



**IEEE SCV LEOS Chapter Meeting
6 June 2007**

High Reliability Diode Pump Lasers

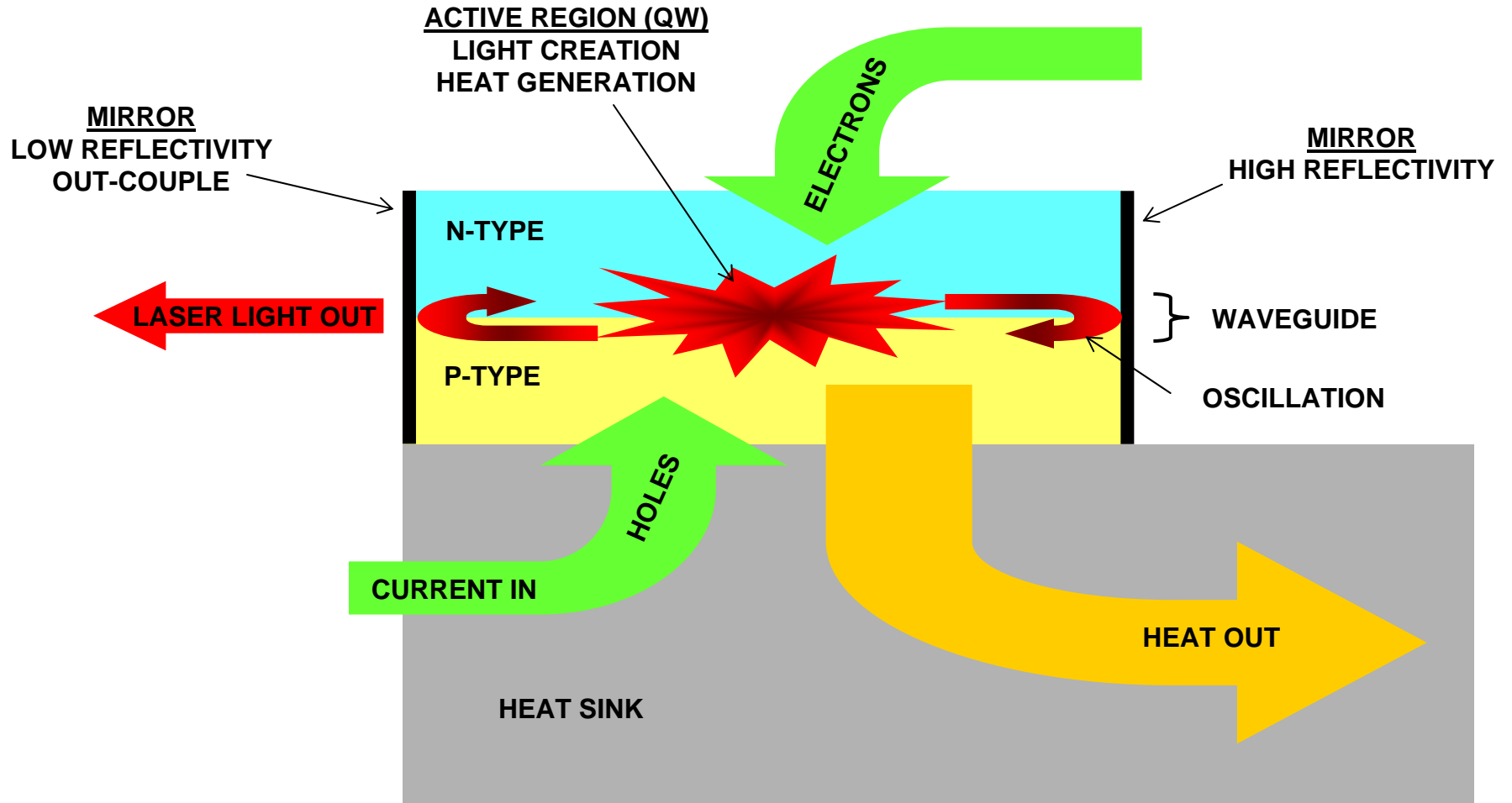
Toby Strite

Manager of High Power Laser Marketing

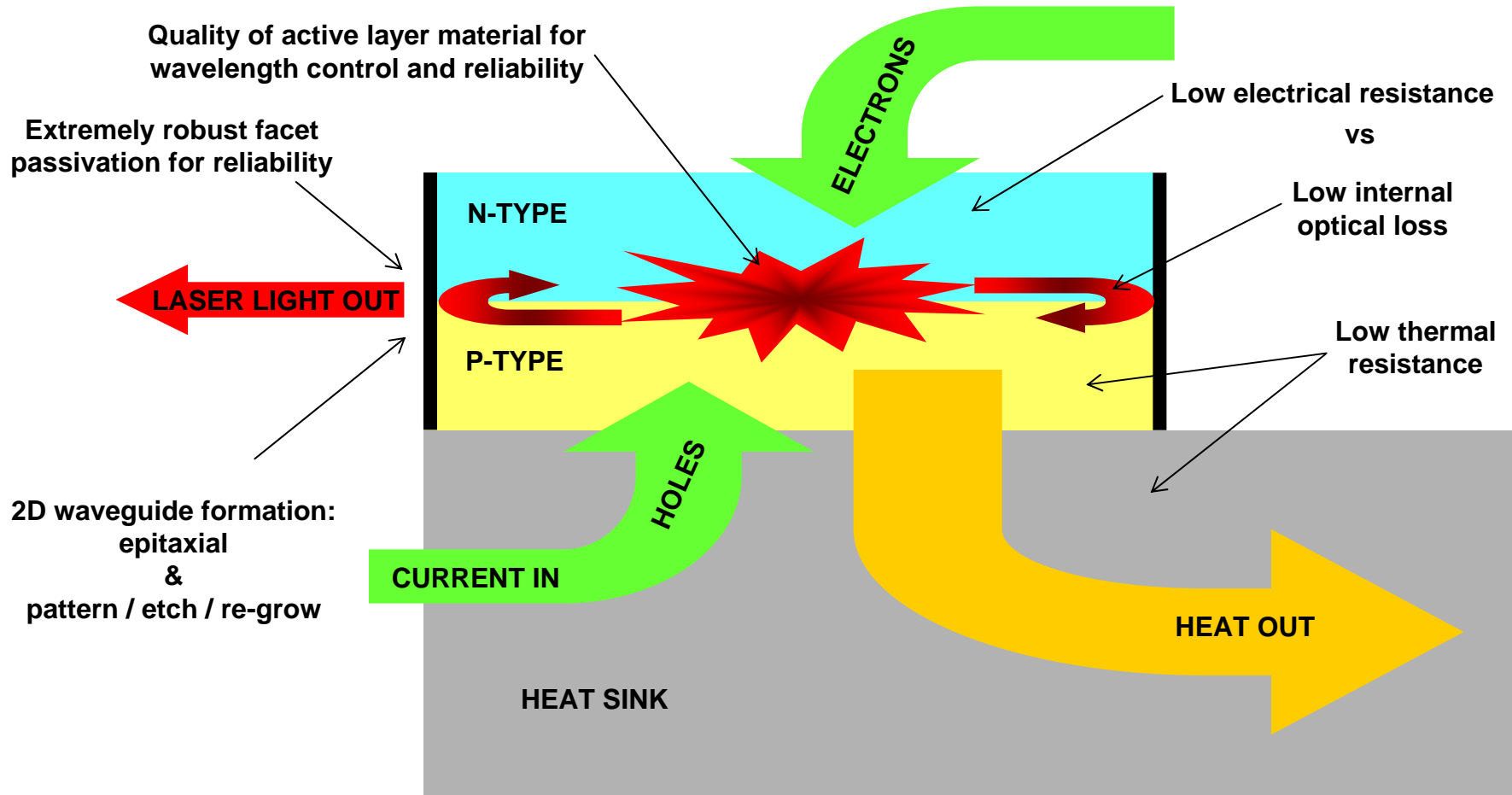
Outline

- AlGaInAs High Power Diode Lasers basics
- Evolution of High Power AlGaInAs LDs
- What is a telecom grade diode laser?
- Fiber in lasers paradigm shift

