SHEDs at nLight: DARPA-Supported Collaborative Technology Development

Paul Crump

Contents

- **Introduction to nLight**
- **Collaborating with industry e.g nLight**
  - What nLight looks for
  - What nLight offers
- **DARPA SHEDs – case study**
  - Goals
  - Path followed
  - Example collaborations
  - Results obtained
  - Follow-on programs
- **Conclusions**

Contents

nLIGHT

nLight Overview

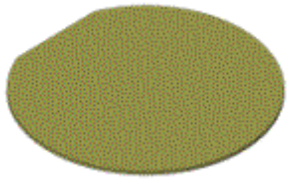
Company
- Founded in 2000

Mission
- Leading supplier of high power laser diodes for OEM applications

Products
- 635 to 2100 nm laser diodes
- Broad range of packages and OEM optical assemblies

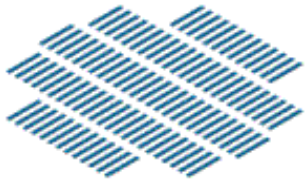
nLIGHT

nLight End-to-End Capabilities

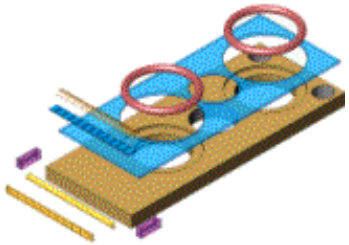


Wafers (3” GaAs)

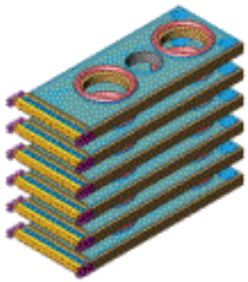
Wafer Processing



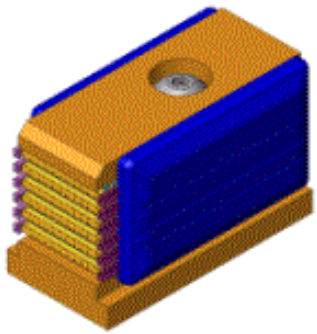
Bar Processing



Bar Assembly



Stack Assembly



Package Assembly

Front End Processes

- MOCVD
- Lithography
- Etch
- Metallization

Back End Processes

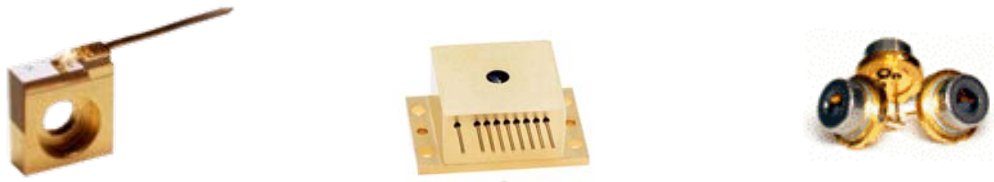
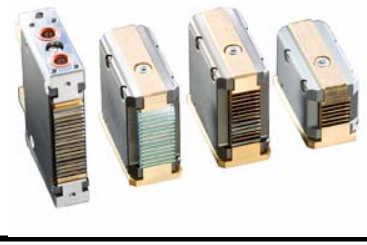
- Cleaving
- Dielectric Coating
- Solder Deposition
- Die Attach
- Wire bond
- Test/burn-in

Packaging

- Microlens fabrication
- Lens attach
- Stack assembly
- Custom Packaging
- Test/burn-in

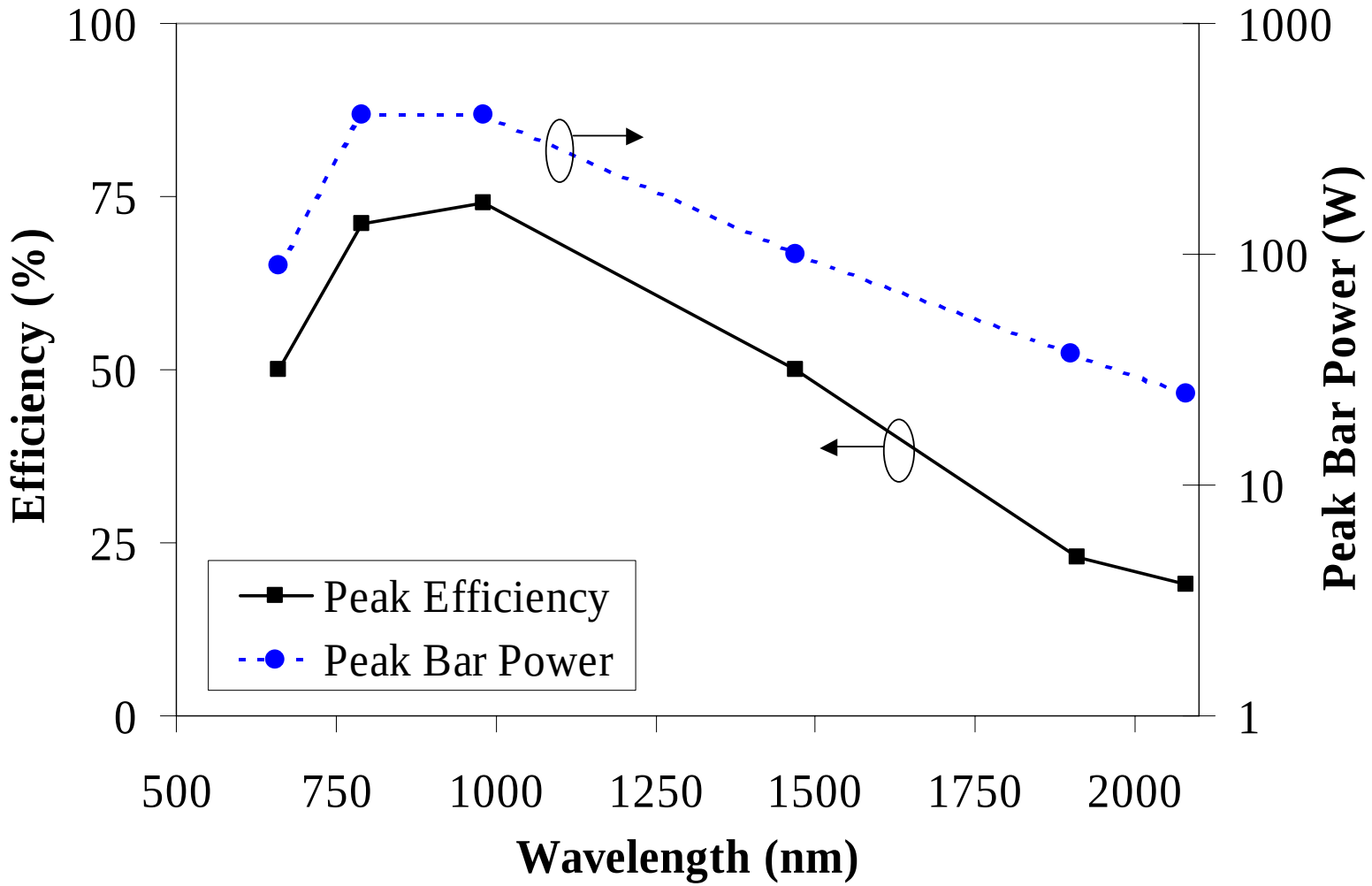
nLIGHT

nLight's broad product range

Product category	nLight product platforms
Single Emitter Up to 7W	
Diode Arrays 10 to 100 Watts	
Stacks of Arrays 100W to multi-KW	

