CNC/CIE-CIE/USA Technical Conference 2015

Organic light emitting diodes for solar-grade lighting

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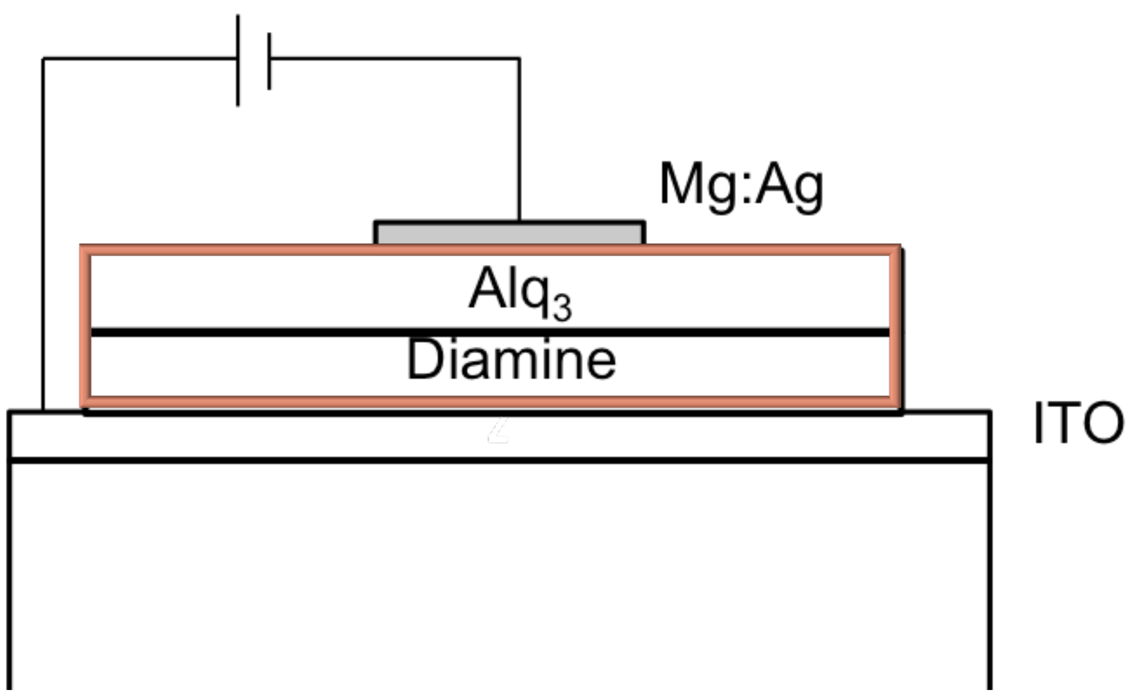
FACULTY OF APPLIED SCIENCE & ENGINEERING

Outline

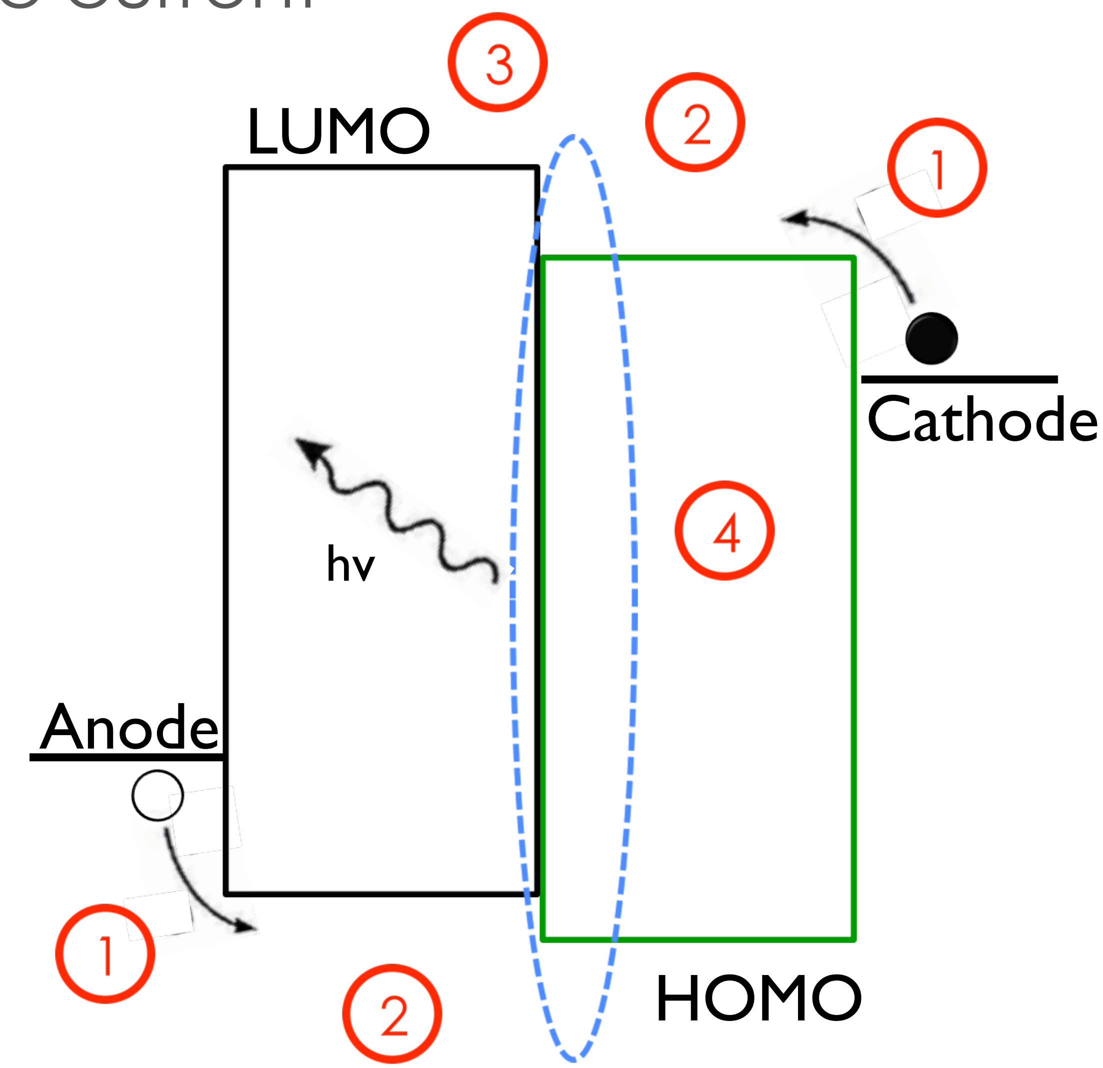
- Organic Light Emitting Diodes (OLEDs)
  - Device structure and working principles
  - Organic materials
  - Application for solid-state lighting
- White OLED device design
  - Phosphorescent emitters
    - Cascade structure
    - Exciton harvesting
  - Fluorescent-Phosphorescent hybrid
  - TADF
- Conclusions
  - Best performing devices

Organic Light Emitting Diodes

Multi-layered device capable of emitting light in response to an applied electric current



Tang and VanSlyke, 1987



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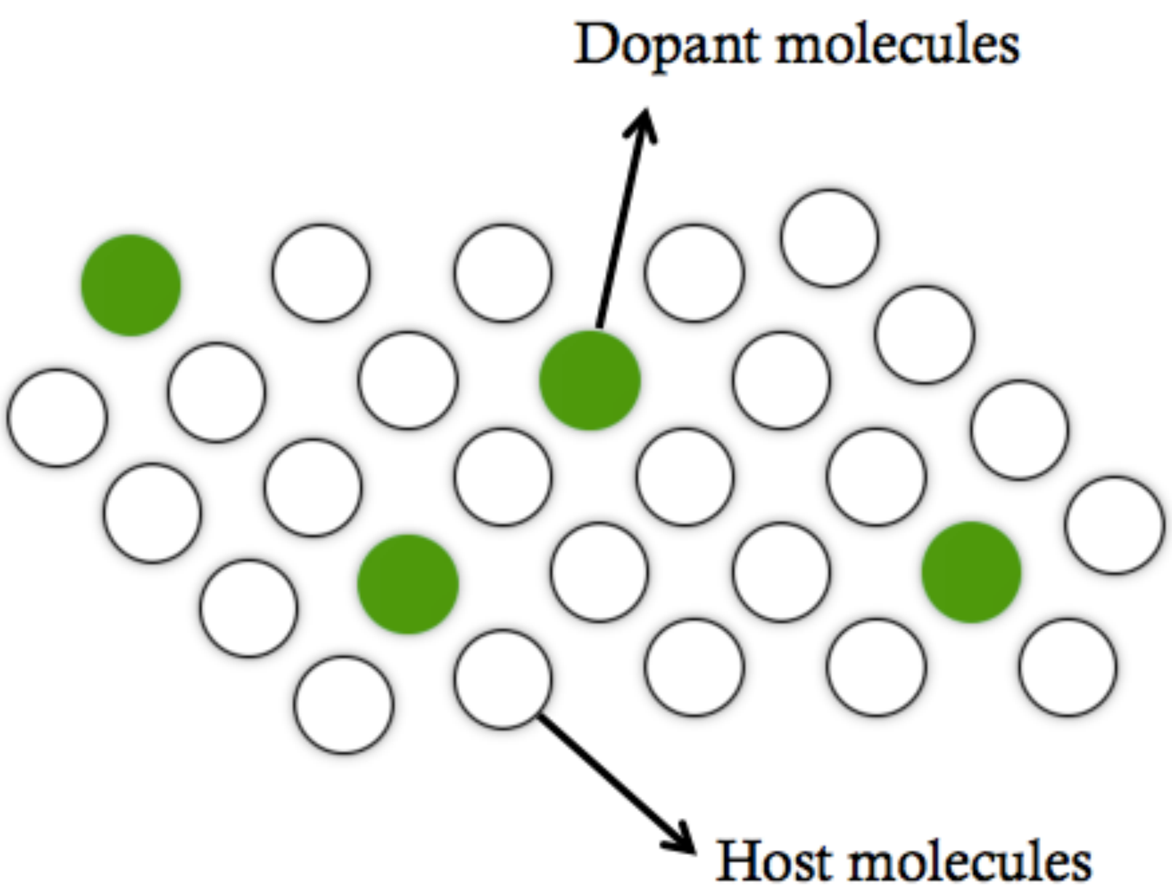
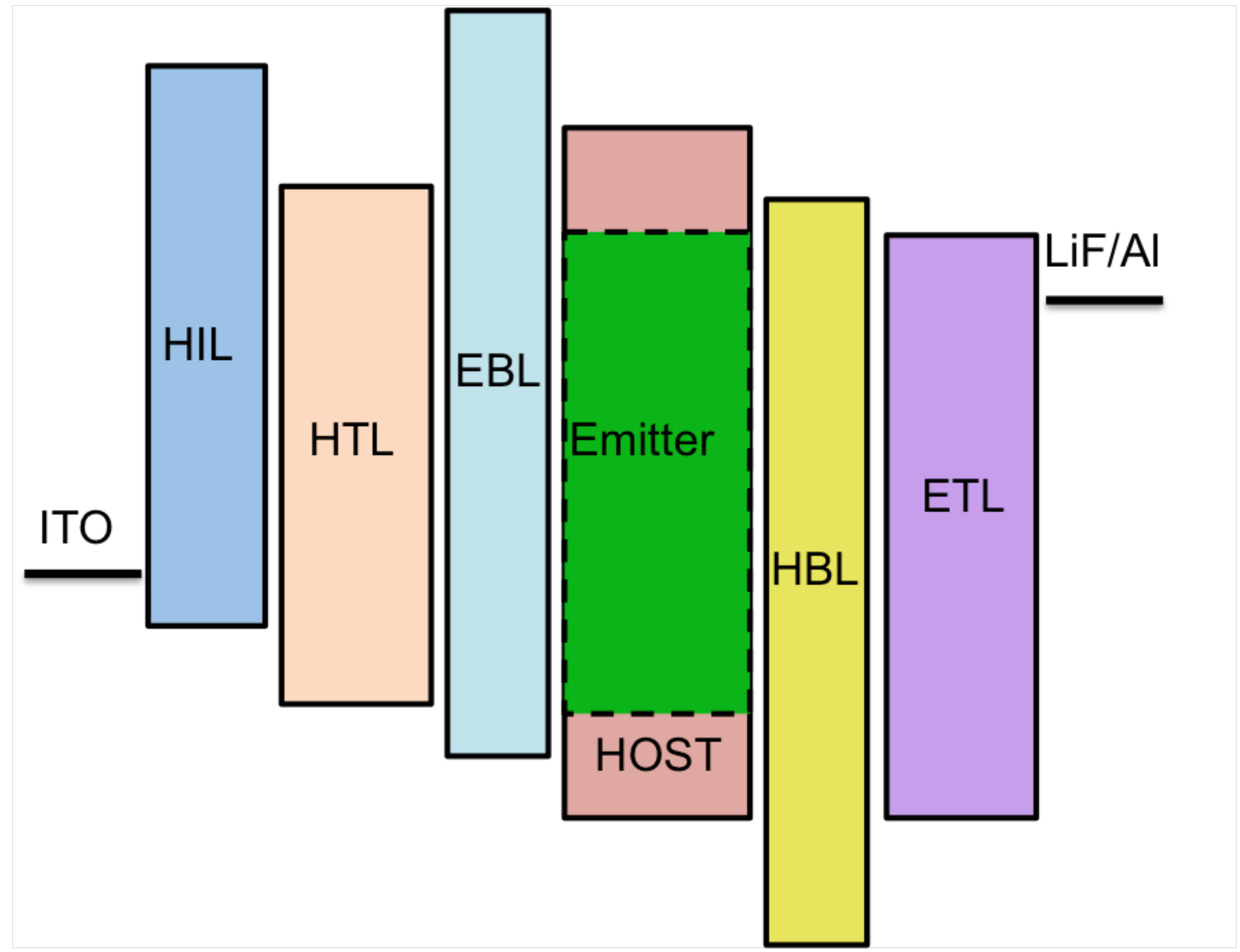
and photon emission

