LED Technology Progress

February 26, 2008

Mark McClear
Director, Business Development
mark_mcclear@cree.com
Who is Cree?

• Semiconductor company, headquarters in Durham NC, USA

• Revenue of $394 million in FY 2007

• 12 locations worldwide, 2600 employees

• Technology leader with 827 U.S. and 1,800 foreign patents

• Leader of the LED Lighting Revolution
Traditional Lighting Technologies

**Incandescent**

*Pros:* Very cheap, great color
*Cons:* Very short lifetime, poor energy efficiency

**Fluorescent**

*Pros:* Cheap, efficient
*Cons:* Can not run in cold temp; difficult/costly to dim, control, Hg

**High Intensity Discharge**

*Pros:* Cheap, efficient
*Cons:* Poor color, long restart, Hg

**Compact Fluorescent**

*Pros:* Energy efficient
*Cons:* Hg, Cold temp operation, High cost vs. Incand

**Halogen**

*Pros:* Great color, focused light
*Cons:* Very short lifetime, poor energy efficiency
Basic Advantages of LED Light

- LEDs are very energy efficient → >90LPW (near-term roadmap to >150LPW...)
- Are directional → No wasted light, any pattern possible
- Have very long lifetime → >50,000 hours to 70% Lumen Maintenance (L70)
- Are inherently rugged → No filament to break
- Start instantly → nanoseconds vs. >10 min re-strike (HID)
- Are environmentally sound → no Hg, Pb, heavy metals
- Are infinitely dimmable, controllable → New lighting features, power savings
- Love cold temperatures → No cold starting or performance issues
LED Performance Continues To Increase

Light Source Efficiency Trends

- LED
- Current XLamp® LED
- 1 Year Ago XLamp® LED
- Cree R&D Best

100% Improvement in last 18 months
Oakland, CA

Courtesy of BetaLED
Jackson Hole, WY

Courtesy of Relume
Toronto, Canada

Courtesy of Leotek
Durham, NC

Cree Headquarters

Before

After

Courtesy of BetaLED
Guangzhou, China

Courtesy of Multi-Cell Semiconductor Lighting Technology Co., Ltd.

Hybrid Solar/ Grid Powered Street Lamps
Better Day BP - Racine, Wisconsin

First Ever LED Lighting Gas Station

“We’re the first ones in the world, period, to use all LED lighting for a gas station...the product is unbelievable; it gives everything a very clean look. You can stand under it, your car looks clean, your shoes look clean.”

Courtesy of BetaLED
Hastings, UK Town Centre

Courtesy of Advanced LED
Racine, WI

Courtesy of BetaLED

140W LED vs. 300W HPS Comparison
Split, Croatia

Courtesy of Schréder

Warm White Street Lamps
Waukesha, Wisconsin

Courtesy of BetaLED
Sentry Equipment Corp., Oconomowoc, WI

Courtesy of BetaLED
Torraca, Italy

- 530 Luminaires Installed
- 75% Power Savings
- 9 month payback

Courtesy of Elettronica Gelbison, SRL
Crocina Tunnel, Arezzo, Italy

Courtesy of BetaLED
Ann Arbor Streetlight Retrofit

50% reduction in energy
5x lifetime
4.4 yrs. payback

 Courtesy of Relume
Austin, TX

Courtesy of BetaLED
Next Wave: Indoor SSL

- Different requirements than outdoor
  - Warm White Color Temperature (~3000K) required
  - High CRI (>80)
  - Lamp maintenance not a driving factor
  - High style content
  - Focus on energy, green
  - Different market channels, cost expectations (consumer product)

Yes, these are LED!
Excellent Results Indoor

Grand Prize Winner:
LED Lighting Fixtures, Inc.
2007 Lighting For Tomorrow Design Competition

- 600 lumens @ 2950K, 11W total power
- 55 LPW wall-plug (verified independently)
- CRI 95
BEFORE

Incandescent  65W BR30 - Total Power = 5,135W
AFTER
LR6 - Total Power = 948W
# Packaged LED Classes

<table>
<thead>
<tr>
<th>Lamp Type</th>
<th>Drive Current</th>
<th>Light Output</th>
<th>Brands</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1-type</td>
<td>5 – 20 mA</td>
<td>&lt;1 – 4 lm</td>
<td>(Commodity product)</td>
<td>• Indicators</td>
</tr>
<tr>
<td>(3 – 7 mm)</td>
<td></td>
<td></td>
<td></td>
<td>• Votive lights</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Rope lights</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Traffic signals</td>
</tr>
<tr>
<td>Surface mount</td>
<td>20 – 100 mA</td>
<td>1 – 30 lm</td>
<td>(Commodity product)</td>
<td>• Cell phone backlighting</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Automotive</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Channel sign lighting</td>
</tr>
<tr>
<td>High power</td>
<td>&gt; 300 mA</td>
<td>&gt; 80 lm</td>
<td>• XLamp®</td>
<td>• General illumination</td>
</tr>
<tr>
<td>(Lighting-Class)</td>
<td></td>
<td></td>
<td>• Luxeon/Rebel</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• NS6XXXX</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Ostar</td>
<td></td>
</tr>
</tbody>
</table>

NOTE: T1 and surface mount LEDs are usually rated in microcandela (mcd) for light output instead of lumens (lm). For the purposes of explanation, we converted mcd to lm to measure total light output.
Good LED Luminaire Design Will Be Different…

- LED Light is inherently directional
- LED thermal path accomplished by conduction
  - No IR, no UV in the light beam
- Power LEDs provide conductive thermal path; 5mm and SMD LED lamps normally do not
50,000hrs & Other LED Fairy Tales*

- **5mm LEDs are not recommended for lighting applications**
- **Risk:** 5mm LEDs are cheap, readily available. Who will have the discipline *NOT* to use them? Impact on the public perception of SSL?

* ref: John Curran, Dialight

The 5mm LED Risk Realized

Time zero

16.5" Linear
97.8% Drop

1000 hours

LED Puck
84.1% Drop

22" Linear
96.9% Drop
Lighting-Class LEDs

- New in the last 12-18 months
- Stable, High-output, Warm & Cool White
- CRI 75-85 typical
- Thermal path & optics designed for lighting applications

<table>
<thead>
<tr>
<th>Lighting-Class LEDs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Output</strong></td>
</tr>
<tr>
<td><strong>High Efficacy</strong></td>
</tr>
<tr>
<td><strong>Stable Color Point</strong></td>
</tr>
<tr>
<td><strong>Long Lifetime</strong></td>
</tr>
<tr>
<td><strong>Isolated Thermal Path</strong></td>
</tr>
<tr>
<td><strong>High Color Rendering Index</strong></td>
</tr>
<tr>
<td><strong>Avail in full range of CCT</strong></td>
</tr>
<tr>
<td><strong>Binning</strong></td>
</tr>
</tbody>
</table>
Some Early Attempts

- Philips & Cree DOE PAR38 R&D results: 56 LPW, CRI >90
- LLF PAR38 R&D results: 113 LPW, 2760K, CRI 91
- New Energy Bill awards for A-lamp & others

More Recently
Summary

- LEDs have made unprecedented technological advances in the last 12-16 months
  - Light Output
  - Lumens per watt
  - Color, CRI, and color point stability
- First installations beginning to appear; fixtures designed for LED
- LED Bulb replacements are more challenging, but we’ll get there
- LEDs and the SSL market runs a risk of poor quality
  - Not all LEDs are Lighting-class