Greentech Lighting:
The OIDA’s Solid State Lighting Technologies and Roadmaps

Speaker:
Michael Lebby
President and CEO
OIDA
Overview

- **Opto**mism
  - The next 10yrs for optoelectronics
- Technical trends for solid state lighting
  - Areas that will impact all of us; our lifestyle, our family
  - Technical challenges for LEDs, OLEDs and lasers
- Roadmaps for lighting with High Brightness LEDs
- Summary
Mission → Vision

Current Mission

Promote optoelectronics worldwide, & Advance competitiveness of its members

Focus on quality
Broaden horizon of OE
Leverage DC government center of mass
Grow membership base
Primary reference in OE
Develop and participate in industry-university development initiatives
Recognized internationally
Organize key trade show

Primary reference in OE

OIDA is the focal point for OE industry vision, transformation, and growth

Focus on the business of technology, not just technology itself

Optoelectronics = OE
OIDA is broadening optoelectronics with “Green” opportunities

Value Chain
- Service Providers
- Systems
- Modules
- Components

Opportunities
- Active Presence
- Focus

Killer Service ??? = $$$
Eco System “Ecomation” 😊
(Closed loop Energy control = lighting + heating)
Home display, solar cell, lighting windows/panels

Sources: OIDA, Erwin Vergeest, ALiveLights

Balanced perspective in optoelectronics
Next decade in Optoelectronics
In a decade…
our communicator…our PIP (personal information pet)

Optoelectronics will support our lifestyle

Highest bandwidth to human brain

Sources: OIDA, Philips, RIM, Digital Optics, Sony Ericsson, HP, Siemens, Apple, OIDA members
Evolution from 1971 to 2004 of World Total Primary Energy Supply* by Fuel (Mtoe)

Why energy matters...

Source: IEA

Double 1971 - 2004
Solid State Lighting “-abilities”

• Using electron transitions in solid materials for light
  – Efficiency: materials technology is limitation, but theoretically nearly perfectly efficient
  – Reliability: no moving parts, no leaking gases, no filaments, no bulbs to break, low heat
  – Disposability: not toxic, not fragil
  – Colorability: tunable, adjustable color and mood
  – Designability: no more traditional light bulbs, fixtures opens up design space, can use anything from emitting panels to fiber optics
  – Flexibility: unique surfaces and shapes

But....
In a decade...solid state lighting is everywhere

Ubiquitous in everyday life...

Source: Kaist, KAPID
Next decade in optoelectronics

- Combined OE components and enabled products
  - 2004-16 CAGR 11% with SSL lighting ~$50B by 2016

Global optoelectronics 10yr forecast for components and enabled products with SSL

SSL grows quickly in a $T industry
Lighting market share forecast

- SSL will grow quickly over next decade

SSL fueled by LEDs and OLEDs
## Comparative Efficiencies

<table>
<thead>
<tr>
<th>Category</th>
<th>Source</th>
<th>Luminous Efficacy (lm/W)</th>
<th>Luminous Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion</td>
<td>candle</td>
<td>0.3</td>
<td>0.04%</td>
</tr>
<tr>
<td>Incandescent</td>
<td>100 W tungsten incandescent</td>
<td>17.5</td>
<td>2.60%</td>
</tr>
<tr>
<td></td>
<td>glass halogen</td>
<td>16</td>
<td>2.30%</td>
</tr>
<tr>
<td></td>
<td>quartz halogen</td>
<td>24</td>
<td>3.50%</td>
</tr>
<tr>
<td></td>
<td>high-temperature incandescent</td>
<td>35</td>
<td>5.10%</td>
</tr>
<tr>
<td>Fluorescent</td>
<td>28 W fluorescent tube (T5)</td>
<td>104</td>
<td>15.20%</td>
</tr>
<tr>
<td>Light-emitting diode</td>
<td>white LED</td>
<td>26–70</td>
<td>3.8%–10.2%</td>
</tr>
<tr>
<td></td>
<td>white LED (prototypes)</td>
<td>up to 150</td>
<td>up to 22%</td>
</tr>
<tr>
<td>Arc lamp</td>
<td>xenon arc lamp</td>
<td>30–50</td>
<td>4.4%–7.3%</td>
</tr>
<tr>
<td></td>
<td>HID (auto)</td>
<td>80</td>
<td>12%</td>
</tr>
<tr>
<td>Gas discharge</td>
<td>high pressure sodium lamp</td>
<td>150</td>
<td>22%</td>
</tr>
<tr>
<td></td>
<td>low pressure sodium lamp</td>
<td>183 up to 200</td>
<td>27%</td>
</tr>
<tr>
<td></td>
<td>1400 W sulfur lamp</td>
<td>100</td>
<td>15%</td>
</tr>
<tr>
<td>Other sources</td>
<td>Ideal black-body radiator at 4000 K</td>
<td>47.5</td>
<td>7.00%</td>
</tr>
<tr>
<td></td>
<td>Class G star (Sun, Capella), 5800 K</td>
<td>80</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td>Natural sunlight</td>
<td>93</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td>Ideal black-body radiator at 7000 K</td>
<td>95</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td>Ideal white light source</td>
<td>242.5</td>
<td>35.50%</td>
</tr>
<tr>
<td></td>
<td>Ideal monochromatic 555 nm source</td>
<td>683</td>
<td>100%</td>
</tr>
</tbody>
</table>


