POLITECNICO DI MILANO
Piazza Leonardo da Vinci, 32 - 20133 Milano
Tel. +39.02.2399.1 - http://www.polimi.it

Advanced Course on

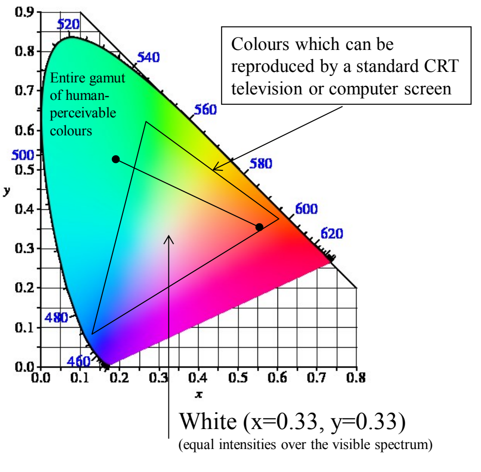
ORGANIC ELECTRONICS
Principles, devices and applications

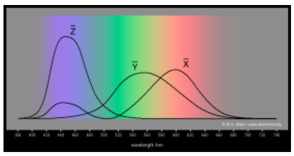
Organic lighting: White OLED

Marco Sampietro

White light evaluation parameters (1)

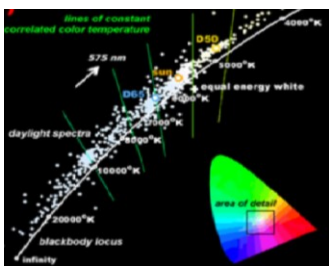
CIE coordinates : How to make a colour by adding varying proportions of “primaries“.





$$x = \frac{X}{X+Y+Z} \quad y = \frac{Y}{X+Y+Z} \quad z = \frac{Z}{X+Y+Z}$$

$$x+y+z=1$$



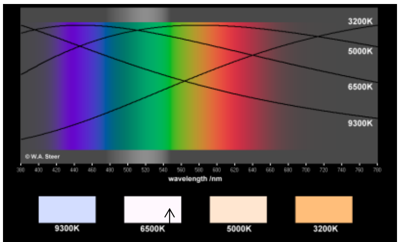
 The colour of any light-emitter can be unambiguously defined by CIE x,y coordinate.

White light evaluation parameters (2)

The colour appearance of any passive (reflective, non-emissive) material can be defined by CIE x,y coordinate only under a given source of illumination.

CT, colour temperature

A piece of metal, when heated, glows.
Its spectral distribution depends only on temperature



Sun-light (in space) has characteristic temperatures around 5000-6500K (close to black body radiation)

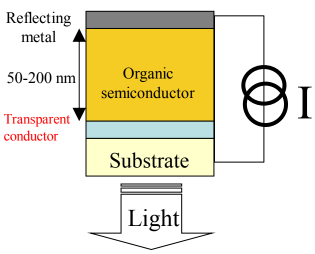
CRI, colour rendering index

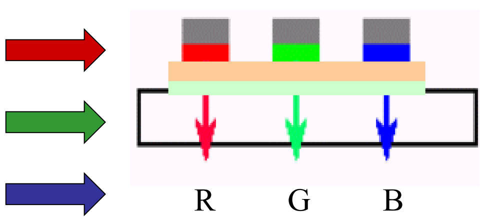
CRI, colour rendering index (quoted for lamps) : indicates how accurately that light will portray colours relative to a blackbody source at the same nominal colour temperature.

