OLEDs, PLEDs, QLEDs Perovoleds and RELEDs

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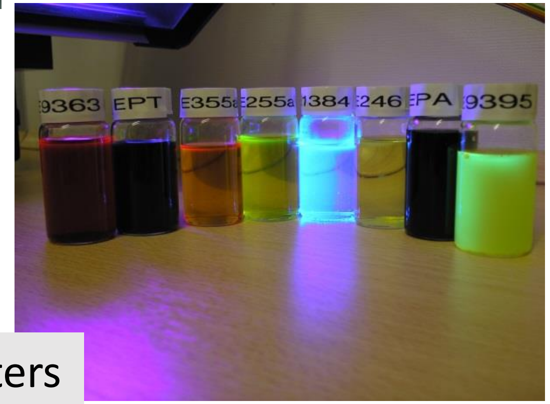
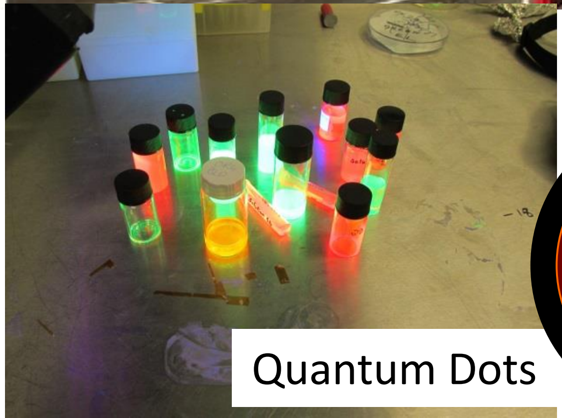
OLED Emitters





Quantum Dots

Topics

1. Background
2. OLEDs
3. Quantum Dots for Rec 2020
4. High Triplet Energy Hole Transporters and Electron Transporters

Our Recent Work

http://youtu.be/D0WV1R9RfI0

http://youtu.be/Ws76e-AAApI

http://youtu.be/SKIsnei0k4A

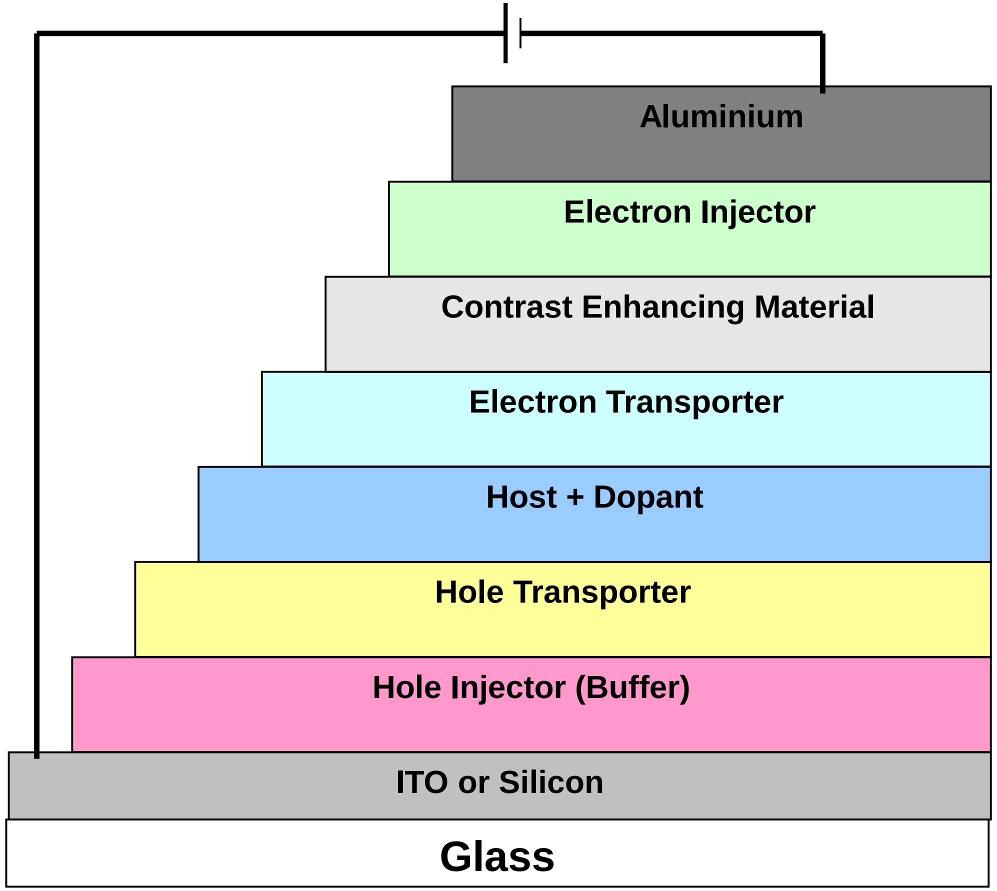
http://youtu.be/p4aDAkC61Wk

http://youtu.be/RgoMnroRnhc

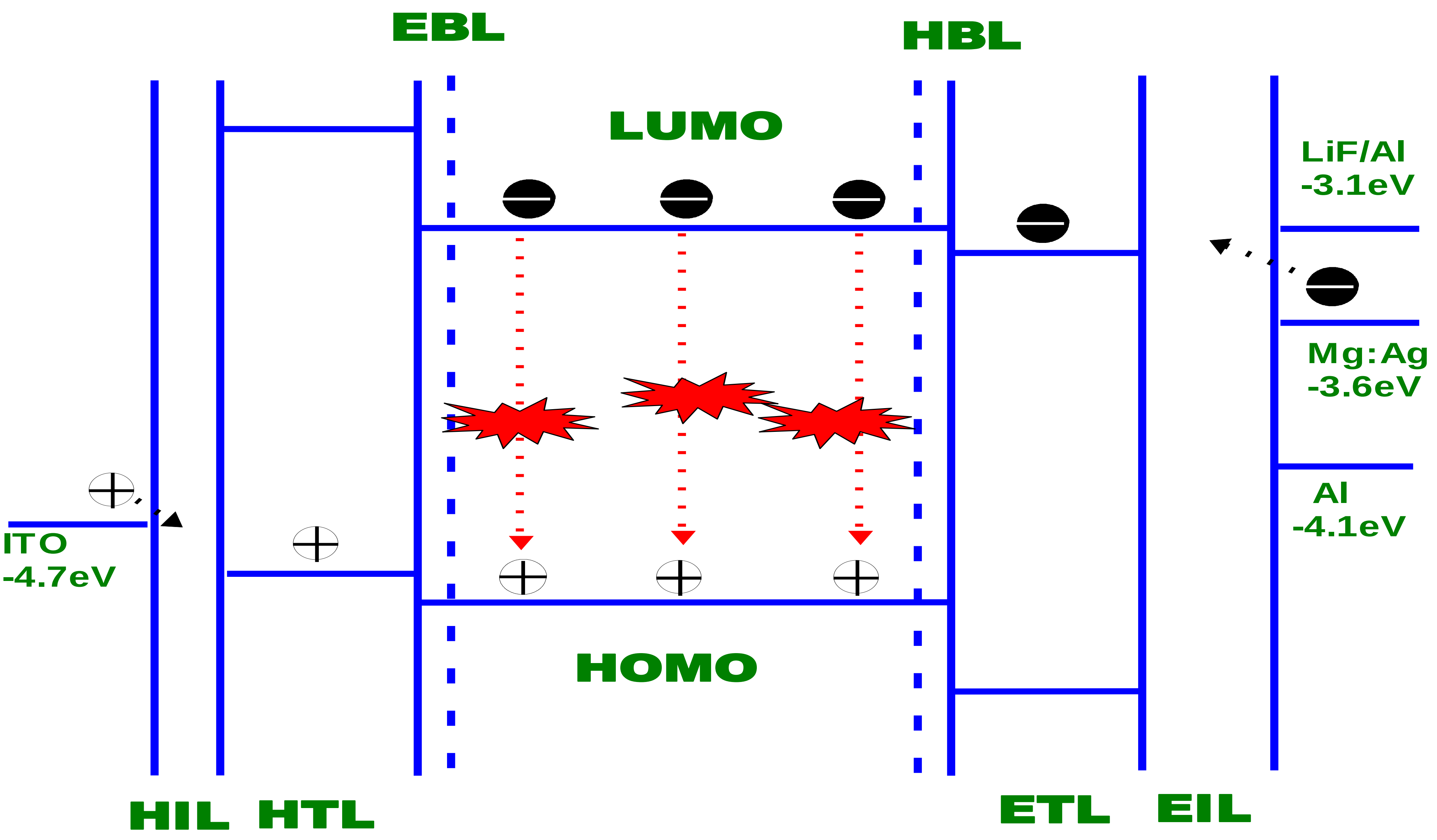
http://youtu.be/HGHg-f74NAA

http://youtu.be/UWKoJjViOUg

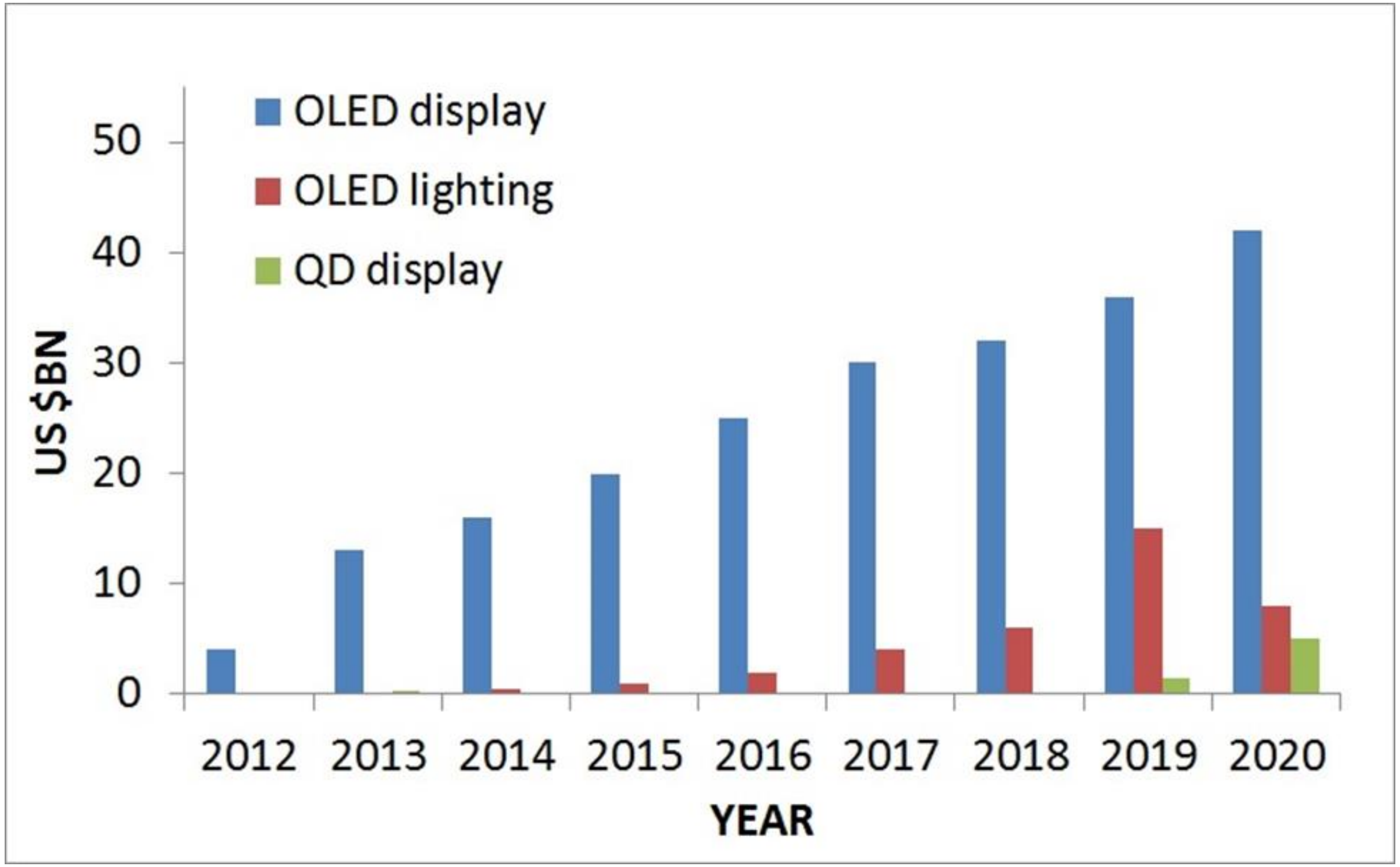
http://youtu.be/QC-nUMkMOFc



Over the last 10 years, we made over 2500+ ETL, 400+ EIL, 100+ Li Complexes, 600+ emitters, 100+ hole transporters and 9000 OLED test panels (100 mm x 100 mm).



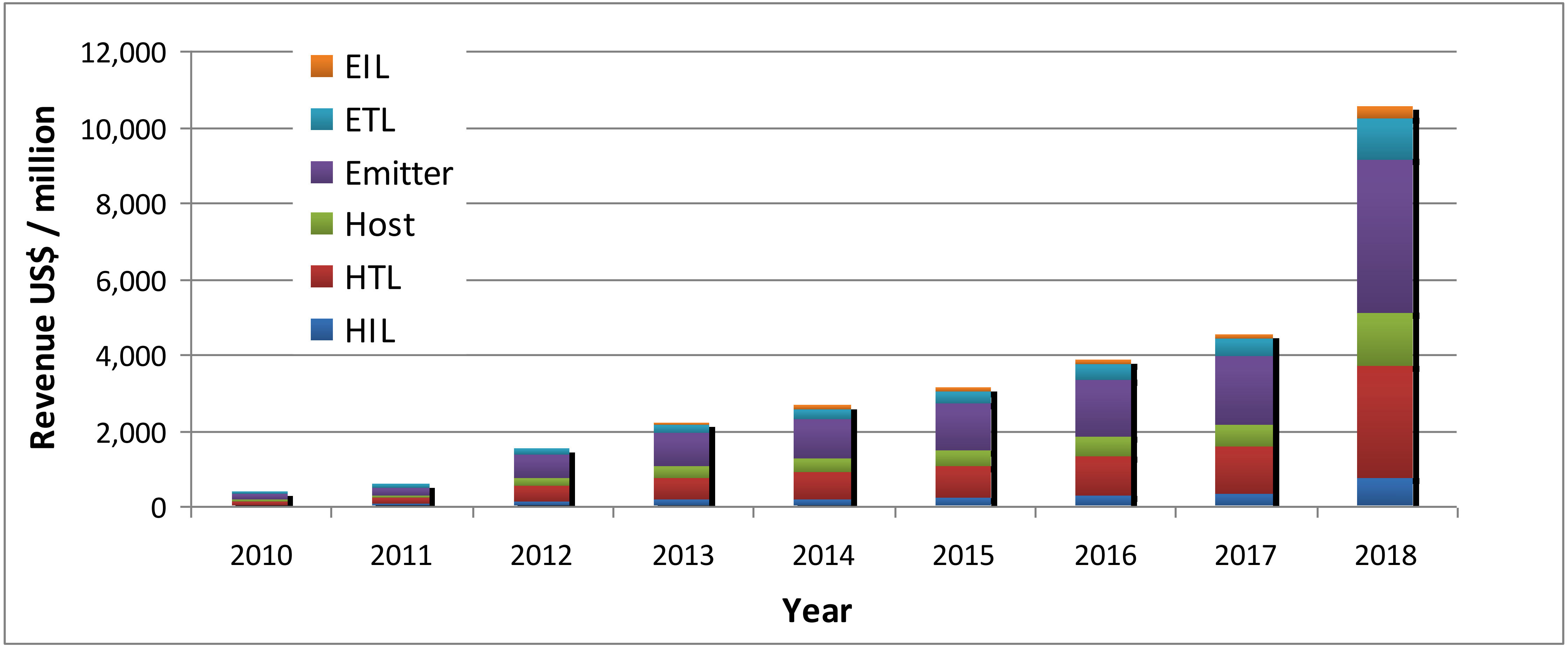
EBL
HBL
LUMO
LiF/Al
-3.1eV
Mg:Ag
-3.6eV
Al
-4.1eV
ITO
-4.7eV
HOMO
HIL
HTL
ETL
EIL

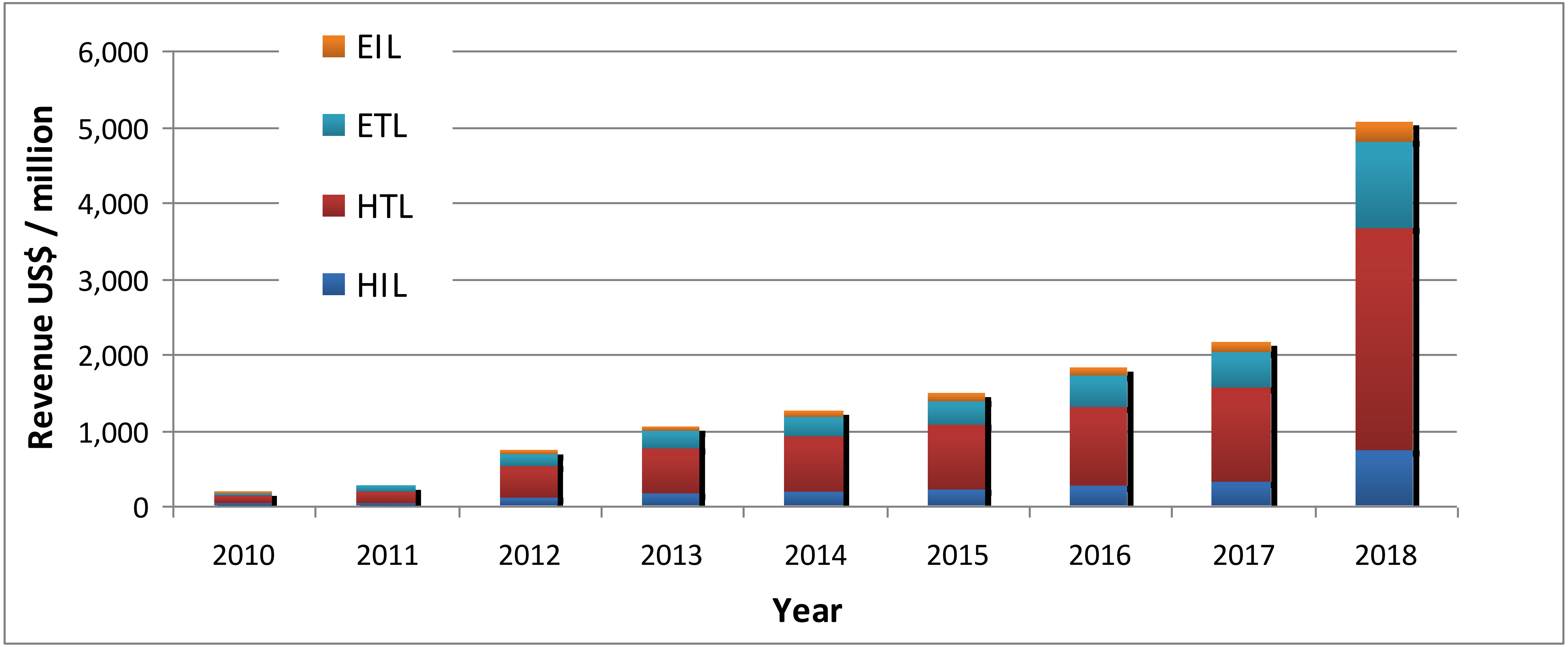


OLED display
OLED lighting
QD display
US $BN
50
40
30
20
10
0
2012
2013
2014
2015
2016
2017
2018
2019
2020
YEAR

IDtechEX

Market: Oled Materials





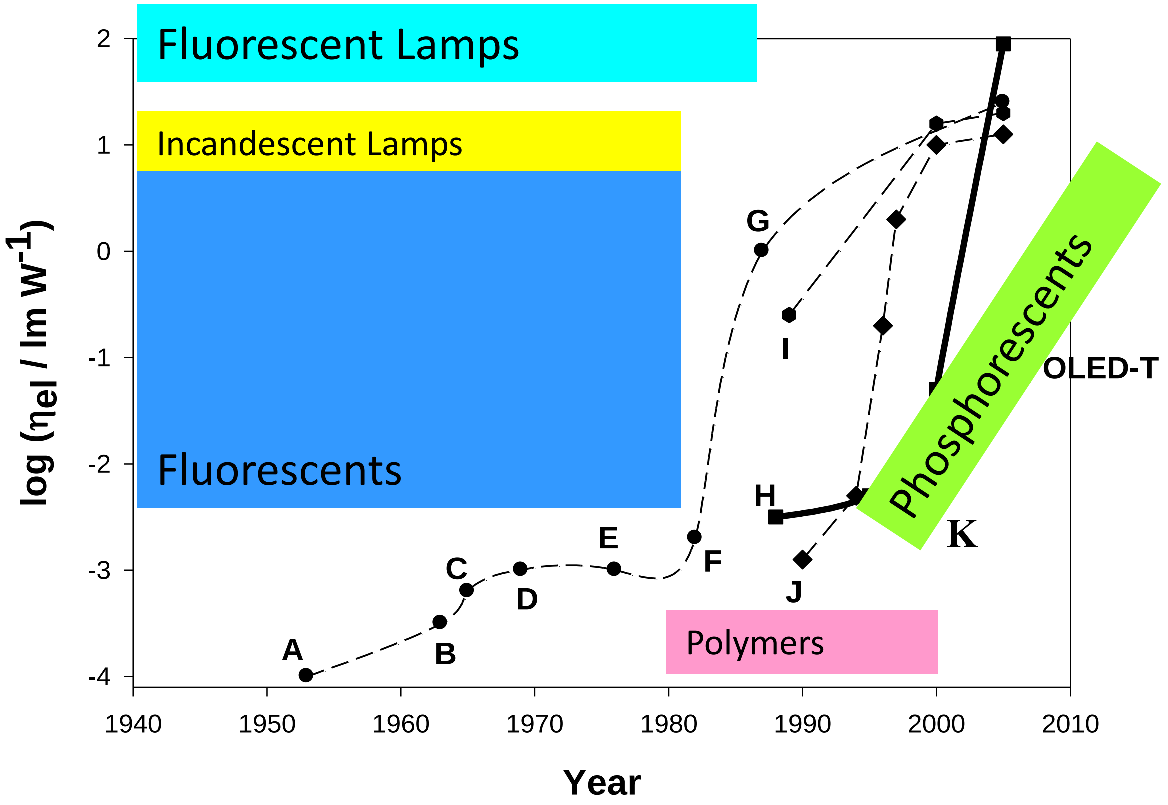
6,000
5,000
4,000
3,000
2,000
1,000
0
Revenue US$ / million
EIL
ETL
HTL
HIL
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year

Current Market

- ALUMINIUM
- ELECTRON INJECTOR*
- CONTRAST ENHANCING MATERIAL
- ELECTRON TRANSPORTER*
- HOST & DOPANT
- HOLE TRANSPORTER*
- HOLE INJECTOR (BUFFER)
- ITO / SILICON

GLASS / PLASTIC

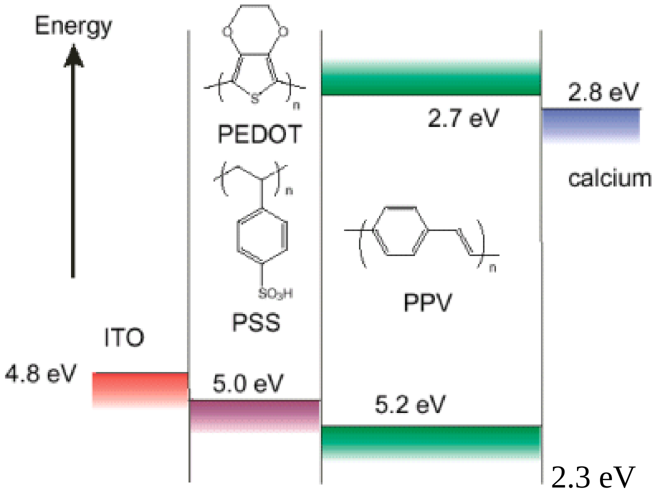
Organic Electroluminescence



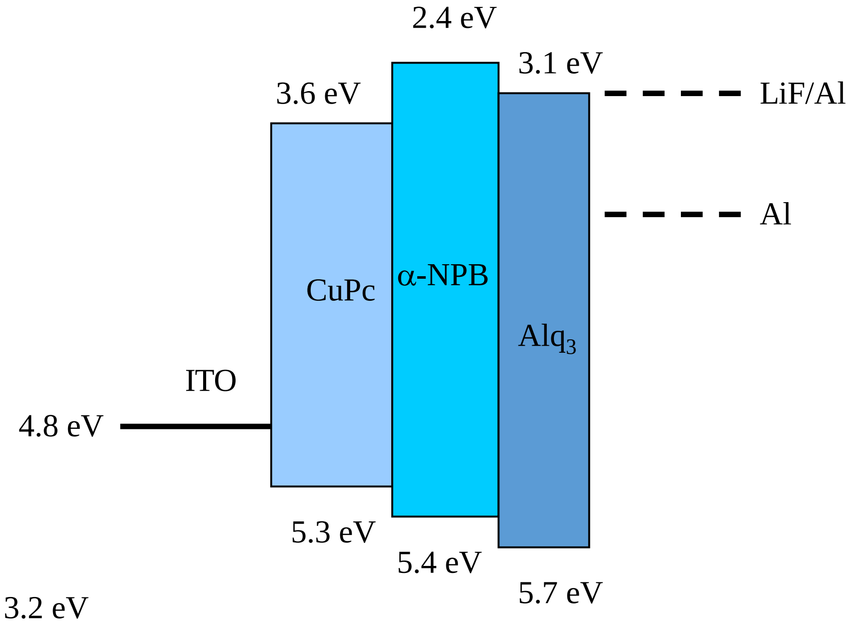
A: A. Barnose *et al.*
B: M. Pope *et al.*
C: Helfrich *et al.*
D: J. Dresner *et al.*
E: R. Partridge *et al.*
F: P. S. Vincentt *et al.*
G: C. W. Tang *et al.*
H: C. Hosokawa *et al.*
I: P. Kathirgamanathan *et al.*
J: J. H. Burrough *et al.*

K: Princeton Univ., UDC, Novaled and Kathirgamanathan et al..

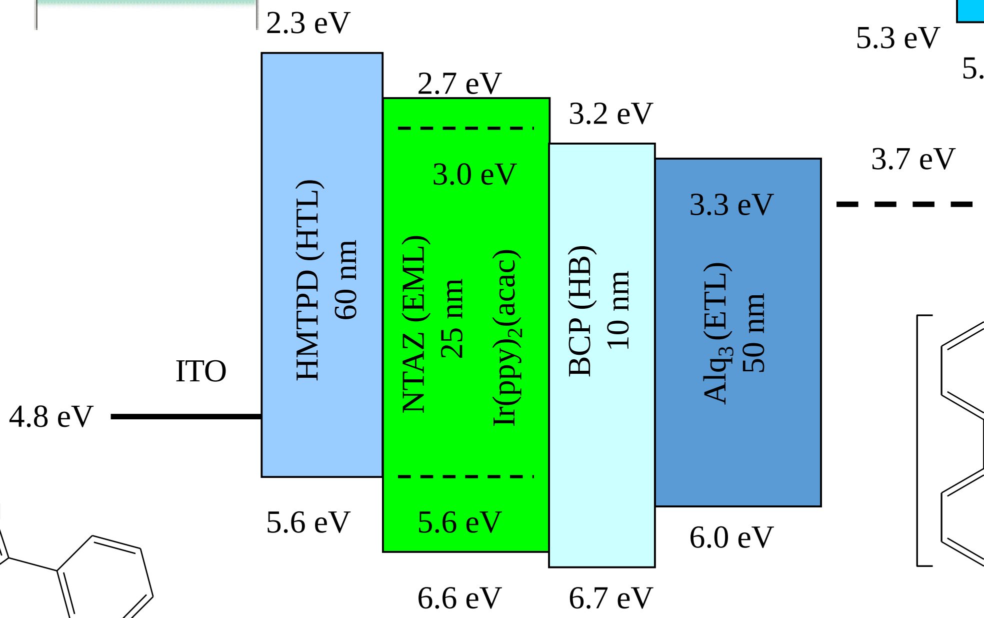
PLED Configuration

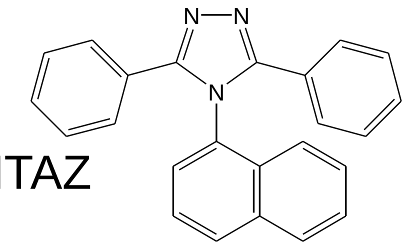


Small Molecules OLED Configuration

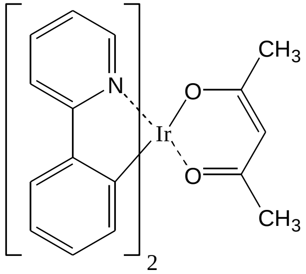


1988



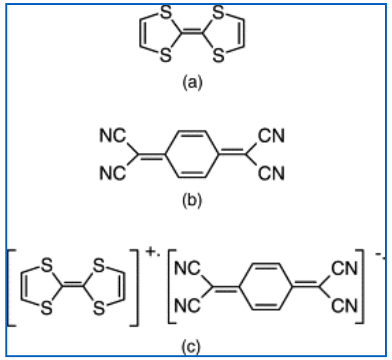


NTAZ

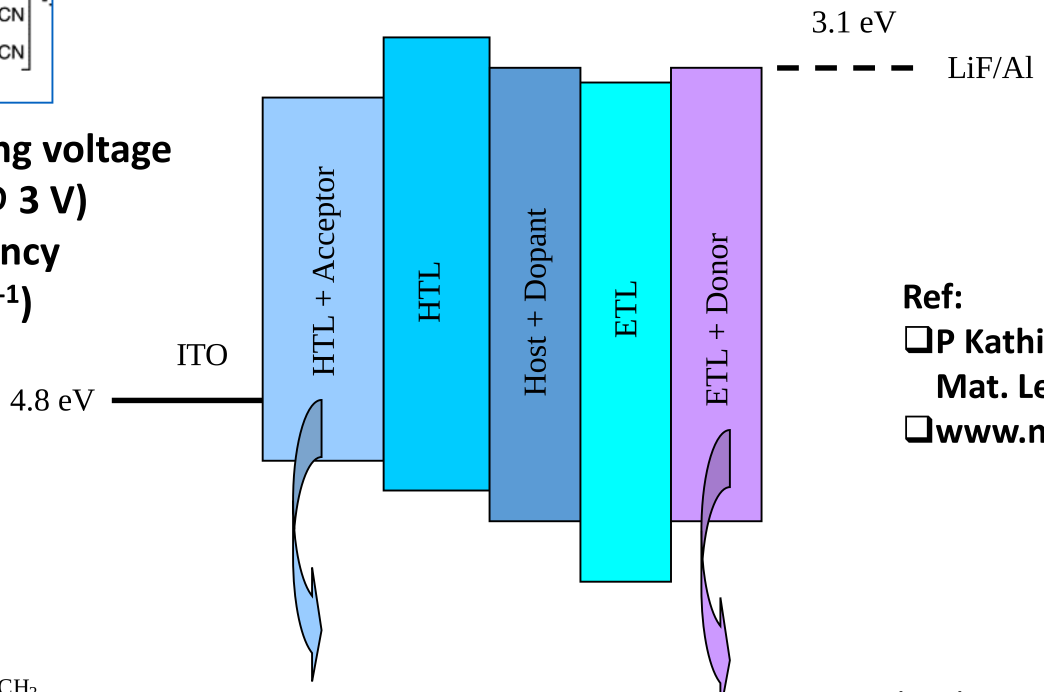


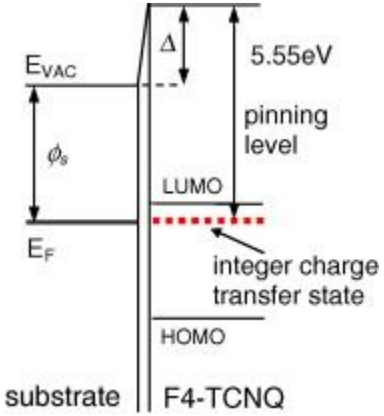
Ir(ppy)2(acac)

Doped HTL and ETL



- ➢To reduce operating voltage (1000 cd m^{-2} @ 3 V)
- ➢To enhance efficiency (over 100 cd A^{-1})

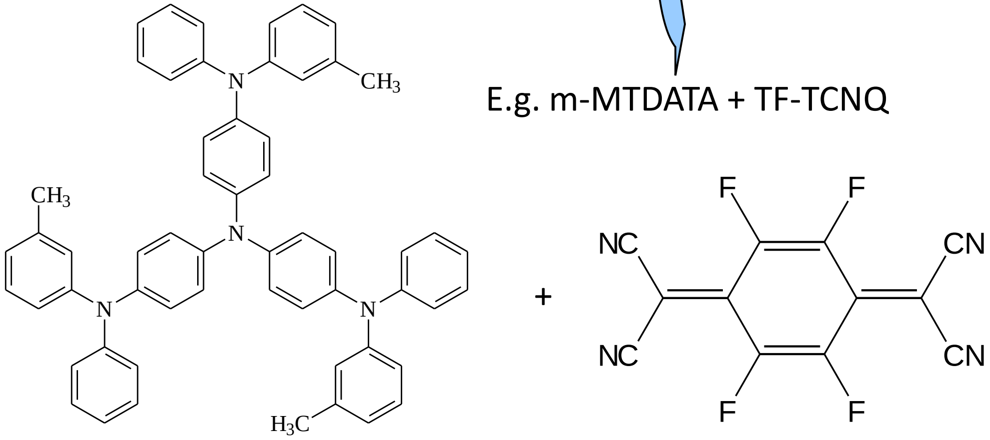




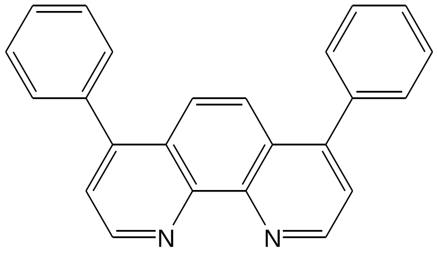
Ref:

- ❑P Kathirgamanathan et al., Mat. Lett., 6, 40 (1999)
- ❑www.novaled.com

E.g. m-MTDATA + TF-TCNQ

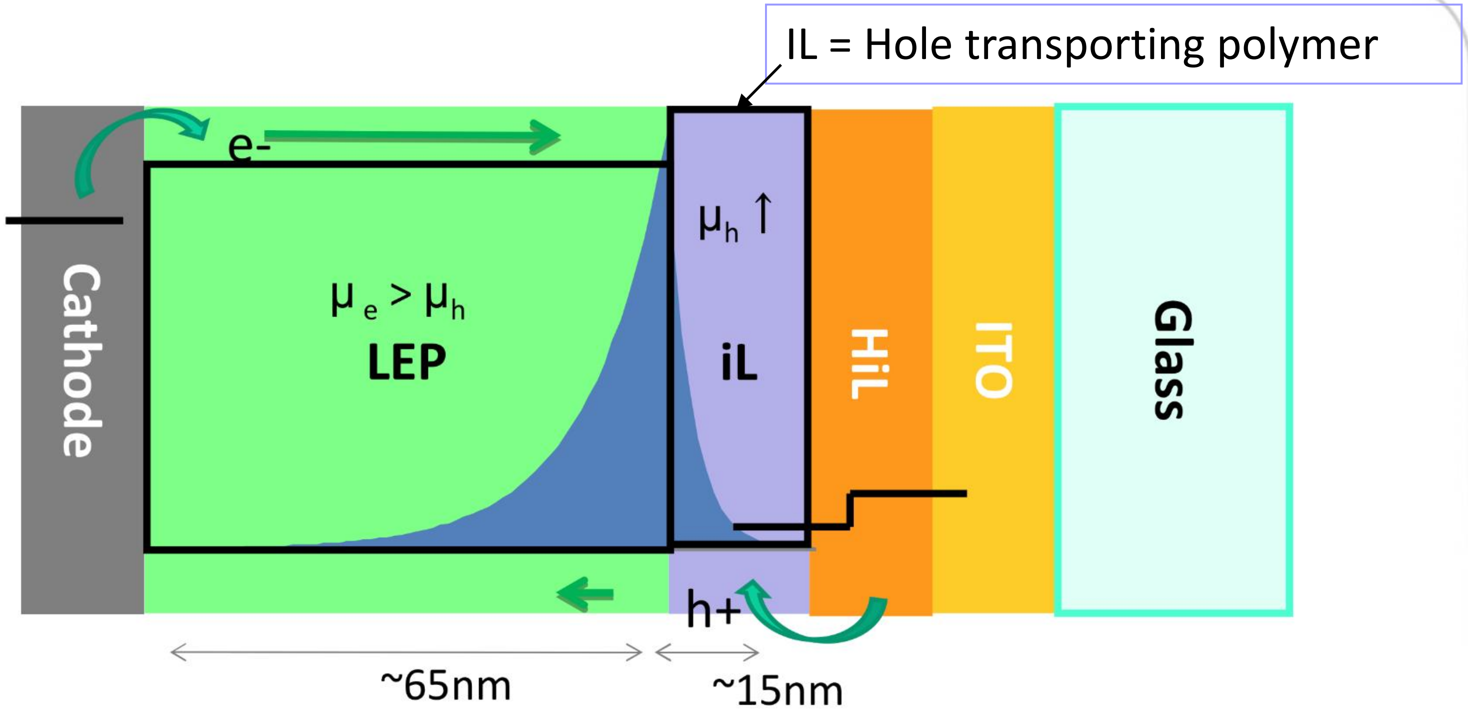


E.g. Bathophen + Li

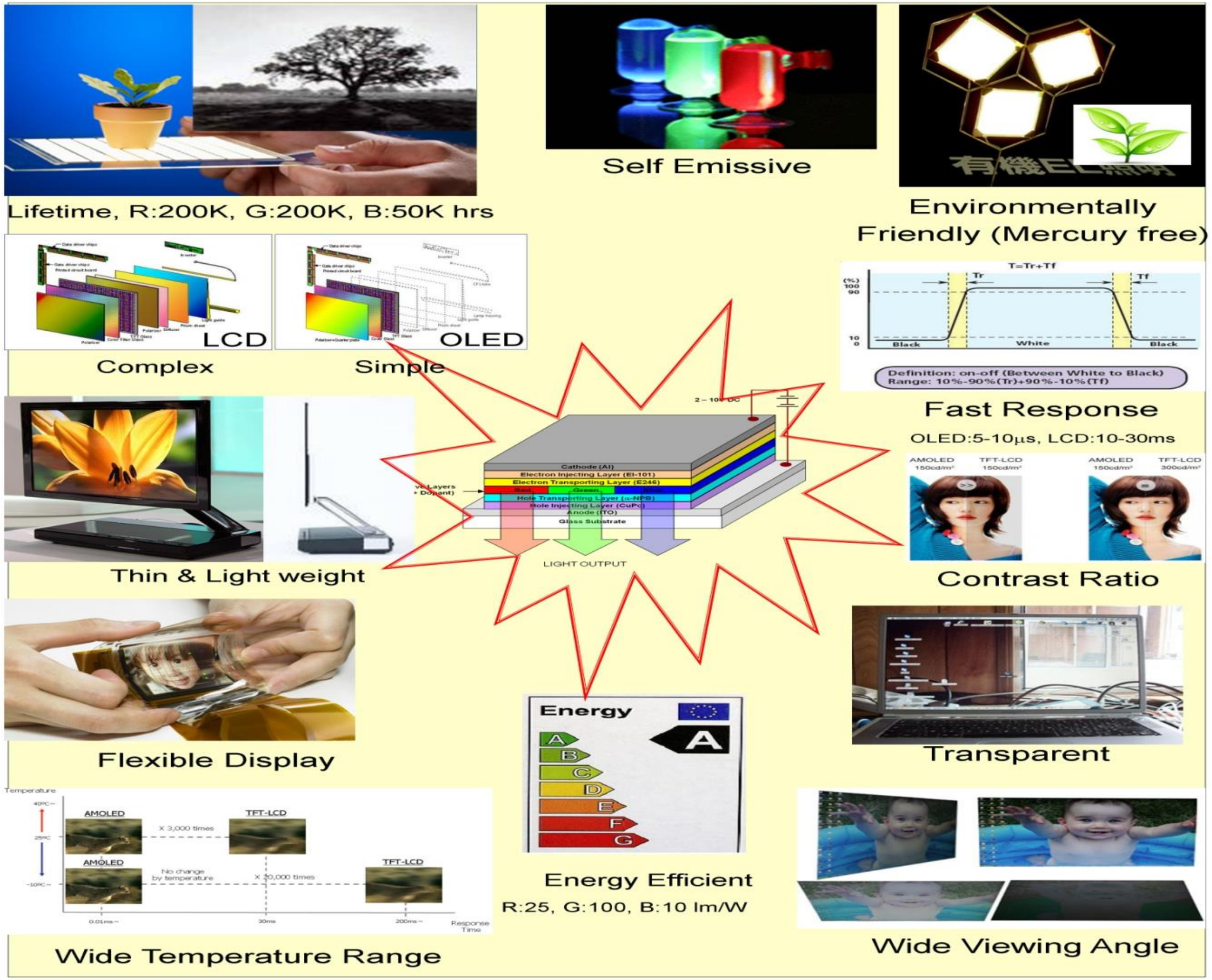


Device structure of Polymer-OLED (PLED)

CDT



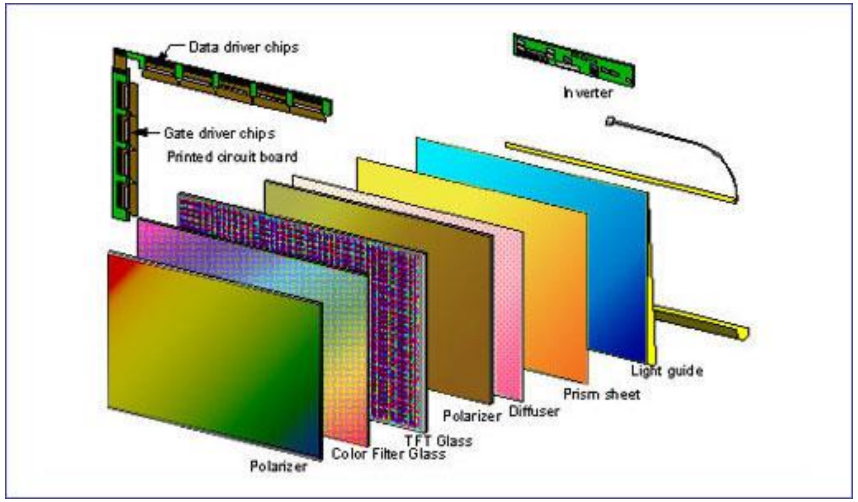
1. LEP thickness and carrier mobilities → Optimum RZ and outcoupling
2. Introduction of iL → Hole injection, efficiency and lifetime
3. HIL and ITO thicknesses → Colour and outcoupling
4. Electrodes / charge injection layers → Stable electron/hole injection

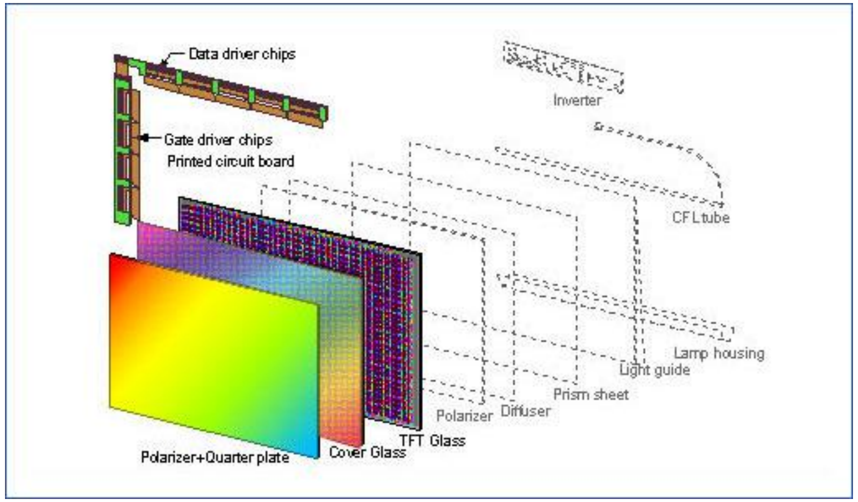


Lifetime, R:200K, G:200K, B:50K hrs
Self Emissive
Environmentally Friendly (Mercury free)
LCD
OLED
Complex
Simple
T=Tr+Tf
Tr
Tf
Black
White
Black
Definition: on-off (Between White to Black)
Range: 10%-90%(Tr)+90%-10%(Tf)
Fast Response
OLED:5-10μs, LCD:10-30ms
Cathode (Al)
Electron Injecting Layer (EI-101)
Electron Transporting Layer (E246)
Hole Transporting Layer (α-NPB)
Hole Injecting Layer (CuPc)
Anode (ITO)
Glass Substrate
LIGHT OUTPUT
Thin & Light weight
AMOLED
TFT-LCD
Contrast Ratio
Flexible Display
Energy
A
B
C
D
E
F
G
Transparent
AMOLED
TFT-LCD
X 3,000 times
No change by temperature
Response Time
Wide Temperature Range
Energy Efficient
R:25, G:100, B:10 lm/W
Wide Viewing Angle

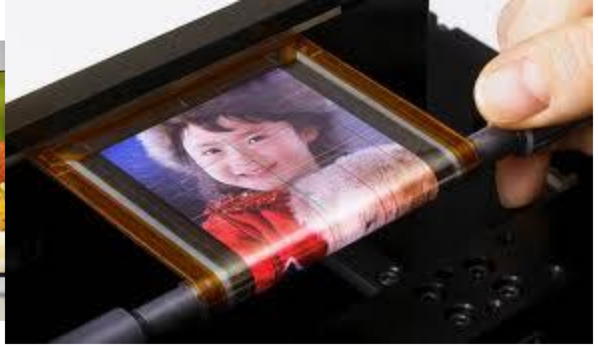
LCD’s vs. OLED’s

The Complexity of LCD’s vs. The Simplicity of OLED’s





Pioneer's first OLED Display
(Car Radio)



CRT

LCD

OLED TV

1930-2000

1970-?

2010-?

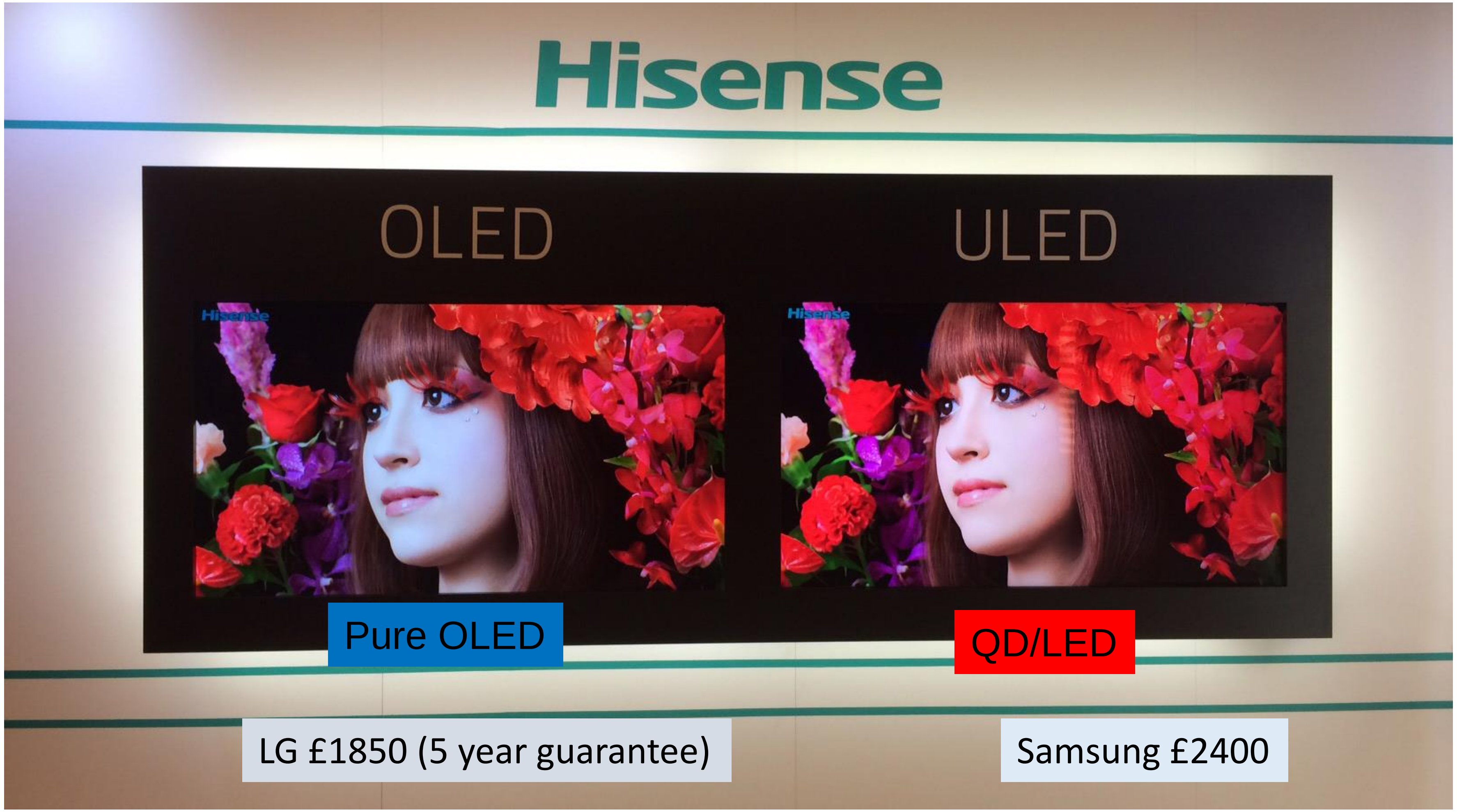

LG OLED TV UHD
올레드
자연색 그대로 볼 수 있는 차원이 다른 단 하나의 TV

IMID 2015


Curved


Brillare

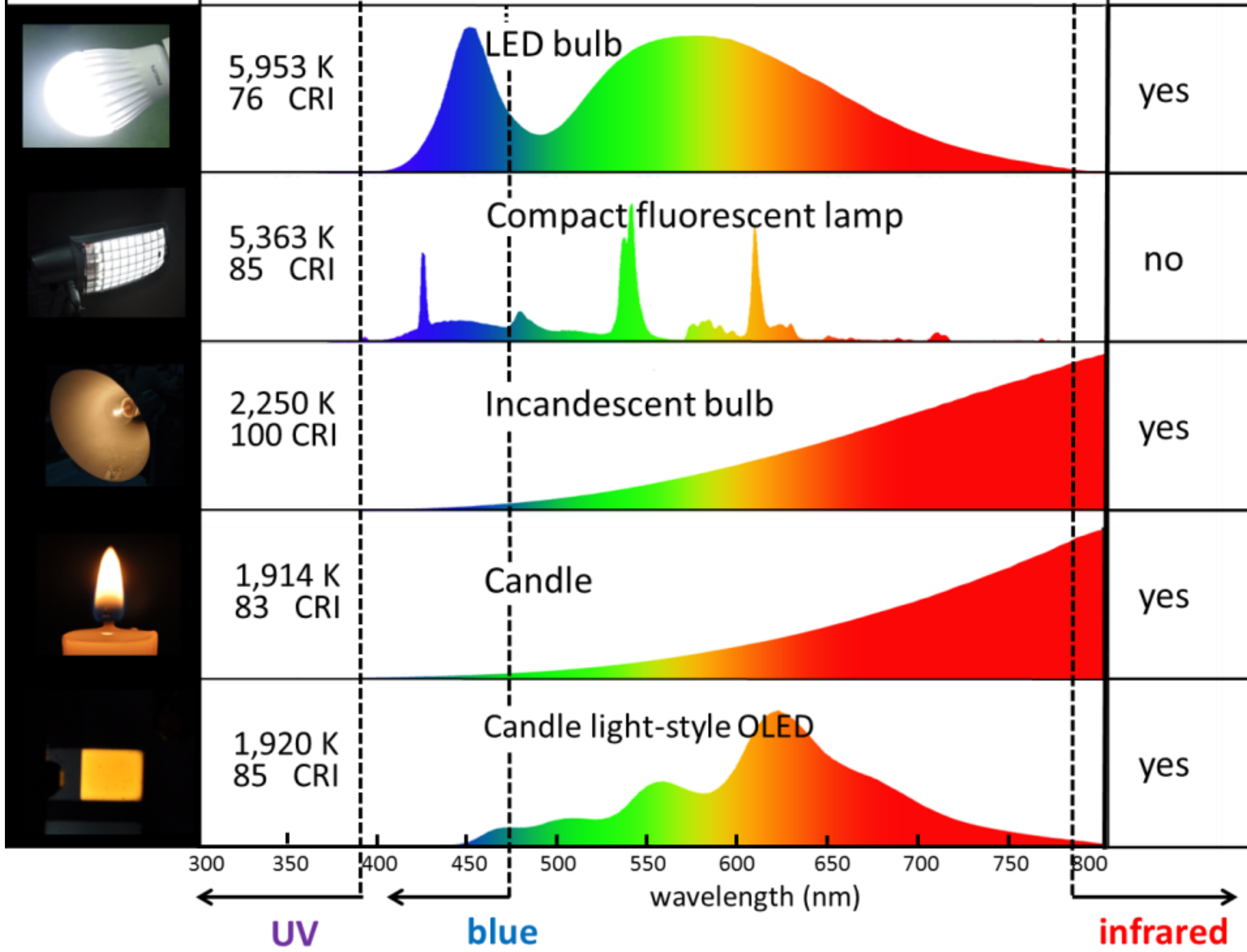

주식회사 영풍씨엠씨
YOUNG POONG CMC CO., LTD.
Brillare gioiello
55” Transparent Display
SAMSUNG
SAMSUNG DISPLAY


Hisense
OLED
ULED
Pure OLED
QD/LED
LG £1850 (5 year guarantee)
Samsung £2400

Konica Minolta, 15, 000 flexible OLEDs, TULIP Festival

Konica Minolta’s OLED Lit Signage.

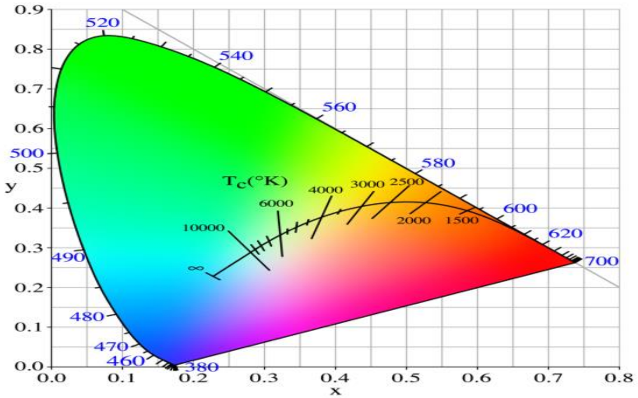
Spectral Output

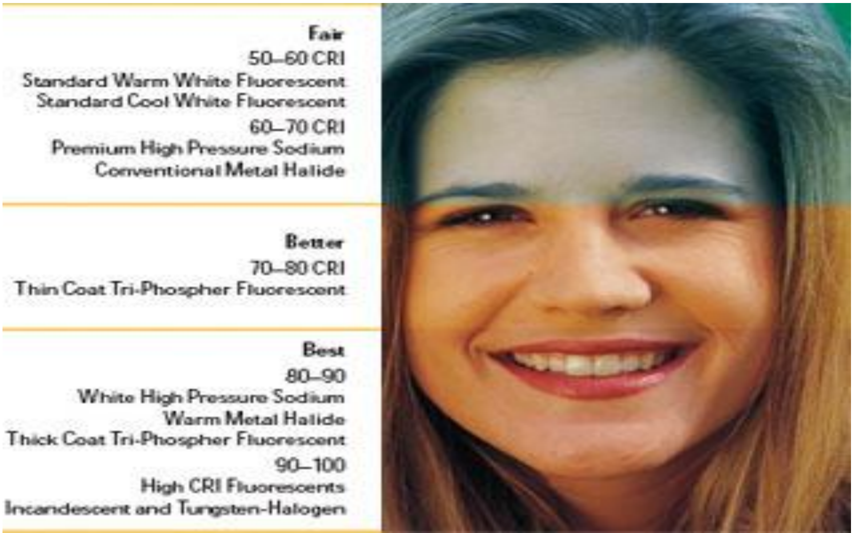


Light source	Spectrum	Free of: Hg	Flicker-ing	Glare	UV	IR
LED bulb	5,953 K, 76 CRI	yes	yes	no	no	yes
Compact fluorescent lamp	5,363 K, 85 CRI	no	no	no	no	yes
Incandescent bulb	2,250 K, 100 CRI	yes	yes	no	yes	no
Candle	1,914 K, 83 CRI	yes	no	no	yes	no
Candle light-style OLED	1,920 K, 85 CRI	yes	yes	yes	yes	yes

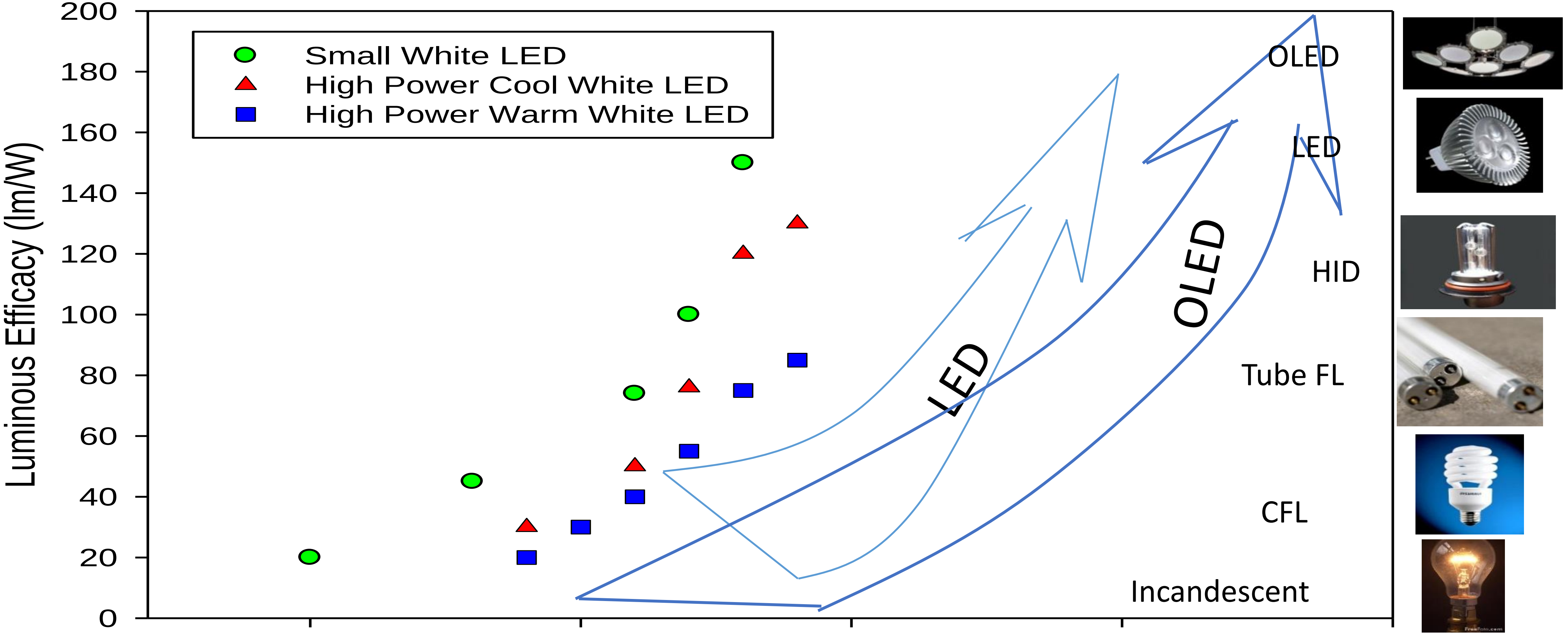
J.-H. Jou et al., **Advanced Functional Materials, 23(21),** pages 2750–7, June 6, 2013

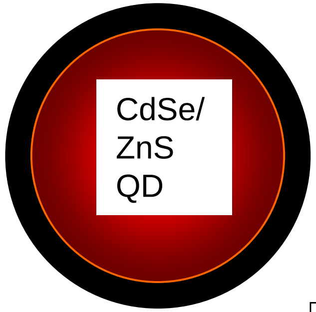
Parameter	Incandescent	CFL	Inorganic LED	OLED
				
Efficiency/ lm W^{-1}	8-15	50-80	30-100	40-100
CRI	100	70-80	40-85	85-90
Lifetime/hours	800	10000-20000	15000-60000	20000
Consumption Cost	High	Low	Low	Low
Environmental Impact	Bad	Bad Hg, UV, Poor CRI	Point Source	Good Planar/ Diffuse

