IESSF Emerging Technologies in Lighting

The Hottest, Smartest, & (Mostly) Non-IoT

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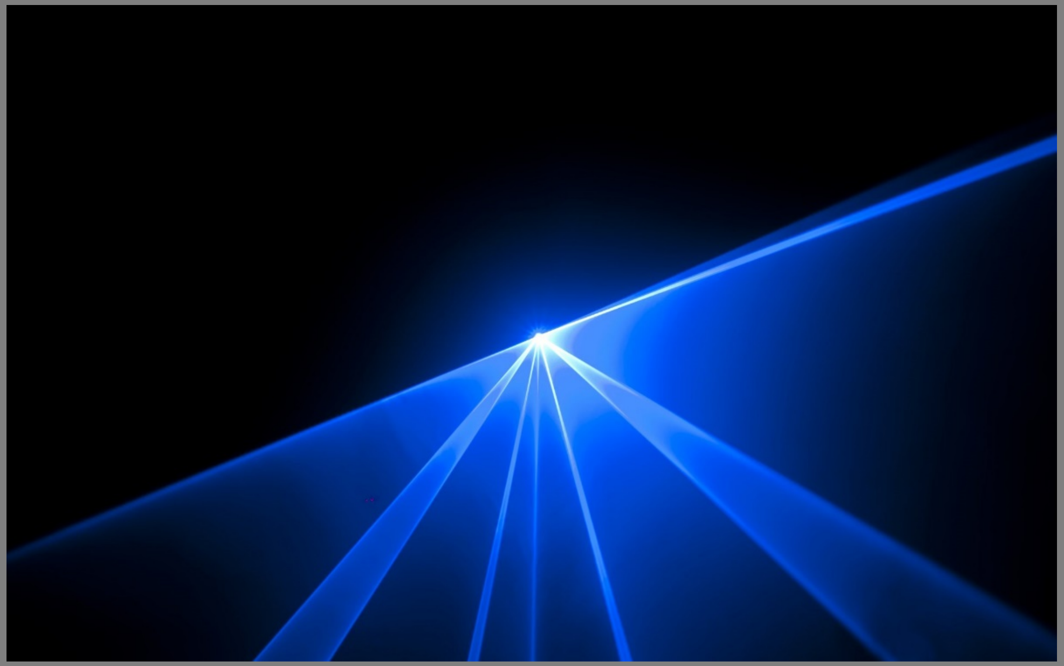
LaserLight

Dr. Paul Rudy

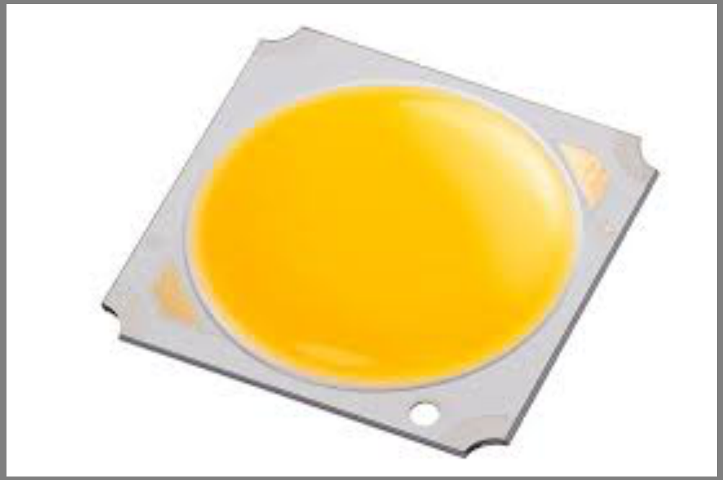
Cofounder and SVP BD, SoraaLaser

Agenda and Key Messages

- **Introduction and Motivation for Laser Illumination**
- Laser Diode Development
- LaserLight Device Development
- LaserLight MicroSpot Module Development
- Outlook for Laser Illumination
- Conclusion



Benefits of High Luminance



Benefits of LEDs:

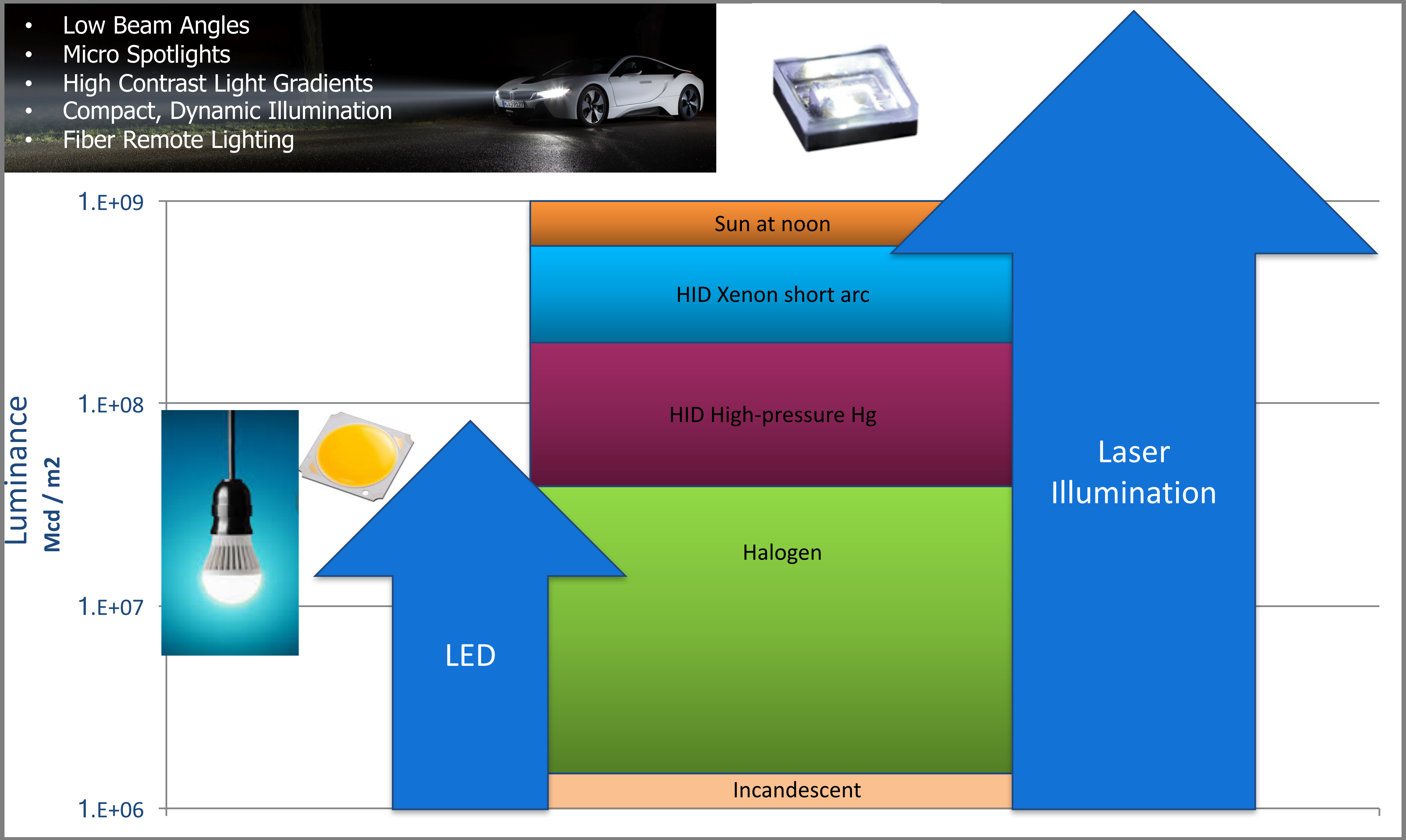
- High Efficiency
- High Reliability
- Mercury-Free (SSL)

Where LED Falls Short:

- Low Beam Angles
- Micro Spotlights
- Ultra Short Throw Illumination
- High Contrast Light Gradients
- Micro Luminaires
- Compact, Dynamic Illumination
- High Efficiency Waveguide Delivery
- Fiber Remote Lighting
- High-Speed LiFi

Luminance is Limiting Broader Solid State Lighting Adoption

LaserLight: High Luminance SSL



Luminance = Spatial Brightness, Etendue, OCF

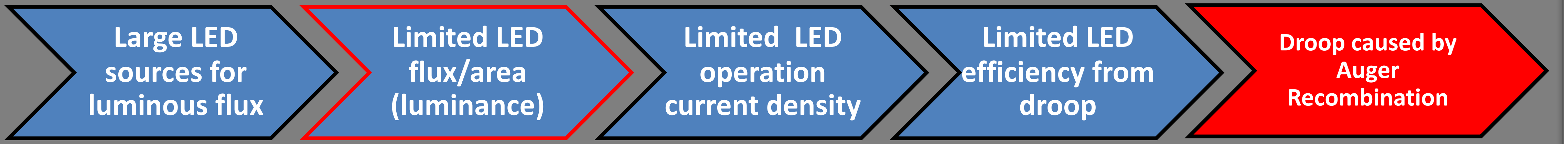
$$\text{Luminance} \; \alpha \; \frac{\text{Lumens Out}}{\text{Solid Angle} \times \text{Emitting Area}} = \frac{\text{Lum}}{\Omega \times \varnothing}$$

<u>This is also known as…</u>

- OCF *(Some SSL Applications)*
- Spatial Brightness *(Physics)*
- Etendue *(Display)*
- Optical Invariant *(Optics)*

Luminance is Limiting LED Adoption

Insufficient LED luminance constrains luminaire beam angle & CBCP



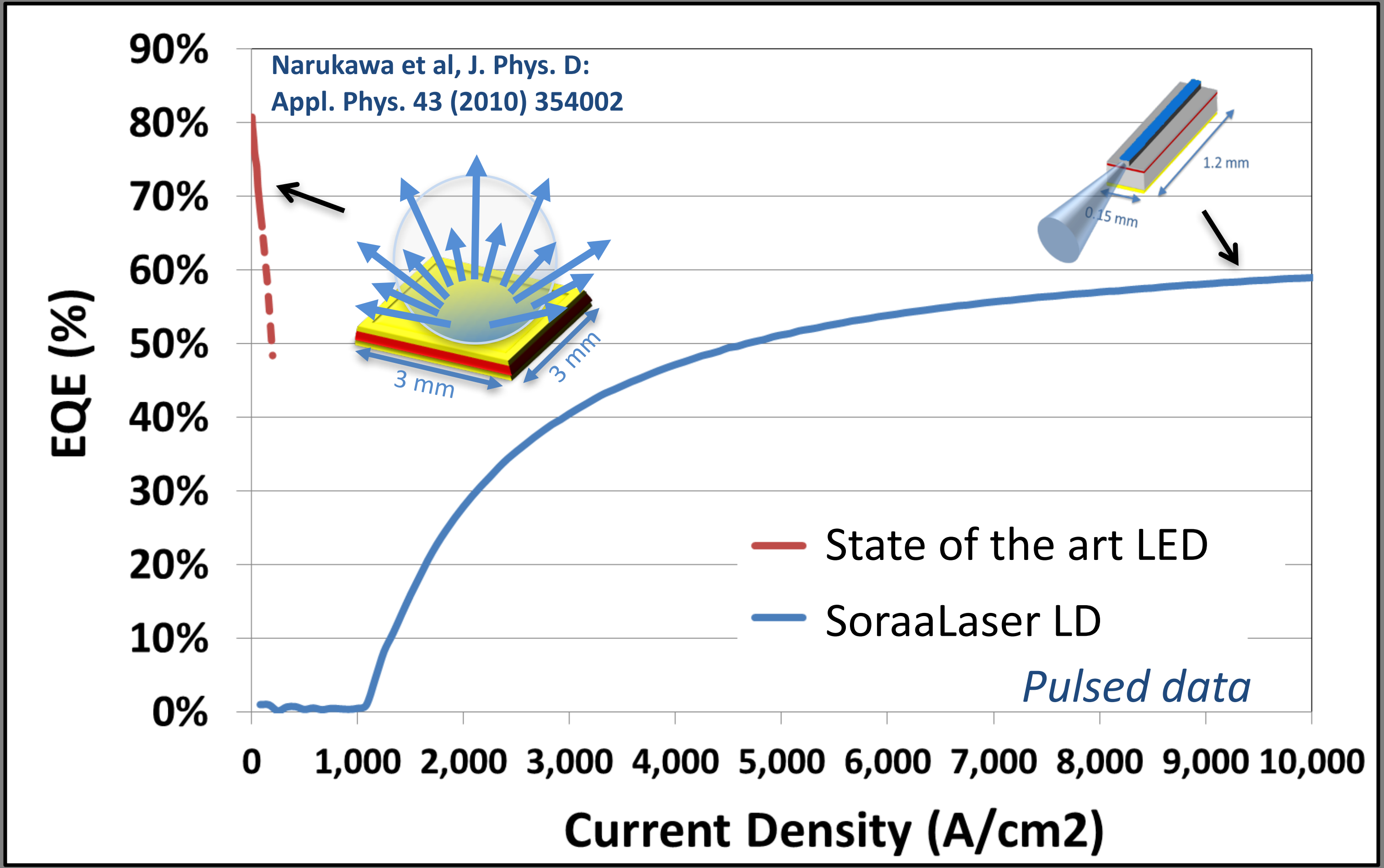
→ ***Limited by fundamental physics; Auger and Conservation of etendue***

"The real focus needs to be on solving lighting challenges where LEDs are still not an obvious choice..... One major LED lighting challenge that remains unsolved is directional indoor lighting."

"It's the optical control that's holding us all back….. Higher OCF can greatly reduce the size and cost of the entire LED lighting system, including optics, drivers and thermal management."