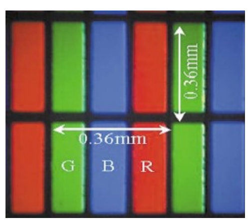
$0 < CRI < 100$
↑ all backbody sources

CRI of 80-85 being classed by the manufacturers as 'good' or 'very good' colour-rendering

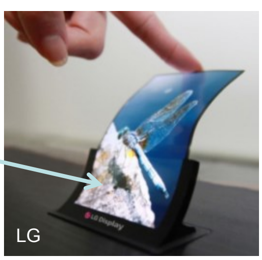
From OLED to Pixels to white







White color



Turn an OLED into a <u>Power</u> efficient light source

3 key parameters must be addressed:

- High IQE *(ideal limit of 100%)*
- High outcoupling efficiency : a high fraction of the internally created photons must escape

} High EQE

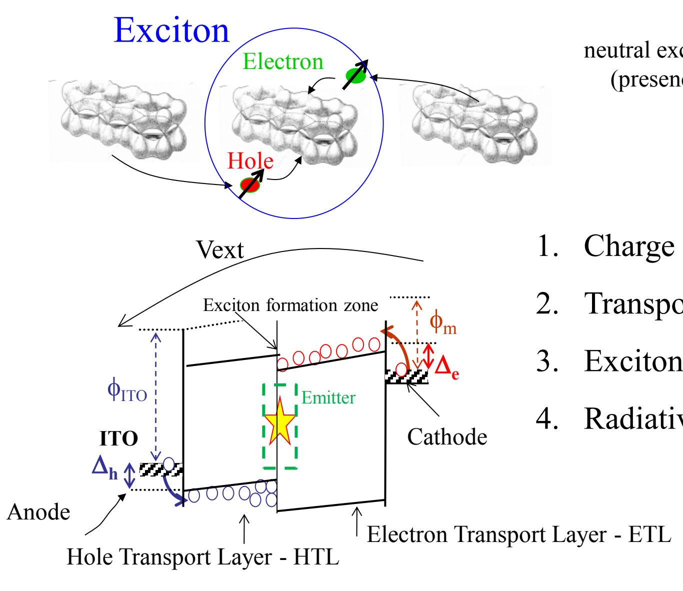
- Low operating voltage : the energy loss during electron-photon conversion should be small *(ideal limit ~ 3V of the blue emitter)*

Target : 70 lm/W of fluorescent tubes

(100% efficiency would correspond to 680 lm/W !)

5

EXCITON DYNAMICS



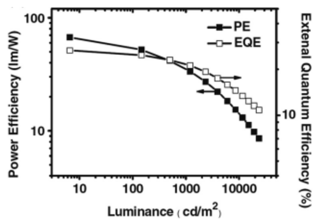
EXCITON
neutral excited entity (molecule)
(presence of e^- - h^+ couple)

1. Charge injection
2. Transport
3. Exciton formation
4. Radiative recombination

EXCITON QUENCING

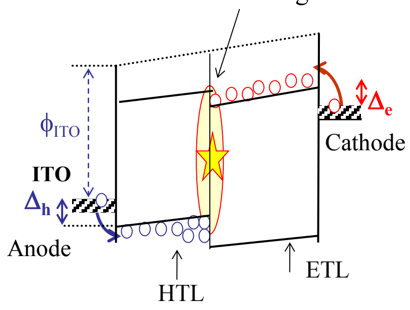
EXCITONS may interact with each other and with charge carriers

These interactions lead to reduced efficiency with increased current density
(carriers unbalance, accumulation of long-lived triplet states, etc.)



Exciton formation zone

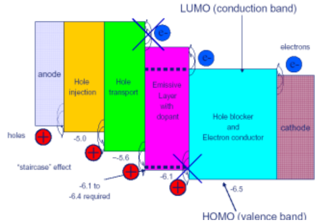
Coincident with high level of excitons and charges



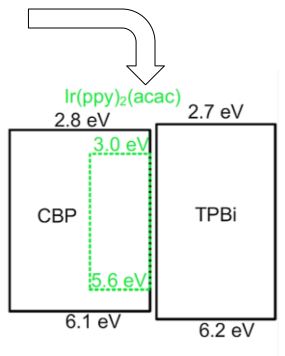
Techniques to reduce bimolecular interactions are important for «power» devices