Device Structure

Multi-layered device capable of emitting light in response to an applied electric current

Host-Guest System

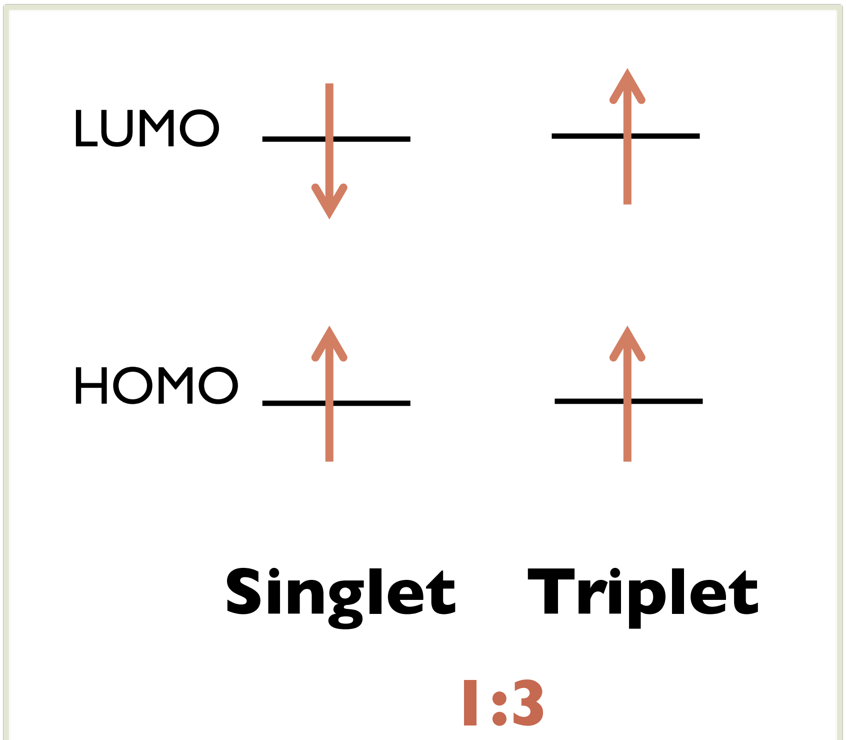


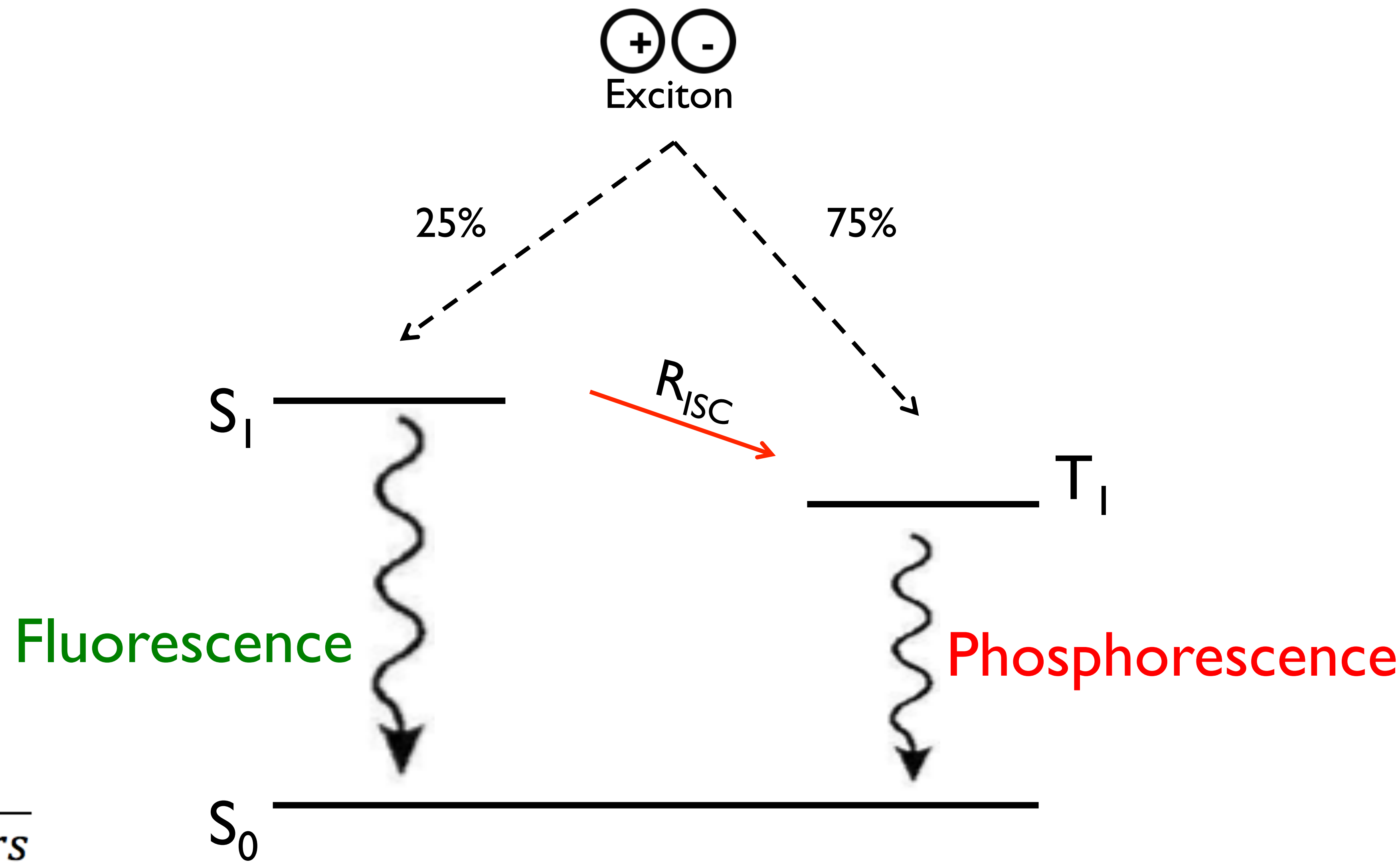


Complex modern OLED

Organic Materials

Traditionally two types of radiative decay pathways





$$EQE = \frac{\#\ emitted\ photons}{pair\ of\ injected\ carriers}$$

Fluorescent: EQE ≤ 25%

Phosphorescent materials: EQE ≤ 100%

Lighting Technologies

Incandescent

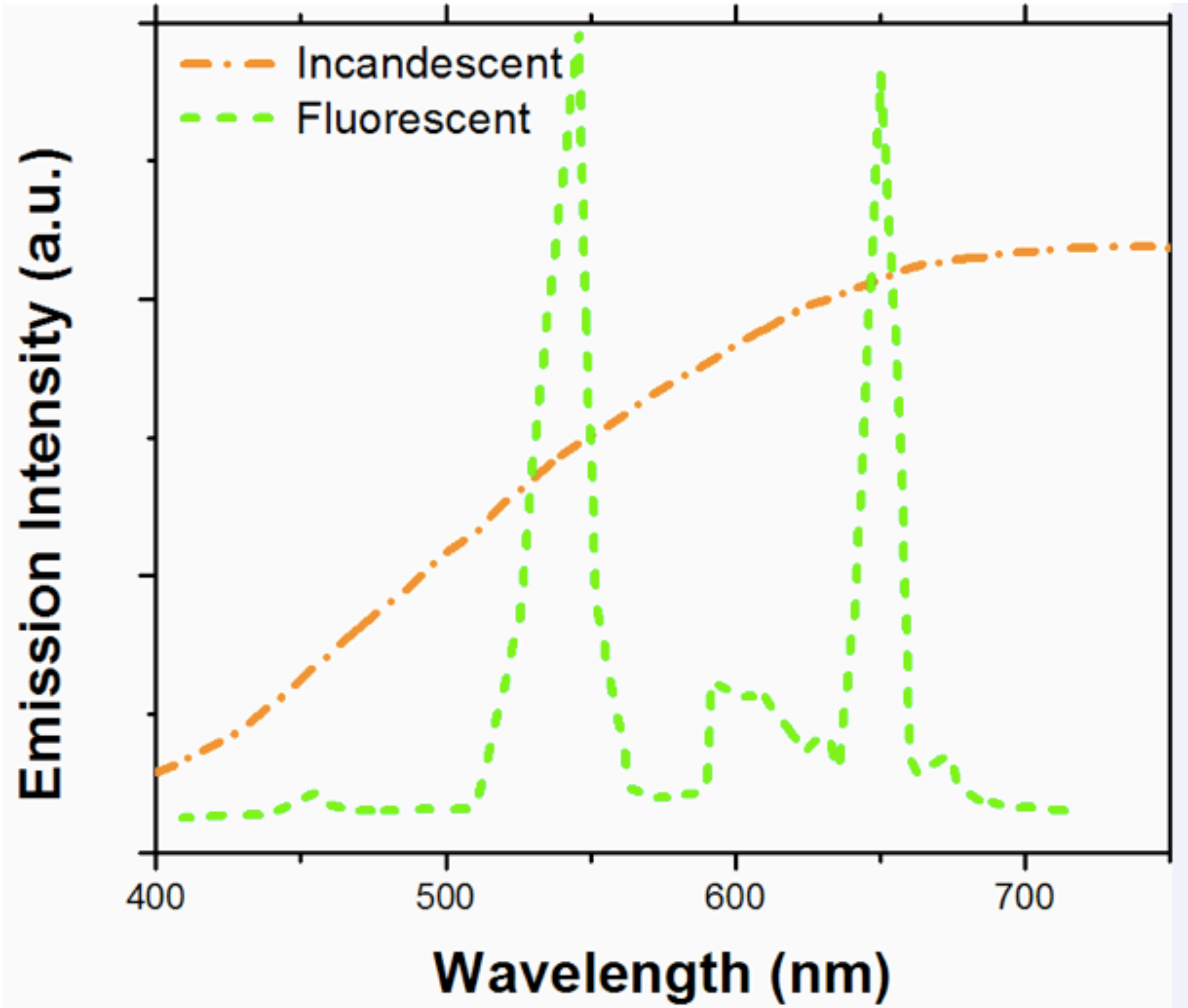
Inefficient

17lm/W

Fluorescent