- http://www.solidstatelightingdesign.com/optical-control-factor-the-missing-metric-for-directional-lighting/

Laser Diode vs LED

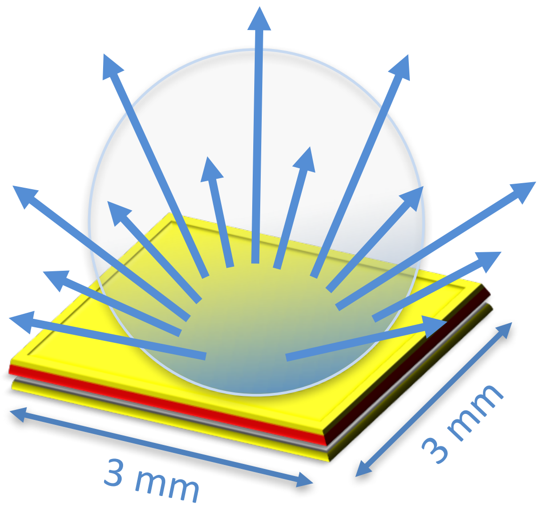


<u>LDs are droop free at 100X the current density of LEDs</u>

- 20X power per chip area [>4W from 0.2mm^2]
- 10,000X power per aperture area [>4W from 35um^2]

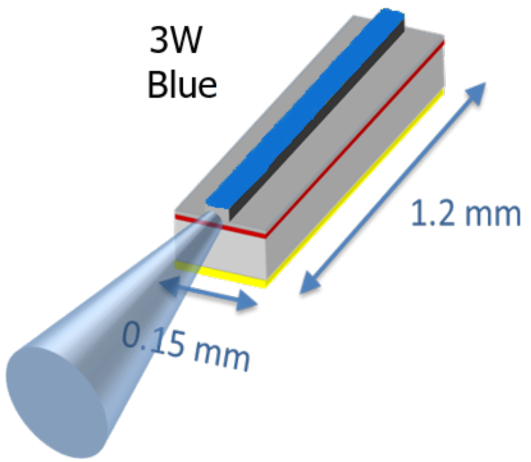
Types of SSL Sources

LED



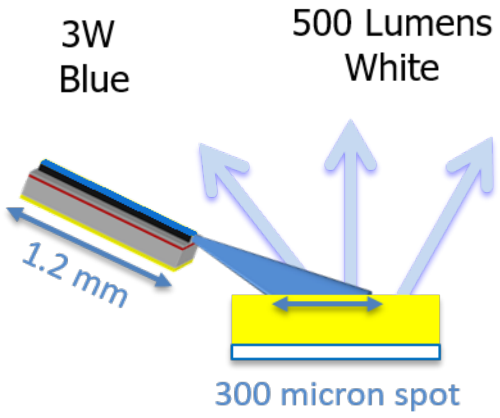
- Low Luminance
- Safe

Direct laser diode



- High Luminance
- Not Safe

LD Phosphor (LDP)



- High Luminance
- Safe

- **LDP Low Etendue + High brightness make ideal excitation source versus LED**
- **LDP Incoherent emission provides safety & regulatory acceptance versus direct LD**

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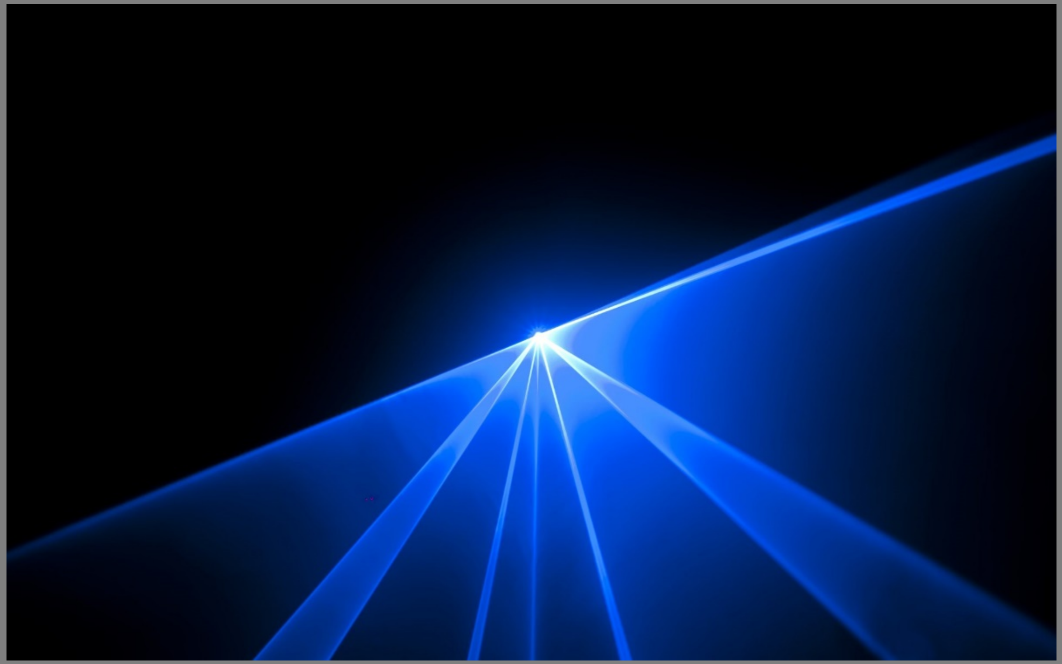
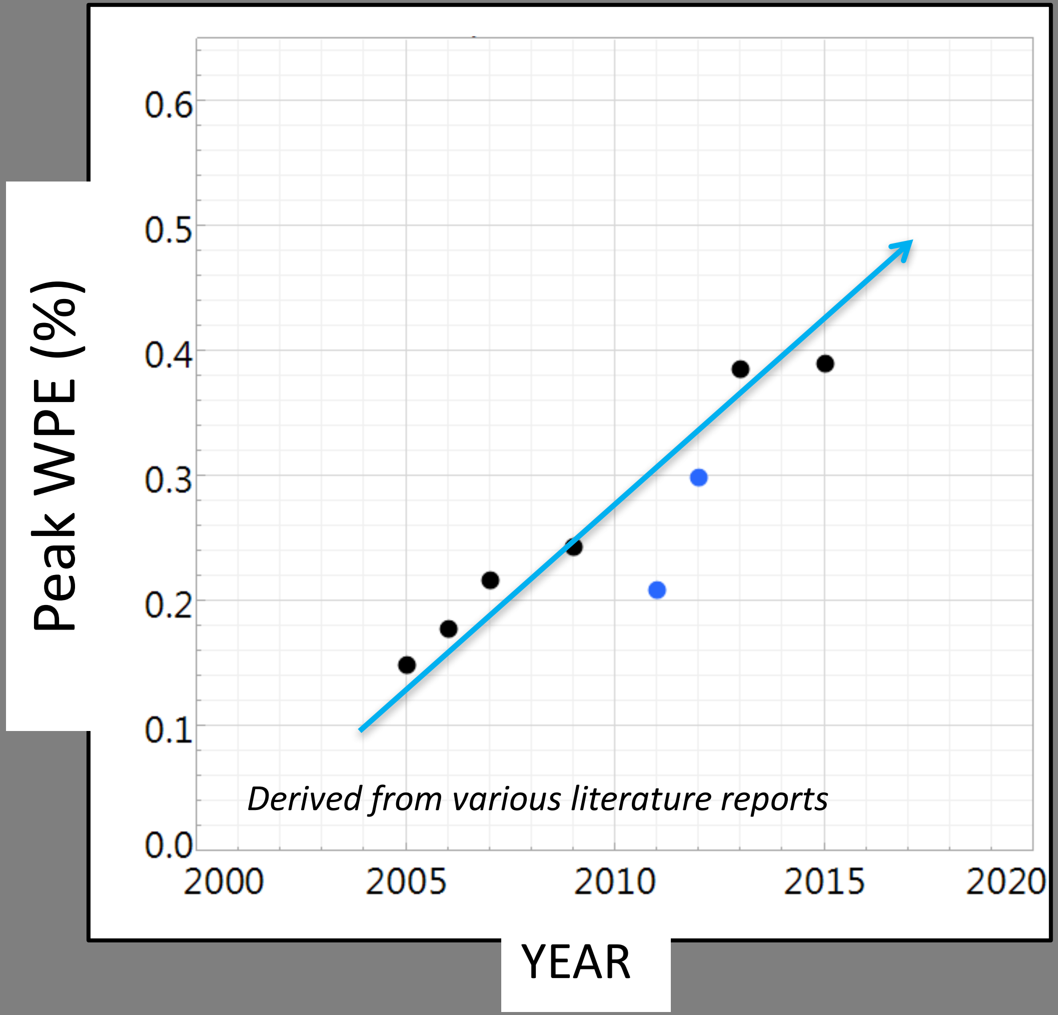
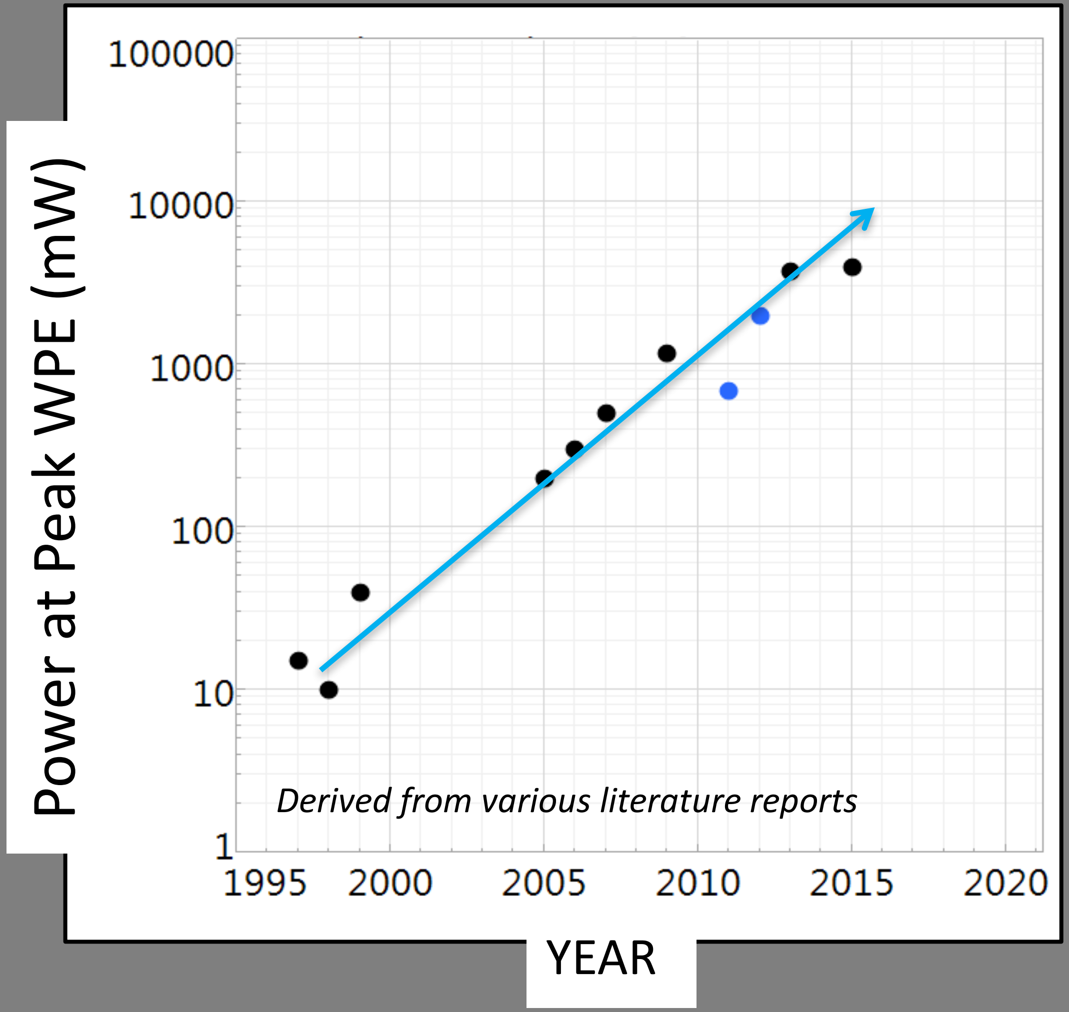


Laser Diode Progress

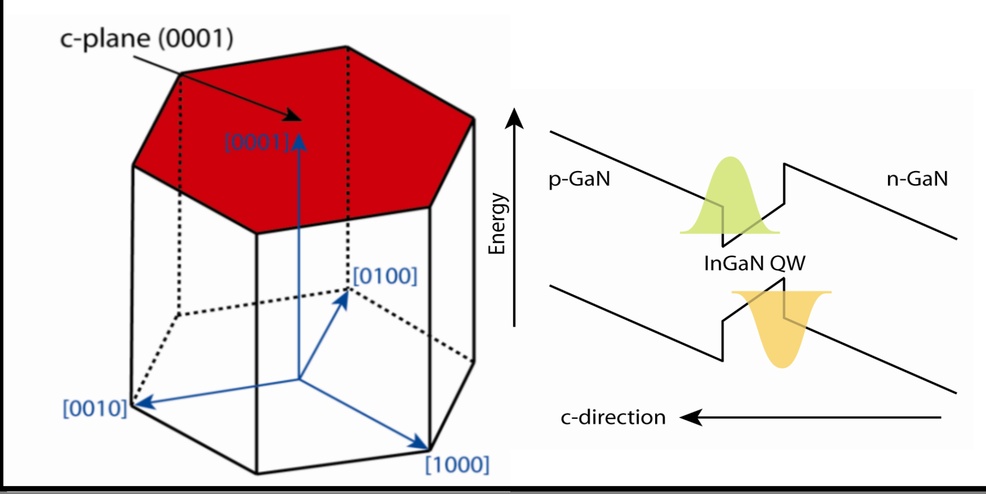




WPE increased from 15% in 2005 to ~40% in 2015 (GaAs LDs at >75%)
P @ max WPE increased from 10mW in 1997 to 4W in 2015