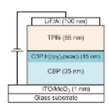
ELIMINATION of ACCUMULATED CHARGES at Heterojunctions

From



to highly simplified design with closely matched HOMO and LUMO levels to reduce charge accumulation



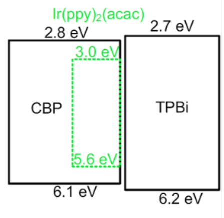


EQE = 25% at brightness =1000cd/m^2

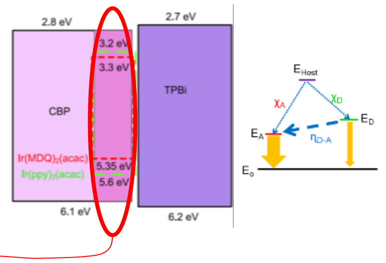
G.L.Ingram and Z.H.Lu, Journal of Photonics for Energy, Vol.4, 2014

4'-bis(carbazol-9-yl)biphenyl (CBP)
2,2',2''-(1,3,5-benzinetriyl)-tris(1-phenyl-1-H-benzimidazole) (TPBi)
bis(2-phenylpyridine)(acetylacetonate)iridium(III) (Ir(ppy)$_2$(acac))

EXCITON HARVESTING & CO-DOPING

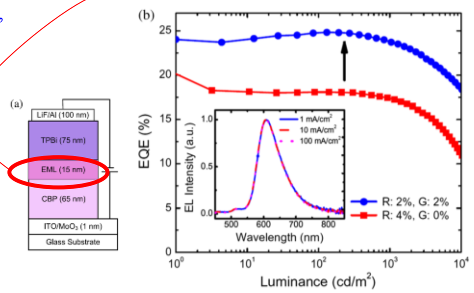


Use the Ir(ppy)$_2$(acac) harvester to enhance emission of a second emitter, Ir(MDO)$_2$(acac)



Host (CBP) – Emitter (Ir(ppy)$_2$(acac)) combination has proven to be very efficient, suggesting that Ir(ppy)$_2$(acac) is a good exciton harvester

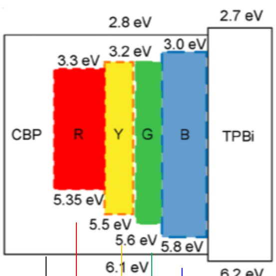
Forster-type energy transfer length

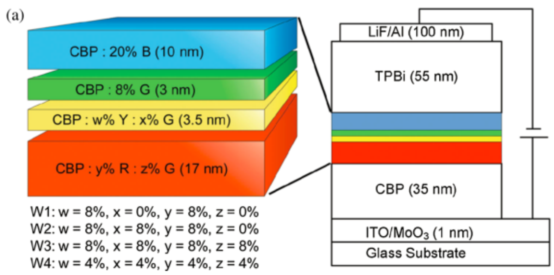


Forster-type energy transfer is prevalent (low concentration of both harvester and emitter, so that only a small number of exciton harvesting dopants will have an adjacent emitter)

G.L.Ingram and Z.H.Lu, Journal of Photonics for Energy, Vol.4, 2014

Exciton harvesting for WHITE OLED





Y.-L. Chang et al., Adv. Funct. Mater. 23(25), 3204–3211 (2013).

→ 4'-bis(carbazol-9-yl)biphenyl (*host material*)

Iridium (III) bis(4,6-difluorophenyl-pyridinato-N,C2')(picolinate) - *Firpic*

Ir(ppy)$_2$(acac)

Ir(BT)$_2$(acac)

Ir(MDQ)$_2$(acac)