Poor light quality
Contains Hg

100 lm/W
50-80 lm/W

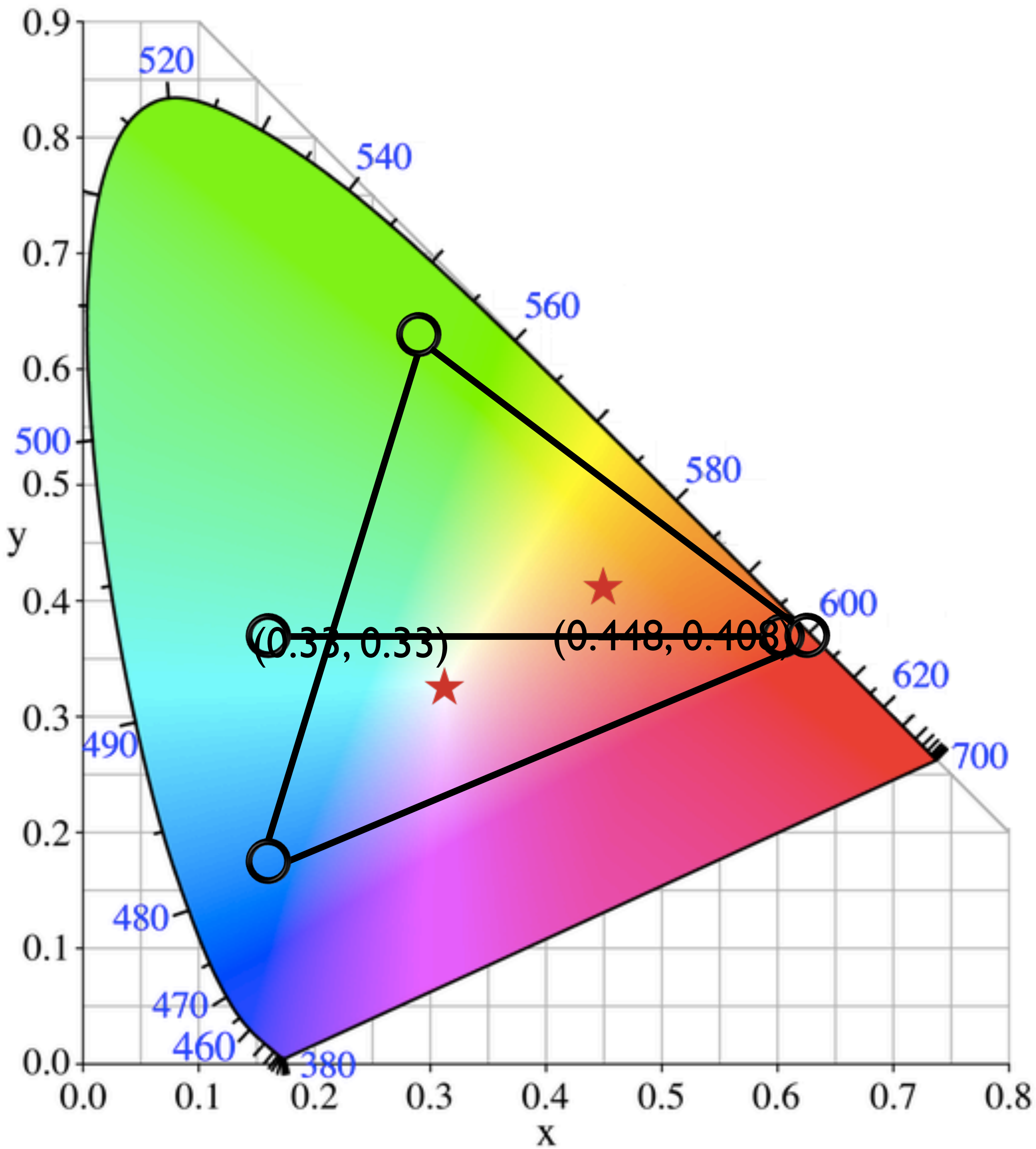


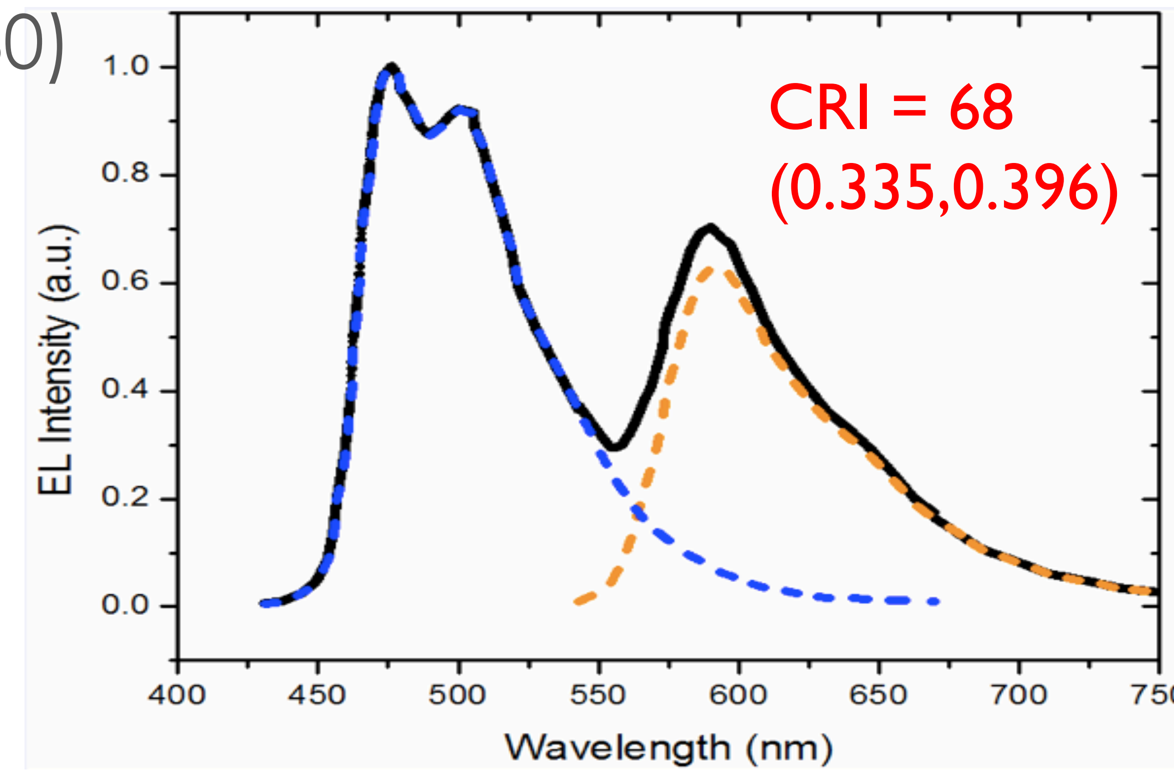
100-120 lm/W
230 lm/W

50 lm/W
100 lm/W

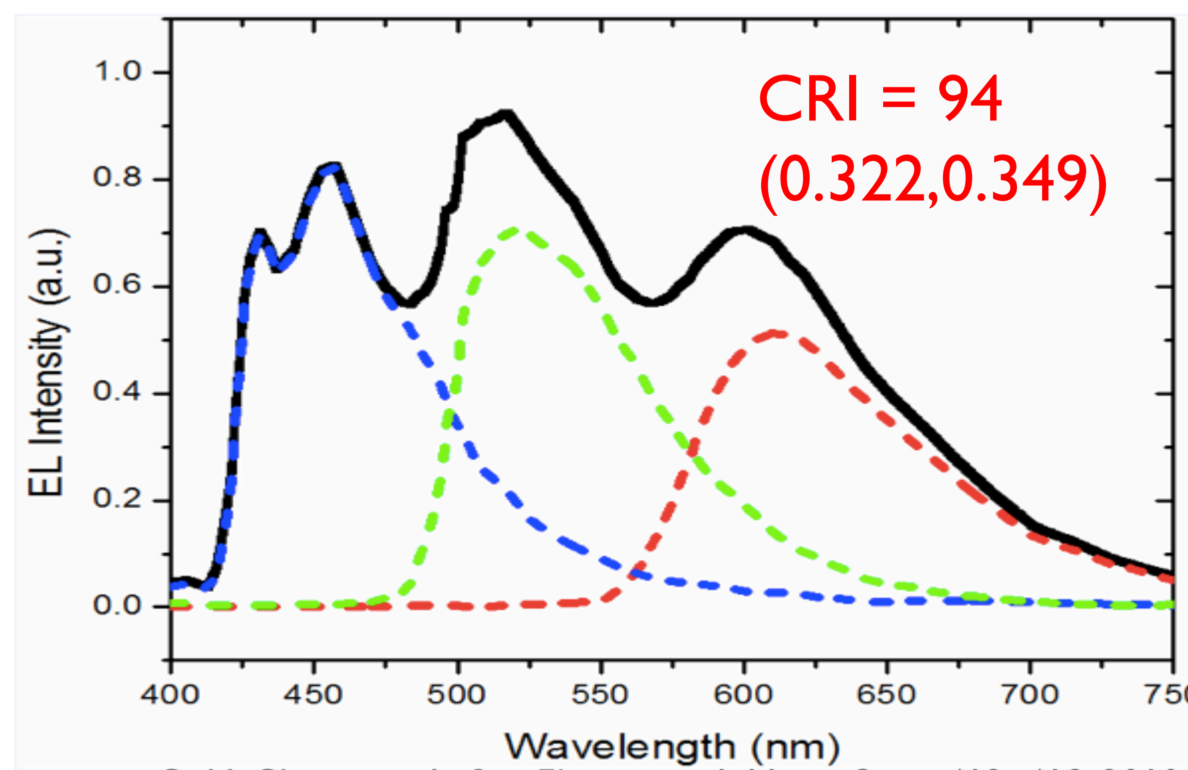
White OLEDs for Lighting

Requires: High color quality (CRI > 80)





S. J. Su, et al. *Adv. Mater.*, vol. 20, no. 21, pp. 4189–4194, 2008



C.-H. Chang, et al., *Org. Electron.*, vol. 11, no. 3, pp. 412–418, 2010.

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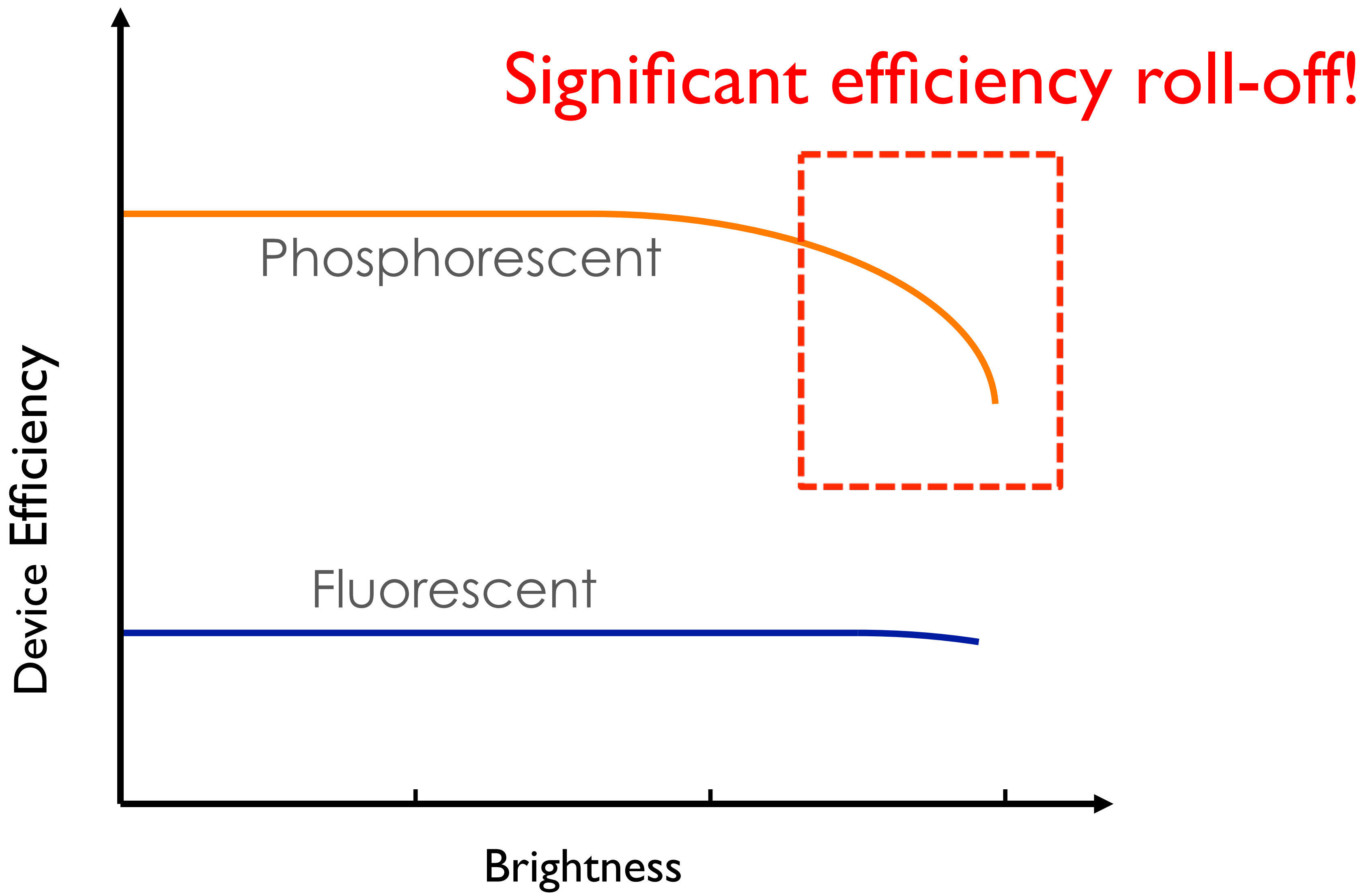
White OLEDs for Lighting

