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Comparison of Lighting Technologies

	OLEDs	LEDs	Incandescent	Fluorescent
Efficacy	45 - 70 lm/W Lab demos	70 lm/W – White 65 lm/W – warm white	17 lm/W	83 lm/W
CRI	–85	80 – white 90 – warm white	100	78
Form Factor	Large area thin diffuse light source. Conformable or flexible	Point source high intensity lamp	Heat generating	Long or compact gas filled glass tube
Safety concerns	None	Very hot in operation	Very hot	Contains mercury
LT70 (K hours)	7 (currently)	50	1	20
Dimmability	Yes, efficiency increases	Yes, efficiency increases	Yes, but much lower efficacy	Yes, efficiency decreases
Color Tunability	Yes	Yes	No	No

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OLED Fundamentals

Maximize

Maximize

$$\eta_p \propto \frac{\eta_{IQE}\,\eta_{out}}{V}$$

Minimize

- Power Efficiency = η_P
- Internal Quantum Efficiency = η_{IQE}
- Outcoupling Efficiency = η_{OUT}
- Device Voltage = V

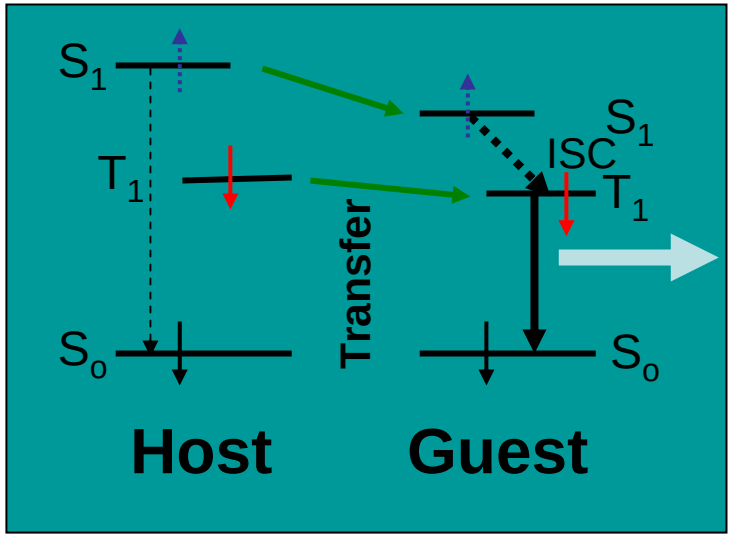
Maximize IQE by Phosphorescence

…phosphorescence is key

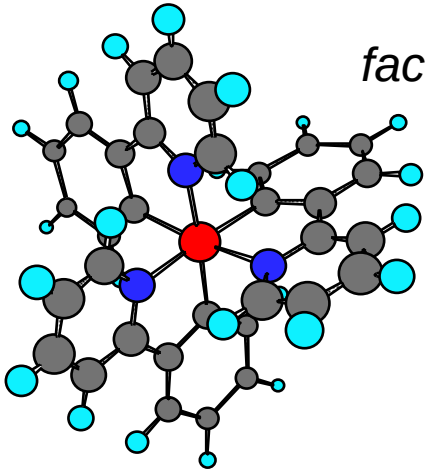
- 100% IQE achieved

$$\eta_p \propto \frac{\eta_{IQE}\eta_{out}}{V}$$

eg: spin-orbit coupling via heavy metal atom (Pt or Ir)



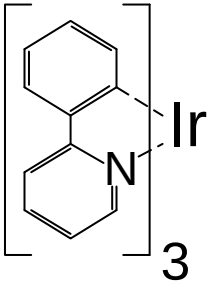
M.A. Baldo, *et. al.*, *Nature.*, **1998**



fac tris(2-phenylpyridine) iridium

$Ir(ppy)_3$

green emission
EQE ~19%
τ ~0.5μs



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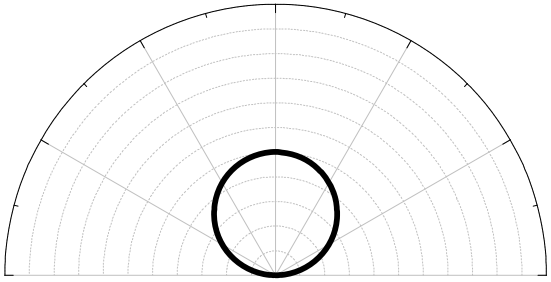
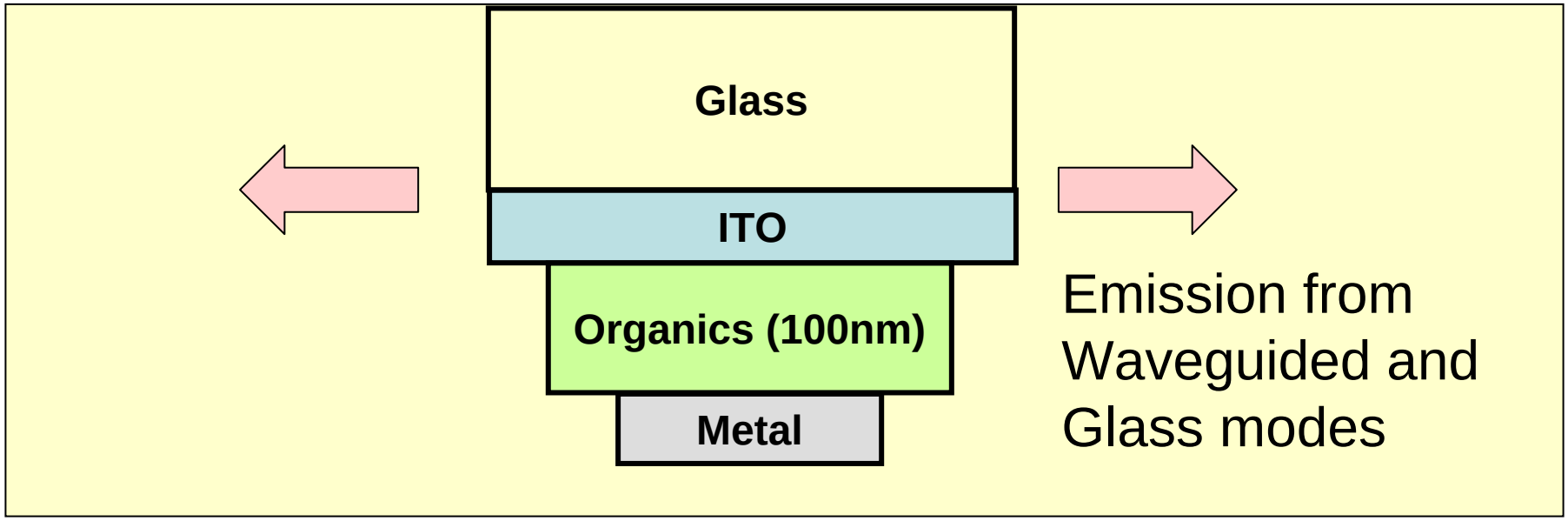
Outcoupling Efficiency