Semiconductor laser basics



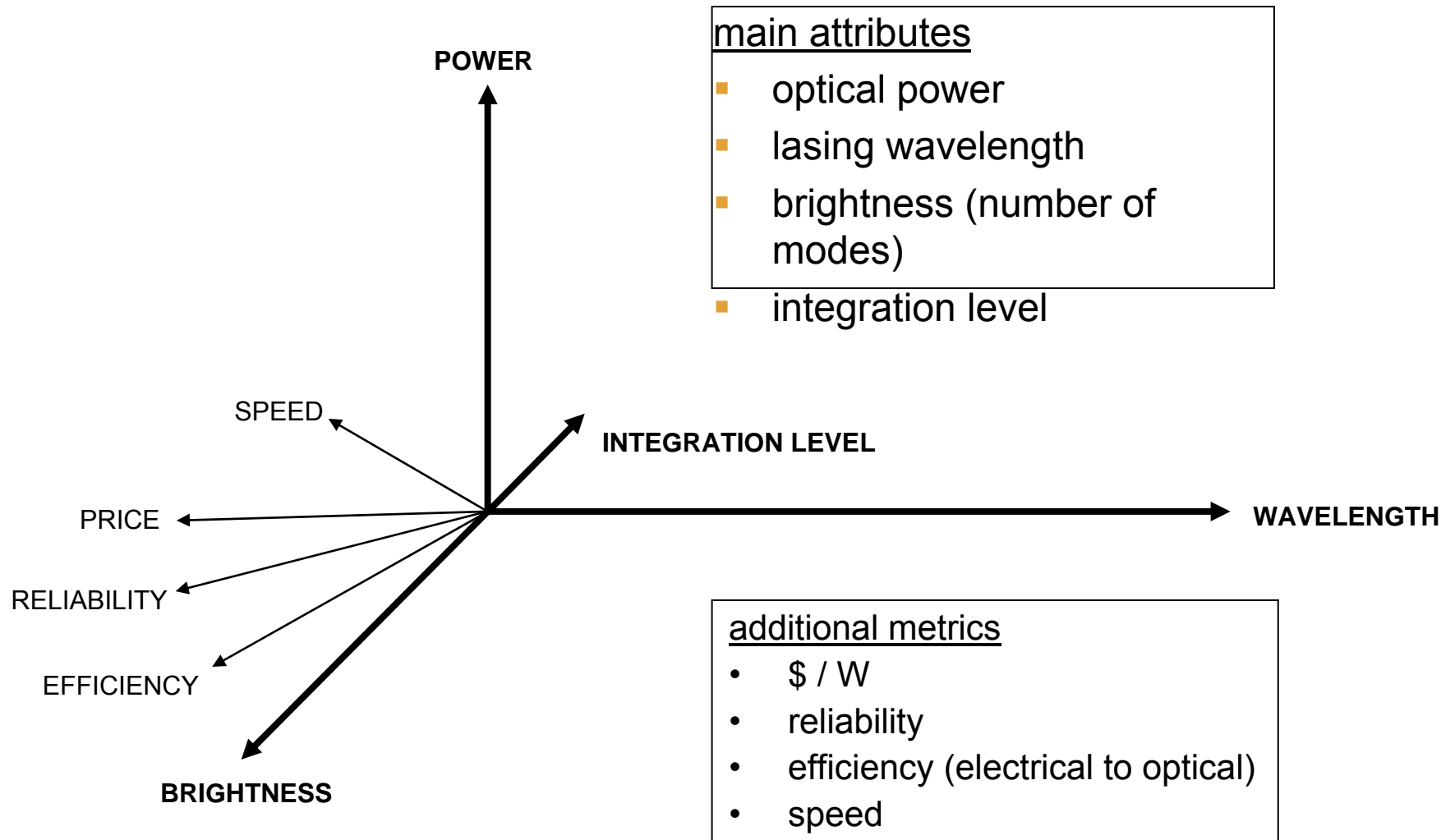
What's important?



NIR (800 – 1000nm) Diode Laser Sweet Spot

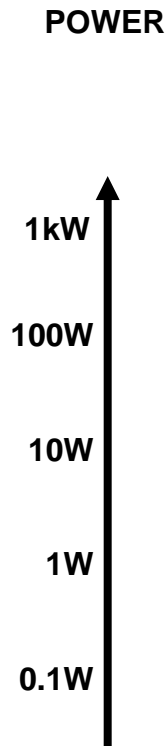
- Material Quality
 - Excellent substrates, MBE/MOCVD
 - Bi-polar dopability, low optical absorption
 - Mirror passivation for high optical power density
 - Low electrical resistance, low optical loss
- Diode Laser Design
 - Pseudomorphic InGaAs QW's
 - Symmetric heterostructure band offsets
 - AlGaAs/GaAs index contrast/lattice match
 - Low threshold, good confinement, wide λ range
- Moderate $\sim 1\text{eV}$ Photon Energy
 - Between Auger and lattice damage thresholds