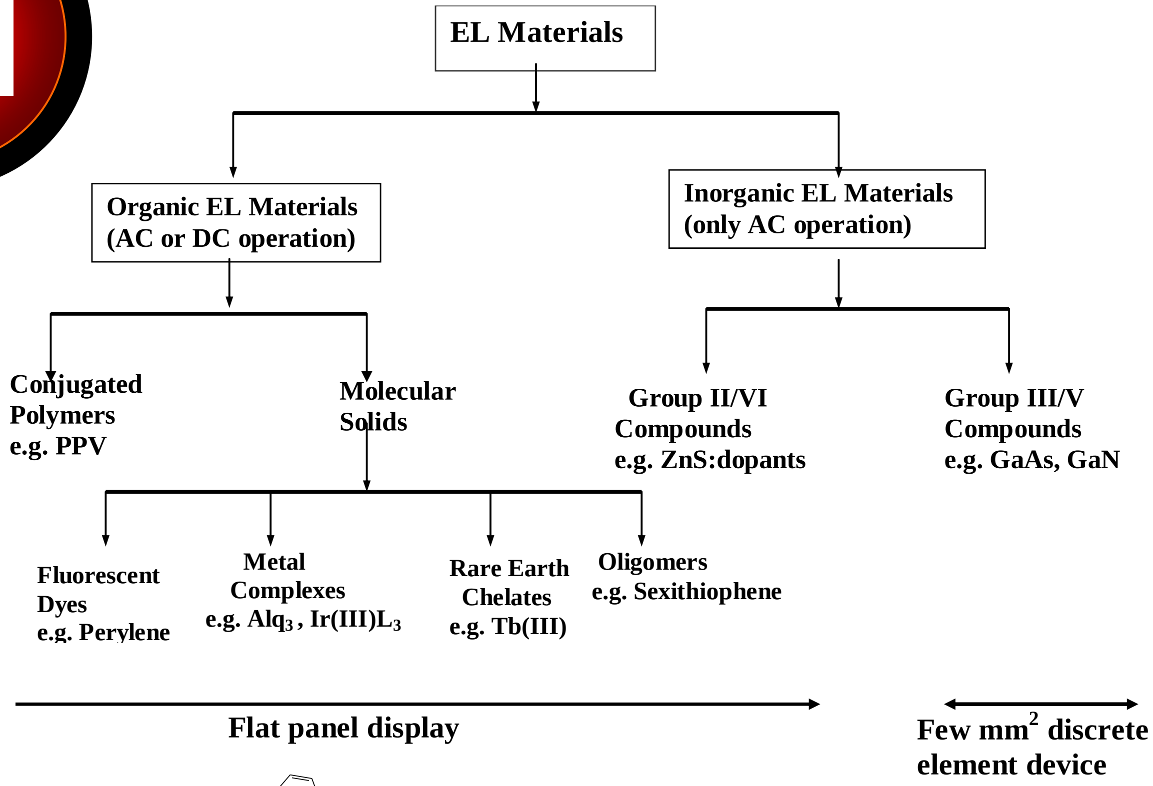


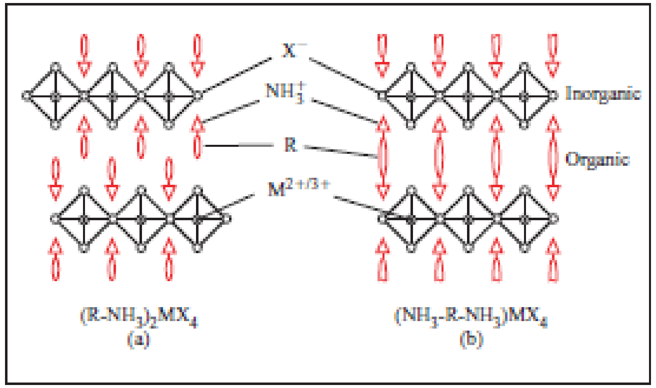


Efficiency : LED's vs. OLEDs



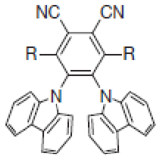




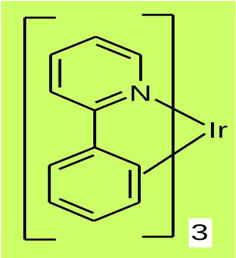


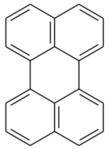
Perovskites

TADF

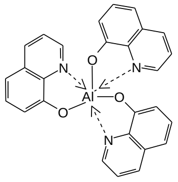


4CzPN: R = carbazolyl
2CzPN: R = H

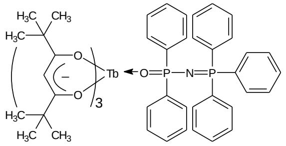




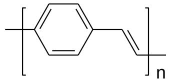
(a) Perylene



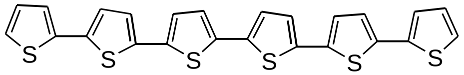
(b) Metal chelate



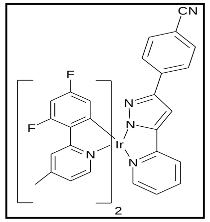
(c) Rare earth chelate



(e) Polymer



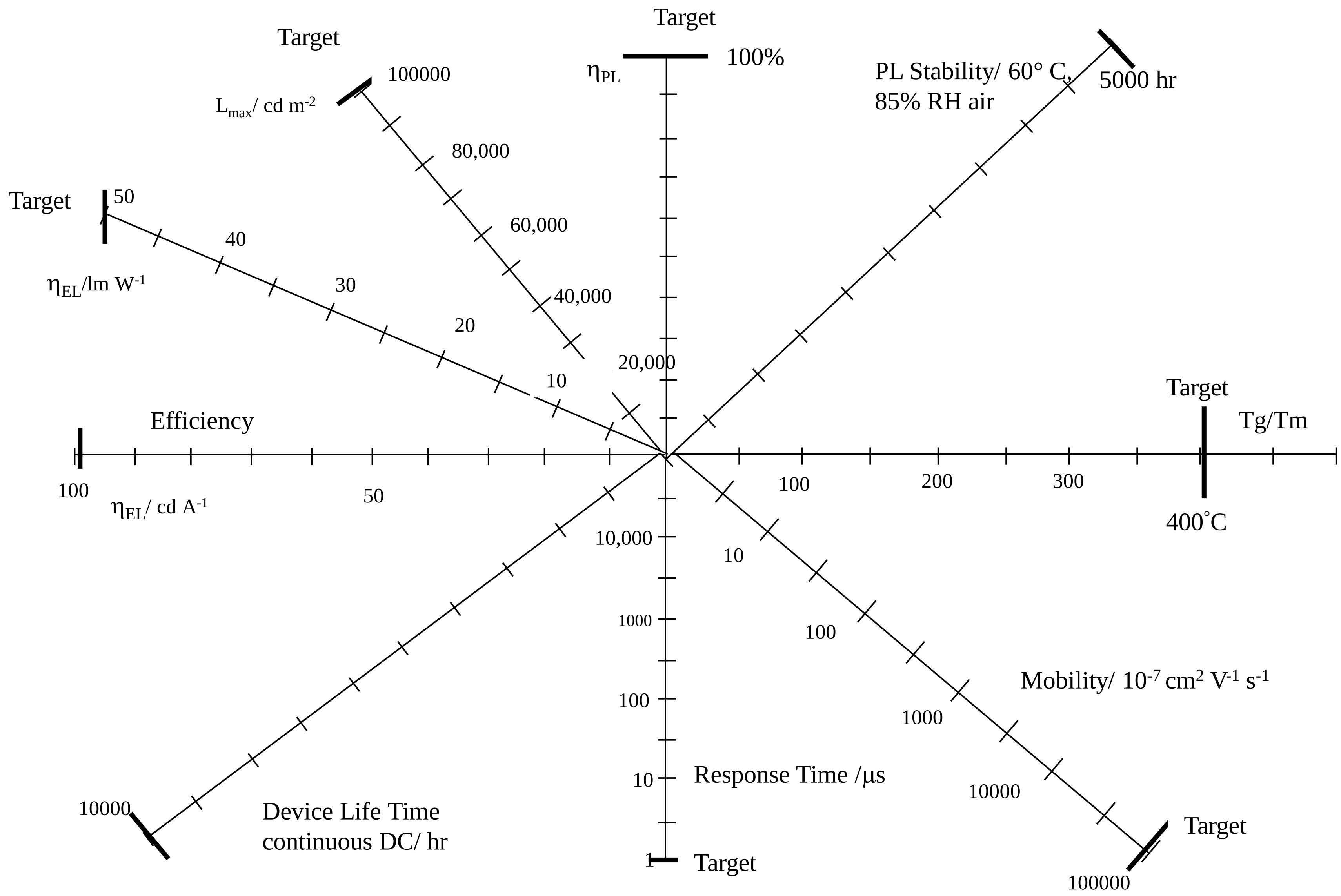
(e) Sexithiophene



Small Molecules

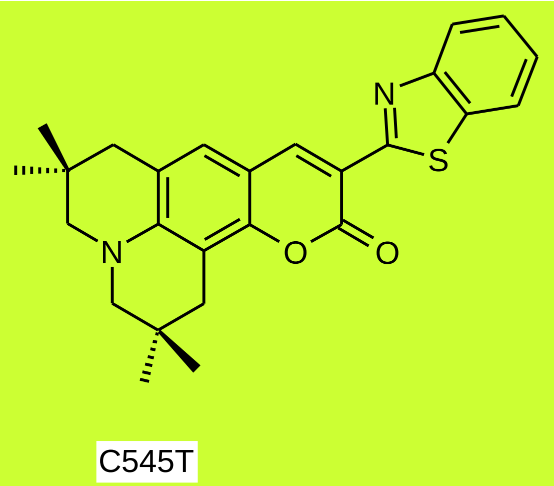
Polymer

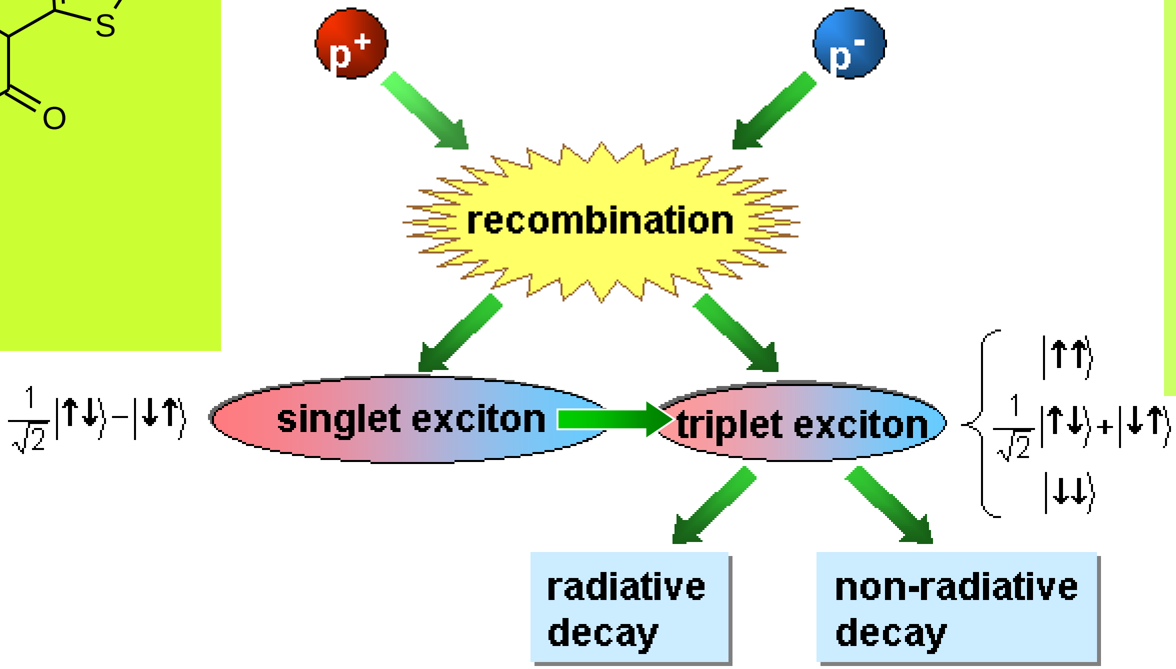
Oligomers

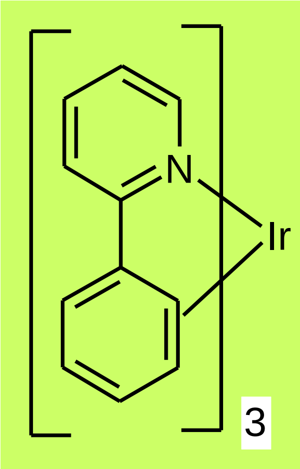


Target
Target
100%
η_{PL}
100000
L_{max}/ cd m^{-2}
PL Stability/ 60° C,
85% RH air
5000 hr
80,000
Target
50
40
60,000
η_{EL}/lm W^{-1}
30
40,000
20
20,000
10
Target
Tg/Tm
Efficiency
100
200
300
100
50
η_{EL}/ cd A^{-1}
400˚C
10,000
10
1000
100
Mobility/ 10^{-7} cm^2 V^{-1} s^{-1}
100
1000
10
Response Time /µs
10000
10000
Device Life Time
continuous DC/ hr
Target
1
Target
100000

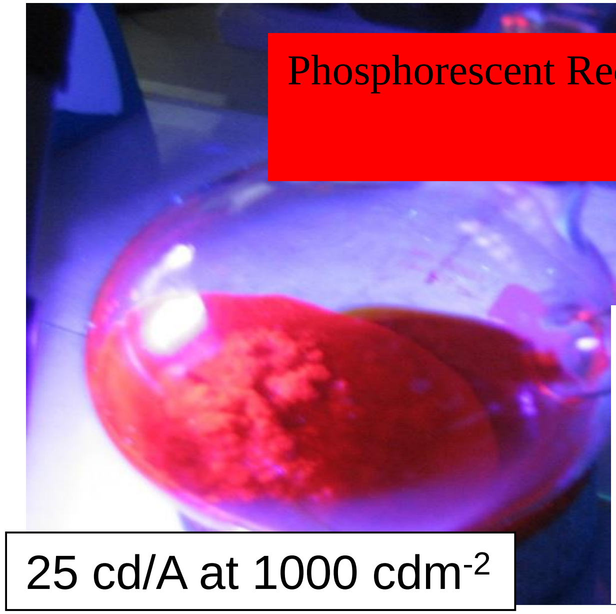
Fluorescent vs. Phosphorescent Emitters



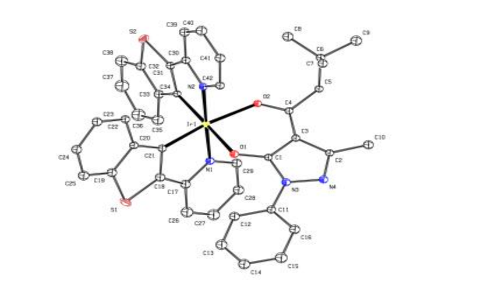




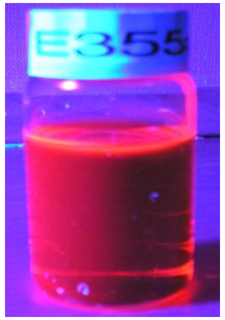
- Complete conversion of singlets to triplets
- Potential for 100% internal efficiency in OLEDs

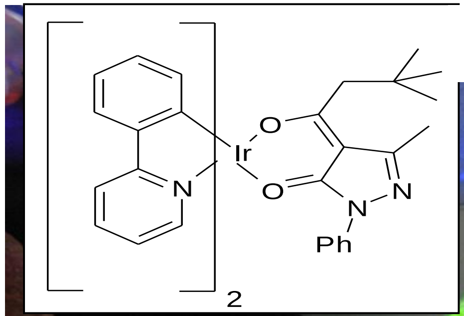


Phosphorescent Red (30g)

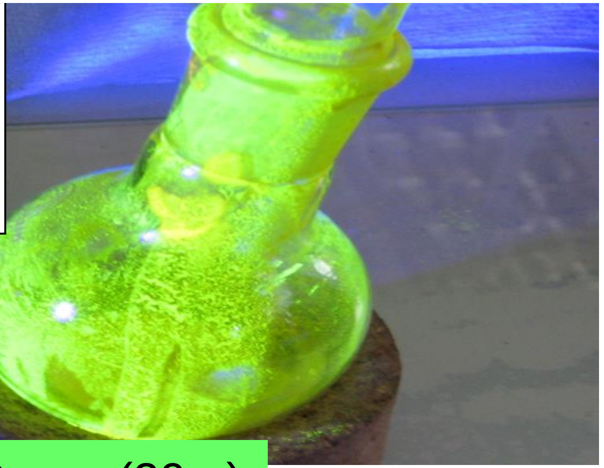


25 cd/A at 1000 cdm^{-2}

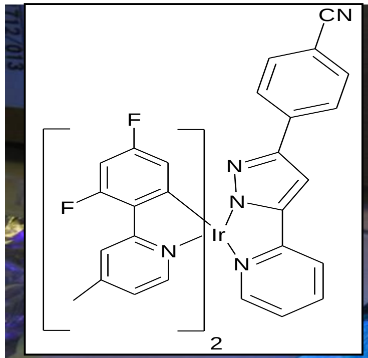




50 cd/A at 1000 cdm^{-2}



Phosphorescent Green (20 g)



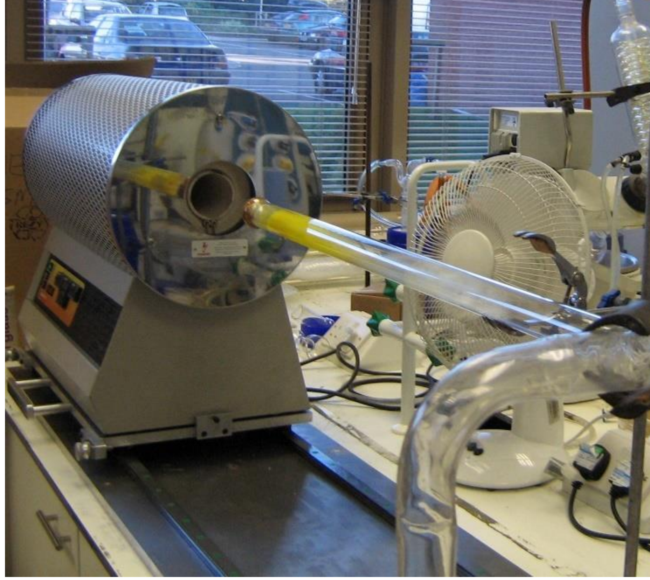
Phosphorescent Blue

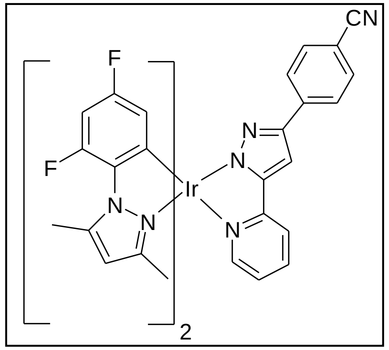
22 cd/A at 1000 cdm^{-2}

Purity Level: 99.98%

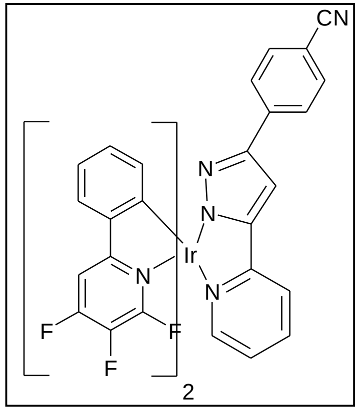
Solution Processable

Green Phosphorescent Materials

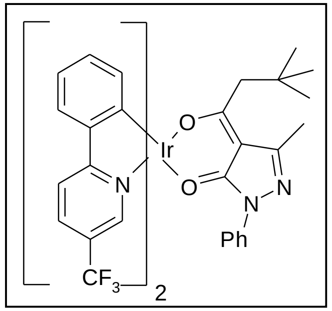




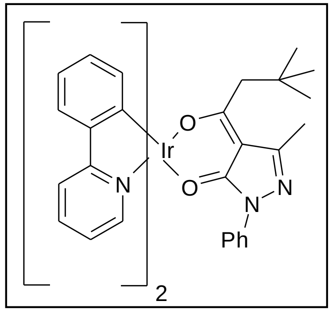
λ_{max} 502nm (DCM)



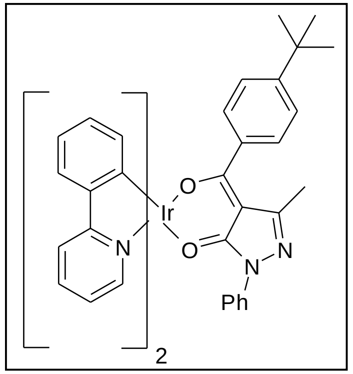
λ_{max} 509nm (DCM)



λ_{max} 520nm (DCM)



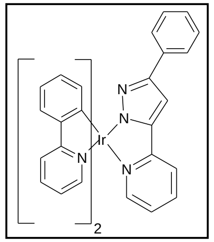
λ_{max} 526nm (DCM)



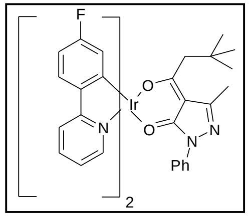
λ_{max} 528nm (DCM)

Ref: P. Kathirgamanathan, R.Price, S.Ganeshamurugan, G.Paramaswara, M.Kumaraverl, A.Partheepan, S.Selvaranjan, J.Antipan-Lara and S. Surendrakumar., Patent No: WO 2005/080526; Priority date: 14 February 2004

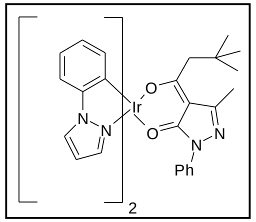
Blue Phosphorescent Materials



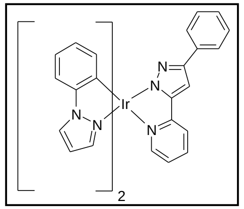
λ_{max} 495nm (DCM)



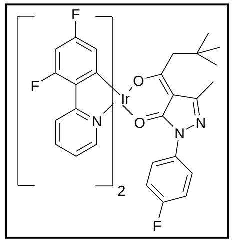
λ_{max} 493nm (DCM)



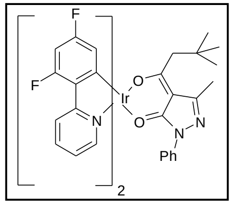
λ_{max} 485nm (DCM)



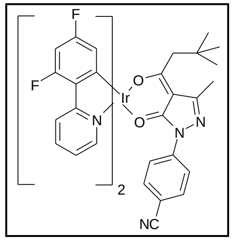
λ_{max} 485nm (DCM)



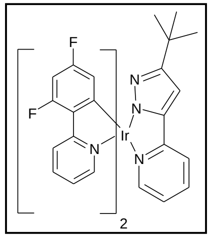
λ_{max} 484nm (DCM)



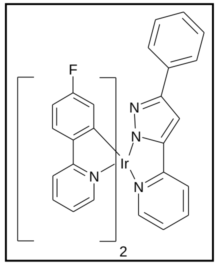
λ_{max} 483nm (DCM)



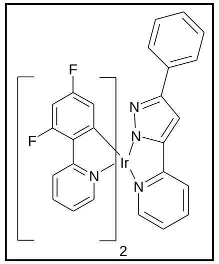
λ_{max} 480nm (DCM)



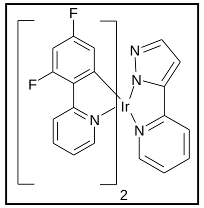
λ_{max} 479nm (DCM)



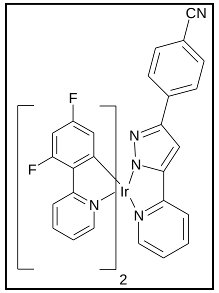
λ_{max} 477nm (DCM)



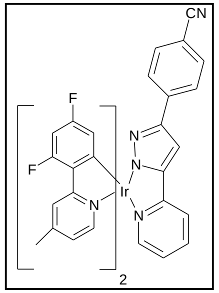
λ_{max} 470nm (DCM)



λ_{max} 469,493nm (DCM)



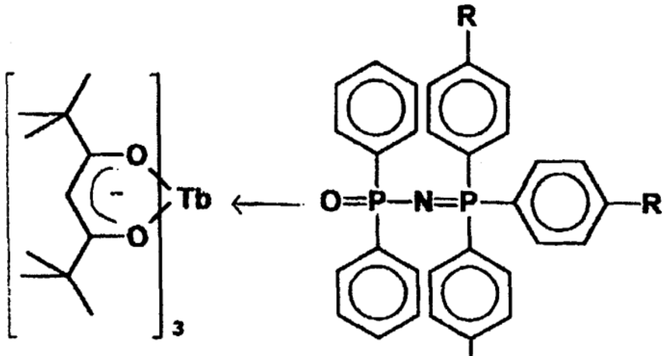
λ_{max} 468nm (DCM)



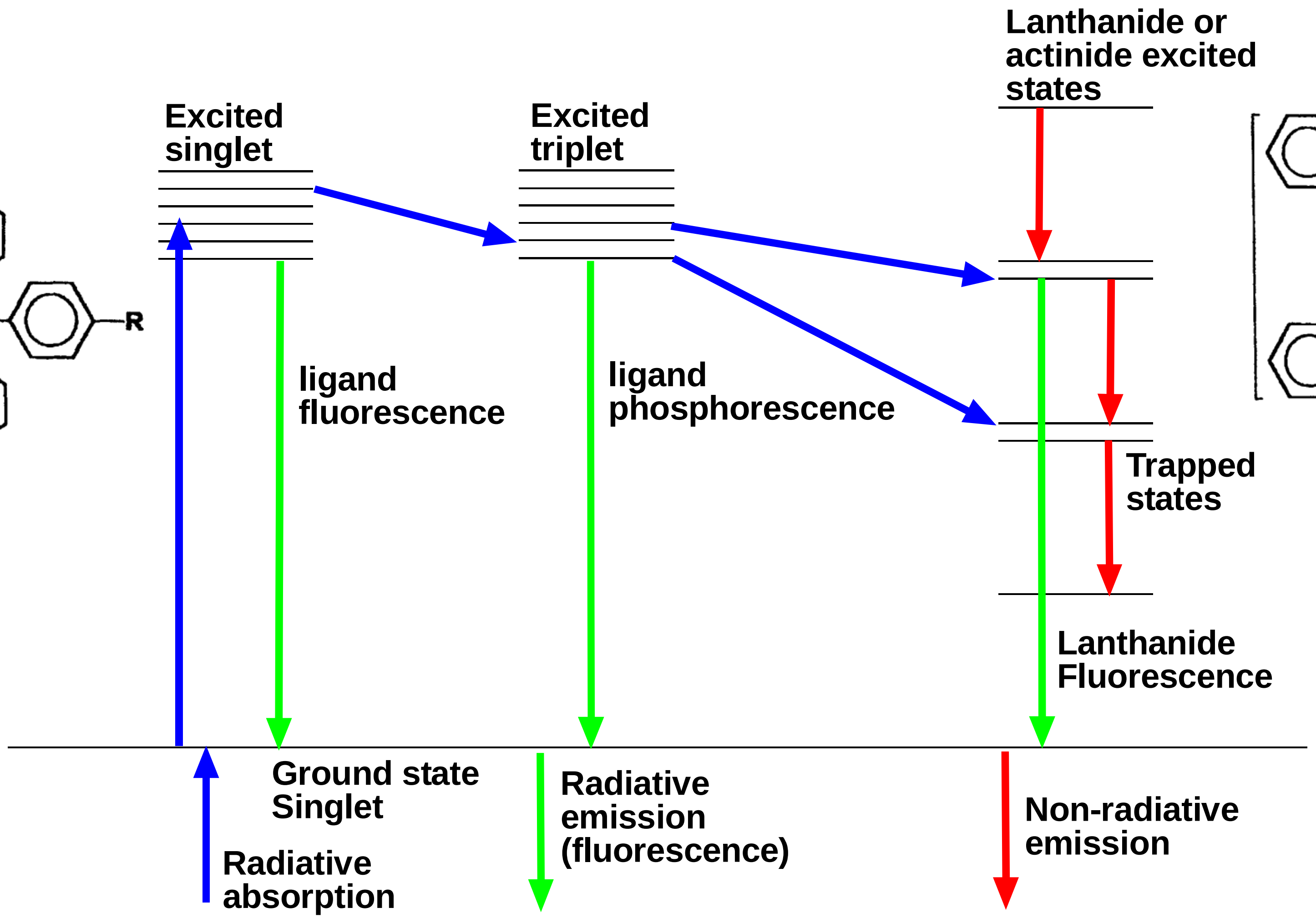
λ_{max} 462nm (DCM)

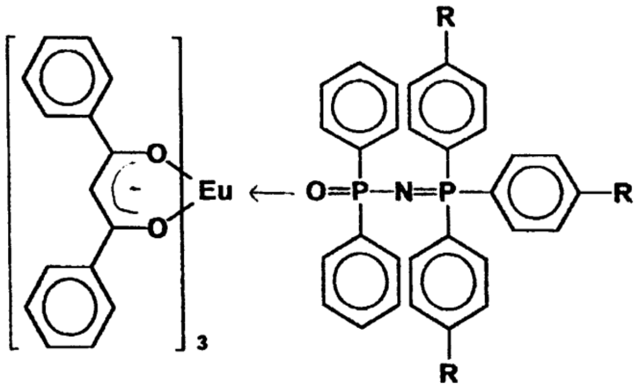
Ref: P. Kathirgamanathan, R.Price, S.Ganeshamurugan, G.Paramaswara, M.Kumaraverl, A.Partheepan, S.Selvaranjan, J.Antipan-Lara and S. Surendrakumar., Patent No: WO 2005/080526; Priority date: 14 February 2004

Excitation and Emission Mechanism: Rare Earths

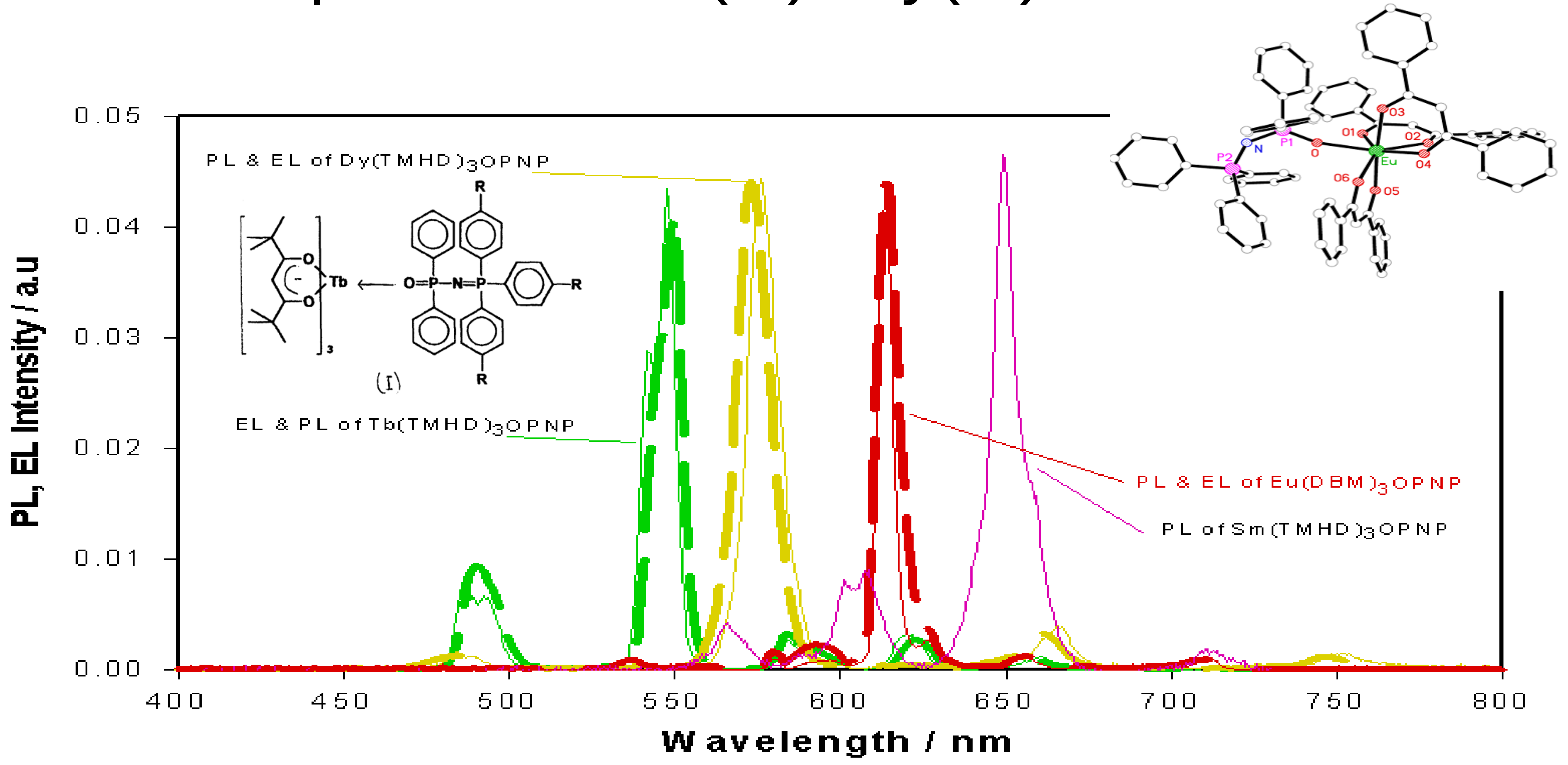


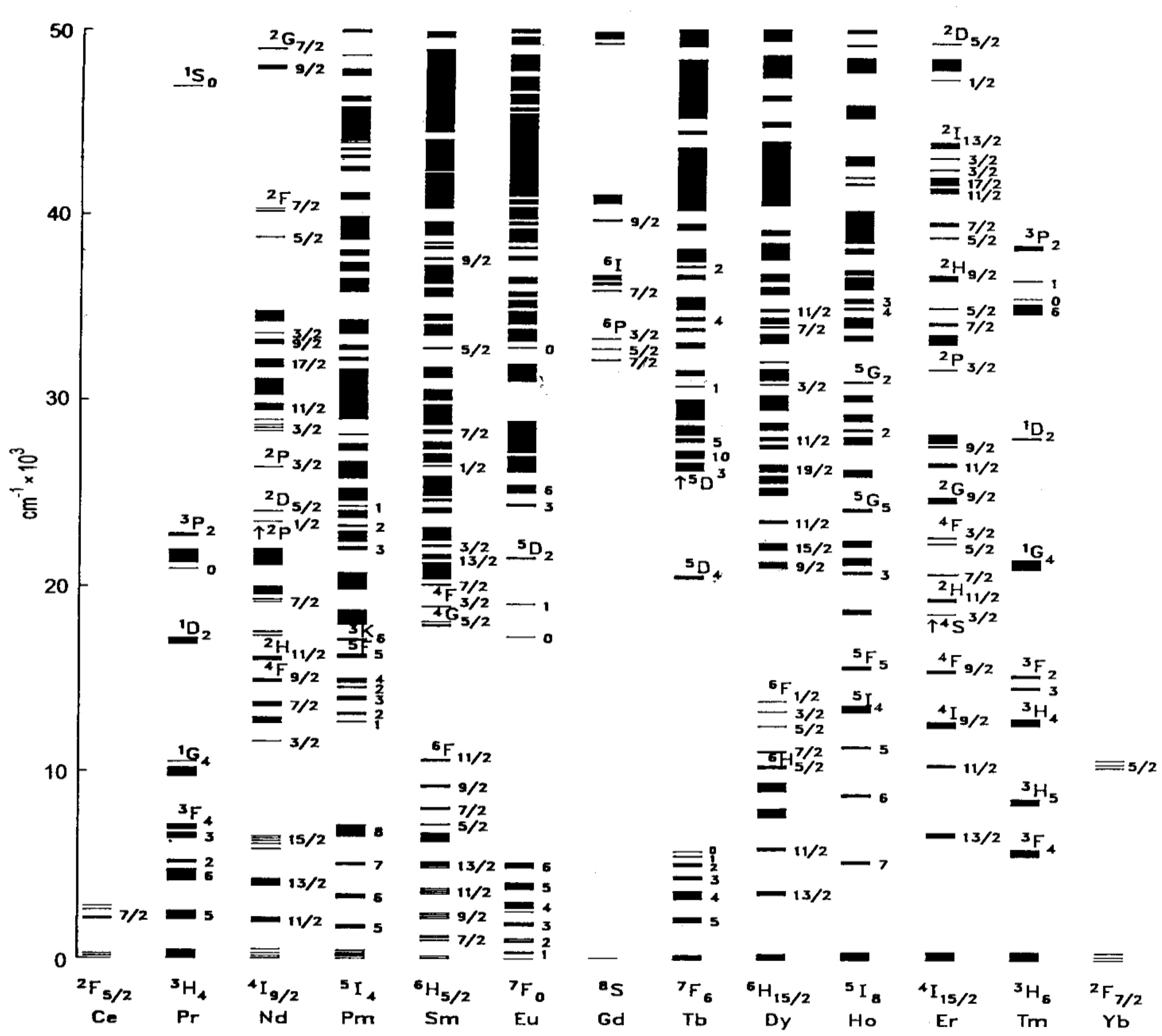
(I)



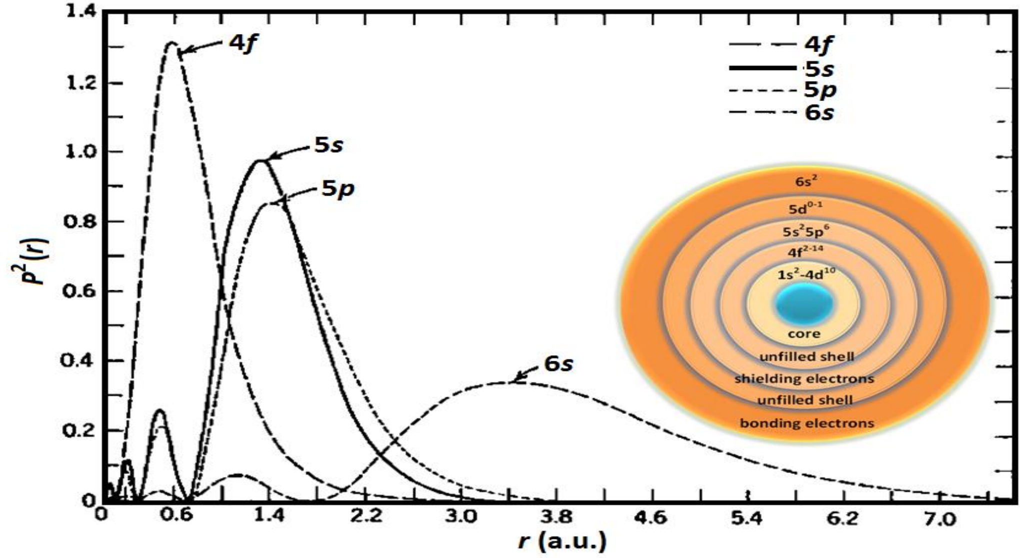


PL and EL Spectra of Tb(III), Dy(III), Eu(III) & Sm(III)



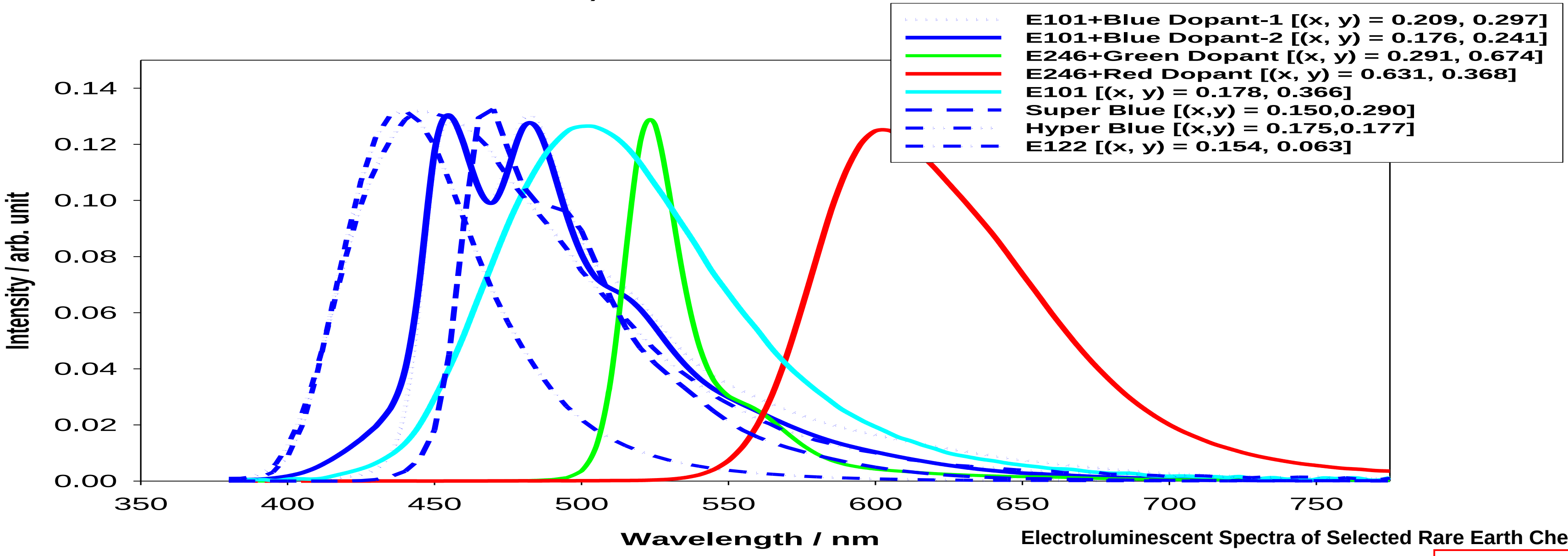


cm⁻¹ × 10³
0
10
20
30
40
50
Ce
Pr
Nd
Pm
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb

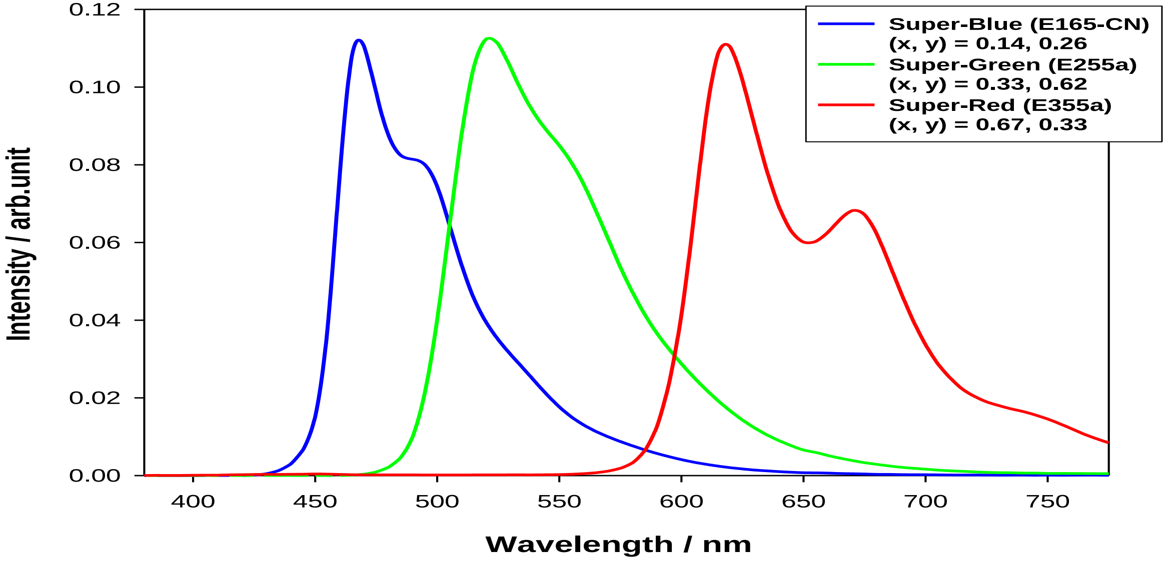


4f
5s
5p
6s
P²(r)
r (a.u.)
0
0.6
1.4
2.2
3.0
3.8
4.6
5.4
6.2
7.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
6s²
core
unfilled shell
shielding electrons
unfilled shell
bonding electrons

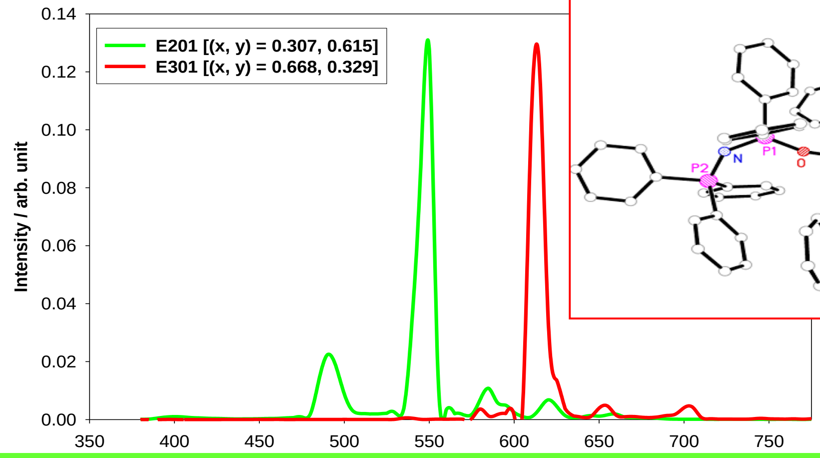
Electroluminescent Spectra of Selected Fluorescent Red, Green and Blue Materials

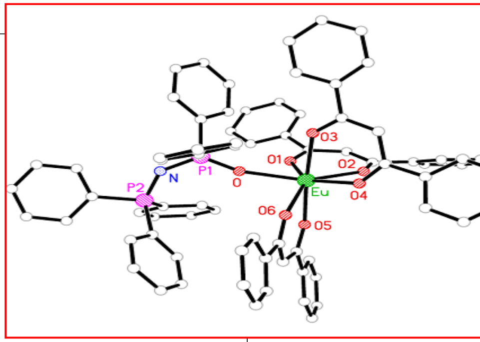


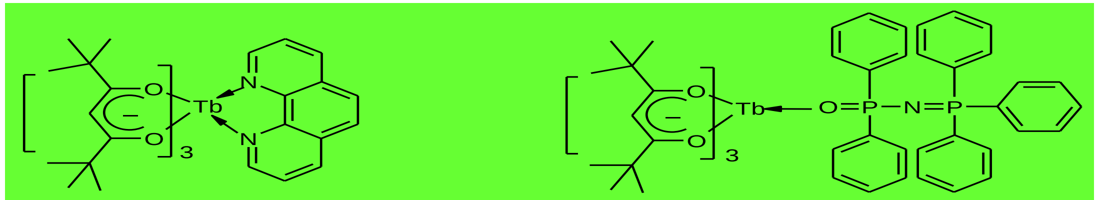
Electroluminescent Spectra of Selected Phosphorescent Materials (Super Colours)



Electroluminescent Spectra of Selected Rare Earth Chelates

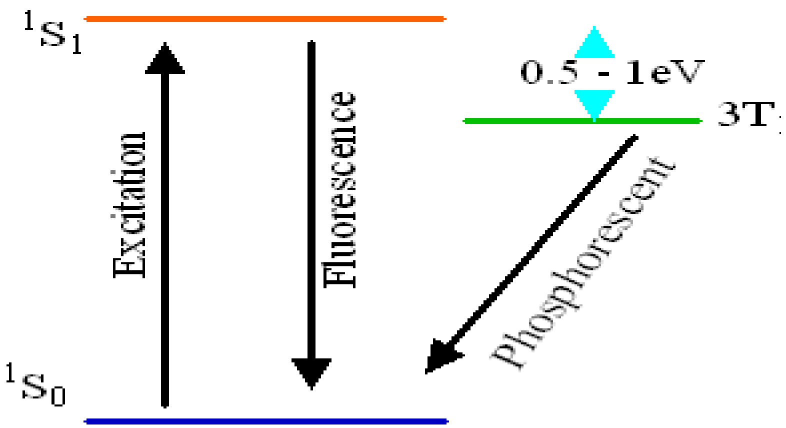


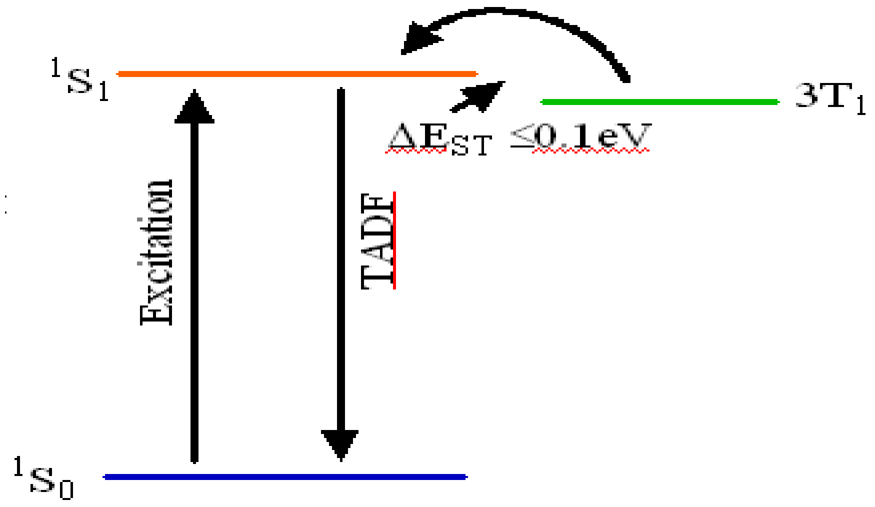




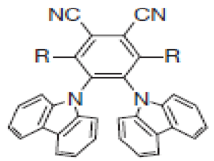
$Tb(TMHD)_3$.Phen $Tb(TMHD)_3$.OPNP

Conventional vs. Thermally Activated Delayed Fluorescence

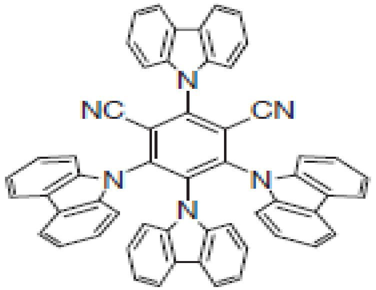




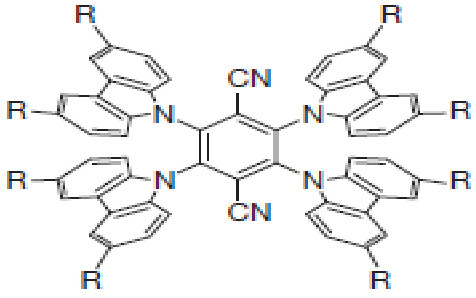
Metal free !



4CzPN: R = carbazolyl
2CzPN: R = H



4CzIPN

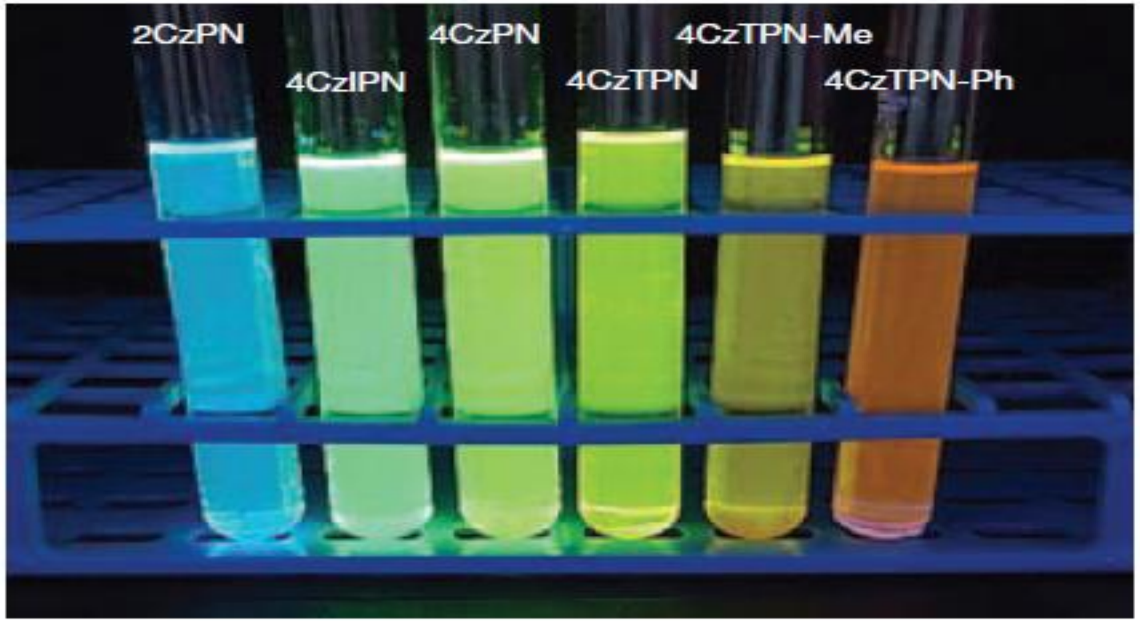


4CzTPN: R = H
4CzTPN-Me: R = Me
4CzTPN-Ph: R = Ph

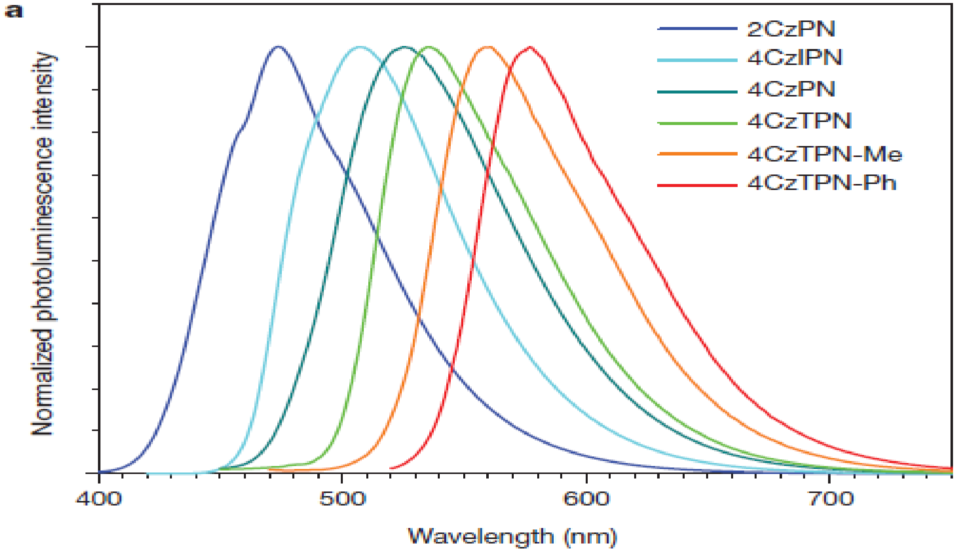
Uoyama, Goushi, Shizu, Noumura and Adachi, Kyushu University,Nature, 492 (2012)234

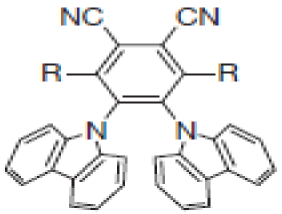
Conventional vs. Thermally Activated Delayed Fluorescence

b

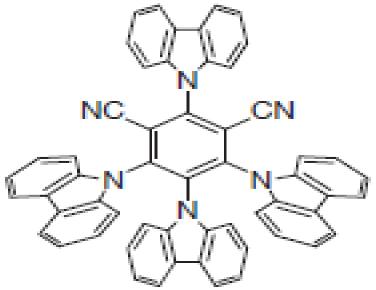


a

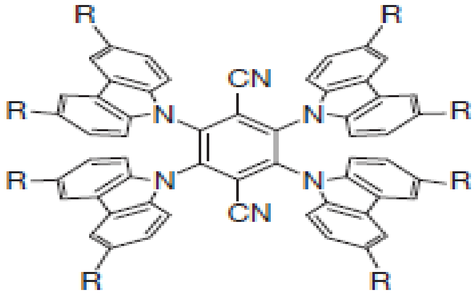




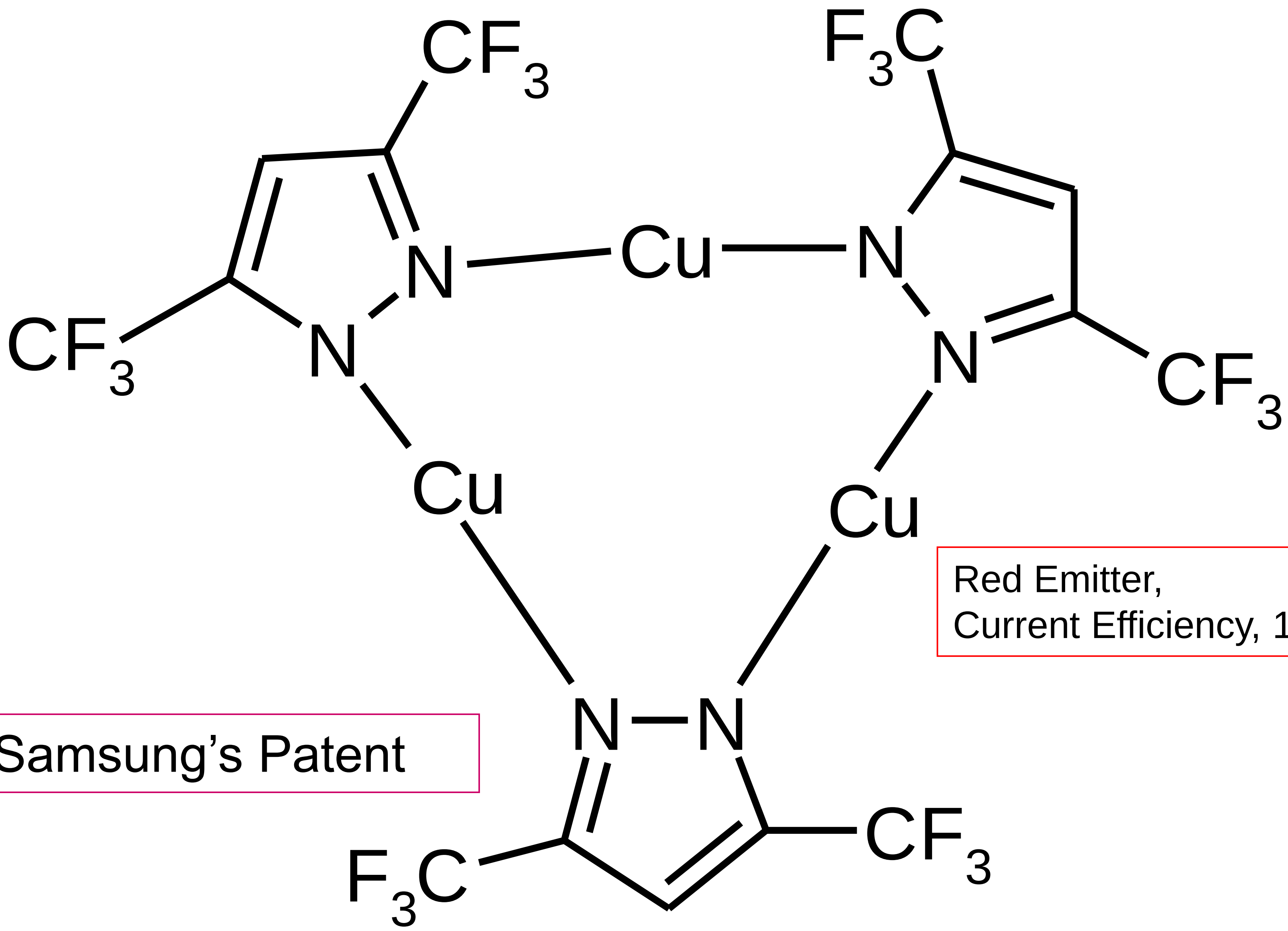
4CzPN: R = carbazolyl
2CzPN: R = H



4CzIPN



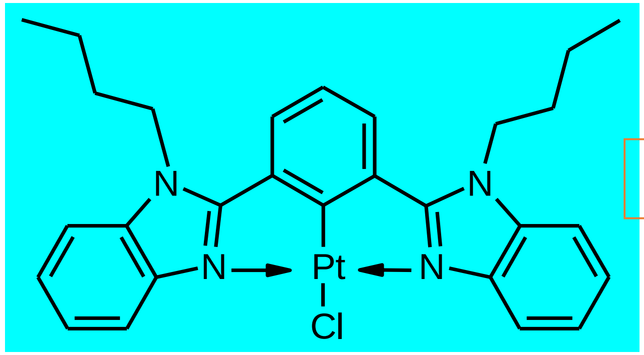
4CzTPN: R = H
4CzTPN-Me: R = Me
4CzTPN-Ph: R = Ph



Red Emitter,
Current Efficiency, 1 cd/A

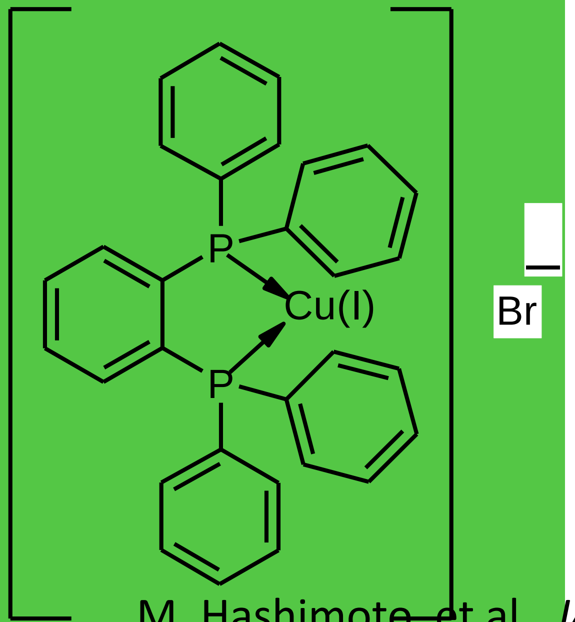
Samsung’s Patent

Analogous Ag complex was also reported.

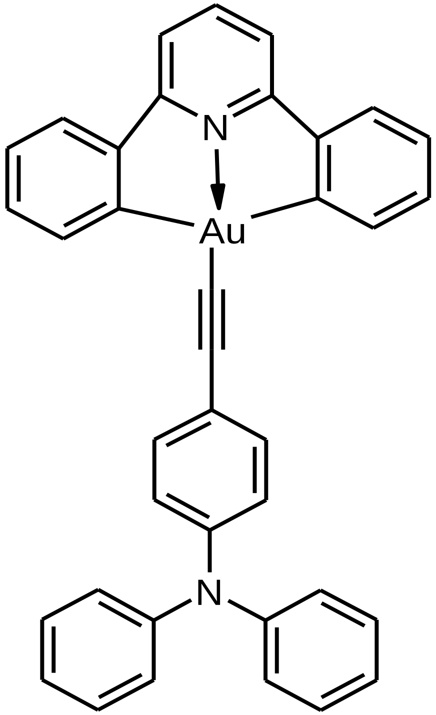


HK University

ηext = 11.6 %
ηl = 39 cd A-1
ηp = 27.2 lm W-1
X,y = (0.19, 0.32)

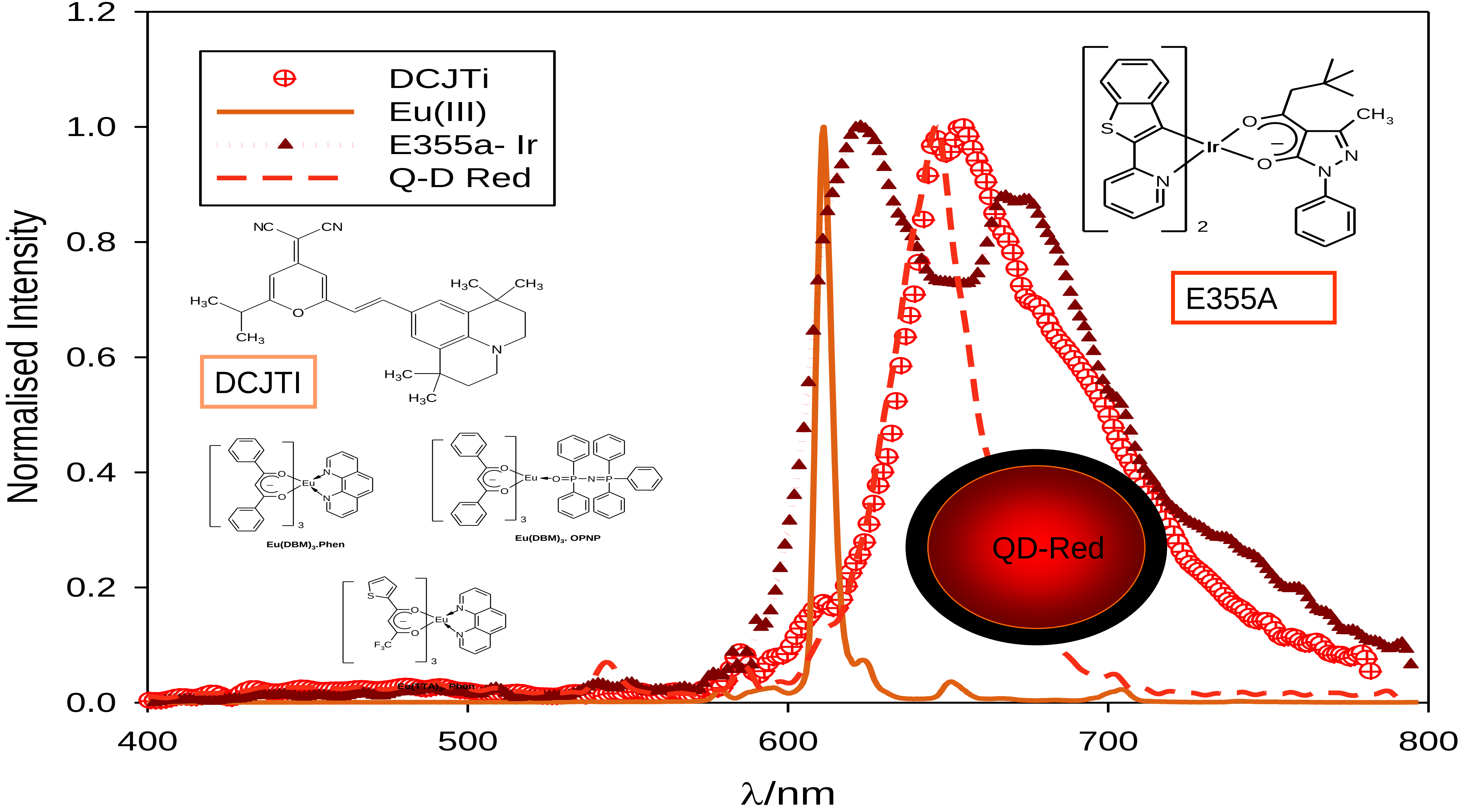


5 cd m-2
50 lm W-1
63 cd A-1
ηext 21.3 %



ηext = 12.8 %
ηl = 36 cd A-1
ηp = 26 lm W-1
x,y = (0.29, 0.37)

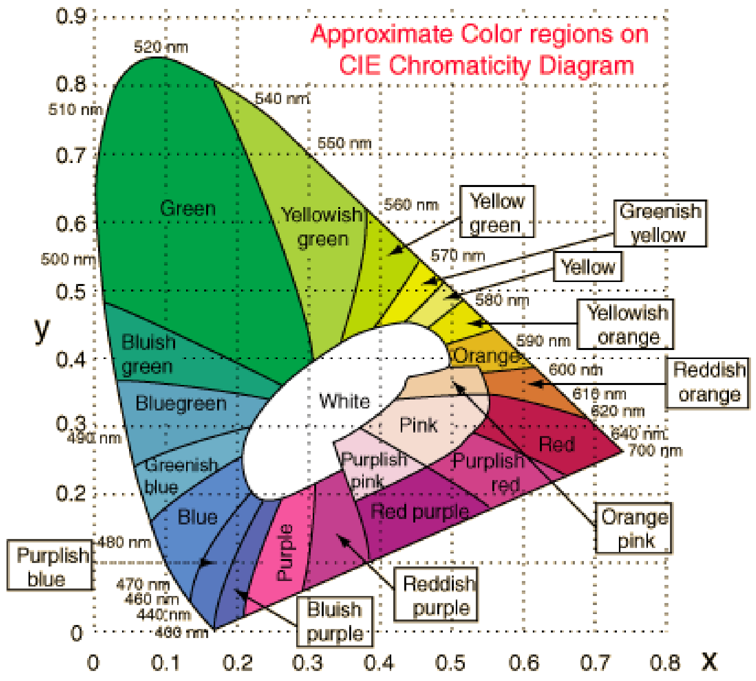
M. Hashimote, et al., *JACS. Commun*, 2011, 133, 10348-10351

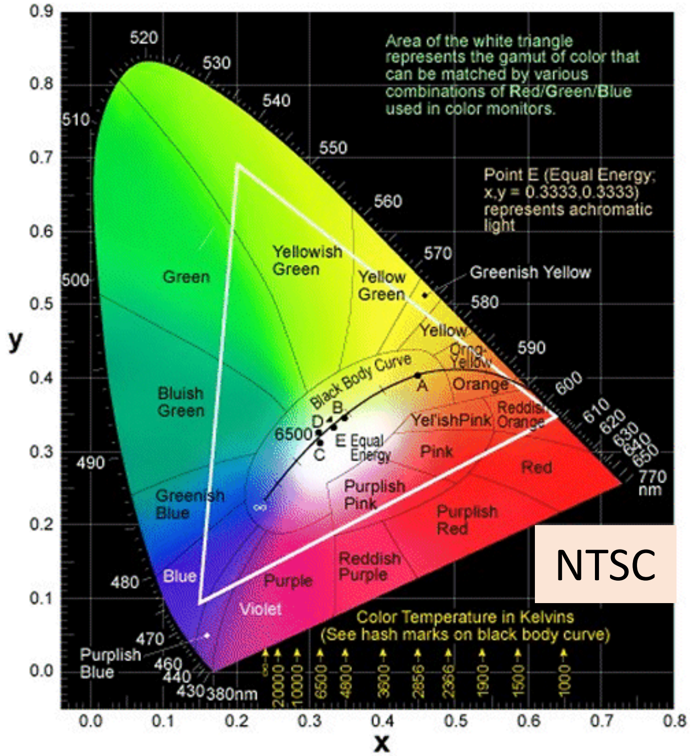


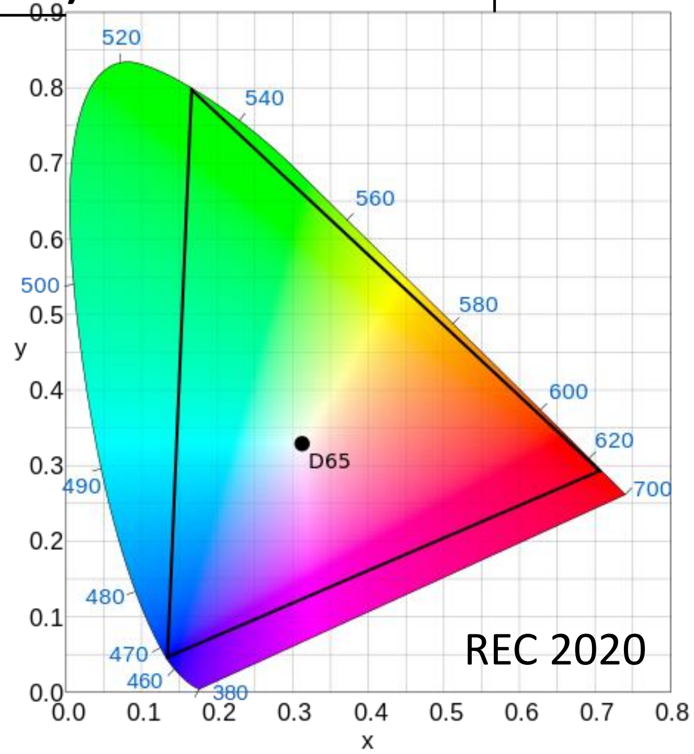
Normalised Intensity
λ/nm
0.0
0.2
0.4
0.6
0.8
1.0
1.2
400
500
600
700
800
DCJTi
Eu(III)
E355a- Ir
Q-D Red
DCJTI
Eu(DBM)3.Phen
Eu(DBM)3. OPNP
E355A
QD-Red

REC 2020

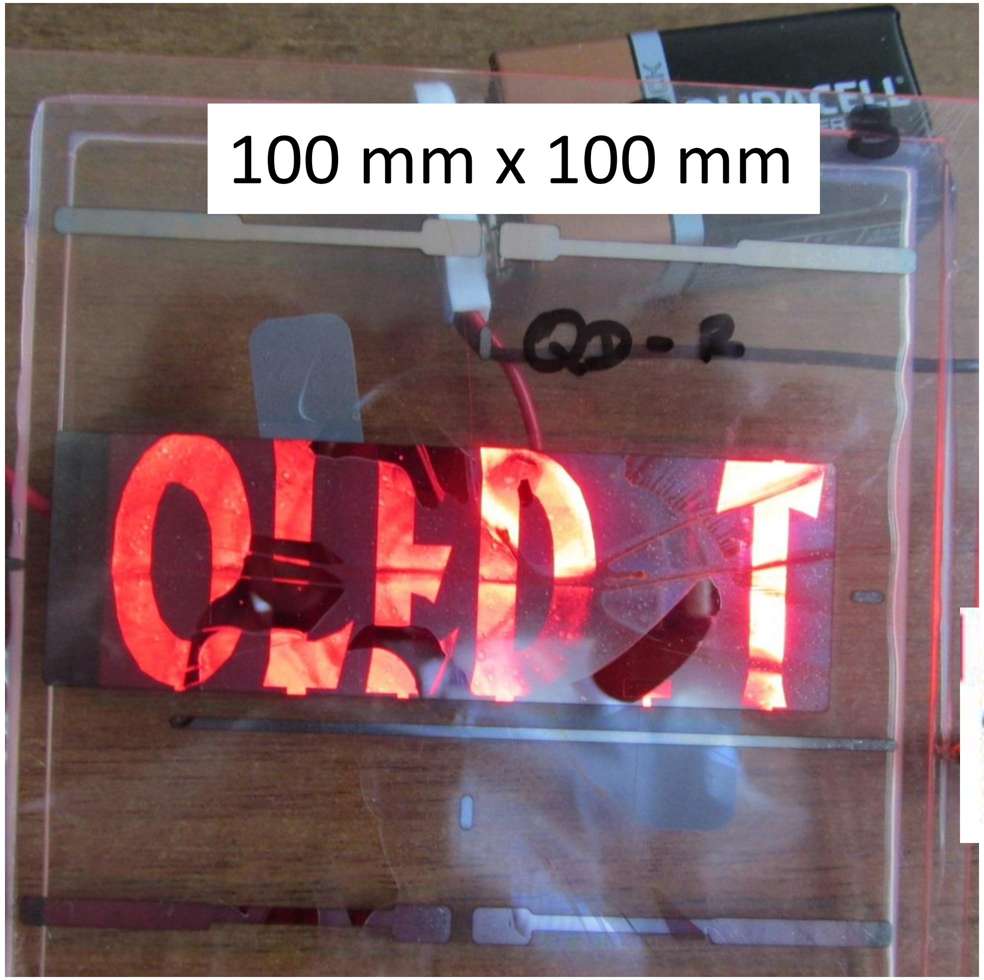
Colour	NTSC	Rec 2020
Red	(0.670, 0.33)	(0.708, 0.292)
Green	(0.210, 0.710)	(0.170, 0.797)
Blue	(0.140, 0.080)	(0.131, 0.046)
White	(0.310, 0.316)	(0.3127, 0.3290)