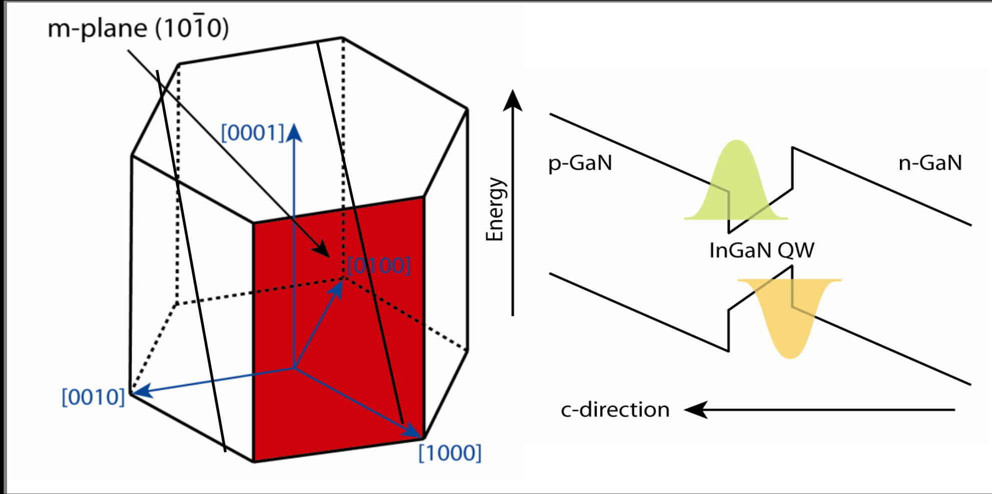
SoraaLaser SemiPolar Technology

Conventional Technology: C-plane



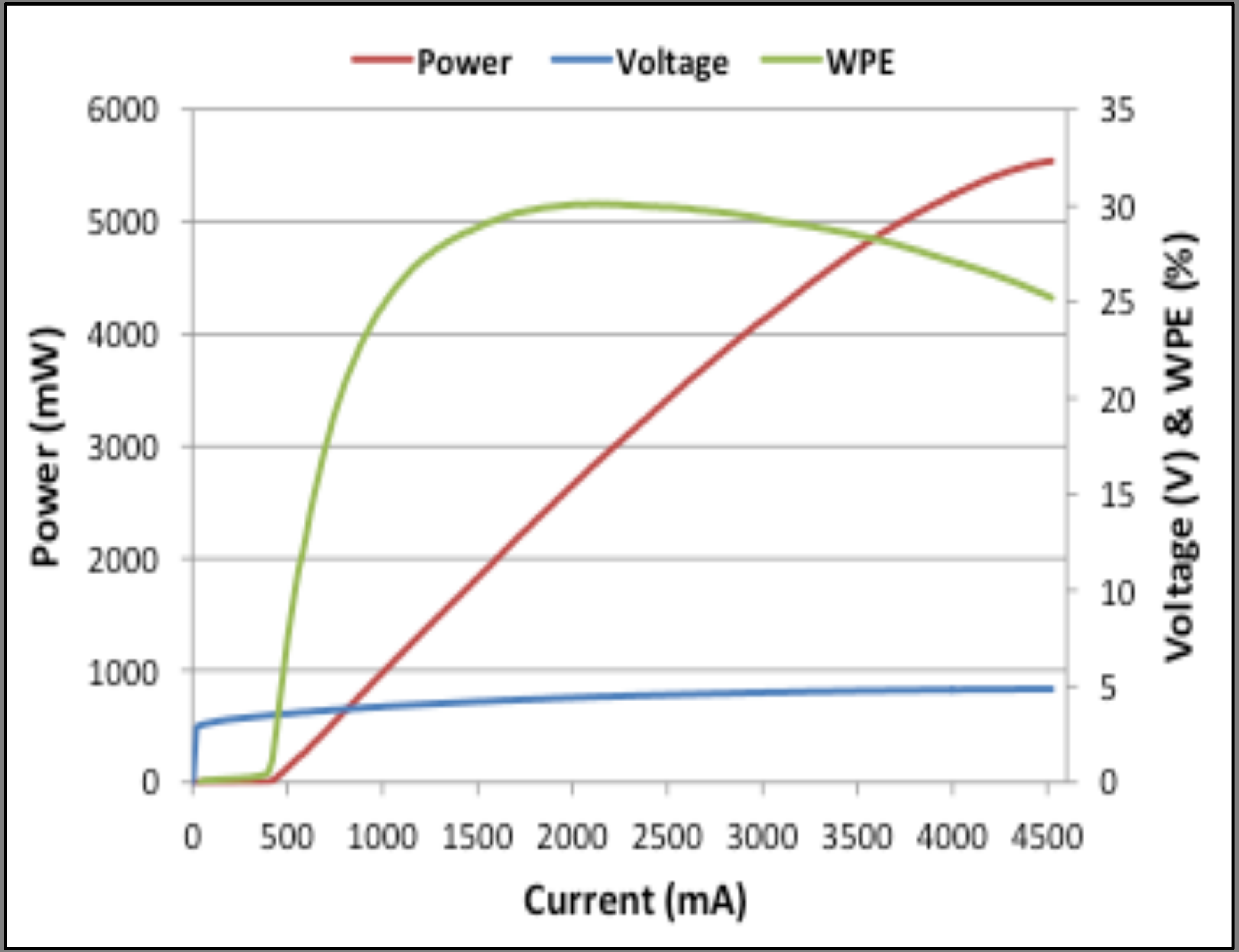
- Electron and hole pairs separation due to polarization
- Lower radiative recombination rate -> low gain
- Highly constrained epi; thin QWs & Al cladding layers
- Performance and efficiency ceiling resulting from constraints

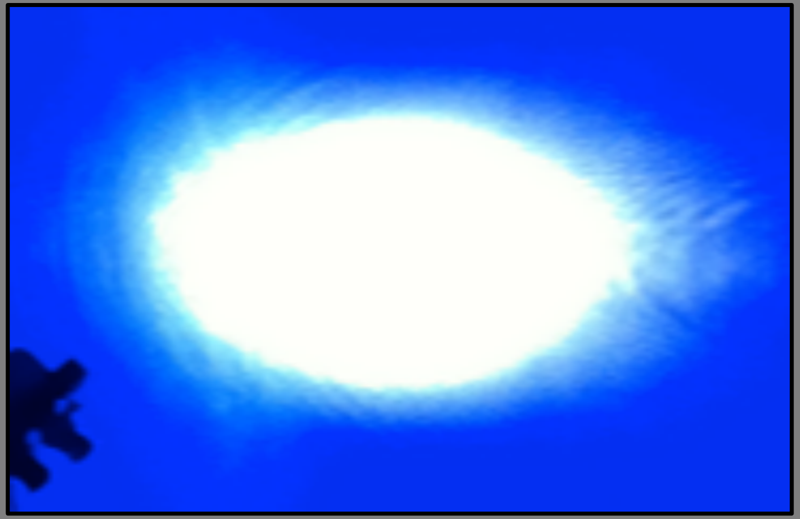
SoraaLaser Technology: Semipolar

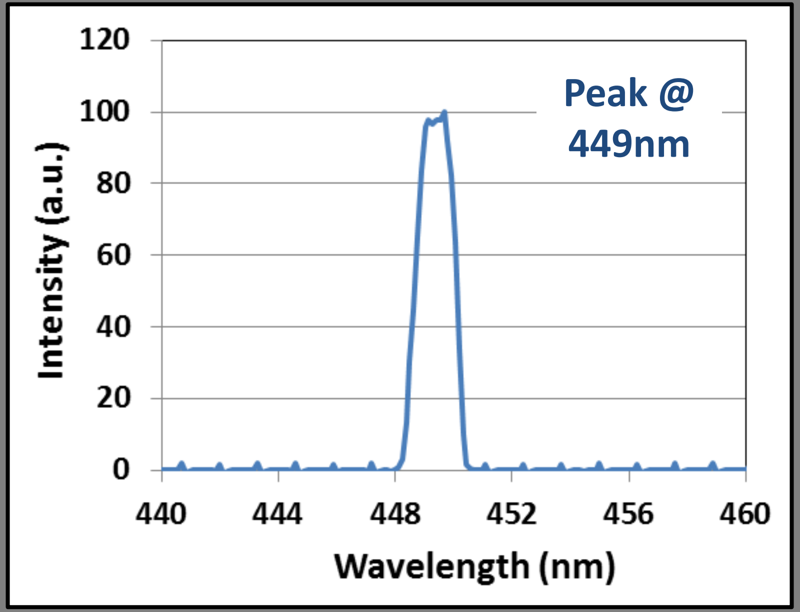


- Mitigated separation of electron and hole pair
- High radiative recombination rate -> high gain
- 3x higher gain enables highest efficiency & output power LDs
- Flexible epi design: Thick QWs, optimized claddings

