High luminance LEDs:
LED- and luminaire-level performance

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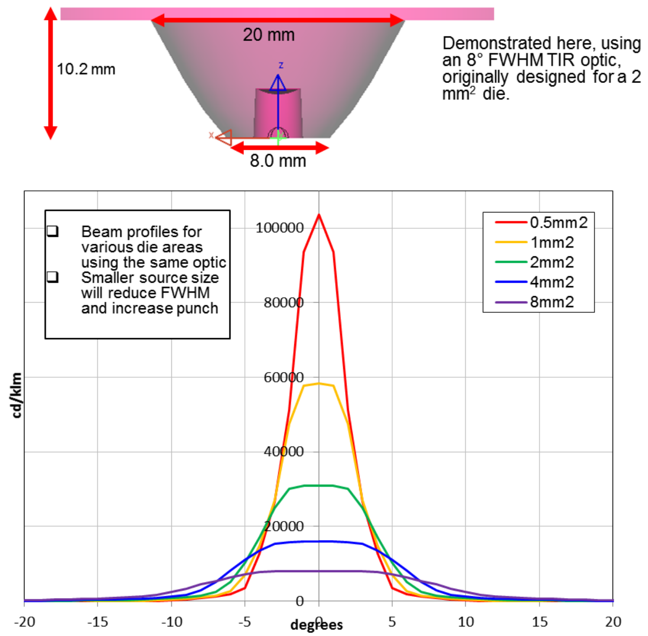
LUMILEDS

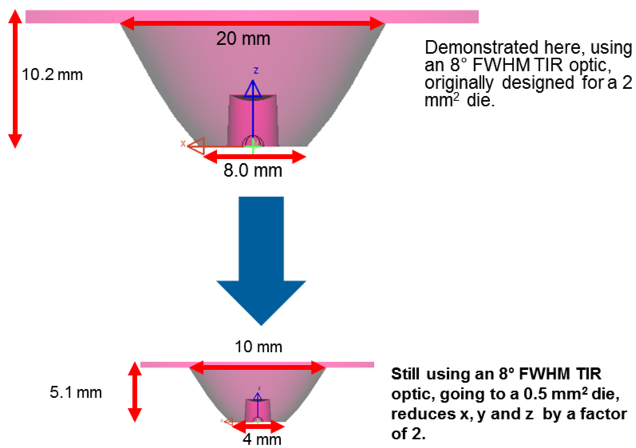
High luminance enables better optical control

Luminance $L_v = d^2\phi / (dS \, d\Omega \cos\theta)$

Luminous flux from a given **source area** within a given **solid angle**

Benefits of high luminance in directional applications





Narrower beam angle
for the same optic size

Smaller optics
for the same beam angle

→ More light delivered on target, energy savings

→ Volume reduction, cost savings

Luminance vs. LED efficacy

$$\eta_L = WPE \times CE$$

The efficiency of a "white" LED converting electrical power to light perceptible by the human eye (lm/W)

$$WPE = IQE \times EXE_n \times ELE$$

IQE : Internal Quantum Efficiency
EXE_n : Extraction Efficiency
ELE : Electrical Efficiency

Power conversion efficiency of blue LED (W_{opt}/W)

$$CE = LE \times QED \times QD \times PE$$

LE : Lumen Equivalent
QED : Quantum Efficiency in Down Conversion
QD : Quantum Deficit
PE : Package Efficiency

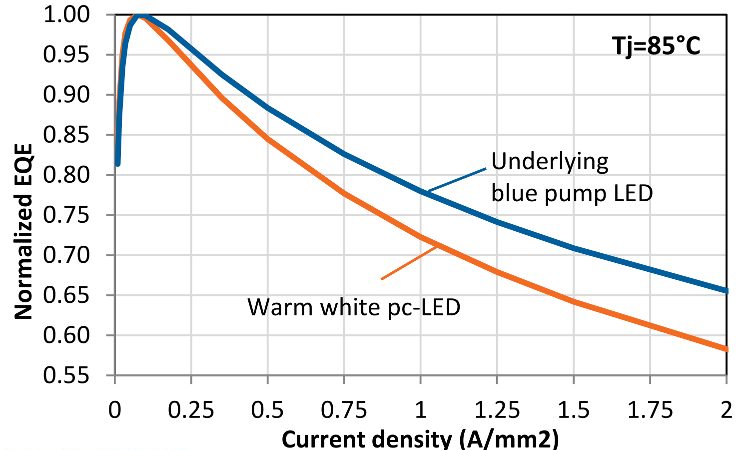
Phosphor conversion efficiency (lm/W_{opt})