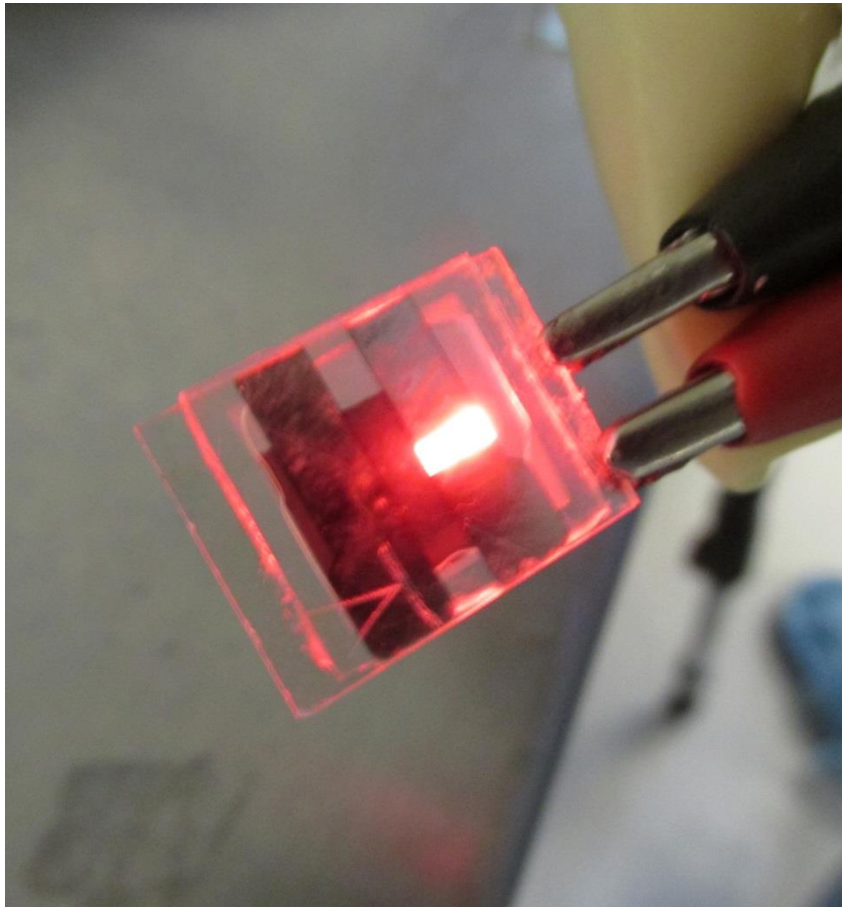




Red Qoleds Based on CdSe/ZnS



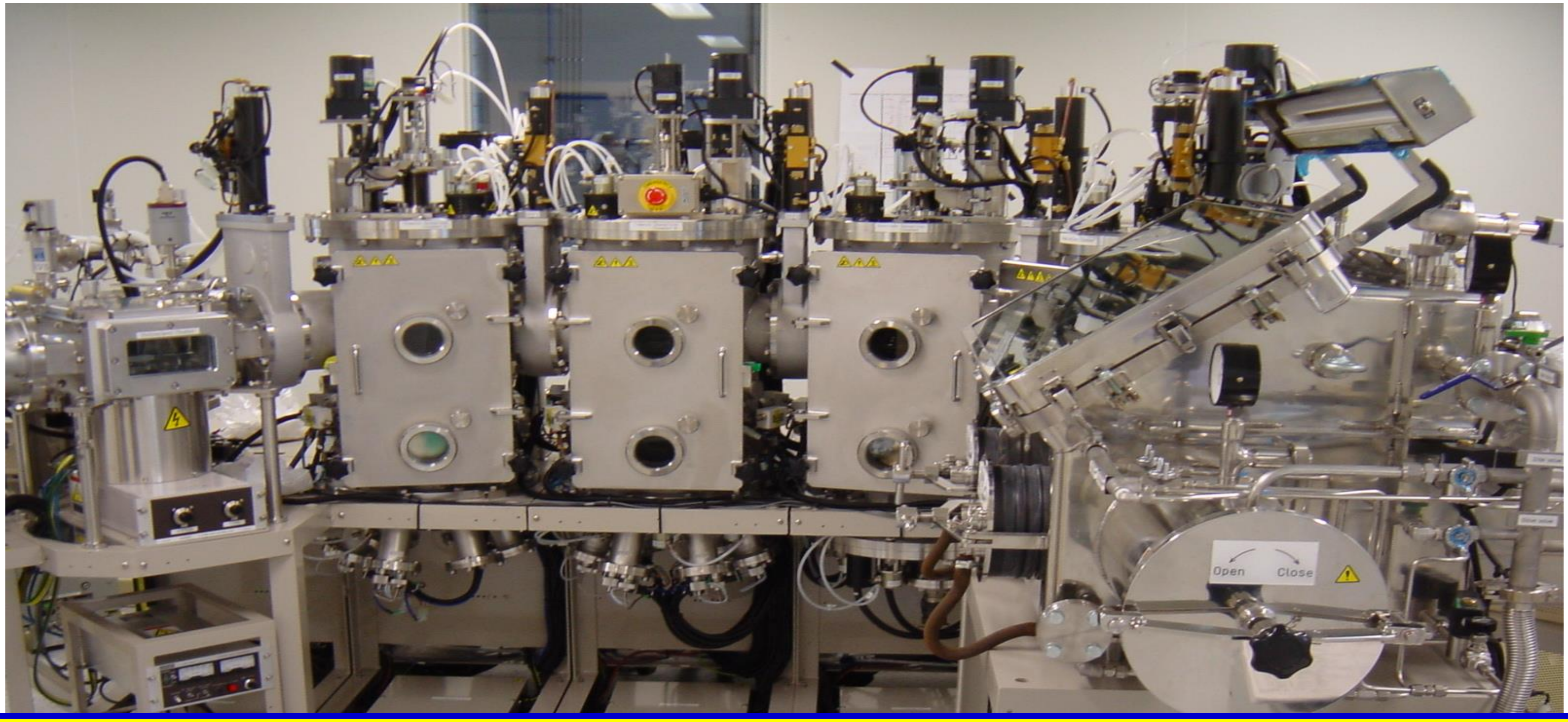
Brunel University London



Performance Data.All data at 1000 cdm^{-2}.

Colour	Fluorescents (v)	Phosphorescents (v)	Polymers/Dendrimers (s)	Quantum Dots (s)
Red	(0.65, 0.35), 300-500 kh, 10 cd/A	(0.64, 0.36), 330 kh, 30 cd/A, 22 lm/W	(0.63, 0.37), 350 kh, 30 cd/A	
Red		(0.69, 0.31), 250 kh, 17 cd/A, 10 lm/W	(0.67, 0.32) 200 kh, 11 cd/A	(0.69, 0.31), 2 kh, 15-20 cd/A, 15 lm/W
Green	(0.29, 0.61), 65 kh, 31 cd/A	(0.34, 0.62), 400 kh, 78 cd/A 50 lm/W	(0.30, 0.63), 140 kh, 50 cd/A	(0.17, 0.73) 2 kh 70 cd/A 50 lm/W
Blue	(0.15, 0.14), 50 kh, 10 cd/A, 5 lm/W	(0.18,0.40), 20 kh 50 cd/A 30lm/W	(0.15, 0.14), 21 kh 6 cd/A	(0.16, 0.05) 0.01 kh, 0.55 cd/A 0.26 lm/W

Displays Development
Solciet (ULVAC)



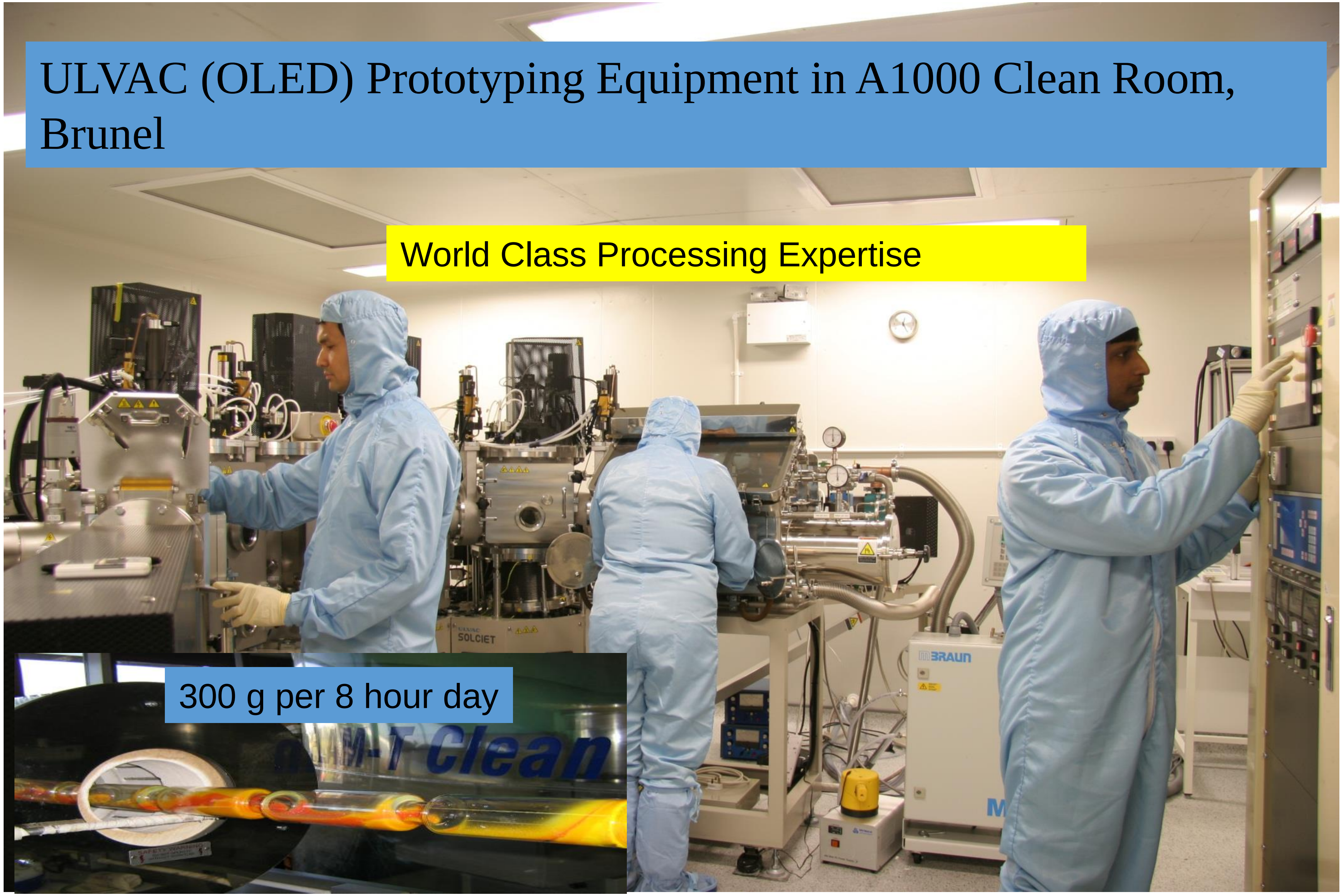
Solciet – £1 million (100 mm x 100 mm), Tact Time: 1-2 hours

Satella- Cluster tool , £3 million(200mm x 200 mm), Tact Time: 30 minutes

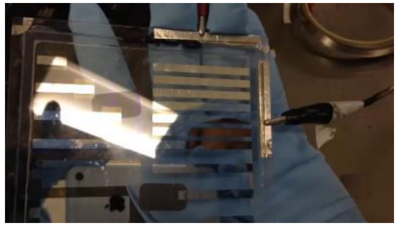
Zelda – Mass Production, £20 million (400 mm x 500 mm), Tact Time: 4 minutes

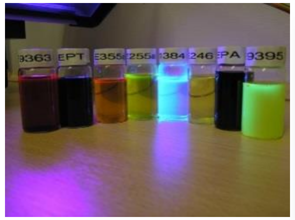
ULVAC (OLED) Prototyping Equipment in A1000 Clean Room, Brunel

World Class Processing Expertise



300 g per 8 hour day





FLEXOLIGHTING

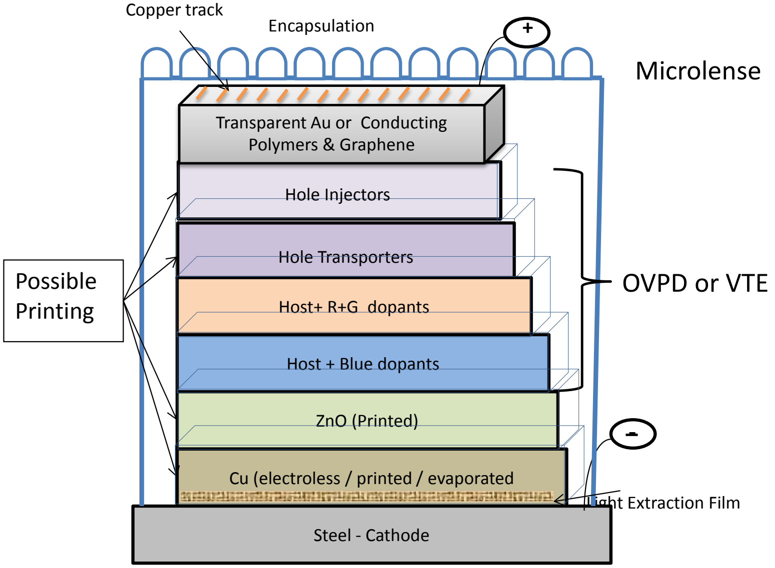
Brunel University London

TATA STEEL

AIXTRON

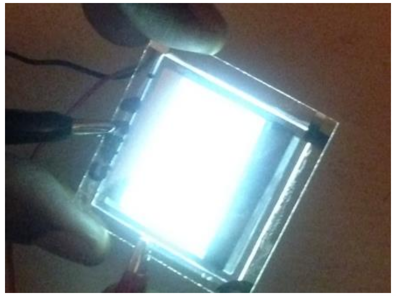
BENEQ

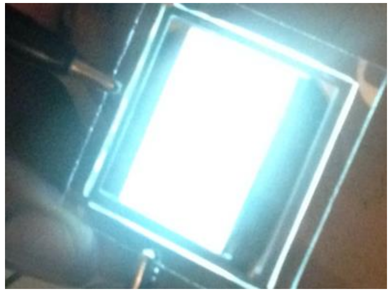
Long Life, Large Area, Large (High) Uniformity, Flexible and Conformable OLEDs for Lighting



www.flexolighting.eu

25 lm/W, 40 cd/A



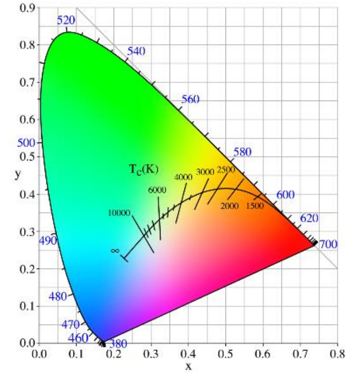


RobinsonBrothers
Excellence in Chemistry

NOVALIA

intrinsiq materials

MARKS & SPENCER



PHOTONICS21
PHOTONICS PUBLIC PRIVATE PARTNERSHIP

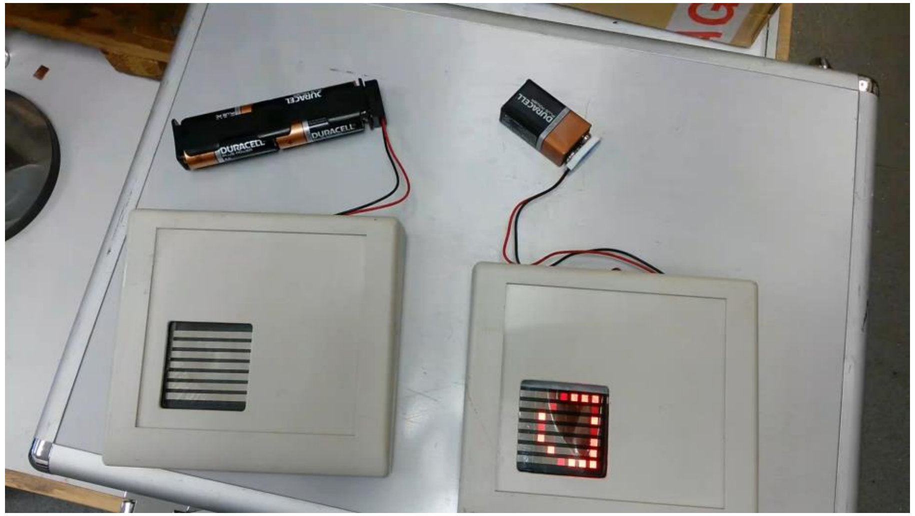
Photonics Public Private Partnership
Annual Meeting 2016

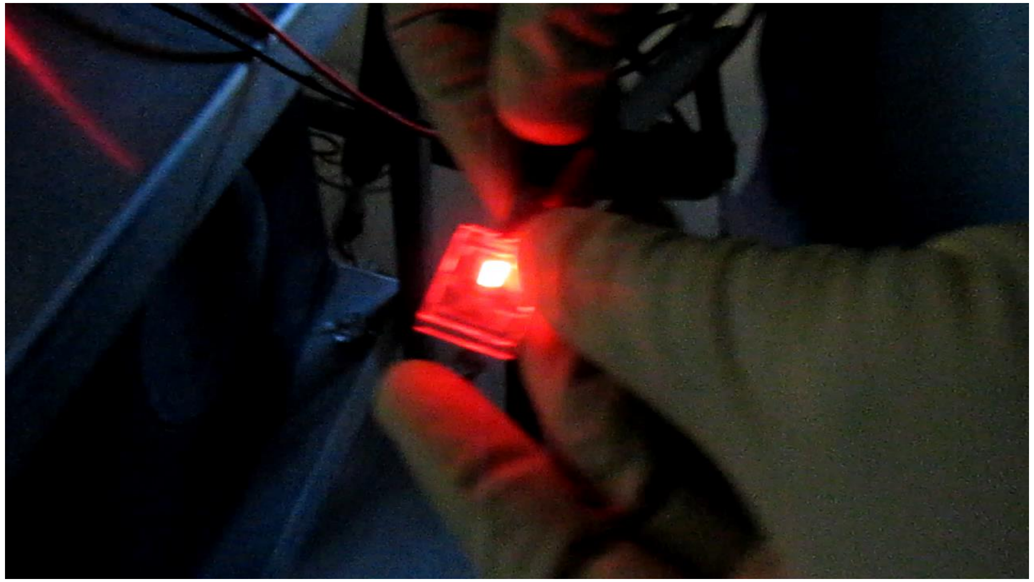
Red and Green Quantum Dot Based LEDs (QLEDs): Towards Achieving REC 2020 Color Coordinates

Brunel University London

THE WOLFSON CENTRE FOR MATERIALS PROCESSING

Our Recent Work





http://youtu.be/D0WV1R9Rfl0

http://youtu.be/Ws76e-AAApI

http://youtu.be/SKIsnei0k4A

http://youtu.be/p4aDAkC61Wk

http://youtu.be/RgoMnroRnhc

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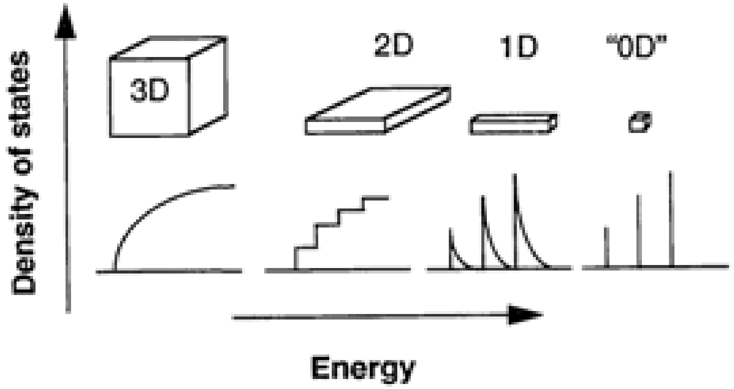
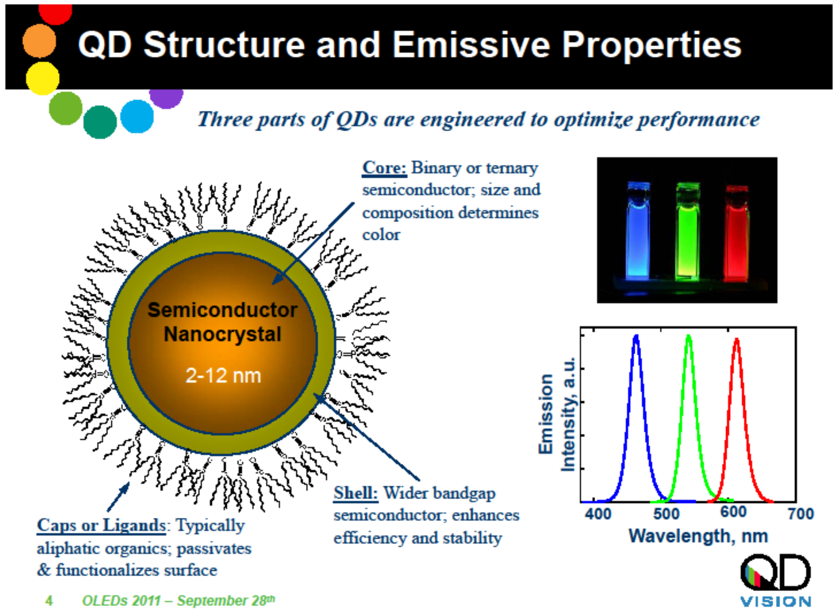
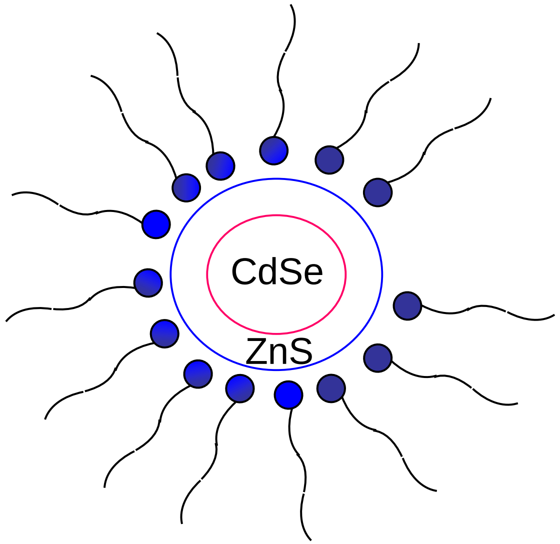
http://youtu.be/QC-nUMkMOFc



Density of states
3D
2D
1D
"0D"
Energy

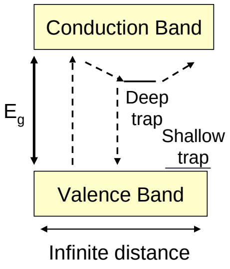


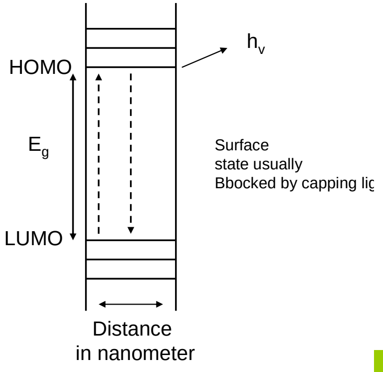
QD Structure and Emissive Properties
Three parts of QDs are engineered to optimize performance
Core: Binary or ternary semiconductor; size and composition determines color
Semiconductor Nanocrystal
2-12 nm
Shell: Wider bandgap semiconductor; enhances efficiency and stability
Caps or Ligands: Typically aliphatic organics; passivates & functionalizes surface
Emission Intensity, a.u.
400
500
600
700
Wavelength, nm
QD VISION
4 OLEDs 2011 – September 28th

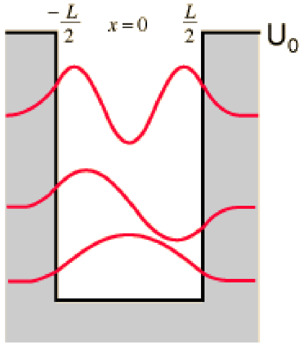


CdSe
ZnS

Quantum Dots

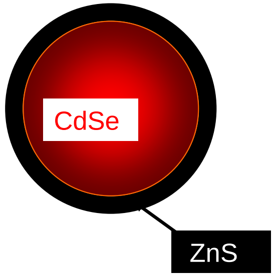






What are quantum dots ?

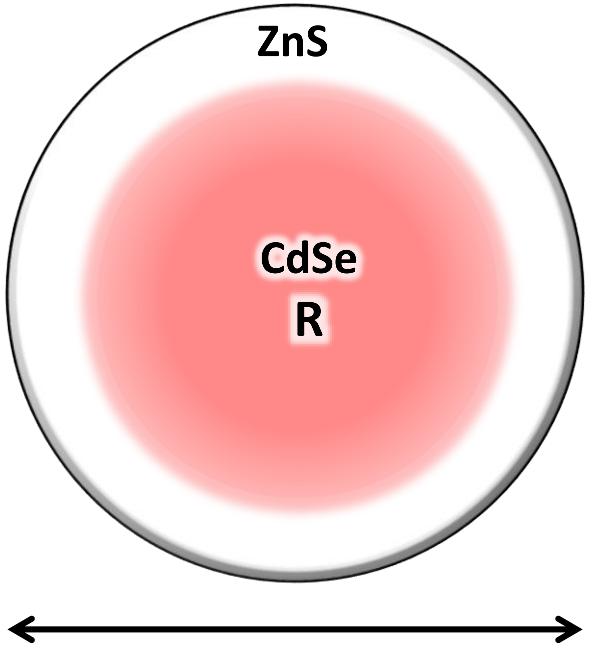
- Crystalline fluorophores
- CdSe semiconductor core
- ZnS Shell