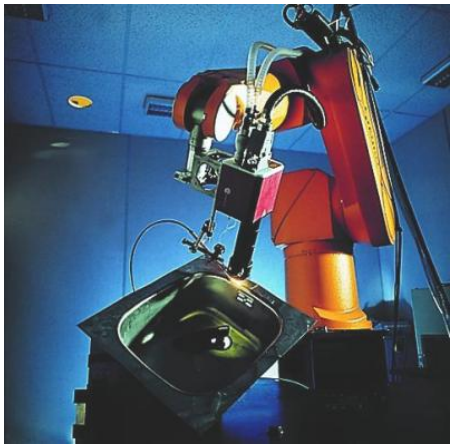
nLIGHT

Wide Range of Powers, Wavelengths Available



nLIGHT

Key applications today



Industrial
- Welding
- Marking
- Heat treating

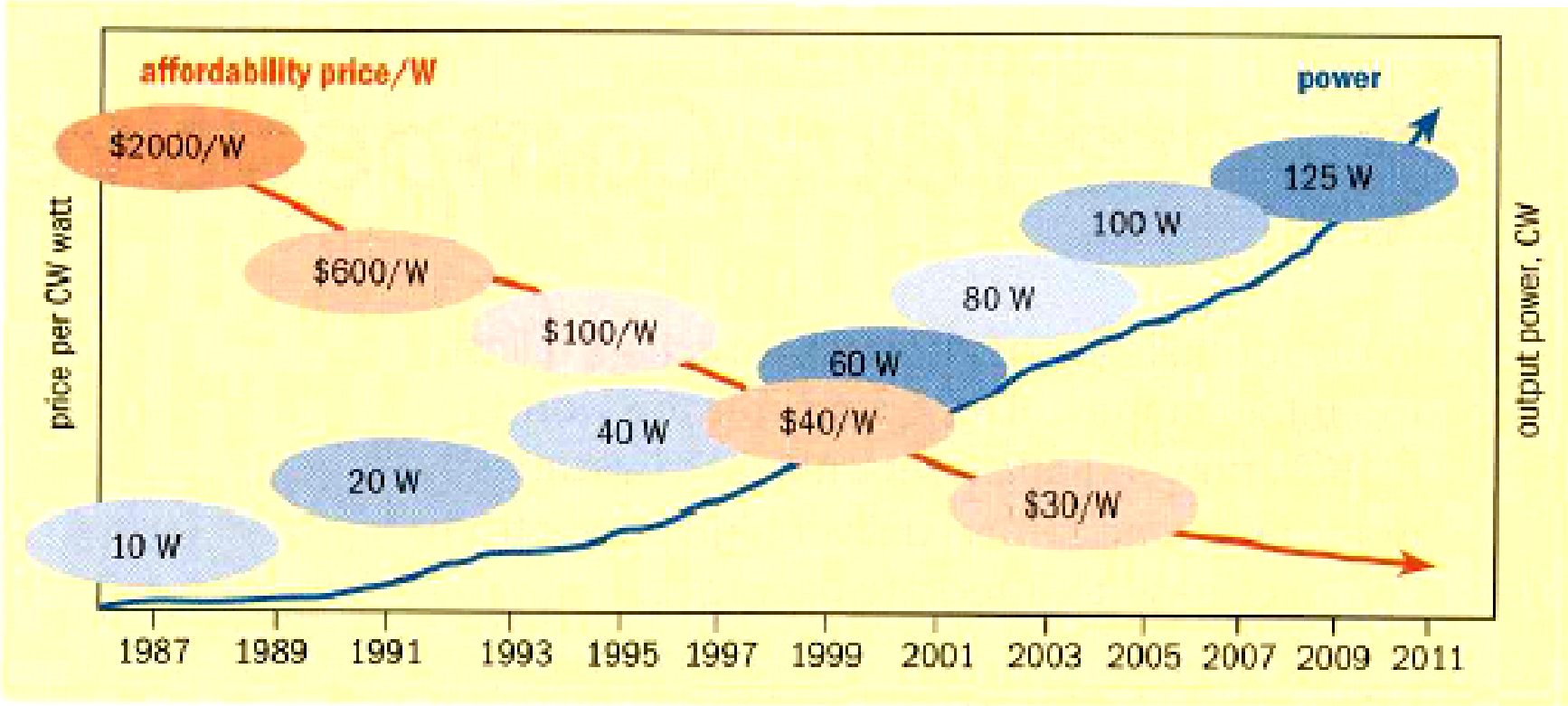
Defense
- Aircraft defense
- Illumination
- Targeting

Medical
- Dermatology
- Oncology
- Dentistry

Consumer
- Mobile projection
- Rear projection TV
- Hand-held medical

nLIGHT

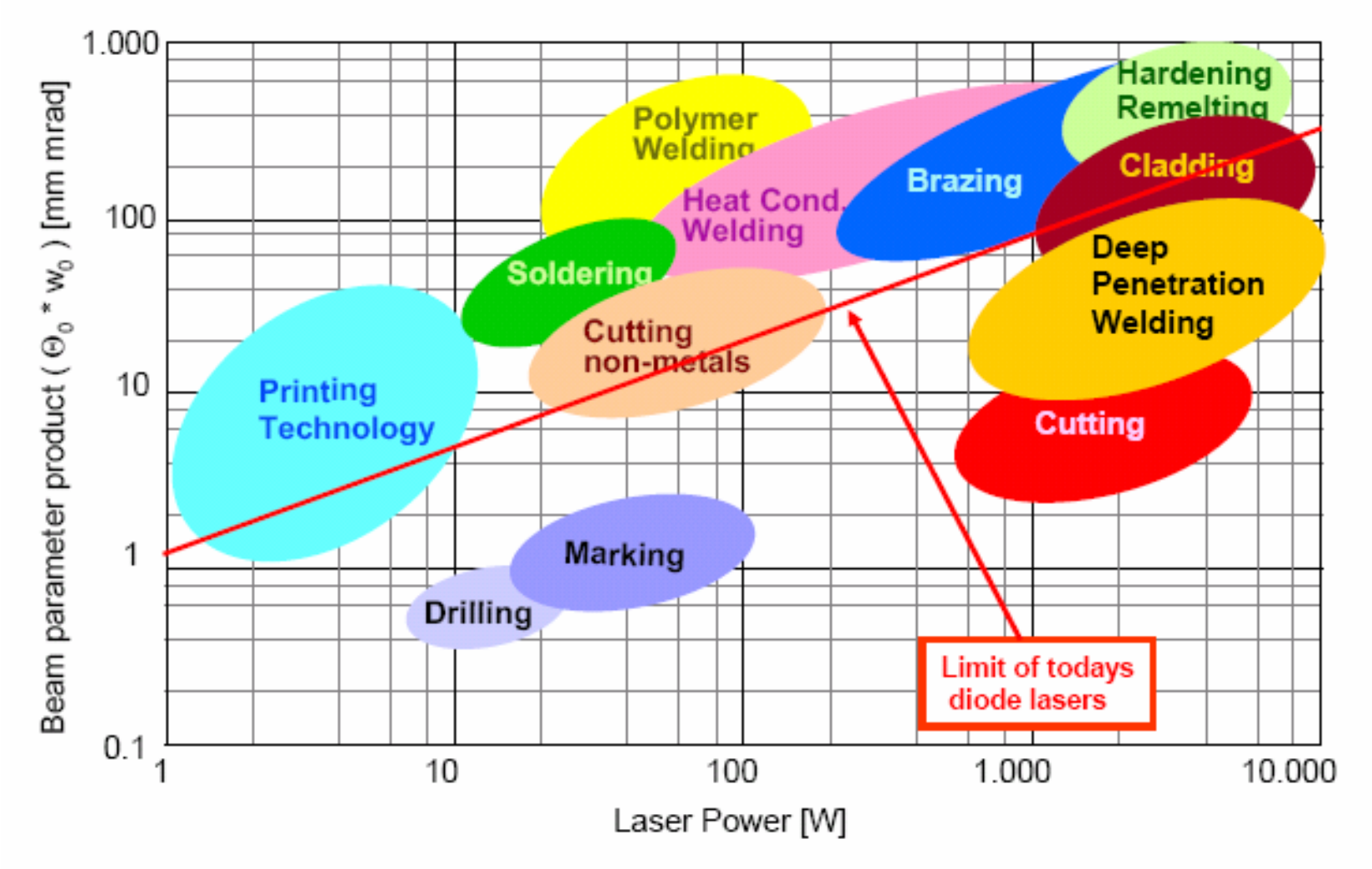
Diode Laser Bar Performance And Cost Rapidly Improving



