White Light-Emitting Device on Flexible Plastic Substrates

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Contents

Introduction – Solid-State Lighting

From Siemens

From Philips

High efficient LEDs for conventional light sources

www.ollaproject.org

Introduction – Back Light for LCD

LG Philips LCD 100" LCD TV (SID 2006)

UDC 2.2" white PHOLED backlight

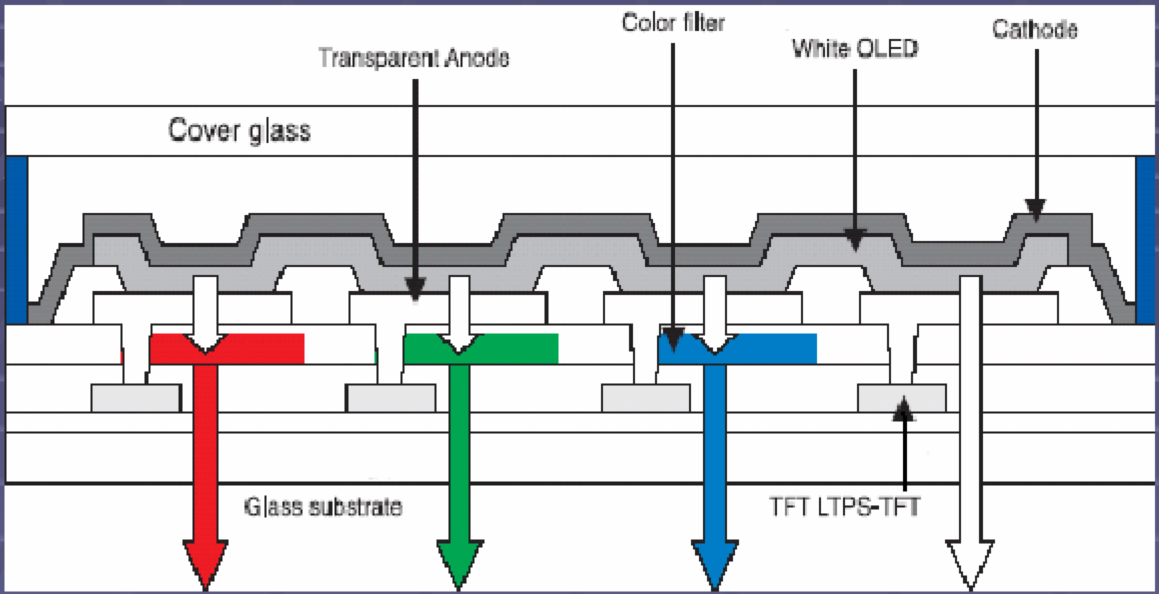
Problems of conventional line source backlight

- 10~40 fluorescent lamp and inverters are used
- Complicate assembly & high cost

→ **Plane light source is needed for AM-LCDs**

Y. Tung et al, *Proceeding of* ***SID, 2004.***

Introduction : Full color AM-OLED



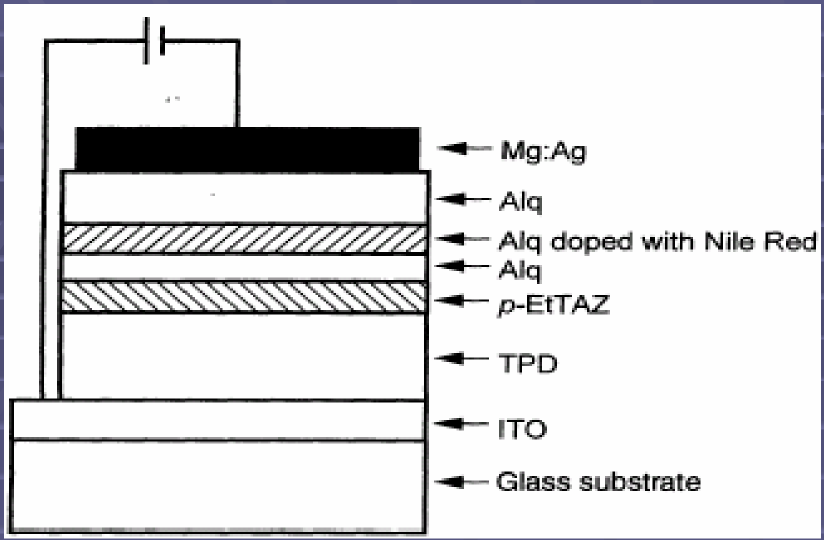
15" full color AM display by Eastman Kodak Co. and SANYO Electric Co.

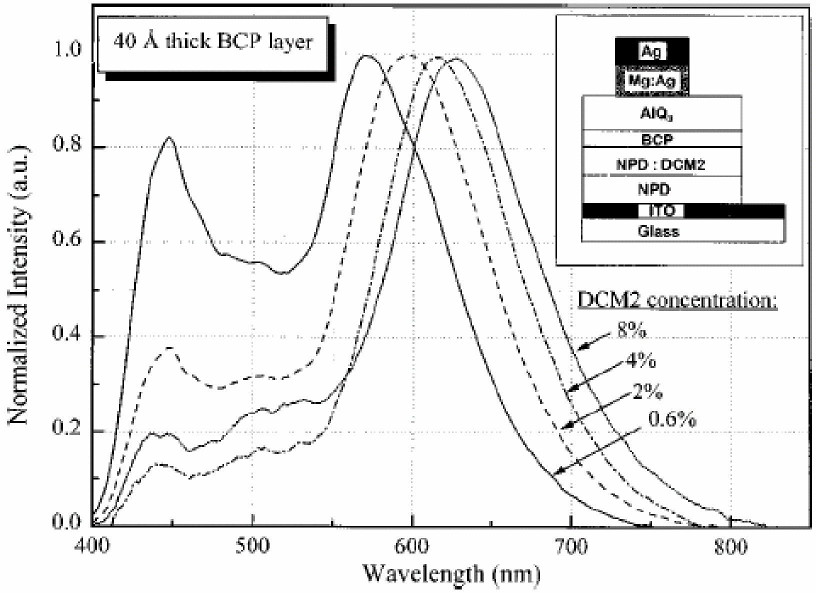
Color filters		Efficiency (cd/A) @ 20 mA/cm2	Color (CIEx, CIEy)
	Initial white color	16.9 cd/A	0.38, 0.39
Red filter	Red color	3.4 cd/A	0.64, 0.36
Green filter	Green color	8.8 cd/A	0.34, 0.57
Blue filter	Blue color	1.4 cd/A	0.12, 0.12