High Power Lasers - Key Attribute Space



High Power Lasers - Key Attribute : Power

Power = optical watts



– power at required reliability level

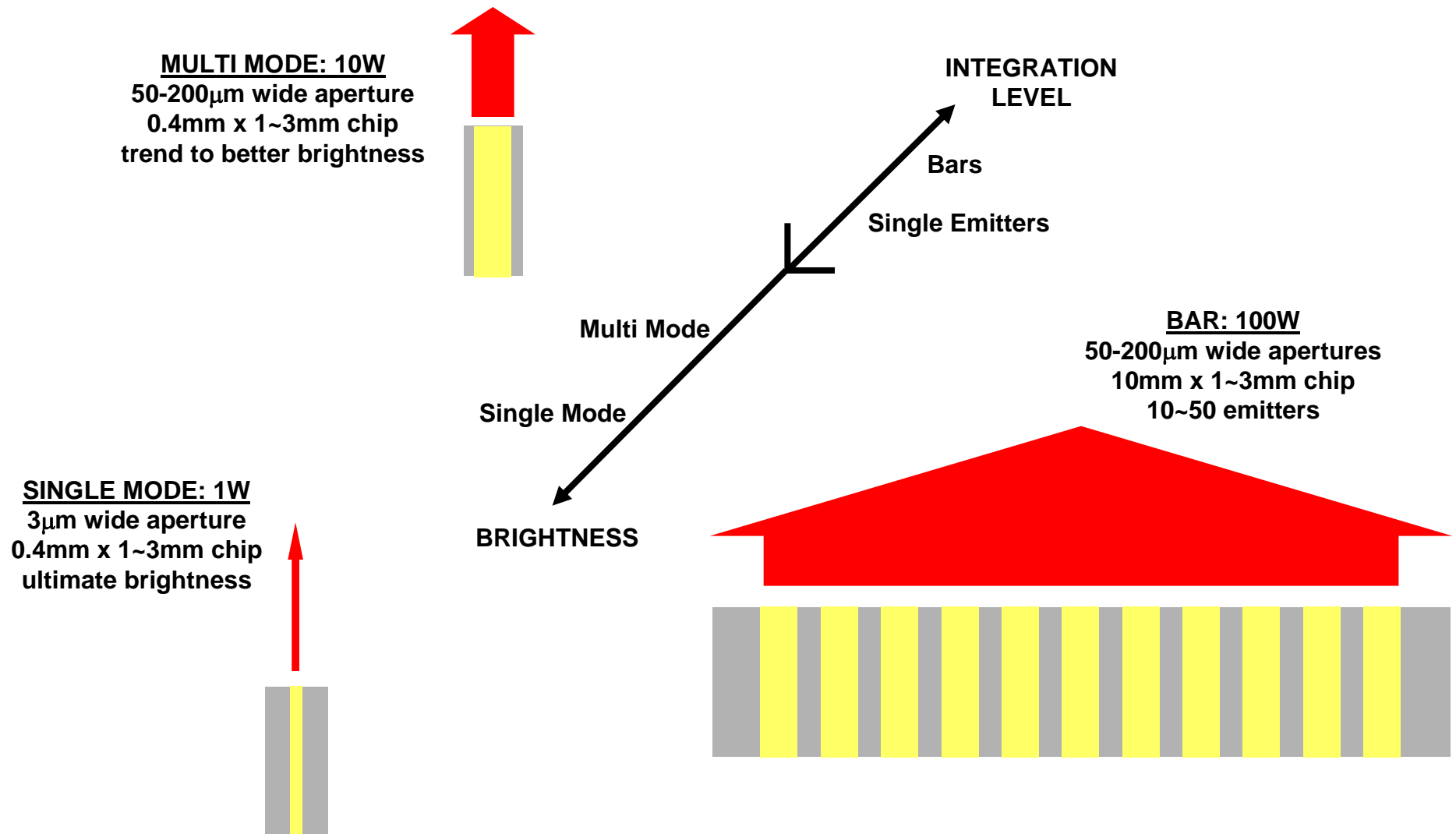
- power per deployed hour
- telco: ~10M-hr MTBF (100 FIT)
- industrial: ~250k-hr MTBF (~4000 FIT)

– power per dollar

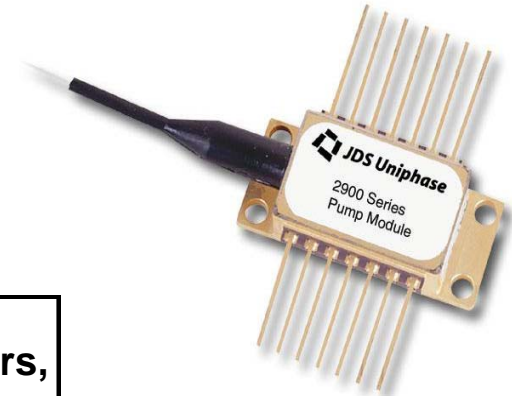
- customers often use multiple components in single application

– power at required brightness

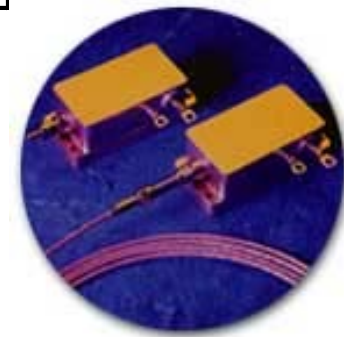
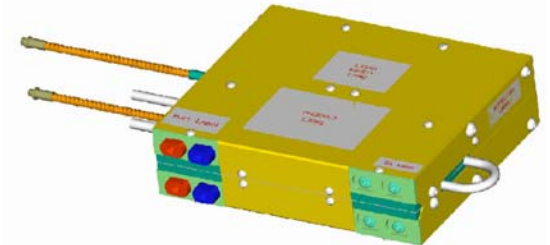
HPL Key Attributes: integration level



High Power Laser Product Segments



	single emitters	multi-emitters, bars	multi-bars, stacks
fiber-coupled	Telecom, Industrial, Modules	Bundles, High Brightness	Remote Delivery
non-fiber-coupled	Chip/Carrier Windowed	Bare chips, Submounts, Coolers	Direct Illumination



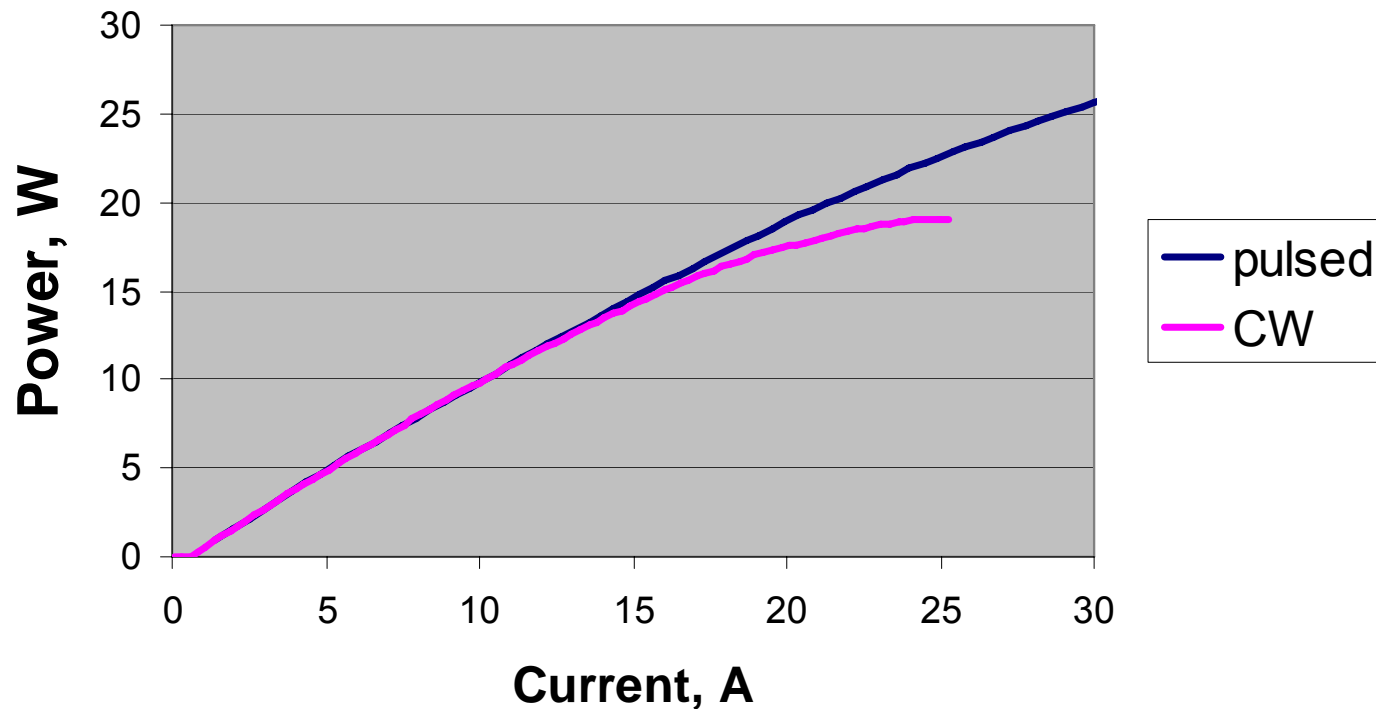
Industrial Diode Laser Eras

- Reliability (inception → 2003) “\$\$\$’s and *#&%^!!”
 - DPSS is considered *technology of the future* (“always has been, always will be...”)
 - Diode laser investment focused in telecom
 - Unreliable, low brightness bars often the only choice
- Telecom-grade (2003 → ?) “\$/Watts”
 - Telecom migrants disrupt brightness, drive \$/Watt
 - Even low-end bars reliably deliver 10,000hrs
 - Reliability and \$/Watts begin to de-couple