As power level per bar increases, $/W falls

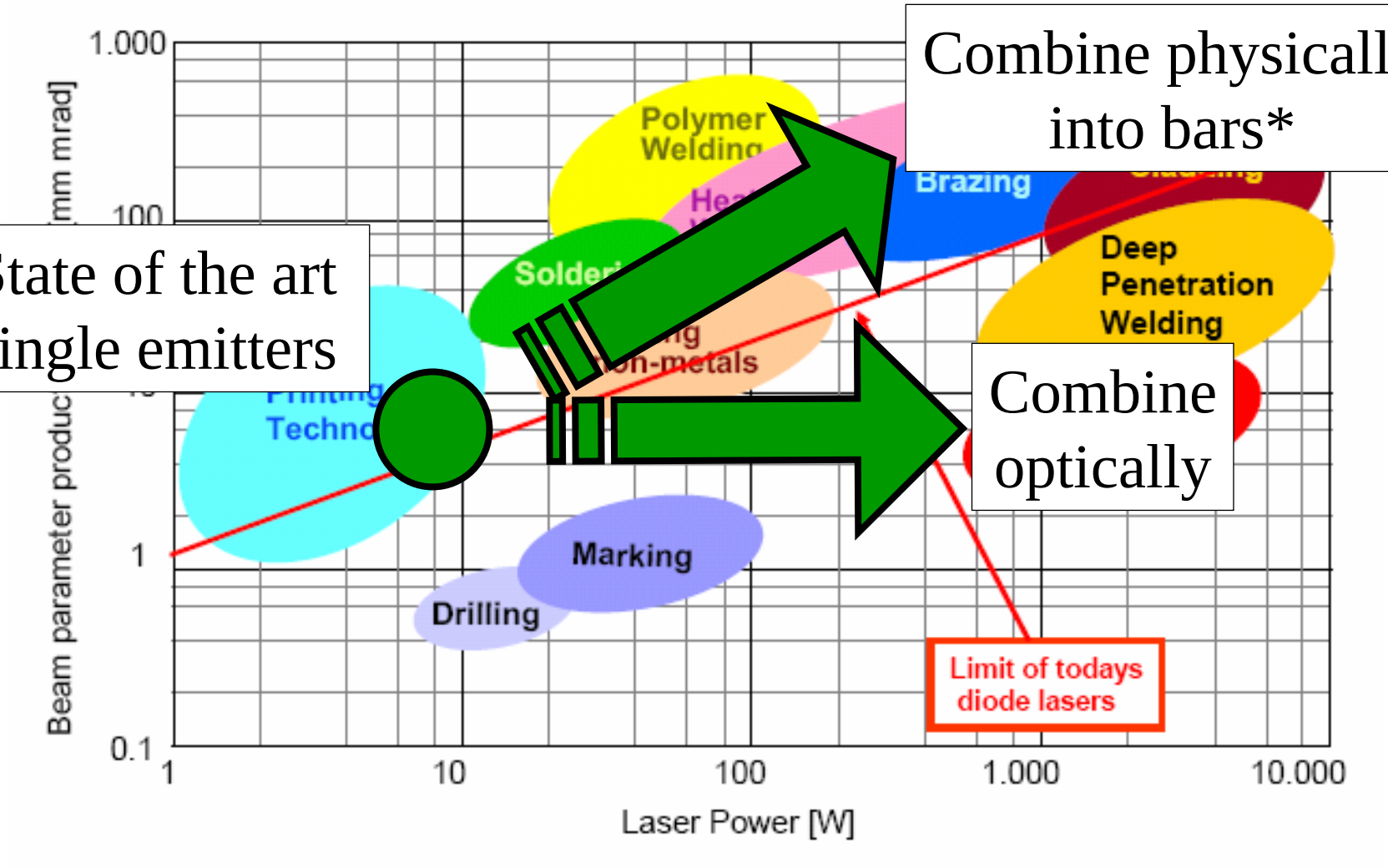
nLIGHT

Segmentation of Market for Laser Material Processing



nLIGHT

Single Emitters Allow Access to All These Markets



** The focus in this presentation*

nLIGHT

Contents

- Introduction to nLight
- **Collaborating with industry e.g nLight**
  - What nLight looks for
  - What nLight offers
- DARPA SHEDs – case study
  - Goals
  - Path followed
  - Example collaborations
  - Results obtained
  - Follow-on programs
- Conclusions

What nLight Looks For

- **Commercial relevance**
  - Programs only exist where there is a clear route to product
  - Customer “pull” required – DoD, Prime contractor, commercial
  - Enable new market or address known issue with existing material

- **Technical plausibility**
  - Low risk items guarantee good progress against goals for DARPA
  - High risk items to show convincing, well worked route to far exceed goals
  - Careful diagnostics to ensure we are on the correct path

- **Access to skills outside nLight core competence**
  - Novel materials e.g. quantum dots, photonic crystals etc.
  - Novel diagnostic tools e.g. STM, cryogenic testing
  - Theoretical skills e.g. photonic bandgap calculations

- **Good contractors**
  - Timely, honest feedback and on-time completion of tasks
  - Realistic deliverables and timelines
  - Helpful technical feedback – especially when it won’t work

- **Success – to enable follow on contracts**

What nLight Offers

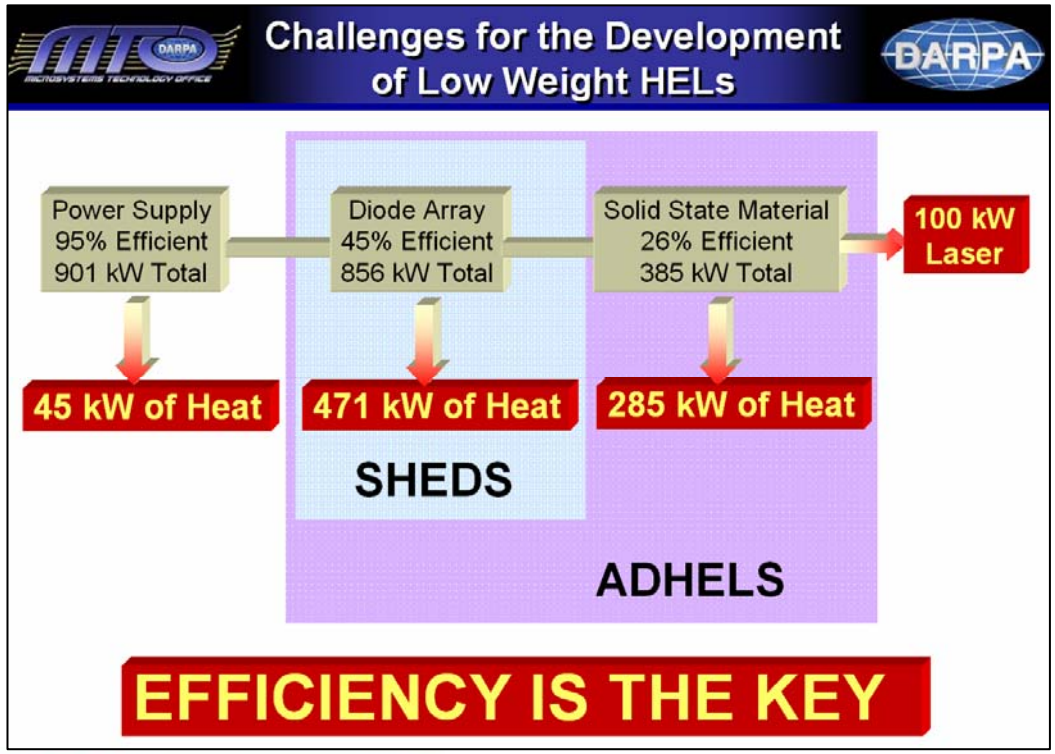
- **Path to Funding**
  - Many DoD grants require collaboration
- **Fertile source of technical challenges to overcome**
  - Understanding of issues that really limit industry
- **Market connection – route into commercialization**
  - Strong sales and development relationships in defense and commercial sectors
- **High quality material and processing**
  - Source of material, benchmark for development
- **Good collaborator**
  - Good track record of developing, commercializing novel products from programs
- **Employment**
  - Internships, full time positions for graduating students
- **Success – to lead to follow on programs**