Two ways to increase LED luminance:

- Drive harder – affects mostly IQE and QED
- Reduce package size / improve collimation – affects mostly PE

Luminance vs. LED efficacy | Droop

Droop: Decrease in LED efficacy with increasing drive current



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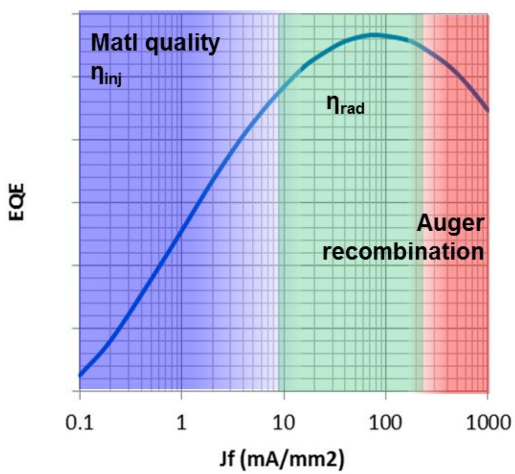

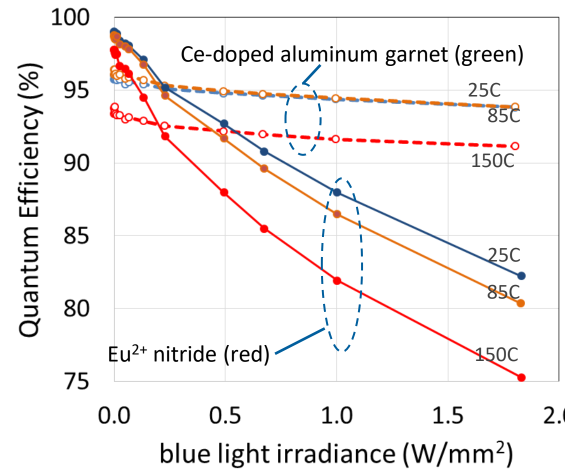

Epi droop: non-radiative recombination in active layers at high current density

Phosphor droop: photothermal saturation of quantum efficiency of phosphor materials (esp. red)

Luminance vs. LED efficacy | Package architecture

Package efficiency: Efficiency of extracting converted white light from the LED package

Two key factors affecting package efficiency:

- Fresnel reflection at exit surface
- Reflectivity of package enclosed by exit surface

η_L = WPE x CE — *The efficiency of a "white" LED converting electrical power to light perceptible by the human eye (lm/W)*

WPE = IQE x EXE_n x ELE — *Power conversion efficiency of blue LED (W_{opt}/W)*

- IQE : Internal Quantum Efficiency
- EXE_n : Extraction Efficiency
- ELE : Electrical Efficiency

CE = LE x QED x QD x PE — *Phosphor conversion efficiency (lm/W_{opt})*

- LE : Lumen Equivalent
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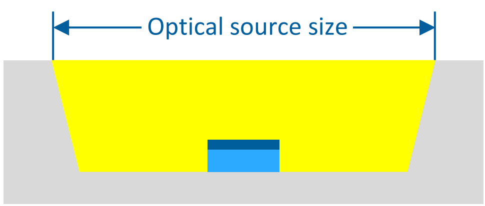
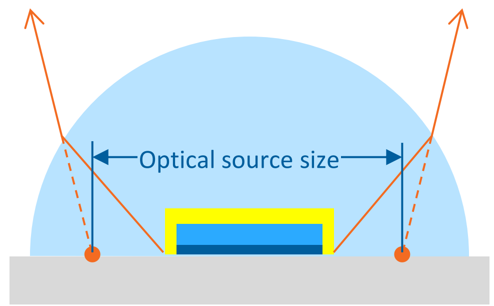
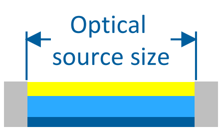


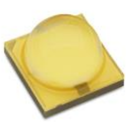




Mid-power LED

Reflective cup helps direct light back towards interface until angle is within extraction cone

Package efficiency: ~**90%**



High-power domed LED

Hemispherical dome reduces angle of incidence to near-normal for efficient extraction

