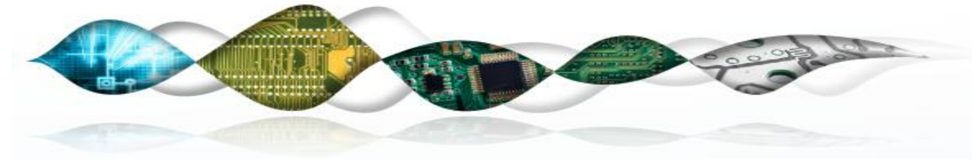
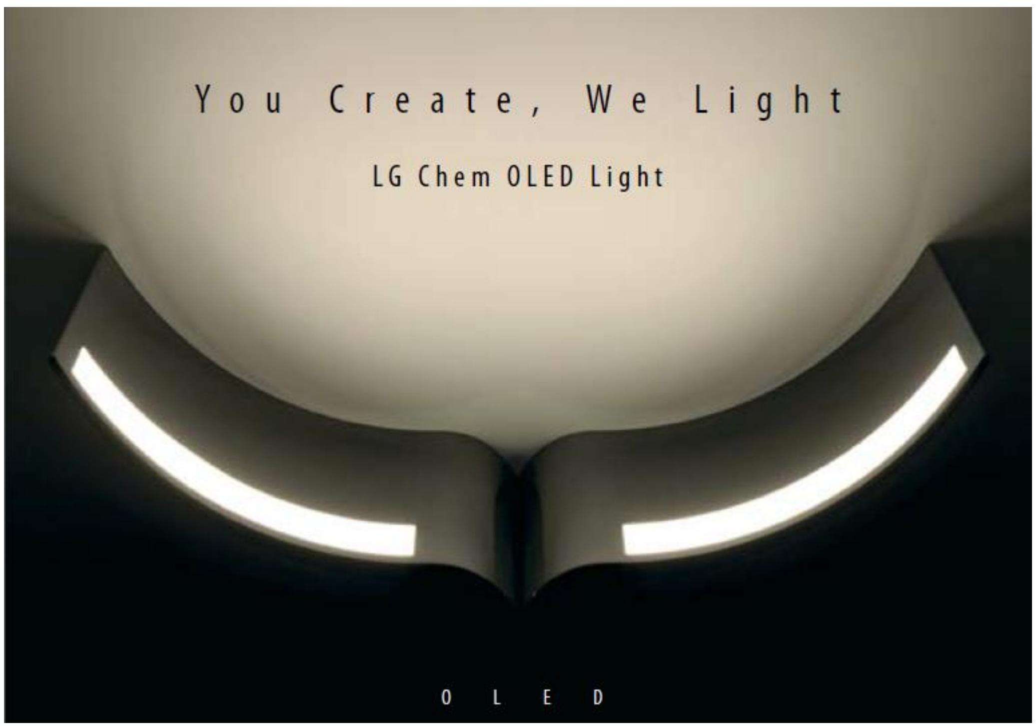


OLED Efficacy



Introduction

Common statement from lighting customers: „OLEDs are only interesting for us if they reach an efficacy of 100 lm/W or more.“

What is an OLED and how does it generate light?

Terminology: Efficacy and efficiency?

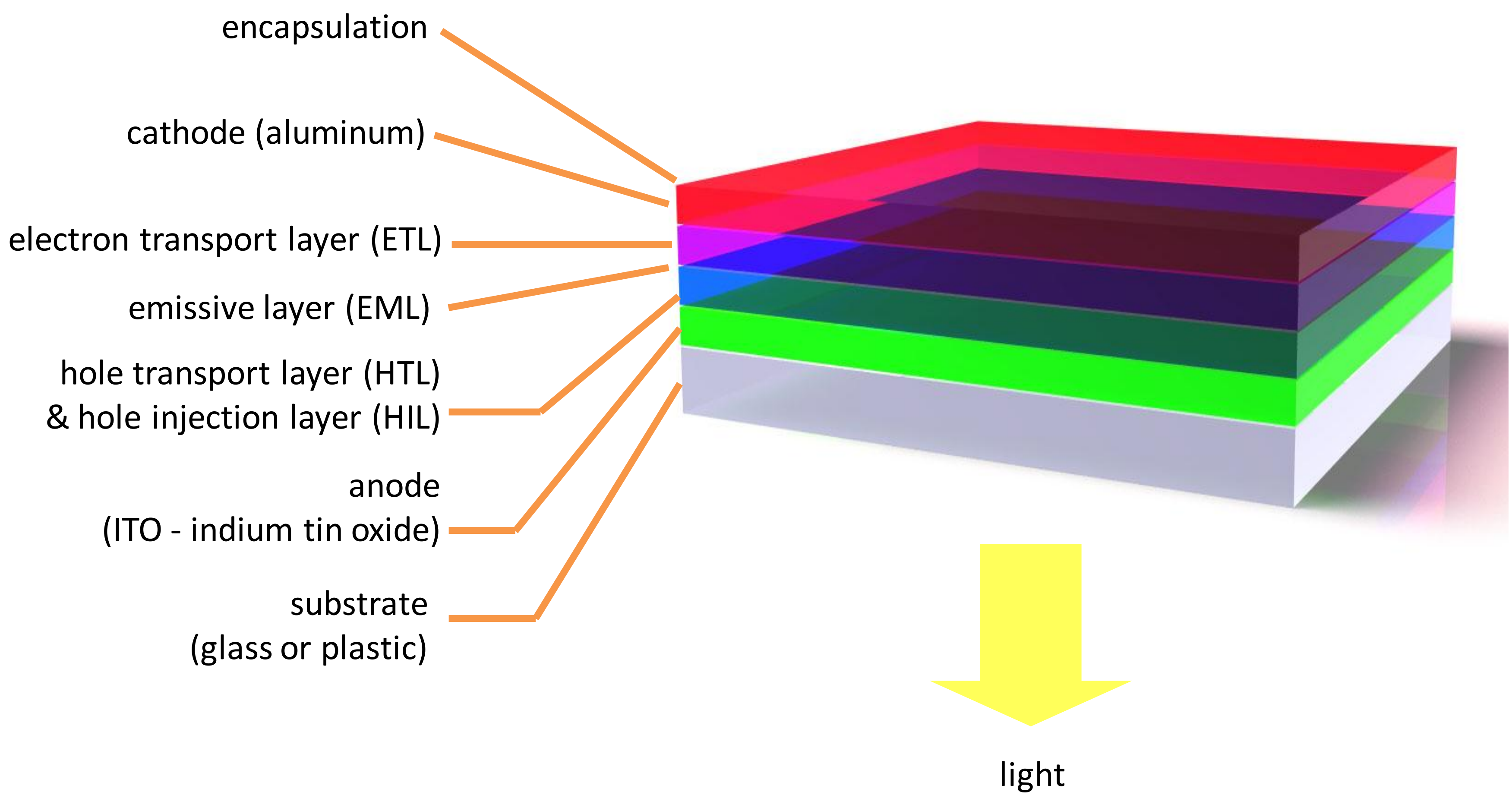
Efficacy and efficiency – technological overview on current OLED technology.