Contents

- Introduction to nLight
- Collaborating with industry e.g nLight
  - What nLight looks for
  - What nLight offers
- **DARPA SHEDs – case study**
  - Goals
  - Path followed
  - Example collaborations
  - Results obtained
  - Follow-on programs
- Conclusions

nLIGHT

Rationale For SHEDs



Commercially produced 700 kW refrigeration plant

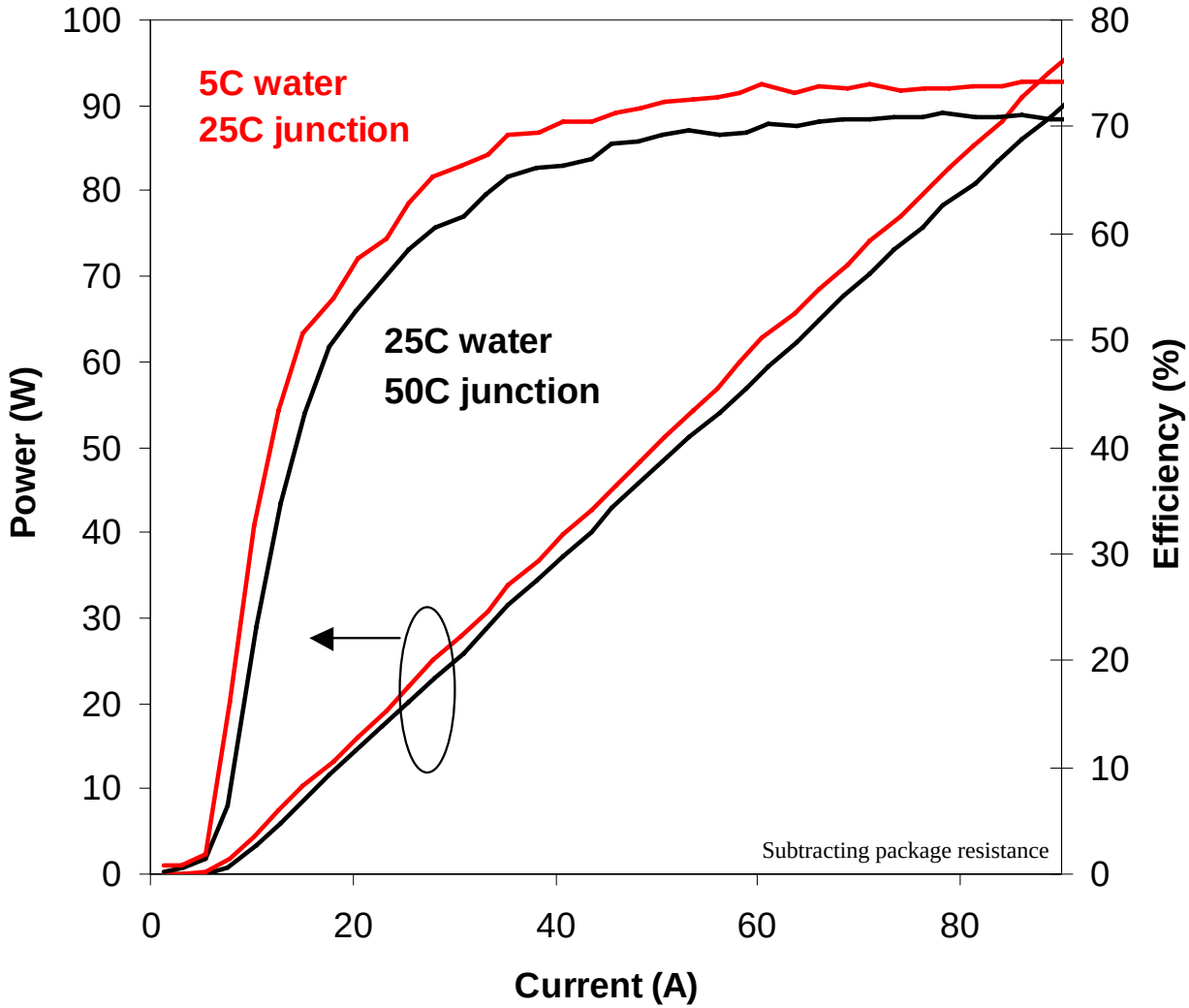
Commercially produced portable 1 MW electrical power supply

nLIGHT

Goals

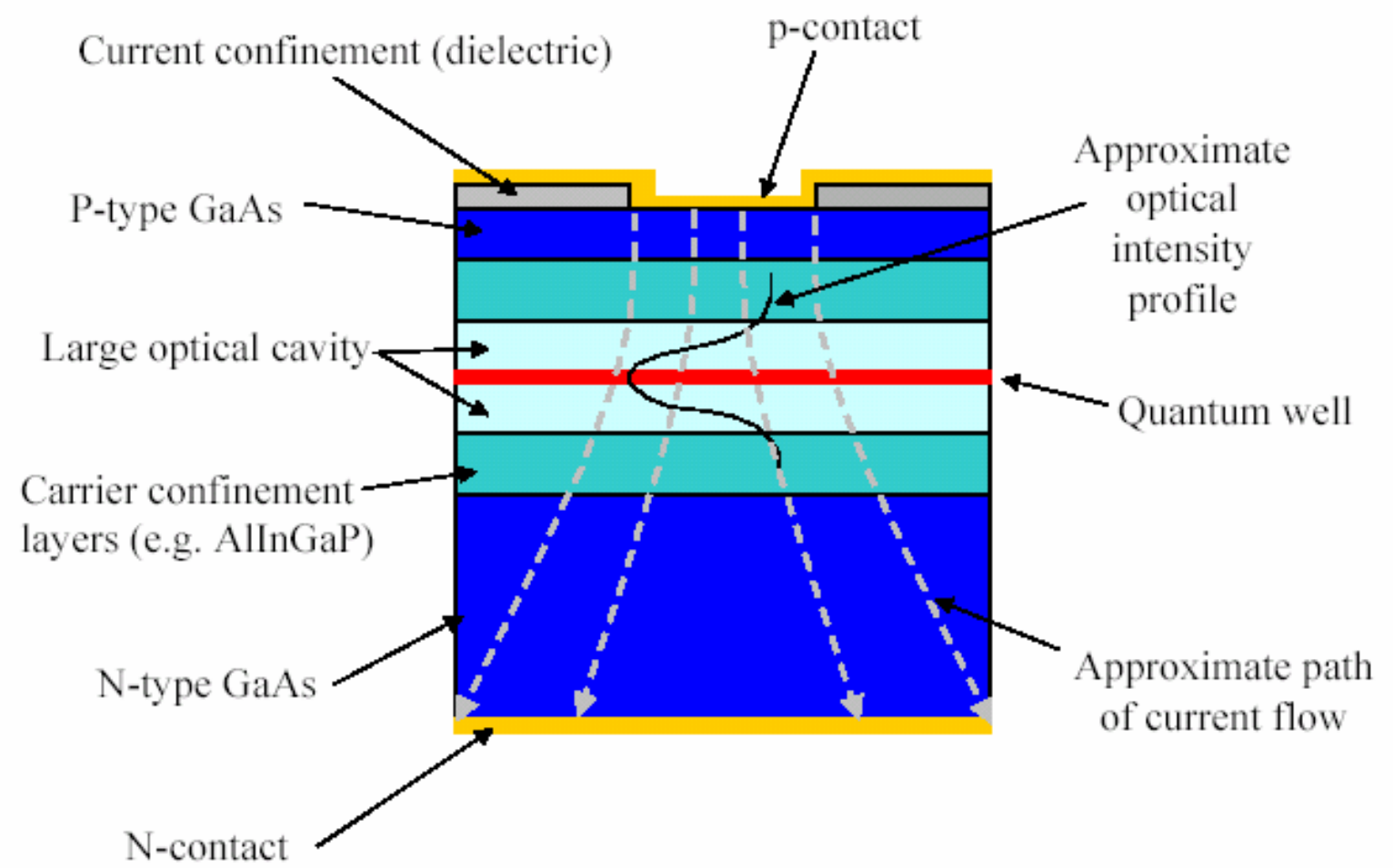
Attribute	Dec. 2003 Program Start	18 Mo. Goals	36 Mo. Goals
Bar Power Conversion Efficiency (PCE)	45%	65%	
Bar Power Output	80 W	80 W	
Spectral Width	5 - 10 nm	2 ± 1 nm	3 ± 1.5 nm
Junction Temperature		50°C	50°C
Stack Power Conversion Efficiency (PCE)	45%		80%
Stack Power	480 W		480 W