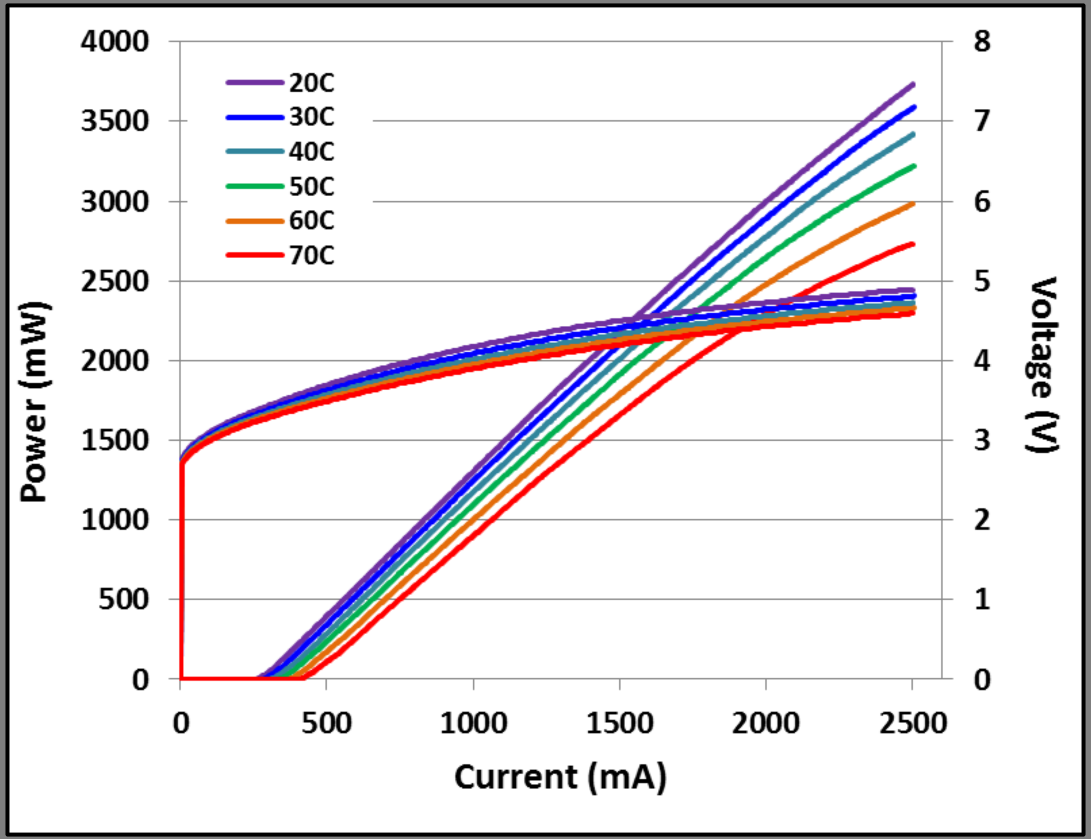
High Power LD with > 5W CW

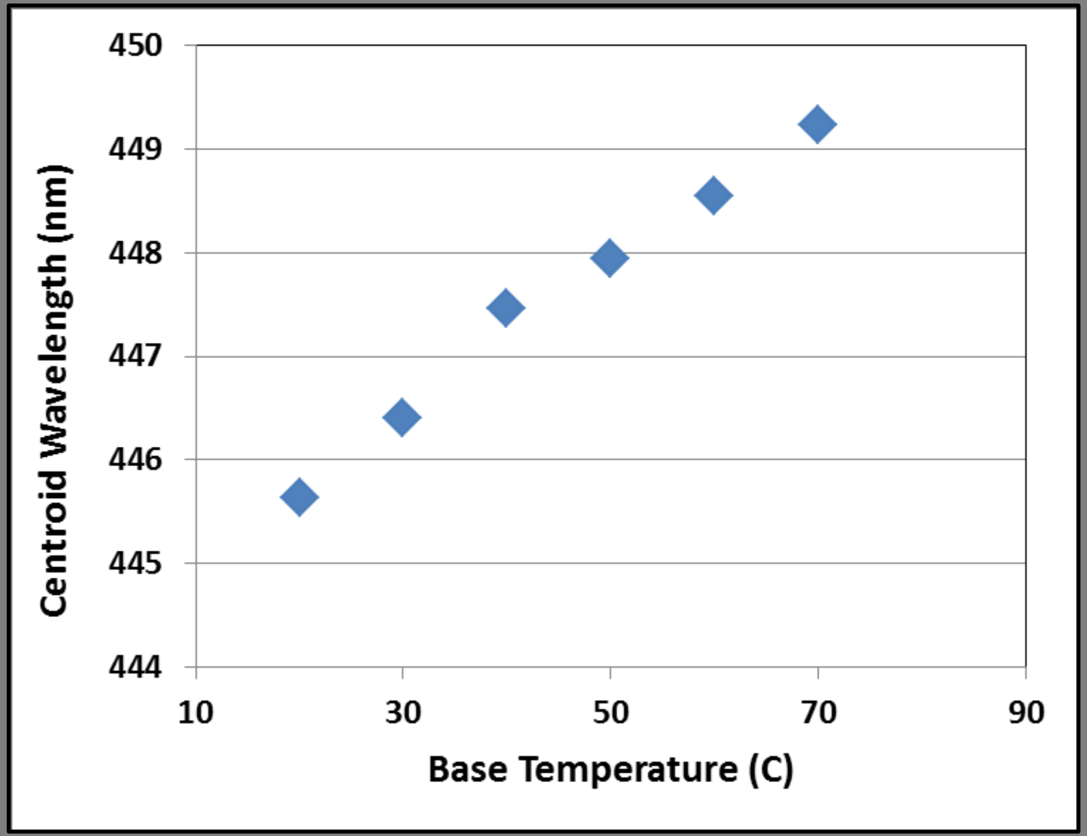






High Power Blue LD Temp Performance





Continuous Wave Performance vs Temperature

- 20um x 1200um on submount
- Case temp 20-70°C
- 0.07nm/°C

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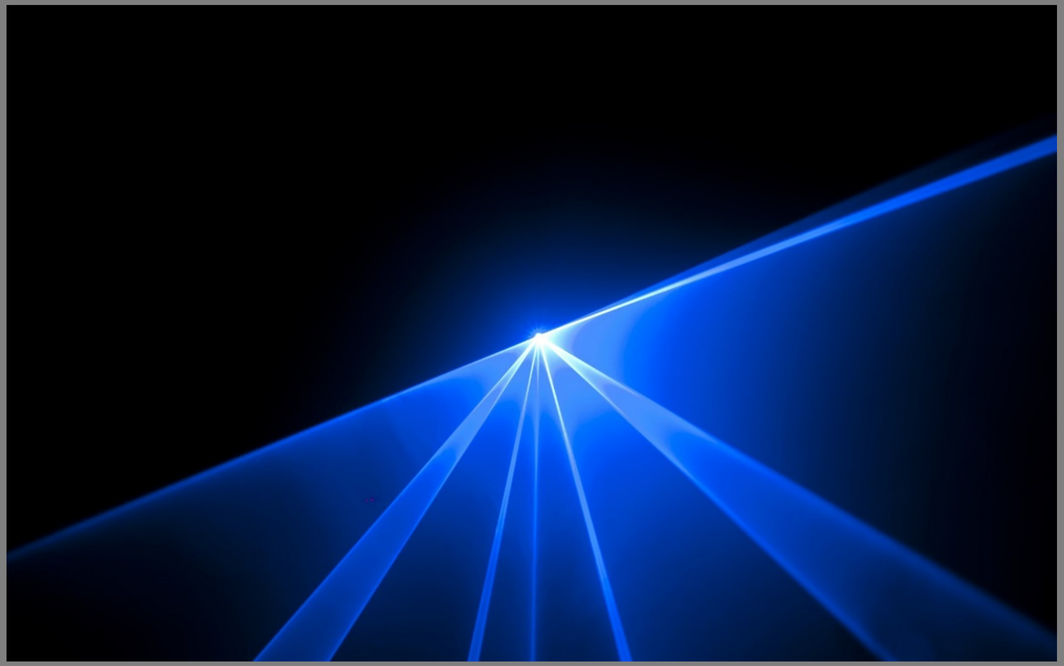
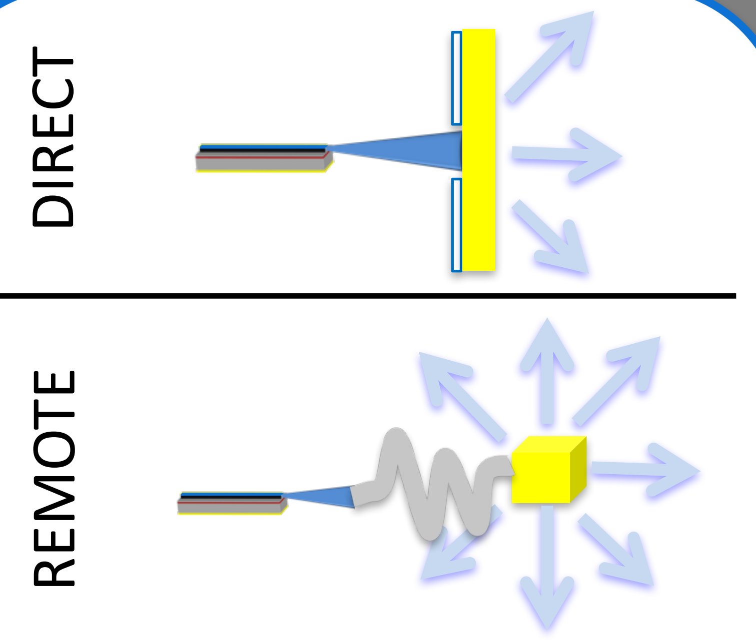


Laser Pumped Phosphor Configurations

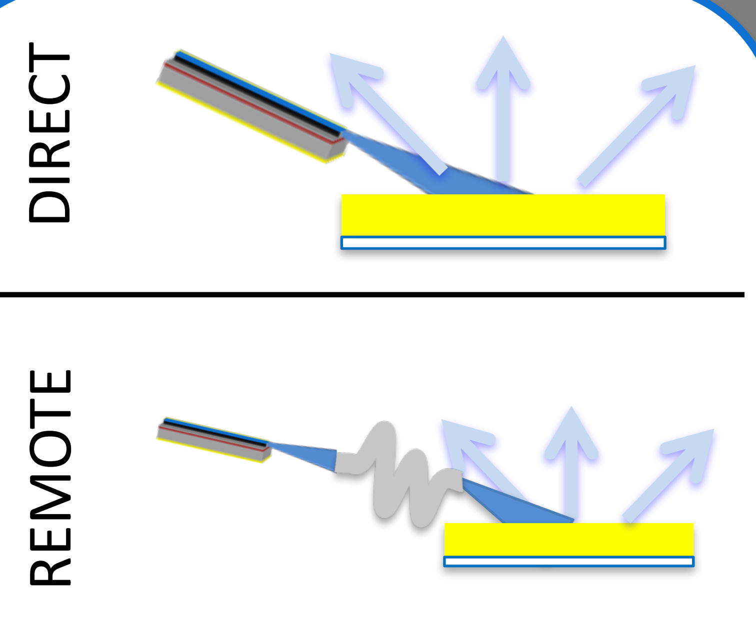
LDP >100X brighter than LED + safe incoherent emission

Transmission



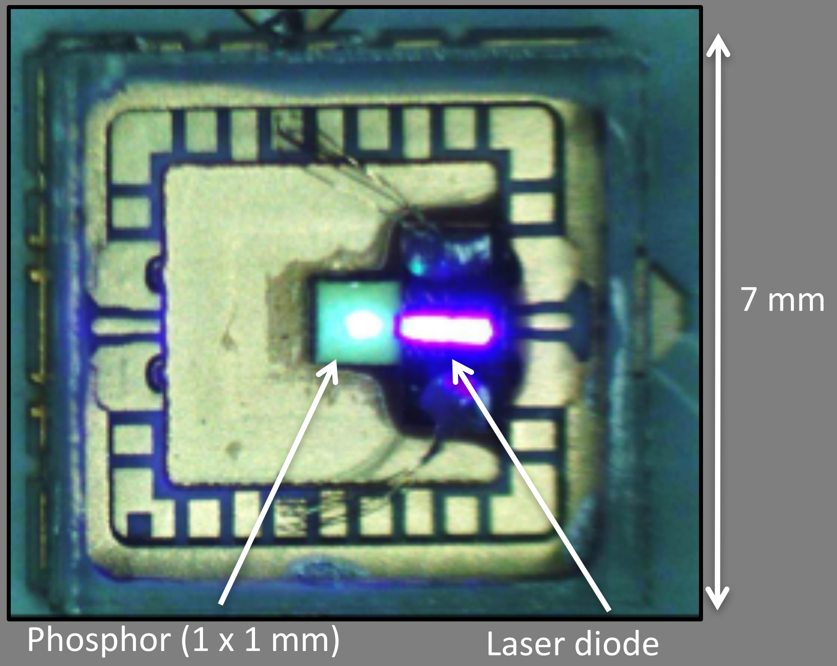
- Easy Optical Access
- Safety Challenges
- Thermal Challenges

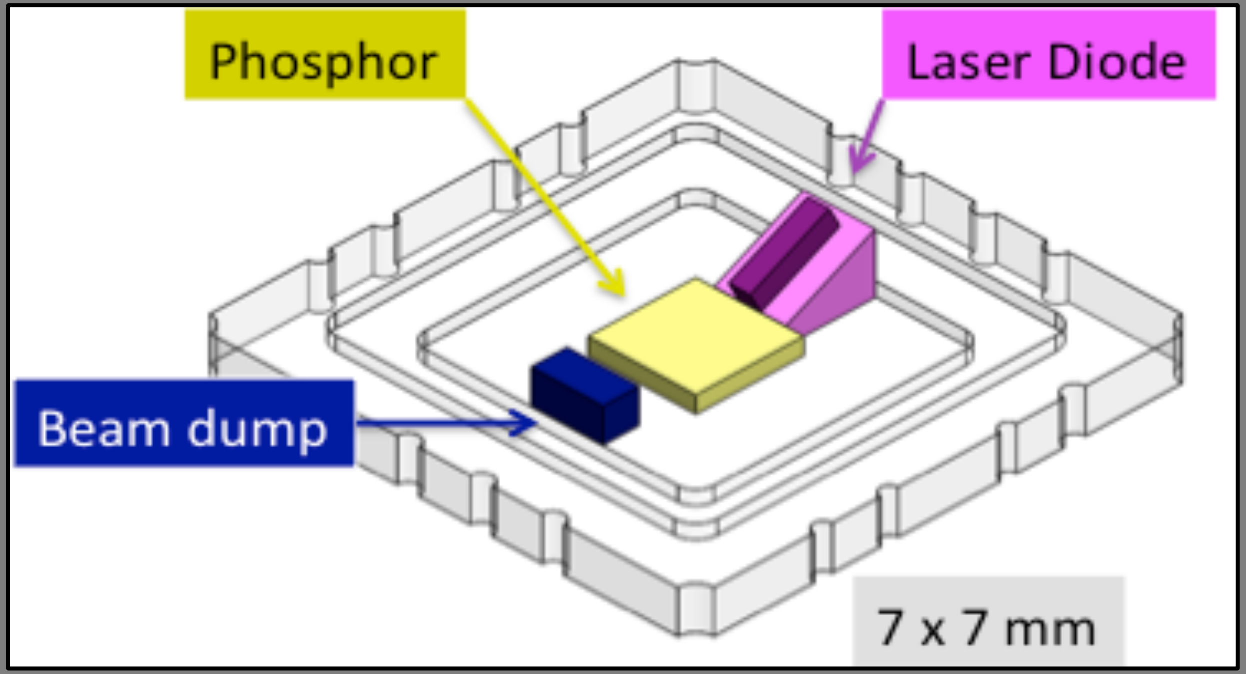
Reflection



- Careful Optical Design Needed
- Safety by Design
- Excellent Thermal Performance

White LaserLight SMD

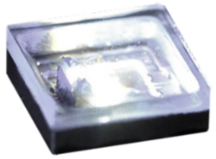




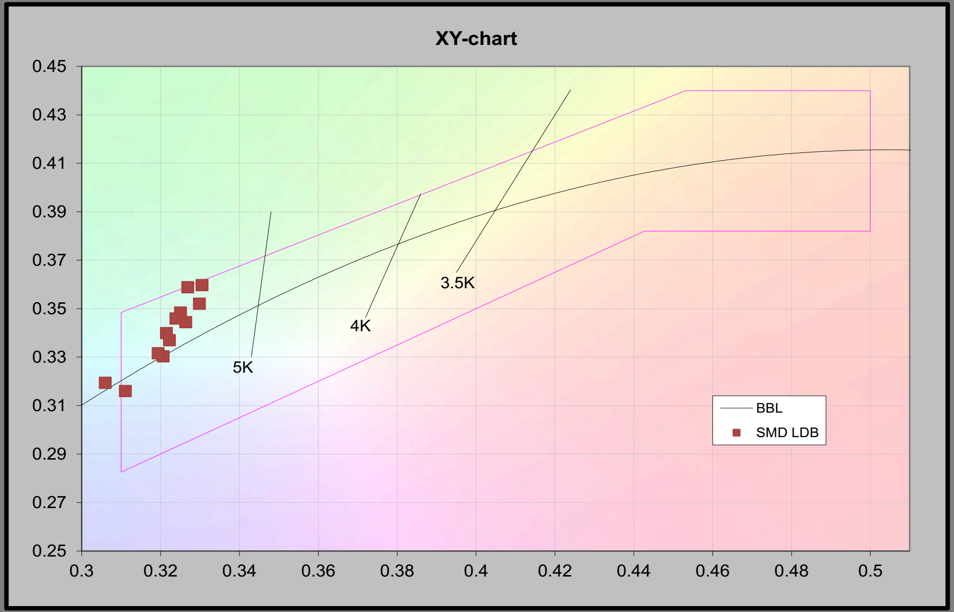
- 300 - 500 lumens from 300 – 400 micron emission diameter
- Enables <2 deg beam angle from 1” optics
- Safe reflective design with beam stop for residual Fresnel reflection
- Compact SMD package for integration with starboards and drivers

