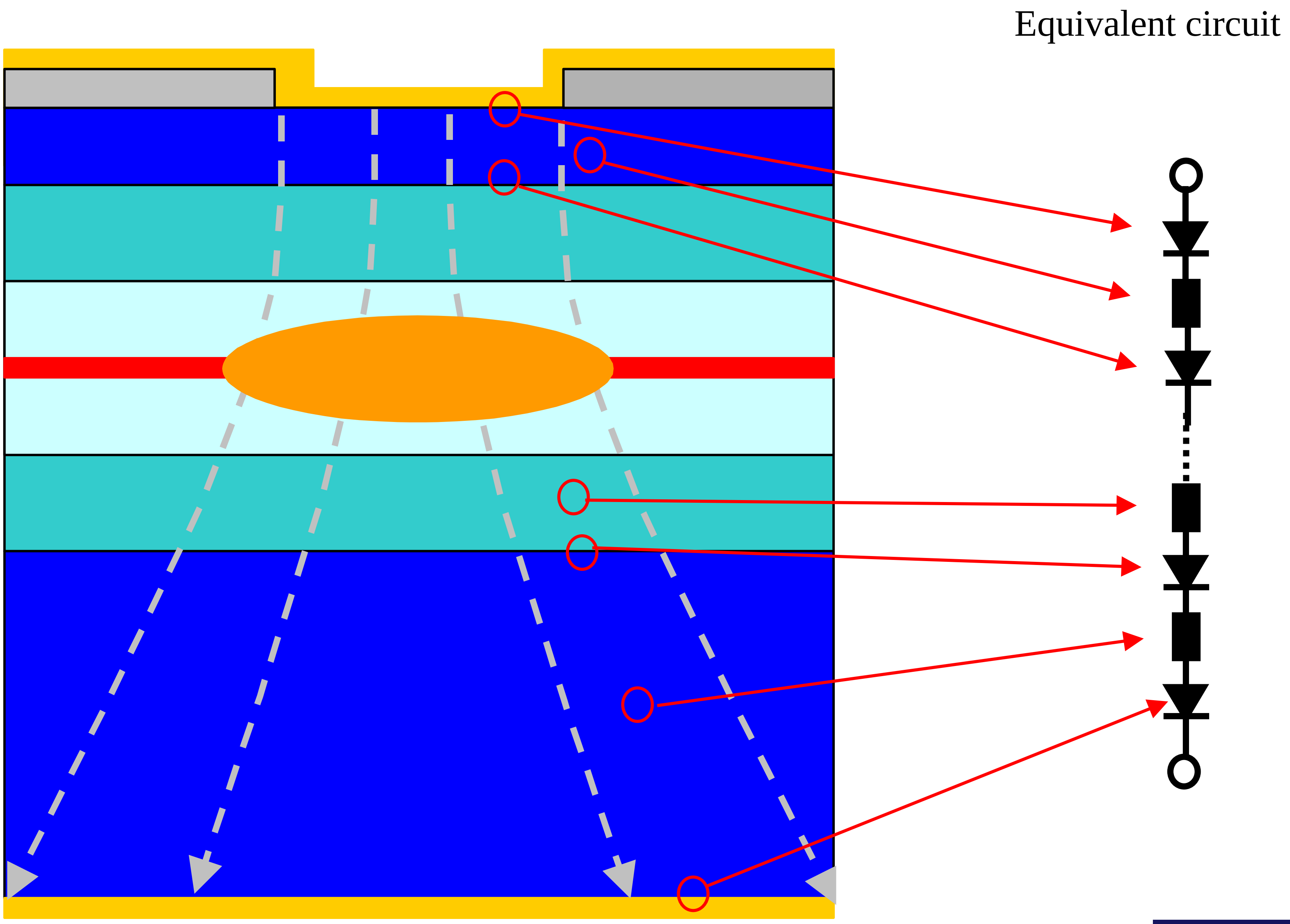


Minimum voltage for lasing

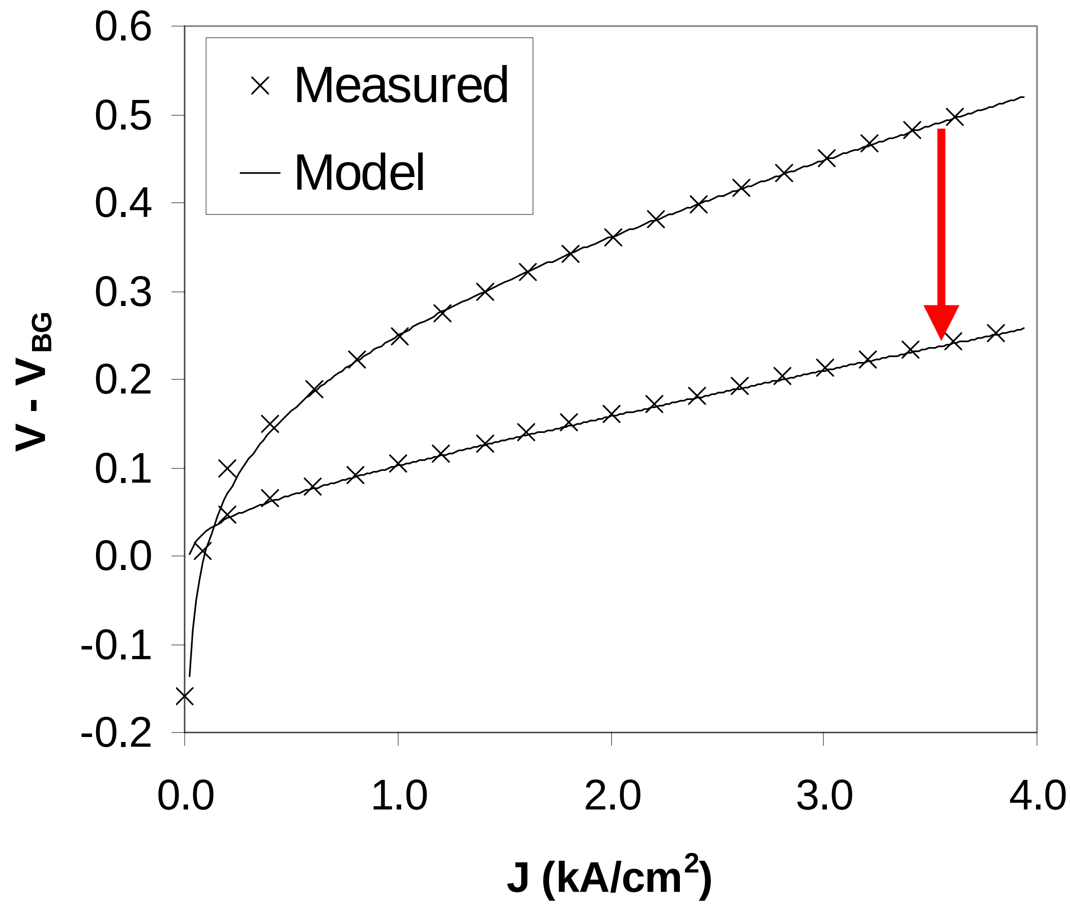


Minimum voltage is band-gap of quantum well
Any more is called the "voltage defect"

