LASER DIODES FOR NEXT GENERATION LIGHT SOURCES

Providing the brightest, most efficient laser light sources to the world

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DOE SSL R&D Workshop
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OUTLINE AND KEY MESSAGES

• LDs are solution to droop and offer 10-20X more power per chip area and 10,000X the spatial brightness of LEDs
  • LD + phosphor source can provide superior “delivered” lm/W

• LDs must overcome challenges such as wall plug efficiency to achieve maximum adoption in lighting
  • Evolution of GaAs LDs paved a proven pathway for GaN LDs

• GaN LDs have a bright future
LDS DOMINATED BY STIMULATED EMISSION

Laser Diode

Input = \( l/qV \)

Output = \( R_{st} \)

\[ R_{nr} = A_n + C_n^3 \]

Output = \( R_{sp} = Bn^2 \)

Coldren et al

1 mm x 1 mm

1.2 mm x 0.15 mm

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Current LDs produce 10-20X more light per chip area

- State of the art LED
- Sora Laser LD


Pulsed data
LED vs LD: Output Power Density

LD aperture 10,000X brighter than LED emitter

Pulsed data


State of the art LED
Soraa Laser LD

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LD + PHOSPHOR FOR ILLUMINATION

• Low etendue + high brightness make LDs ideal excitation source

<table>
<thead>
<tr>
<th>LD + Phosphor</th>
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<td>3W in &lt;100µm Ø spot on phosphor</td>
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<tr>
<td>&gt;380 W/mm²</td>
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LDs >300X brighter than LED: Superior for directional applications

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

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LD + PHOSPHOR CONFIGURATIONS

- Phosphor technology for high power density LD excitation exists today
  - Ceramic and single-crystal YAG:CE demonstrate low thermal quenching, high IQE, and robust lifetimes at >200°C
- Infinite number of LD + phosphor configurations; Opportunity

**Transmission**
- e.g. spotlights, headlights, directional bulbs, etc

**Reflection**
- e.g. spotlights, headlights, directional bulbs, etc

**Remote: T or R**
- e.g. street, bridge, tunnel light; integrated bldg materials

BMW i8; motorauthority.com

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• GaN LDs have a bright future
Blue LD WPE increased from 15% in 2005 to ~40% in 2015

P @ max WPE increased from 10mW in 1997 to 4W in 2015
Example 4W/40% WPE Blue LD;

\[ WPE = EQE \left( \frac{h \nu}{q V} \right) \]

- \( \eta_{inj} \) from imperfect slope
- \( \eta_{inj} \) from Ith

<table>
<thead>
<tr>
<th>LD</th>
<th>GaN</th>
<th>GaAs</th>
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<tbody>
<tr>
<td>WPE (%)</td>
<td>35 - 40</td>
<td>75 - 80</td>
</tr>
<tr>
<td>( \eta_{inj} ) (%)</td>
<td>&gt;80</td>
<td>&gt;95</td>
</tr>
<tr>
<td>( \alpha_i ) (cm(^{-1}))</td>
<td>1.0 - 3.0</td>
<td>0.3 - 0.5</td>
</tr>
<tr>
<td>( \frac{h \nu}{qV} ) (V)</td>
<td>&gt;1.5</td>
<td>0.15</td>
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In 2003 DoD launched SHEDS (super-high-efficiency diode sources) - Featured 8 partners; JDSU, nLight, Alphalight, several universities etc

Program goal to drive GaAs 9xx nm LDs from 45-50% to 80% WPE - Motivated by interest to improve the efficiency of diode-pumped solid-state lasers

SHEDS was huge success driving WPE 75-85% by program end; - In <1 year achieved 65% WPE, by program end in 2006, ~75% WPE at RT and 85% at -50C
ADDITIONAL CONSIDERATIONS

Cost
Volume driven; LD fab yield, substrate costs, etc
GaAs LD pathway mapped to <$0.03/W in studies

Lifetime/Reliability
Low defect densities and optimized process
Wide stripe, specialized facet coating technology

Thermal Management
Current 4W LD has >400X waste power density of 1W LED
P-side down bond, thermal materials, remote light

Eye Safety Concerns
Laser + phosphor; Design for safety will be key element
Laser based projectors already in wide-spread use
LDs offer inherent benefits over LEDs; Next Gen light sources

- LDs are Droop-Free at >100x current density
- LDs are 10,000x brighter and can yield 10-20x more power from epi area
- LD sources already provide superior “delivered lm/W” in directional apps

LD adoption will grow with tech maturity and Next Gen lighting

- GaAs LDs paved a proven pathway towards performance and cost for GaN LDs
- SHEDs as example of a program to drive GaN LDs to GaN LED efficiencies
- Benefits of LDs will become further attractive in Next Gen lighting

Thank you for your attention