Comparison to LED technology: are current OLEDs fit for the market?

What is an OLED and how does it generate light?

ECOMAL®
Electronic Components and Logistics

What is an OLED and how does it generate light?



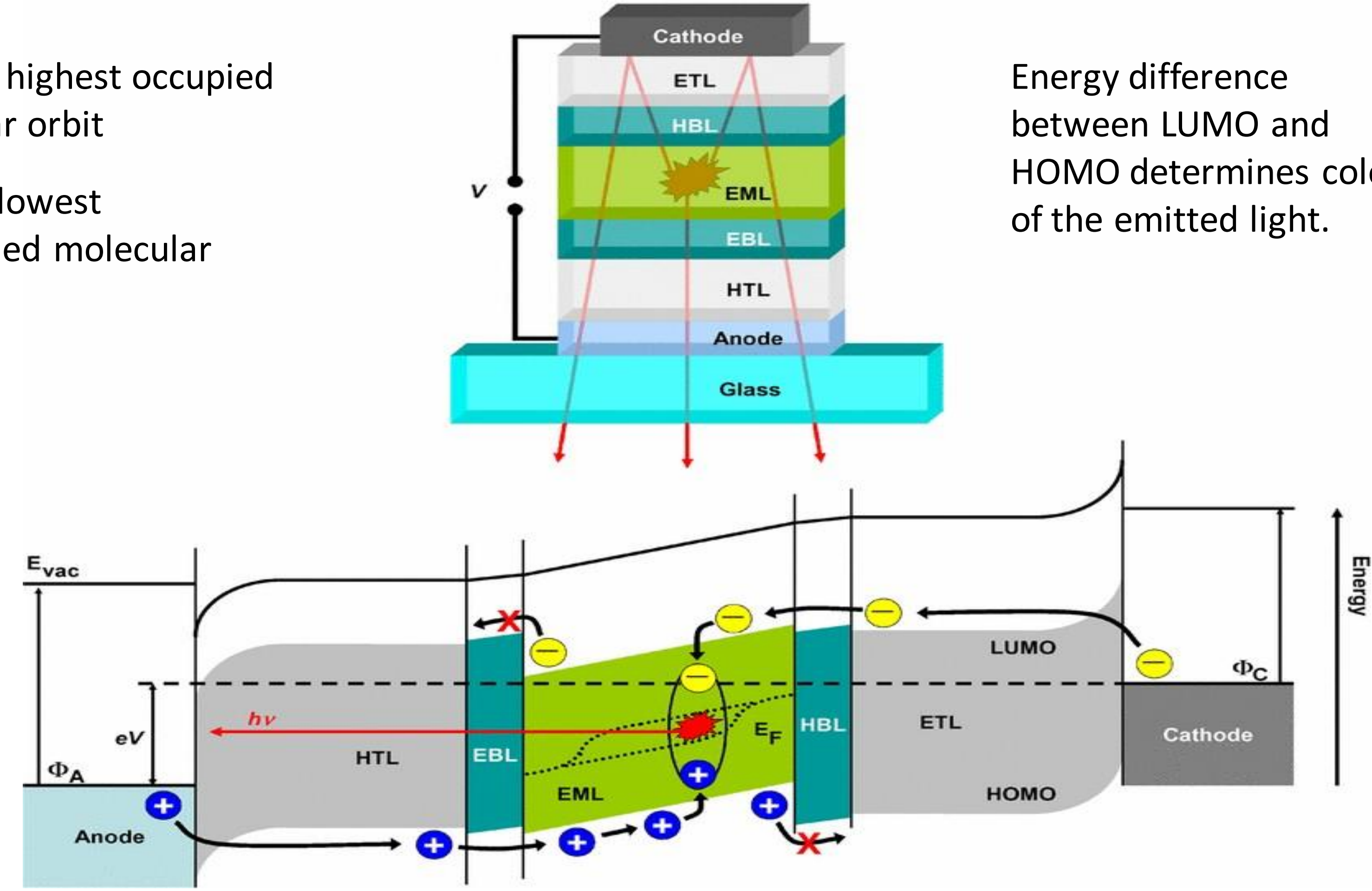
Example: bottom-emitting OLED → most commonly used design today

What is an OLED and how does it generate light?

HOMO = highest occupied molecular orbit

LUMO = lowest unoccupied molecular orbit

Energy difference between LUMO and HOMO determines color of the emitted light.