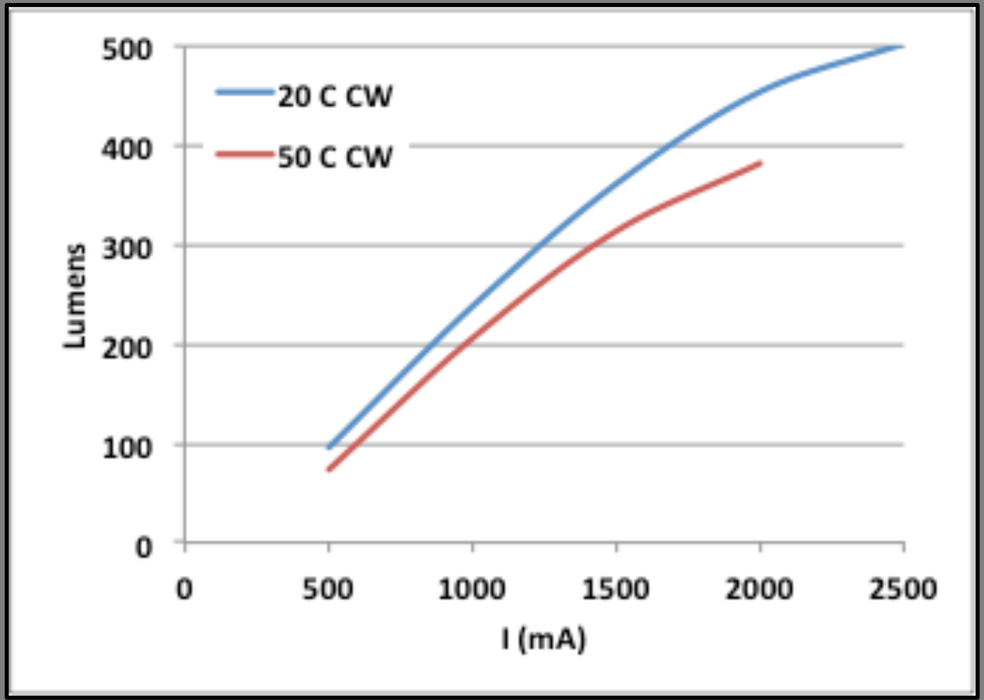
White LaserLight SMD Performance

LaserLight-SMD



7 x 7 mm



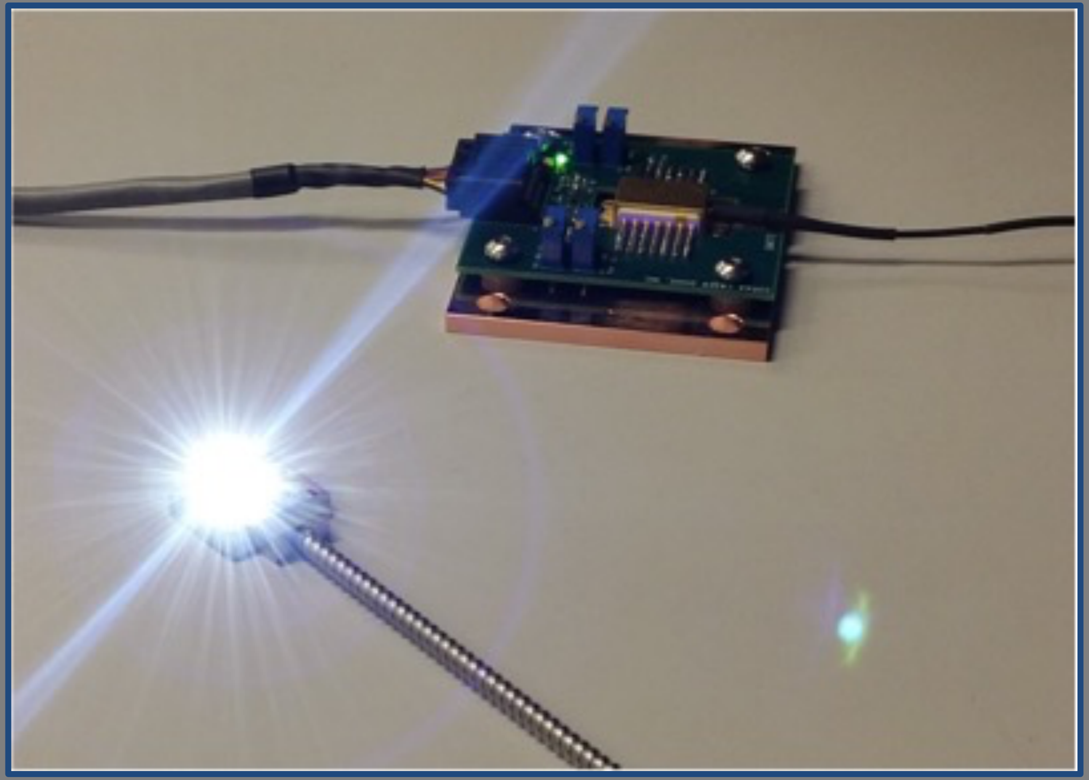


Parameter	Average Values
CCT	5825 K
CRI	63%
Cx	0.325
Cy	0.345

Fiber Delivered Laser Light Sources

Technology approach

- High power blue semipolar laser diode
- Thermally stable, mil standard compliant, space qualified packaging
- Remote reflective phosphor
- Monitor detectors in laser module for safety

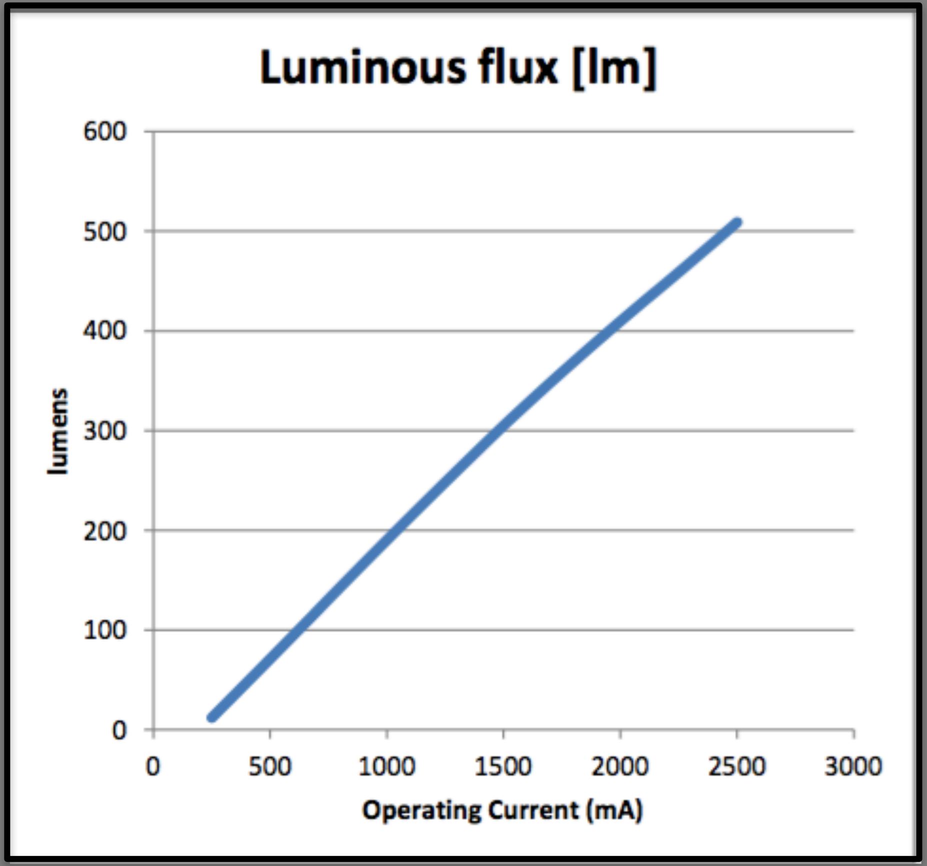


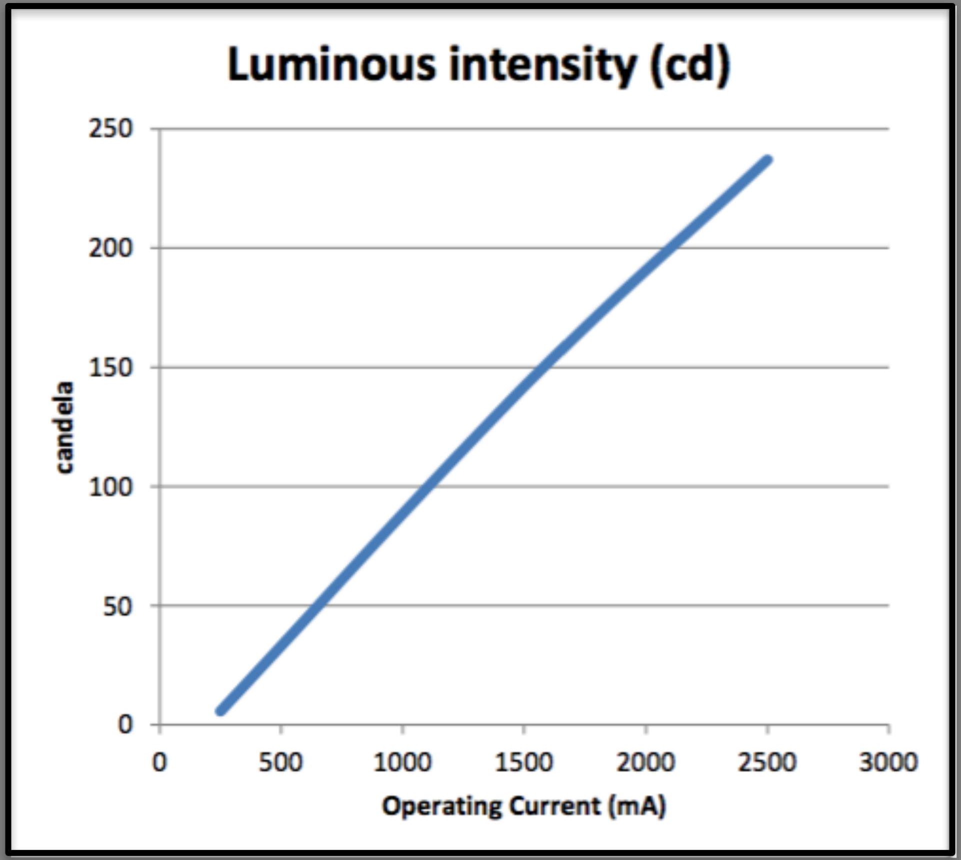
"Remote lighting" or "Central lighting"

- Within buildings, bridges, tunnels, stadiums
- Bury the electronics and light sources
- Passive illumination head