Every Laser Interface and Bulk Layer Adds Voltage



Voltage Improved by Eliminating Junction Voltages

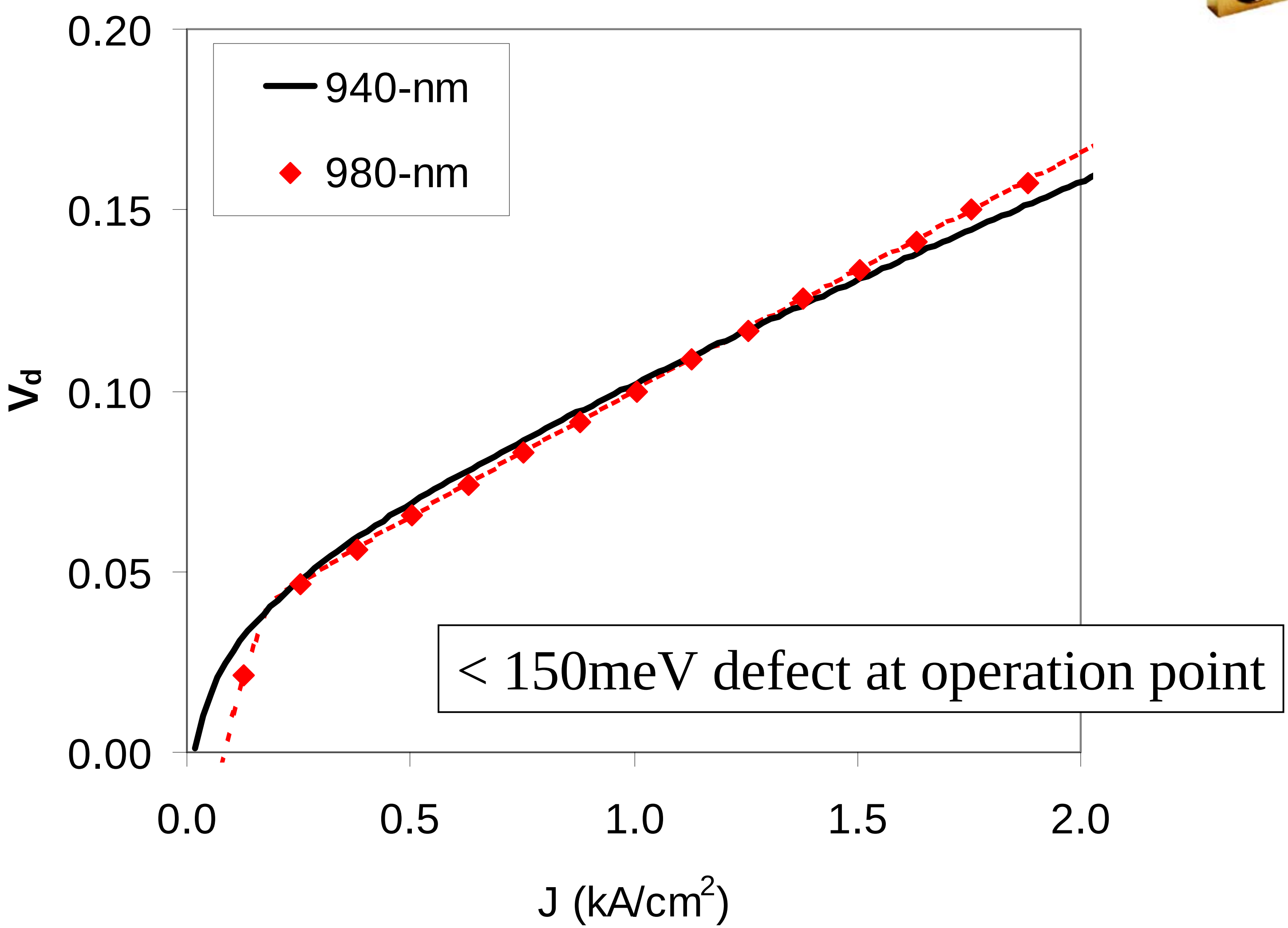


$$V = V_{BG} + \sum_i \sigma_i J + \sum_j V_j \ln\left(\frac{J}{J_j}\right)$$

Resistive Term

Diode Term

Wavelength Independent



3 key Terms Limit Power Conversion Efficiency

$$PCE = \frac{E_{ph} \times \eta_{ext}^{(d)} (I - I_{th})}{I \times (\mathrm{V}_{BG} + \mathrm{V}_{D})}$$