Prof Monkman, OEM Research Group Department of Physics, Durham University

Generating white light: LED vs. OLED

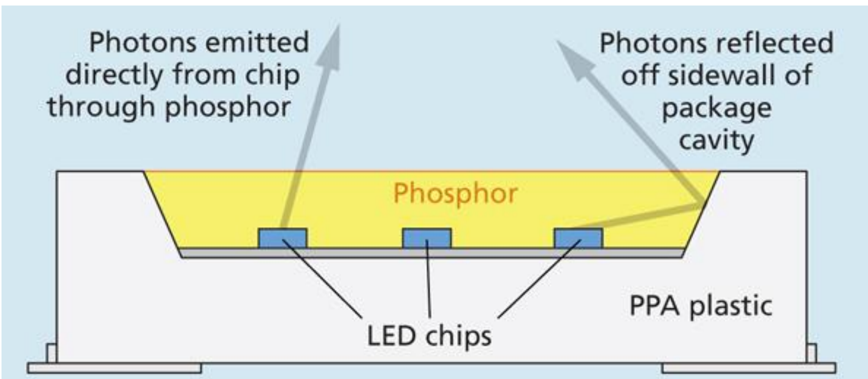
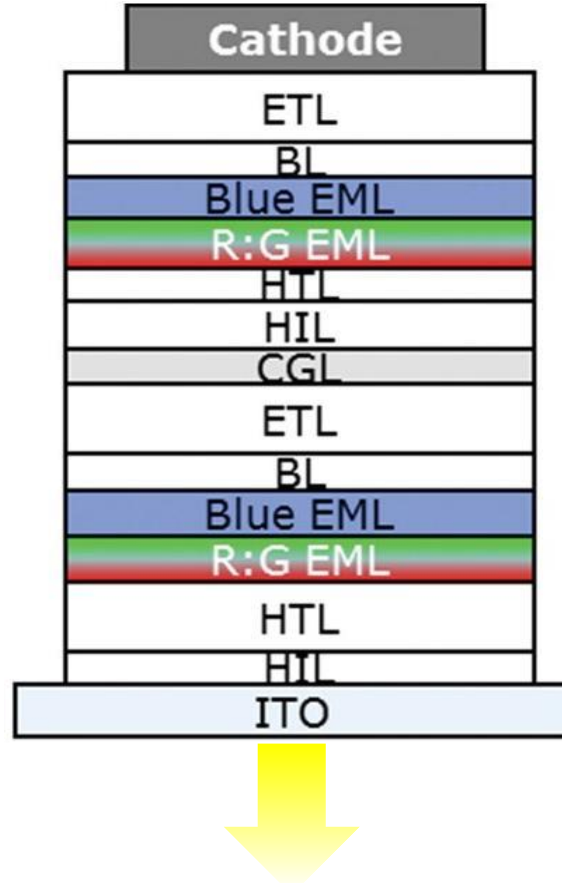


FIG. 1. A simplified cross-section of a plastic LED package.



LED: blue chip with yellow phosphor filter

OLED: RGB layer structure

Efficacy and efficiency - terminology

Efficacy of a light source (E): $E = \frac{L}{U * I}$

L: luminous output of the device
U: operating voltage
I: operating current

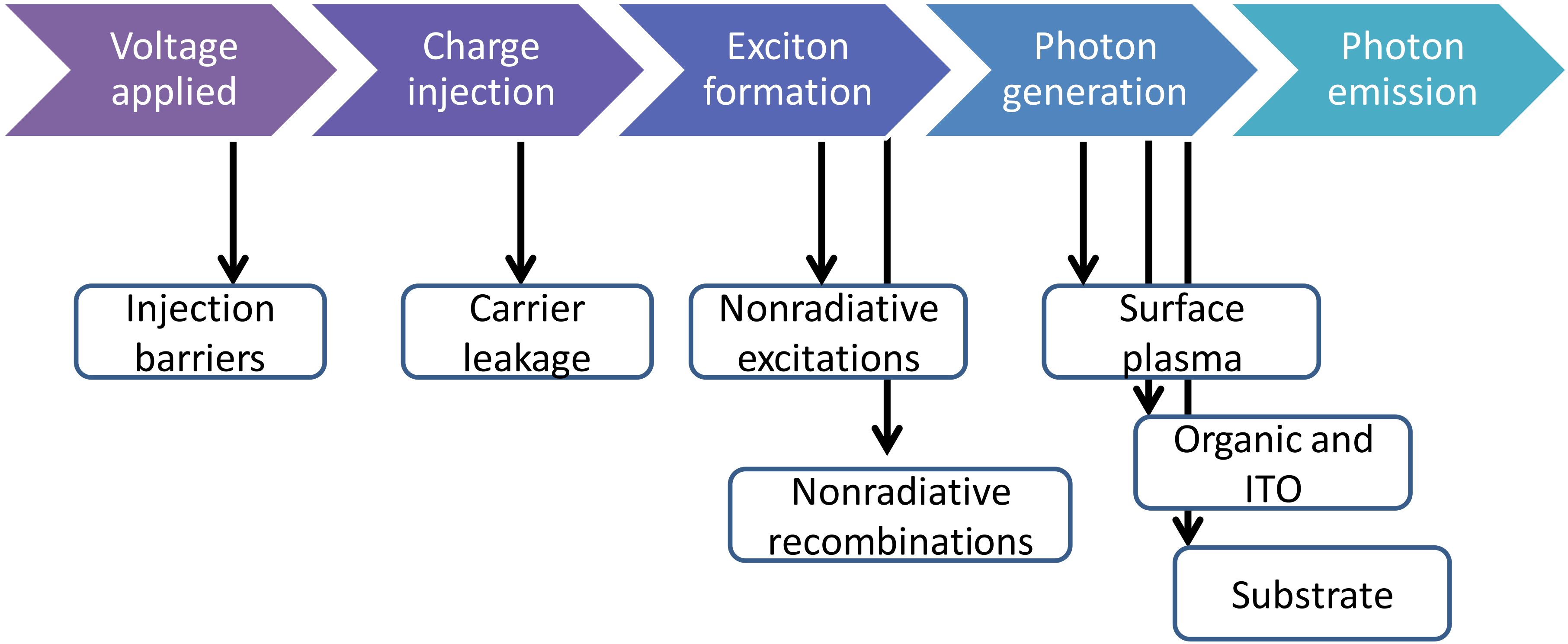
Internal Quantum Efficiency (IQE): % of electrons the generate photons