T. K. Hatwar et al, *Proceedings of SPIE, vol. 5214, 2004*

Historical Review for White Light-Emitting Devices

White Light Development – Small Molecules (1)





TPD : Blue emission (~420 nm)

(triphenyldiamine derivatives)

Alq_3 : Green emission (~520 nm)

(tris(8-hydroxyquinolinato) aluminum III)

Nile Red : Red emission (~600 nm)

→ L_{max} = 2200 cd/m^2 at 16V

J. Kido et al, *Science, 1995*.

α-NPD : Blue emission (~430 nm)
(4,48bis[*N*-(1-napthyl-*N*-phenyl-amino)biphenyl)

Alq_3 : Green emission (~520 nm)

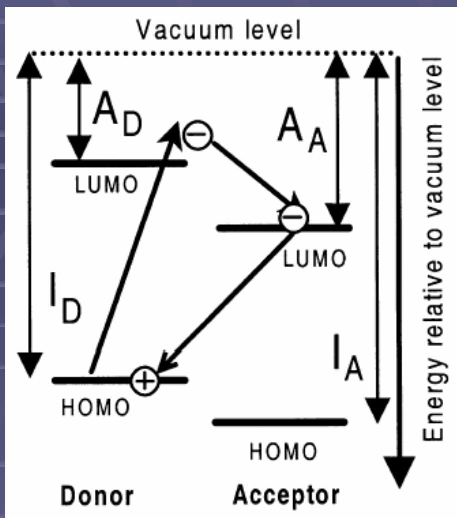
DCM_2 : Red emission (~580 nm)
([2-methyl-6-[2-(2,3,6,7-tetrahydro-1H, 5H-benzo [*ij*] quinolizin-9-*y*)!ethenyl]-4H-pyran-4-ylidene]propanedinitrile)

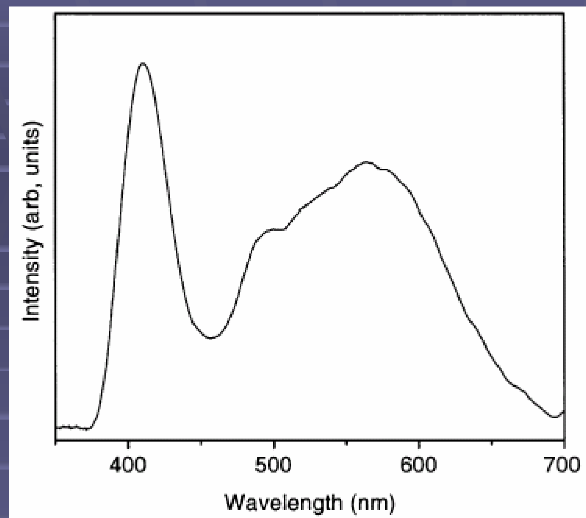
→L_{max} = 13500 cd/m^2 at 18.2V

CIE Coordinates : (0.33, 0.33)

R. S. Deshpande et al, *Appl. Phys .Lett., 1999*.

White Light Development – Small Molecules (2)





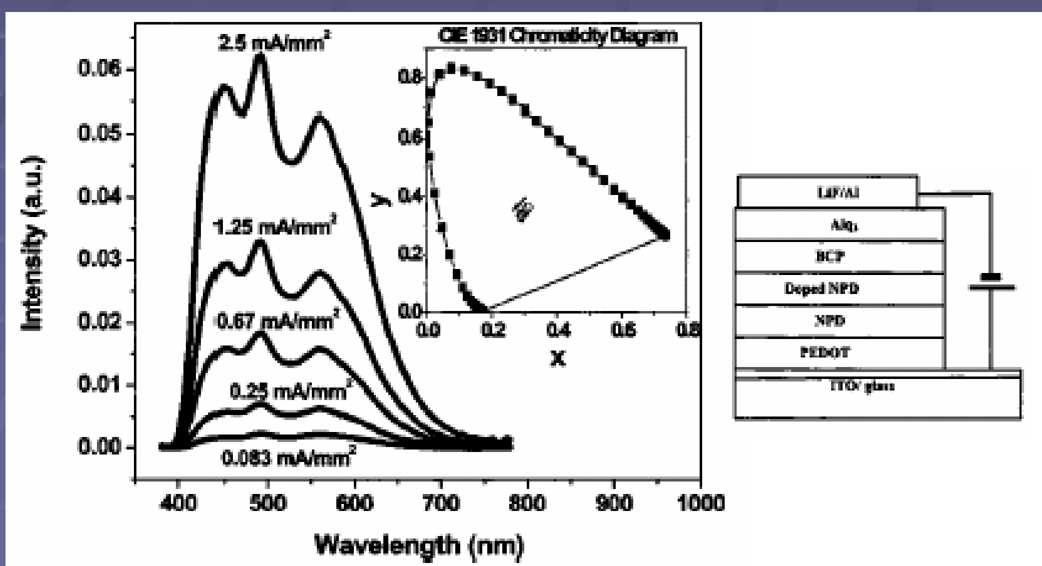
Blend of 90% TPD and 10% STO
(2,5-bis(trimethylsilyl thiophene)-1,1-dioxide)

Both blue emission (~ 400nm)

→ Lmax = 150 cd/m2

CIE coordinates: (0.34, 0.38)

M. Mazzeo et al, *Physica E, 2002*.



α-NPD: Hole transporting layer

BCP: Hole blocking layer
(2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline)