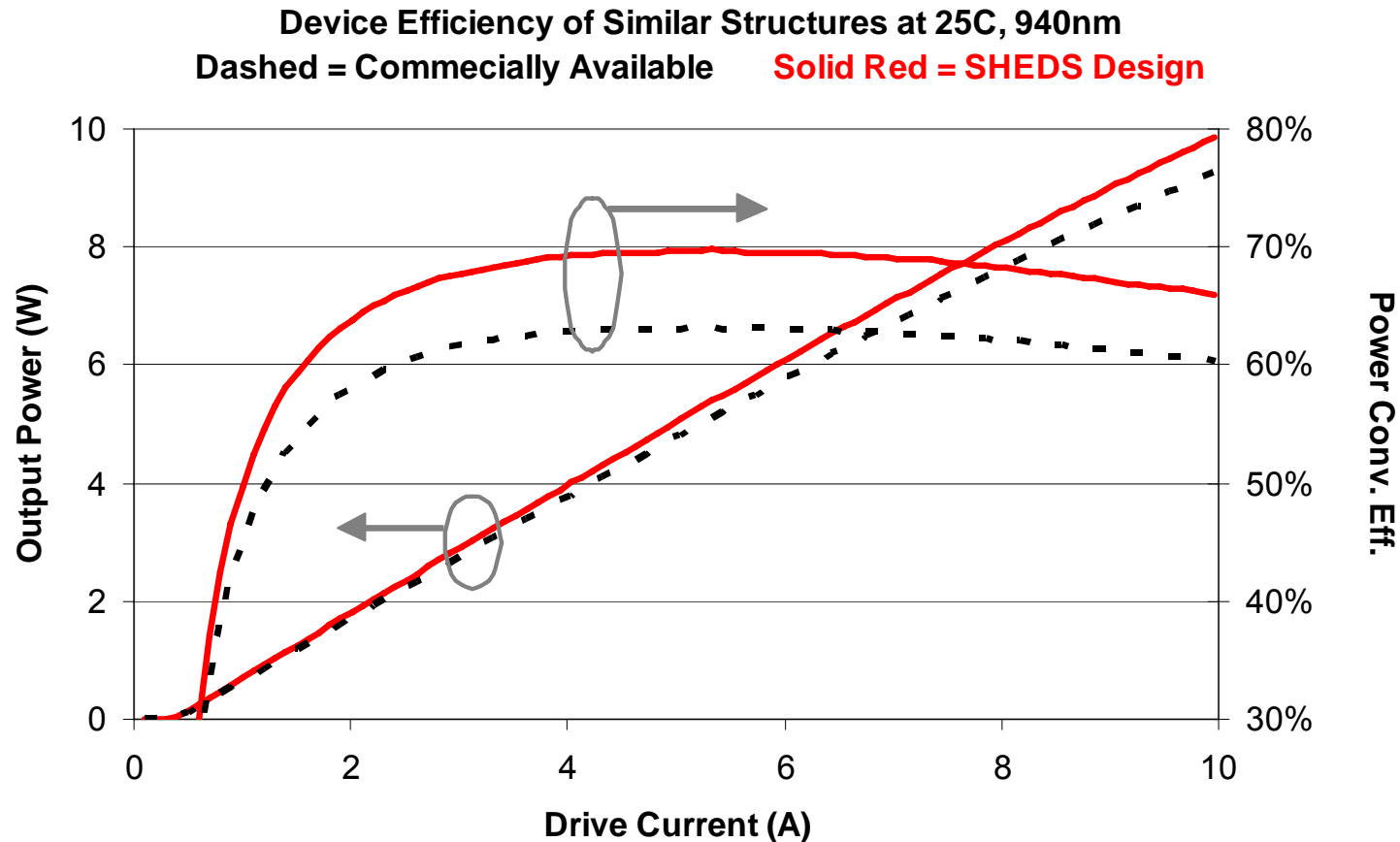
Third Industrial Diode Era - Efficiency

- Diode Efficiency (2005 → ?) “still \$/Watts”
 - reliable power is limited by waste heat

T=15C



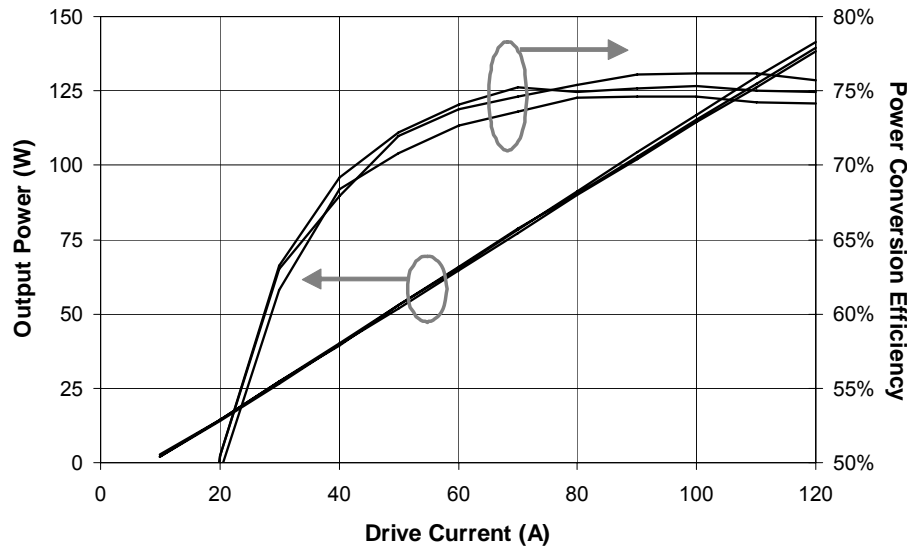
Optimizing single-emitter efficiency



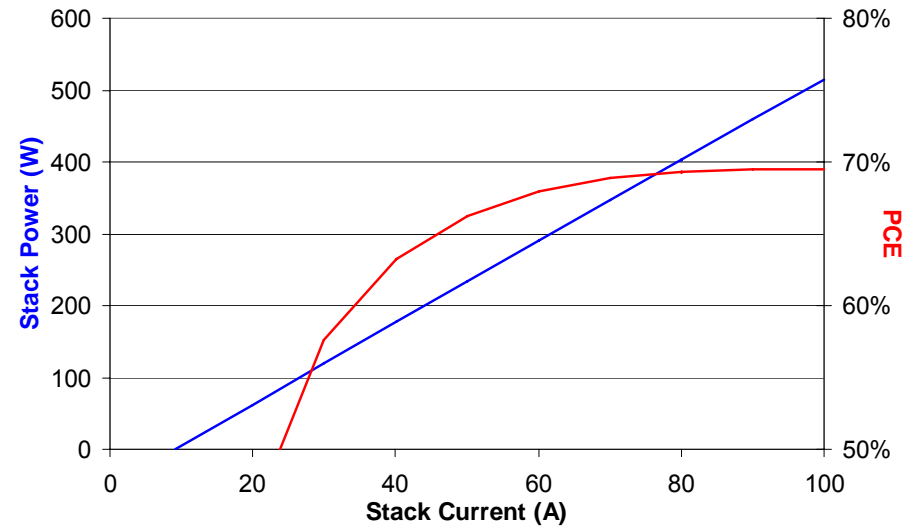
Research funded by DARPA SHEDS program promises power conversion efficiency improvements in future fiber laser pumps