External Quantum Efficiency (EQE): % of generated photons that exit the light source

ECOMAL®
Electronic Components and Logistics

Light emission process and main loss factors

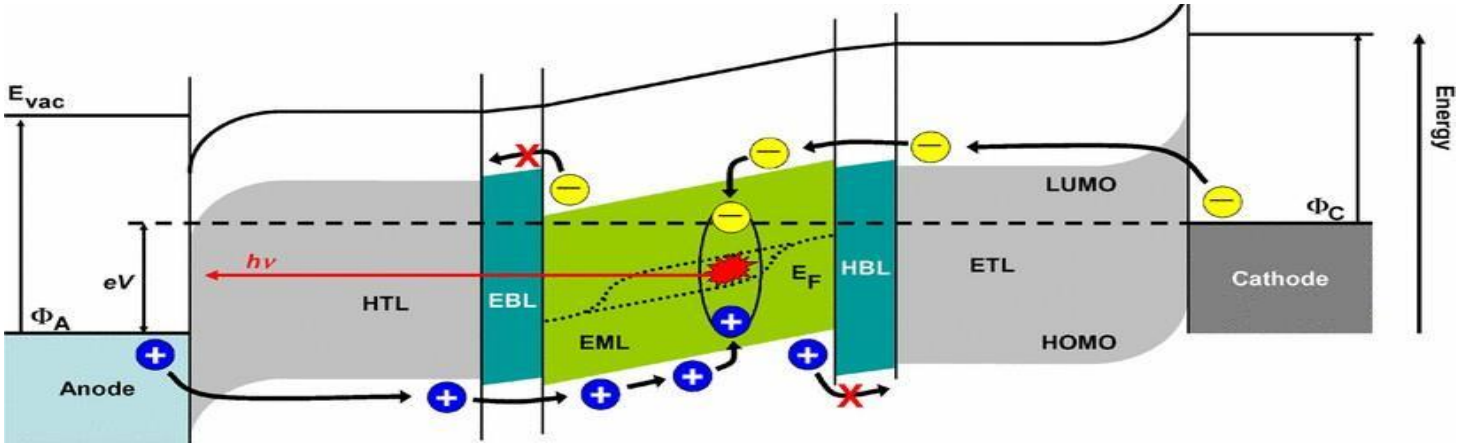
$$\eta_c + \eta_s + \eta_r = IQE + \eta_{extr} = EQE$$



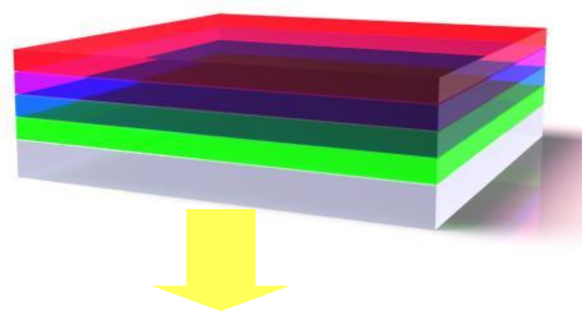
ECOMAL
Electronic Components and Logistics

Light emission process and main loss factors

$\eta_s + \eta_r$ = % of radiative (light emitting) electron/hole combinations → IQE



η_{extr} = % of photons that leaves the device → EQE



light

The major component in your success!

ECOMAL®
Electronic Components and Logistics

Internal Quantum Efficiency (IQE)

Fluorescent materials:

→ Very **stable, long lifetime** achievable but very **low efficiency**

→ Traditional view: η_{smax} **< 25%**

→ **Latest research: η_s = 40-60% achieved** in the lab

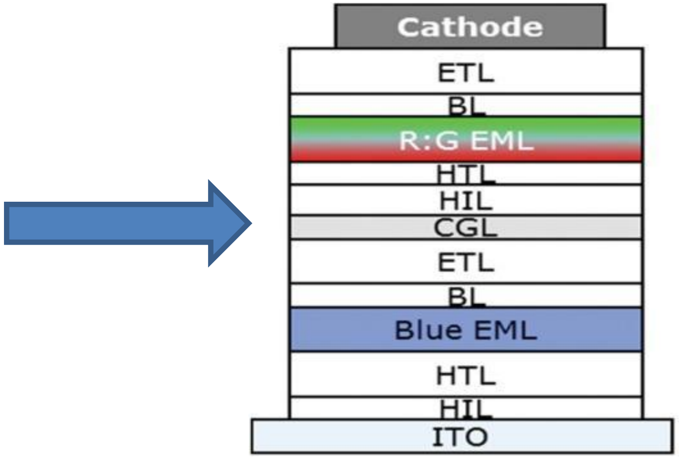
Phosphorescent materials:

→ Much **higher efficiencies**

→ η_{smax} **≈ 100%**

→ Currently **no phosphorescent blue emitter** with acceptable **lifetime/ stability**

Tandem structure common:
Fluorescent blue emitter +
phosphorescent red/ green emitter



The major component in your success!