Alq_3 : Electron transporting layer

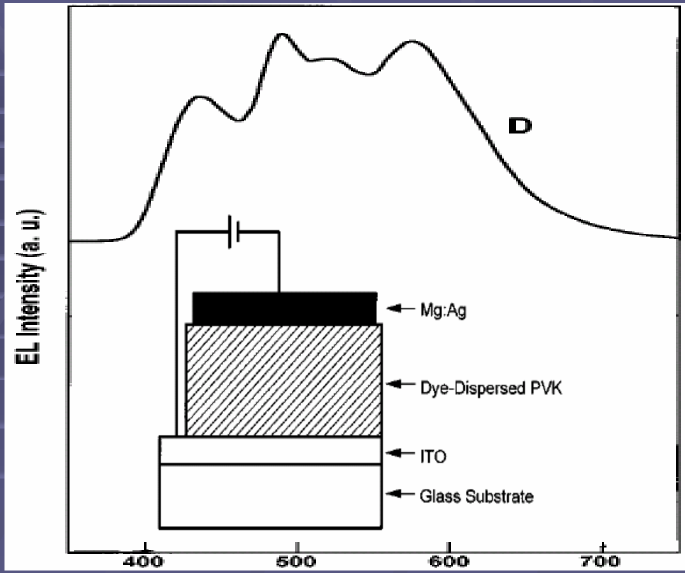
Doped NPD: White light-emitting material

→L_{max} = 2200 cd/m^2 at 16V

CIE coordinates: (0.29, 0.33)

Y. Shao et al, *Appl. Phys. Lett.*, *2004*.

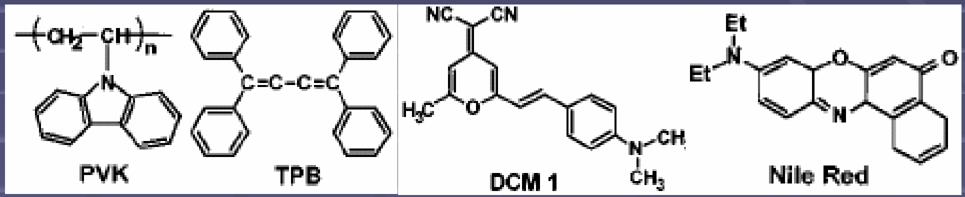
White Light Development – Polymers (1)



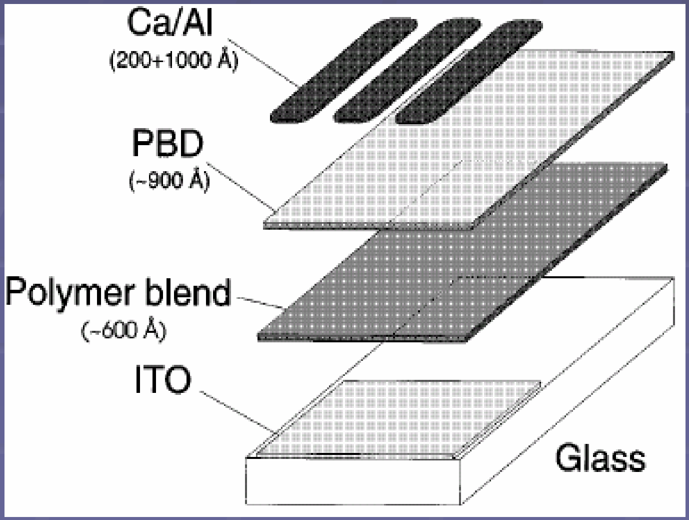
Dye dispersed PVK layer

(TPB at 440 nm, Coumarin 6 at 490 nm, DCM 1 at 520 nm, and Nile Red at 580 nm)

→L_{max} = 4100 cd/m^2 at 20V

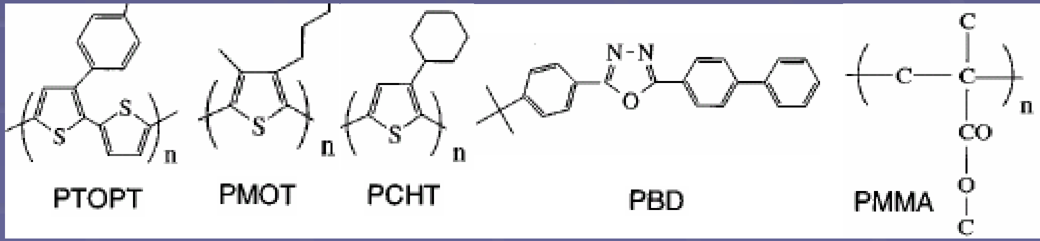


J. Kido et al, ***Appl. Phys. Lett.*****, *1995*.**



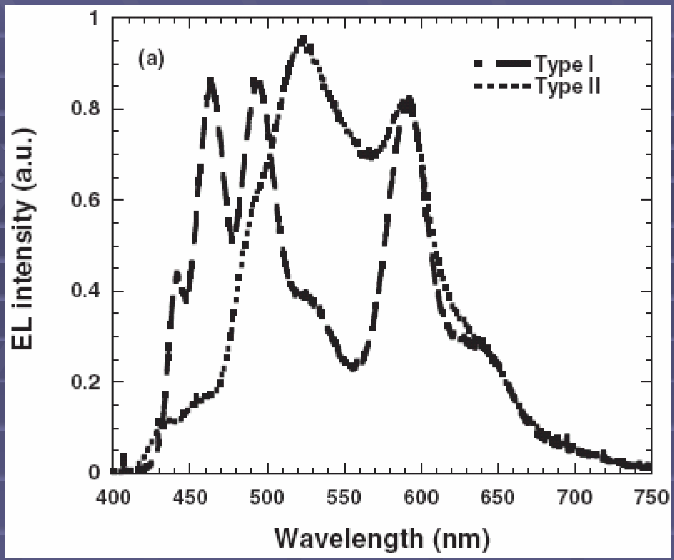
Polymer blend light- emitting layer
(the weight ratio 10:4:1:1 of PMOT, PCHT, PTOPT, and PMMA)
PBD: electron transporting layer