Total EQE = Forward+Waveguided+Glass
(*used for WOLED light source*)

$$\eta_p \propto \frac{\eta_{IQE}\eta_{out}}{V}$$

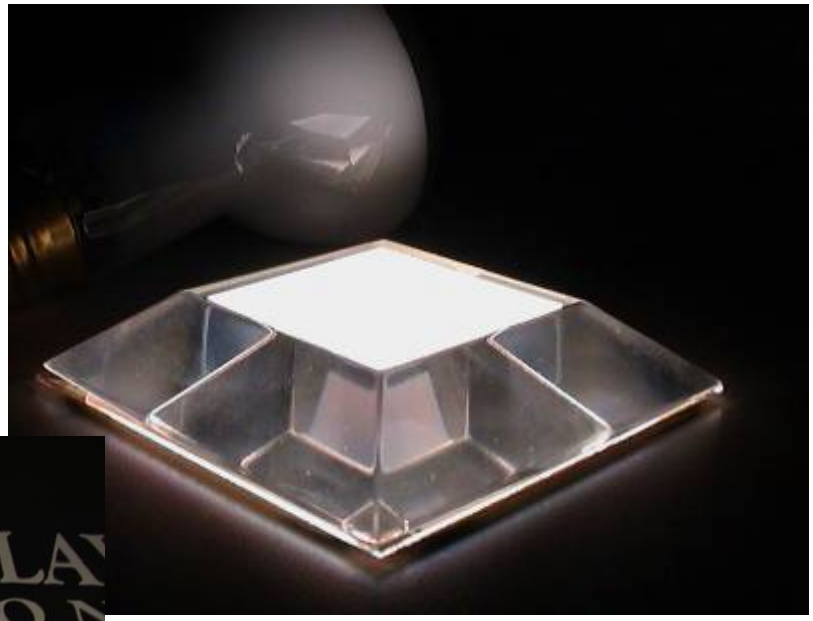


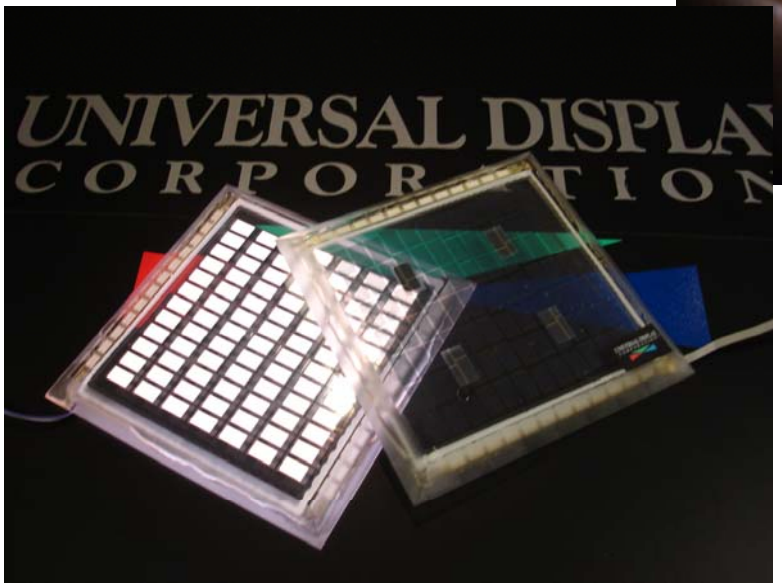
Forward Emission
(*used to report PHOLED EQE performance*)



OLED Luminaire and Outcoupling

- WOLED with Luminaire has Total EQE = ~**1.7** x Total EQE of WOLED without luminaire.
- WOLED with Luminaire has Total EQE = ~**2.0** x WOLED Forward EQE.





V_{OLED}?