Internal Quantum Efficiency (IQE)

	% Photon		
CCT	Blue	Green	Red
2700	10.9	21.1	68
3000	14.2	22.4	63.4
3500	18.5	23.1	58.4
4000	23.1	23.5	53.4
4500	27.5	22.7	49.7
5000	31.2	22.2	46.6
5700	35.4	20.8	43.8
6500	39.8	19.4	40.8

Source: Design Considerations for OLED Lighting, Tyan et al., 2015

In the absence of stable/ long-life phosphorescent blue emitters, **most manufacturers** use **tandem structures:**

Fluorescent blue emitter + phosphorescent red/ green emitter

Consequence:

→ Red/ green emitters have a much higher efficiency than blue emitter

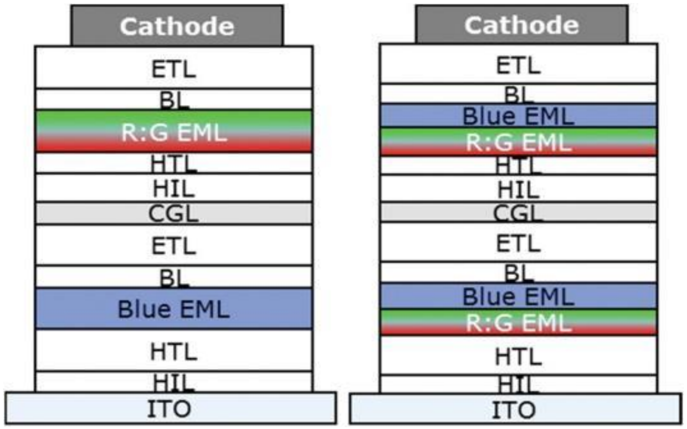
→ The higher the blue content, the smaller the overall device efficiency

Does OLED luminance decrease with increasing colour temperature?

→ It depends on the design focus of the manufacturer.

ECOMAL®
Electronic Components and Logistics

Consequences for OLED panel design



Additional considerations:

1. Emitters can be stacked
2. Voltage and luminance in a stack are the sum of the individual emitters
3. Panel lifetime decreases superlinerarly with increasing current (and vice versa)
4. Panel costs increase with number of stacks

Example LG Chem panel range:

3000K panels use **3 stack layer structure**, **4000K** use **2 stacks**.

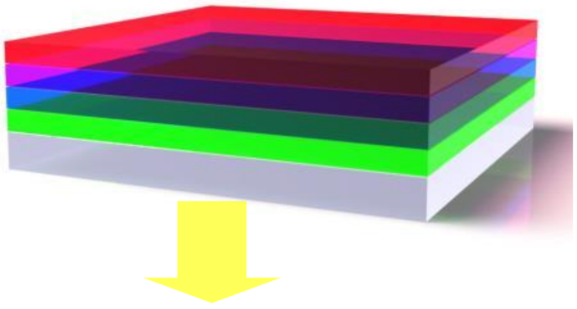
→ **3000K** are driven with **higher voltage** at **lower current**

→ **Panel life** significantly **higher** for **3000K** compared to 4000K

→ **Same rated efficacy** and **luminous flux** for both types

Extraction efficiency

η_{extr} = % of photons that leaves the device → EQE

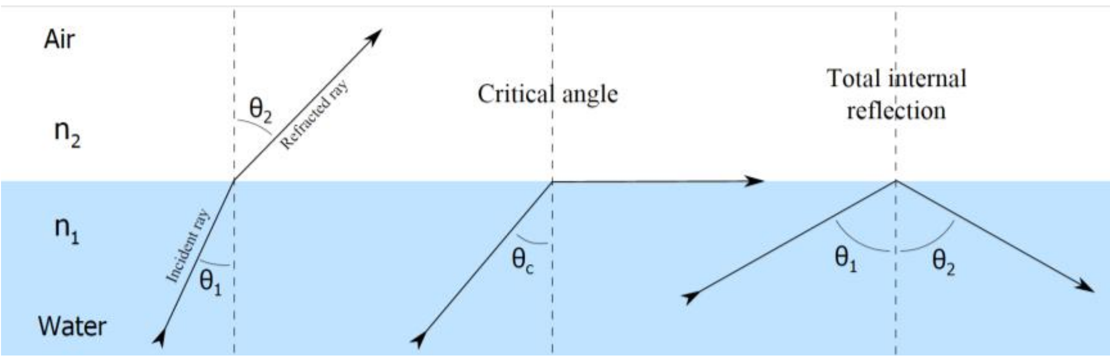


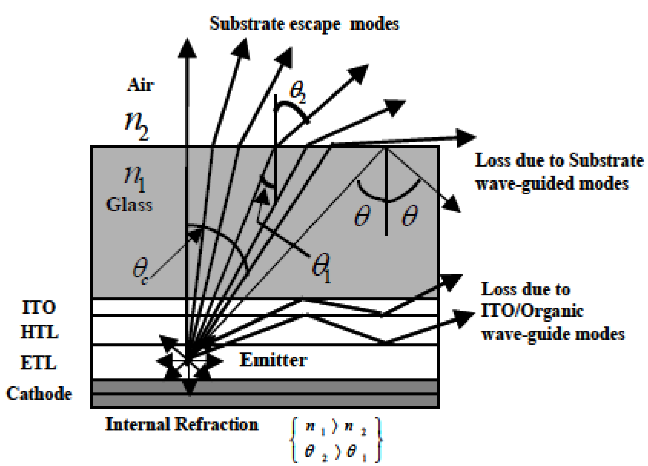
light

Only $\frac{1}{n^2}$ of the generated light gets out of the device

→ N = refractive index of layer materials the light has to pass through
→ N > 1
→ < 20% of the generated light actually leaves the OLED

Extraction efficiency





Mehta et al: **Light out-coupling strategies in organic light emitting devices, New Dehli, 2013)**

OLED – out coupling efficiency influenced by several factors:

- Number of layers → reflection/ refraction at the barrier between two materials
- TIR – total internal reflection → light "trapped" inside the panel
- Light emitted at an disadvantageous viewing angle due to refraction
- Light emitted through the side of the panel due to refraction

Extraction efficiency

Some strategies to increase extraction efficiency

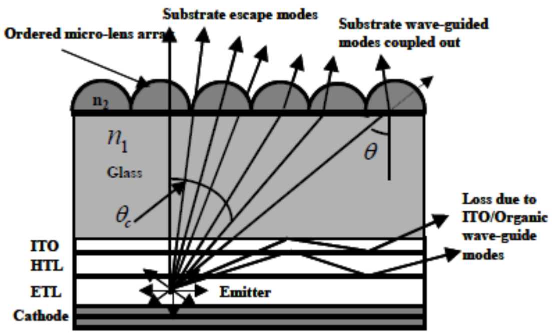


Figure 3 Use of micro-lenses for extracting substrate wave-guided modes.