Phosphorescent emitters allowing to harvest triplet excitons ⟶ 100% IQE

Exciton harvesting for WHITE OLED

EQE = 20.4%

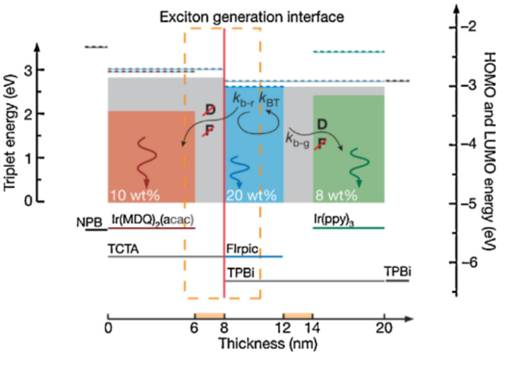
CRI = 85

@ 5000 cd/m^2

Y.-L. Chang et al., "Highly efficient greenish-yellow phosphorescent organic light-emitting diodes based on interzone exciton transfer," Adv. Funct. Mater. 23(25), 3204–3211 (2013).

Highly engineered Emitting Layers

Double-emission-layer structure



S. Reineke et al. Nature 459 (2009), 234-U116.

Blue phosphor within the EML

Triplet energy of Blue phosphor in resonance with its Host

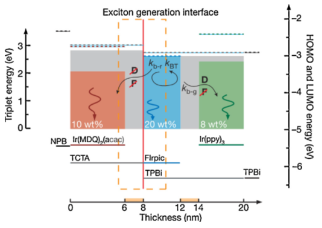
Blue surrounded by Red and Green to harvest unused excitons

Very small barriers for e- and h+ untill exciton formation region

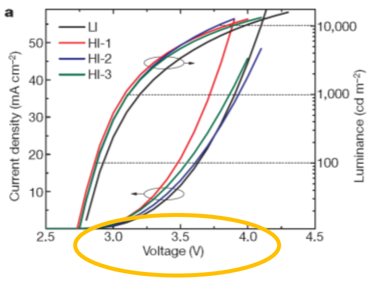
Excitons created in the Blue region on host or dopant do not migrate to Red due to the higher triplet-energy TCTA interlayer

Emitting sublayers decoupled by thin intrinsic interlayers of the corresponding Hosts

Highly engineered Emitting Layers



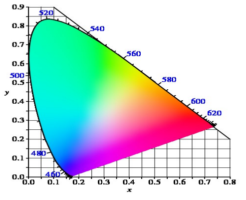
Final objectives :
- Control energy transfer to Red
- Minimize voltage drop



90 lm/W @1000cd/m^2

CIE = 0.44, 0.46

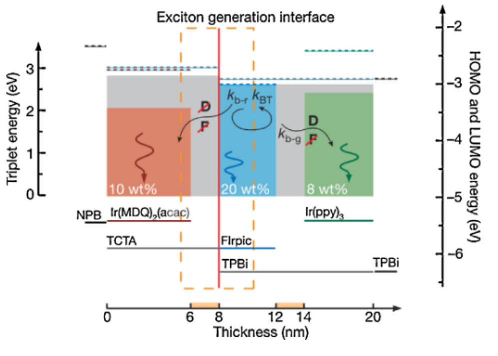
CRI 80



S. Reineke et al. Nature 459 (2009), 234-U116.

Degradation of blue phosphorescent emitter

Problem : Blue phosphorescent emitters are unstable (device degradation) as the energy necessary to excite the molecule is close to C-C and C-N bonds in the same molecule



Hybrid fluorescent-phosphorescent OLED

One solution to the instability of blue phosphorescent emitters is to use a blue fluorophore (very stable) in combination with lower-energy phosphorescent emitters.