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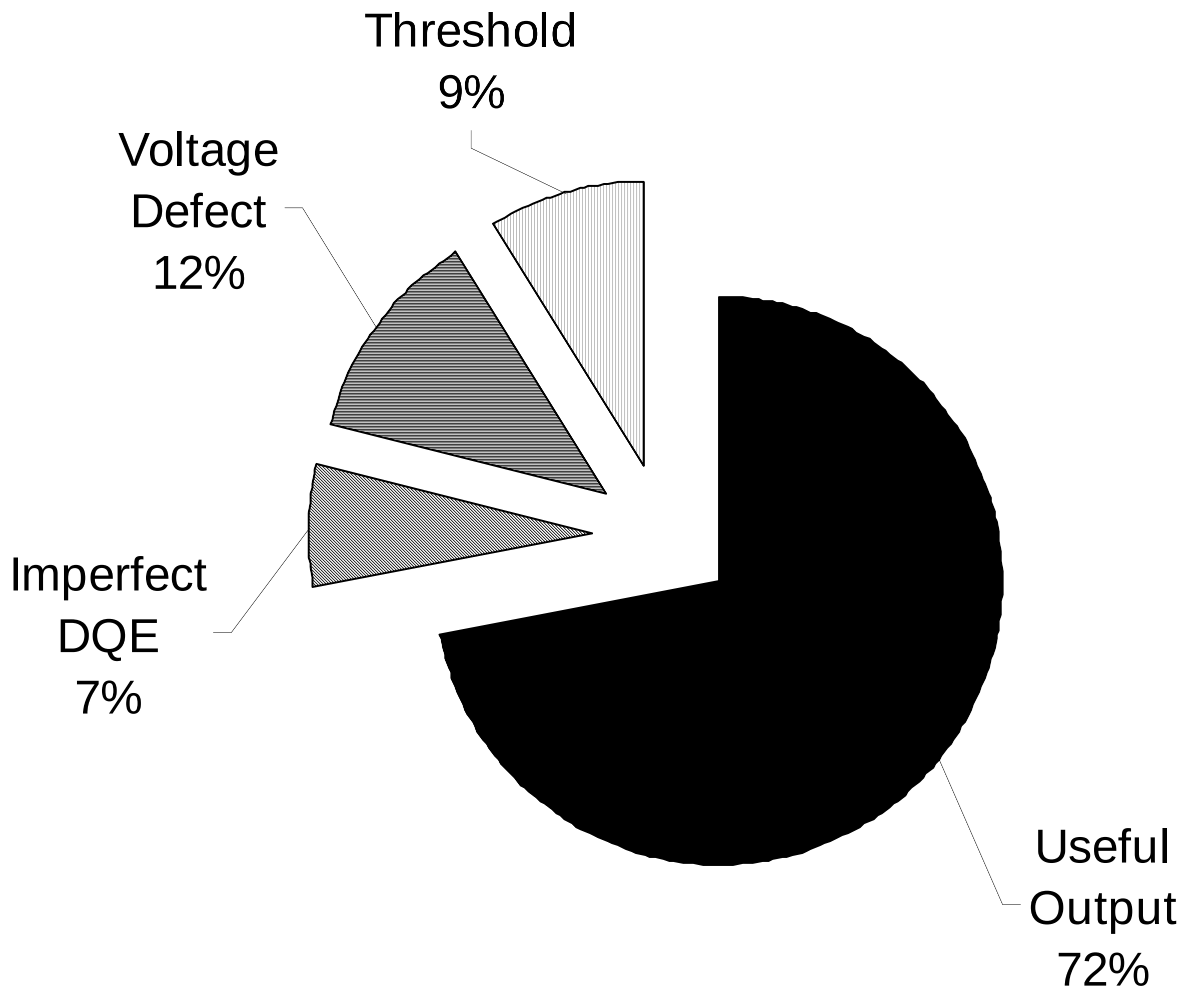
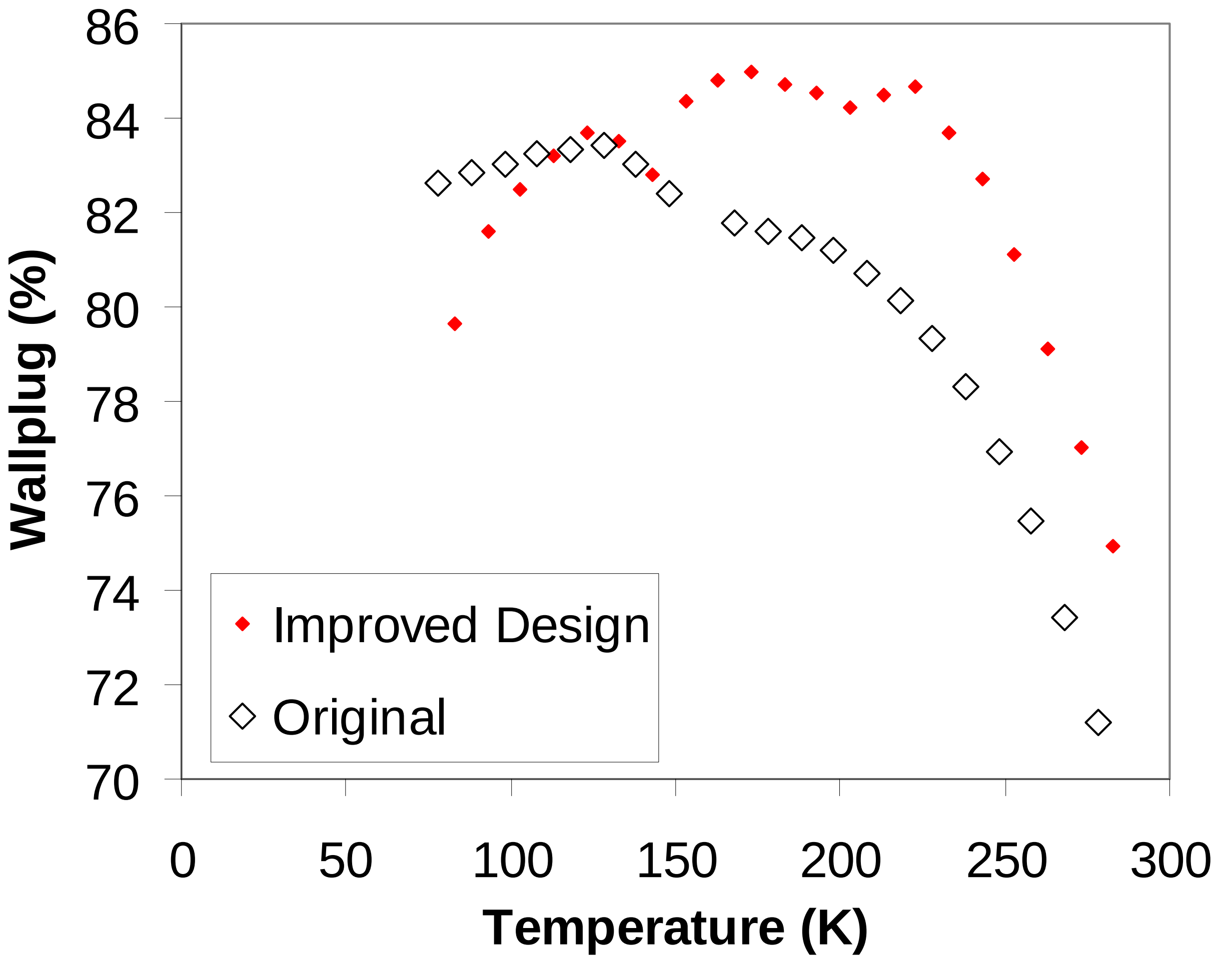
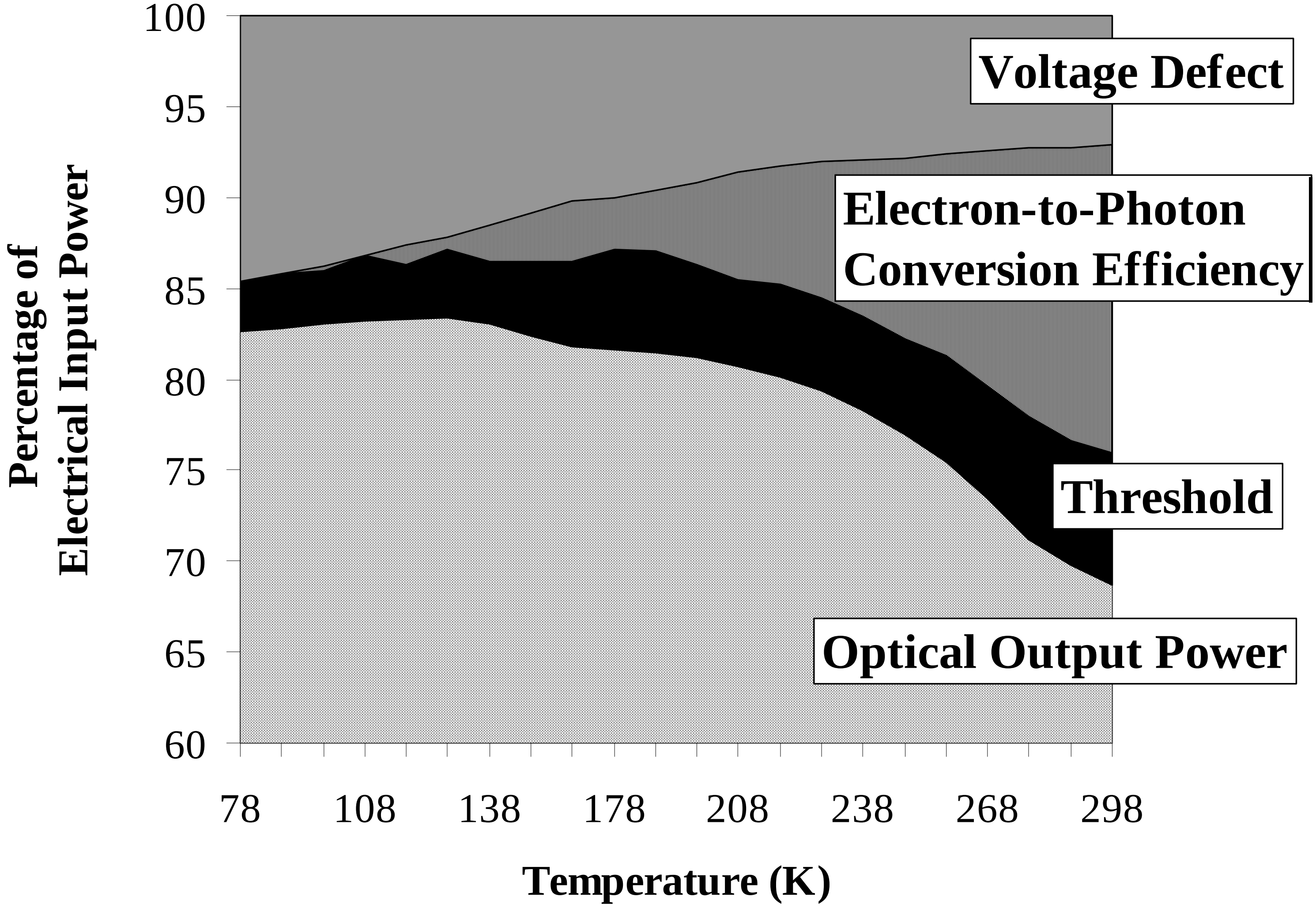
Overall Efficiency Break-Down