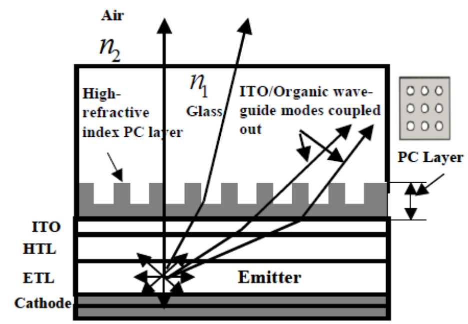


Figure 5. Use of two-dimensional photonic-Crystal structure for extracting the ITO/Organic wave-guided modes

Mehta et al: **Light out-coupling strategies in organic light emitting devices, New Dehli, 2013)**

External extraction schemes (EES) Internal extraction schemes (IES)

- EES easier to apply but less effective → only 1 material barrier can be addressed
- IES much more effective but difficult to apply → risk of damaging the organic layers

→ Design optimization for the ideal OLED device:

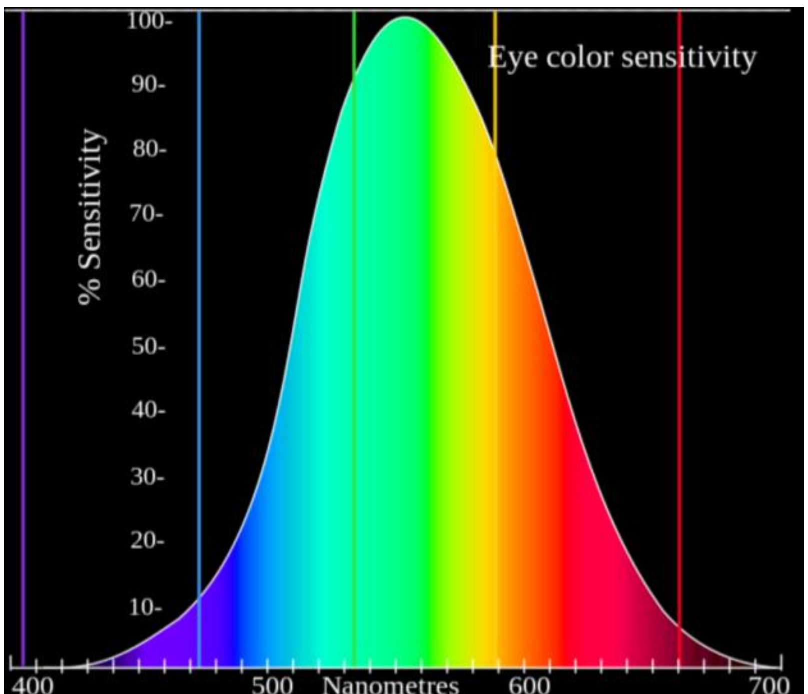
- ➢ Improving electrical efficiency, photon generation and life time by adding layers
- ➢ Additional layers will come at the cost of higher refractive index

Luminous efficacy

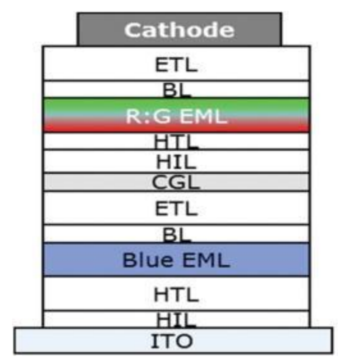
Efficacy of a light source (E): $$E = \frac{L}{U * I}$$

L: luminous output of the device
U: operating voltage
I: operating current

L is the photonic output of the device **weighed by** the **colour sensitivity** of the **human eye**.



Key factor for improving efficacy is an optimised devise structure of the emissive layer → enabling each colour to emit at achievable efficiency without too much de-tuning.



Luminous efficacy

	% Photon			All phosphorescent Tandem RGB+RGB	Hybrid Tandem B+RG
CCT	Blue	Green	Red		
2700	10.9	21.1	68	EQE_{max} = 49.0%	EQE_{max} = 56.1%
3000	14.2	22.4	63.4	EQE_{max} = 52.6%	EQE_{max} = 58.3%
3500	18.5	23.1	58.4	EQE_{max} = 57.1%	EQE_{max} = 61.3%
4000	23.1	23.5	53.4	EQE_{max} = 62.4%	EQE_{max} = 65.0%
4500	27.5	22.7	49.7	EQE_{max} = 67.0%	EQE_{max} = 69.0%
5000	31.2	22.2	46.6	EQE_{max} = 71.5%	EQE_{max} = 64.1%
5700	35.4	20.8	43.8	EQE_{max} = 76.1%	EQE_{max} = 56.5%
6500	39.8	19.4	40.8	EQE_{max} = 81.7%	EQE_{max} = 50.3%

Source: Design Considerations for OLED Lighting, Tyan et al., 2015

Device structure does matter!

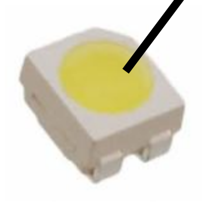
OLED efficacy vs. LED efficacy

Status 2015
Standard LED efficacy >120 lm/W → high end > 150 lm/W
Standard OLED efficacy 60 lm/W → high end 90 lm/W

Is the rated efficacy of an OLED and an LED directly comparable?