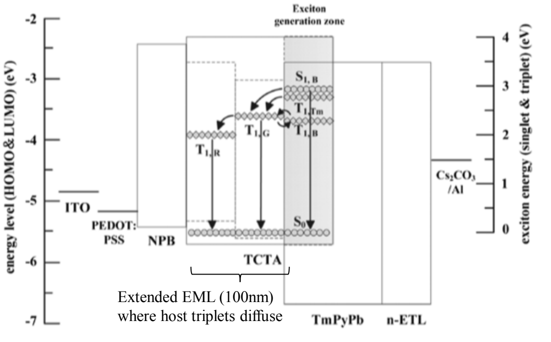
If blue fluorophore harvests all singlet excitons

⇩

100% IQE is still possible

⇩

Good color balance (1:3 singlet:triplet matches 25% of blue in white light

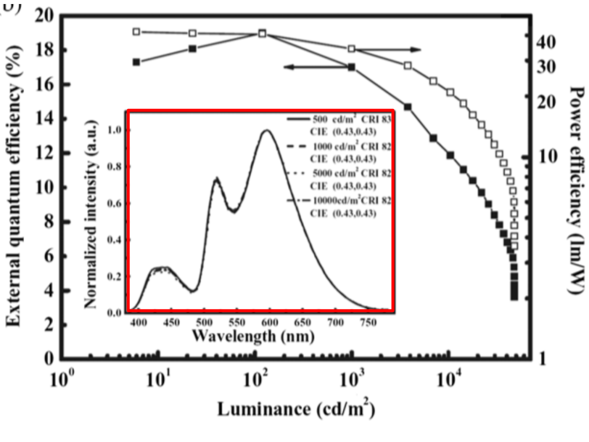


N. Sun et al., Adv. Mater. 26(10), 1617–1621 (2014).

The difficulty with this strategy is ensuring that singlet and triplet excitons are captured and decay on the appropriate molecules (Triplets on the blue are lost; Singlets on red & green reduce the blue emission)

WHITE Hybrid OLED

White emission balance stable on current density

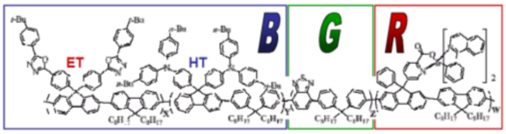


N. Sun et al., :High-performance hybrid white organic light-emitting devices without interlayer between fluorescent and phosphorescent emissive regions," Adv. Mater. 26(10), 1617–1621 (2014).

Single molecule WHITE OLED

Block copolymer

Al/CsF/polimero/PEDOT/ITO   Organic Electronics 11, 2012 (2010)

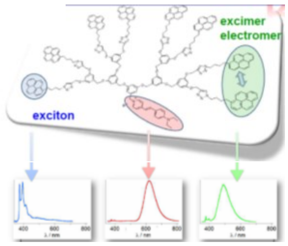


W3 X=Y=0.2496n, Z=0.0004n, W=0.0004n.

EQE =4%   8.2 cd/A 7.2 lm/W   1000 cd/m^2
CIE (0.33, 0.36)   CRI 82

Dendrimeri ad antenna

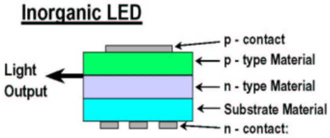
White light (0.35; 0.40)



17   S.Chicchi et al. Chem.Phys.Chem. 11, 683 (2010)

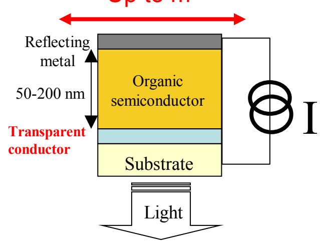
LED vs OLED

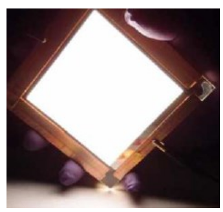
Point source emission



Emission over an area

Up to m^2





Philips Lumiblade OLED Panel GL350 (125x125mm^2, 120 lm)

AREA source of light - ILLUMINATION (1)

OLED (area source) competes with fluorescent bulbs (line source) and LED (point source)

Large active area
(wallpaper, light panels, …)

- diffused light, minimized shadows, ..

