LED Technology and developments

Colin Beale | 1st December | CIBSE – South Wales
## This evenings topics

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<td><strong>1.</strong></td>
<td>What's behind the latest developments in LED performance and efficiency. What else can be achieved?</td>
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<td>LED Production: Why can't I specify the highest efficiency LEDs?</td>
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<td>Is LED colour consistency any better than it used to be?</td>
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<td>Where are the efficiency losses? What can be done to improve LED lighting efficiency?</td>
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The latest LED developments: What's behind them? What else can be achieved?
Maximising LED flux and efficiency: The major factors

The LED 'Chip':

Task: Maximise the internal quantum efficiency

OSRAM solution:

- Minimise absorption by producing surface emitters
- OSRAM Thin Film (green to red / IR) and Thin GaN (Blue to Green) chip technology
- Thin Film production since 2002
Maximising LED flux and efficiency: Additional benefits of Thin Film and Thin GaN

Additional benefits of surface emitters

Higher chip surface luminance

  – Virtually all light radiates from one surface compared to five for a volume emitter. Luminance is approx 1.8 x higher

Reliance on package reflectivity is minimised

  – Light is emitted vertically from the chip - the required direction

Secondary optic size is reduced, light coupling is increased

  – Optics have to image a small high luminance surface rather than an emitting cube plus the package reflecting surfaces
Maximising LED flux and efficiency: The major factors

The LED 'Chip':

Task: Reduce 'contact shadowing' by reducing the chip surface metalisation area
   Solution:
   - OSRAM UX3 Thin GaN chip technology has no metalisation on the chip surface

Task: Improve current spreading through the LED chip
   Solution:
   - OSRAM UX3 Thin GaN chip technology optimises current spreading
Maximising LED flux and efficiency: The major factors

The LED 'Chip':

Task: Maximise the electrical efficiency by reducing the forward Voltage ($V_F$)

Solution:
- Reduce Ohmic losses due to metal contacts to semiconductor material as far as possible.
- Improve chip crystal structure as far as possible: Imperfections cause losses
- Semiconductor physics dictates an absolute limit:
  \[ \lambda (\mu m) = \frac{hc}{\epsilon_{PH}} = 1.24 / \epsilon_{PH} \]

Task: Minimise the reduction of light output with temperature

Solution:
- Improve the chip construction (epitaxy) to reduce the effect
- For white LEDs: Optimise phosphor performance for high temperatures
Maximising LED flux and efficiency: The major factors

The LED package:

Maximise the package extraction efficiency

Solution:

── Match refractive indexes of chip and light coupling materials as closely as possible to extract light from the LED chip

── Minimise total internal reflection by using shaped lenses and surfaces to extract light from the package

── Use reflective materials and surfaces to recycle reflected light out of the package

OSRAM OSLON Square

OSRAM Golden Dragon Plus
Maximising LED flux and efficiency: How far is it possible to go?

For OS: OSLON Square (3000 K, CRI 80) at 350 mA, 85°C;

- **Internal Quantum Efficiency**: OSRAM OS (85%), Limit (90%)
- **Extraction Efficiency**: OSRAM OS (86%), Limit (90%)
- **Electrical Efficiency**: OSRAM OS (97%), Limit (99%)
- **Wallplug Efficiency**: OSRAM OS (65%), Limit (76%)
LED production:
Why can't I specify the 'brightest' LEDs?
Why can't I specify the brightest LEDs?: Production limitations

The epitaxial growth process introduces variances across the LED wafer in...

- Flux \( \varphi_V \)
- Peak wavelength \( \lambda_{\text{PEAK}} \)
- Forward Voltage \( V_F \)

LEDs are grouped as a final production stage

- Distribution of flux and wavelength over a number of wafers will be close to normal (Gaussian)
- Yield of extreme groups can be very small

Data sheets will show the full potential production range

- Extreme groups may not yield in sufficient quantity to satisfy demand
LED Colour consistency: Has it improved?
Various factors influence the resultant colour of a white LED

- Blue LED chip peak wavelength (colour)
- Chip spectral power distribution
- Consistency of the multi phosphor mix
- Relative radiant flux from the blue LED chip and phosphor