→ CIE is dependant of applying voltage



M. Granström et al, ***Appl. Phys. Lett.*****, *1996*.**

White Light Development – Polymers (2)



Polymer blend light-emitting layer (LEL)

(Al:Ba/LEL/PEDOT:PSS/ITO/Glass)

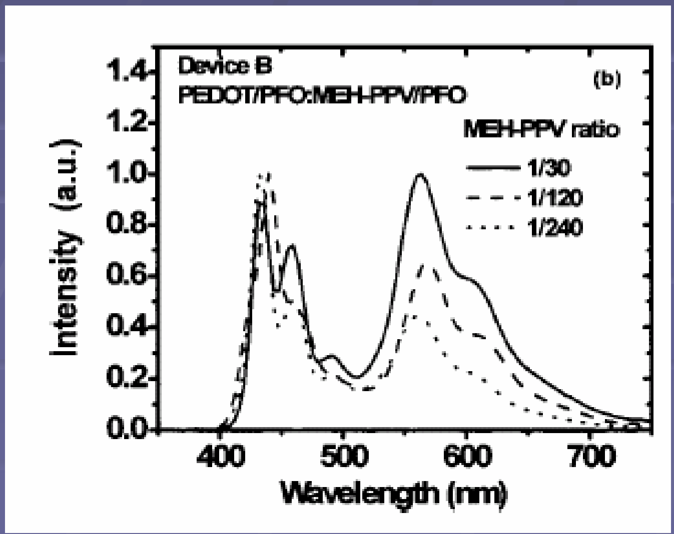
Ratio of Ir(HFP)$_3$:PFO (Red: Blue & Green) ≤ 10^{-3}

(tris (2,5-bis-2'-(9',9'-dihexylfluorene) pyridine) iridium $_{III}$)

- Type I: Ir(HFP)$_3$:PFO, Type II: Ir(HFP)3:PFO:PFO-F(1%)

→L_{max} = 11000 cd/m^2 at 17V / 1973 CIE (0.33, 0.32)

X. Gong et al, *Adv. Mater.*, ***2004*.**



Polymer blend light-emitting layer

(Al:Ca/PFO/PFO:MEH-PPV/PEDOT/ITO)

PFO: Blue emission (~ 430 nm)

(Poly (9,9-dioctyl-fluorene))

MEH-PPV: Orange emission (~ 560 nm)
(Poly [2-methoxy-5 (2'-ethylhexyloxy)-1,4-phenylene vinylene])

→L_{max} = 3000 cd/m^2 at 10V / 1973 CIE (0.34, 0.34)

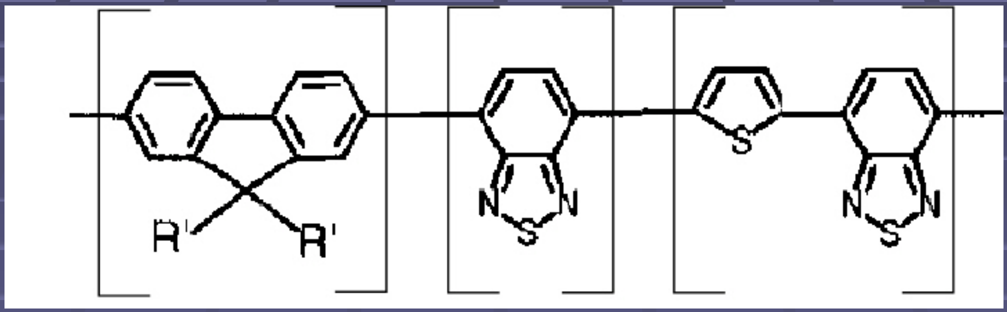
G. Ho et al, *Appl. Phys. Lett.*, ***2004*.**

Preparation Details for Polymer Blend

Polymers Used to Make a Polymer Blend

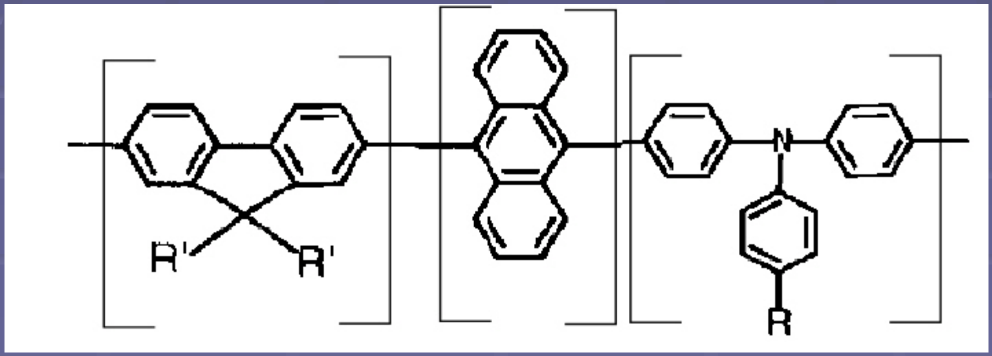
Dow Chemical Red F (Guest : Acceptor)

- Poly(fluorene-co-benzothiadiazol-co-thienyl-benzothiadiazol)