85% Power Conversion at –50C at 980-nm



Insights from Cryogenic Testing



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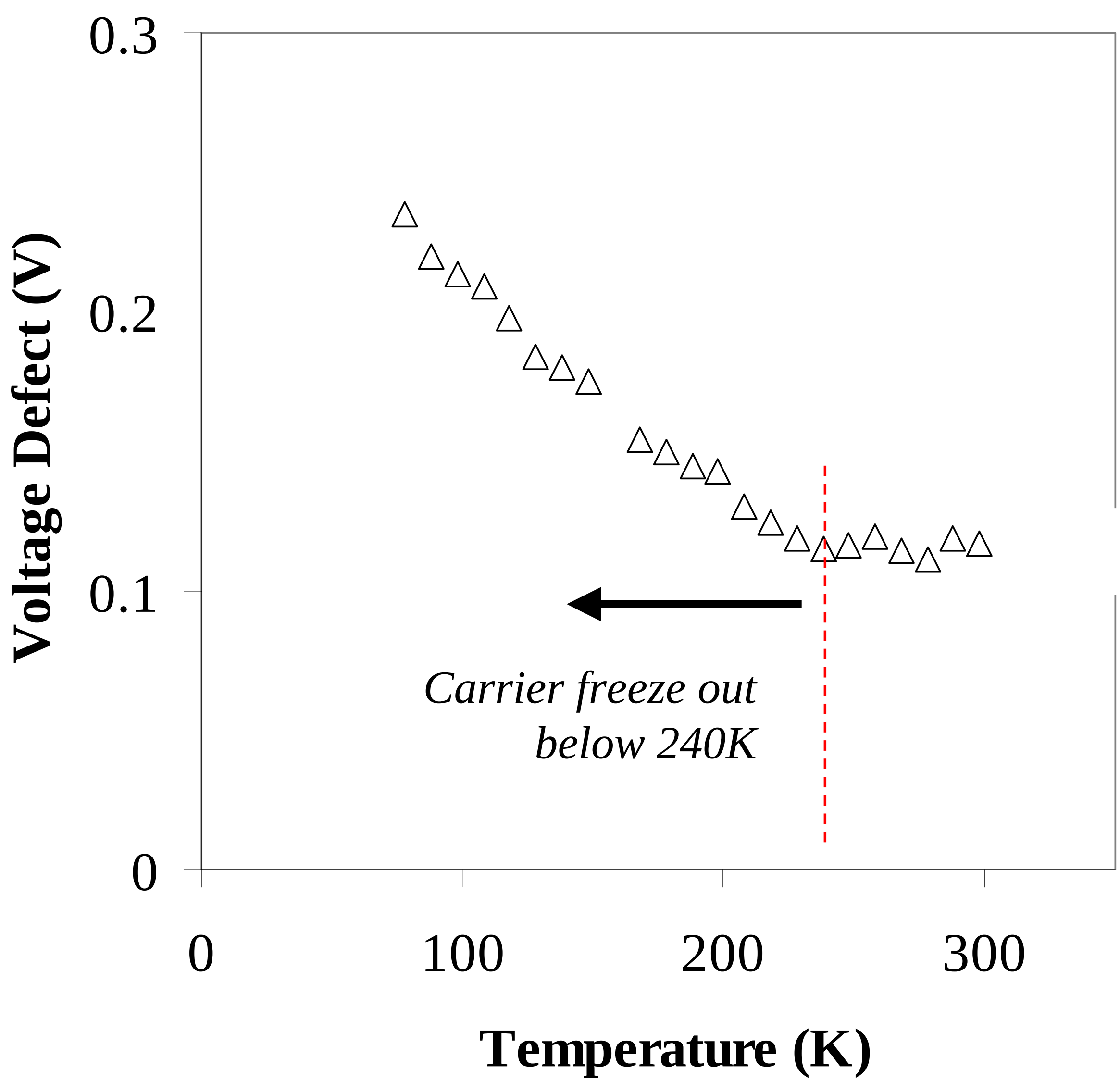
No Voltage Penalty Above 240K



