Large Area
Intelligent
Efficient
High Quality
Solid-state
Lighting

Highlights

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Outline

• Thin large area solid-state lighting modules

• The technological background

• LASSIE-FP7: Highlights (http://lassie-fp7.eu)
Thin large area solid-state lighting modules

- **Why large-area?**
  - Light distribution over a large area
  - Reduced intensity → Reduced glare
  - Reduced luminaire losses

- **Why thin?**
  - Aesthetics
  - Design
  - Weight & Space

- **Which technologies?**
  - OLEDs
  - LEDs
Large Area Solid-state Lighting

Efficiency

LEDs

![Cree LED Efficiency Chart](chart.png)

OLEDs

- **60 lm/W**
  OSRAM
  (2008)

- **90 lm/W**
  Novaled
  (2009)

- **114 lm/W**
  Panasonic / UDC
  (2013)

- **139 lm/W**
  Konica Minolta
  (2014)

- **156 lm/W**
  NEC / Yamagata Univ.
  (2013)
Lighting quality

We need a new definition and measure of lighting quality beyond CRI based on the whole source spectral characteristics of SSL sources

M. Schaer, P. Cotte, L. Zuppiroli (Lumières du Futur, PPUR, 2011)
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LEDs vs. OLEDs

- High color rendering
  - ... but de-saturates red colors (e.g. skin tones)
- Modest to good luminance uniformity
  - ... but slow variations
- Large optical losses (e.g. light trapping in glass modes)
  - ... but with out-coupling foils > 50% improvement
- Low efficiency de-glaring solutions
  - ... due to poor light recycling
- Difficult beam shaping
  - ... OLEDs are large area lambertian emitters
LEDs vs. OLEDs

- Possible medium to high color rendering
  - ... but with increasing price and/or complexity
- High luminous intensity
  - ... but “hot spots” can be an issue
- Possible limited lumen output / chip
  - ... but LED arrays can provide enough lumens
- Small source dimensions (i.e. point sources)
  - ... ~1mm\(^2\) vs 10\(^4\)mm\(^2\)
- Lambertian point sources
  - ... bright spots, multi-shadows, glare, etc.
## Commercial LED & OLED lighting modules

<table>
<thead>
<tr>
<th></th>
<th>LEDs</th>
<th>OLEDs</th>
<th>OLEDs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Philips</strong></td>
<td></td>
<td>OLEDworks (Philips)</td>
<td>LG Chem</td>
</tr>
<tr>
<td><strong>Highest lumen output</strong></td>
<td></td>
<td>Lumiblade Brite FL300</td>
<td>Largest Area</td>
</tr>
<tr>
<td></td>
<td>Fortimo LED DLM 5000</td>
<td>102x102</td>
<td>N6SD30</td>
</tr>
<tr>
<td><strong>55W/830 Gen5</strong></td>
<td>5’940</td>
<td>300</td>
<td>100x100</td>
</tr>
<tr>
<td><strong>Emissive area (mm²)</strong></td>
<td>2’940</td>
<td>800-1’200</td>
<td>1.97</td>
</tr>
<tr>
<td><strong>Thickness (mm)</strong></td>
<td>43.6</td>
<td>3.0</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Luminous flux (lm)</strong></td>
<td>4’500-5’500</td>
<td>300</td>
<td>80</td>
</tr>
<tr>
<td><strong>Lumen Efficacy (lm/W)</strong></td>
<td>79</td>
<td>&gt;50</td>
<td>80</td>
</tr>
<tr>
<td><strong>CCT (K)</strong></td>
<td>3’000</td>
<td>3’000</td>
<td>3’000</td>
</tr>
<tr>
<td><strong>CRI</strong></td>
<td>&gt;80</td>
<td>&gt;80</td>
<td>&gt;90</td>
</tr>
<tr>
<td><strong>Lifetime – LT70 (10³ hrs)</strong></td>
<td>50</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td><strong>Price / unit</strong></td>
<td>69 EUR</td>
<td>136 EUR</td>
<td>600 EUR</td>
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</tbody>
</table>

### Notes:

1. Other products exist with lower lm
2. Based on the technical drawings
3. Module
4. System
5. eBay (source)
6. Including thermal backplate, housing and wiring
7. At 340mA and 19V
8. At 300 lumen
9. 4000K planned
10. At 300 lumen
11. At 125 lumen
12. For orders above 40 OLEDs
13. Bare OLED
14. At 1700mA / 8.5V (OLED-info)
15. At 3’000 cd/m²
16. Using LG proprietary “Face Seal” technology
17. OLED-info 29.01.15 (680 USD)
18. With housing and wiring
19. Initial luminance not specified
20. Source
Commercial LED & OLED lighting modules

Luminous flux (lm/EUR):
LEDs >> OLEDs
(> x50)

In order to have a better cost-performance for OLEDs:

• Reduce manufacturing costs
  o ... the OLED display industry may help

• Increase the emitting area
  o ... but reduces yield & transport/handling/cleaning issues

• Increase the lumen output:
  o ... but performance decrease and glare
Large Area Solid-state Lighting

How to improve the quality of LED lighting?