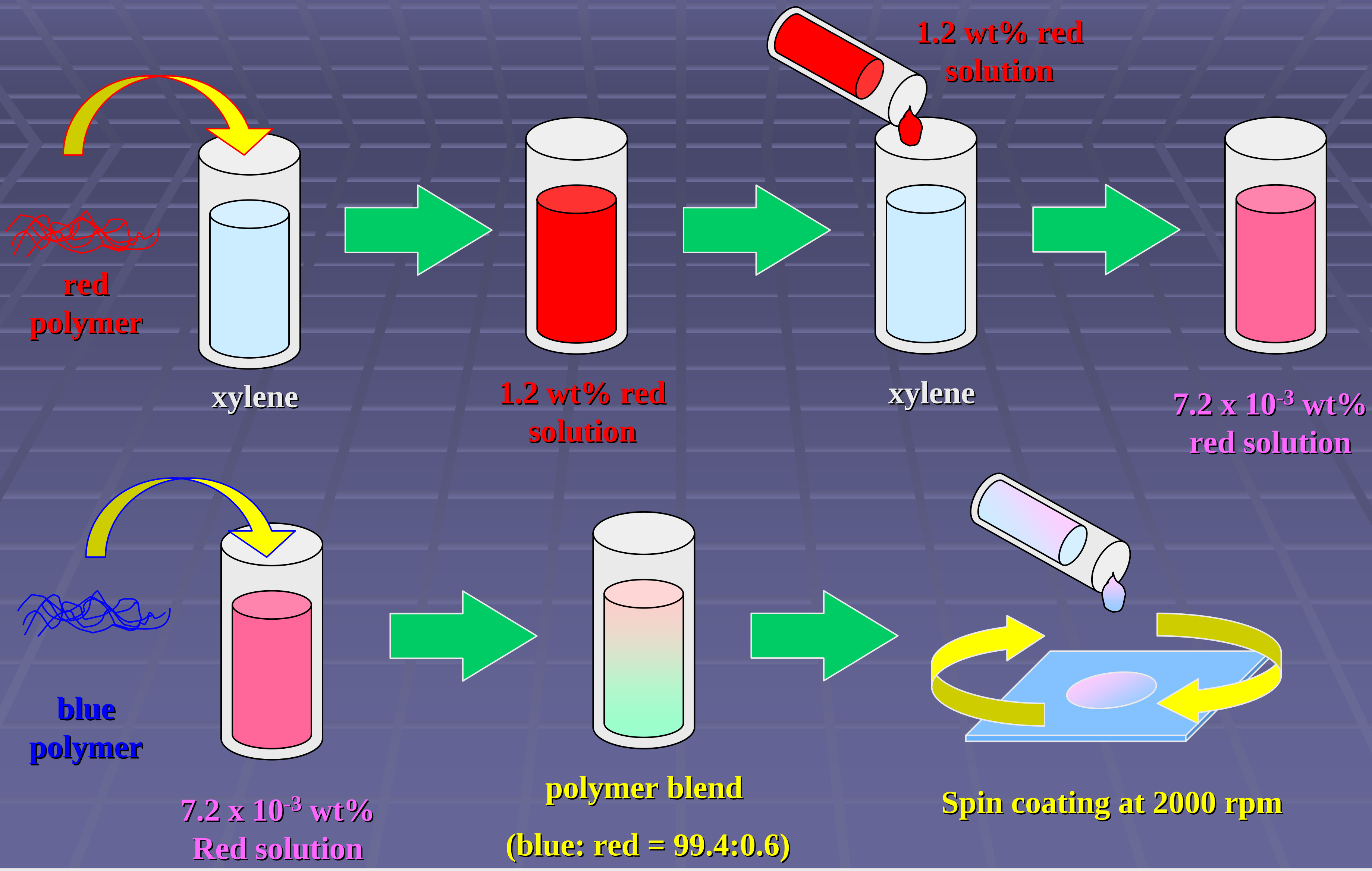
Dow Chemical Blue BP (Host : Donor)

- Poly(fluorene-co-antracene-co-p-tolylamine)



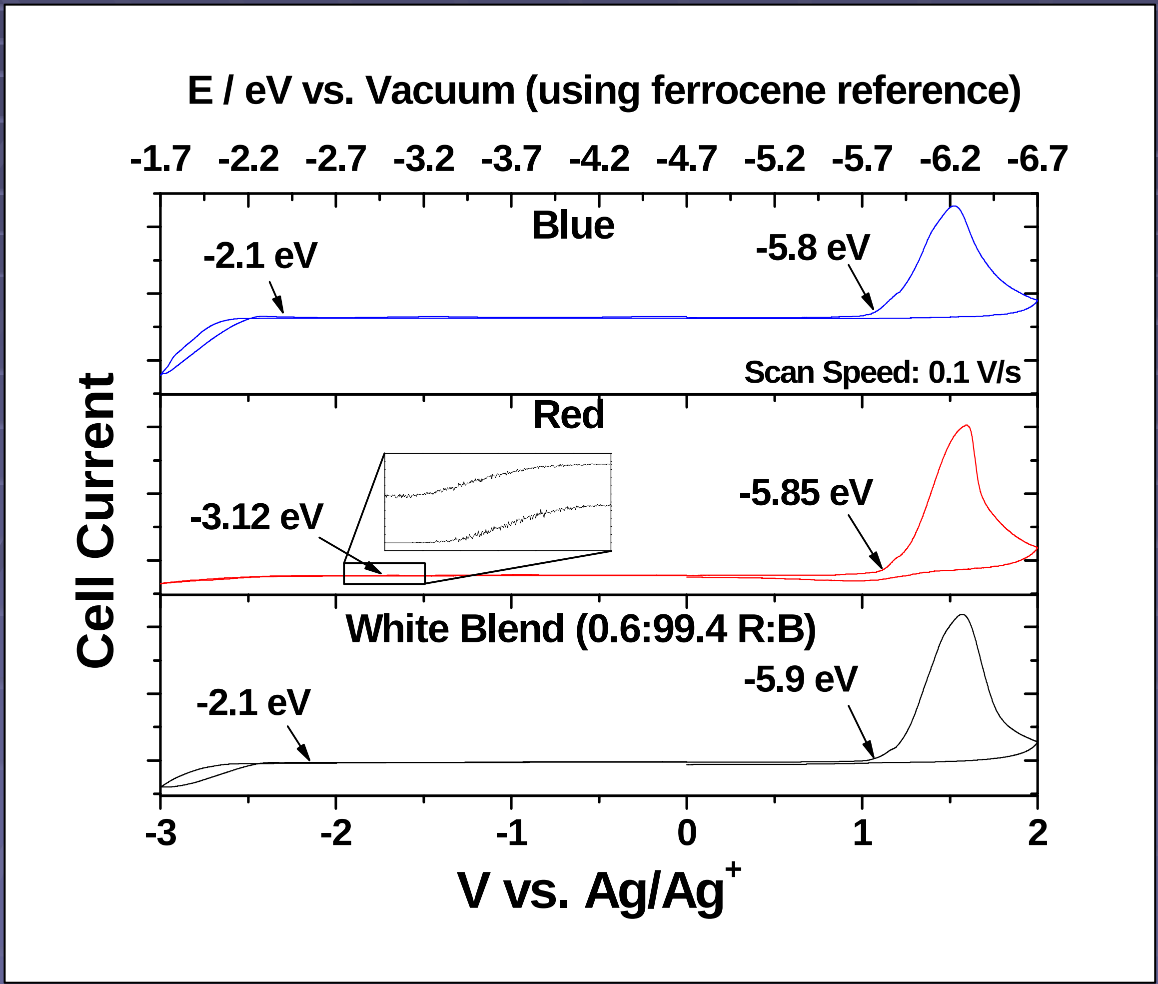
M. Inbasekaran et al, *US Patent 6353083*, 2002