$$E_n = \frac{n^2 \hbar^2 \pi^2}{2mL^2} = \frac{n^2 h^2}{8mL^2}$$

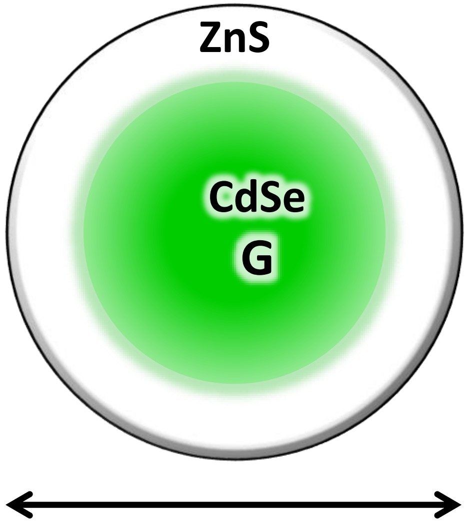
$$E = \frac{n^2 h^2}{8mL^2}$$

Some Players – QD Vision, Nanoco, Nanosys, Samsung, Sony, Dow, Merck



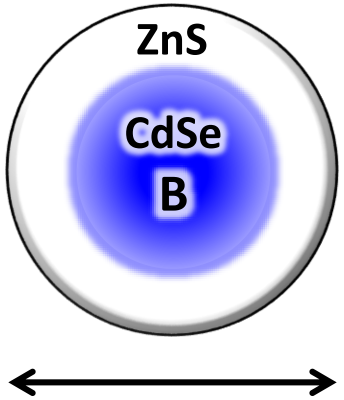
6 nm

λ_{em} = 650 nm



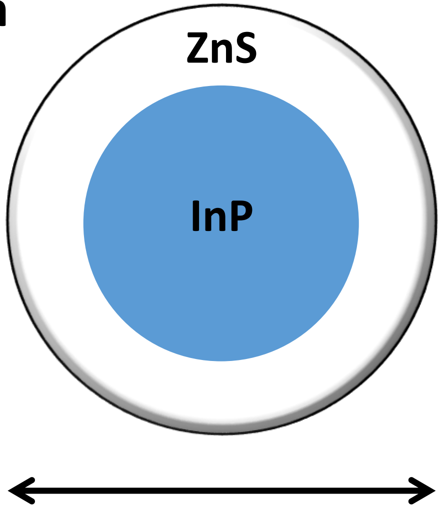
3.5 nm

λ_{em} = 520 nm



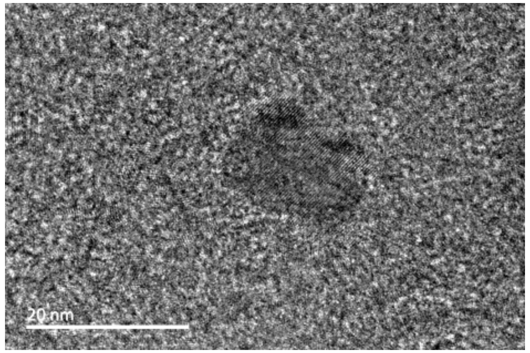
2.5 nm

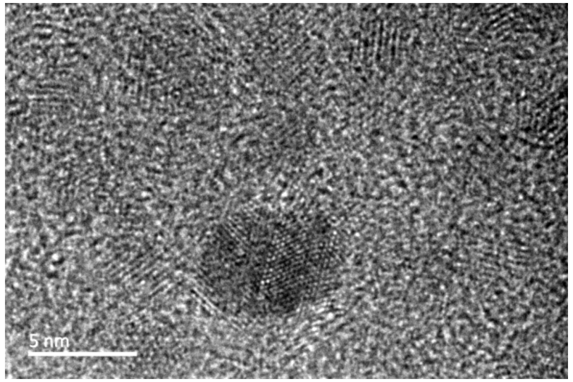
λ_{em} = 480 nm



4 nm

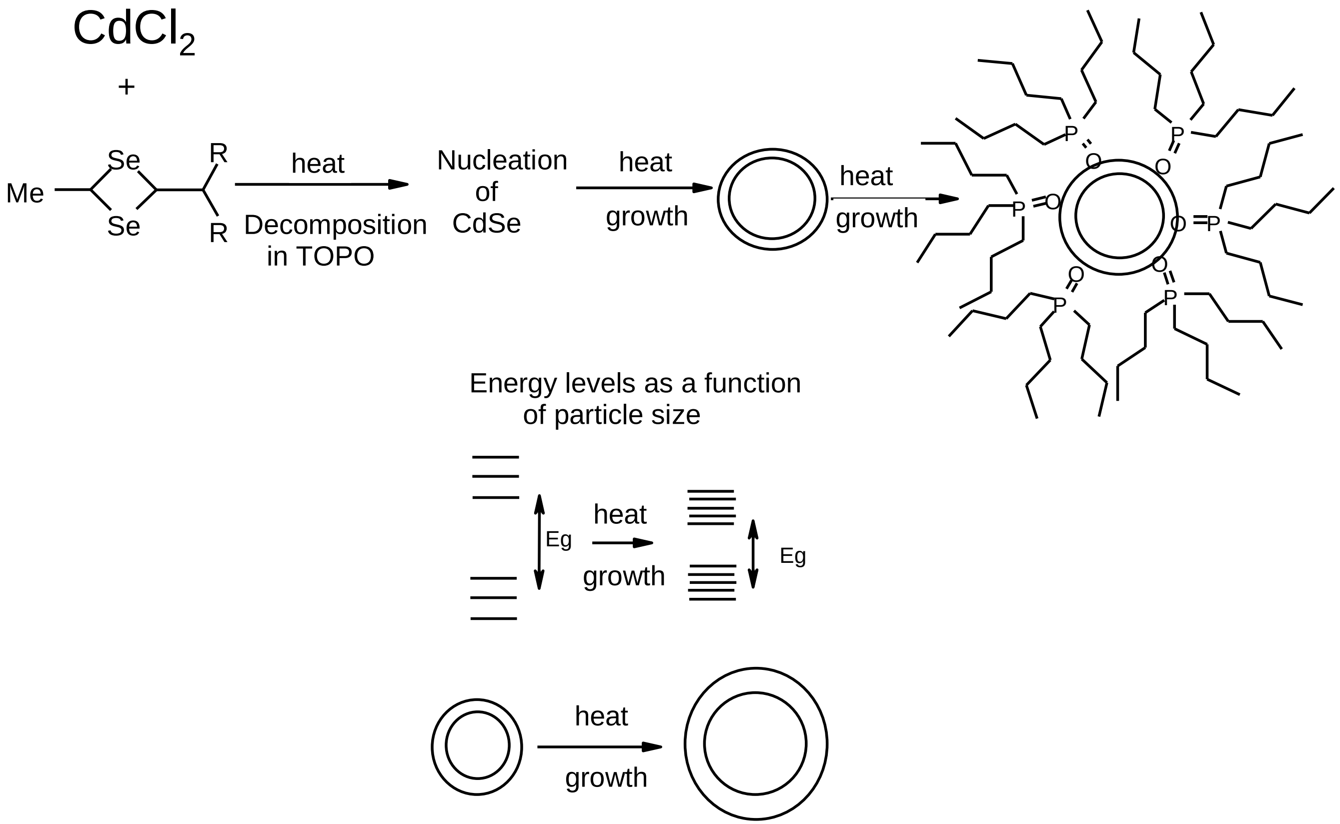
λ_{em} = 530 nm





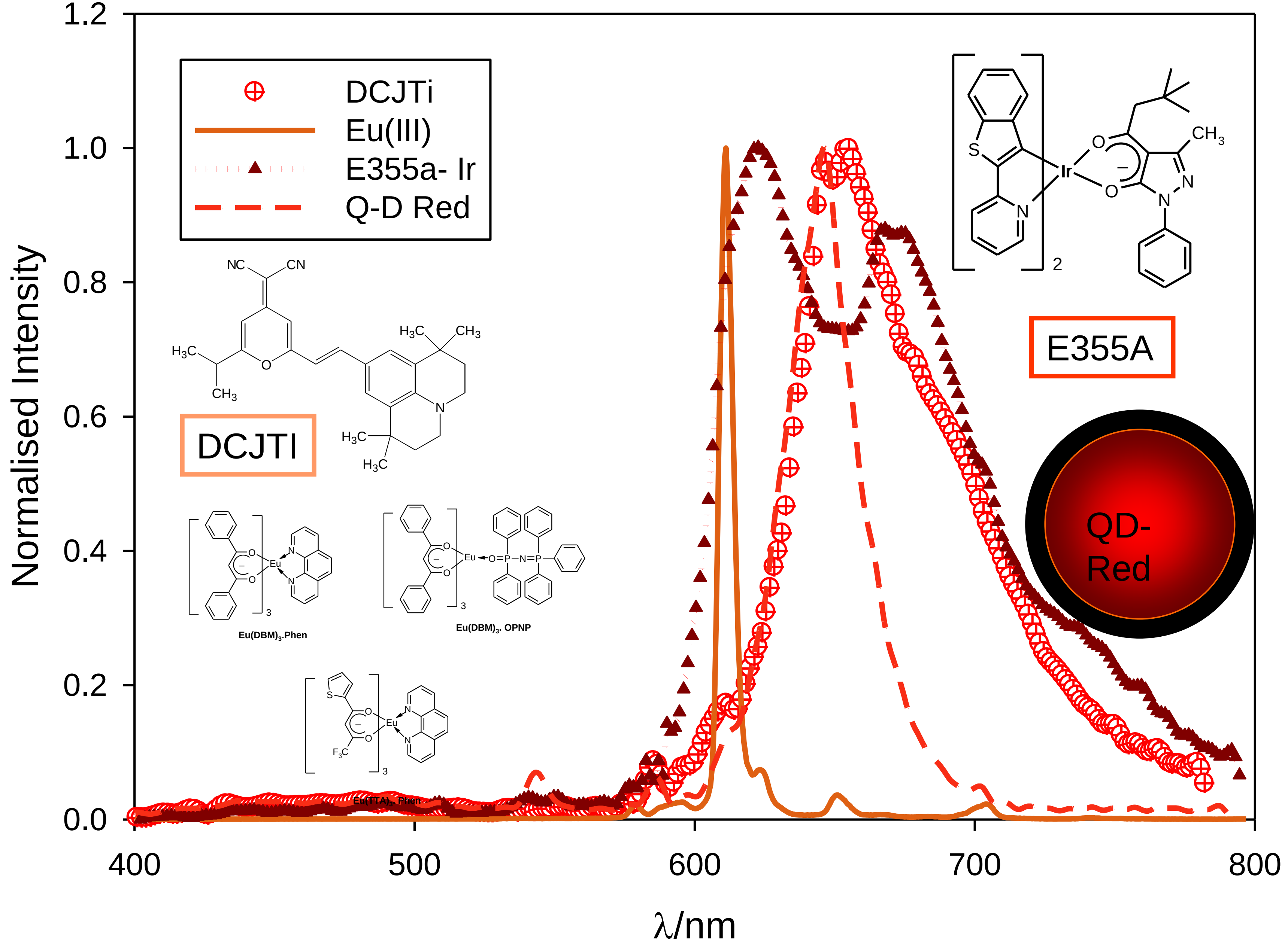
$$E = \frac{n^2 h^2}{8mL^2}$$

Synthesis of CdSe Quantum Dots

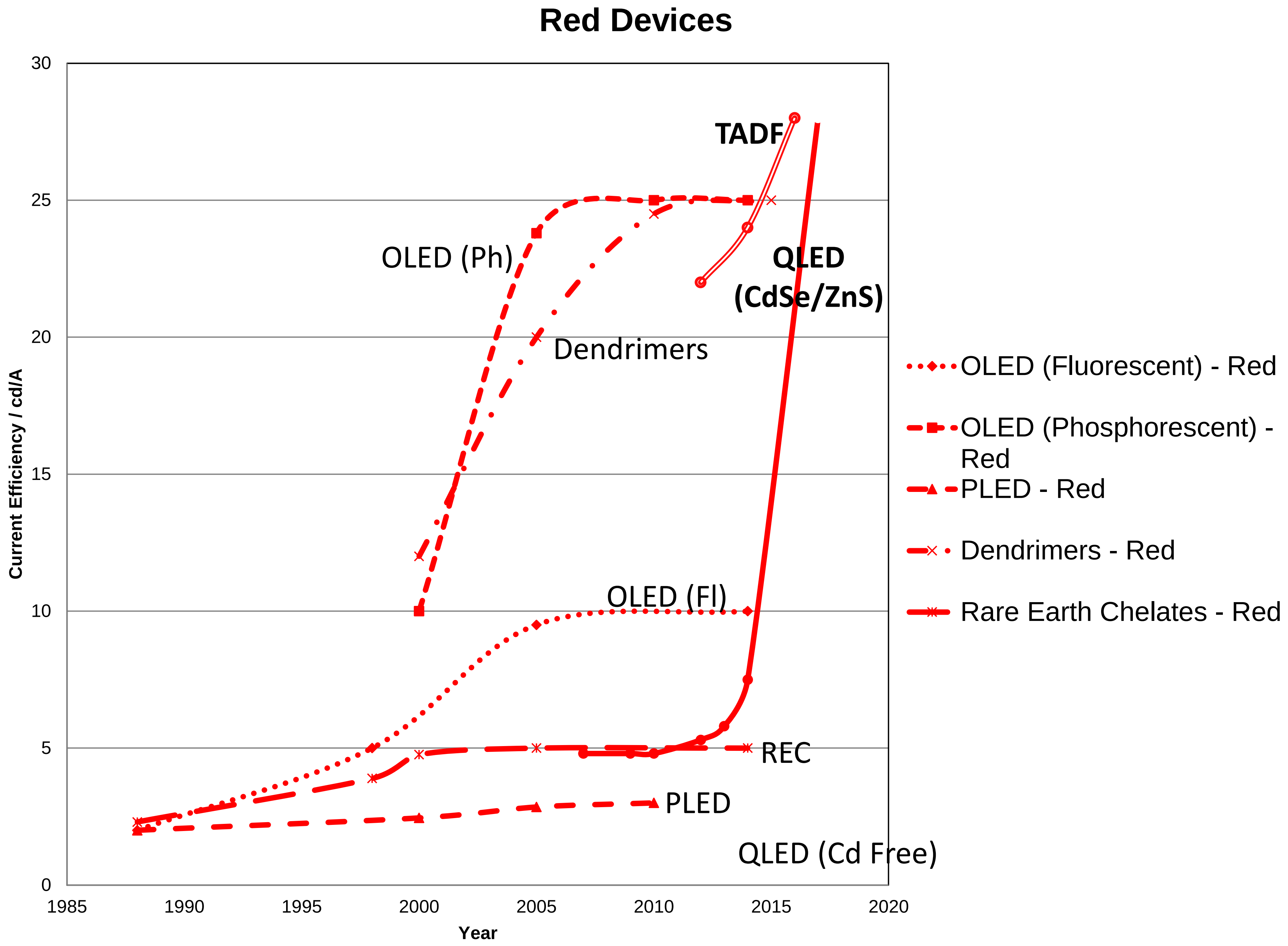


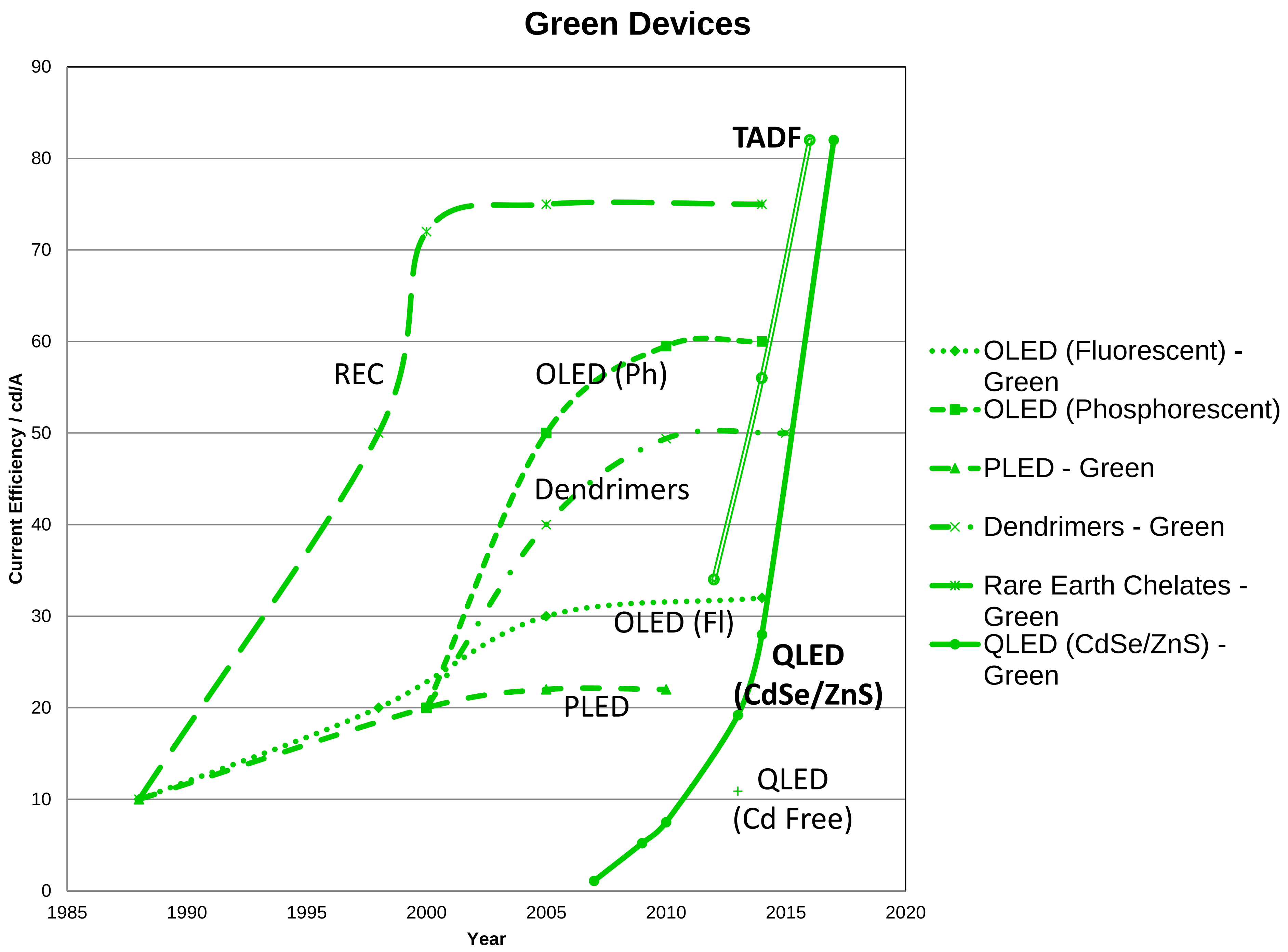
Theoretical decomposition schematic for the preparation of TOPO capped CdSe using a single source precursor

Paul O'Brien, Manchester
Co-Founder, Nanoco

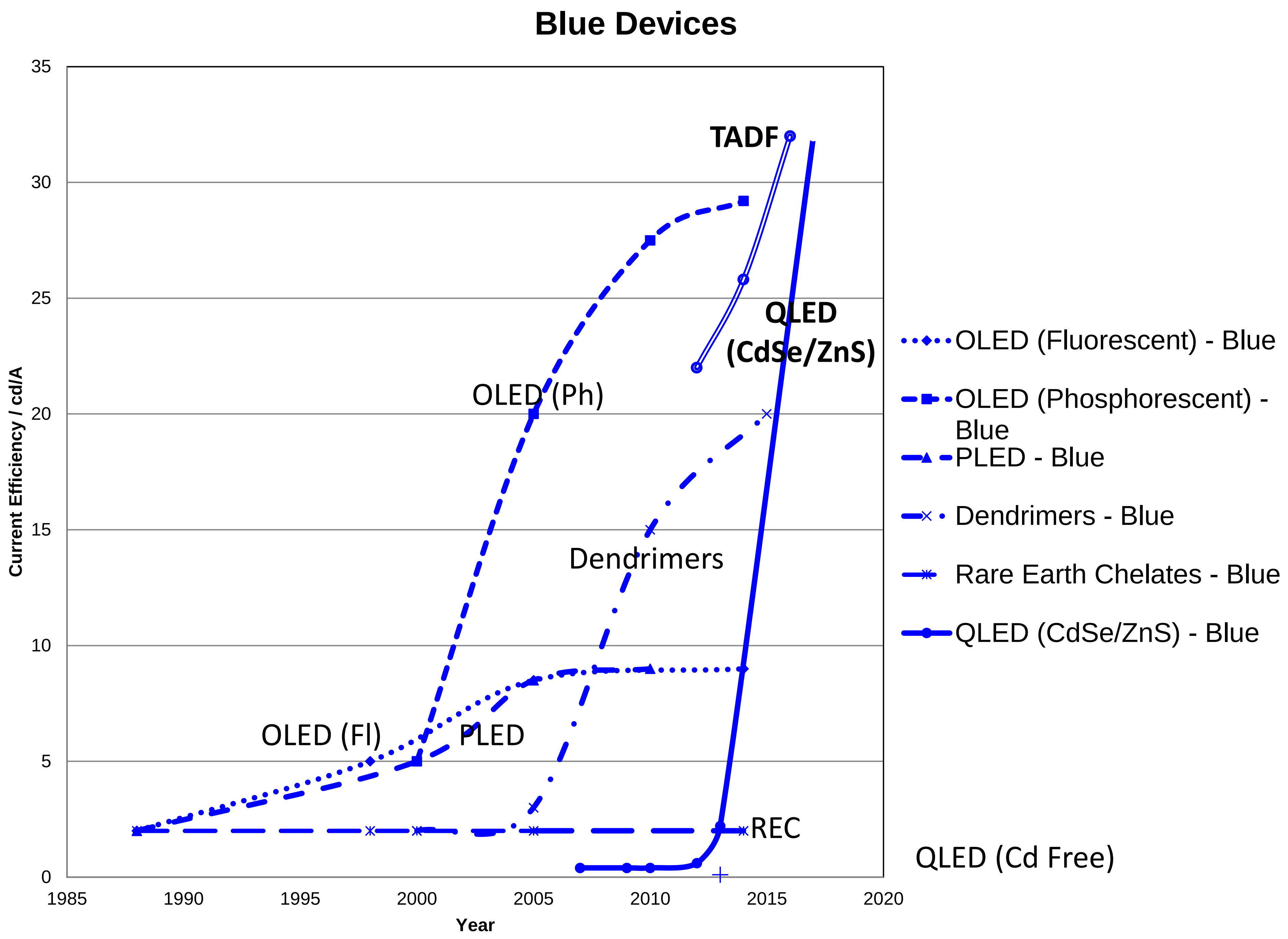


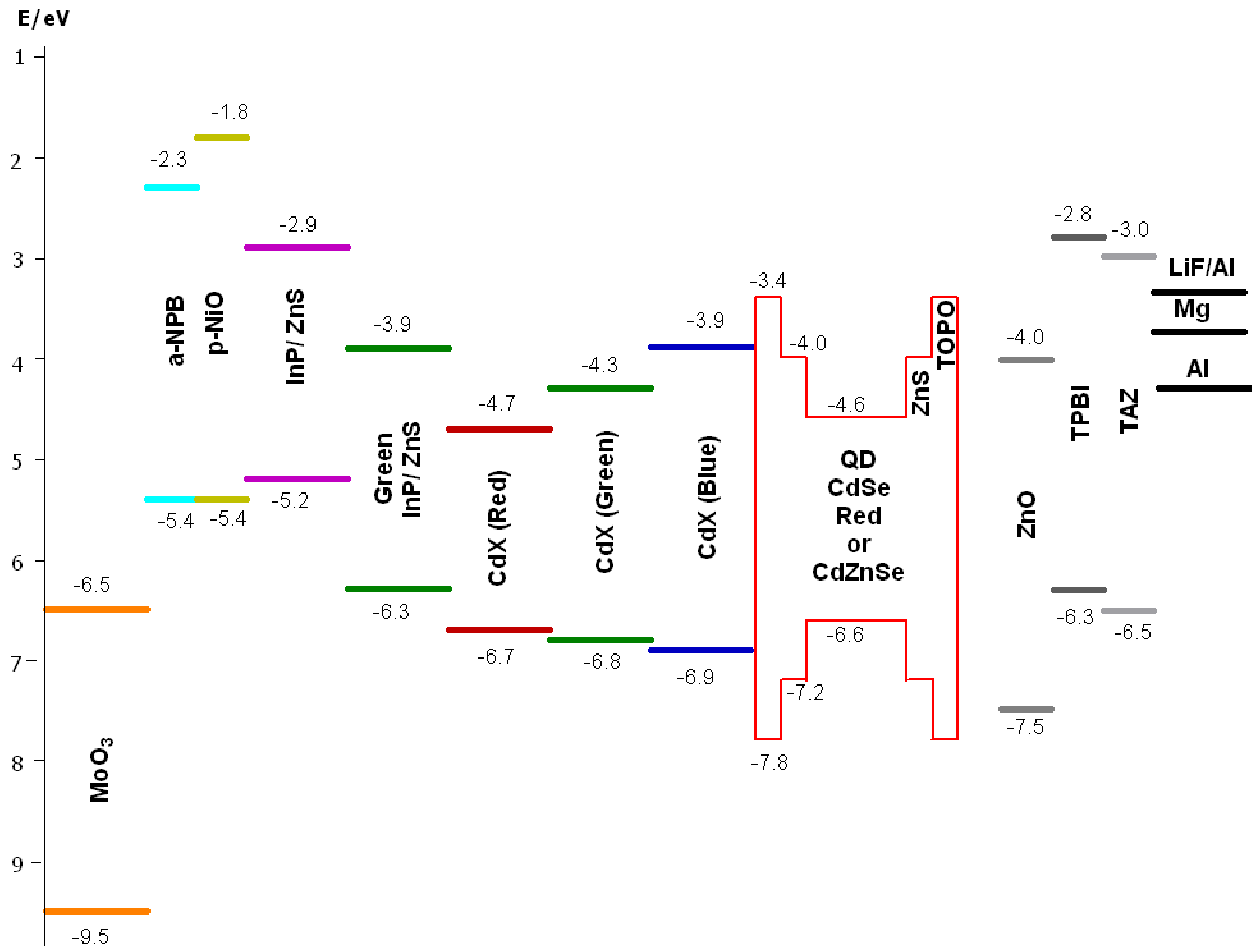
DCJTi
Eu(III)
E355a- Ir
Q-D Red
DCJTI
E355A
QD-
Red
Eu(DBM)3.Phen
Eu(DBM)3. OPNP
Normalised Intensity
λ/nm
0.0
0.2
0.4
0.6
0.8
1.0
1.2
400
500
600
700
800


Red Devices
Current Efficiency / cd/A
Year
30
25
20
15
10
5
0
1985
1990
1995
2000
2005
2010
2015
2020
TADF
OLED (Ph)
QLED
(CdSe/ZnS)
Dendrimers
OLED (Fl)
REC
PLED
QLED (Cd Free)
OLED (Fluorescent) - Red
OLED (Phosphorescent) - Red
PLED - Red
Dendrimers - Red
Rare Earth Chelates - Red



Green Devices
Current Efficiency / cd/A
Year
0
10
20
30
40
50
60
70
80
90
1985
1990
1995
2000
2005
2010
2015
2020
TADF
REC
OLED (Ph)
Dendrimers
OLED (Fl)
QLED
(CdSe/ZnS)
PLED
QLED
(Cd Free)
OLED (Fluorescent) - Green
OLED (Phosphorescent)
PLED - Green
Dendrimers - Green
Rare Earth Chelates - Green
QLED (CdSe/ZnS) - Green

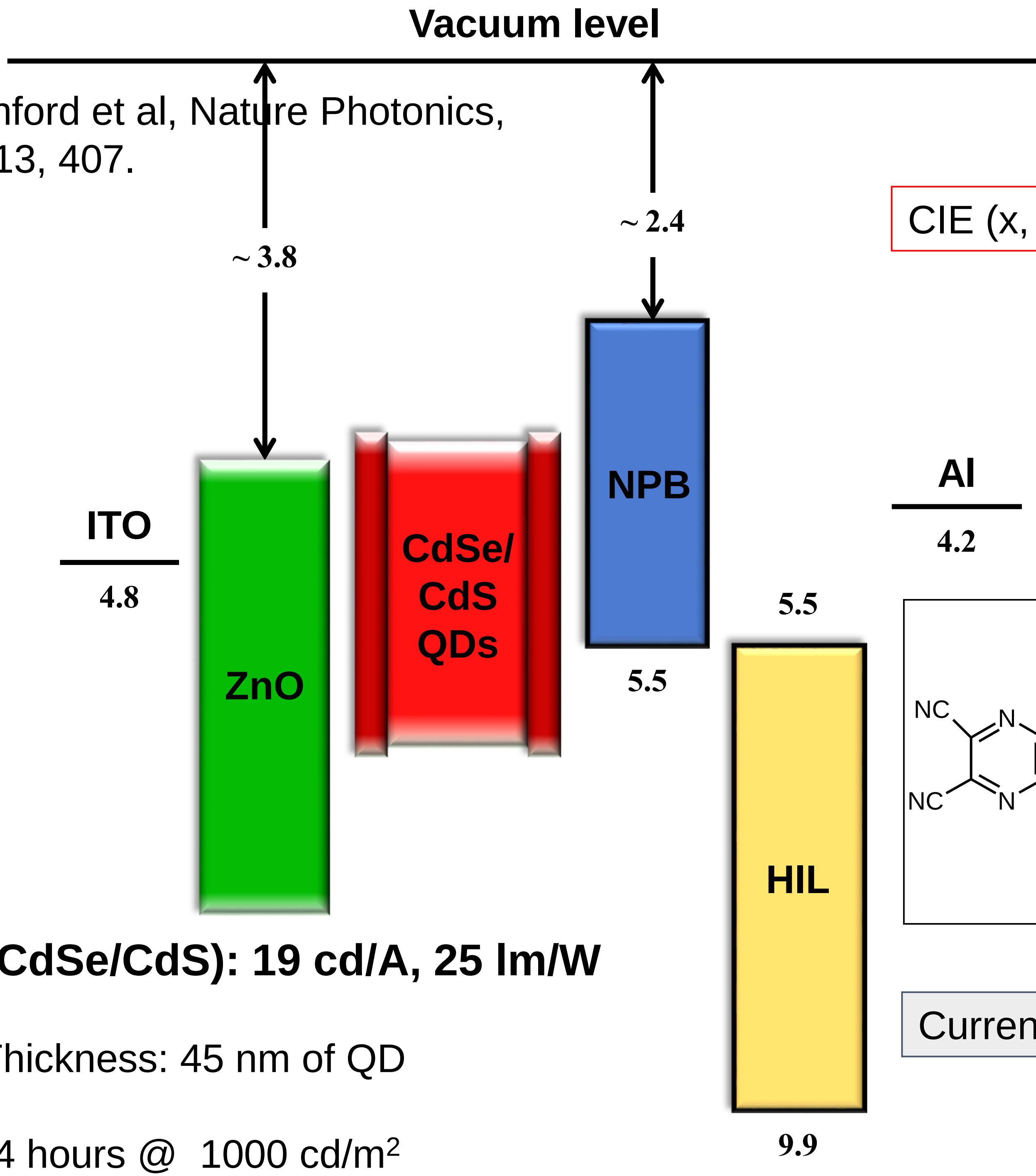

Blue Devices
35
30
25
20
15
10
5
0
1985
1990
1995
2000
2005
2010
2015
2020
Current Efficiency / cd/A
Year
TADF
QLED
(CdSe/ZnS)
OLED (Ph)
Dendrimers
OLED (Fl)
PLED
REC
QLED (Cd Free)
OLED (Fluorescent) - Blue
OLED (Phosphorescent) - Blue
PLED - Blue
Dendrimers - Blue
Rare Earth Chelates - Blue
QLED (CdSe/ZnS) - Blue

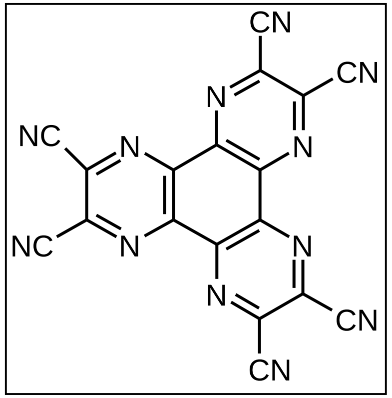


E/eV
1
2
3
4
5
6
7
8
9
-6.5
-9.5
MoO3
a-NPB
-2.3
-5.4
p-NiO
-1.8
-5.4
InP/ ZnS
-2.9
-5.2
Green InP/ ZnS
-3.9
-6.3
CdX (Red)
-4.7
-6.7
CdX (Green)
-4.3
-6.8
CdX (Blue)
-3.9
-6.9
-3.4
-4.0
-4.6
ZnS
TOPO
QD CdSe Red or CdZnSe
-6.6
-7.2
-7.8
ZnO
-4.0
-7.5
TPBI
-2.8
-6.3
TAZ
-3.0
-6.5
LiF/Al
Mg
Al

B. S. Mashford et al, Nature Photonics, 7, May 2013, 407.

CIE (x, y) = 0.68, 0.31)



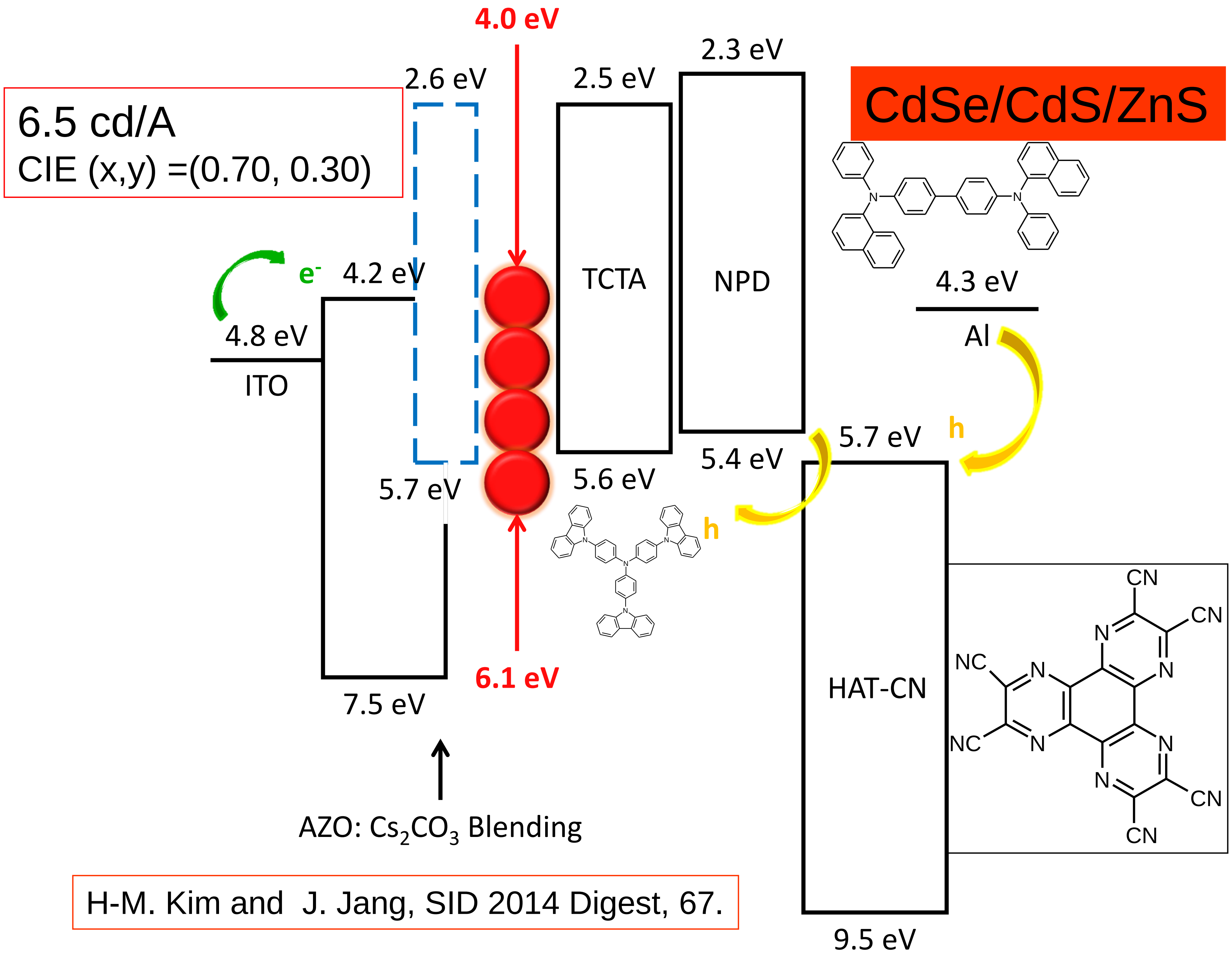


Red QD (CdSe/CdS): 19 cd/A, 25 lm/W

Current Injection: SCL

Optimum Thickness: 45 nm of QD

Life-Time: 4 hours @ 1000 cd/m^2

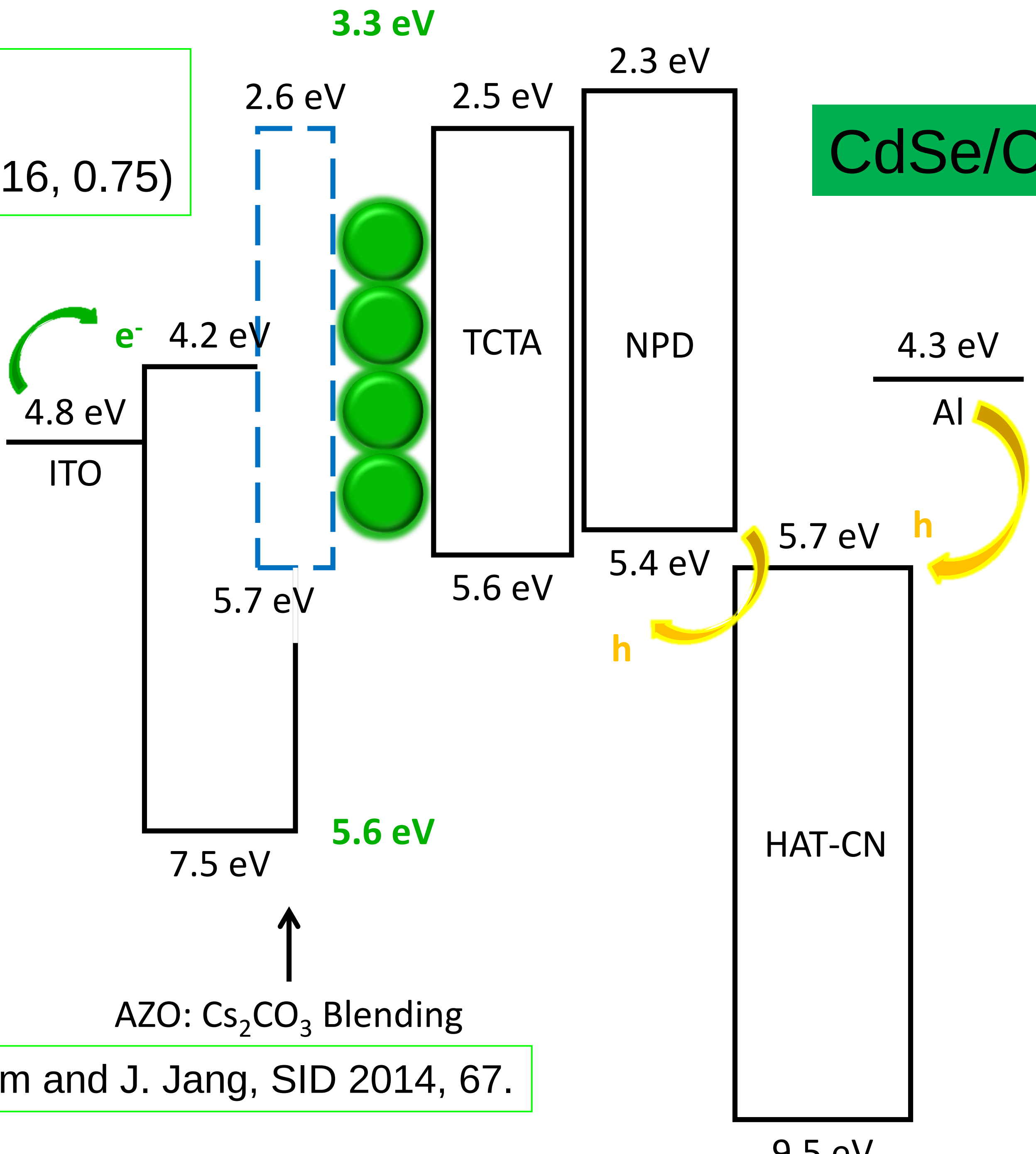


6.5 cd/A
CIE (x,y) =(0.70, 0.30)
CdSe/CdS/ZnS
4.0 eV
2.6 eV
2.5 eV
2.3 eV
e-
4.2 eV
4.8 eV
ITO
TCTA
NPD
4.3 eV
Al
5.7 eV
5.6 eV
5.4 eV
5.7 eV
h
h
7.5 eV
6.1 eV
HAT-CN
CN
CN
NC
NC
N
CN
CN
9.5 eV
AZO: Cs2CO3 Blending
H-M. Kim and J. Jang, SID 2014 Digest, 67.

