Energy Efficient LEDs
For Sustainable Solid-State Lighting

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Solid-State Lighting and Display Center

- One of the largest University Cleanrooms (13,000 ft\(^2\))
  - 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
10 Industrial Partners

Matsushita Electric Industrial Co., Ltd.

Matsushita Electric Works, Ltd.
Solid State Lighting UCSB Contributions (63)

Faculty (9)
• Prof. Shuji Nakamura
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Luminous Efficacy of Various Light Sources

Current number for GaN white LED at UCSB is 160lm/W ucsb chip.

First white LEDs were only 5lm/W at 20mA (1995).

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><strong>90%</strong></td>
<td><strong>64</strong></td>
</tr>
<tr>
<td>T8 Fluorescent Tube</td>
<td>80</td>
<td>77%</td>
<td>62</td>
</tr>
</tbody>
</table>

*Courtesy Cree Inc*
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.
GaN Emits All Colors of Light
(Blue, Green, UV -> White)
Ban the Light Bulb?

- “Ban the Incandescent Light Bulb” gaining momentum
- California Legislator Lloyd Levine introduces bill to ban the incandescent light bulb – February 1, 2007
- Australia passes legislation to ban the light bulb by 2010 – February 21, 2007
- EU to ban light bulbs – March 9, 2007
- United States ????
Lighting is single biggest users of Electricity

- Incandescent Light Bulb - 1-4% efficient
- Fluorescent – 15-25% efficient
- LED - 25-60% efficient (90% theoretical)
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 – up to 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
3 Methods of Generating White LEDs

- **Multi-Chip, RGB**
  - best efficiency
  - highest cost

- **UV + Phosphors**
  - best CRI, color
  - uniformity
  - low cost
  - improved reliability

- **Blue + Phosphors**
  - lowest cost
  - >30lm/W
  - >90% market share
“The Promise” Energy Usage Comparison

LEDs Save 53 Watts

Power Used (Watts)

Light Source

- 60W Bulb
- Compact Fluor.
- LED

“Best” White LED and Compact Fluorescent vs. 60Watt Light Bulb Comparison
If a 150 lm/Watt Solid State White LED source were developed, then in the United States alone:

• We would realize $115 Billion cum. Savings in 2025*
• Alleviate the need of 133 new power stations!*
• Eliminate 258 million metric tons of Carbon*
• Save 273TWh/year in energy**

Key Materials Technologies for Energy Efficient White LED

Light Extraction Eff.

Conversion Efficiency
- New phosphors

Electrical Efficiency
- Contacts, semi-polar
- Internal Q. Efficiency
- Semi, nonpolar

ZnO mega-cone

Photonic crystal

SLEO low defect

New ZnO

Etched PC

Quantum wells

Buried PC/LEO
Summary of Nonpolar/Semipolar LEDs

- Nonpolar/semipolar LEDs is close to c-plane EQE
GaN Crystal Structure

C-Plane \{0001\}

a1 [1000]
a2 [0100]
a3 [0010]
c [0001]

M-Plane \{1\bar{1}00\}

A-Plane \{1\bar{1}20\}
Motivation – Polarization Effects

Spontaneous and piezoelectric polarization cause:
1. band bending
2. charge separation in QW

- Emission red shift
- Low recombination efficiency
- High threshold current

Growth on non-polar GaN will solve these problems
Historical Evolution of Nonpolar/Semipolar LEDs at UCSB

- Improved output power and EQE in $m$-LEDs.

![Graph showing the evolution of EQE (%)](image-url)
Current LED Applications

- Cell Phone (Nokia)
- Traffic signals (Gelcore)
- TVs (LED DLP\textsuperscript{tm}) (samsung)
- Large Displays (NASDAQ)
- Streetlights
- Automotive
Laser TV

Mitsubishi "Laser TV" with Arasor and Novalux components (left) and Plasma (right)
Future SSL Displays
Pocket Projector/Cell Phone

Prototype from Novalux using frequency double lasers
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 71 LPW due to several factors that need further research and development in
  – Fixture Efficiency
  – Heat Sinking
  – Scale up to Mass production

• Stay Tuned....