Preparation of Red-Blue Polymer Blend



Cyclic Voltammerty Measurement

HOMO and LUMO Levels



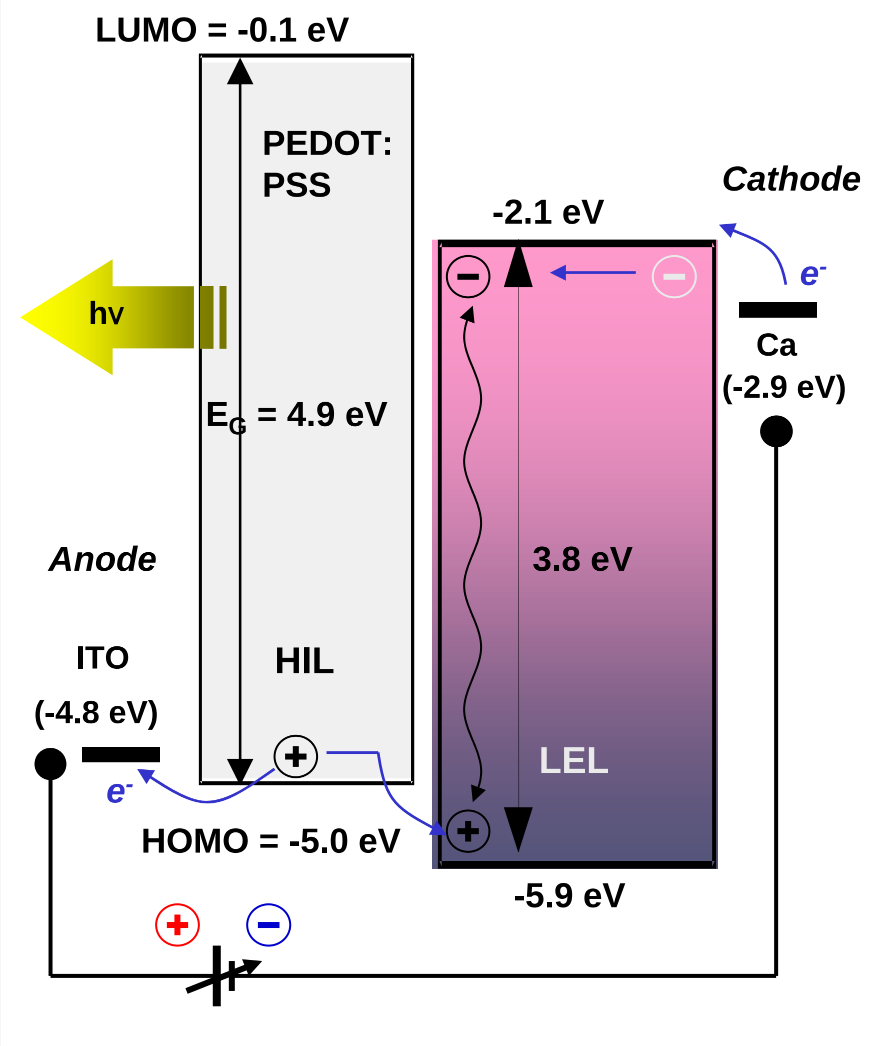
- Ionization Potential I_p (HOMO)

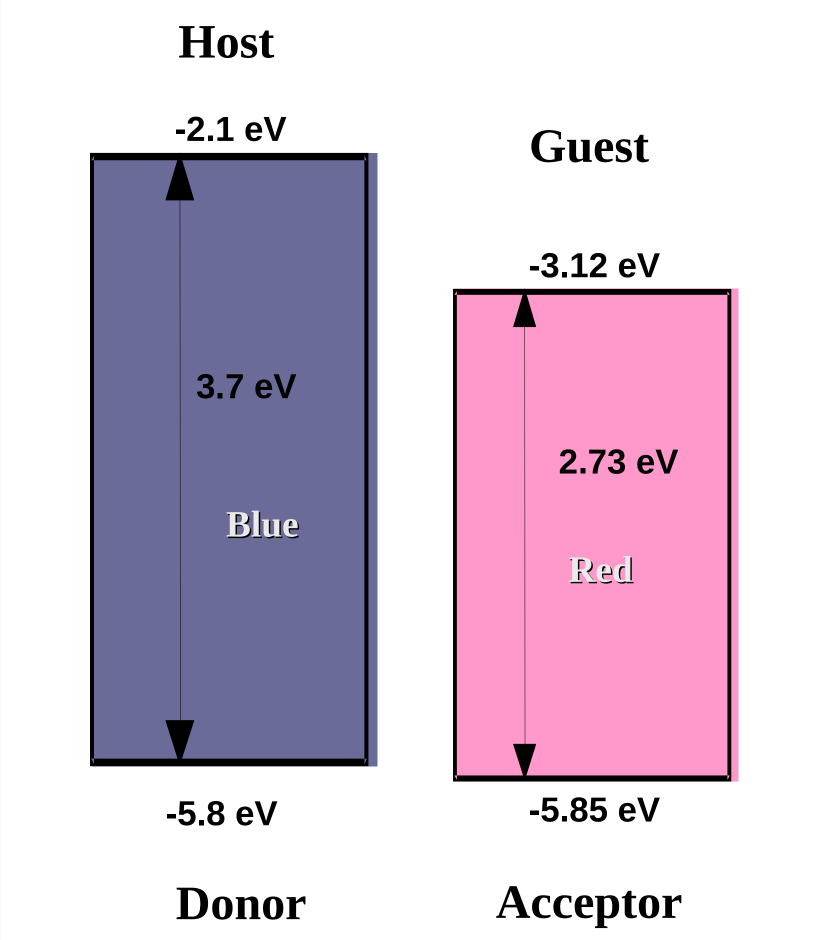
$$I_p = -q(4.8 + V^{ox}_{Ag/Ag^+} - V^{ferrocene}_{Ag/Ag^+})$$