nLight Delivers > 70% Efficiency bars at Room Temperature



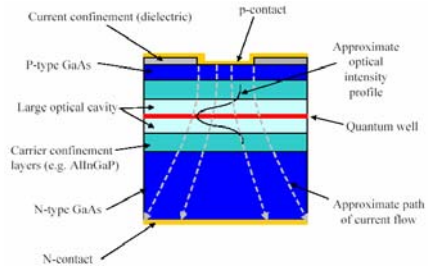
nLIGHT

Laser Cross-Section



nLIGHT

Overall Design Approach



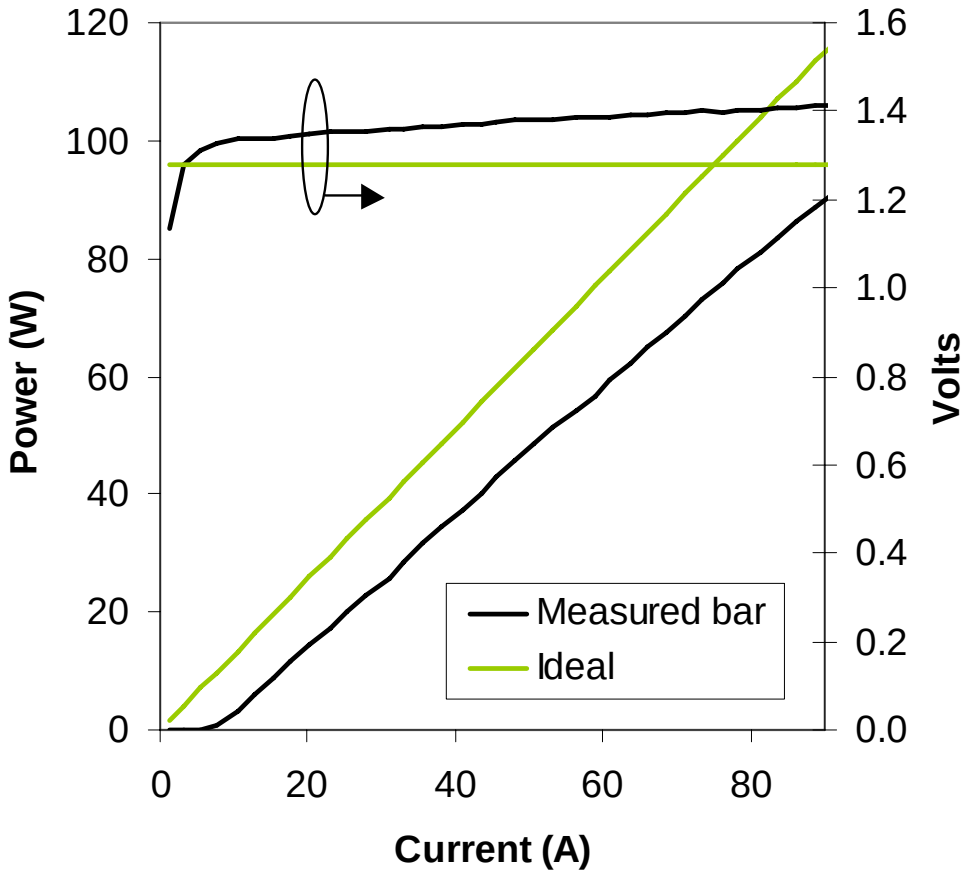
- **Break down all contributors to laser efficiency**
  - Characterize, model, optimize
- **Optimize materials and interfaces by experiment**
  - Contact / interface resistance
  - Bulk mobility
  - Low temperature photoluminescence
- **Systematic approach**
  - Rigorous physics-based modeling
  - Detailed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

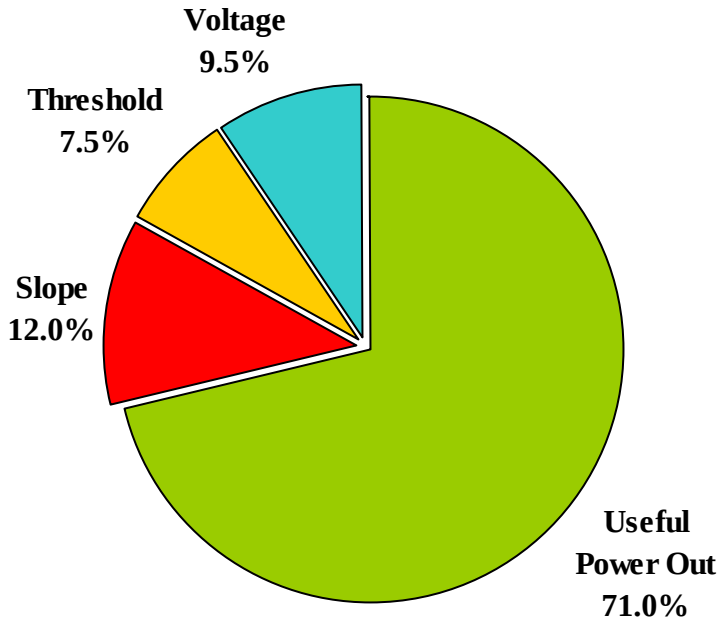
nLIGHT

Collaborations Pursued

Benefit Sought	Technical Approach	Collaborators	Result
Low threshold	Photonic Crystals	2 external groups	No clear path to date to use in product
Low voltage	Edge Injection	1 external group	Hole mobility too low for overall benefit
	Eliminate Junction Voltages	1 external group	Success
Improved slope	"Optimize structure"	1 external groups	Success
Clear Route to Exceed Goals	Detailed Diagnostics	4 external groups	Success
	Theoretical analysis	3 external groups	Success

