Energy Efficient White LEDs
For Sustainable Solid-State Lighting

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Solid-State Lighting and Display Center

- One of the largest University Cleanrooms (13,000 ft²)
  - 7 equipment bays

- World Class MOCVD/MBE Facilities
  - 6 MOCVD Systems, 7 MBE (3 Nitride)

- Optical Test Facilities (LED and Laser)

- Materials Characterization (TEM, SEM, FIB, XPS, AFM, SIMS)

- Package and Lamp (LED and Laser) Assembly and Test
What is an LED?

L.E.D.= Light Emitting Diode (Runs on 3.2V DC Power)

Blue LED

LED produces light by combining Positive and negative charges inside Gallium nitride crystal
• Forward Bias p-n junction: **LEDs**
• Light is created by flowing current from battery
The Advantage of LED Lighting

Long life – lifetimes can exceed 100,000 hours as compared to 1,000 hrs for tungsten bulbs.

Robustness – no moving parts, no glass, no filaments.

Size – typical package is only 5 mm in diameter.

Energy efficiency – 50-90% less energy used translates into smaller power supply.

Non-toxicity – no mercury.

Versatility – available in a variety of colors; can be pulsed.

Cool – less heat radiation than HID or incandescent
GaN Emits All Colors of Light
(Blue, Green, UV->White)
LED Market Size

- Status indicators and alphanumeric displays: 37.5%
- IR transmitters: 21.3%
- Backlighting: 17%
- Transportation: 4.3%
- Decorative lighting: 1.4%
- Automotive: 6.7%
- Signage: 10.3%

Total 2009 market: $2 billion
Luminous Efficacy of Various Light Sources

Current number for GaN white LED at UCSB is 116 lm/W ucsb chip
143 lm/W partner chip

Graph taken from www.lampteck.co.uk
# Lighting System Efficacy

<table>
<thead>
<tr>
<th>Luminaire Type</th>
<th>Lumens Per Watt</th>
<th>Fixture Efficiency</th>
<th>Usable Lumens Per Watt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halogen Incandescent</td>
<td>17</td>
<td>45%</td>
<td>8</td>
</tr>
<tr>
<td>Compact Fluorescent</td>
<td>45</td>
<td>33%</td>
<td>15</td>
</tr>
<tr>
<td>150 W Cobra Head Type II Streetlight (HPS)</td>
<td>91</td>
<td>50%</td>
<td>46</td>
</tr>
<tr>
<td>400W HID w/Glass Housing (MH)</td>
<td>70</td>
<td>54%</td>
<td>38</td>
</tr>
<tr>
<td>XLamp LED Lighting Fixture</td>
<td>71</td>
<td>90%</td>
<td>64</td>
</tr>
<tr>
<td>T8 Fluorescent Tube</td>
<td>80</td>
<td>77%</td>
<td>62</td>
</tr>
</tbody>
</table>
LED Market Penetration

Drivers
- Maintenance Benefit
- Energy Savings
- Battery Life
- New Feature/Capability
“The Promise” Energy Usage Comparison

“Best” White LED and Compact Fluorescent vs. 60Watt Light Bulb Comparison

Power Used (Watts)

<table>
<thead>
<tr>
<th>Light Source</th>
<th>60W Bulb</th>
<th>Compact Fluor.</th>
<th>LED</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>50</td>
<td></td>
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<td></td>
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<tr>
<td>40</td>
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<td></td>
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<tr>
<td>30</td>
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<td></td>
</tr>
<tr>
<td>20</td>
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<td>10</td>
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<td>0</td>
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</tbody>
</table>

53 watts saved

SSLECO
Solid State Lighting and Energy Center
Global Warming/Energy Savings Potential of LEDs

->Lighting Consumes 22% of all Electricity Produced

->If a 150 lm/Watt Solid State White LED “system” was developed, and employed, then in the United States alone:
  • Alleviate the need of 133 new power stations!*
  • Eliminate 258 million metric tons of Carbon*

The Reality

- Commercial White LED “Bulb” 15-100 LPW
- Fixture Efficiency all over the map 10-80%
- Luminaire System Efficacy 15-80 LPW
- HEAT is the Biggest Problem

![Graph showing efficiency drop with temperature increase]

25C to 60C in fixture, Efficiency from 100 LPW to 71 LPW

<table>
<thead>
<tr>
<th>Company</th>
<th>LED</th>
<th>Fixture Eff.</th>
<th>System Efficacy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LED A</td>
<td>80 LPW</td>
<td>80%</td>
<td>64LPW</td>
</tr>
<tr>
<td>LED B</td>
<td>45LPW</td>
<td>50%</td>
<td>22.5LPW</td>
</tr>
<tr>
<td>LED C</td>
<td>50LPW</td>
<td>30%</td>
<td>15LPW</td>
</tr>
<tr>
<td>CFL</td>
<td>60LPW</td>
<td>50%</td>
<td>30LPW</td>
</tr>
</tbody>
</table>

– Better wait for Energy Star Ratings
Current LED Market $2B/yr

- Cellphone (Nokia)
- Traffic signals (Gelcore)
- Streetlights
- TVs (LED DLP™) (samsung)
- Large Displays (NASDAQ)
- Automotive
LEDs in Architectural Lighting

Installation Benjamin Franklin Bridge, PA, USA (Color Kinetics Inc.)

Lighting Systems by Color Kinetics Inc.
Takarazuka University of Art and Design
AUTOMOBILE LED Headlights expected 2008 from Tokyo Motor Show

Nissan

Honda

Daimler Chrysler

Toyota

0.5-1% better fuel efficiency
Ultra-Mobile LED Enabled products

- Uses Blue, Green, Red LEDs

- CellPhone Camera Flash

(Osram Opto)
LED Plant Growth

- Blue and Green LEDs used to grow Wasabi at night,
- It is known that chlorophyll has the second distinct absorption peak in the vicinity of 450nm (blue light region) other than the first peak in the vicinity of 660nm (red light region) in its light absorption spectrum.
- The blue light is also indispensable to the morphologically healthy growth plant.
- On the other hand, the red light contributes to the plant photosynthesis.
Solar(Photovoltaics) + LED (Off-grid)

www.lutw.org

•Kerosene lighting and firewood are used by 1/3 of the world; they cause countless fires and are very inefficient (0.03 lm/watt).

•The average villager spends 10-25% of their annual income on kerosene.

•LED Lighting costs much less on an annual basis and payback period is just 6 months.

•LED Lighting /Solar Cell Off-Grid

www.lutw.org

“In the few months we have had the White LED lamps the improvement in the children’s academic performance has been absolutely remarkable”
Headmaster, Mubarak Village, Pakistan June 2004

Light Up The World Foundation
Air/Water Purification

• Fruit and Vegetable Storage Life Extended 1 week
• Water Purification: UV LED to kill bacteria

Mitsubishi Refrigerator MR-W55H,
UV LED 375 nm, 590 nm

(Credit: Hydro-Photon Inc.)
CONCLUSION

• R&D Level LED Single lamp efficacy (150lm/W) now exceeds CFL, but:

• Commercial based LED Lamp Fixtures are much lower 64LPW due to several factors that need further research and development in
  – Fixture Efficiency
  – Heat Sinking
  – Scale up to Mass production

• Stay Tuned….