Requires: High efficiency at high brightness (L > 5,000 cd/m^2)

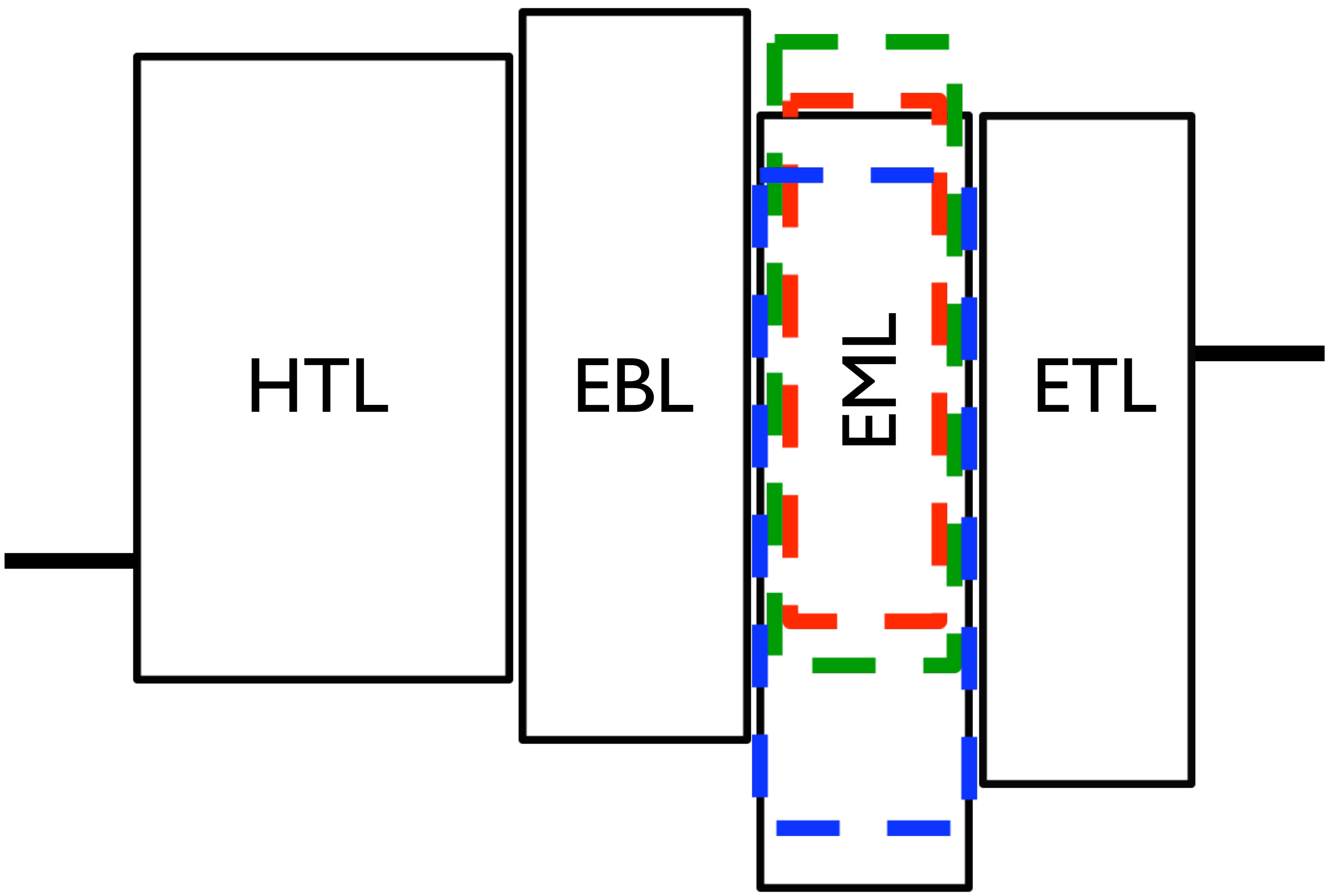


High density of triplet states lead to undesirable annihilation processes

Phosphorescent WOLED

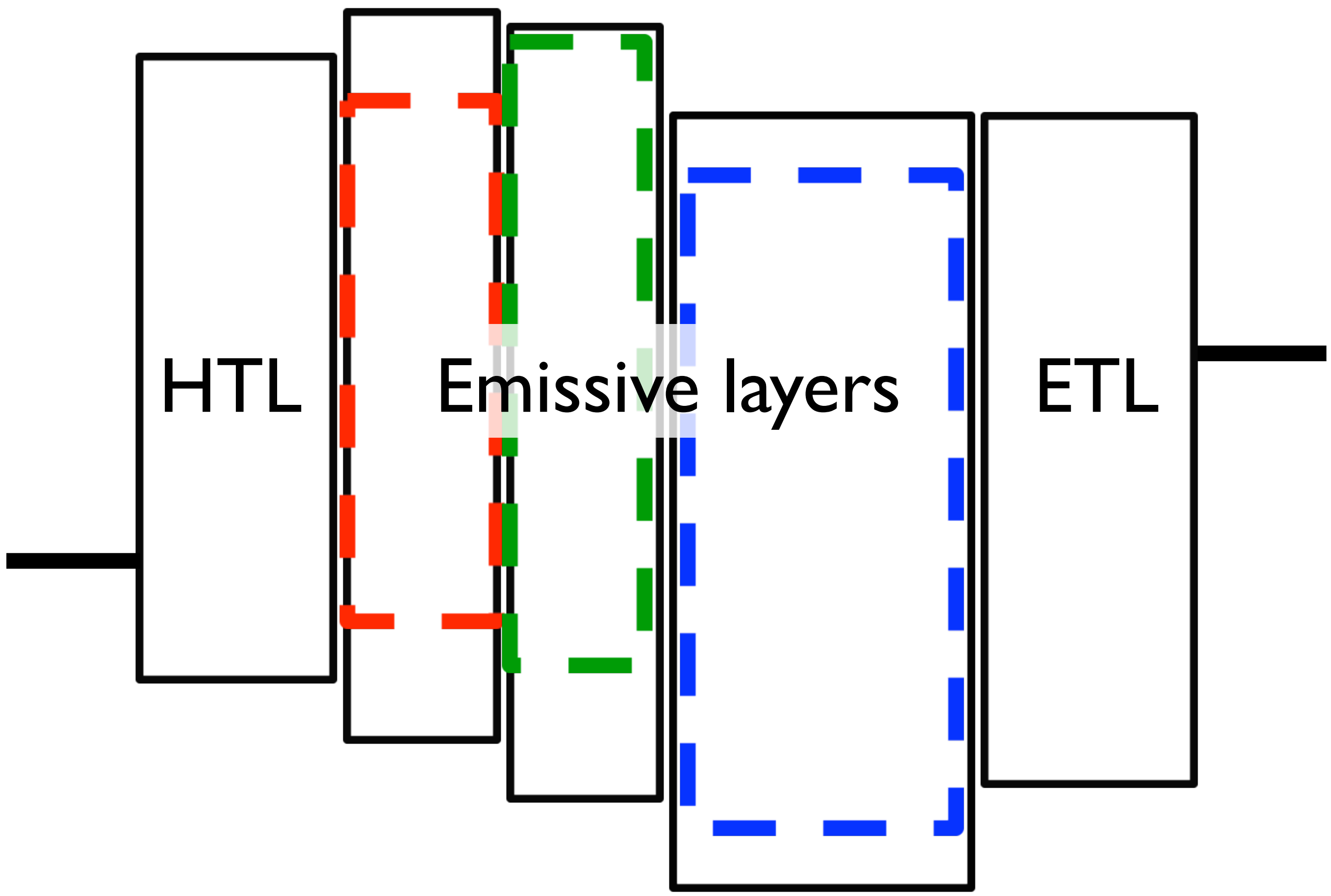
Single vs. multi-layered emissive zone

CRI = 78 @ 1000 cd/m^2
EQE = 6.7%
PE = 11.1 lm/W



B.W. D'Andrade et al., *Adv. Mater.*, vol. 16, no. 7, pp. 624–628, 2004.

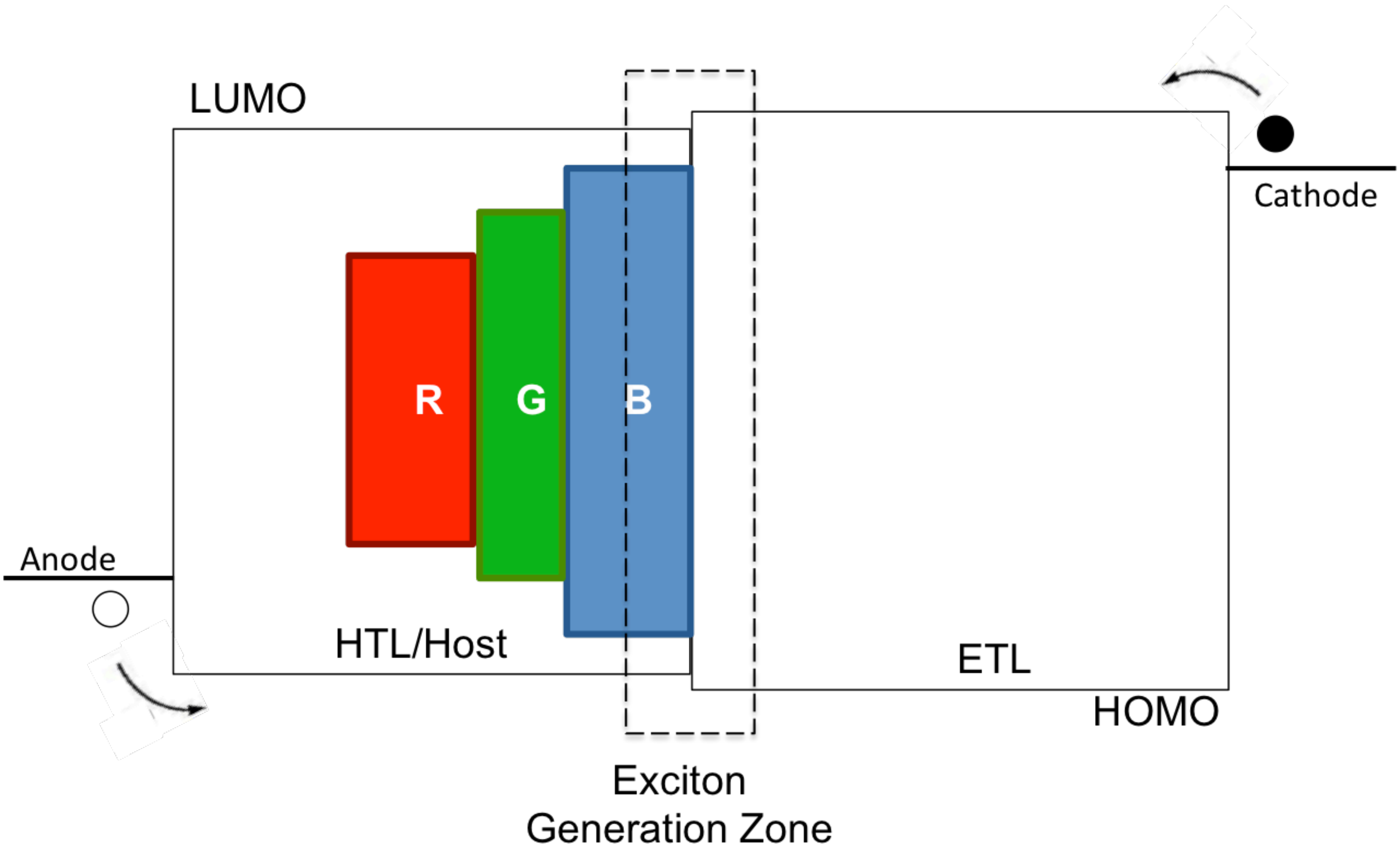
CRI = 81 @ 1000 cd/m^2
EQE = 12.9%
PE = 20 lm/W