SHEDS 940 nm Bars – Final Status

Performance of JDSU/SHEDS 80W Bars



SHEDS Performance of Lensed Water Cooled 950nm Stack
NIST Measured and Calibrated



- >75% Bar Efficiency at 80W and above
- >69% Stack Efficiency (NIST) to 500W and beyond

Fourth Industrial Diode Era - Brightness

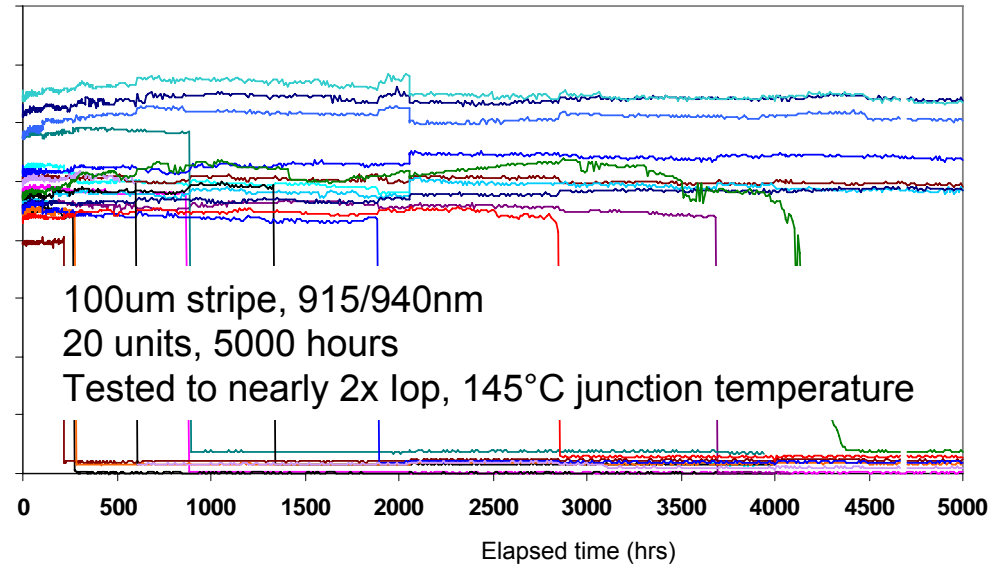
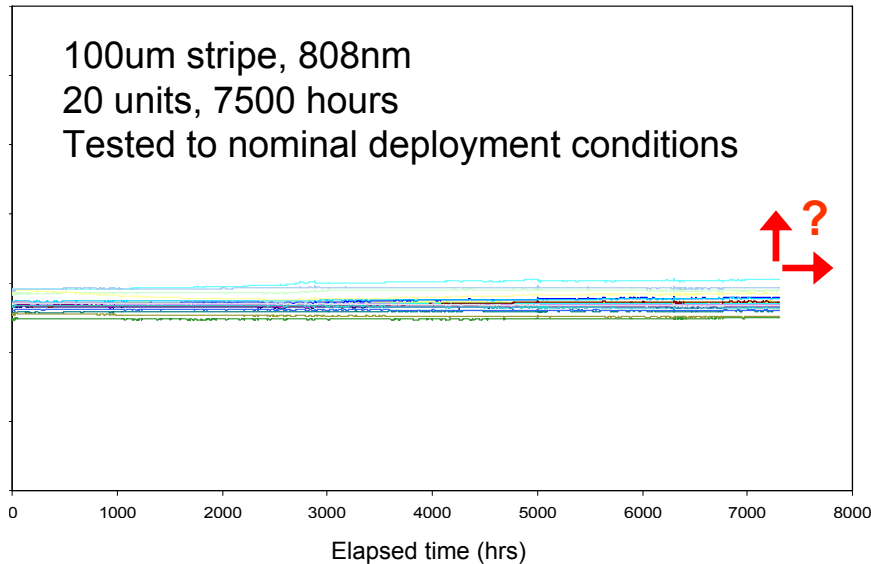
- Diode Efficiency (2009 (?) - ???) “\$/Watts/sterradian”
 - How useful is our low cost, ultra-reliable, efficient source?
- Reliable 980nm pump lasers for telecom operate 25yrs at $>50 \text{ MW/cm}^2$
- Preserve the inherent brightness of diode lasers
 - *Cut out the solid-state middleman*

What's in the box?

What is a Telecom-Grade Diode Laser?

- Operational Excellence and Business Breadth
 - Large, fully-absorbed fab (ISO-9001 a decade ago, now TL-9000)
 - High-volume off-shore assembly
- Technical and Cost Roadmaps, Extensive Track Record
 - Platforms, not just products
- Predictable, sustained performance
 - Rigorous NPI, PCN and PDN processes
 - Reliability understanding surpasses the qualification report
- ... Confidence and Transparency for the Customer!

Which data would you prefer to see your supplier present?



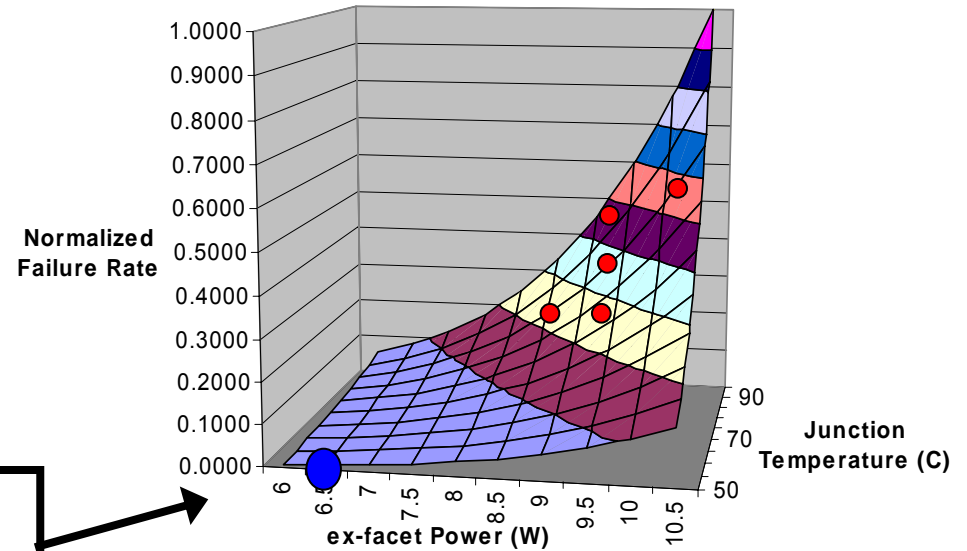
- JDSU is proud to offer both devices to the market...
 - ...but all recently released and future products are tested to failure
- Weaknesses of “rose-colored glasses reliability”
 - No data on robustness (what happens at 1.2x Pop? What happens in Year Two of deployment?)
 - How does reliability scale with temperature, power, current (i.e. real use conditions)?