- Electron Affinity E_a (LUMO)

$$E_a = -q(4.8 + V^{red}_{Ag/Ag^+} - V^{ferrocene}_{Ag/Ag^+})$$

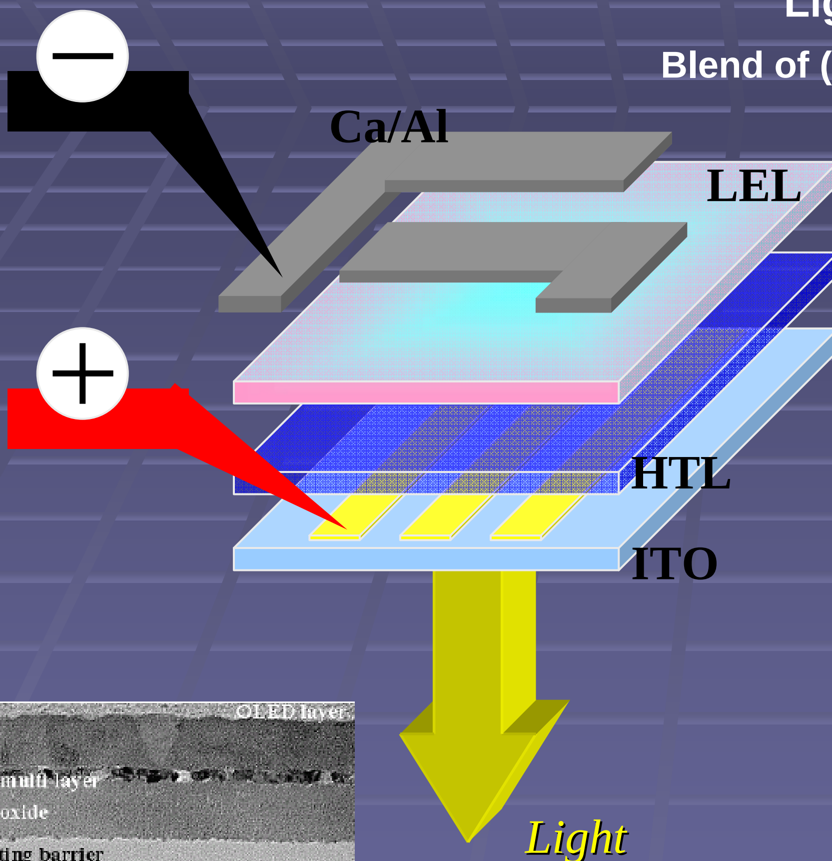
PLED Energy Band Diagram





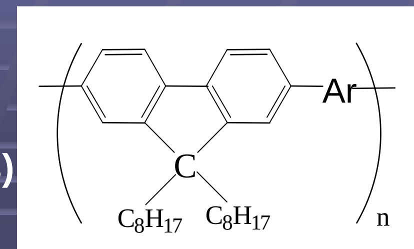
Fabrication and Opto-Electronic Properties of Polymer Blend LED

Fabrication of Polymer Blend LED

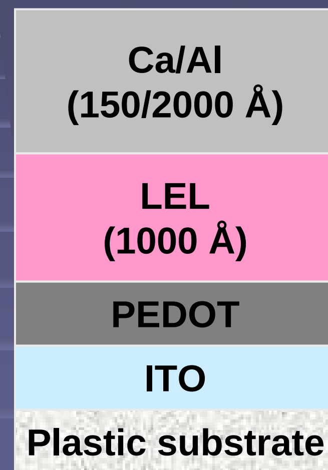


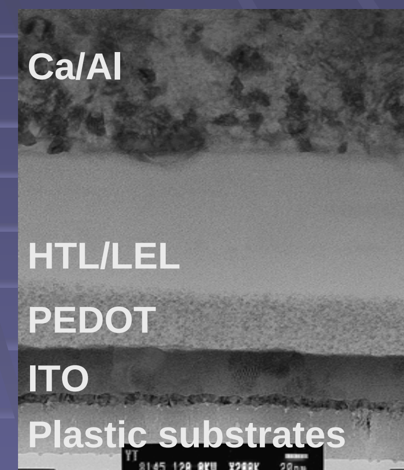
Light Emissive Layer

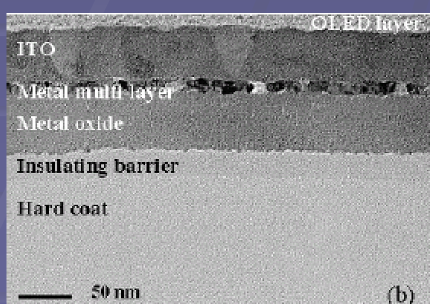
Blend of (poly (fluorene) co-polymers)