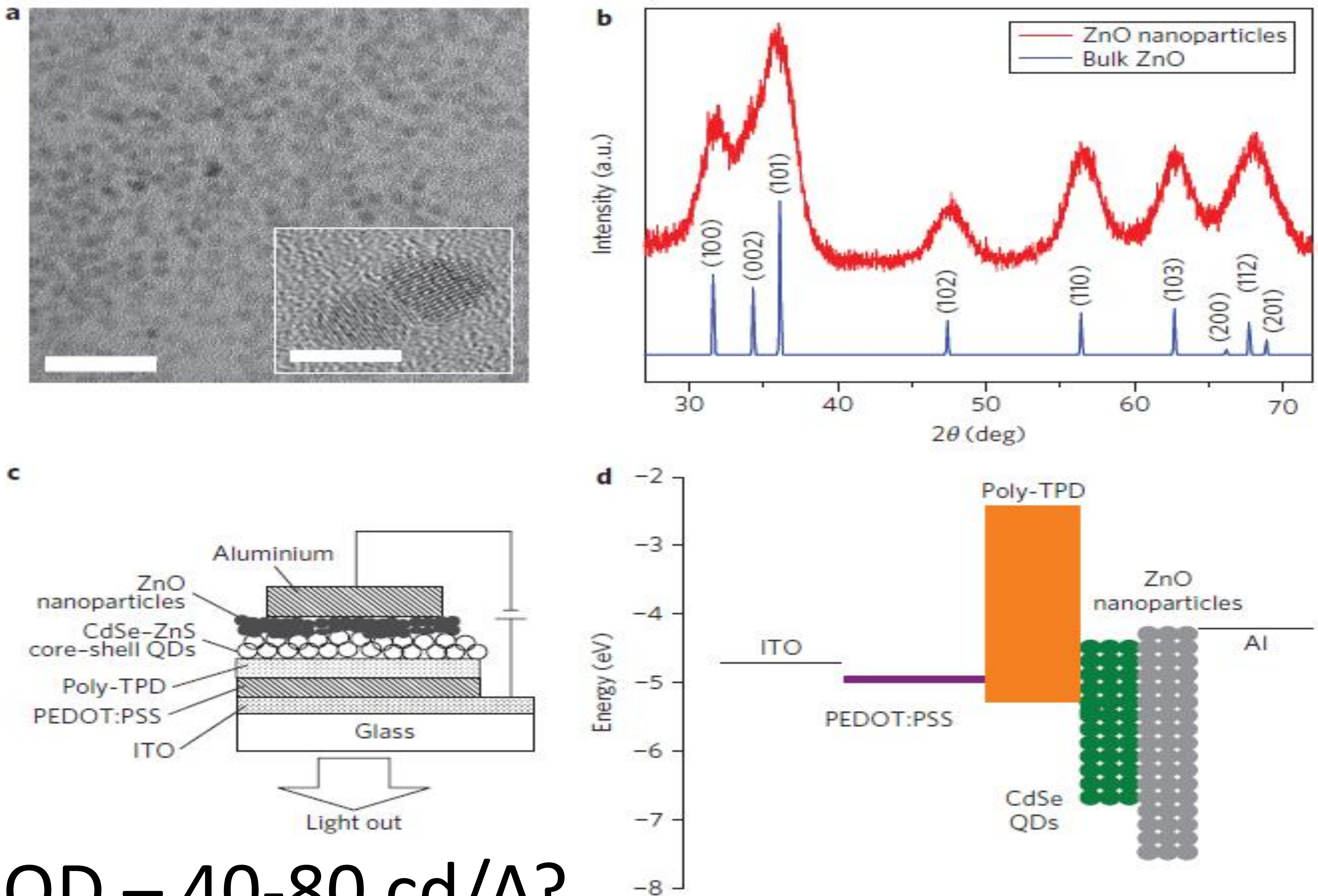
28 cd/A

CIE (x,y)=0.16, 0.75)

CdSe/CdS/ZnS



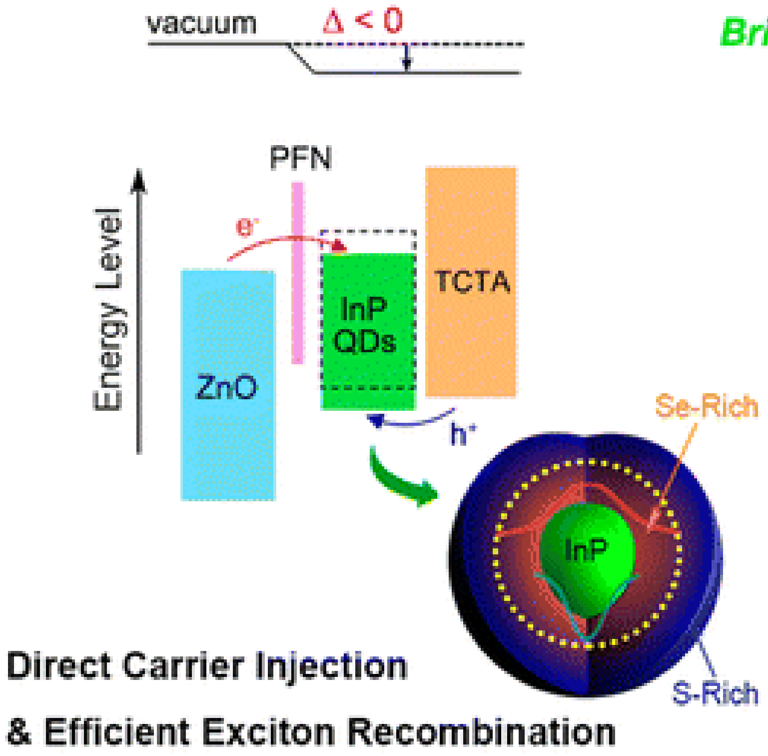
H-M. Kim and J. Jang, SID 2014, 67.

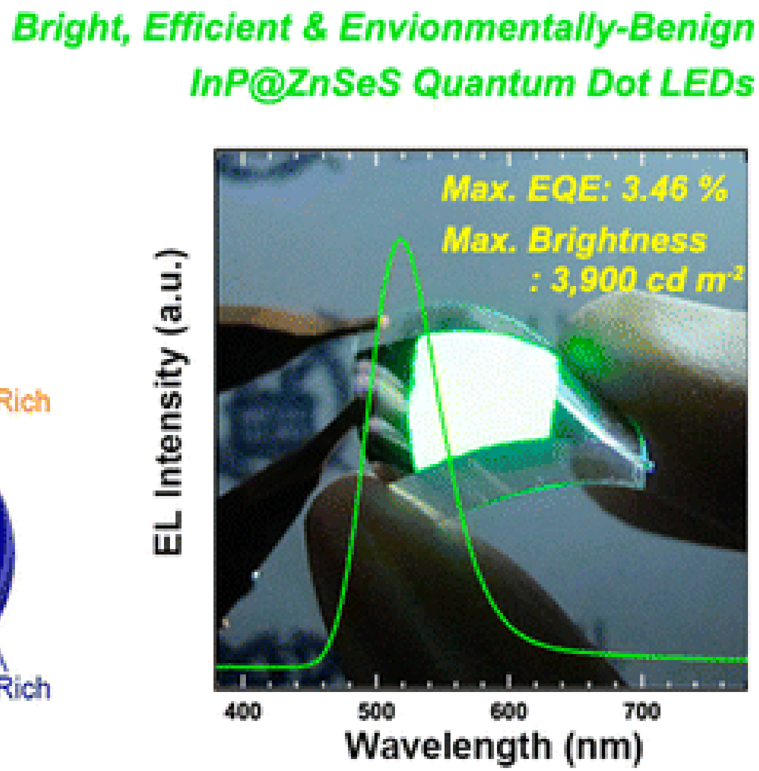


Green QD – 40-80 cd/A?

Holloway et al, SID, 2015

10.9 cd/A



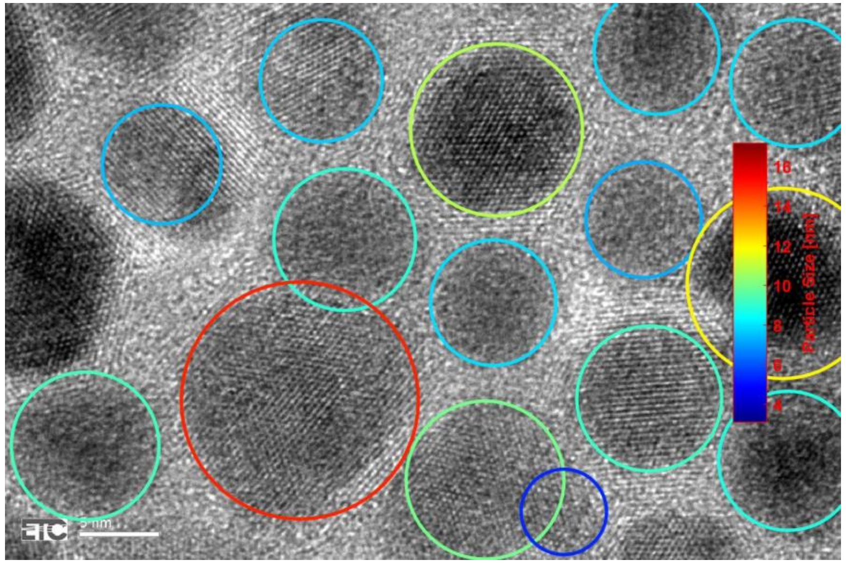


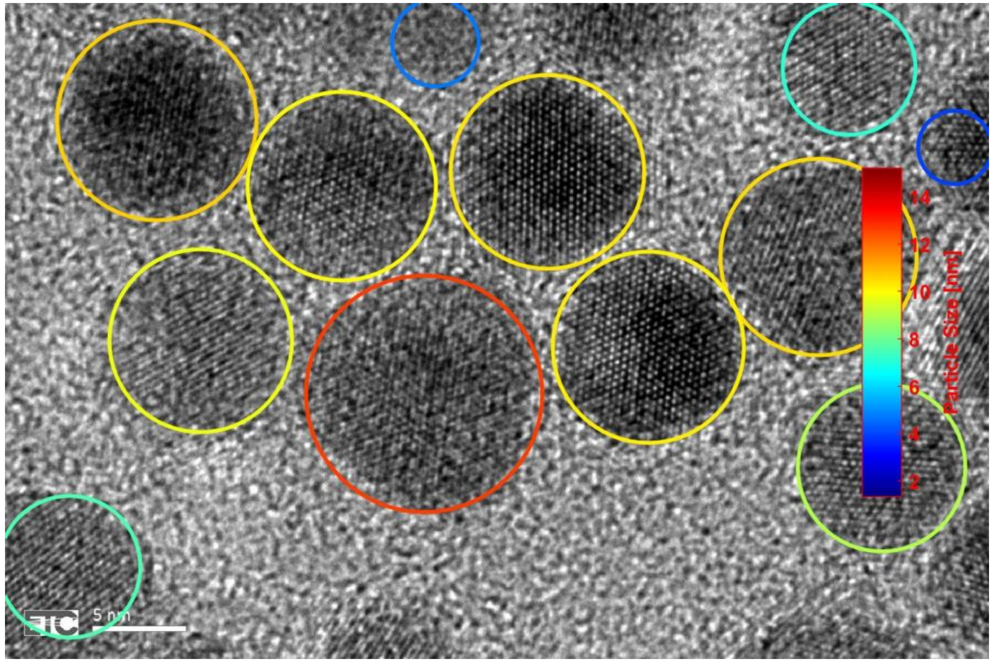
J. Lim et al, ACS Nano., 7, 9019 (2013)

NANOMET

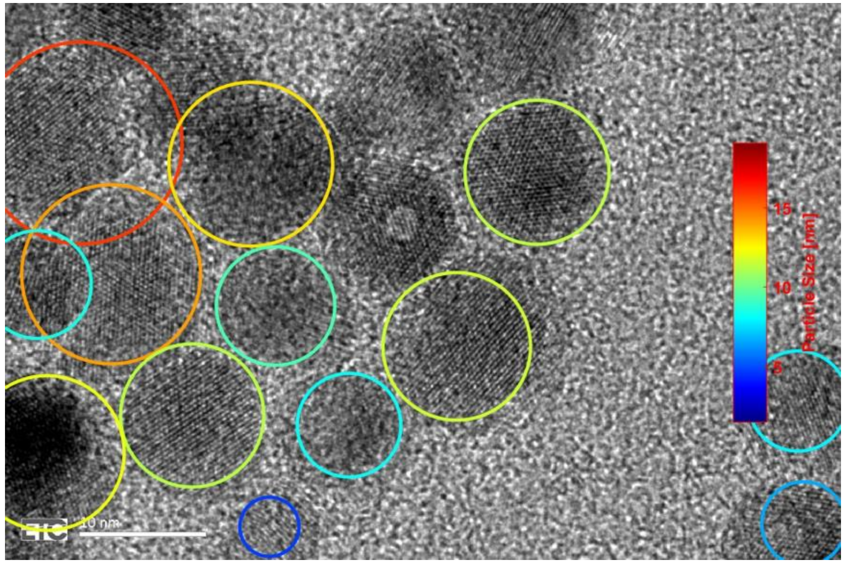
Mean: 8.859485 nm
Std. Dev.: 2.582179 nm
Max: 12.62415 nm
Min: 3.923416 nm
Num. of Measurements: 12
CPU Time: 9.5 sec

Mean: 9.011328 nm
Std. Dev.: 2.265977 nm
Max: 14.90578 nm
Min: 5.368823 nm
Num. of Measurements: 15
CPU Time: 7.4 sec

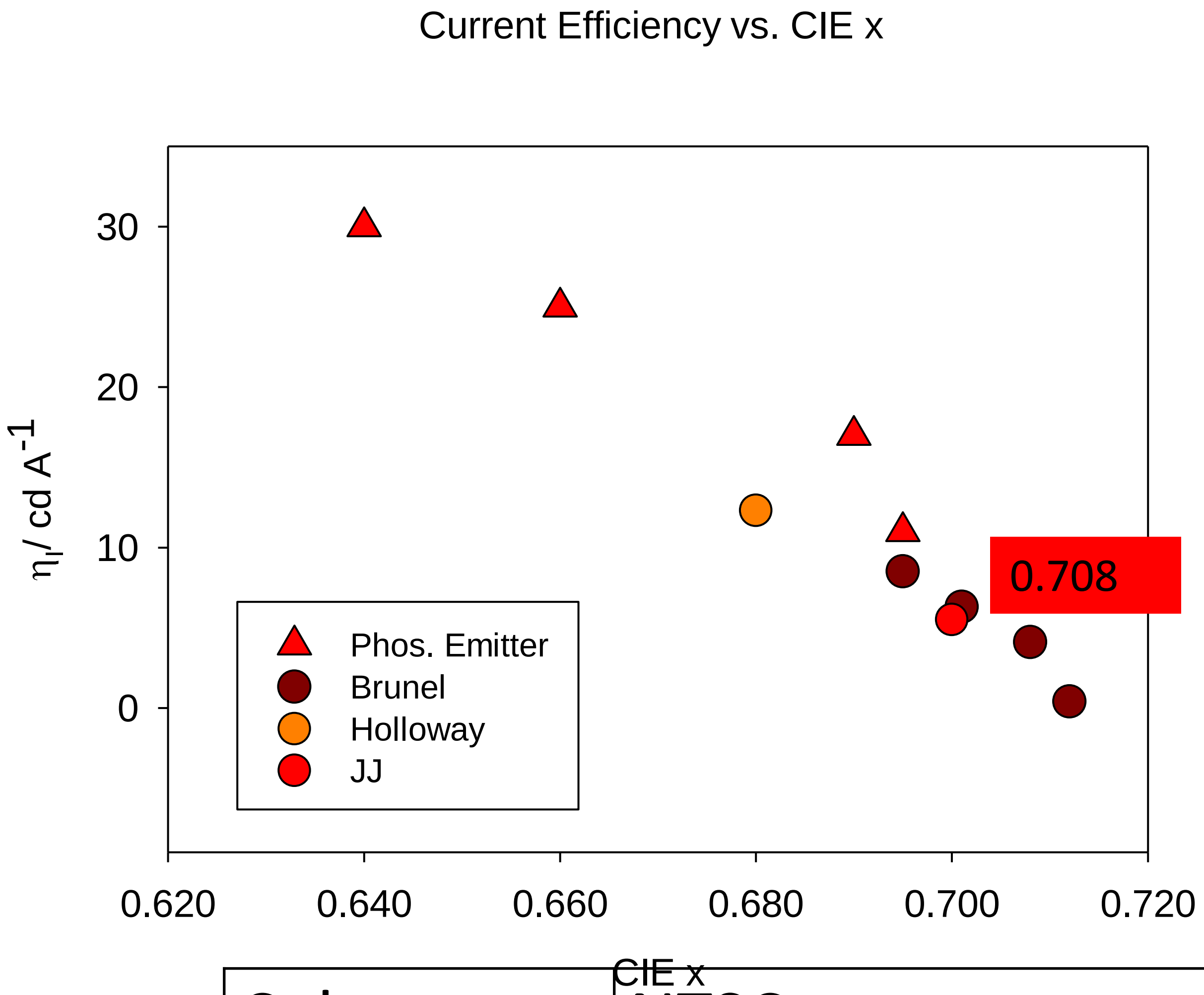


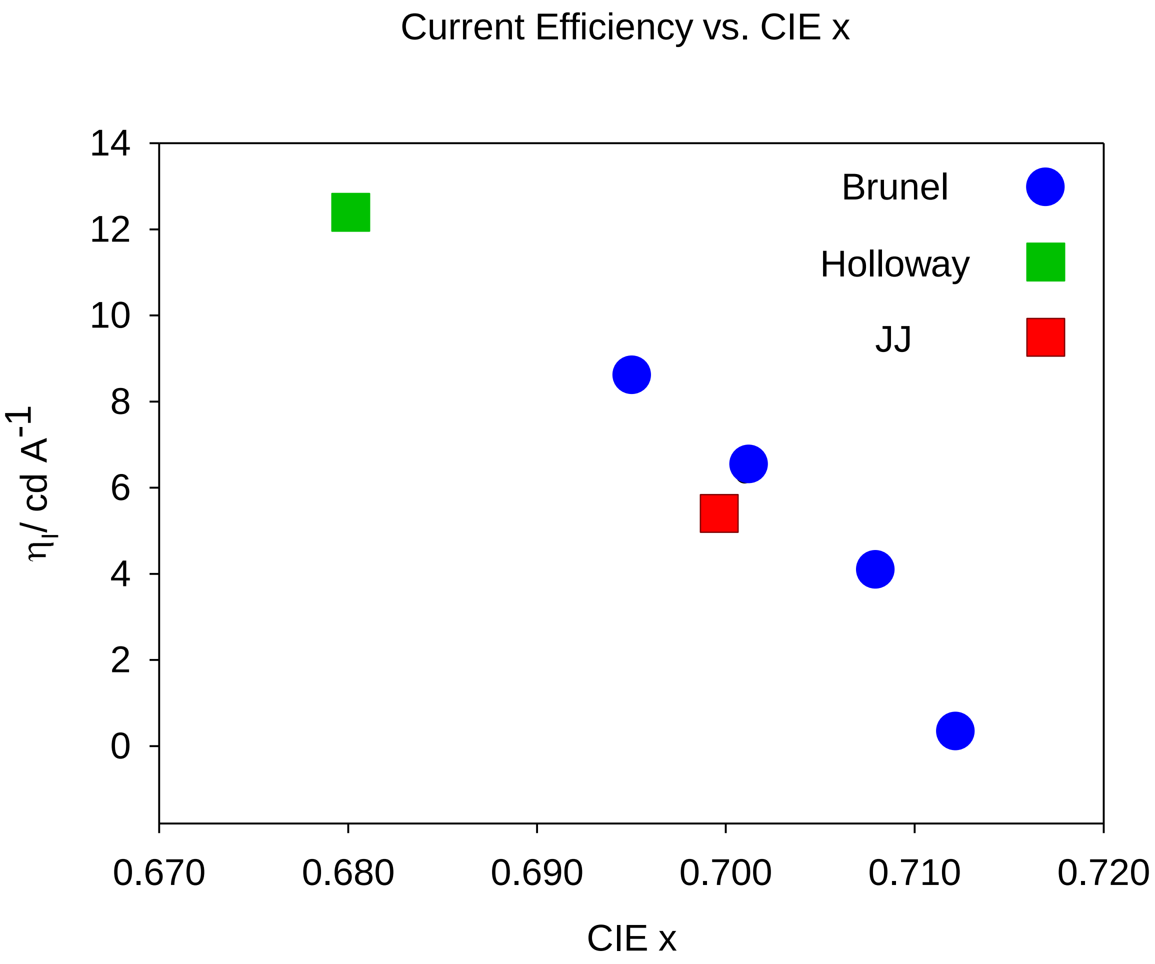


Mean: 10.33649 nm
Std. Dev.: 3.158291 nm
Max: 15.89002 nm
Min: 4.66029 nm
Num. of Measurements: 13
CPU Time: 2.3 sec

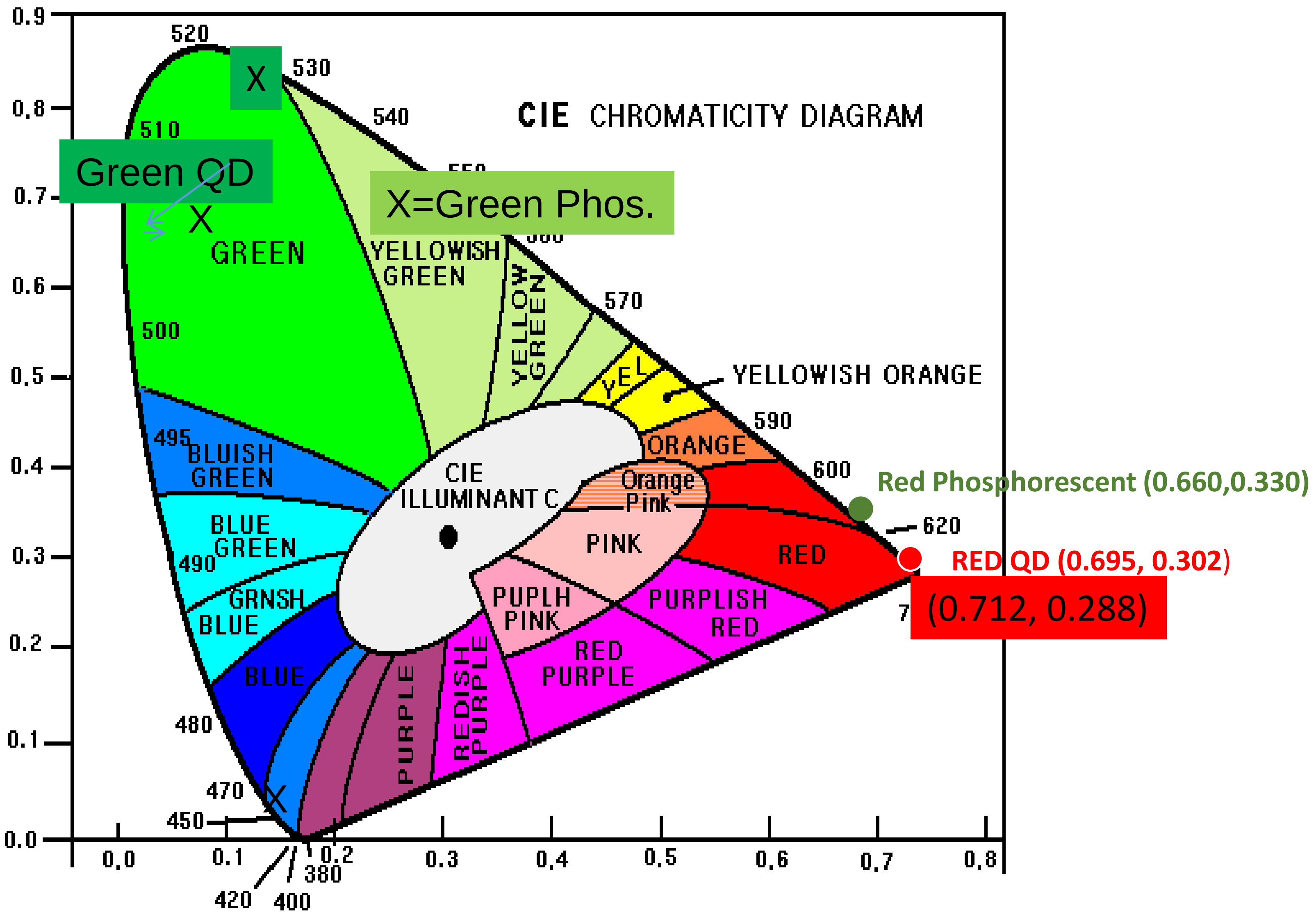


FULLSCALENANO





Colour	NTSC	Rec 2020
Red	(0.670, 0.33)	(0.708, 0.292)
Green	(0.210, 0.710)	(0.170, 0.797)
Blue	(0.140, 0.080)	(0.131, 0.046)


CIE CHROMATICITY DIAGRAM
Green QD
X=Green Phos.
X
GREEN
YELLOWISH GREEN
YELLOW GREEN
YEL
YELLOWISH ORANGE
ORANGE
BLUISH GREEN
BLUE GREEN
GRNSH BLUE
BLUE
CIE ILLUMINANT C
Orange Pink
PINK
RED
PUPLH PINK
PURPLISH RED
RED PURPLE
REDISH PURPLE
PURPLE
Red Phosphorescent (0.660,0.330)
RED QD (0.695, 0.302)
(0.712, 0.288)
520
530
540
510
500
495
490
480
470
450
420
400
380
570
590
600
620
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

Material	CIE(x,y)	Current Efficiency/cd/A	Life-Time at 1000 cdm^{-2}
Phosohorescent red	(0.64, 0.36)	24-30	200000 hours
QD (CdSe/CdS)-QD Vision, MIT	(0.68, 0.32)	18	?
QD (CdSe/CdS/ZnS) Holloway et al	(0.69. 0.30)	12	?
QD (CdSe/CdS/ZnS) JJ et al	(0.70, 0.30)	6.5	?
Brunel	(0.695, 0.305)	10	1000 + hours
Brunel	(0.708, 0.292)	4	250 hours
Brunel	(0.712, 0.288)	0.5-1.0	On going

Conclusions:

1. Highly saturated red (0.712, 0.288) and green [Two types, (0.118, 0.665) and (0.186, 0.738)] QOLEDs have been demonstrated.

2. Life-Time in excess of 1000 hours has been obtained at 1000 cdm^{-2}

High Triplet State and High Tg Hole Transporters: High Performance at High Luminance

Prof. J. Jang

Brunel University London

Kyung Hee University

POWER OLED

TAKOMA

Key Technical Requirements for Deep Blue PHOLEDs

High triplet energy HTL (E_T > 2.8 eV)

- Triplet exciton blocking: No triplet exciton quenching by HTL

High triplet energy ETL (E_T > 2.8 eV)

- Triplet exciton blocking: No triplet exciton quenching by ETL

High triplet energy host (ET > 2.8eV)

- Efficient energy transfer to dopant
- Little back energy transfer from dopant to host

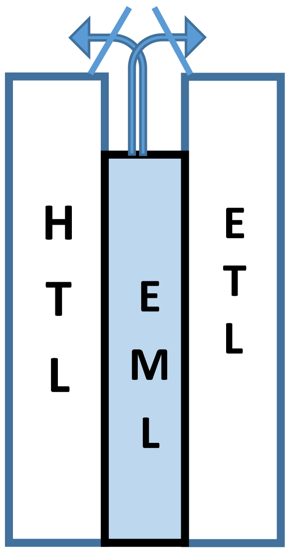
High efficiency blue dopant (ET ~ 2.7 eV)

- Deep blue emission
- High quantum efficiency

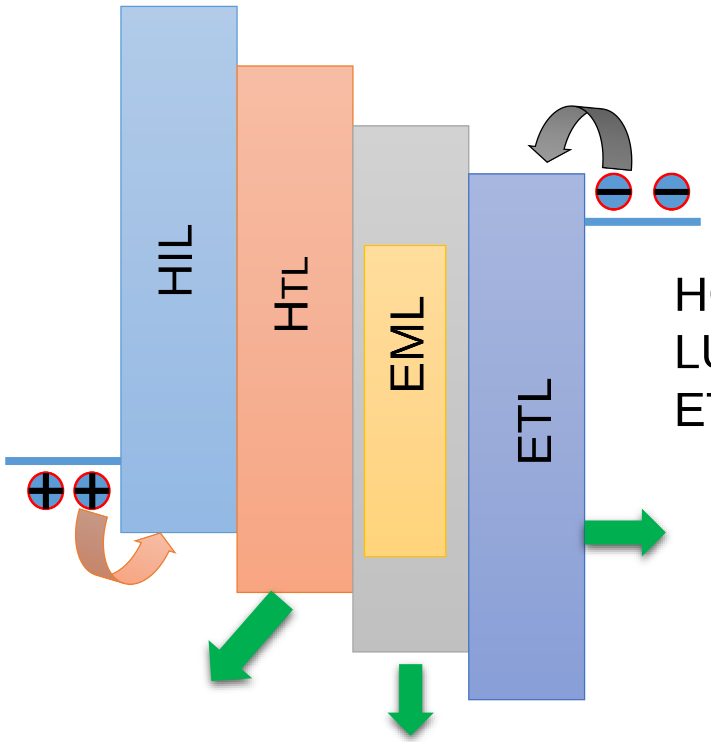
Prof. Jun Yeob Lee, IMID 2014

Ideal Device Design For Phosphorescent OLEDs

Triplet energy diagram



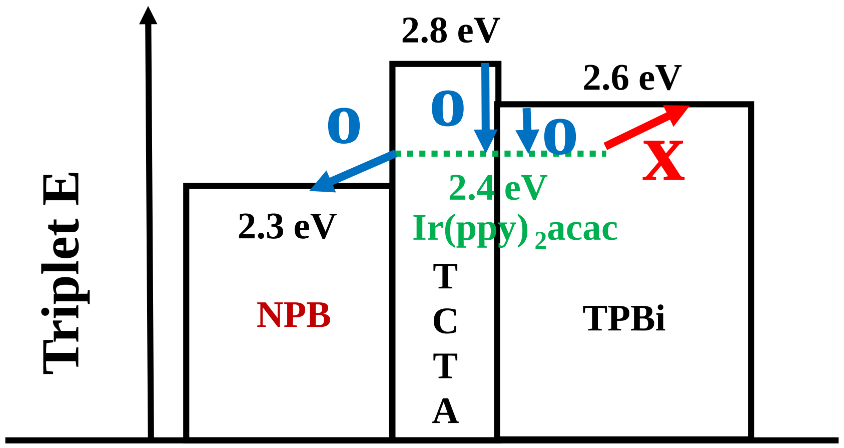
$HOMO_{HIL} < HOMO_{HTL} = HOMO_{EML}$
$LUMO_{HTL} < LUMO_{EML}$
$HTL\ (E_T) > EML\ (E_T)$

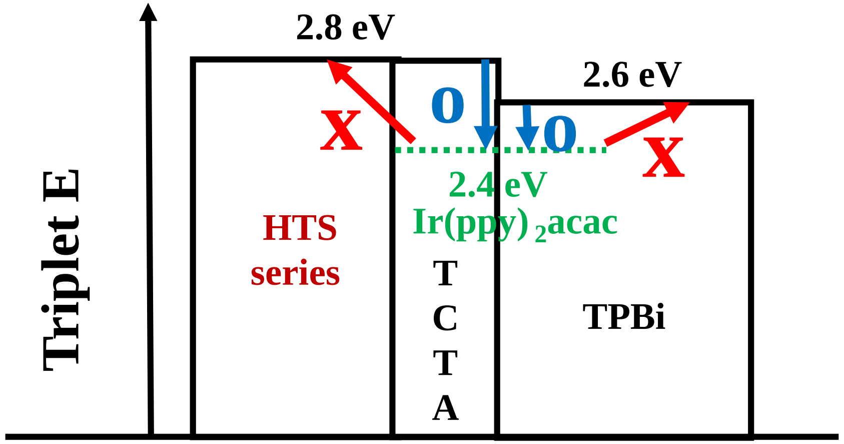


$HOMO_{ETL} > HOMO_{EML}$
$LUMO_{ETL} = LUMO_{EML}$
$ETL(E_T) > EML(E_T)$

High triplet energy host ($Host(E_T) > Dopant\ (E_T)$)
Bipolar charge transport properties
→ Charge balance