OLED power ~ $I_{OLED} * V_{OLED}$

For example: CuPc/NPD/Ir(ppy)$_3$:CBP/BAlq/Alq$_3$/LiF

Layer	Standard Layer Thickness [nm]	Normalized Voltage [%]
HIL	10	5
HTL	30	8
EML	30	40
BL	10	6
ETL	40	35
EIL	1	6
Total	121	100

Ways to Reduce V

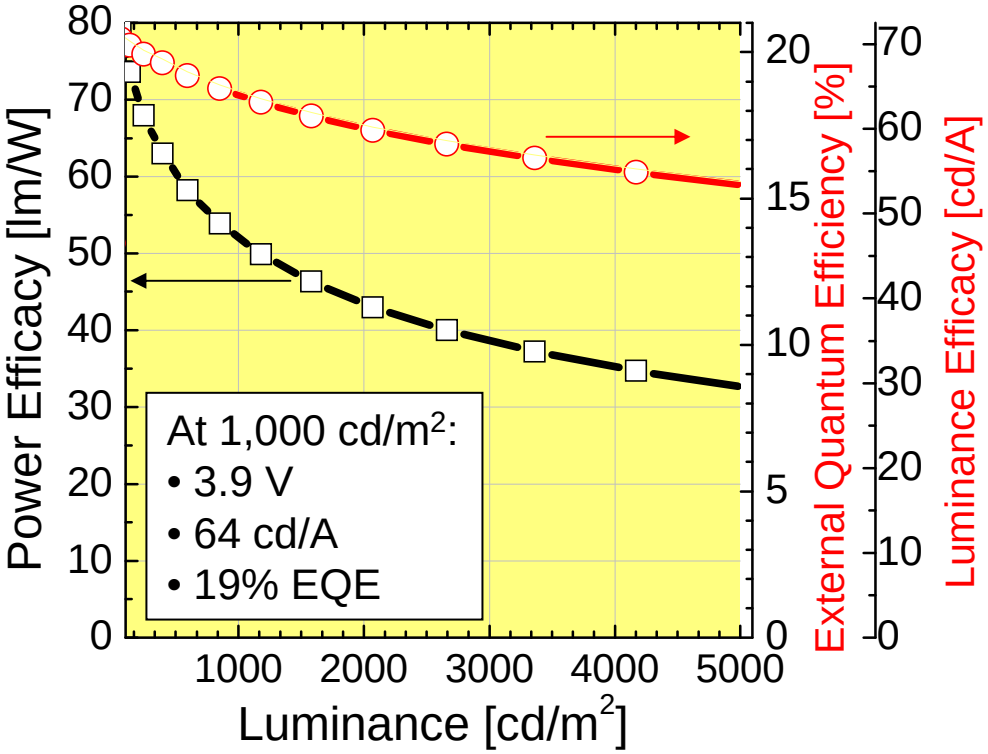
High conductivity layer

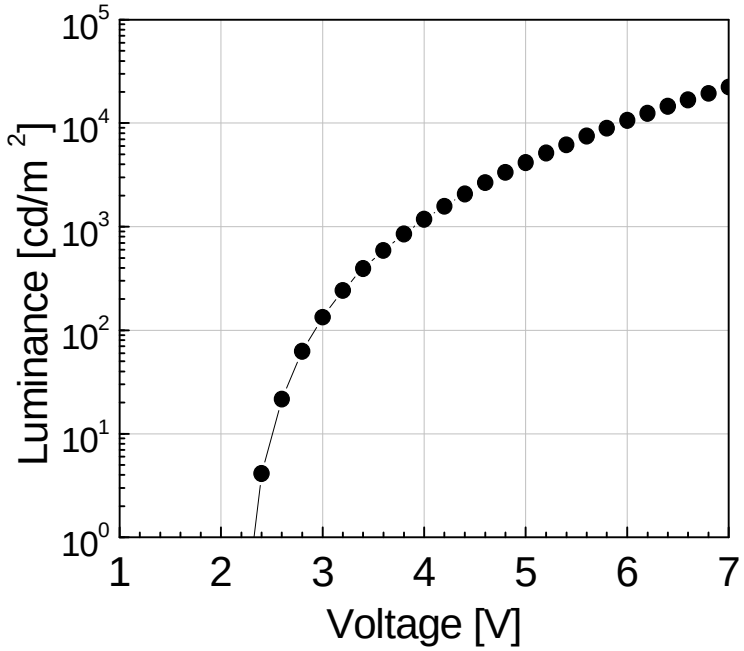
Thinner EML
Optimized Host

High conductivity layer or n-dopant

Note: EML can be thinner with more conductive transport layers.