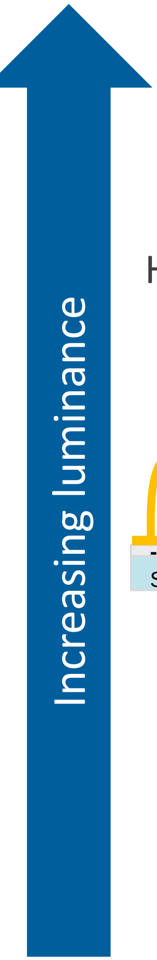
Package efficiency: ~**90%**

High-power undomed LED

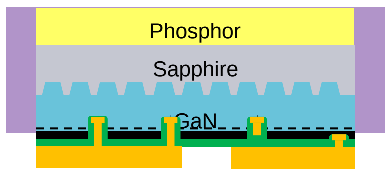
Luminance is higher without dome, but more light is reflected back into die

Package efficiency: ~**75%**

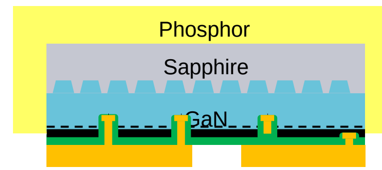
Diversification in LED architectures to address a range of needs



Chip-Scale Package (CSP)
Surface Emitter

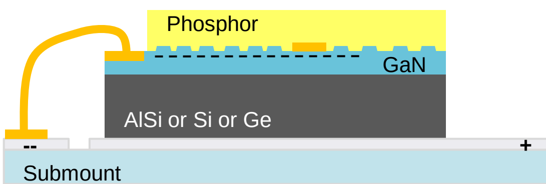


Chip-Scale Package (CSP)
Volume Emitter

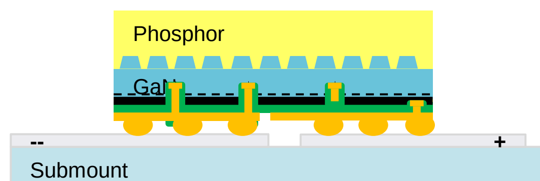


High-drive performance with smallest source size (in dense arrays) for high luminance and low cost

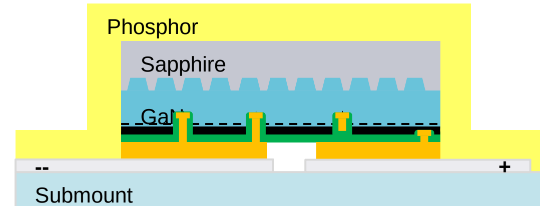
Vertical Thin Film (VTF)



Thin Film Flip-Chip (TFFC)

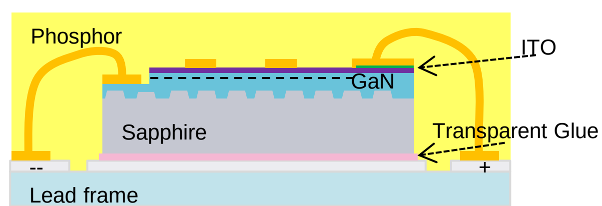


Patterned Sapphire Substrate Flip Chip (PSS-FC)



High-drive performance with submount for efficient heat spreading and dome

Lateral Die (Mid- & Low-Power)



High efficacy and lowest cost for low-medium drive conditions

Product performance

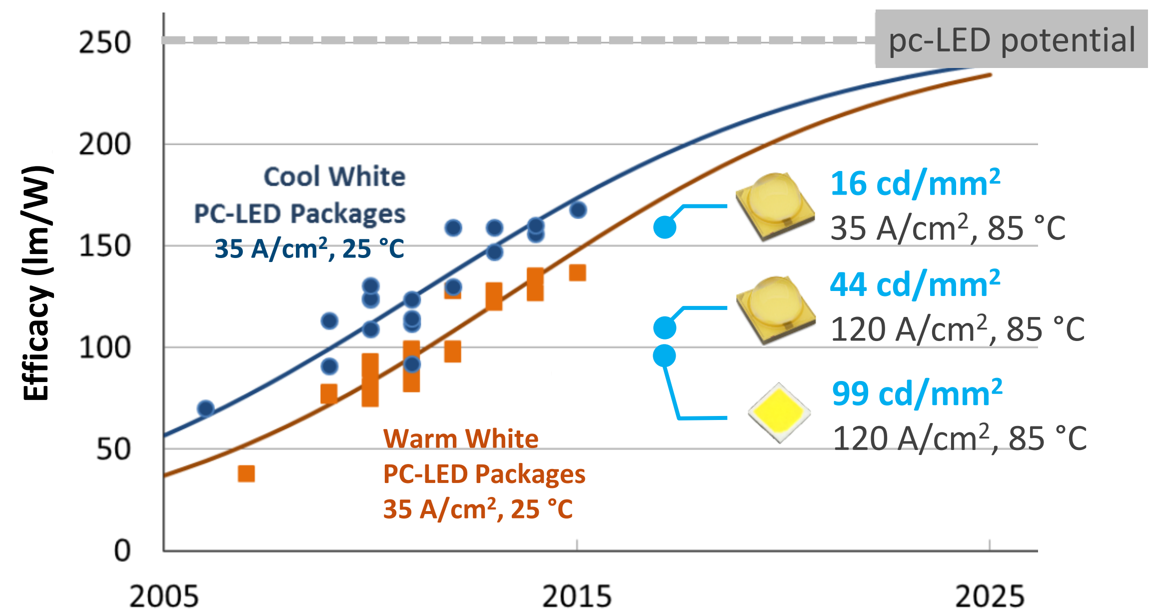
Luminance *L_v* and luminous emittance *M_v* at maximum rated drive current and T_j=85 °C