Fiber Delivered White Light Sources

>500 lumens achieved from package, ~450 lumens form 60deg cone

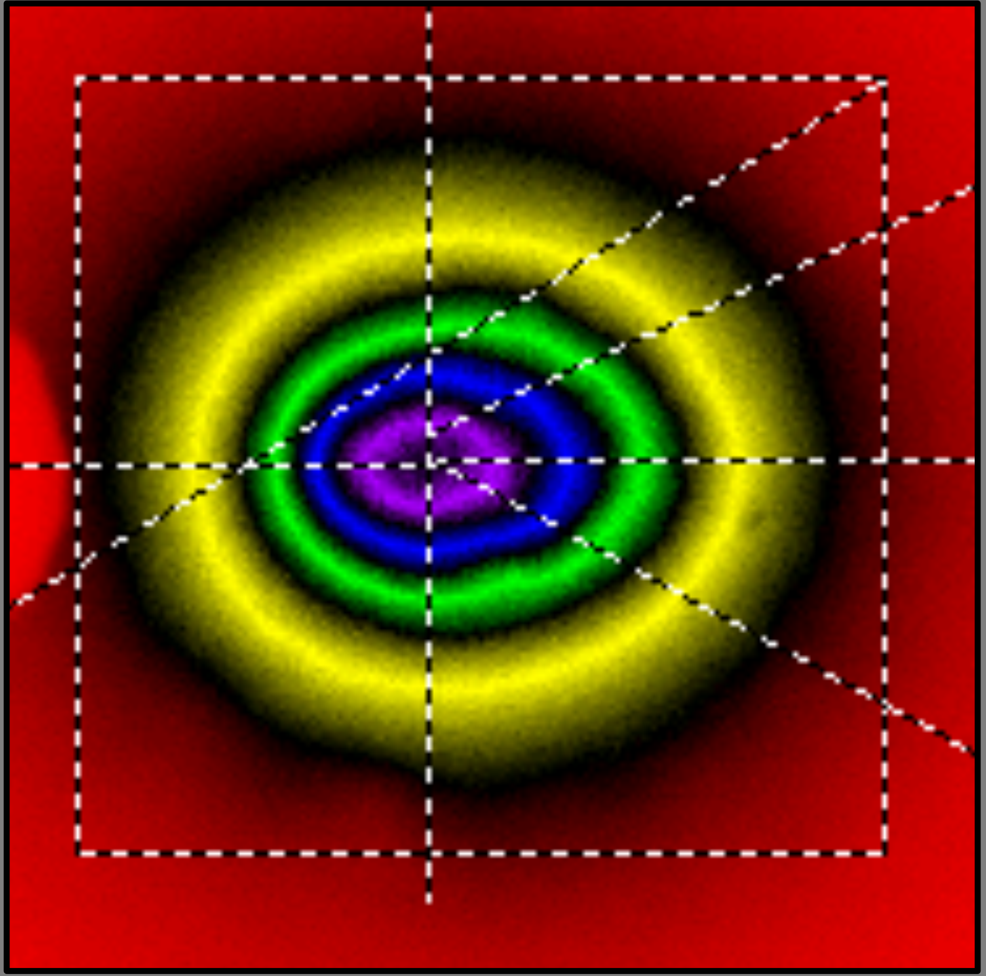


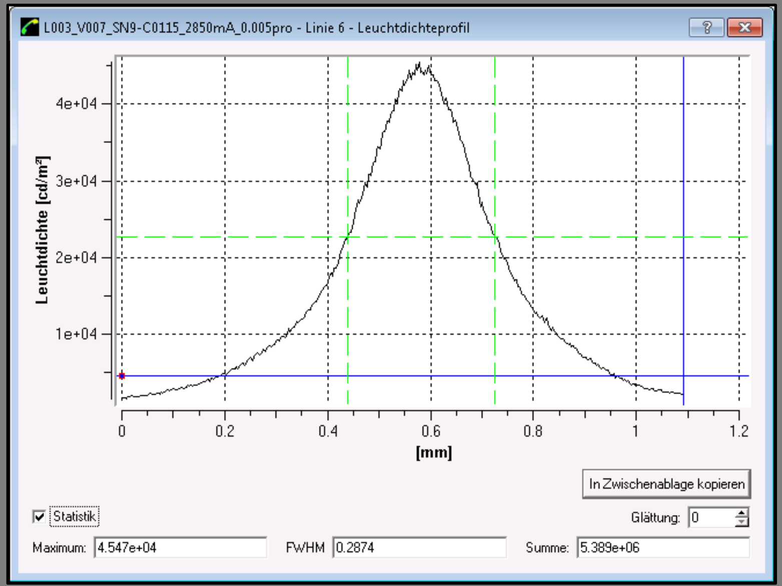


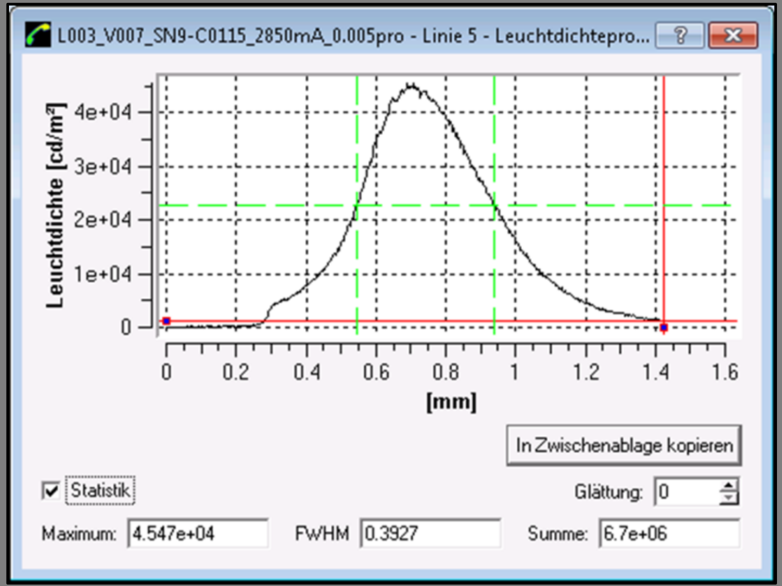
Fiber Delivered White Light Sources: Luminance

336 micron spot achieved, 200 candela, 960 cd/mm2 achieved

Spot-Size	Short axis	287	µm
	Long axis	393	µm
	Mean diameter	336	µm

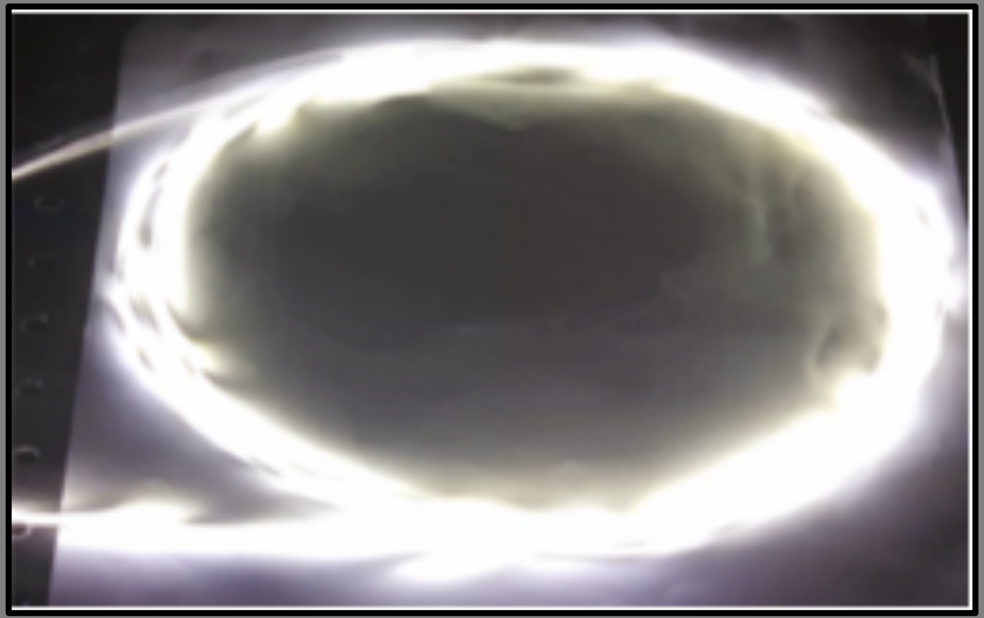






White Light Emitting Fiber Sources

Laser collimation enables side-emitting fiber sources



New linear sources possible

- ✧ <1mm diameter vs LED T5 at 16mm diameter
- ✧ Long, sharp stripe of light 12” wide from 30’
  ie, ~ 2 degree beam angles

Several approaches possible

- LDP white light enters fiber and is side scattered
- RGB laser enters the fiber and is side scattered
- Blue laser light enters fiber and is side scattered, pumps phosphor on fiber

Analogous story in 2D waveguides as well

Laser fiber light demo: >400 lumen white, Omnidirectional line emission

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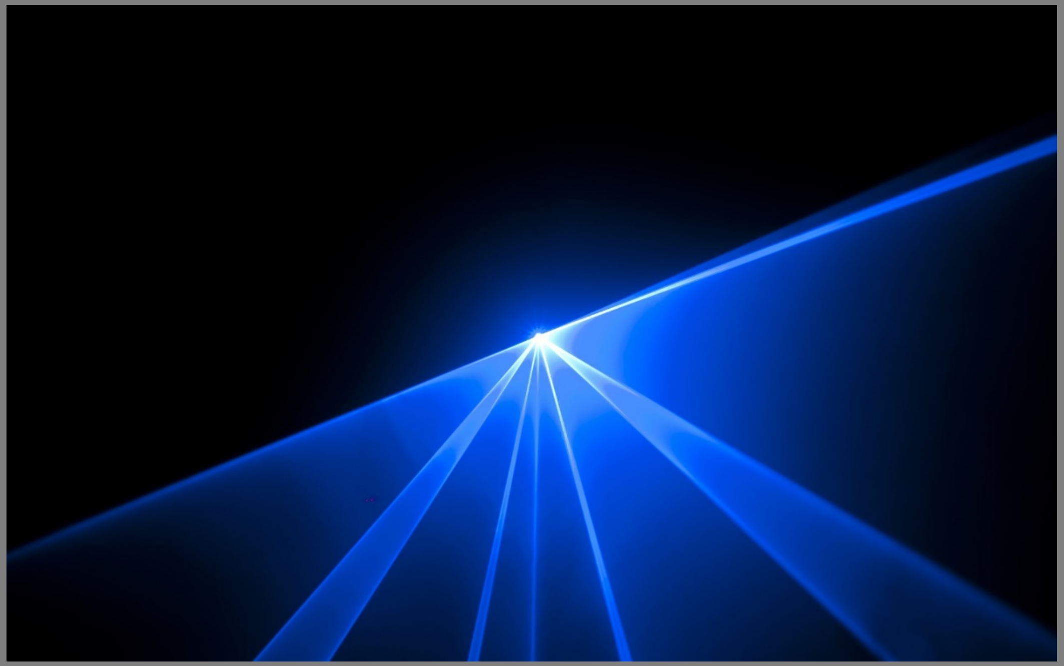
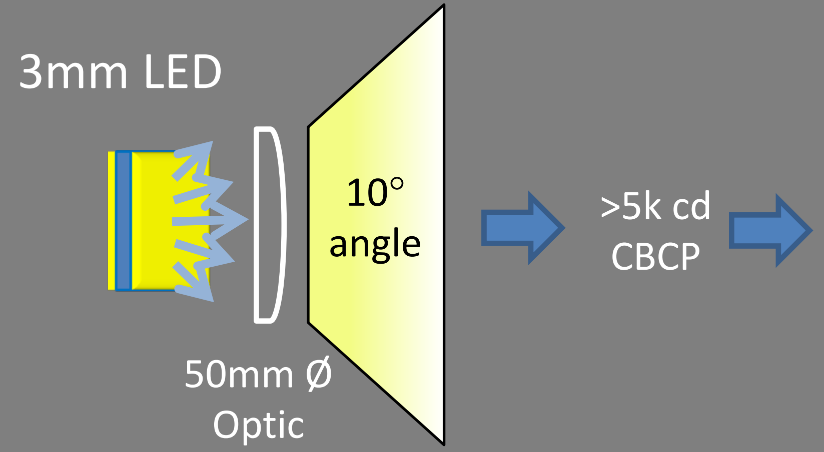


LaserLight: 100X Luminance of LED

Example Light Sources: 500 lm from 50mm optic

LED Source

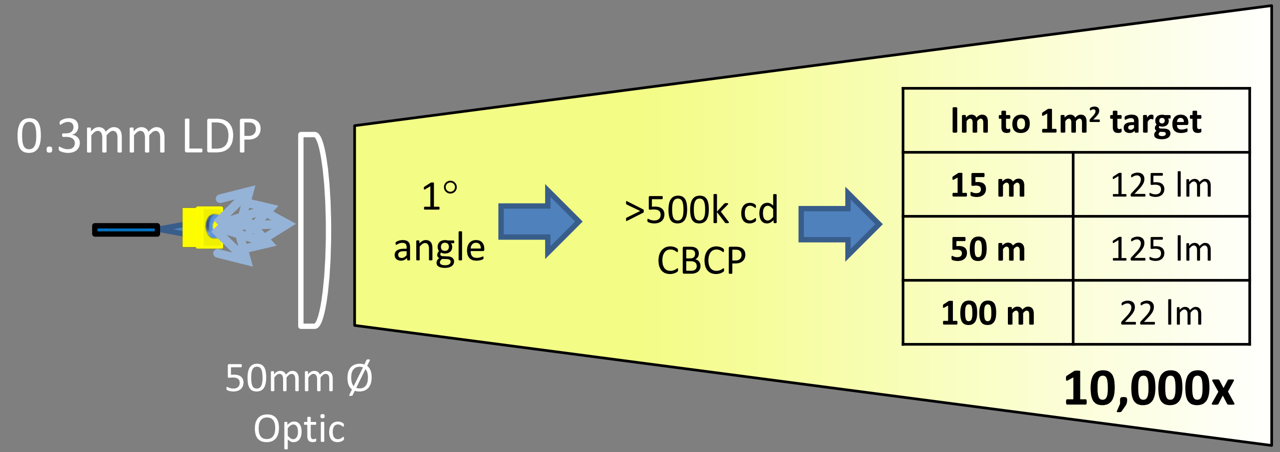
- 500 lm
- Lambertian emission
- 3 mm diameter
- Limited by droop
- Luminance: $1/(3mm)^2$



lm to $1m^2$ target	
15 m	4 lm
50 m	0.4 lm
100 m	0.002 lm

LDP Source

- 500 lm
- Lambertian emission
- 0.3 mm spot on phosphor
- Pumped by 3W LD
- Luminance: $1/(0.3mm)^2$