Voltage reduction: green PHOLED with high conductivity transport layers





% Initial Luminance	50%
Lifetime (hrs) at RT and 1000 cd/m²	>200,000

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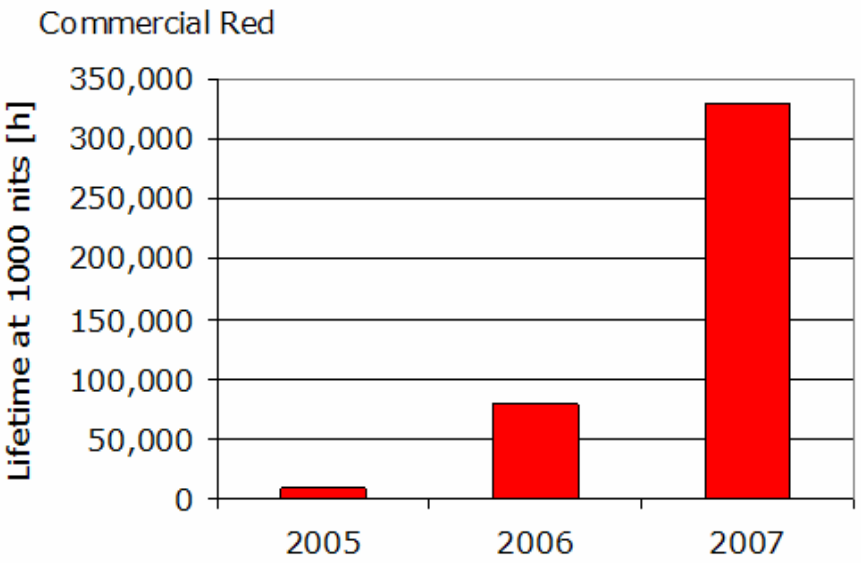
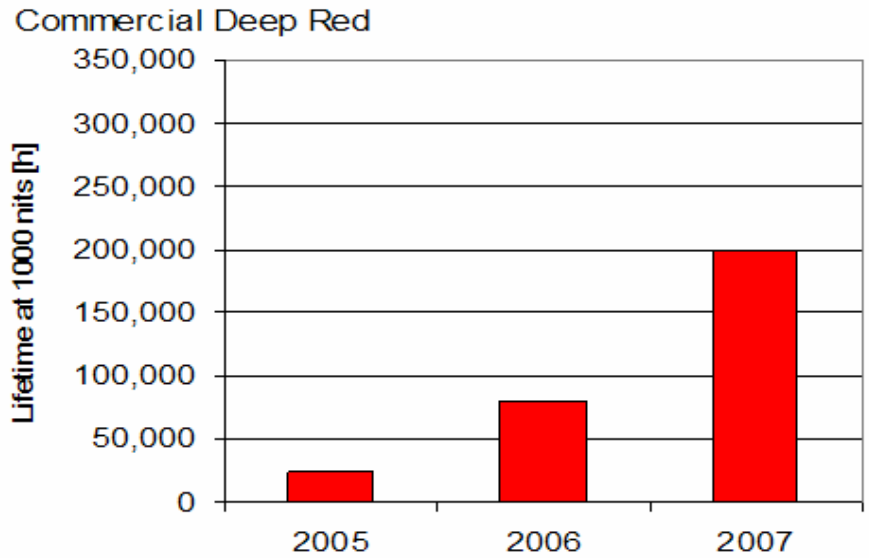
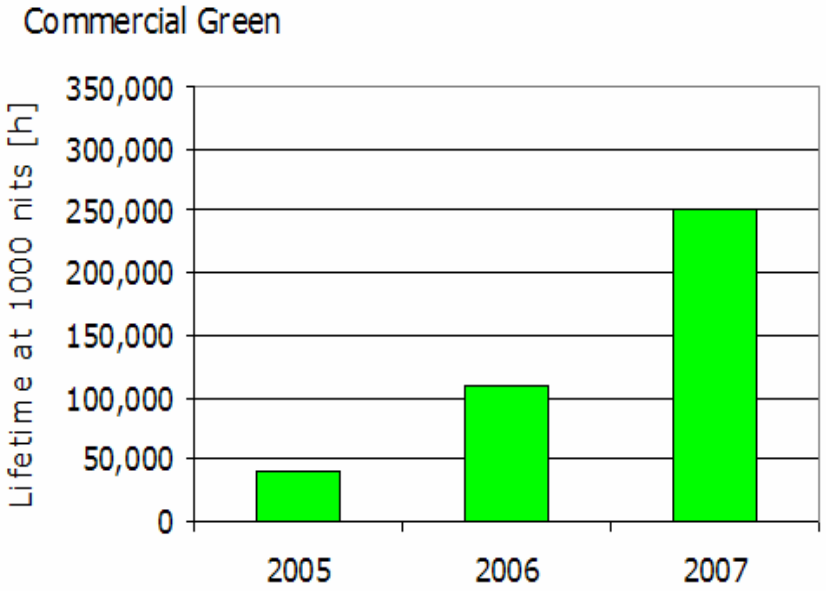
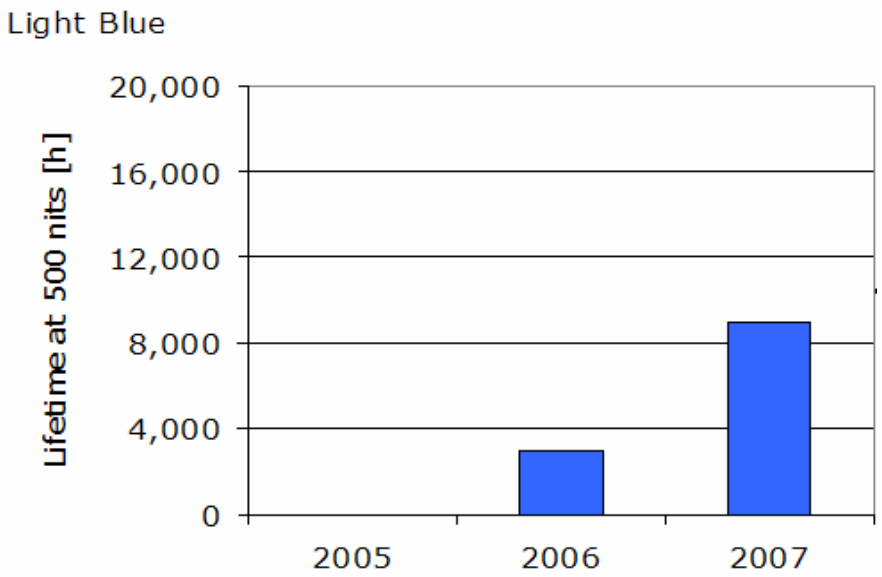
UDC PHOLED Lifetime Progress