Rigorous Reliability: Multi-cell Test Methodology

- Parallel lifetests varying key parameters:

- Temperature
- Optical Power and/or
- Drive Current

- Multi-cell test conditions
- Intended deployment condition



Example for multicell test design

- Reliable AlGaInAs lasers follow:

$$F(T_j, P, I) = F_{op} \cdot \exp\left(-\frac{E_A}{k_B} \left(\frac{1}{T_j} - \frac{1}{T_{op}}\right)\right) \cdot \left(\frac{P}{P_{op}}\right)^n \cdot \left(\frac{I}{I_{op}}\right)^m$$

→ (F_{op}, E_A, m, n) determined from best fit of multi-cell data

Pre-conditions for applying multi-cell method

- Diode technology must be robust
 - Permits aggressive, highly effective infant failure screening
 - Permits multi-cell test to interrogate wide parameter space without generating new failure modes
- Diode technology should have a single dominant failure mode
 - Single-emitter diode lasers are typically dominated by time-independent, sudden, catastrophic failure rates (negligible wear-out)
 - Permits high quality empirical fitting of reliability model to multi-cell reliability data

6390 Diode Laser Multi-cell Test Results

Cell #	fixture temp., °C	junction temp., °C	Power, W	Current, A	number of lasers	hours	device hours	Failures
1	92	129	5.2	7	75	5000	3.6E+05	5
2	55	107	8.4	10	40	5000	1.7E+05	8
3	70	126	7.8	10	19	5000	8.9E+04	2
4	85	145	7.0	10	20	5010	9.2E+04	2
5	55	125	9.5	12	20	5000	5.5E+04	13
6	70	145	8.5	12	19	5000	5.4E+04	11
total					193		8.3E+05	41

Cells 1/3/5 and 4/6 vary I at constant T_j
 → Failure rates increase with current/power

Cells 2/3/4 and 5/6 vary T_j at constant I
 → Failure rates correlate with power, not temperature

6390 Diode Laser Multi-cell Test Analysis

- Maximum likelihood estimate for random exponential failure distribution neglecting current acceleration ($m=0$)

$$F(T_j, P) = F_{op} \cdot \exp\left(-\frac{E_a}{k_b} \left(\frac{1}{T_j} - \frac{1}{T_{op}}\right)\right) \cdot \left(\frac{P}{P_{op}}\right)^n$$

- Key fitting parameters:

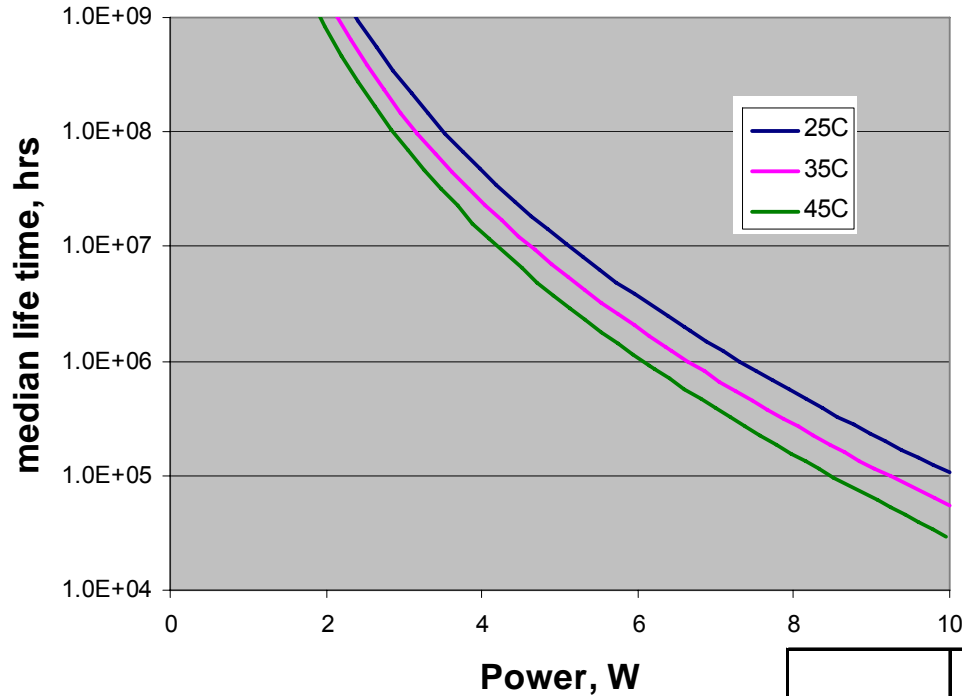
$$E_A = 0.41 eV$$

$$n = 5.7$$

$$F_{op} = 1420 FIT$$

- MTBF = 690,000hrs (with 60% confidence level) at 6.5W/35°C heatsink temperature

Multi-cell testing yields a “user’s manual”

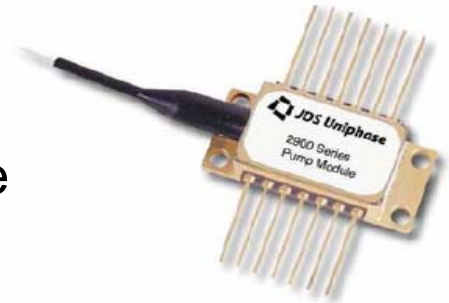


6390 Median time-to-failures for different operating conditions

Heatsink temperature, °C	Power, W	Median time, hrs	Median time with 60% C.L., hrs	Cumulative failures in 1 year	Cumulative failures in 5 years	Cumulative failures in 10 years	Cumulative failures in 25 years
25	2.6	6.0E+08	3.0E+08	0.0%	0.0%	0.0%	0.0%
	5.2	9.1E+06	5.4E+06	0.0%	0.2%	0.7%	2.3%
	6.5	2.1E+06	1.3E+06	0.2%	1.9%	4.4%	11.2%
	8	5.3E+05	3.5E+05	1.4%	9.2%	16.8%	31.8%
35	2.6	3.2E+08	1.7E+08	0.0%	0.0%	0.0%	0.0%
	5.2	4.8E+06	3.0E+06	0.0%	0.6%	1.6%	5.0%
	6.5	1.1E+06	7.4E+05	0.5%	4.2%	8.7%	19.3%
	8	2.8E+05	1.9E+05	3.3%	16.2%	26.9%	45.0%
45	2.6	1.8E+08	9.8E+07	0.0%	0.0%	0.0%	0.0%
	5.2	2.6E+06	1.8E+06	0.1%	1.4%	3.5%	9.2%
	6.5	6.1E+05	4.3E+05	1.2%	8.0%	15.1%	29.3%
	8	1.5E+05	1.1E+05	6.5%	25.5%	38.7%	58.0%

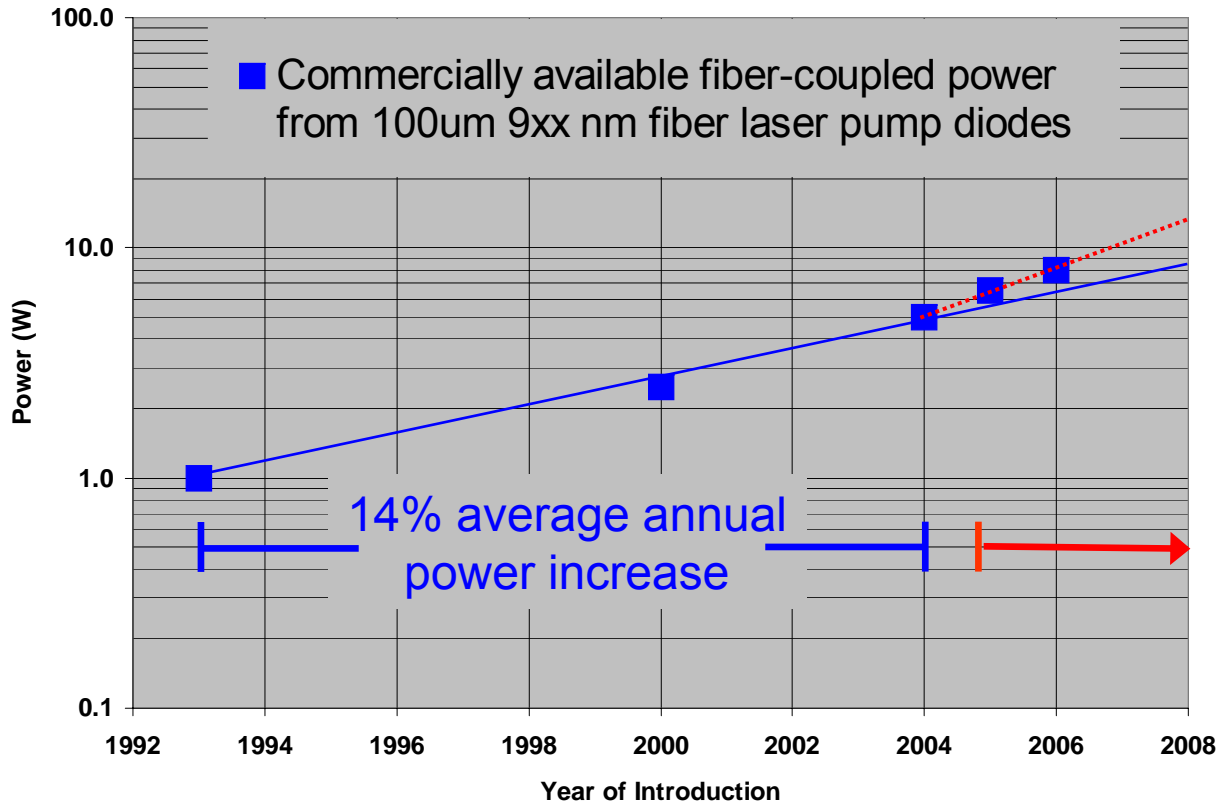
Telecom 980nm pump lasers since 1993...