OSRAM now have an advanced "targeting" system

- A "wafer map" detailing the wavelength of all the LED chips on a wafer is produced at the wafer (front end) factory
- This allows matching of phosphors to LED chip when they are combined into an LED package at the back end factory to reduce colour variance
LED Colour consistency: Guaranteed solutions for light engine manufacturers

OSRAM 'Fine bin' colour system
- Single fine bin colour variance less than 3 SDCM
- OSRAM can consistently supply the same two to four groups in volume
- Introduced 18 months before our competitors

OSRAM 'Mix to Match' solution
- Established kitting and logistics system
- Produces consistent colour point
- OSRAM Mix to Match kits alleviate production difficulties
Where is efficiency lost?:
What can be done to improve LED lighting efficiency?
Where is efficiency lost?: The trade off of efficiency and cost

A compromise has to be made between cost and efficiency. Here is an example based on a CRI80 4000K OSLON Square power LED normalised to 700mA with $T_J = 25^\circ \text{C}$

<table>
<thead>
<tr>
<th>Drive current (mA)</th>
<th>LED Flux (lm)</th>
<th>Efficiency (lm/W)</th>
<th>Efficiency (relative)</th>
<th>Cost per lumen (relative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200mA</td>
<td>82</td>
<td>144</td>
<td>1.31</td>
<td>2.87</td>
</tr>
<tr>
<td>350mA</td>
<td>133</td>
<td>131</td>
<td>1.19</td>
<td>1.76</td>
</tr>
<tr>
<td>500mA</td>
<td>181</td>
<td>122</td>
<td>1.11</td>
<td>1.3</td>
</tr>
<tr>
<td>700mA</td>
<td>235</td>
<td>110</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1000mA</td>
<td>310</td>
<td>99</td>
<td>0.9</td>
<td>0.76</td>
</tr>
<tr>
<td>1200mA</td>
<td>352</td>
<td>92</td>
<td>0.84</td>
<td>0.67</td>
</tr>
<tr>
<td>1500mA</td>
<td>407</td>
<td>83</td>
<td>0.76</td>
<td>0.58</td>
</tr>
</tbody>
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Both increase

Both decrease
Where is efficiency lost?:
Higher CRI costs efficiency

Lower CRI values increase efficiency:

4000K average values based on OSLON Square typical values at 700mA $T_J = 25°C$

<table>
<thead>
<tr>
<th>CRI (min)</th>
<th>LED Flux (lm)</th>
<th>Efficiency (lm/W)</th>
<th>Efficiency (relative)</th>
<th>Cost per lumen (relative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>285</td>
<td>133</td>
<td>1.21</td>
<td>0.82</td>
</tr>
<tr>
<td>80</td>
<td>235</td>
<td>110</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>90</td>
<td>202</td>
<td>94</td>
<td>0.85</td>
<td>1.16</td>
</tr>
</tbody>
</table>
Where is efficiency lost?:
Optics and luminaire cover losses

Light can be reflected as well as refracted when it passes between mediums with differing refractive indexes:

Lenses – losses up to 20%:
- Coupling light from the LED into the lens causes some reflection
- Total internal reflections inside the lens can reduce the amount of light that leaves the lens
- Not all of the light that leaves the lens will contribute to an emission pattern that matches the application requirement (beam candela, lux etc.)

Luminaire covers or diffusers – losses up to 50%:
- Reflection back into the luminaire from the inner surface of the cover
- Total internal reflection within the cover material
Where is efficiency lost?:
LED drivers and resistive losses

LED drivers are not 100% efficient:
— Efficiency is often dependent upon the load being matched to the control gear
— Higher current is less efficient than higher Voltage due to resistive losses ($I^2R$)
Where is efficiency lost?:
Summary of the facts

— Use larger numbers of LEDs at lower drive current - provided that the cost increase is acceptable
  — What is the current density of the LEDs? 0.35A/mm² or less?

— Consider lower CRI solutions. What impact does reducing from CRI 80 to CRI 70 really have?
  — What are the R9 and R13 values for the CRI 80 solution offered?

— Does the luminaire optical system 'place the light where it's required'
  — Is the emission pattern ideal for your application?

— Does the luminaire use efficient optics. Is it possible to use luminaires without front covers?
  — How efficient are the optics used in the luminaire?

— Load should be matched as closely as possible to the maximum efficiency point of the LED driver
Thank you for your time and attention