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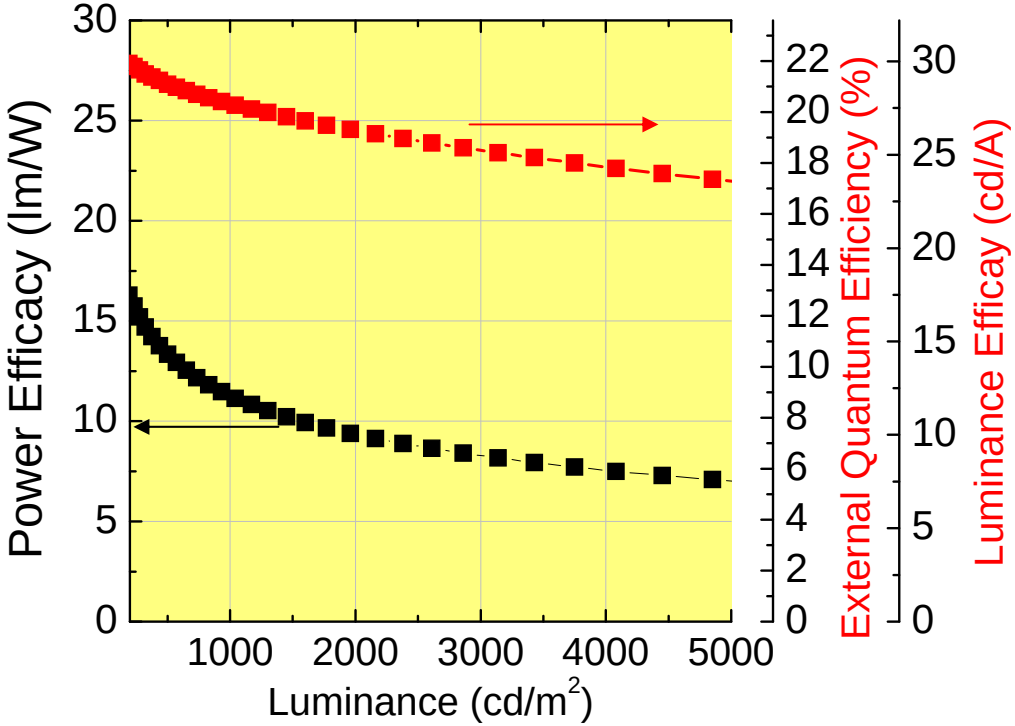
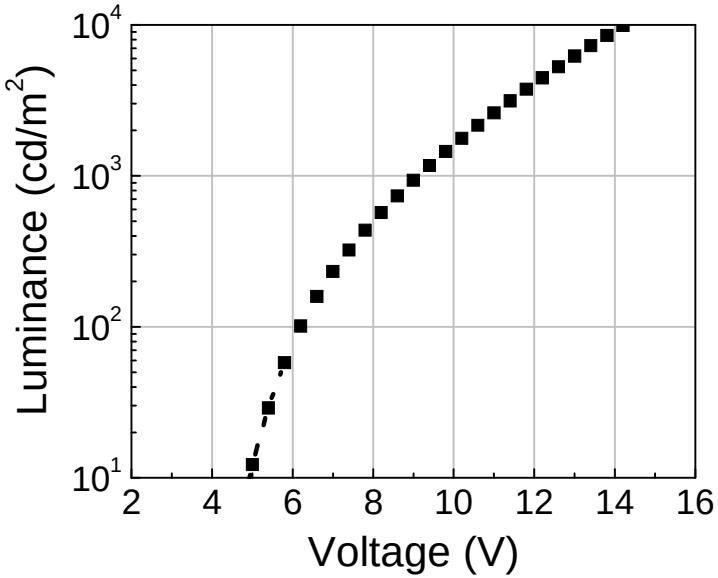
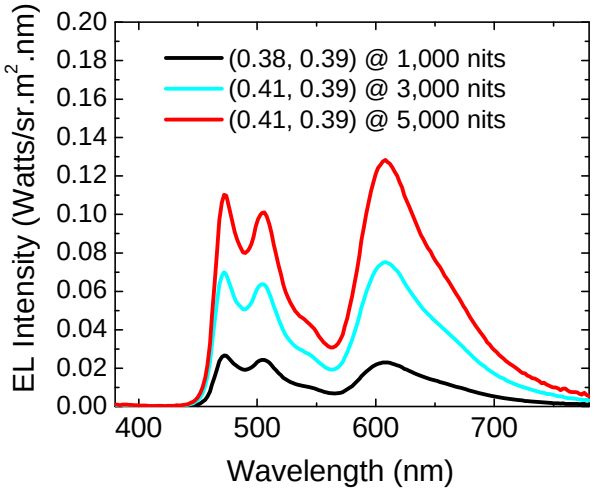
High EQE WOLED







