White Lighting (Illumination) with LEDs

Werner Goetz
Lumileds Lighting
Outline

- Lumileds’ power LED platform
  - Monochromatic
  - White
- Illumination with LEDs
  - Light Source Criteria,
  - Options,
  - and Issues
- Next steps
- Conclusion / Outlook

LED light fixture – 12 Luxeon LEDs, 0.24 klm
Lumileds’ Power LEDs - I

- **Flip-chip LEDs (III-V Nitrides)**
  - 0.1 – 4 mm² die area
  - 2x extraction efficiency gain
  - Efficient heat removal

- **Power Package**
  - Low thermal resistance (4 - 14 K/W)
  - Up to 5 W input power
  - Radiation-resistant encapsulants
Lumileds’ Power LEDs - II

- **Wall-Plug Efficiency**
  - ~20 % for blue
  - Decreases for longer wavelength

- **Input power**
  - 1 W and 5 W

- **Power / Flux (5 W)**
  - >1 W for blue
  - >200 lm for green

![Graph showing Wall-Plug Efficiency vs. Peak Wavelength (nm)](image_url)
White Power LEDs

- Conformal phosphor coating
- Smaller source size
- Improved angular “color” uniformity

Luxeon

“Conventional”, slurry deposited LED

Diagram showing:
- Reflector Cup
- Phosphor Granules
- LED Die
- Submount Die
- Die Attach Epoxy

Graph showing:
- CCT (K) vs. Viewing Angle (deg)

Luxeon vs. Conventional
White Light Criteria: LEDs I

- Lifetime

70% “Lumen Maintenance” at 50k hours

Incandescent: ~1k hours
Fluorescent: ~10k – 20k hours

Luxeon 5 mm white

Lighting Research Center - Sept 2002

Relative Light Output

Time (hrs)
### White Light “Criteria”: LEDs II

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>20 - 38 lm/W</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Incandescent:</strong></td>
<td>7 – 15 lm/W (to 25 lm/W for halogen)</td>
</tr>
<tr>
<td><strong>Fluorescent:</strong></td>
<td>35 – 100 lm/W</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flux per package</th>
<th>~30 and ~150 lm (Luxeon 1 and 5 W)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Incandescent:</strong></td>
<td>110 – 1 klm (15 and 60 W bulbs)</td>
</tr>
<tr>
<td><strong>Fluorescent:</strong></td>
<td>150 – 3 klm (4 – 32 W tubes)</td>
</tr>
</tbody>
</table>

![Graph showing flux/package over time]

- **Efficiency**: 20 x / decade
- **Flux per package**: indicator LEDs

---

Fifth International Conference on Nitride Semiconductors, ICNS-5
Nara, Japan, May 25-30, 2003

Copyright (c) Lumileds Lighting LLC
White Light “Criteria”: LEDs III

- CIE Diagram
  - On or close to “Planckian” locus
  - Range of color temperatures
  - High color rendition ($R_A$)

Fluorescent bulb, $R_a = 83$

Dependent on white LED technology

Blue LED + phosphor

Three color triangle

YAG Phosphor

Blue LED

Incandescent

Planckian Locus

Incandescent: $CCT$ limited to $<\sim 3200$ K

Fluorescent: $R_A$ “artificially” high
Some White LED Options

- **Direct – RGB LEDs**
  - Potentially highest efficiency
  - Very large color gamut
  - Tunable white point

- **Blue LED + yellow phosphor**
  - Simple
  - Decent color rendering ($R_a \sim 75$)

- **UV LED + RGB phosphors**
  - White point determined by phosphors only
  - Excellent color rendering
White LED Issues

- **RGB LEDs**
  - Green LED efficiency
  - Temperature stability of LEDs depends on color
  - Different degradation trends

- **LED + Phosphor(s)**
  - Efficiency of pump LED
  - Reduced extraction efficiency
  - “Quantum deficit” is fundamental
  - Blue LED + YAG phosphor: High CCT and limited color rendering
  - UV LED + RGB phosphor: Degradation of organic encapsulants
Lumileds’ “Warm White”

- Blue LED + yellow and red phosphor

**Dual phosphor**
- CCT = 3800 K
- $R_a = 94.4$

**Single phosphor**
- CCT = 2880 K
- $R_a = 91.9$

- $R_a > 90$, $R_g > 60$
- Tint free: 2800 – 4000 K
- 20 – 25 lm/W
Sunlight Spectrum D65

- “Light box” with RGB and phosphor converted LEDs

- Excellent rendition of daylight spectrum
- Color uniformity $\text{du'v'} \leq 0.005$

**Luxeon Lightbox**
- **CCT:** 6705 K
- **CRI:** $R_{a,8} = 95.6 \%$
  $R_{a,14} = 94.4 \%$
- **Total Flux:** 547 lm
- **Input Power:** 48.9 W

**D65 Spectrum**

![Graph showing sunlight spectrum D65 and Luxeon Lightbox data.](image-url)
Conclusion / Outlook

• Today
  • >150 lm, 30 lm/W, 50k hours
  • LEDs are very efficient in distributing light (small source size)
  • All white LED options have potential strengths
  • Cost ($/lm) is 100 x

• Vision
D65 “Light box”