Y. Sun et al., *Appl. Phys. Lett.*, vol. 91, no. 26, p. 263503, 2007.

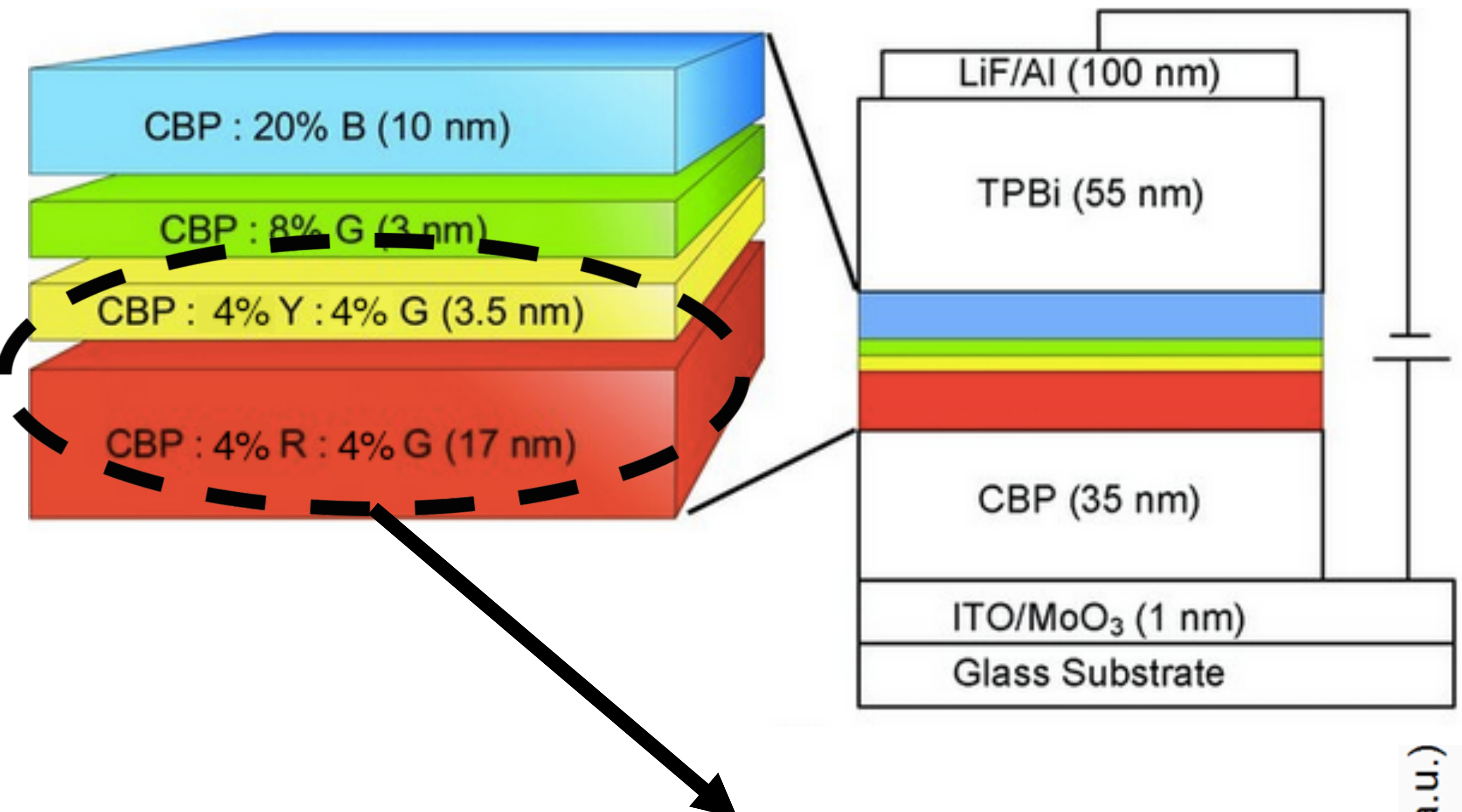
Phosphorescent WOLED

Cascade emission zone



Exciton Harvesting

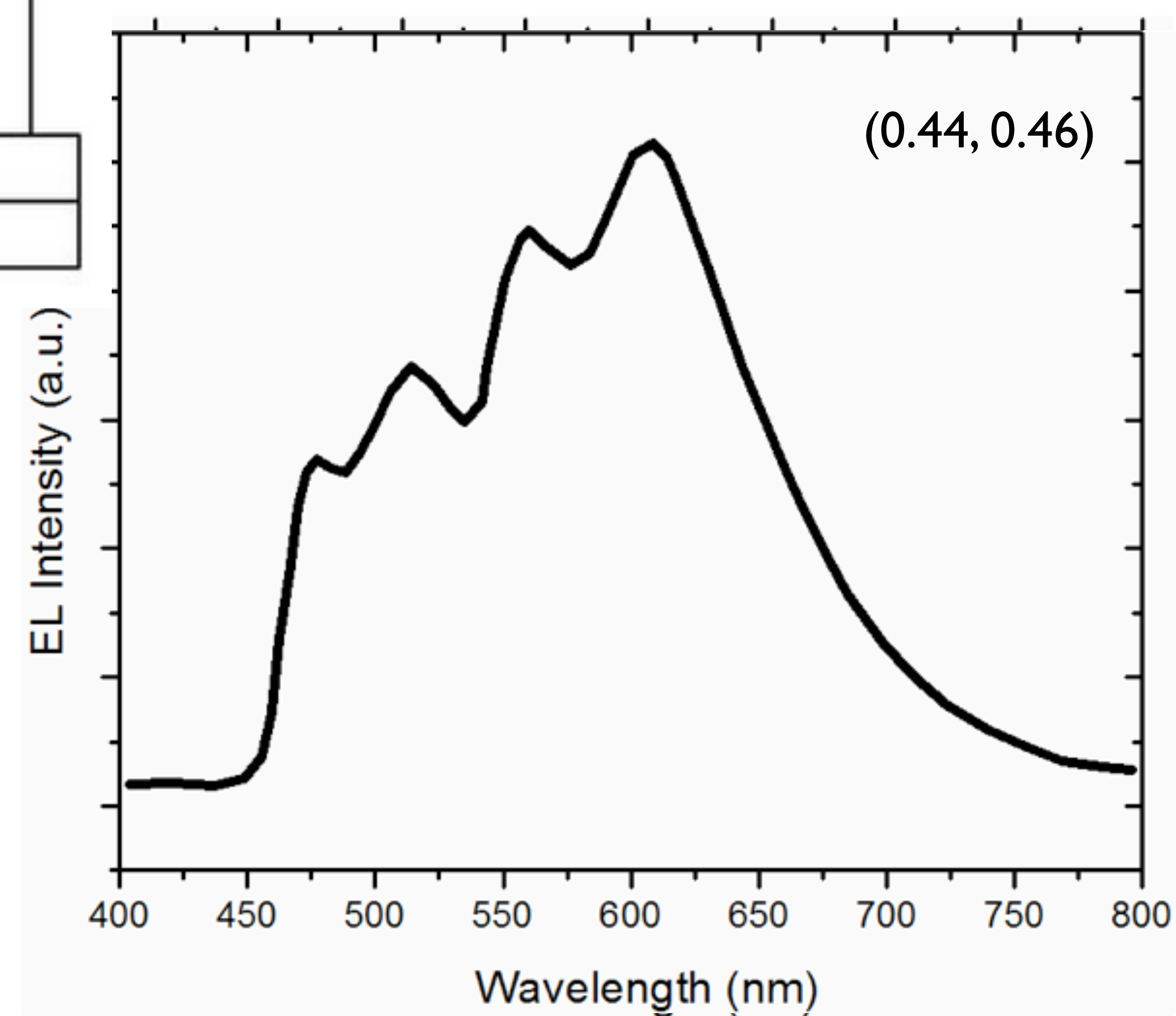
Intrazone



CRI = 81.8

EQE = 23.3% @1000cd/m^2

PE = 31 lm/W



Green dopant acts as exciton harvester for Y and R emitters

Y.-L. Chang, et. al, *Adv. Funct. Mater.*, vol. 23, no. 6, pp. 705–712, Feb. 2013.

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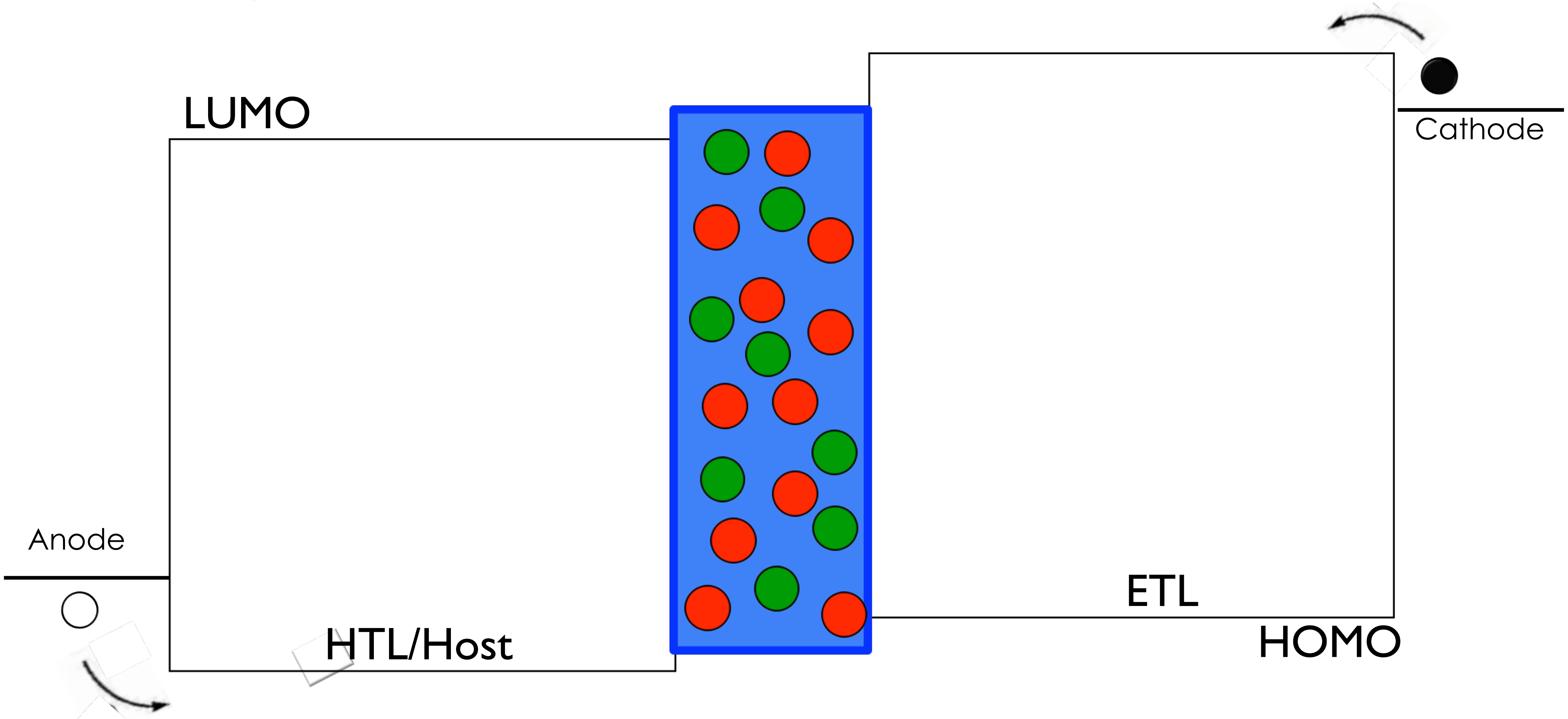
Exciton Harvesting

Intrazone

$$\eta_{ex} = \gamma \eta_{out} \chi \phi_{PL}$$
$$= \gamma \eta_{out} \{ \chi_A \phi_{Pl,A} + \chi_D [\eta_{DA} \phi_{Pl,A} + (1 - \eta_{DA}) \phi_{Pl,D}] \}$$