- **>20% EQE**
- **Stable CIE with lifetime and luminance**

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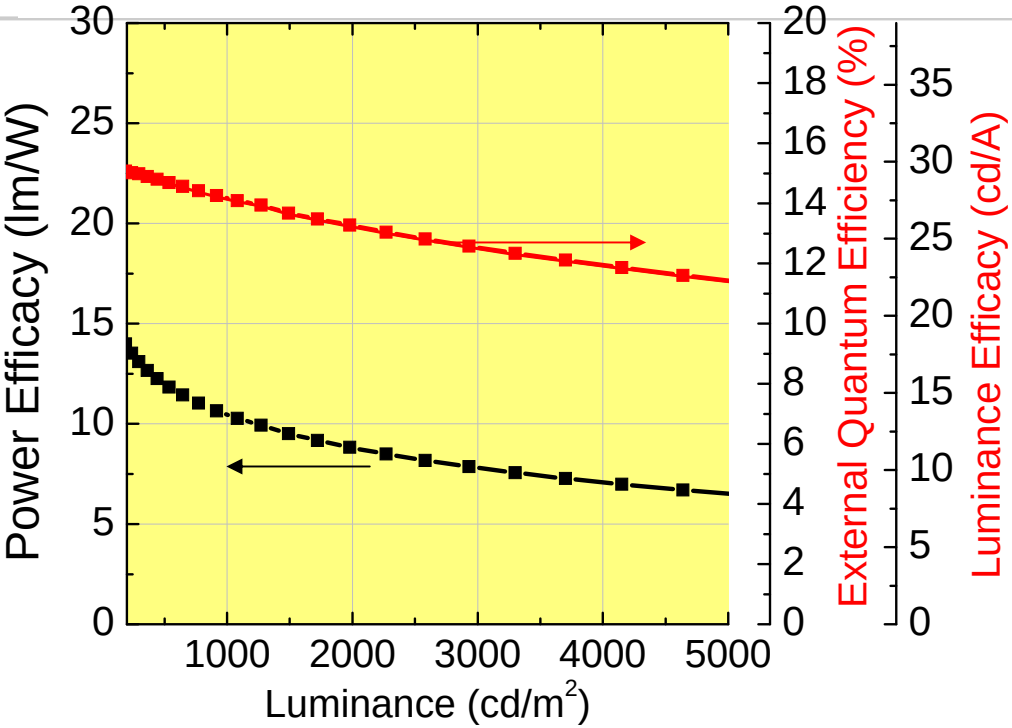
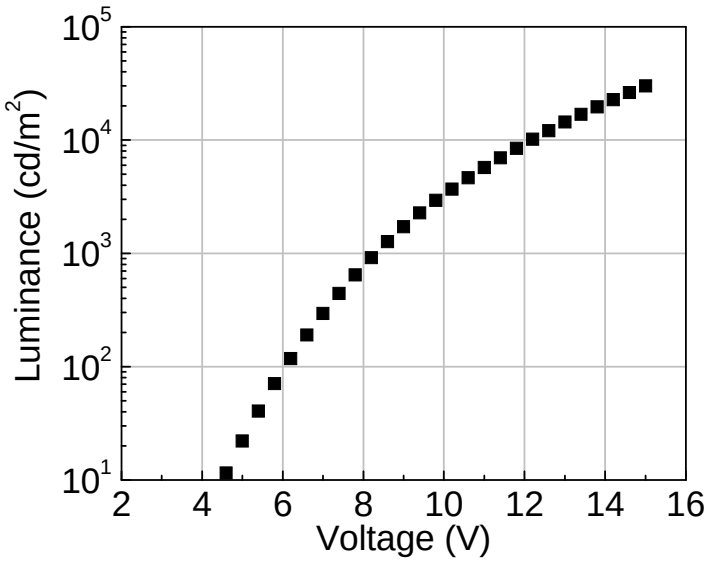
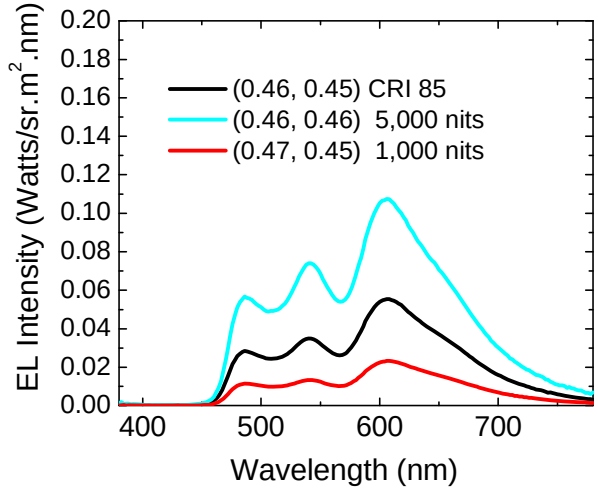
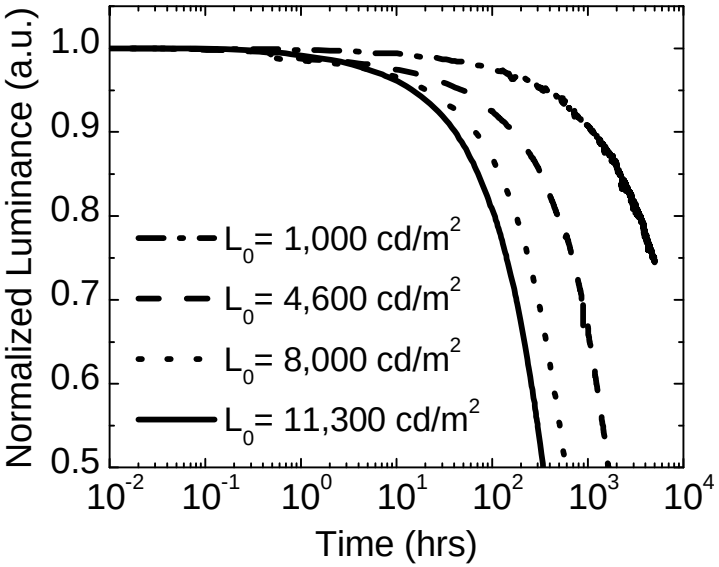
WOLED with Longevity