LEDs are making excellent progress...
Progress in LED and OLED efficacy

Source: Prof. Changhee Lee, SNU, Korea
HBLED white technology
**HB-LED Technology**

AlGaNp/GalP truncated inverted pyramid (Lumiled)

AllInGaP flip-chip (Lumiled)

AllInGaP micro mirror (Osram),

AllInGaN patterned substrate and mesh electrode (Nichia)

*Source: Philips Lumileds, Osram, Nichia*

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**Complex tricks for high brightness**
Designing white HBLEDs

- Issues:
  - Phosphor conversion
    - Quantum deficit, Stokes loss, optical losses, new materials issues, relatively simple, nanotech
  - Color mixing
    - Optical losses, color uniformity, color control circuits (tunable advantage)

Commercial white today

Phosphor popular, mixing is tunable

Sources: Philips Lumileds, OIDA
Thermal dynamics in cooling – caveat emptor

• Incandescent
  – 5% visible (90% IR)
• LEDs pass all heat back to heat-sink and fixture
  – 20% visible (80% conducted away)
• Today’s efficiency
  – Thermal management is major issue and cost driver
• Future anticipated efficiency
  – Heat management will become straightforward

Issues of complex heat sinking will relax

Sources: Philips Lumileds, OIDA
RGB white for illuminating artwork

Mona Lisa Lighting by Fraen Corporation

- Replicates day-light without harmful UV or IR radiation
- Exact color rendition

Sources: Philips Lumileds, OIDA, Fraen Corp
Lighting off-grid

Gimla Yacht – new markets, new opportunities for designers

Sources: Philips Lumileds, LightGraphix, OIDA

For those who can pay for style...
• Fixtures already on the market in Asia

Designing within the infrastructure...
Cost & efficiency requirement for PC white

- Single-emitter Flux
  - 1000 lm desirable
  - same as 60 W light bulb
  - today’s LEDs: 30 – 160 lm

PC White LED: ~150 lm/W

- Cost of Ownership (COO) Analysis – 1000 lm source

<table>
<thead>
<tr>
<th></th>
<th>Input Power</th>
<th>Source cost</th>
<th>Energy cost/yr</th>
<th>COO (1 yr)</th>
<th>COO (5yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 x 60 W incandescent</td>
<td>60 W</td>
<td>$0.25</td>
<td>$48</td>
<td>$48</td>
<td>$240</td>
</tr>
<tr>
<td>7 x LUXEON K2 emitters</td>
<td>40 W</td>
<td>$18</td>
<td>$32</td>
<td>$50</td>
<td>$178</td>
</tr>
<tr>
<td>1 x 150 lm/W LED</td>
<td>6.7 W</td>
<td>&lt;$2.5</td>
<td>$5.30</td>
<td>$8</td>
<td>$28</td>
</tr>
</tbody>
</table>

Sources: Philips Lumileds, OIDA

High efficiency devices drive the value proposition

at $0.10 per kWh
Lighting for off-grid homes using LEDs

- Electric light transforms the lives of the poor, making it possible for families to stay active - and children to study - after night falls. But electricity is scarce in many developing countries; millions of villages are far from the grids, and power is expensive. Now the Light Up the World Foundation has found a way to illuminate whole villages with less electricity than is used by a single 100 watt bulb. Combining simple pedal-powered electric generators with wind turbines and with cutting edge technology from light-emitting diodes it has won a Rolex Award for Enterprise. Already working successfully in Nepalese villages, it is set to spread around the world.

Sources: Philips Lumileds, Photos Courtesy of Light Up the World and PICO Power, www.ourplant.com, OIDA
LED Roadmaps
How achievable is 150 lm/W for the roadmap?