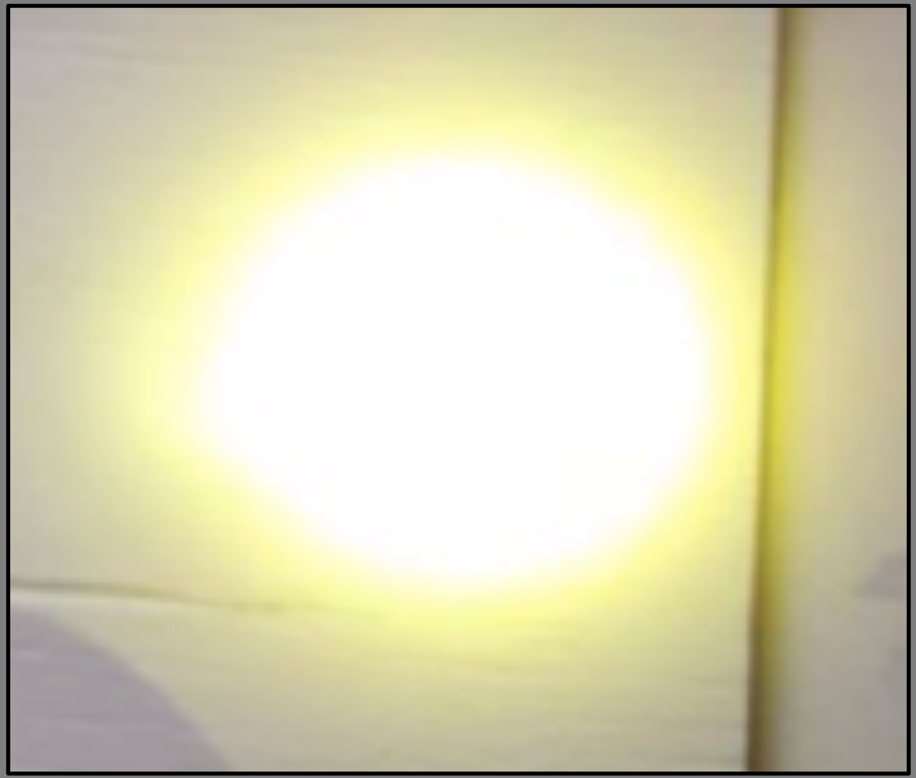


lm to $1m^2$ target	
15 m	125 lm
50 m	125 lm
100 m	22 lm

MicroSpot Using LaserLight SMD

Laser phosphor spotlight

- > 400 lumen white
- <2 degree spot, 1 inch optic



Diameter = 25mm

LDP for >10x Delivered Lumen/Watt

@ 15m LDP delivers >10X lm/W
@ 50m LDP delivers >1,000X lm/W

Example luminaire

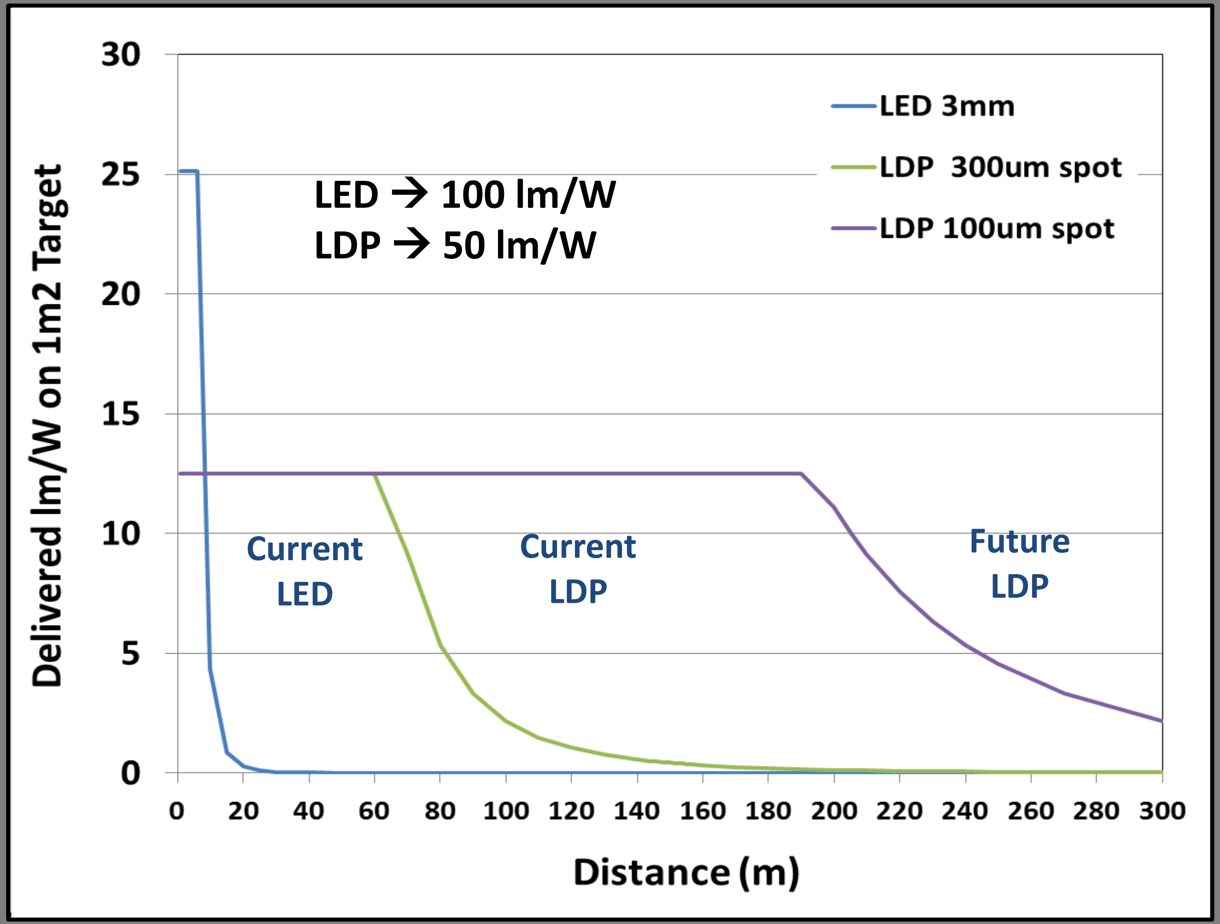
- 500 lumens
- 50mm optic
- Gaussian beam

LED:

- 3mm Ø → 10 deg

LDP:

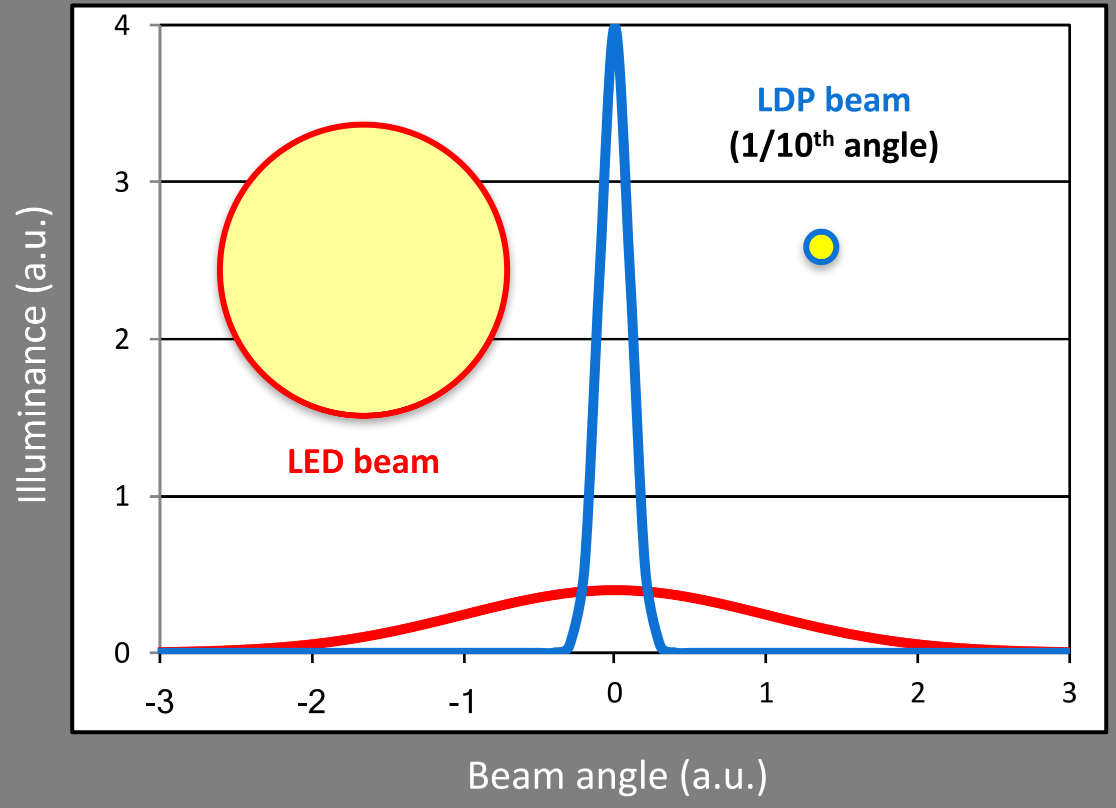
- Current; 300um Ø → 1 deg
- Future; 100um Ø → 0.3 deg

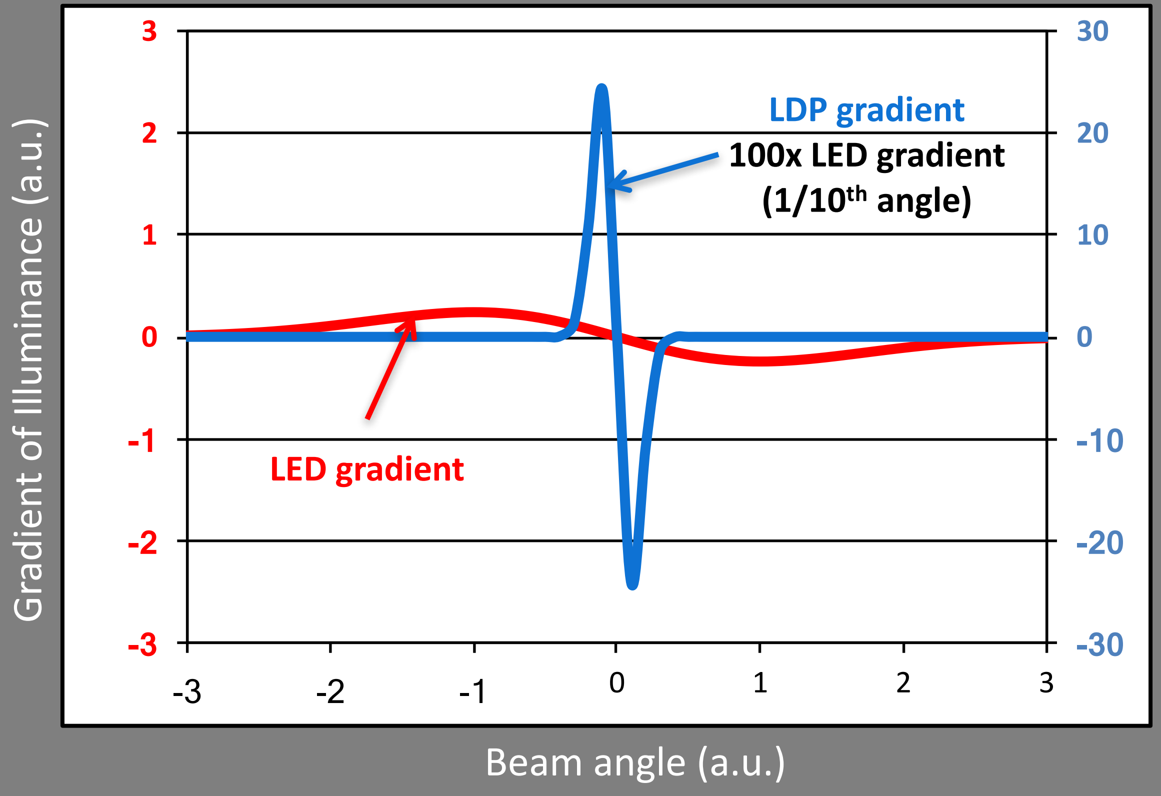


Even with ½ the WPE, LDs can provide higher delivered lm/W

LDP for Spatial Patterning Illumination

- Enables high value, spatially patterned light
- LDP delivers 100 x higher gradients vs LED
- Light only where it is needed: efficiency
- Reduce unwanted light pollution and glare





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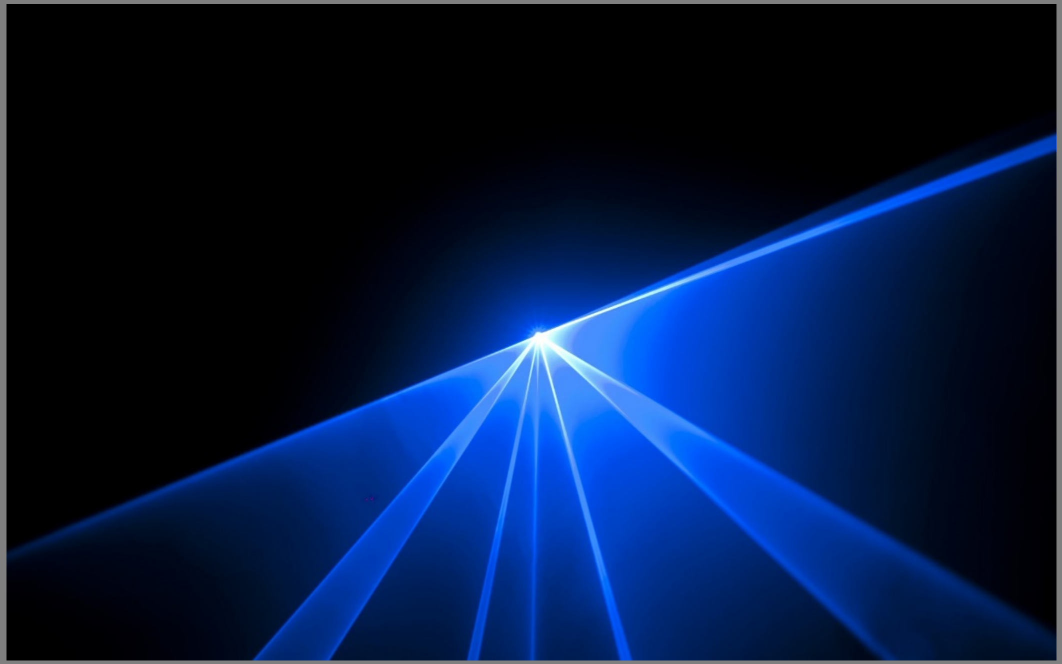
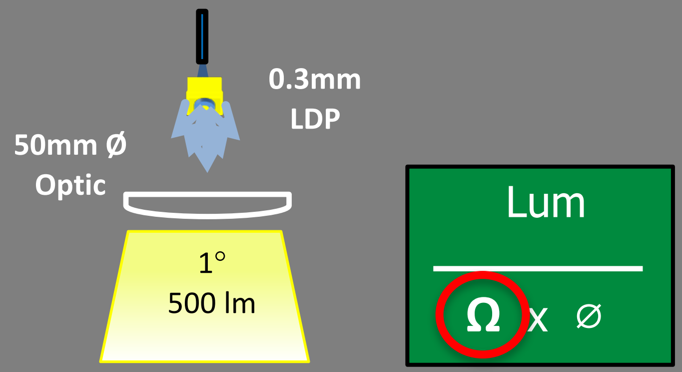
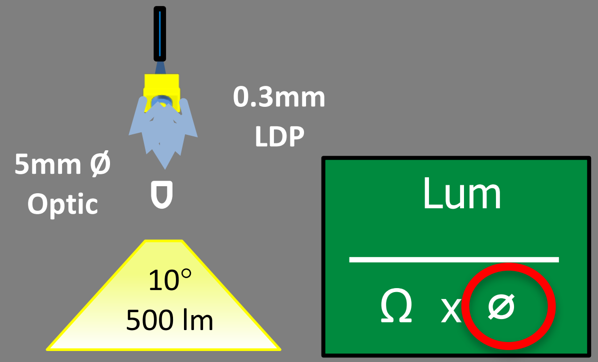