- 90mW 980nm pumps assembled in Boston fetched \$7000
- Five chips, several packages, one transfer to China later...
 - 660mW 980nm pumps sell below \$1000
 - 90mW 980nm pumps cost \$300
 - and 980nm pump vendors are (again) profitable
- Over 13yrs, innovation and focused cost-reduction realized
 - **-21%** annual price reduction for 90mW part
 - **+15%** annual power increase for 980nm pumps
 - **-26%** annual \$/mW price reduction to the market



The Story moves to Fiber Laser Pumps

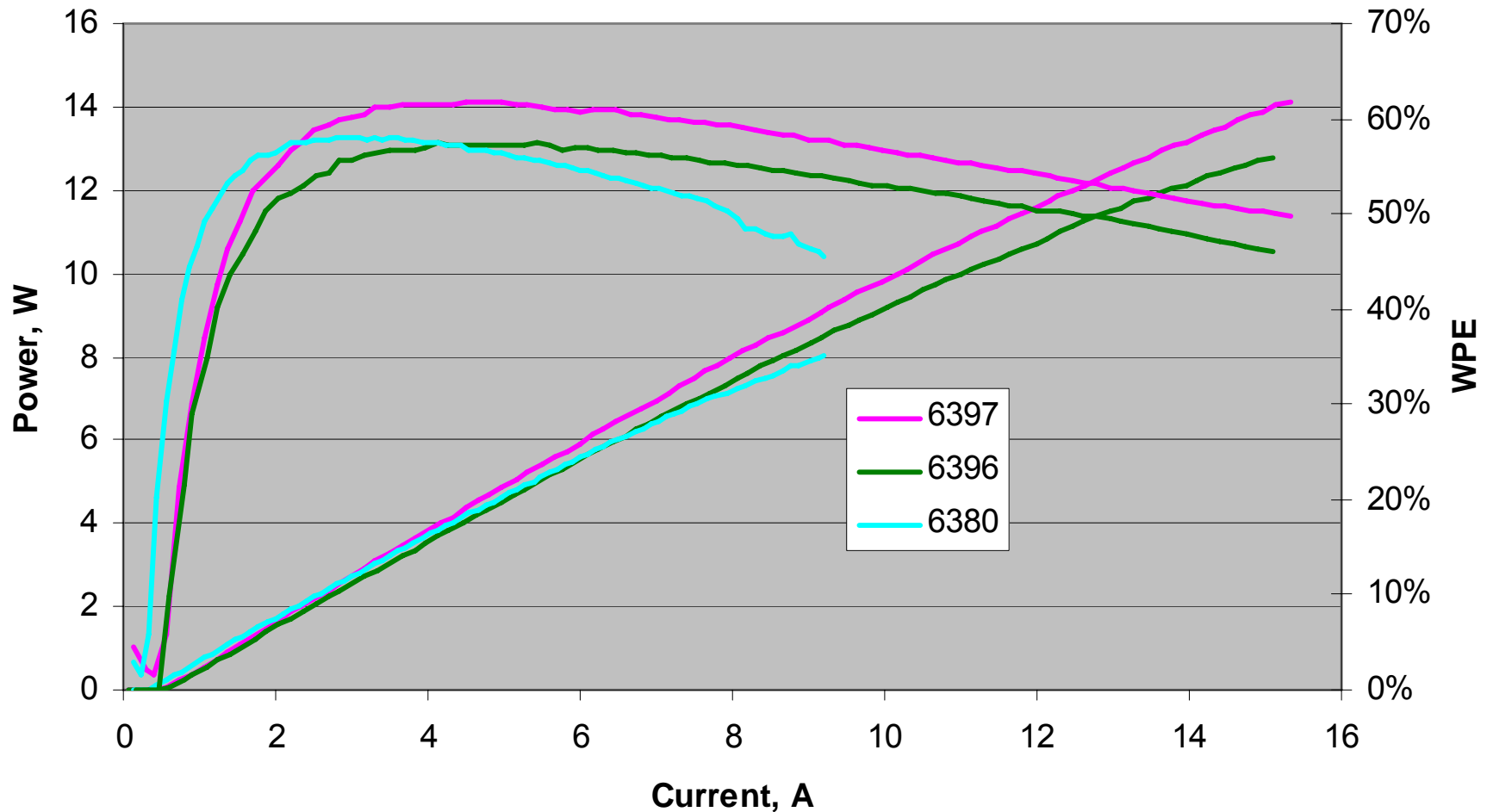
Multi-mode product cycle times have shortened, driving a performance up-tick since the 2004 release of the 5W 6390-L3.



Annual 17.5% (red) power increases enabling 26% annual \$/Watt erosion predicts a reliable 35W fiber-coupled diode will sell for \$70 in 2016....!!

Fiber Laser Pump Performance over Generations

Consistent power scaling through increased cavity length, design and technology improvements



Why Fiber Lasers?

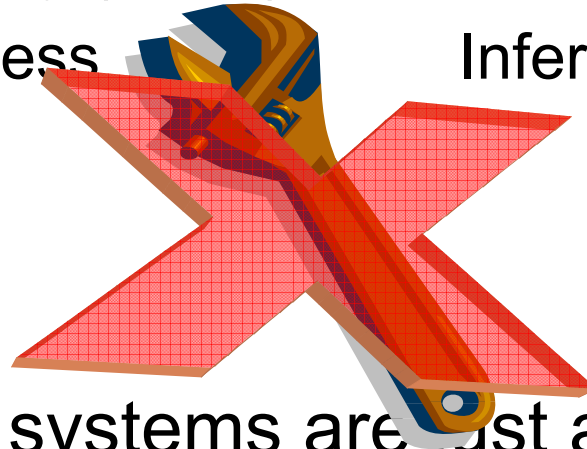
- Telecom grade diodes and fiber – disrupting the laser industry

- Fiber-based Laser

- Modular, spliced
 - Service free
 - High efficiency (25+%)
 - High brightness

- SS/Gas Lasers

- Delicate alignments
 - Disposables
 - Low efficiency (few to 10%)
 - Inferior brightness