MP/COB — L_v ~ 15 cd/mm², M_v ~ 45 lm/mm²

High-power domed — L_v ~ 45 cd/mm², M_v ~ 160 lm/mm²

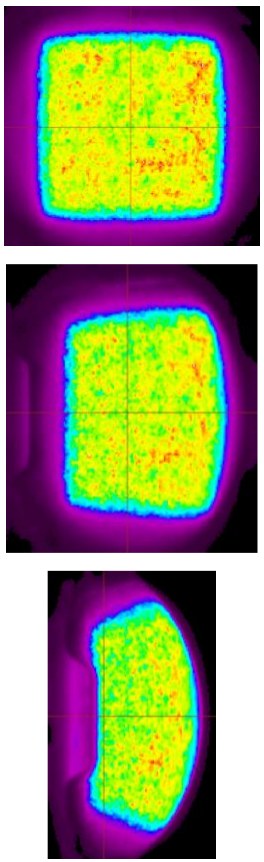
High-power undomed — L_v ~ 100 cd/mm², M_v ~ 310 lm/mm²

Efficacy vs. DOE SSL roadmap

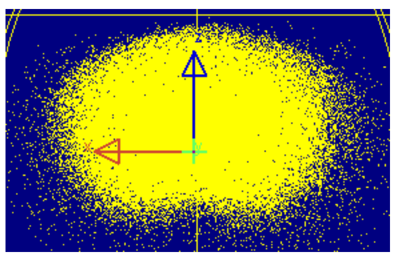


Selecting the right LED for the application

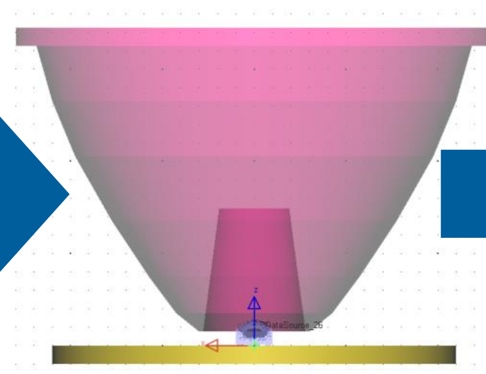
Collect source image data at various angles



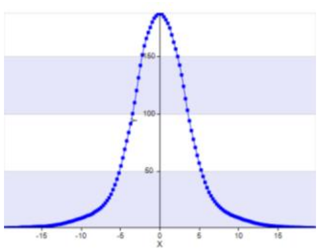
Create ray set (positions, directions, color) from source image data



Insert ray set to system model, including secondary optics, PCB, etc., then ray trace

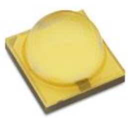


Analyze resulting beam properties



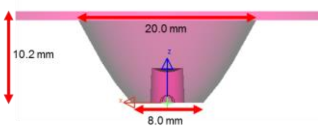
Example: increasing efficacy of delivered light