OLED efficacy vs. LED efficacy

Luminous Flux



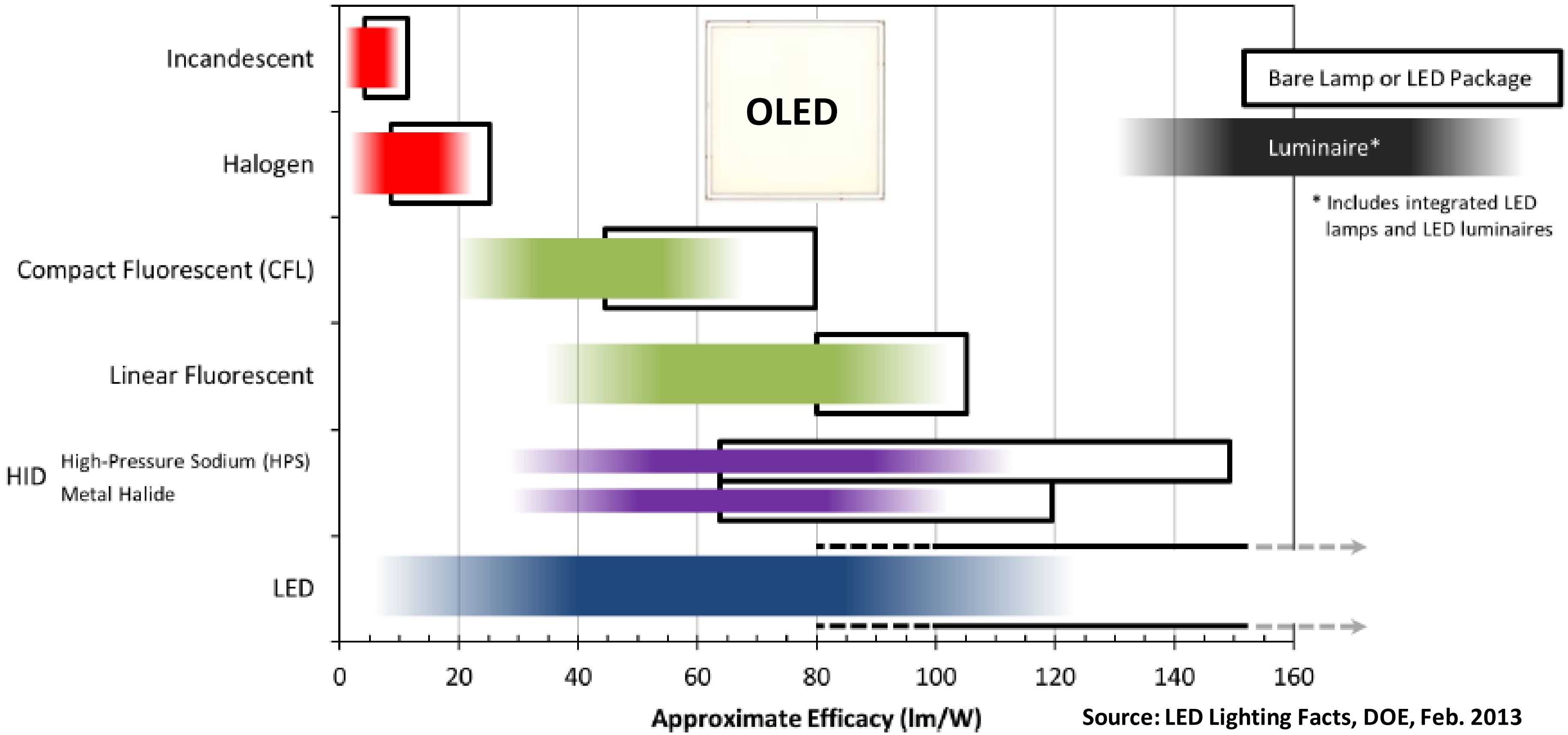
Is that really the most important parameter? How about the application?

Luminaire efficacy much lower than efficacy of the light source.

OLED Panel is effectively a luminaire!

ECOMAL® Electronic Components and Logistics

OLED efficacy vs. luminaire efficacy



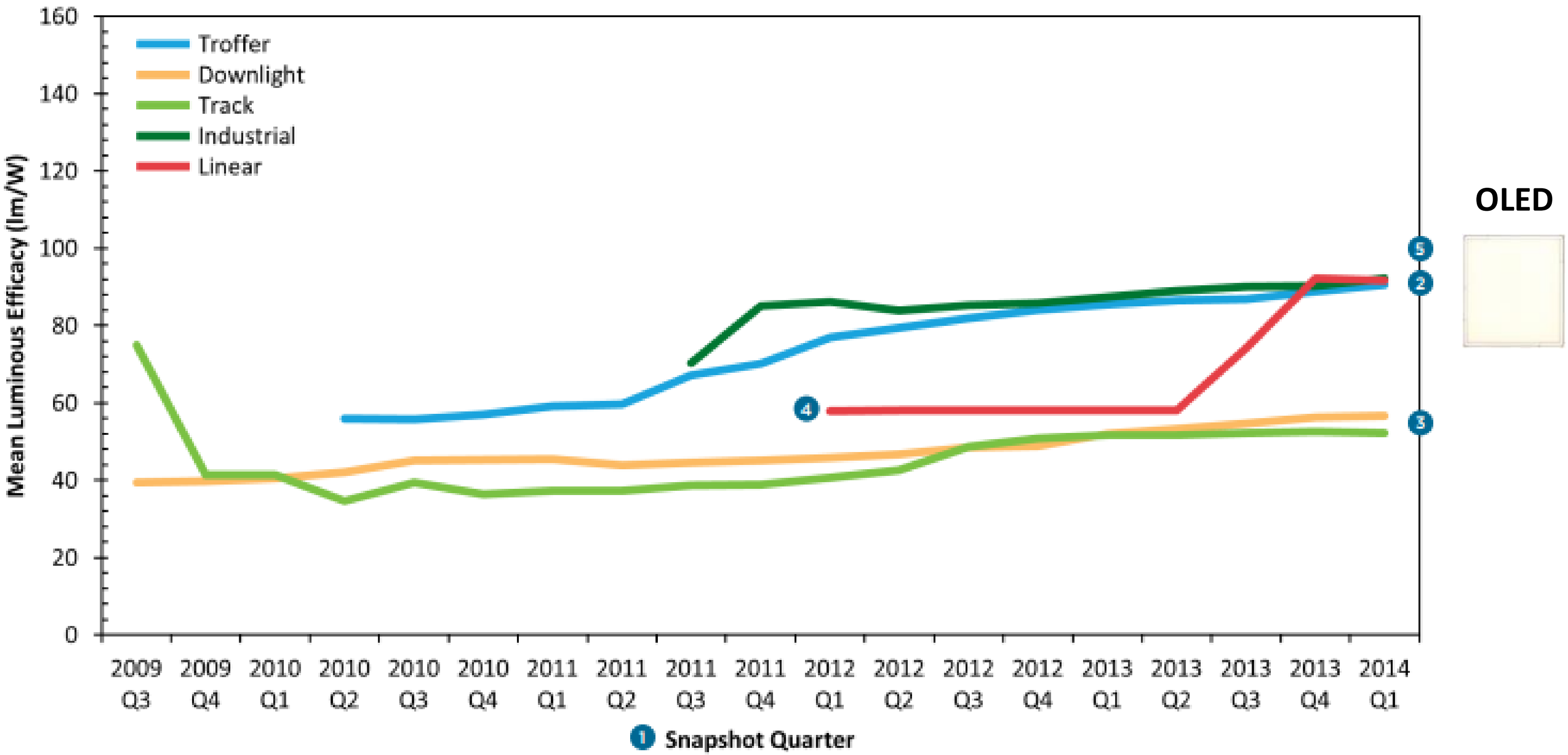
Source: LED Lighting Facts, DOE, Feb. 2013