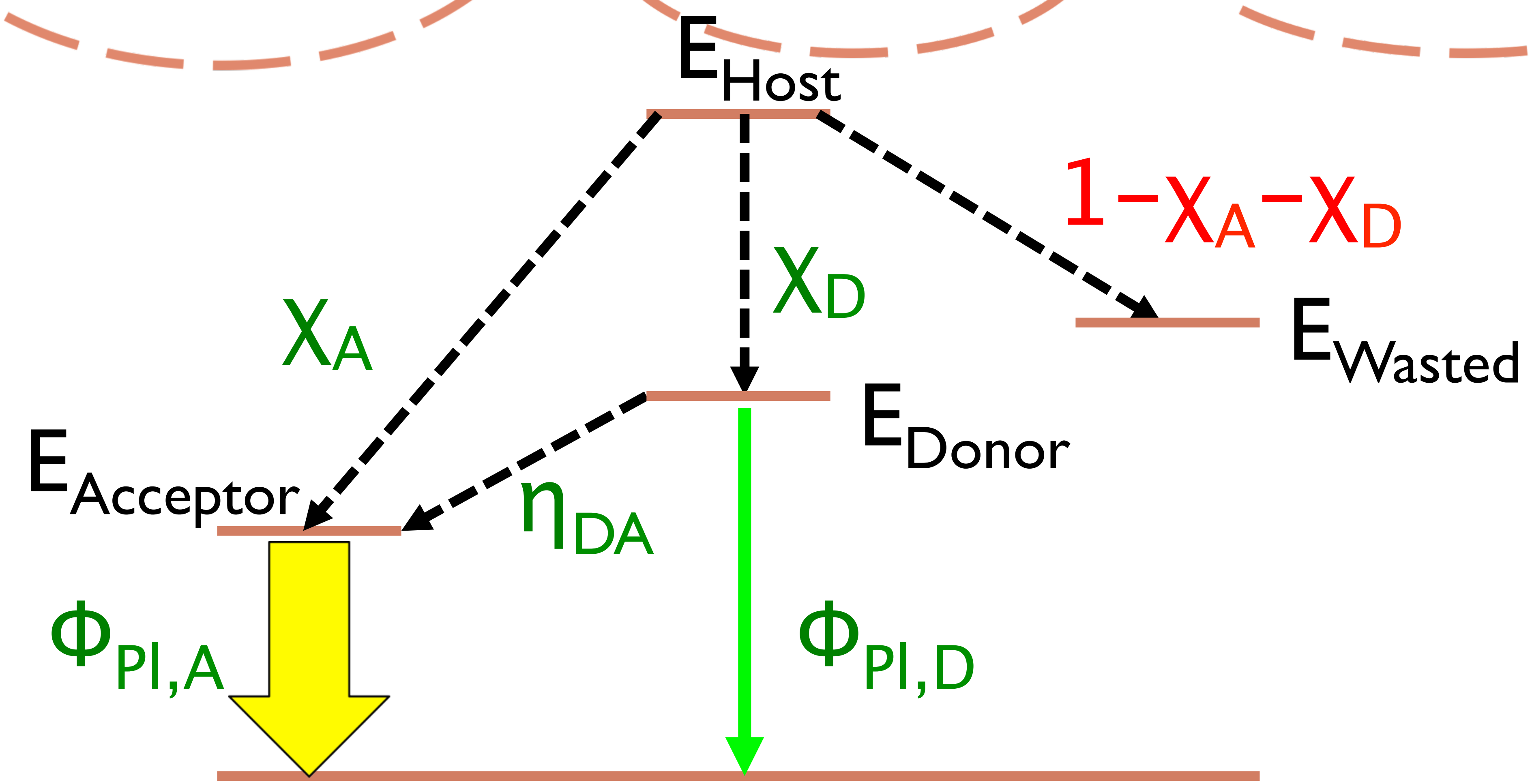


Y.-L. Chang, et. al, *Adv. Funct. Mater.*, vol. 23, no. 6, pp. 705–712, Feb. 2013.

Exciton Harvesting

Intrazone

$$\eta_{ex} = \gamma \eta_{out} \chi \phi_{PL}$$
$$= \gamma \eta_{out} \{ \chi_A \phi_{Pl,A} + \chi_D [\eta_{DA} \phi_{Pl,A} + (1 - \eta_{DA}) \phi_{Pl,D}] \}$$

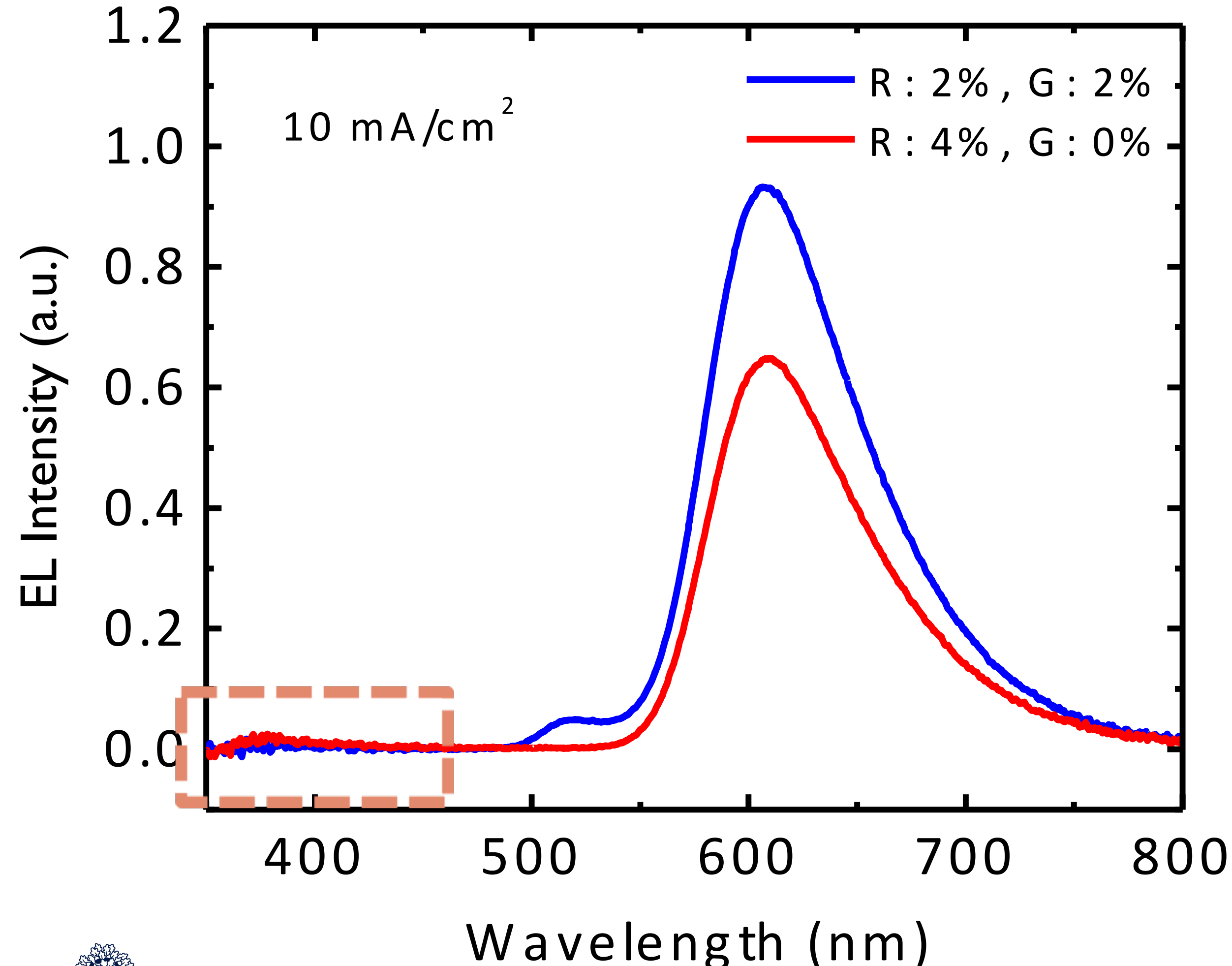


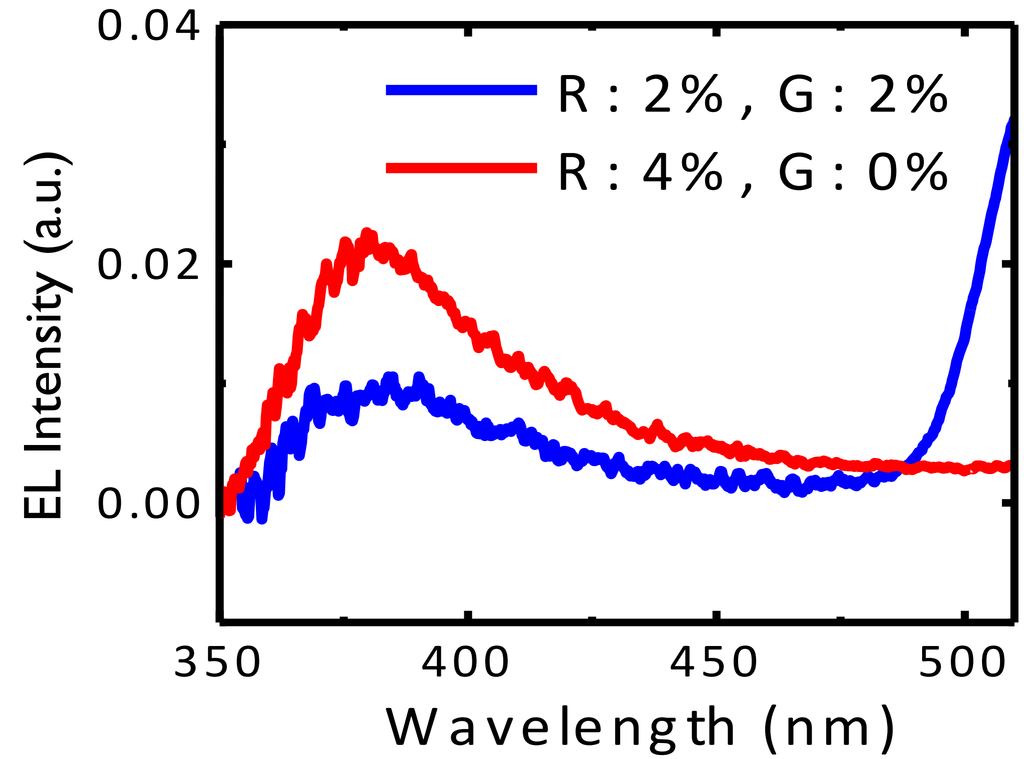
Y.-L. Chang, et. al, *Adv. Funct. Mater.*, vol. 23, no. 6, pp. 705–712, Feb. 2013.