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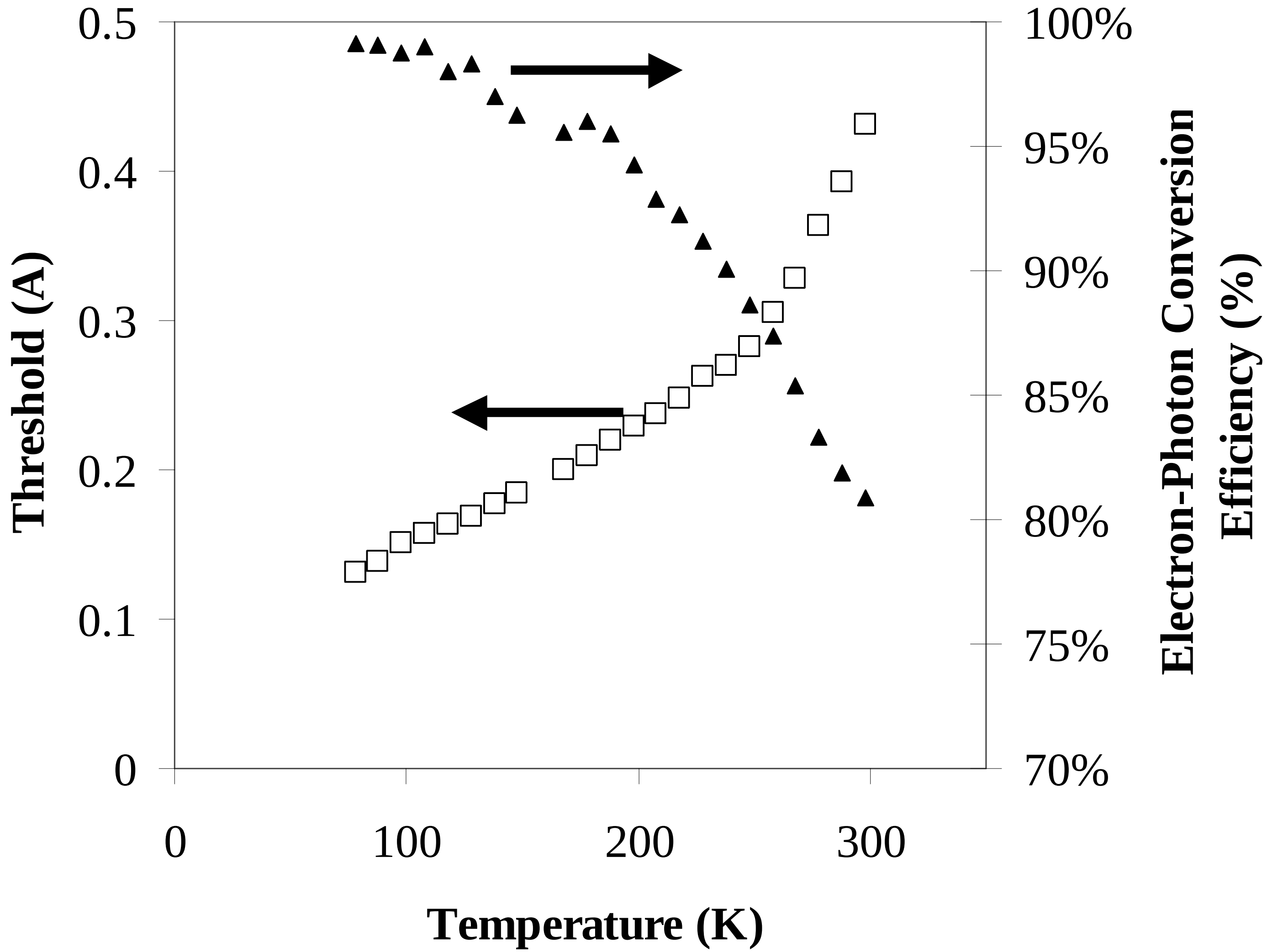
Slope Becomes “Perfect” at Low Temperatures