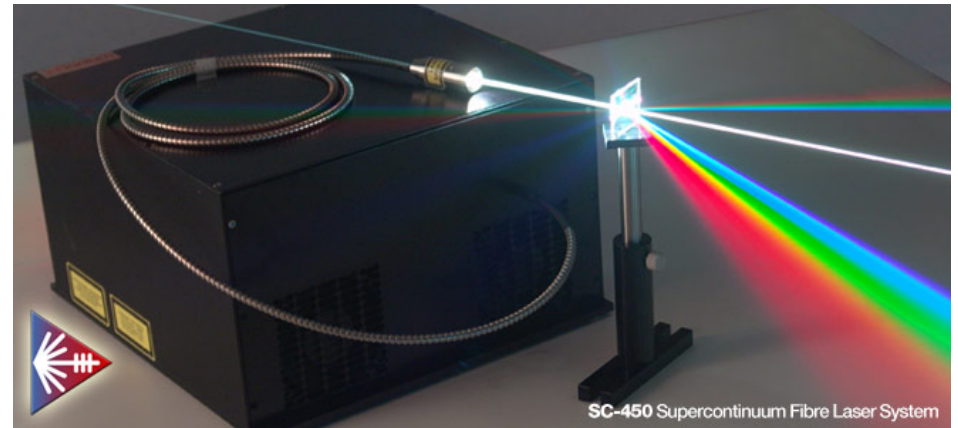
- Direct Diode systems are just another fiber laser
- Solid-state (classic) lasers are adopting fiber

Telecom Grade Diodes and Fiber in Lasers

Yb-doped Fiber Laser



White Super-continuum Fiber Laser



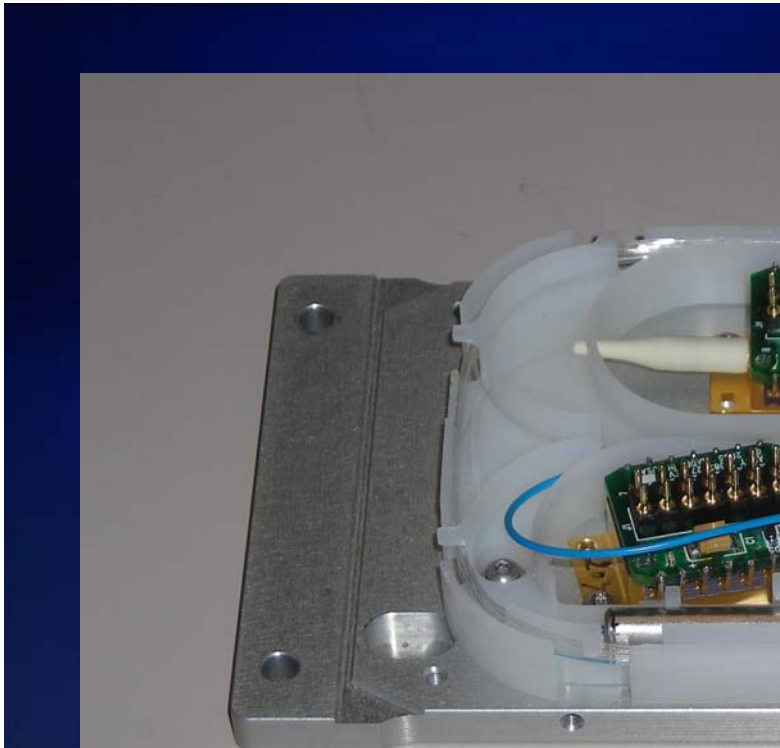
Direct Diode w/ Fiber Delivery



Green, Yellow, Orange, uv Fiber Lasers

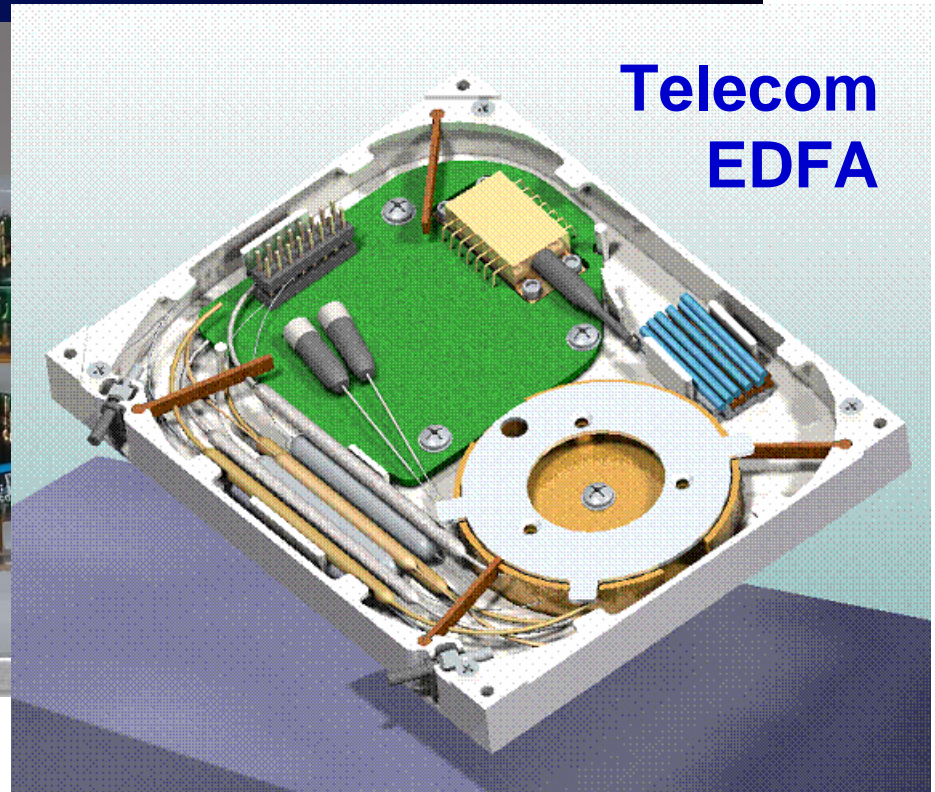


JDSU FCD-488 Blue Laser

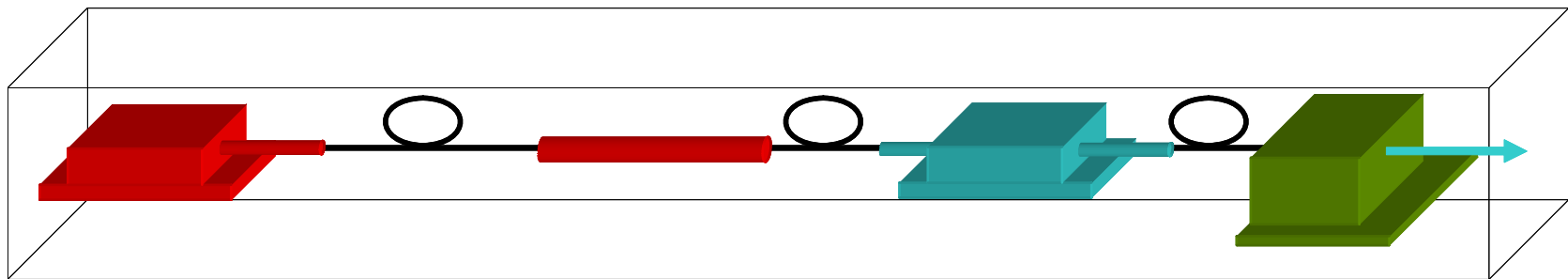


Laser diode

FBG



Telecom
EDFA





Questions?

Thanks to:

**Erik Zucker, Victor Rossin, Thomas Kraft
and many other JDSU colleagues**