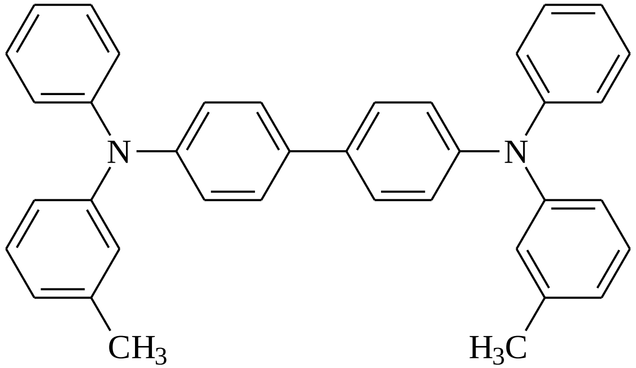
HTS Series - High triplet energy



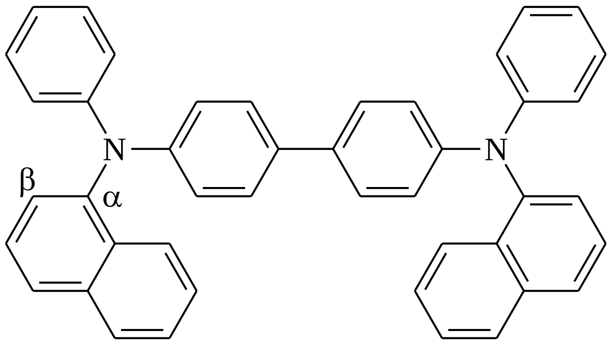


JJ

Hole Transporters

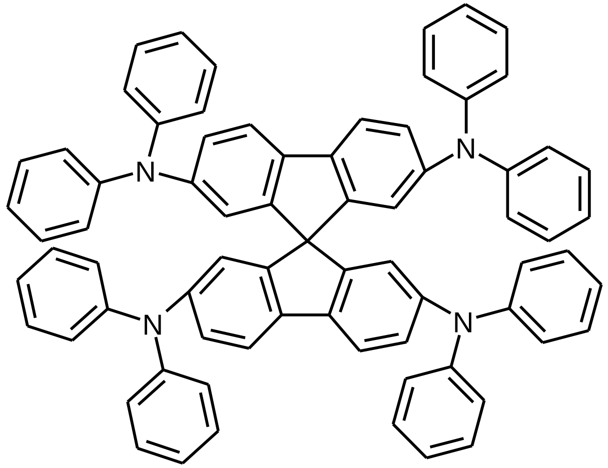


TPD

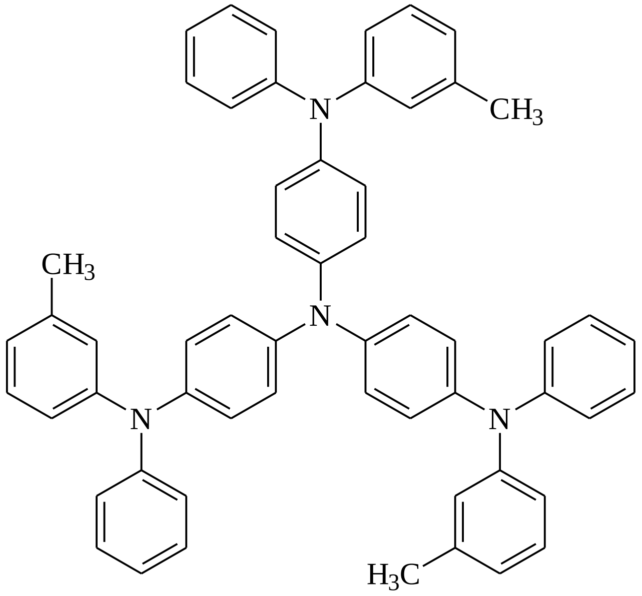


α-NPB

HOMO: -5.4 eV
LUMO: -2.4 eV



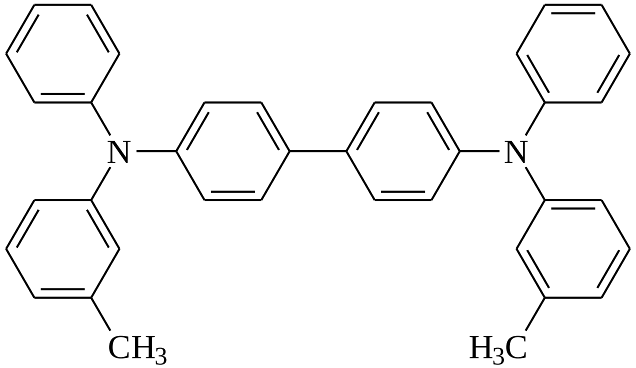
Spiro-TAD



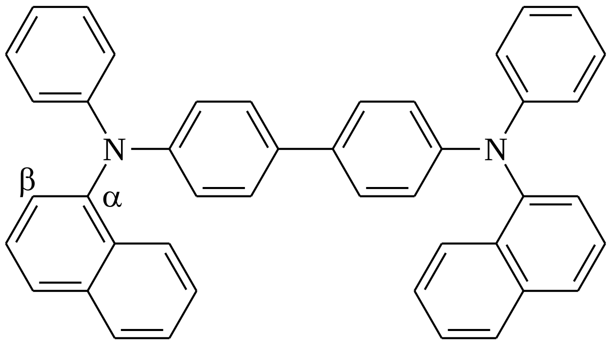
m-MTDATA

Hole Transporter	$\boldsymbol{T_g}$ **(°C)**	$\boldsymbol{\mu_h}$ **(cm^2 *V^{-1} s^{-1}*)**
TPD	61	1×10^{-3}
α-NPB	98	1×10^{-4}
m-MTDATA	75	2.7×10^{-5}
Spiro-tad	133	1×10^{-5}

Hole Transporters

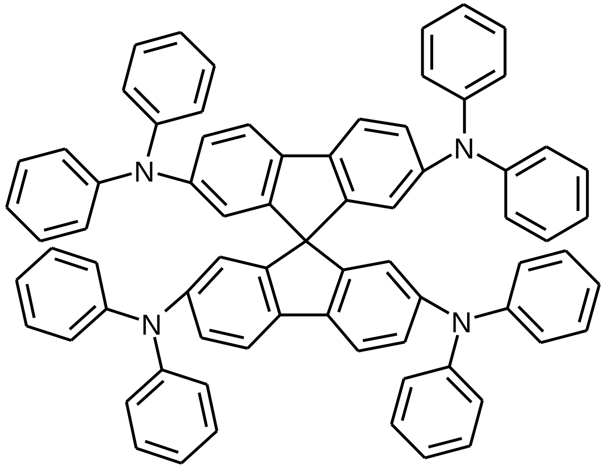


TPD



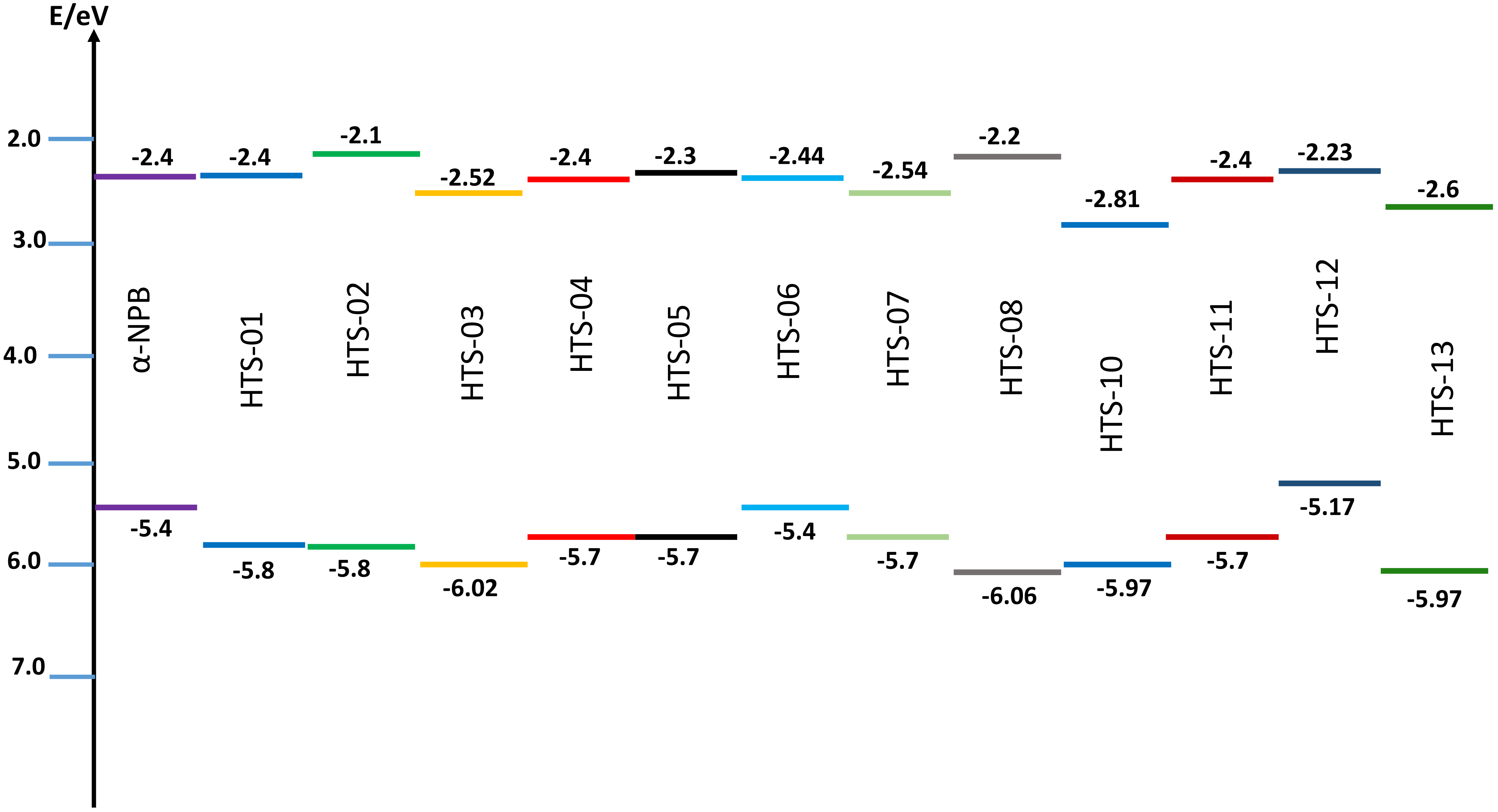
α-NPB

HOMO: -5.4 eV
LUMO: -2.4 eV



Spiro-TAD

Material	Tg/^{0}C	HOMO (eV)	LUMO (eV)	T_1 (eV)
TPD	61	-5.5	-2.3	2.3
α-NPB	99	-5.4	-2.4	2.4
Spiro-TAD	133	-5.4	-2.5	2.4



E/eV
2.0
3.0
4.0
5.0
6.0
7.0
α-NPB
HTS-01
HTS-02
HTS-03
HTS-04
HTS-05
HTS-06
HTS-07
HTS-08
HTS-10
HTS-11
HTS-12
HTS-13
-2.4
-2.4
-2.1
-2.52
-2.4
-2.3
-2.44
-2.54
-2.2
-2.81
-2.4
-2.23
-2.6
-5.4
-5.8
-5.8
-6.02
-5.7
-5.7
-5.4
-5.7
-6.06
-5.97
-5.7
-5.17
-5.97

(12) UK Patent Application (19) GB (11) 2513013 (13) A

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(22) Date of Filing: 27.03.2014

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(51) INT CL:
C07D 339/08 (2006.01) ***C07D 279/36*** (2006.01)
C07D 407/14 (2006.01) ***C07D 409/10*** (2006.01)
C07D 417/10 (2006.01) ***C07D 417/14*** (2006.01)
C09K 11/06 (2006.01) ***H01L 51/00*** (2006.01)
H01L 51/50 (2006.01) ***H01M 14/00*** (2006.01)
H05B 33/14 (2006.01)

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JP 2011178742 A **JP 2009196919 A**
JP 2000186066 A **JP 2000063335 A**
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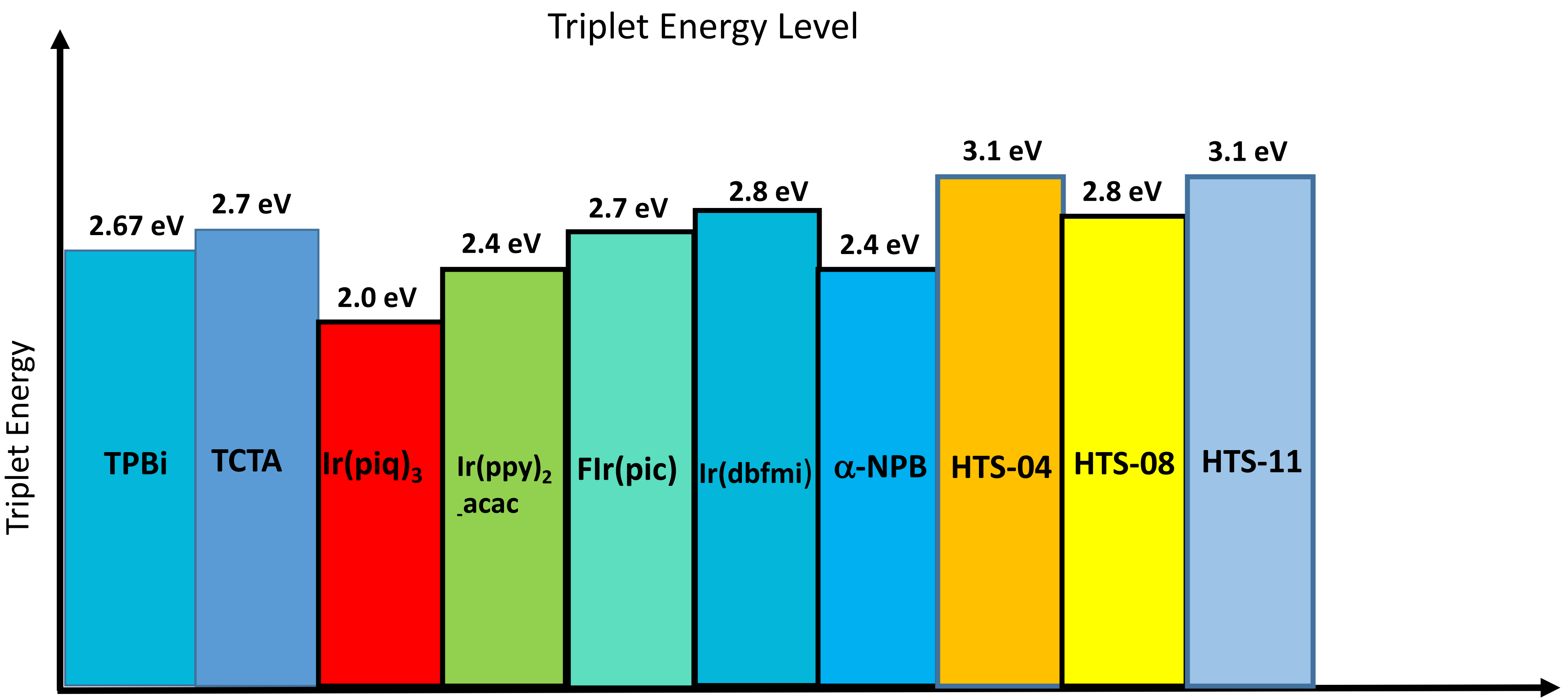
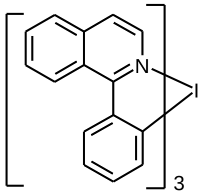
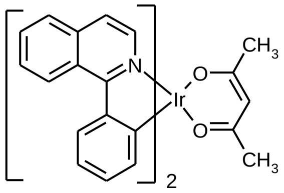
Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

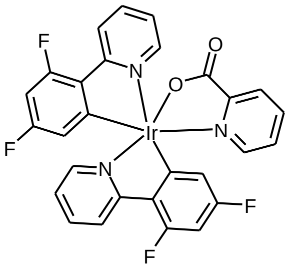




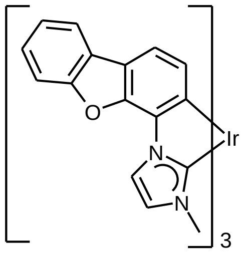
Ir(piq)$_3$



Ir(ppy)$_2$acac

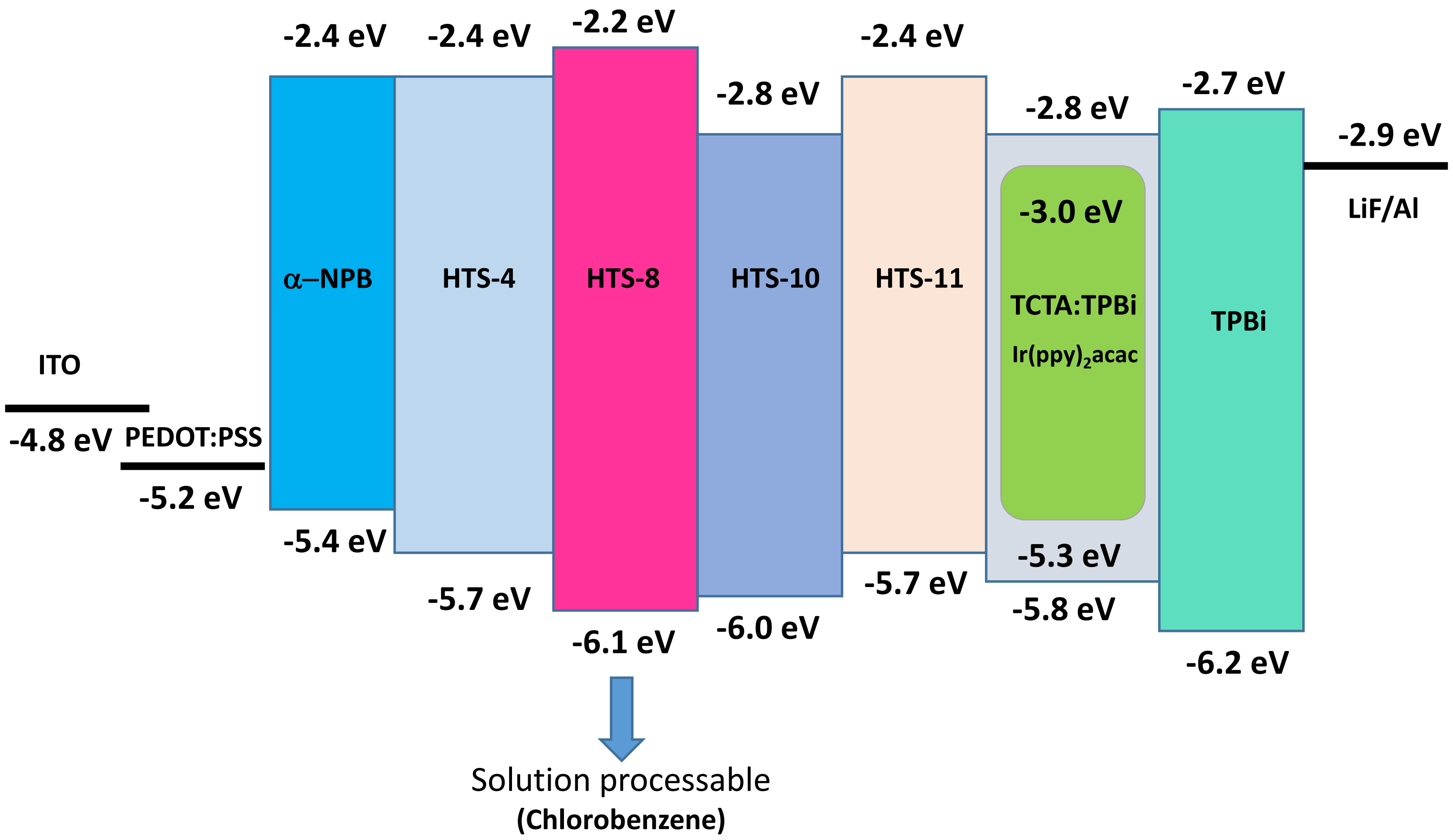


FIr(pic)

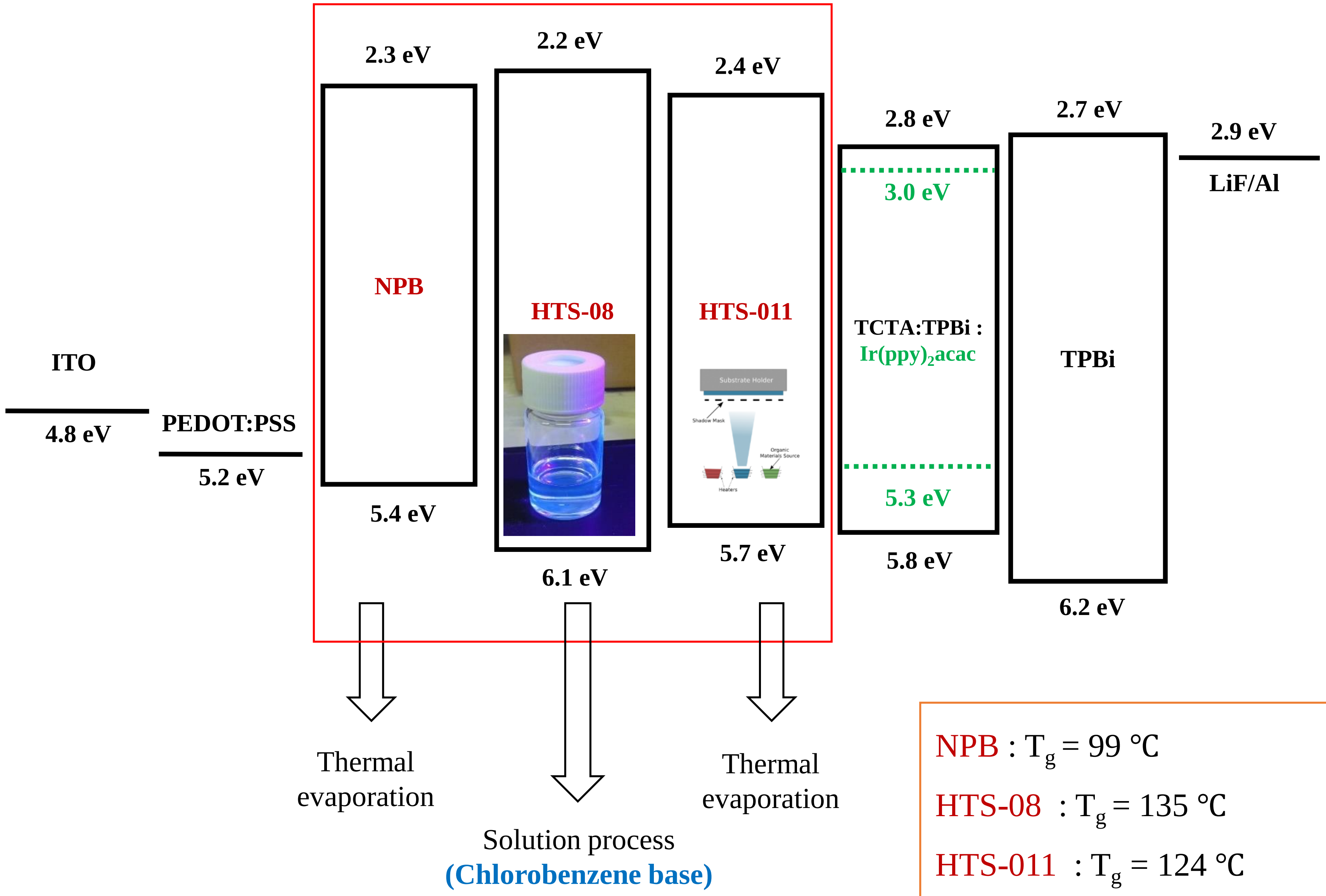


Ir(dbfmi)

HOMO-LUMO values of Hole Transporters



Energy band diagram



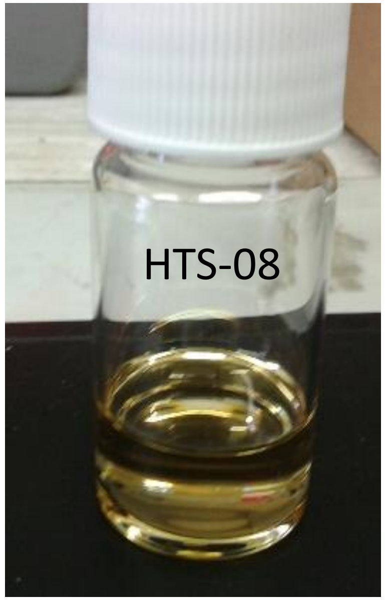
NPB : T_g = 99 ℃

HTS-08 : T_g = 135 ℃

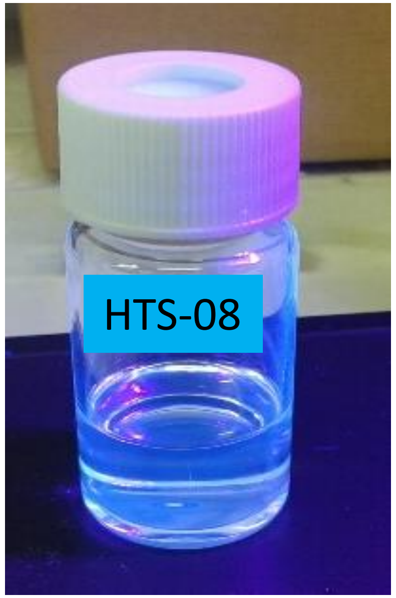
HTS-011 : T_g = 124 ℃

Chlorobenzene : b.p = 131 °C

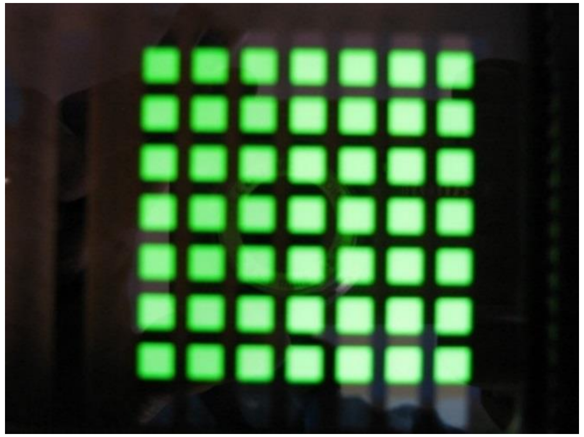
Solution Processed Devices



HTS-8 in Chlorobenzene (Normal light)



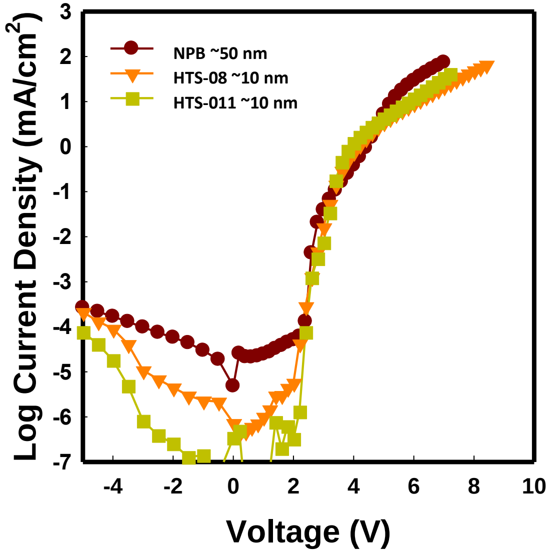
HTS-8 in Chlorobenzene (Under UV light)

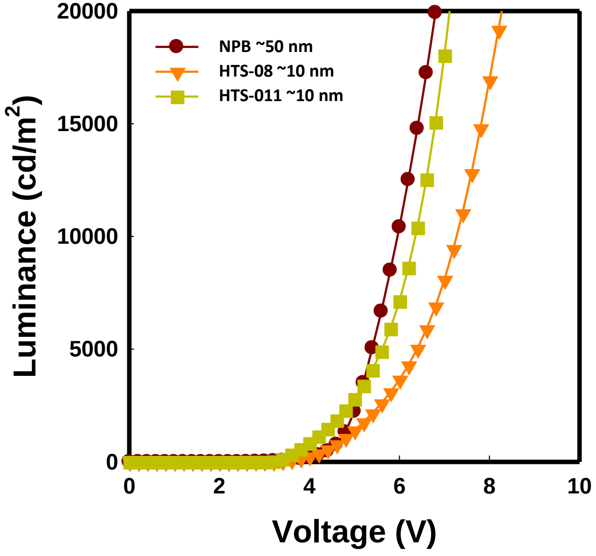


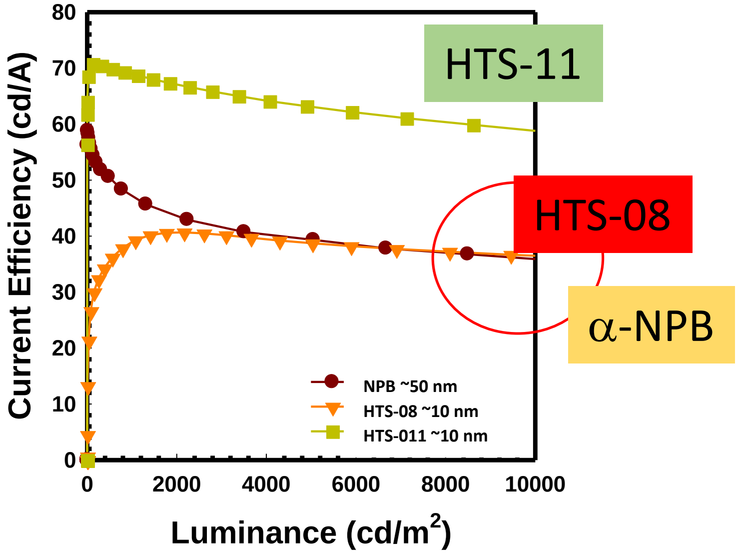
HTS-08

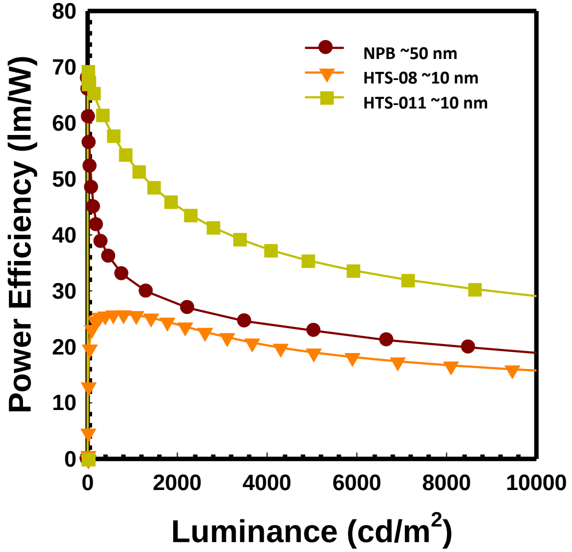
Device structure: ITO/PEDOT:PSS(40 nm)/HTS/TCTA:TPBi(3:7):Ir(ppy)$_2$acac (10 %)(20 nm)/TPBi(30 nm)/LiF(0.5 nm)/Al

Device structure: ITO/PEDOT:PSS(40 nm)/HTS/TCTA:TPBi(3:7):$Ir(ppy)_2acac$ (10 %)(Total thickness 20 nm)/ TPBi(30 nm)/LiF(0.5 nm)/Al







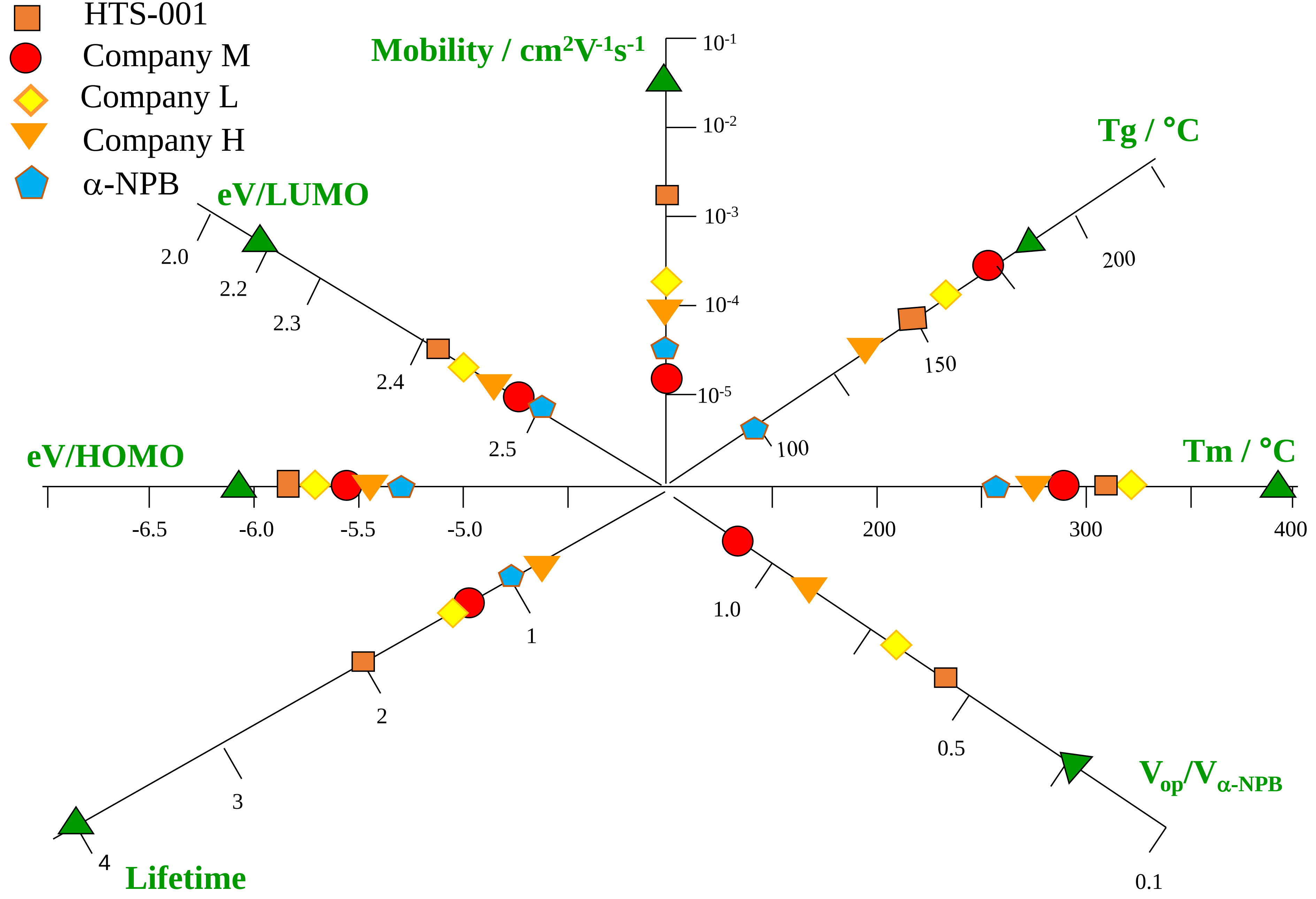


HTL	V_T (V)	V_D (V)	Maximum		@1000nits		@10000nits	
			C/E (cd/A)	P/E (lm/W)	C/E (cd/A)	P/E (lm/W)	C/E (cd/A)	P/E (lm/W)
NPB ~50 nm	2.48	4.66	58.93	68.07	47.02	31.70	35.89	18.93
HTS-008 ~10 nm	3.01	4.75	40.66	25.85	38.92	25.73	36.49	15.77
HTS-011 ~10 nm	2.65	4.11	70.75	69.29	68.95	52.71	58.81	29.07

Improvement of efficiency of HTS-11 over α-NPB (VTE)

Luminance/ cd m^{-2}	Improvement in current efficiency	Improvement in Power efficiency
1000	47%	66%
10000	64%	54%

HOLE Transporters



Typical Energy Level Diagram