Clear link to threshold current seen

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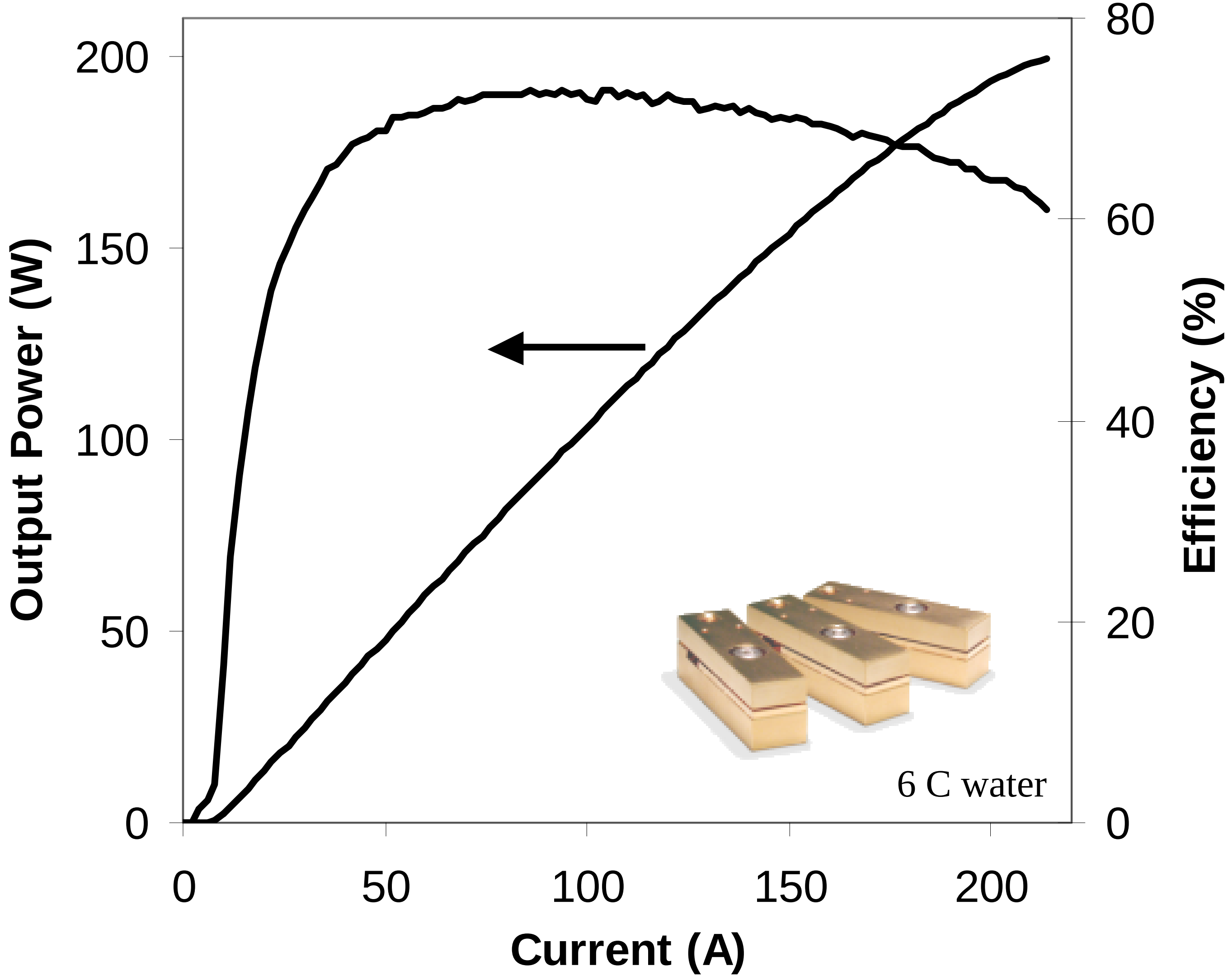
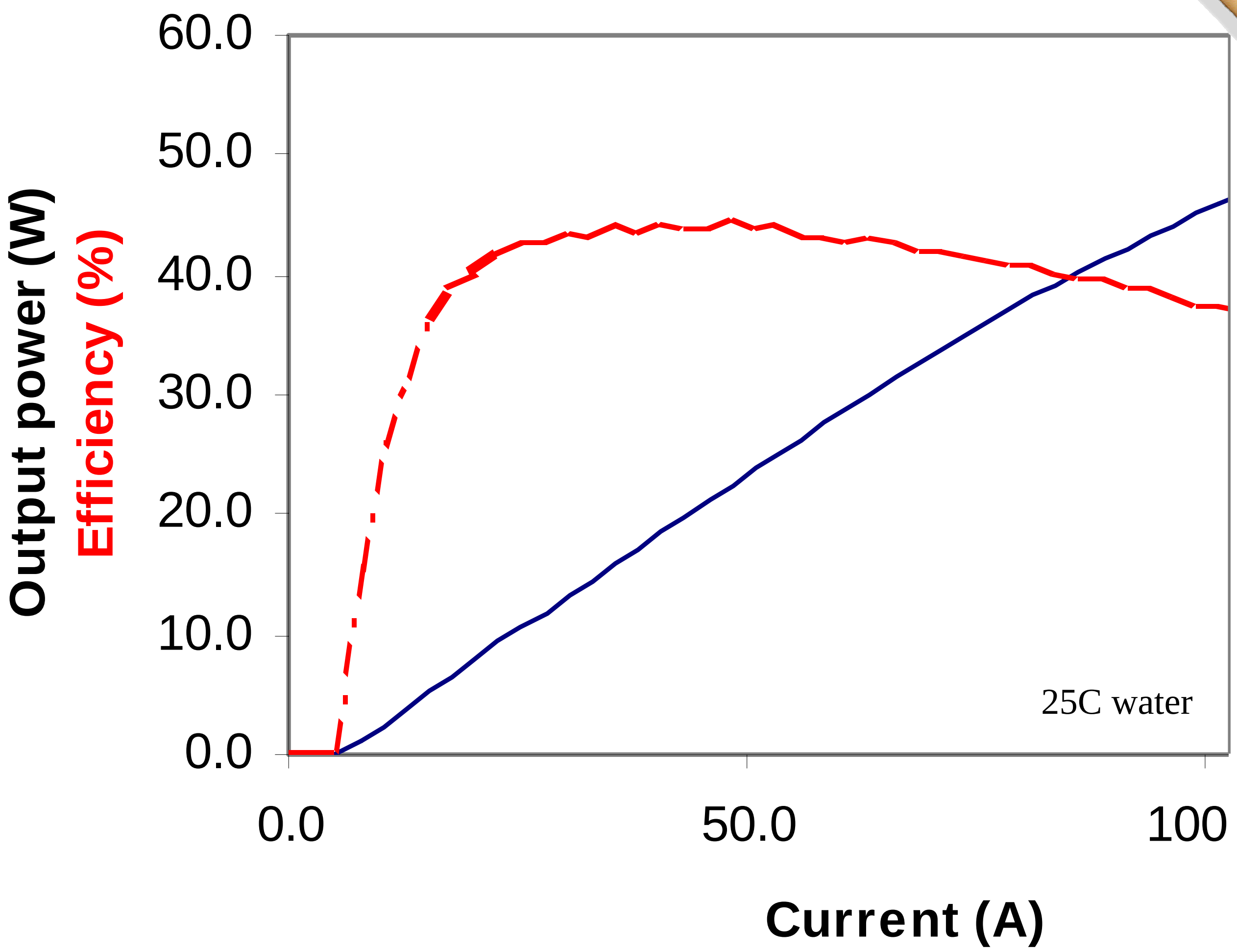
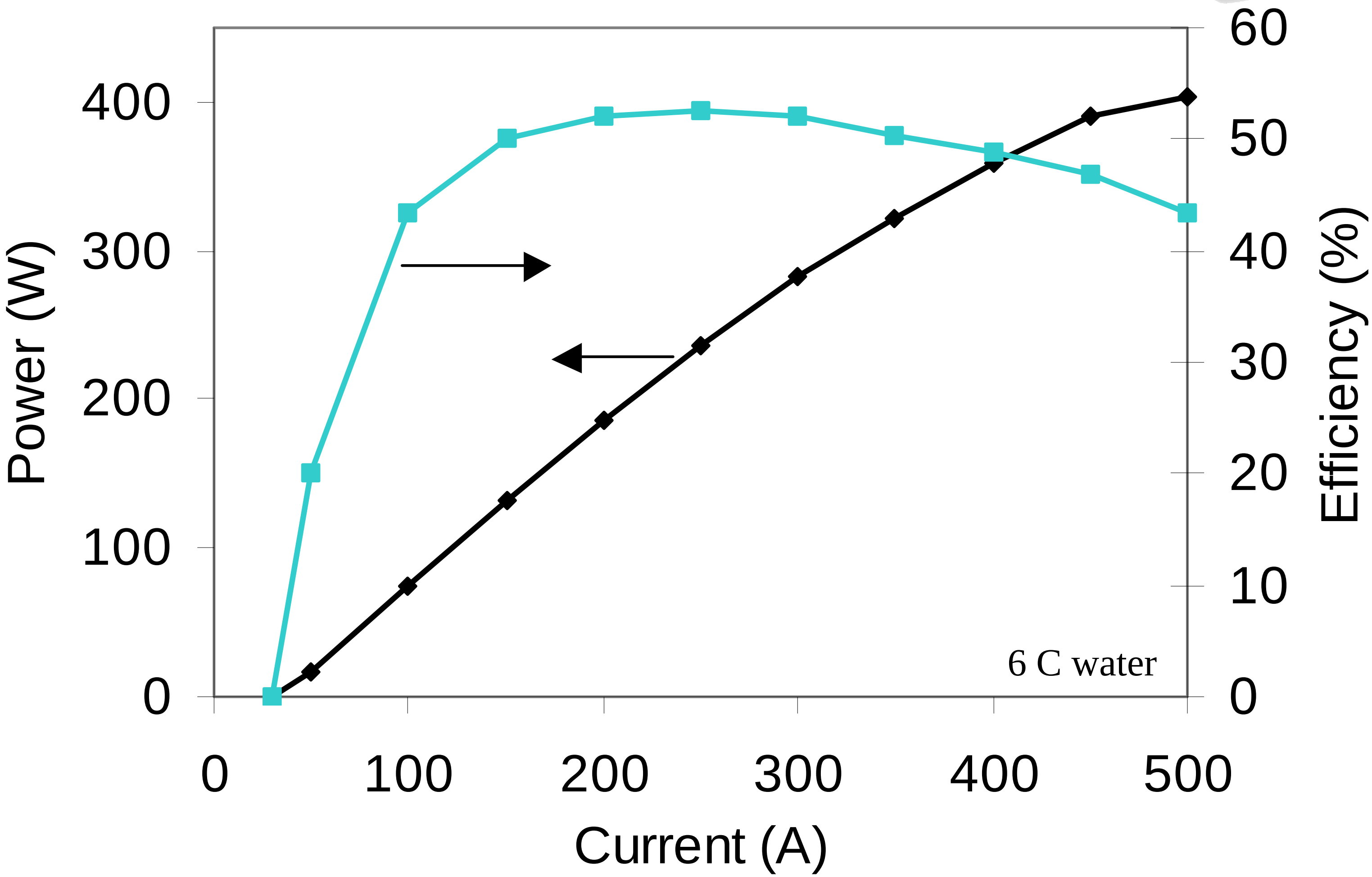
73% Efficiency at 100W at 980-nm