<table>
<thead>
<tr>
<th></th>
<th>PC White</th>
<th>Today*</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{\text{ext}}$ (%)</td>
<td>~80</td>
<td>~90</td>
<td></td>
</tr>
<tr>
<td>IQE (%)</td>
<td>~55</td>
<td>~90</td>
<td></td>
</tr>
<tr>
<td>EQE (%)</td>
<td>~45</td>
<td>~80</td>
<td></td>
</tr>
<tr>
<td>$V_f$ (V)</td>
<td>~3.3</td>
<td>~2.9</td>
<td></td>
</tr>
<tr>
<td>WPE (%)</td>
<td>~35</td>
<td>~75</td>
<td></td>
</tr>
<tr>
<td>LE (lm/W)</td>
<td>~70</td>
<td>~150</td>
<td></td>
</tr>
</tbody>
</table>

- IQE must increase by >1.5X
  - This table assumes a phosphor conversion on 200 lumens/optical Watt for “cool” white (CCT >5000)
- For “warm” white (CCT 3000 – 4000) is significantly lower (eff) and requires development. This is an issue for illumination.

Sources: Philips Lumileds

Warm white will be the challenge
R-G-B color mixing for warm white illumination

Sources: Philips Lumileds, OIDA

Color mixing → potential for higher efficacy
OIDA

Research device predictions in 2006

220lm/W by 2016

HBLED efficacy predictions

Efficacy Predictions 1999-2006

OIDA 2006
OIDA 2002
Haitz 2004
Haitz 1999 Pess.

Sources: Haitz, Philips Lumileds, CREE, OIDA

Industry will solve green efficiency

greentechmedia:
## OIDA LED Technology Roadmap (2007)

<table>
<thead>
<tr>
<th>OIDA</th>
<th>2005</th>
<th>2009</th>
<th>2013</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lum Efficacy (lm/W)</td>
<td>50</td>
<td>75</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>Lifetime (khr)</td>
<td>30</td>
<td>50</td>
<td>&gt;100</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Flux (lm/lamp)</td>
<td>60</td>
<td>150</td>
<td>200</td>
<td>1000</td>
</tr>
<tr>
<td>Input Power (W/lamp)</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>7.5</td>
</tr>
<tr>
<td>Lumens Cost ($/klm)</td>
<td>150</td>
<td>100</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>Lamp Cost ($/lamp)</td>
<td>3</td>
<td>2</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>Color Rendering Index (CRI)</td>
<td>75</td>
<td>80</td>
<td>85</td>
<td>90</td>
</tr>
<tr>
<td>Lighting Markets Penetrated</td>
<td></td>
<td></td>
<td>Incandescent</td>
<td>Fluorescent</td>
</tr>
</tbody>
</table>

### Technology & Components:

Commercial availability in year indicated (Not R&D results!)

<table>
<thead>
<tr>
<th>Chip Temp</th>
<th>Phosphor Temp</th>
<th>I/P Power Density (W/cm²)</th>
<th>2005</th>
<th>2009</th>
<th>2013</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>85</td>
<td>100</td>
<td>150</td>
<td>200</td>
<td>200</td>
<td>250</td>
</tr>
<tr>
<td>75</td>
<td>80</td>
<td>90</td>
<td>125</td>
<td>175</td>
<td>175</td>
<td>200</td>
</tr>
<tr>
<td>100</td>
<td>200</td>
<td>350</td>
<td>500</td>
<td>750</td>
<td>750</td>
<td>1000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OEM Chip Cost ($/cm²)</th>
<th>120</th>
<th>100</th>
<th>80</th>
<th>60</th>
<th>45</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>OEM Packaging Cost ($/cm²)</td>
<td>125</td>
<td>110</td>
<td>90</td>
<td>80</td>
<td>60</td>
<td>40</td>
</tr>
</tbody>
</table>

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Michael Lebby OIDA (2007)

Slanted Font: Major industry efforts are required for commercialization
1000 lumen LED is a great way to source light from a tiny unit

Sources: Philips Lumileds, OIDA

High luminance LED → small low cost device
Summary predictions

- Light bulbs will slowly be replaced
- Controlling light by turning the power switch is becoming old fashioned!
- Networks are in, and controlling light intensity, color with a touch is fashionable!
- Flexible, throw away display are emerging
- Windows on homes may become displays for lighting
- Ceiling tiles will be OLEDs and not cardboard
- General illumination will be a mix of ambient and task:
  - LEDs for task and OLEDs for ambient
Questions?

View the archive at www.greentechmedia.com