Remaining Limits to Efficiency

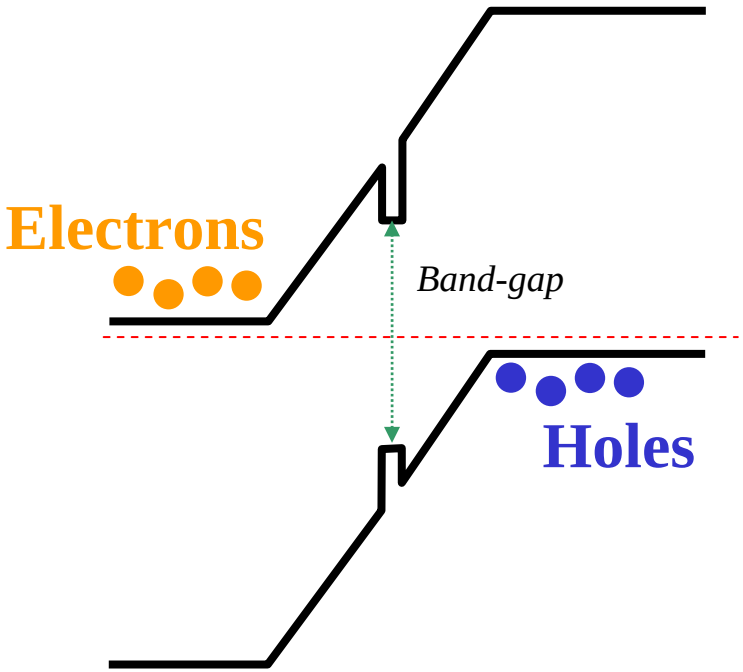




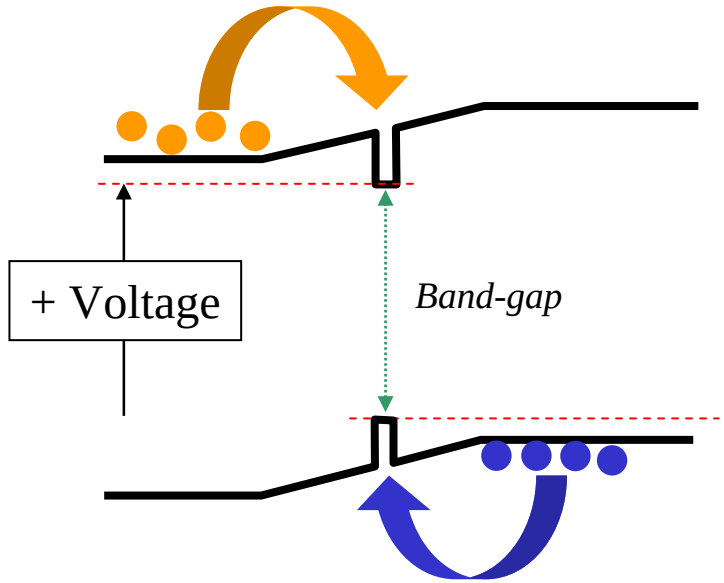
nLIGHT

Key Term 1: Voltage Defect

No voltage



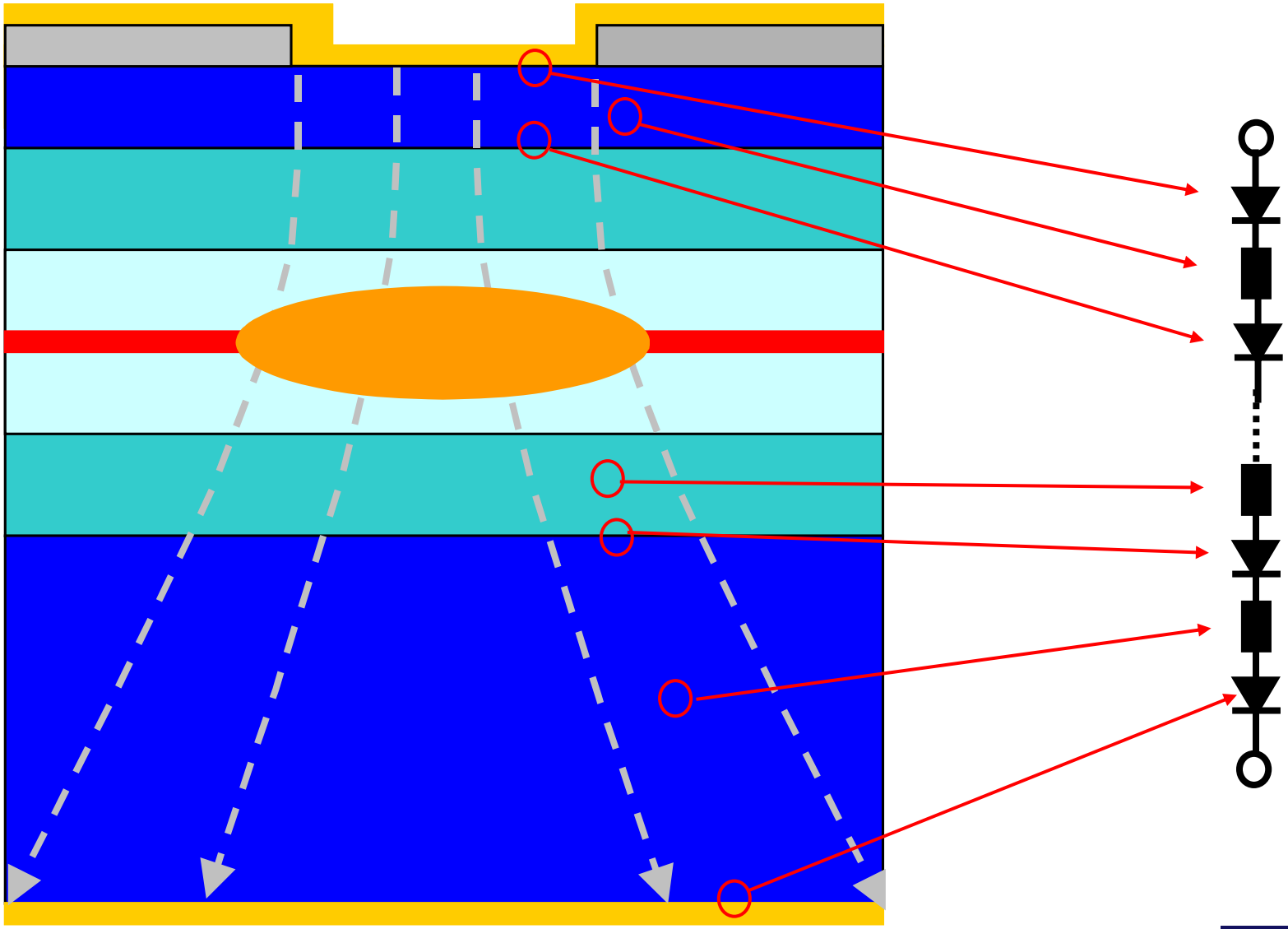
Minimum voltage for lasing



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

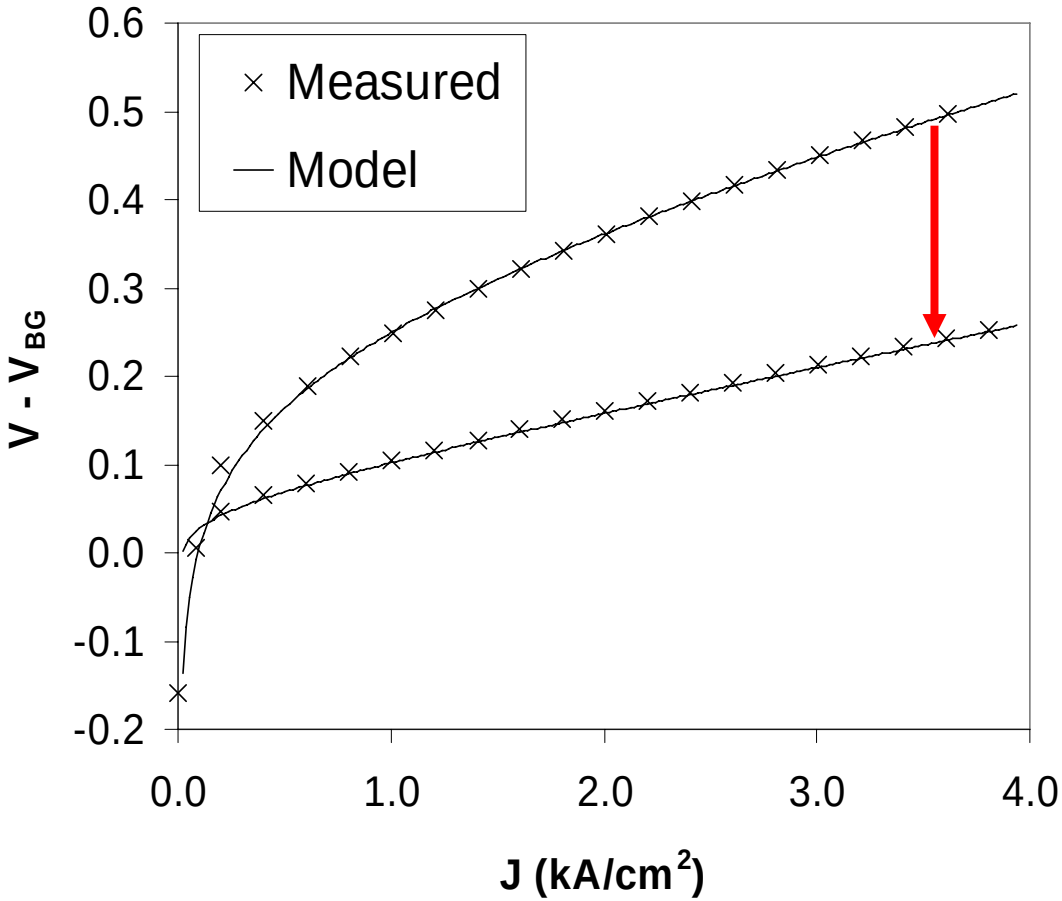
nLIGHT

Every Laser Interface and Bulk Layer Adds Voltage



nLIGHT

Minimize Junction Voltages



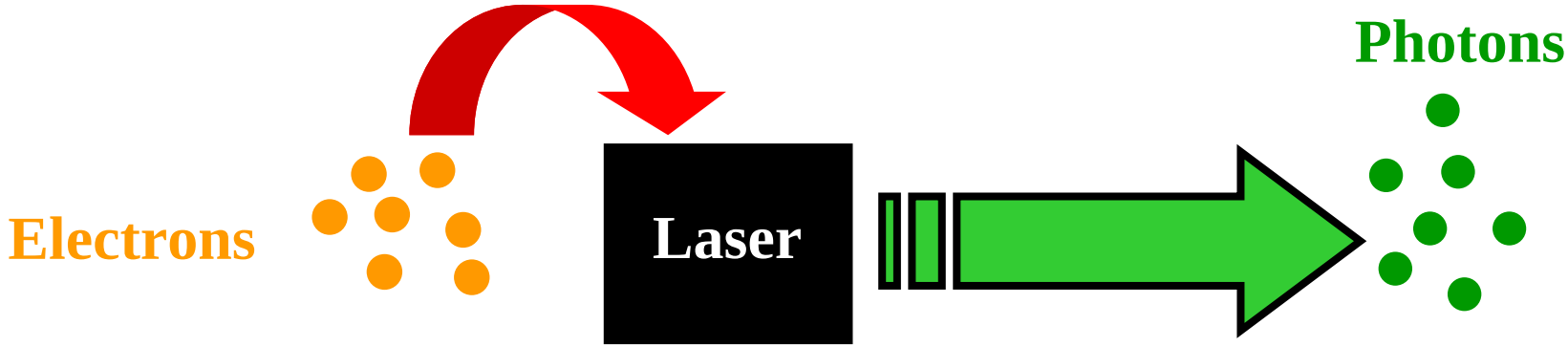
$$V = V_{BG} + \sum_i \sigma_i J + \sum_j V_j \ln\left(\frac{J}{J_j}\right)$$

Resistive Term