- **LT50 = 21,000hrs @ L_0=1,000 nits**
- **Stable CIE with aging**



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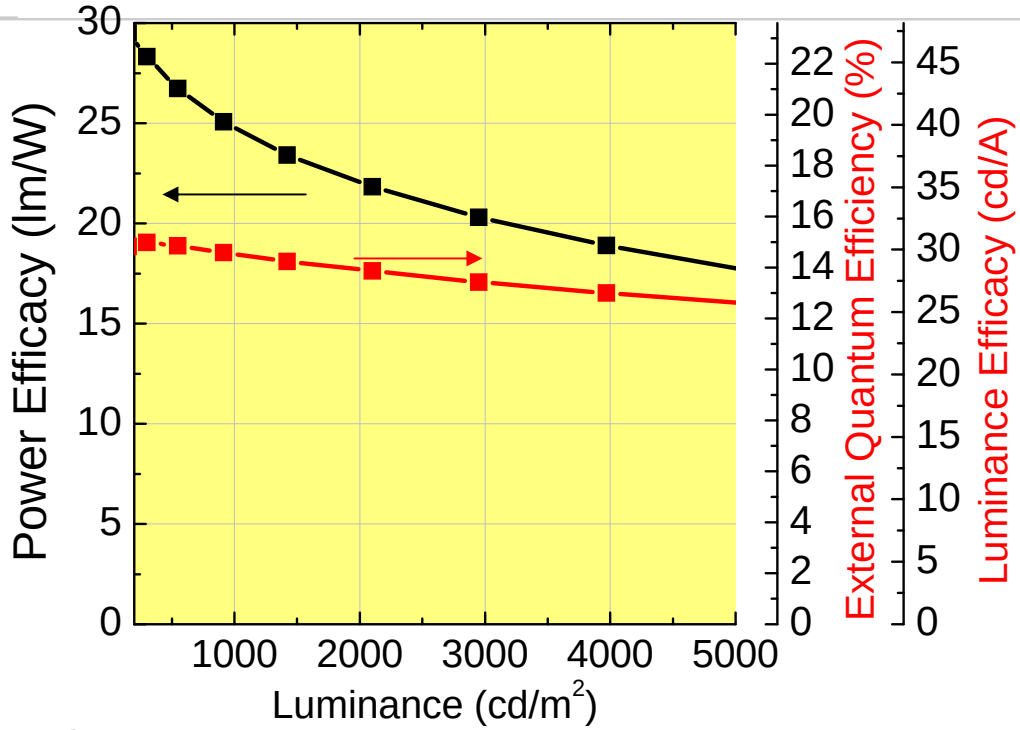
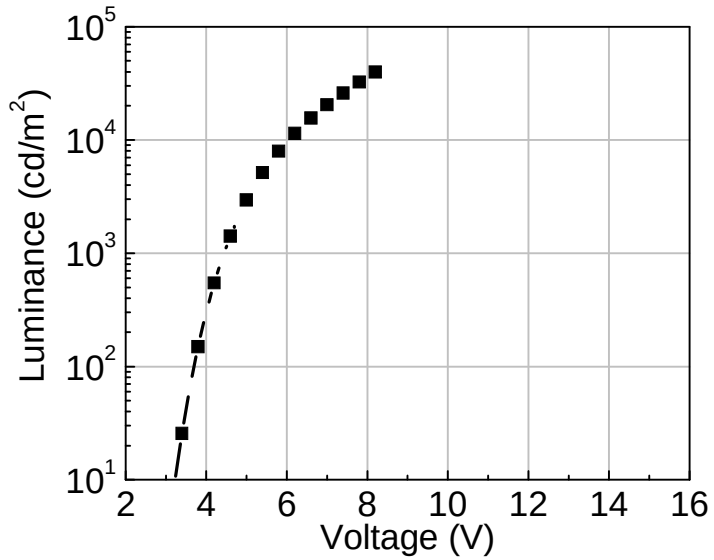
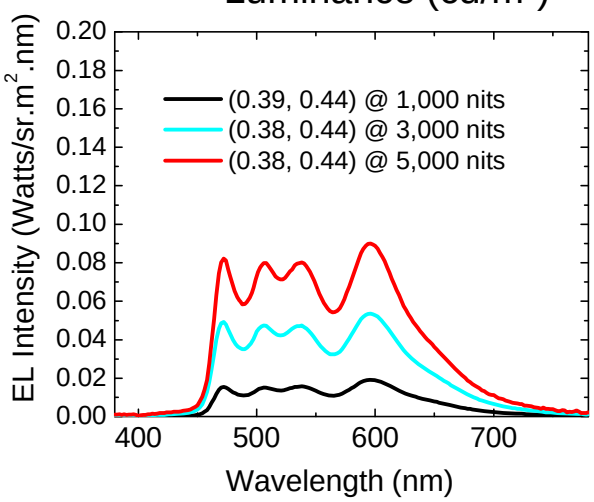
High lm / W