CTI Project « New Color-changing films for lighting applications » (nr. 8184.1 EPRP-IW)

2006-2008

Patents
  - EP08164280.3 & US 2010/0102251
  - US 13/114.558 & PCT/IB2012/052577

[Image of color-changing films]
The « hybrid » solution: (O)LED modules

- Color sensor
- Lumogen® Fluorescent Dyes
- Heat management
- Light management
- Out-coupling structures: R2B for-red/UV-cured high-eficiency
- In-coupling gratings: R2B for-red/UV-cured high-eficiency

Property of the LASSIE-FP7 Consortium
Large area LED modules

**Edge-lit**

- Thin form factor \((T \leq 9\text{mm})\)
- Thick & heavy light guide
  - Not compatible with R2R production
- Moderate luminance uniformity
- Color shift across the emitting area
- Low efficiency

**Direct-lit**

- High uniformity (diffusers)
  - ... but the rule-of-thumb is \(T \geq P\)
- Thinner form factors are possible
  - ... but with reduced pitch, i.e. higher costs
- High lumen output & efficiency
- Very large emitting areas are possible
- Potentially low weight
  - ... with the use of thin-film/on-foil optics

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Acevel

9mm
3’100lm
80lm/W
3.800 Kg

Integral LED

87mm
5’100lm
122lm/W
3.250 Kg

Property of the LASSIE-FP7 Consortium
Beam-shaping « bat-wing » foils

- Pixels of periodic $\mu$-structures (MLAPs)
- Narrow-angle rays: widely deflected off-axis
- Wide-angle rays: unaffected
- On-foil technology
High quality lighting: Color-Changing Foils (CCFs)

- **RGB spectra tuned to** $V(\lambda)$: High luminous efficacy but poor color rendition
- **Inorganic phosphors**: Improved color rendition with lower luminous efficacy
- **CCFs technology**: Excellent color rendition with acceptable luminous efficacy
  - Efficient phosphors $\rightarrow$ Low concentrations
  - Co-extruded into thin-films $\rightarrow$ Roll-to-roll production

<table>
<thead>
<tr>
<th></th>
<th>$u'$</th>
<th>$v'$</th>
<th>$\Delta u'v'$</th>
<th>CCT</th>
<th>LER</th>
<th>CRI</th>
<th>R9</th>
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<tbody>
<tr>
<td>RGB</td>
<td>0.2508</td>
<td>0.5214</td>
<td>0.0001</td>
<td>2'995</td>
<td>379</td>
<td>74</td>
<td>-16</td>
</tr>
<tr>
<td>B+yellow</td>
<td>0.2507</td>
<td>0.5214</td>
<td>0.00001</td>
<td>2'999</td>
<td>269</td>
<td>80</td>
<td>41</td>
</tr>
<tr>
<td>B+CCF</td>
<td>0.2506</td>
<td>0.5213</td>
<td>0.00001</td>
<td>2'999</td>
<td>307</td>
<td>92</td>
<td>51</td>
</tr>
</tbody>
</table>

Property of the LASSIE-FP7 Consortium
Intelligent Lighting

Intelligence: Colour feed-back

*Intelligent luminaires require colour feed-back*

- Compensate for any drift of light output (e.g. ageing)
  - Chromaticity point
  - Color rendering
- Accurate colour-sensing feedback
- Cost-effective colour multispectral sensors

**Targeted solution**

- 16 CMOS photodiodes with different filters
- Up to 16 spectral channels

*Courtesy of FhG IIS*

Property of the LASSIE-FP7 Consortium
Sensor integration

Sensor chip wire-bonded on test board

Packaged sensor

Sensor board with fiber coupling

Property of the LASSIE-FP7 Consortium
LED-based polymer foils

Opportunities

• LED-based polymer foils ➔ Flexible lighting modules
• Printing and assembly with R2R processes
• Improved performance:
  o Optimized electronics layout
  o Traditional electronic SMD components
  o Bare LEDs with no on-chip optics

Challenges

• Heat management
  o Poor thermal conductivity of the polymer foils
Heat management: Final solution & LED foils

Heat management slugs
- Thermal resistance: 2°C/W (module) to 0.2°C/W (luminaire)
- Roll-to-Roll compatible processes

R2R LED foil
- 200 mm x 600 mm
- Possible to integrate with CCFs
Module integration

LED foil assembly
- 49 white LEDs (heat mngt.)
- 84 monochromatic LEDs

Lighting module case

Colour sensor integrated

Finalised test assembly
Exploitation

Targeted market case

LASSIE-FP7 USPs

- High color rendering
  - ≥ 90
- High color accuracy
  - 3 to 1 Step MacAdam on the Planckian-locus
- Constant color over time
  - Intelligence: sensor feedback loop

Niche target market

- High quality and high demanding
- Lighting in stores & boutiques
- Use case: “Color-proof islands”
Thank you for your attention!

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