Different LEDs, same optic



Standard

High luminance



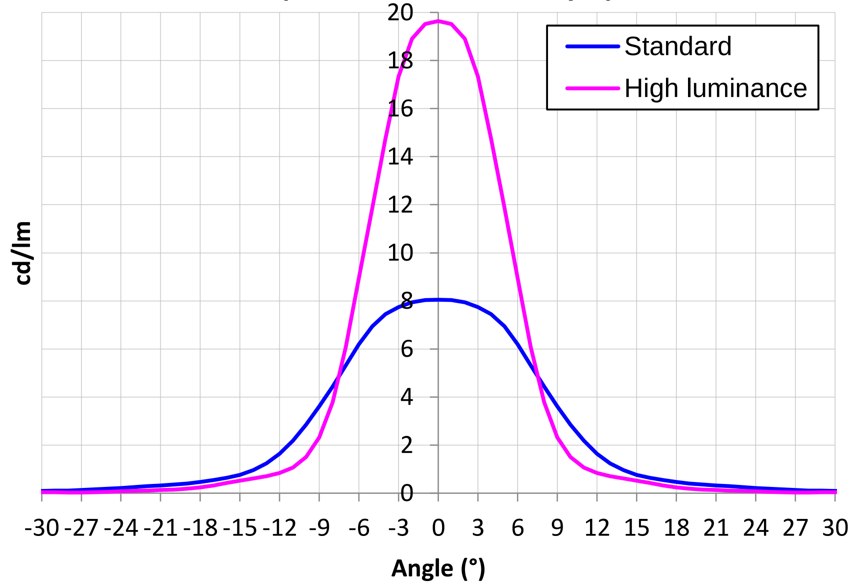
Secondary optic

At LED level, the high-luminance LED has 10% lower efficacy than the standard LED

At lamp / luminaire level, the high-luminance LED enables:

- Higher CBCP: 19.6 cd/lm vs. 8.0
- Higher efficacy of delivered light:
  - 19% higher efficacy within beam angle (FWHM)
  - 3% higher efficacy within field angle (FW10%M)

Beam profile with secondary optic



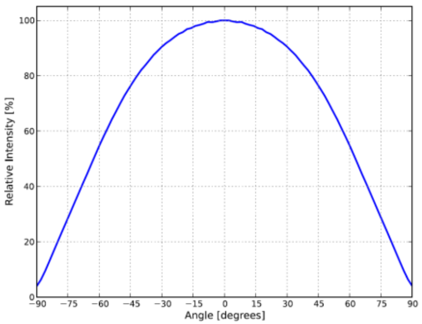
Beam properties				
Emitter	Sys. Eff.	BA (°)	FA (°)	cd/lm
High luminance	89%	11.4	18.7	19.6
Standard	80%	17.0	29.6	8.0

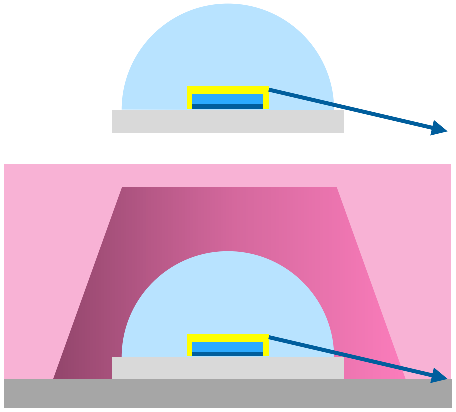
Normalized system flux at same input power			
Angle (°)	High luminance	Standard	Delta
11.4	0.86	0.73	19%
18.7	0.98	0.95	3%
All space	1.00	1.00	0%

Optical performance parameters for directional LEDs

Radiation pattern

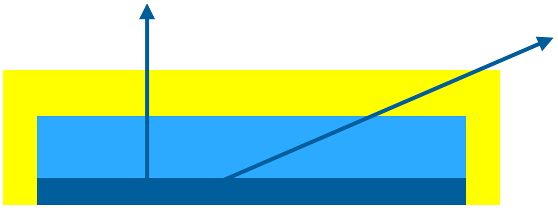
- Important because not all emission angles contribute equally in the application
- LED design factors: die and package geometry, optical properties of package materials
- Generally aim to minimize light below horizon





Color uniformity (angular and spatial)

- Light emitted at different positions and different angles traverses on average different path lengths through phosphor layer
- LED design factors: geometry of phosphor and die, scattering properties of phosphor
- Metrics: color-over-angle (CoA) and color-over-source (CoS) uniformity



Summary

High luminance LEDs are designed to be driven hard with small source area

- Low droop epi design, die with uniform current injection, package with optimized thermal design
- Package design that minimizes source étendue

High luminance LEDs address the needs of directional applications

- Enables smaller luminaire form factor and higher level of beam control
- Enables efficacy benefits at luminaire level that outweigh efficacy penalty at LED level

Optical performance of LEDs is critical to system optical performance

- Radiation pattern, light below horizon
- Angular and spatial color uniformity

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