Diode Term

nLIGHT

Key Term 2: Photons per Electron (DQE)



Current in, A
Coulombs per second

Scale by charge of electron

Electrons per second in

Power out, W
Joules per second

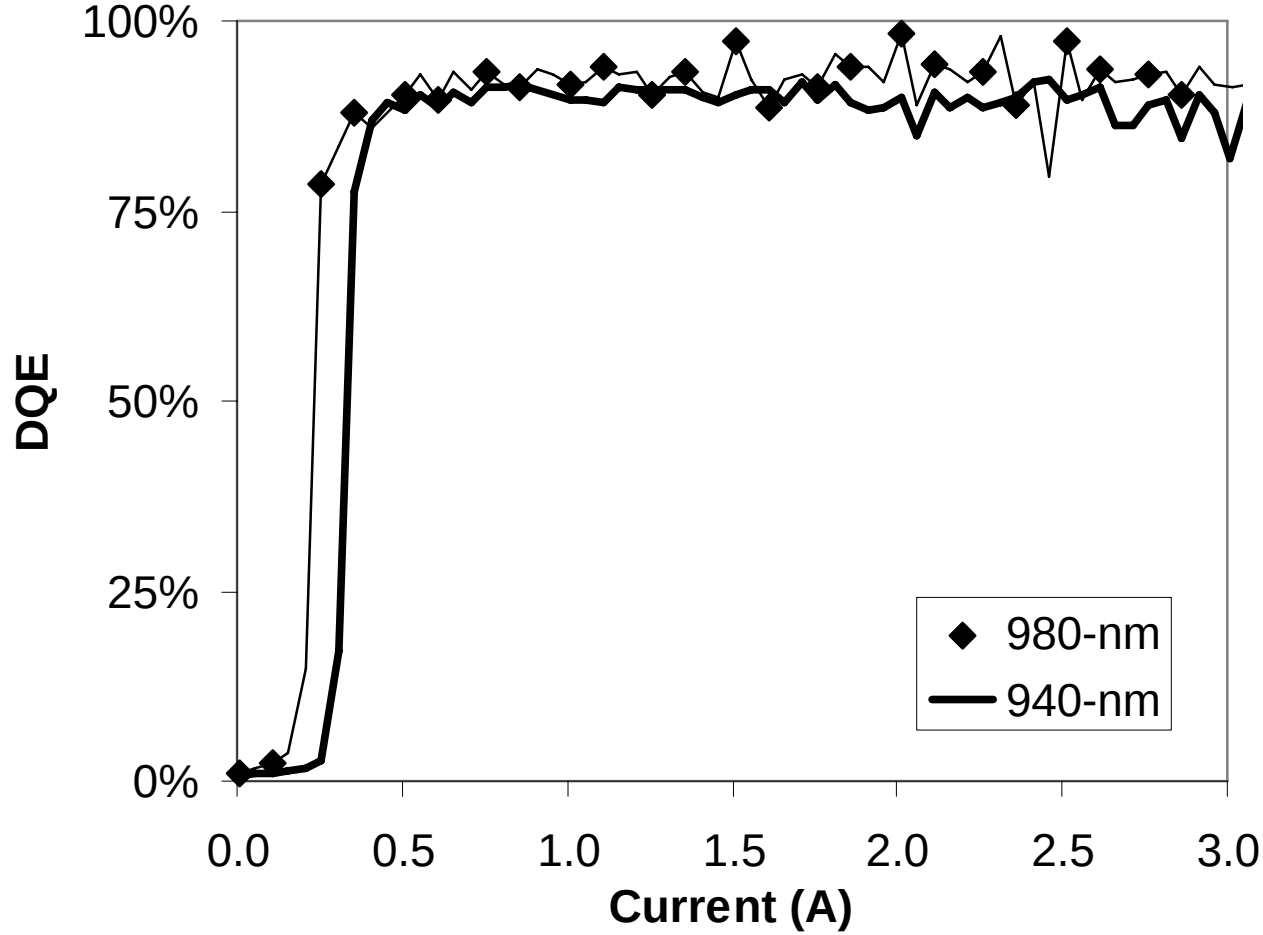
Scale by energy of photon

Photons per second out

Photons out per electron in

nLIGHT

DQE ~ 90% Across Wavelength



nLIGHT

Low Threshold Is Critical for Improvements in Slope Efficiency

$$\text{Slope} = \text{Energy per photon} \times \text{\% supplied electrons converted to useful photons} \times \text{Fraction that gets out laser}$$