Transparent substrate
(glass, light panels, signalling)

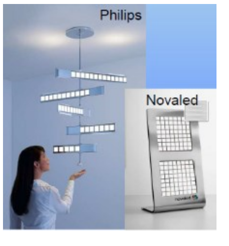
Osram

Philips

AREA source of light - ILLUMINATION (2)

Low power density
(0.0001W/mm^2)

Thermal management not required



LG chemical

Substrates can be:

- very thin
- large variety of materials

You can hold it in your hands

AREA source of light - ILLUMINATION (3)

Mechanical flexibility
(curved lamps, adapting to other forms, …)

Large choice of colors
(ambient light, Color Rendition Index →100)

In perspective : great opportunities for designers and architects

No ultraviolet rays
(no harm to human eyes, little degradation of other materials, no attraction to phototaxis insects, …)

Problems : non-uniformity over large surfaces, lifetimes, …
… a little electrical short can kill a large area OLED !!!

Fancy applications

Hundreds of triangular OLED panels on the car's body

AREA source of light - PRODUCTS

Philips Lumiblade OLED Panel GL350

Dimensions (outer)	124.5 mm x 124.5 mm x 3.3 mm
Dimensions (lit area)	103.8 mm x 103.8 mm
Current	500 mA
Voltage	14.3 V (voltage increase up to 1.6V over lifetime)
Power consumption	7.2 W
Lumen	120 lm
Lumen efficacy	16.7 lm/W
Luminance	4,000 cd/m²
Color Temperature	3,250 K
Color Rendering Index (CRI)	>90
Color stability index	0.009
Lifetime L50	10,000h
Dimming	AM and PWM dimming possible

AREA source of light - PRODUCTS

Panasonic Idemitsu OLED Lighting Co. Ltd. (PIOL)

Specifications of the OLED Lighting Panel and OLED Lighting Module

Product Name	OLED Lighting Panel			OLED Lighting Module		
Color Temperature	5000K Daylight White	4000K Natural White	3000K Bulb color	5000K Daylight White	4000K Natural White	3000K Bulb color
Luminance	2600 cd/m²	2800 cd/m²	3000 cd/m²	2520 cd/m²	2700 cd/m²	3000 cd/m²
Luminous efficiency	27 lm/W	26 lm/W	30 lm/W	17lm/W		
Dimensions (mm)	97 (L) x 90 (W) x 2.11 (H) (light emitting area: 80 x 80)			102 (L) x 95 (W) x 8.9 (H) (light emitting area: 80 x 80)		
Weight	38g			98g		
Color rendering	CRI>90					
Duration	10,000 hours (LT70)					
Dimming control range	-			3 to 100%		
Launch date	July 20, 2012		On sale	Mid-August, 2012		On sale

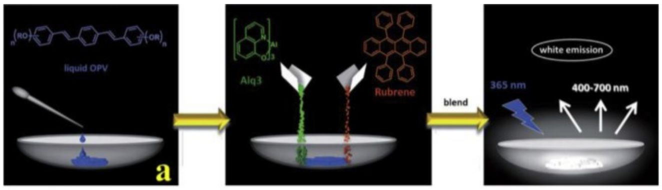
Mercury and UV-free

WHITE EMITTING LIQUID INKS

Blend 1:1.65:0.23

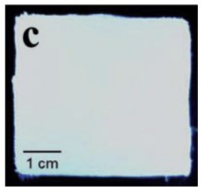
Synthesis of OPV with branched aliphatic hydrocarbon substituents to induce lower viscosity.

OPV acts as a suspension matrix for other fluorophores



CIE = (0.33, 0.34) in the solvent-free state

Text written on paper with a composite ink in a rollerball pen.



5x5 cm^2 area coated using a brush.

All exposed under UV light (365 nm).

Babu SS, Aimi J, Ozawa H, Shirahata N, Saeki A, Seki S, et al. Solvent-free luminescent organic liquids. Angew Chem Int Ed 2012;51:3391e5.

More on WOLED in the next talk by TCI