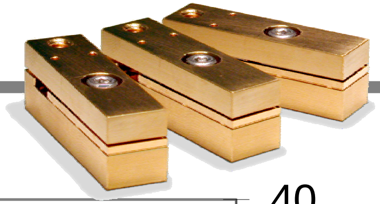
45% Efficiency at 22W at 1470-nm

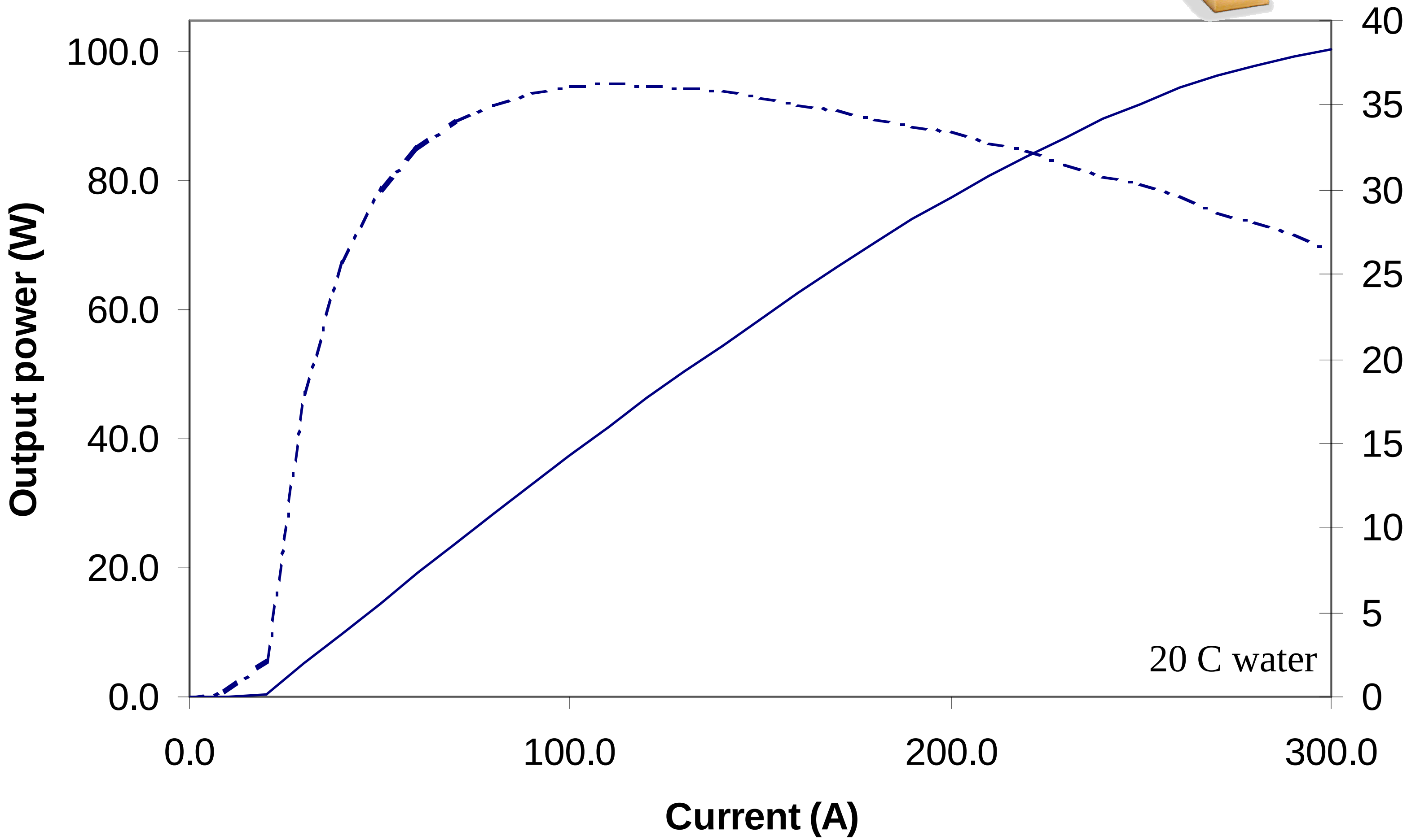


> 400W from Single 808-nm Diode Laser Bar



103W from single 1470-nm Diode Laser Bar





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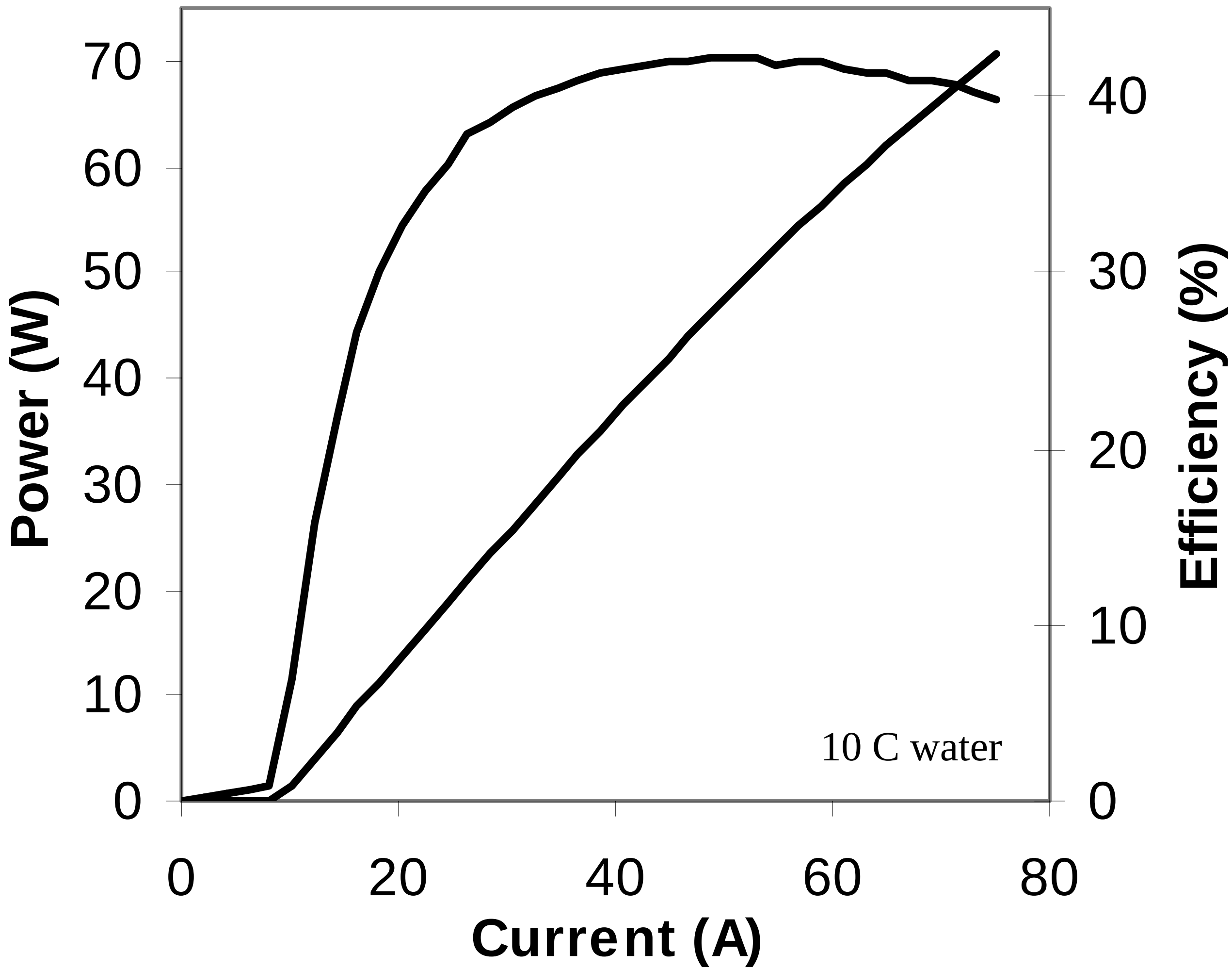
665 nm red laser diode bars produce > 70 Watts



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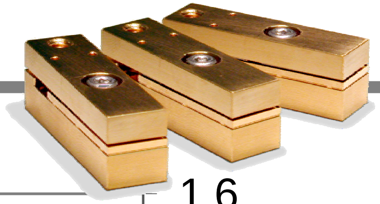
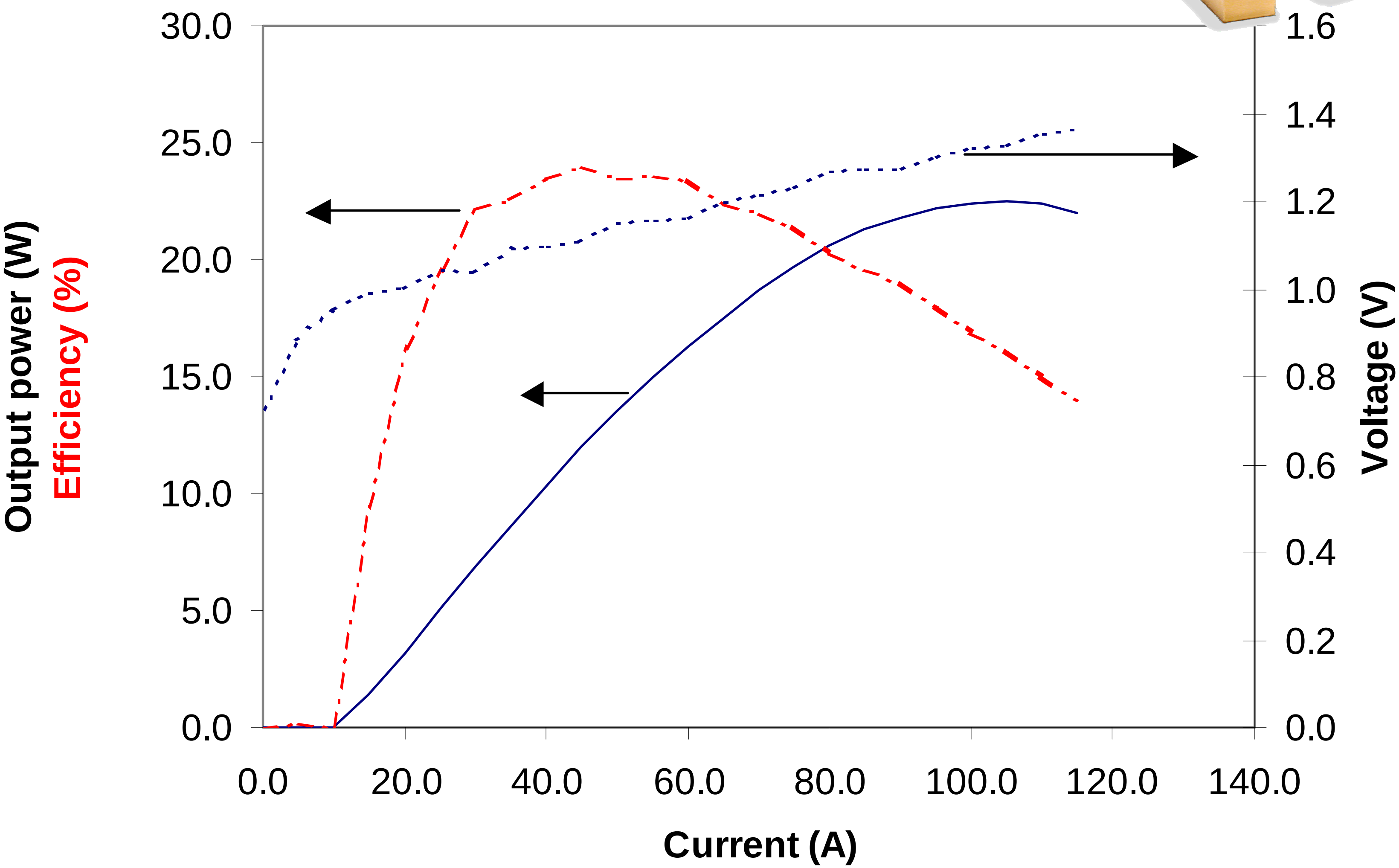
1700-nm diode laser bars produce > 22W





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Conclusions

- **Single emitters technically and commercially compelling**
  - High power density, efficiency and reliability
  - Wide range of commercially available wavelengths
- **Efficiency continues to increase**
  - SHEDs designs showing 85% power conversion
    - When cooled to –50C
  - 45% at 1470-nm, 47% at 660-nm, 24% at 1700-nm
- **Power continues to increase**
  - 140mW/um from 808-nm single emitter
  - > 400W from 808-nm bar, > 100W at 1470-nm, > 22W at 1700-nm
- **The future is getting brighter!**


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PHOTONICS