Potential LDP Luminaires with High Luminance



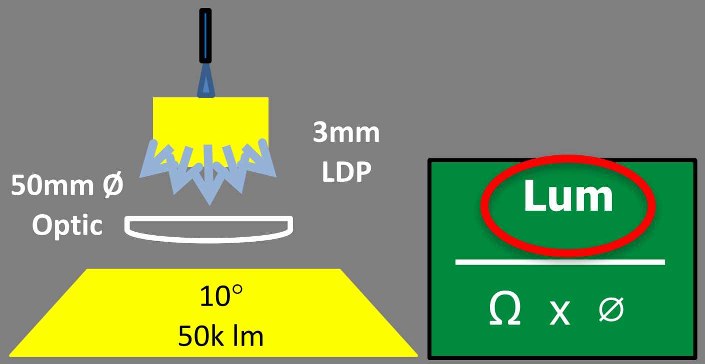
Micro Spotlight

1/10 the Divergence



Micro Luminaire

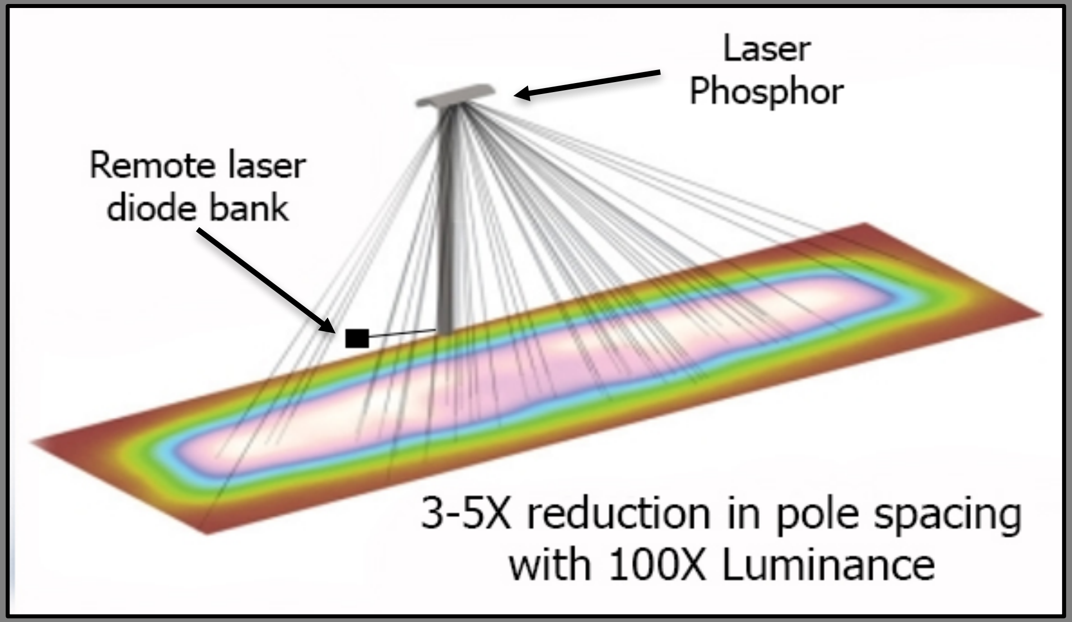
1/10 the Optic Size



High lumen, ultra-compact

100X the lumens

Next Generation Street Lighting



Enables high value, spatially patterned light

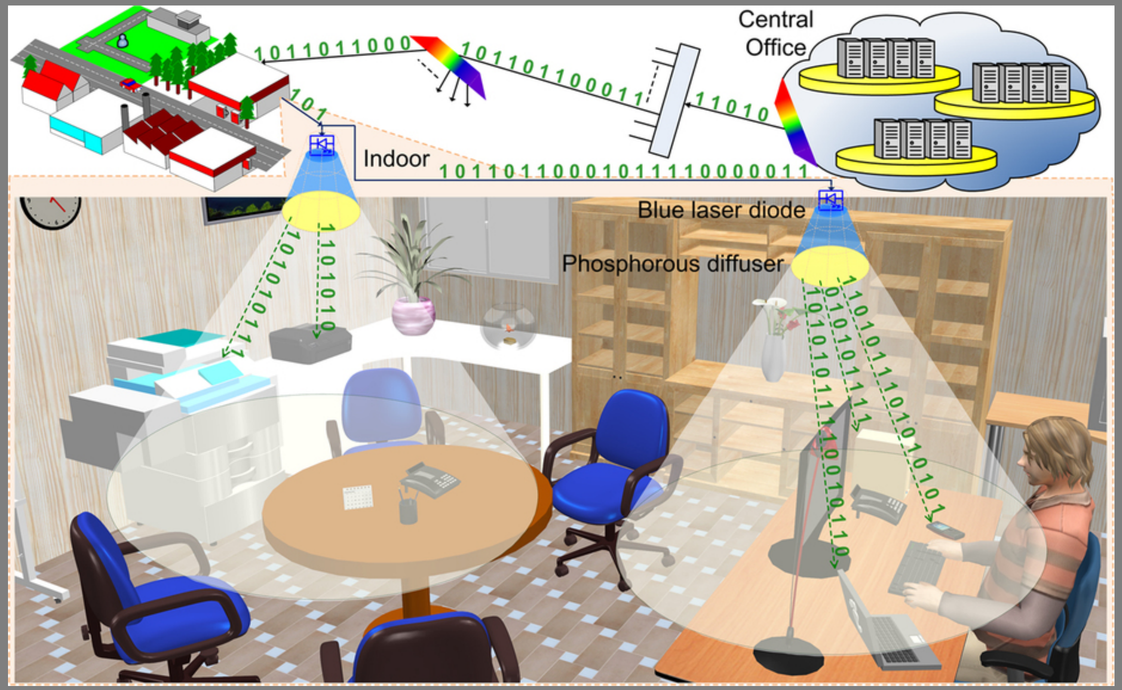
- LDP delivers 100X higher gradients vs LED
- Light where needed: Reduced light pollution
- Potential source for outdoors; streetlights, stadiums
- Bury the LDs and electronics
- Lightweight phosphor/reflector
- Eliminates glare from straight light associated with fog

Enables future technology

- LiFi
- Sensors
- Smart Street Lighting
- On-road projections

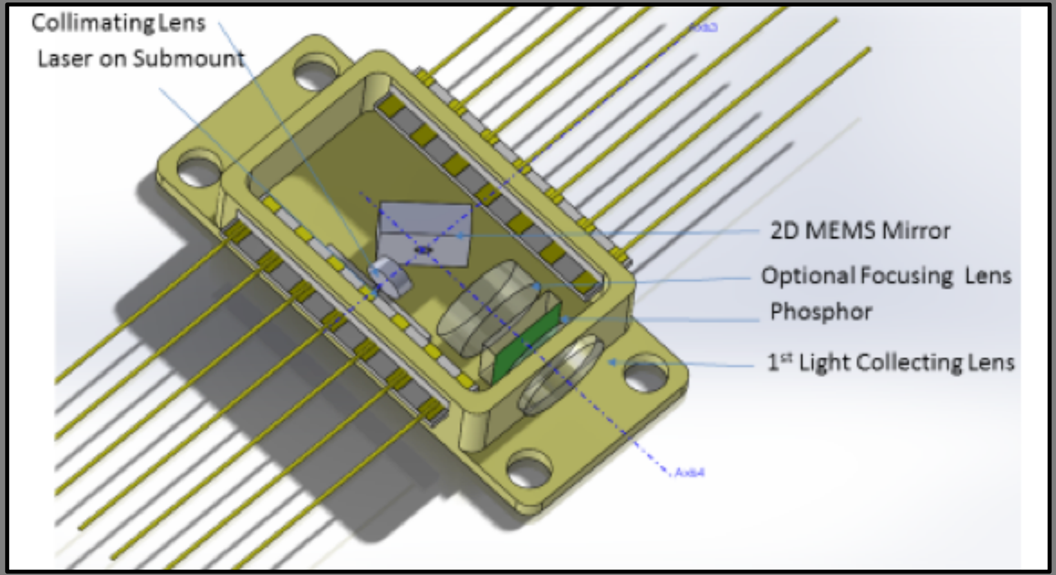
Future Novel Functions: LiFi

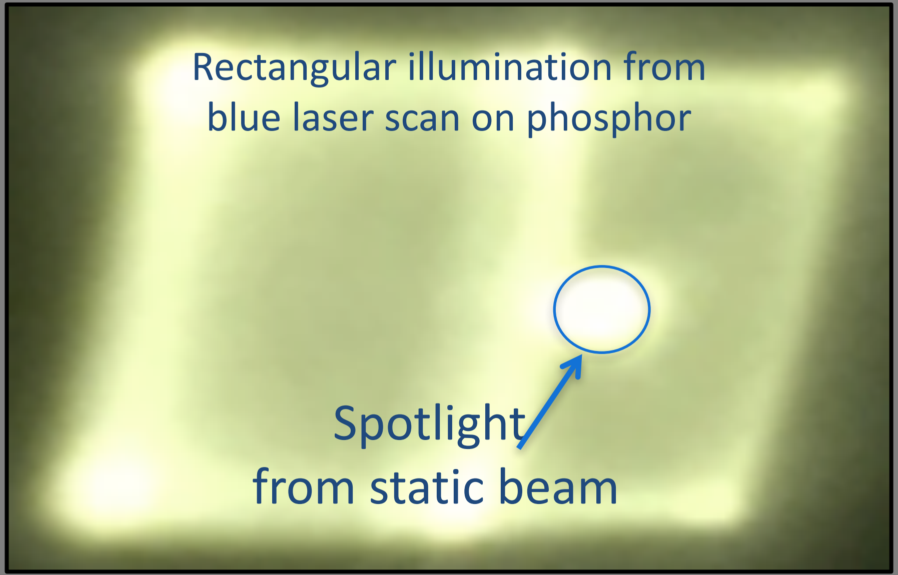
- Laser LiFi is 1,000X faster than wifi and 10X faster than LED LiFi
    - Current LED LiFi per channel - 10s of GB/s
    - Potential LaserLight LiFi per channel - 100 GB/s
- Sensor fusion for Smartlighting / IoT
- Leverage fiber transport
- Sharp light gradients for control



Sources:
University of Edinburgh - http://spectrum.ieee.org/tech-talk/semiconductors/optoelectronics/laser-lifi-could-blast-100-gigabits-per-second
UCSB, National Taiwan University - http://www.nature.com/articles/srep18690#f1
IBTimes - http://www.ibtimes.co.uk/lifi-internet-breakthrough-224gbps-connection-broadcast-led-bulb-1488204

Dynamic Sources for Next Gen Smart Lighting & IoT





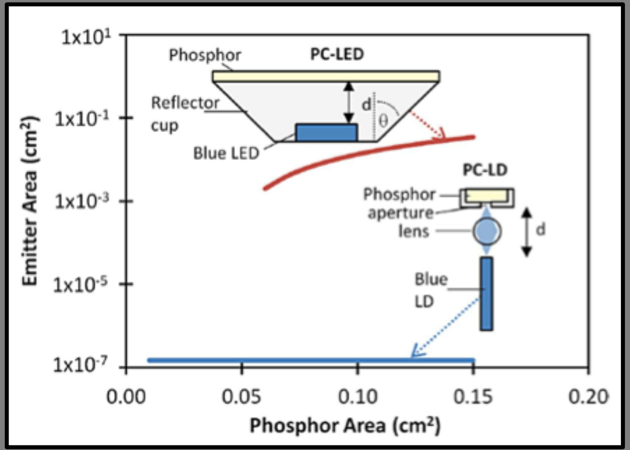
Dynamic LaserLight sources

- High power blue laser
- MEMs mirror
- Phosphor
- Compact integration of LDP with MEMs

- Enormous potential when combined with sensors for Smart lighting, IoT
- Dynamic projection illumination and projection mapping; 3D imaging

LaserLight System Cost Considerations

- **Device Level Considerations**
  - LD volume up as display ramps auto emerges, $/W down (Laser hitting Haitz' Law)
  - # of lumens per wafer since LD chips can be driven 10-100 X higher
  - LD phosphor size is 1/10th size compared to LED
- **Luminaire level considerations**
  - LDs enable micro-luminaires (1/10th optic size) for reduced "$ per delivered lumens"
  - "Higher OCF can greatly reduce the size and cost…" (Cree quote)
- **System Level considerations**
  - LDP higher luminance delivers superior "delivered lum/watt"
  - Ultra compact dynamic illumination sources
  - Example: Number of poles for street lighting; remote light source for serviceability
  - Example: Reduced encryption protection
- **Lighting delivery architectures**
  - SMD, Fiber-Coupled, Side-Emitting Fiber, and Multi-Source Arrays
  - *Semipolar GaN* allows for a greater yield and shorter growth time; higher throughput



Advantages of III-nitride laser diodes in solid-state lighting Jonathan J. Wierer, Jr* and Jeffrey Y. Tsao Online Jan 2015, Phys. Status Solidi A, 1–6 (2014) / DOI 10.1002/pssa.201431700

Agenda and Key Messages

- Introduction and Motivation for Laser Illumination: Directional Solid State Lighting
- Laser Diode Development: Improving efficiency and power per chip
- LaserLight Device Development: High luminance SMD & fiber coupled devices
- LaserLight MicroSpot Module Development: Collimated, compact sources
- Outlook for Laser Illumination Dynamic illumination, fusion with sensors

Thank You!

Dr. Paul Rudy

Prudy@SoraaLaser.com