Low Threshold Is Critical for Further Improvements in Efficiency

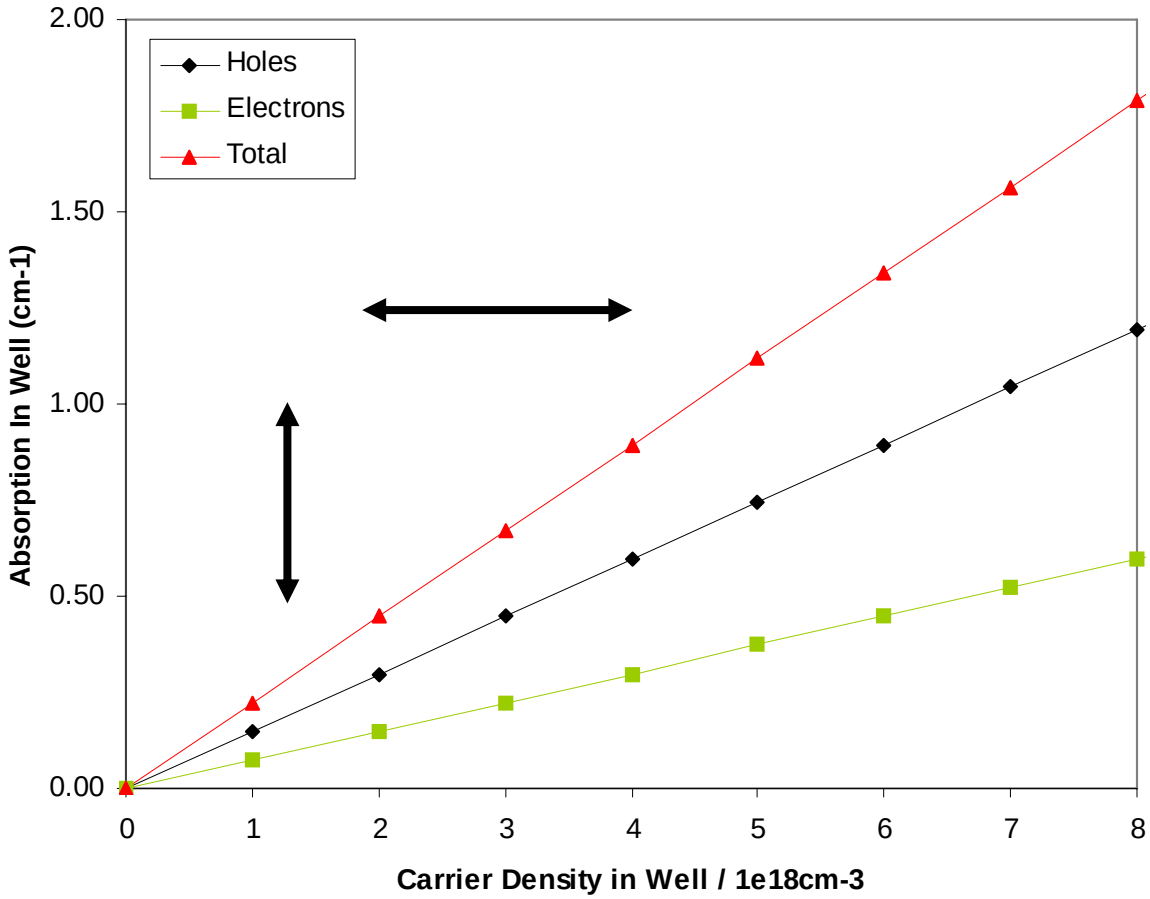
$$\text{Slope} = \text{Energy per photon} \times \text{\% supplied electrons converted to useful photons} \times \text{Fraction that gets out laser}$$

Require > $10^{18}cm^{-3}$ carriers in well to reach threshold

90% of absorption is in the well

Reduce threshold by 50%, efficiency increased by 10%

Theory Supports Most Absorption Being In Well

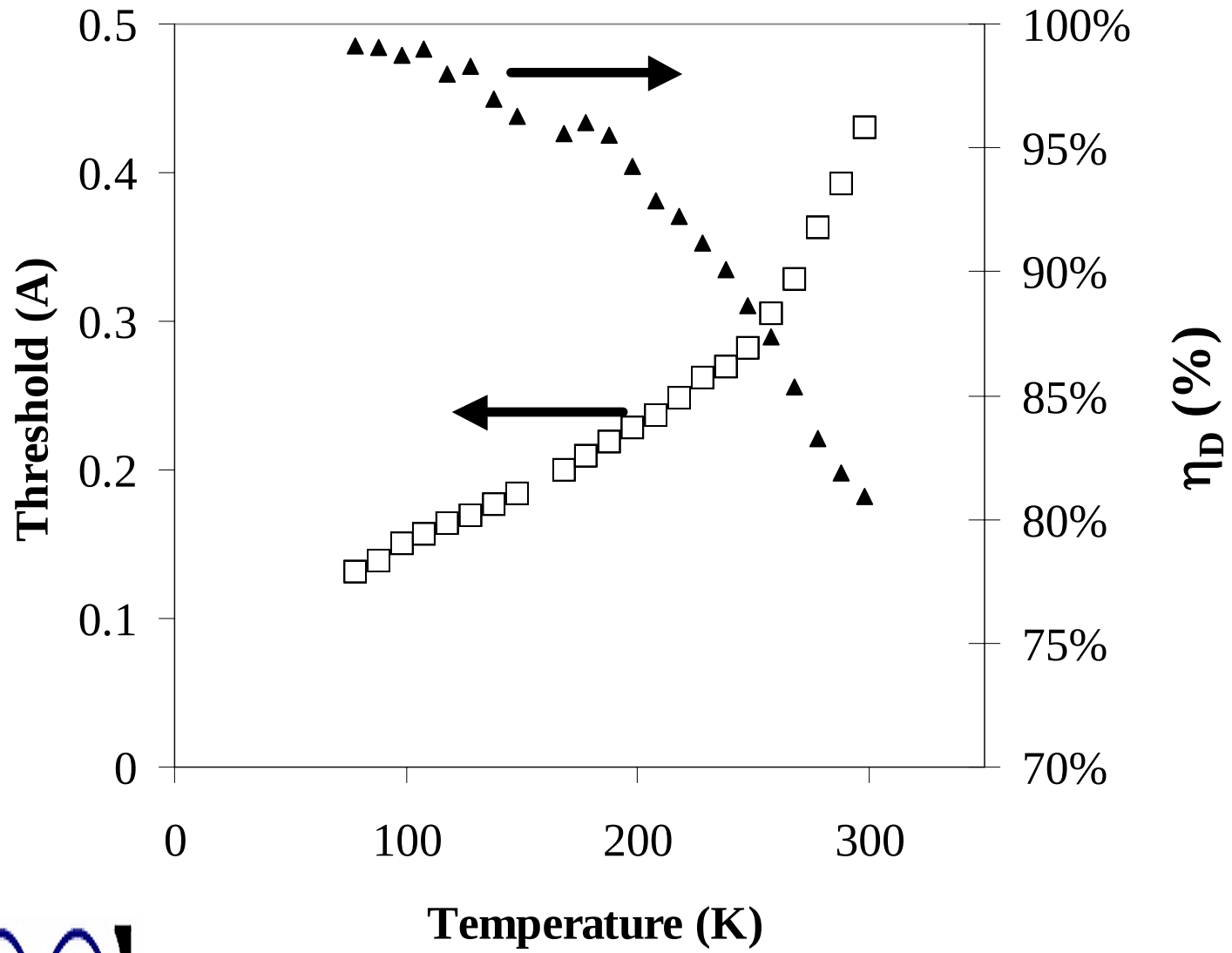


Holes: $12cm^{-1}$ per $10^{18}cm^{-3}$ carriers

Electrons: $6cm^{-1}$ per $10^{18}cm^{-3}$ carriers

nLIGHT

Cryogenic Testing Supports Most Absorption Being In Well



Data courtesy of Directed Energy Solutions, CO

Contents

- **Introduction to nLight**
- **Collaborating with industry e.g nLight**
  - What nLight looks for
  - What nLight offers
- **DARPA SHEDs – case study**
  - Goals
  - Path followed
  - Example collaborations
  - Results obtained
  - Follow-on programs
- **Conclusions**

Conclusions

- **University researchers are key parts of DARPA programs**
  - And many other DoD funded programs
- **nLight is keen to find good collaborators for future programs**
  - And to be a good collaborator!
- **DARPA SHEDs program at nLight had many benefits**
  - Significant progress in diode laser performance
  - Successful product release
  - Supported many Universities
  - Clear diagnosis on root causes and recommended next steps

Paul Crump
paul.crump@nlight.net
Tel: 360-713-5161

nLight Corp
5408 NE 88th St, Bldg E
Vancouver WA 98665
USA

Seeking good collaborators, contractors
Also recruiting engineers, scientists, summer interns

nLIGHT