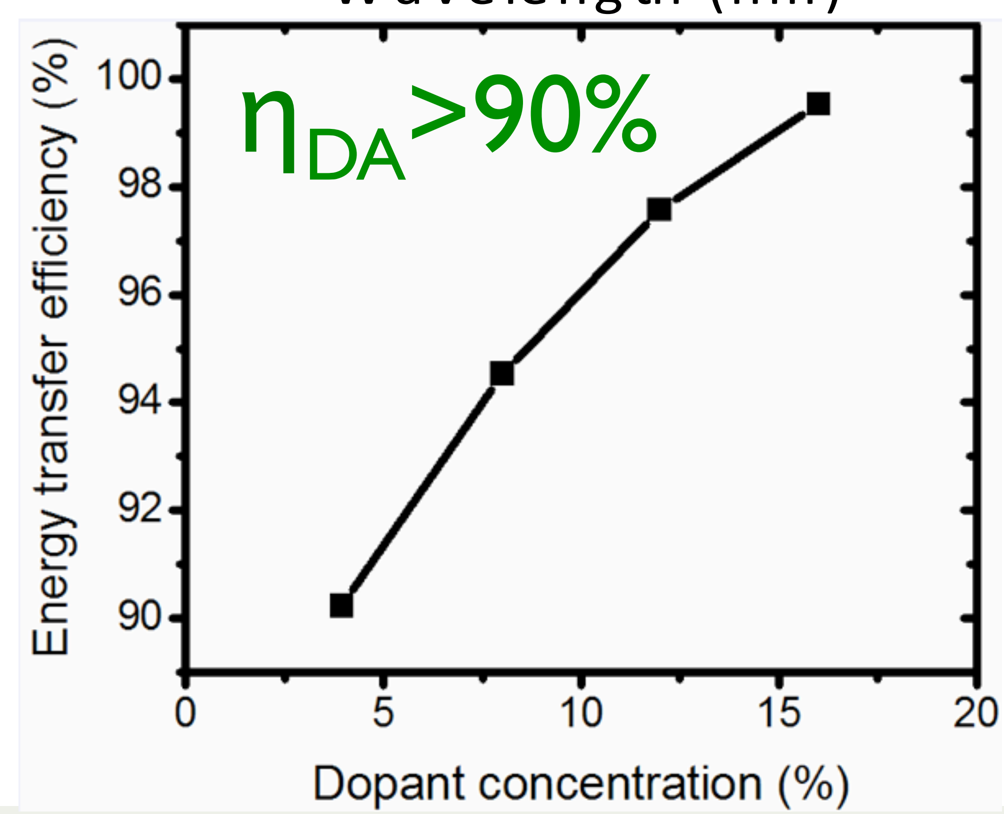
Exciton Harvesting

Intrazone

Enhanced red emission with addition of green harvester dopant







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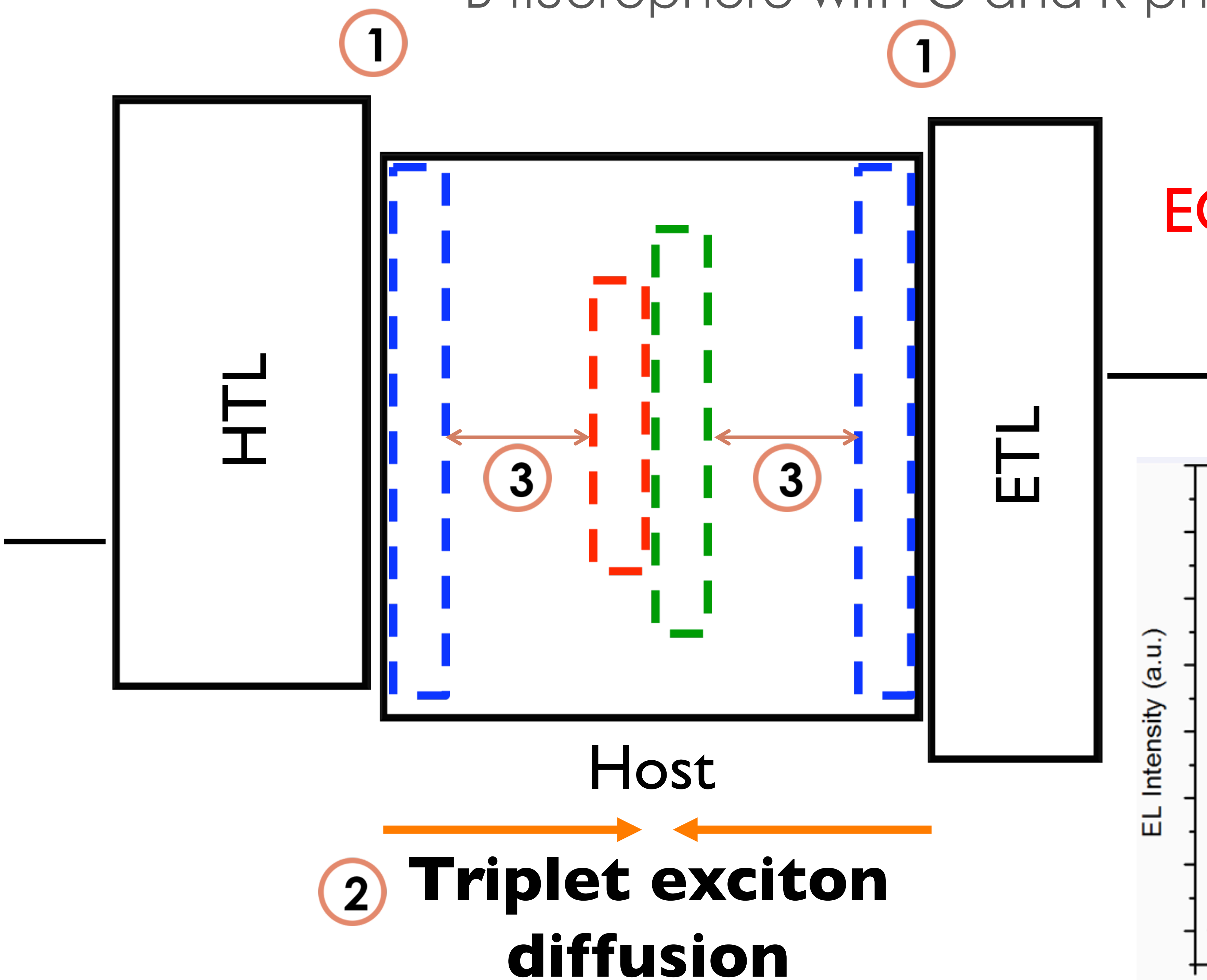
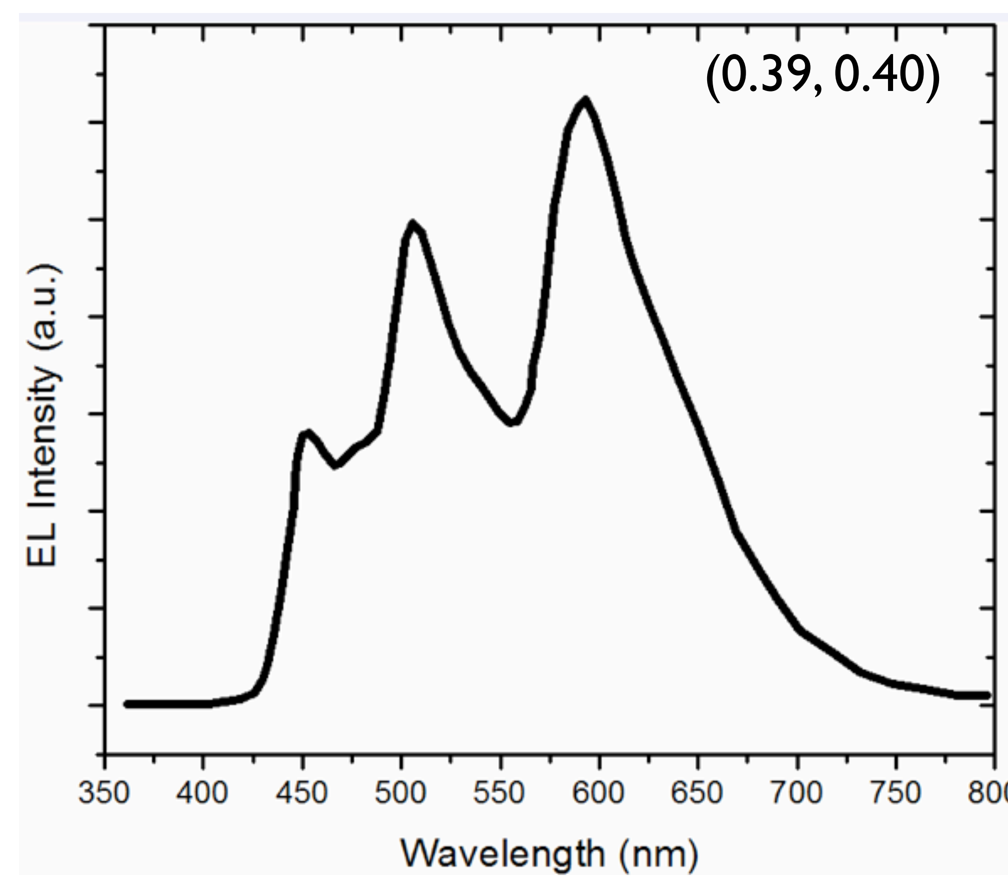
FP White OLEDs

B fluorophore with G and R phosphors



CRI = 85
EQE = 18.4% @500cd/m^2
PE = 23.8 lm/W



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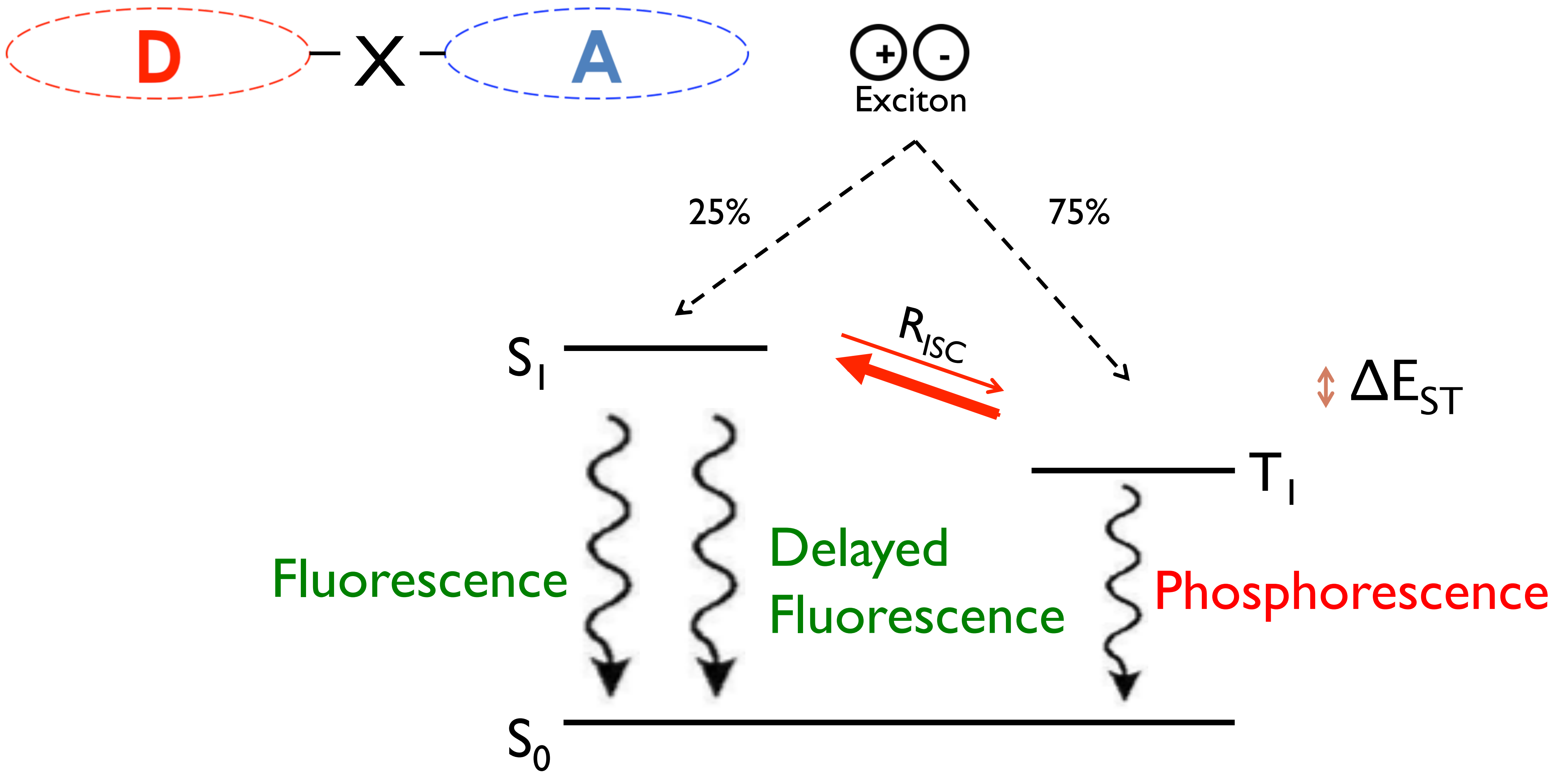
Y. Sun, et al., *Nature*, vol. 440, no. 7086, pp. 908–912, 2006.

Thermally Activated Delayed Fluorescence (TADF)