- **>25 lm/W**
- **Stable CIE with luminance**
- **<5V at 1,000 nits**

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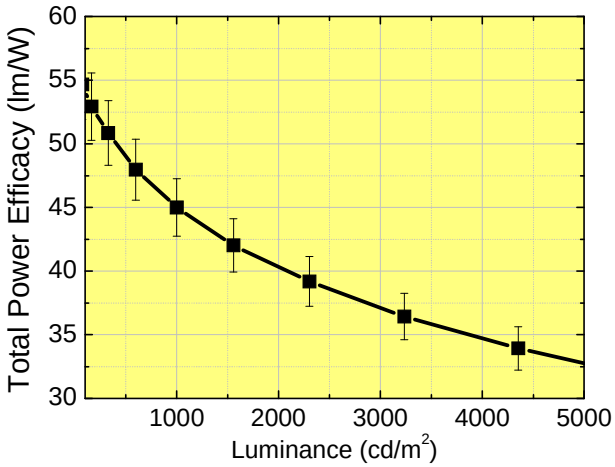
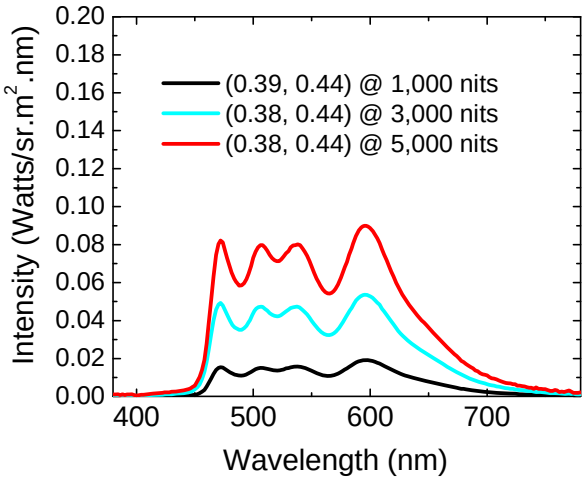
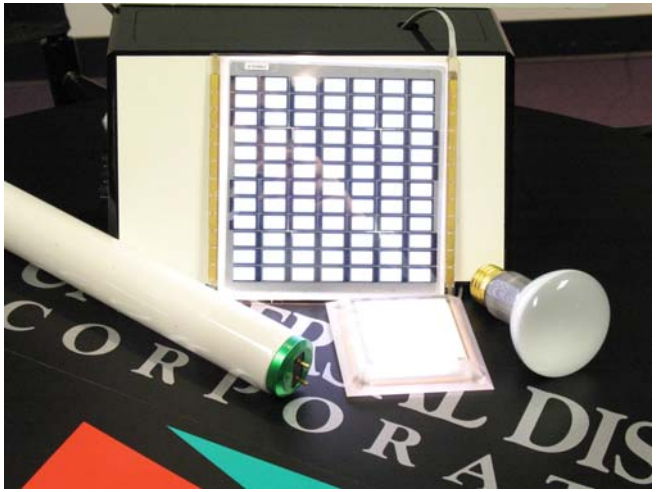
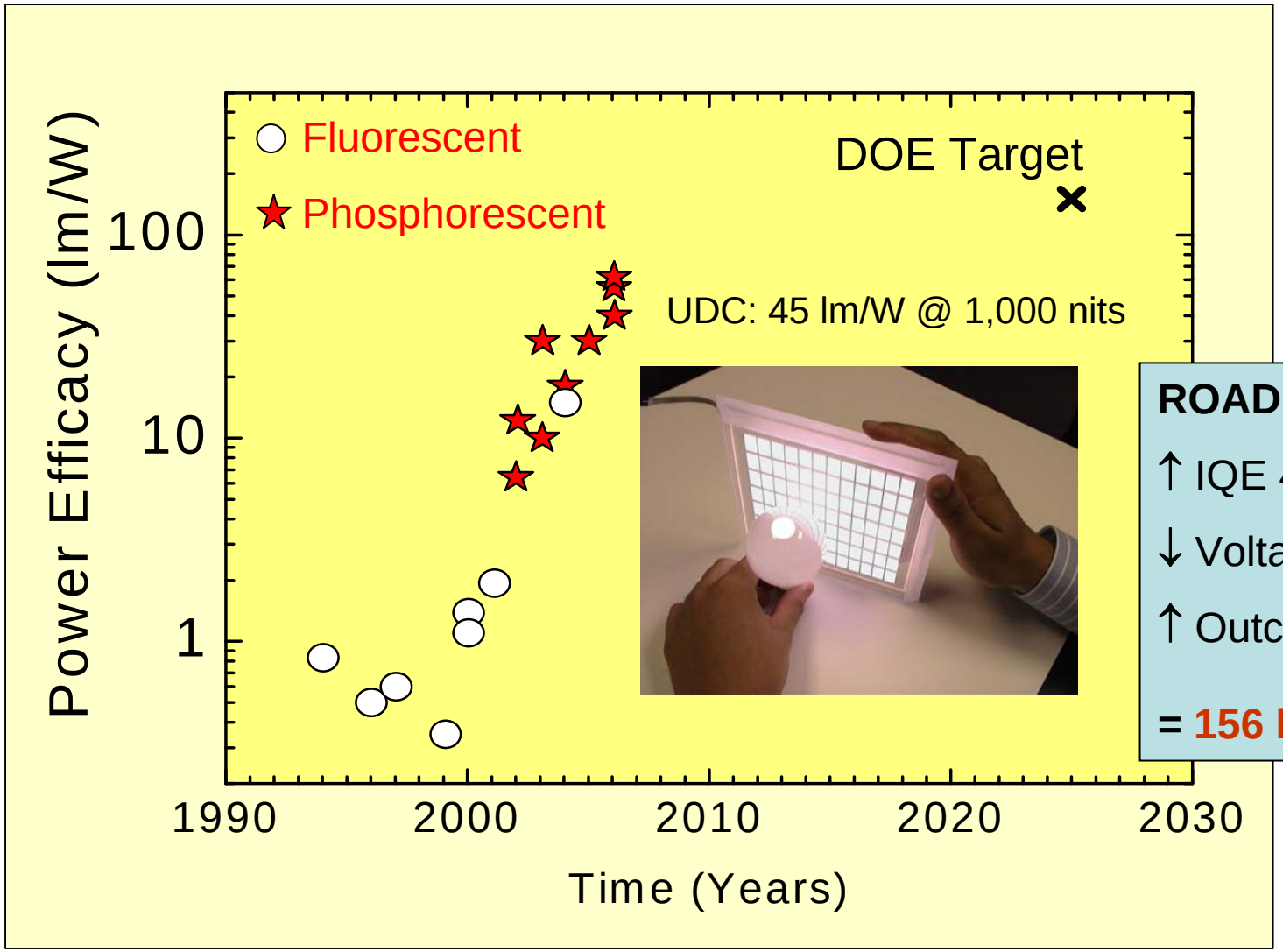
45 lm/W at 1,000 cd/m²







WOLEDs: Recent Results and Path Forward



ROADMAP

↑ IQE 40%

↓ Voltage 50%

↑ Outcoupling 25%

= 156 lm/W