System efficacy: light source, driver, thermal and optical losses

Efficacy of lamp or LED package

The major component in your success!

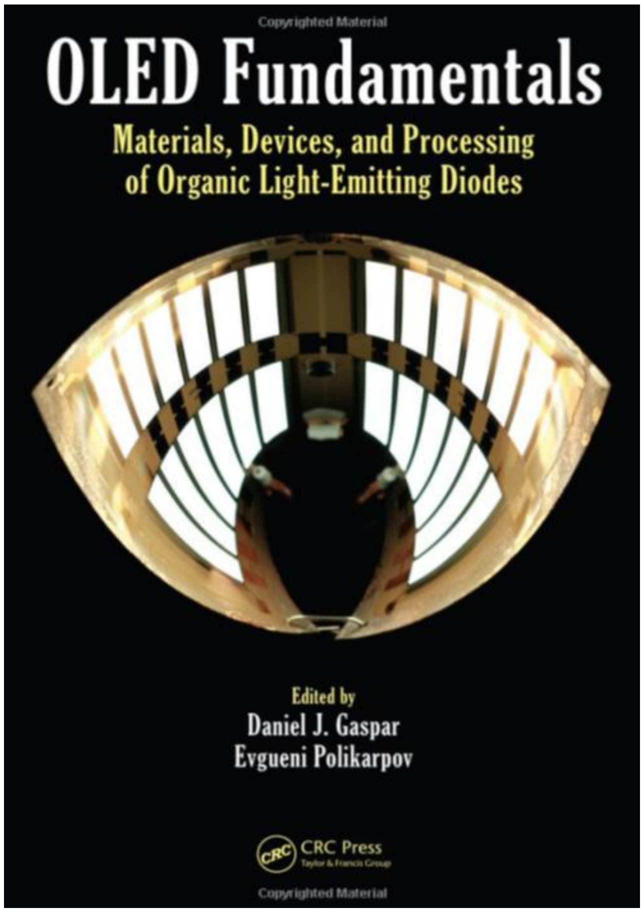
Indoor luminaires efficacy trends

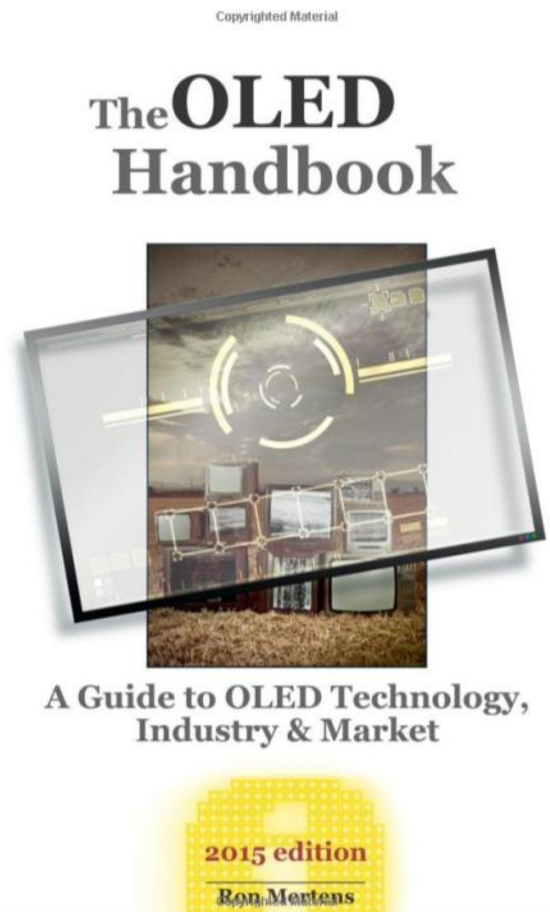


Source: CALiPER: Snapshot Indoor LED Luminaire, DOE, Apr. 2014

Snapshot from the CALiPER program on LED luminaire efficacies.

Further reading





ECOMAL®
Electronic Components and Logistics

Thank you for your attention.

The major component in your success!

Efficiency challenges in OLEDs