Move towards completely fluorescent white OLEDs



TADF materials: EQE ≤ 100%

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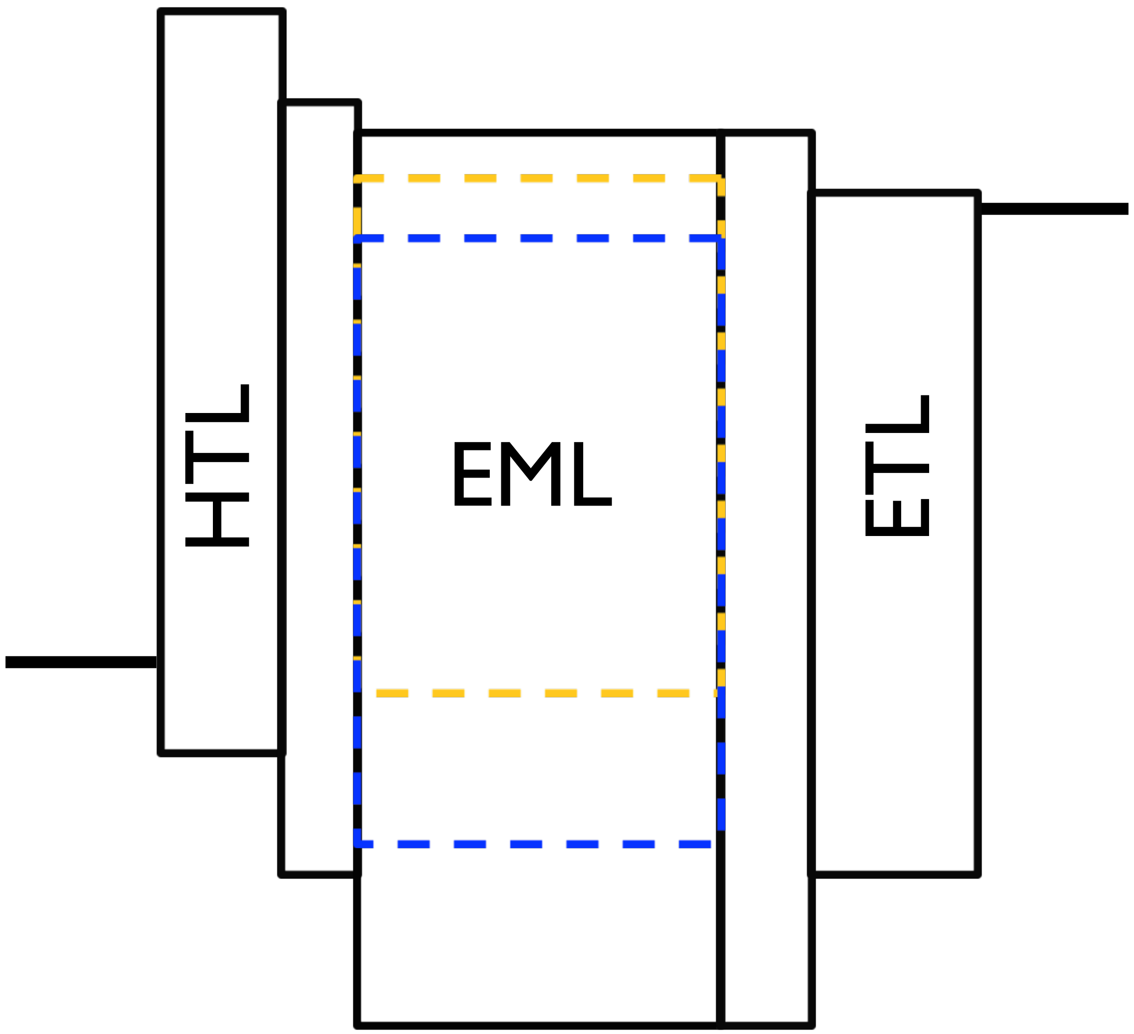
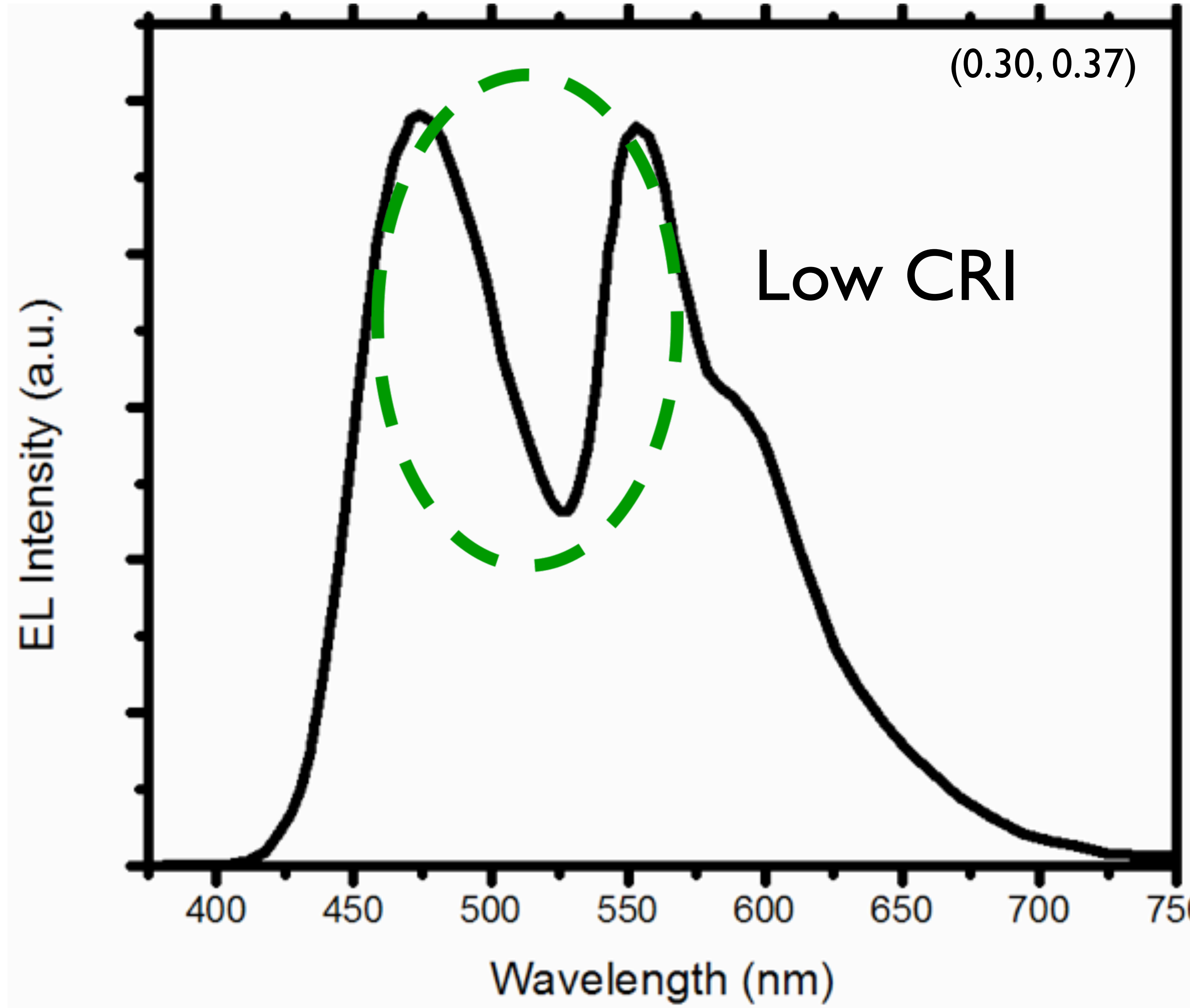
TADF-based White OLEDs

EQE = 18.3% @1000cd/m^2
PE = 33.6 lm/W



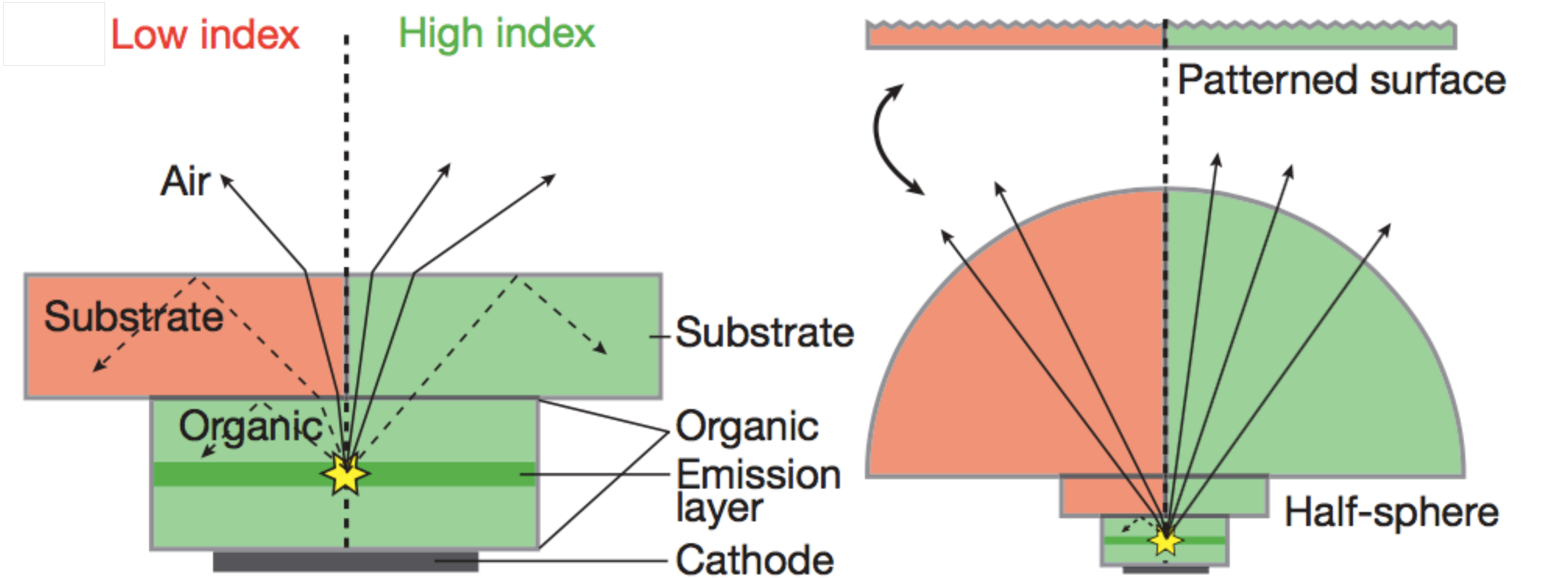
W. Song et al., *J. Phys. D.Appl. Phys.*, vol. 48, no. 36, p. 365106, 2015.



Out-coupling

Cascade EML with exciton harvesting structure:

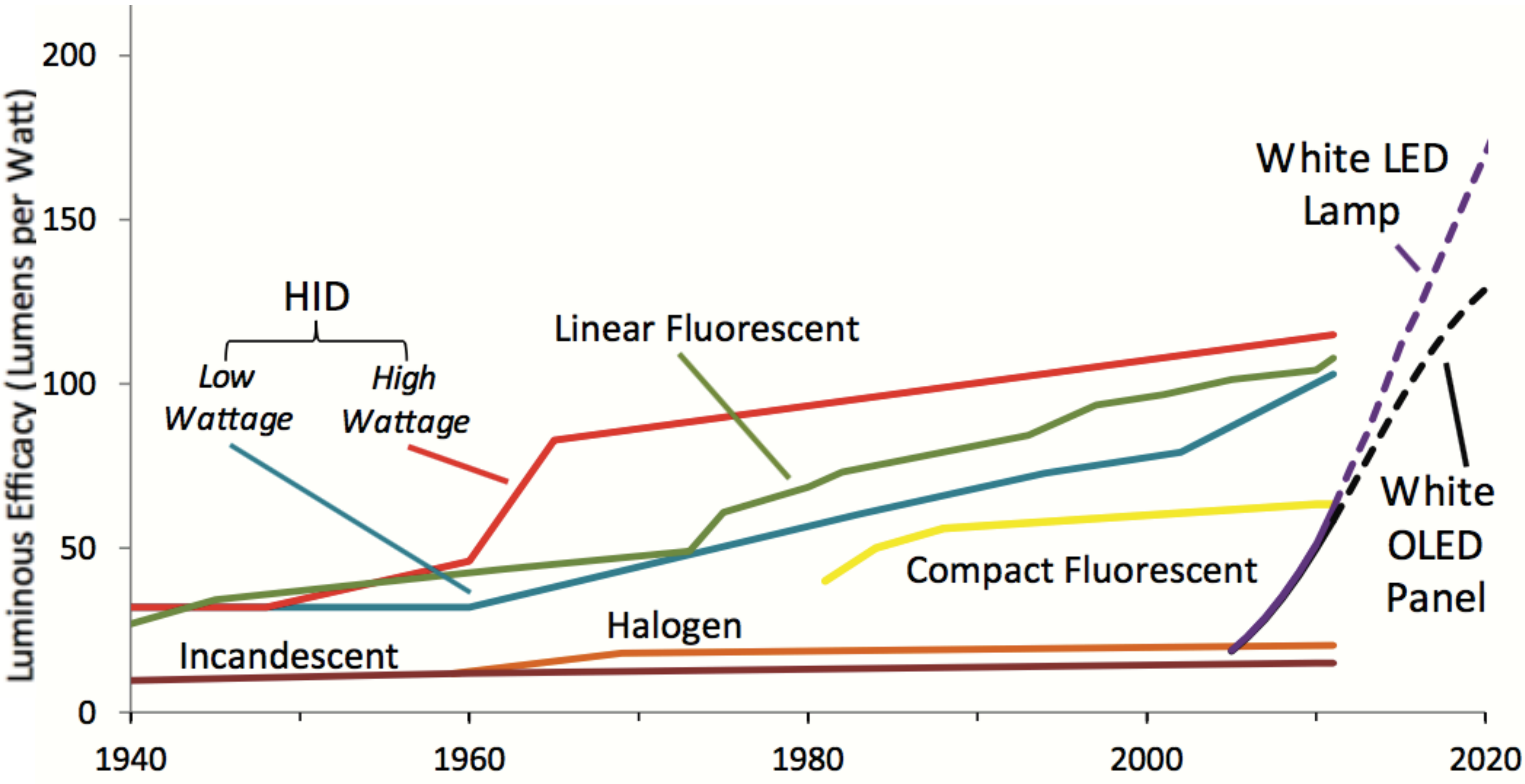
Improved from 31lm/W to 61.7 lm/W with simple out-coupling technique



Highest performing WhOLED with out-coupling: 90lm/W @1000cd/m^2

S. Reineke, et al., *Nature*, vol. 459, no. 7244, pp. 234–238, 2009.

Conclusions and Outlook



SOURCE: DOE *"Assessment of advanced solid state lighting"* (2013, p. 35)

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Thanks!

Questions?

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