Ar = co-monomers



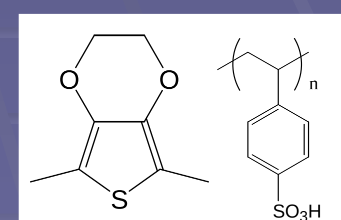




Multi-layer Plastic substrate

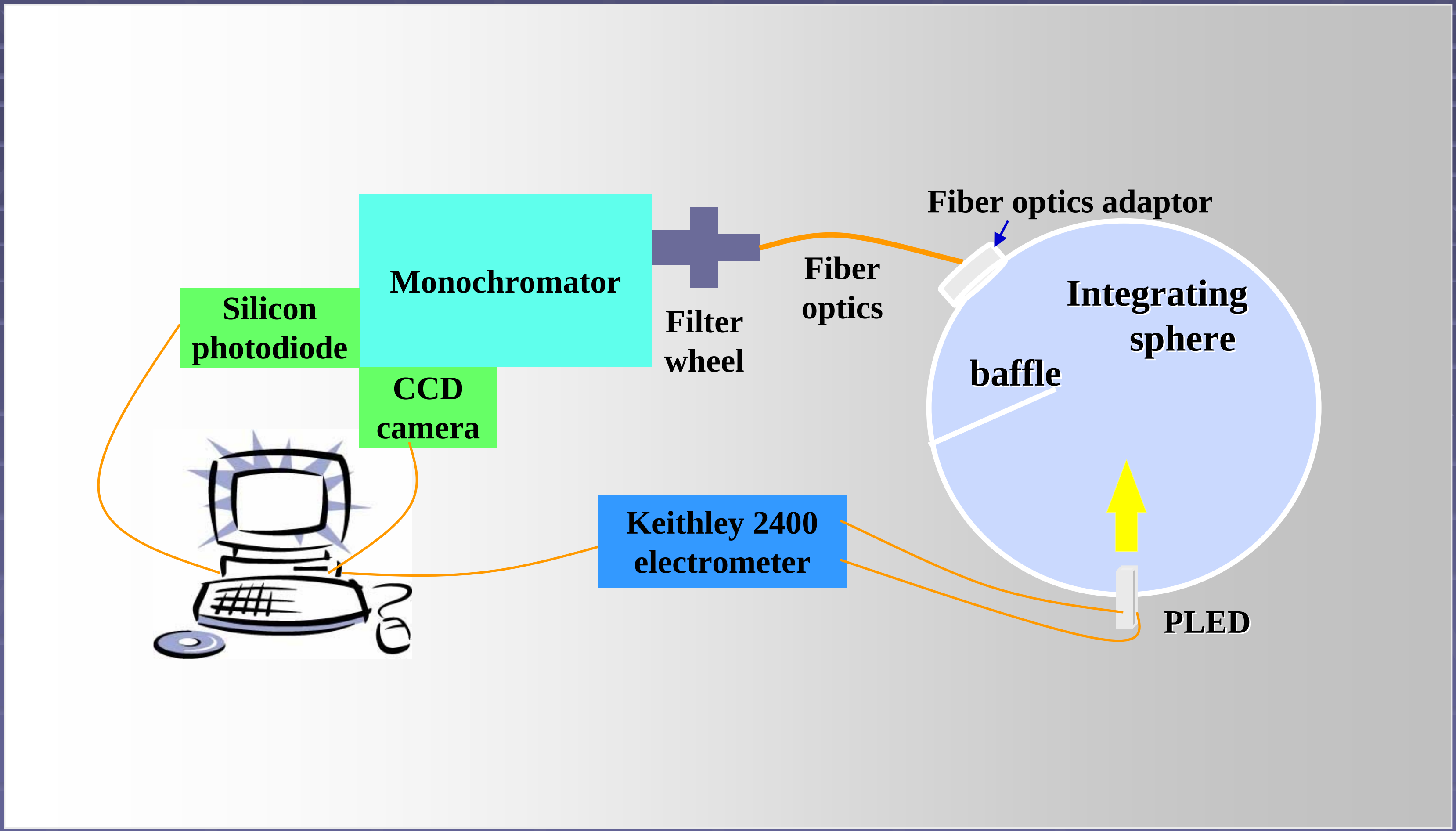
Hole Injection Layer
(PEDOT:PSS)

poly (3,4-ethylene dioxythiophene)
poly (styrenesulfonate)



Y.T. Hong et al, *J. Elec. Mater., 2004.*

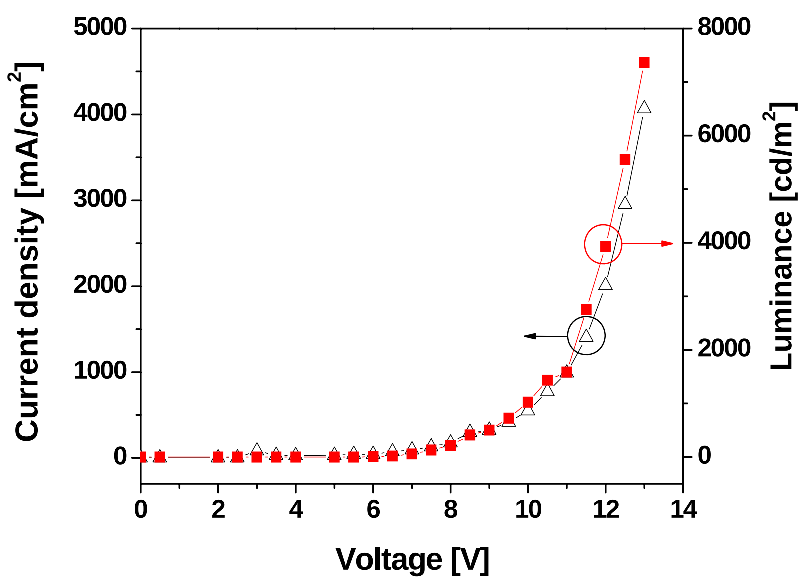
Spectra-Radiometric Measurement Set-up



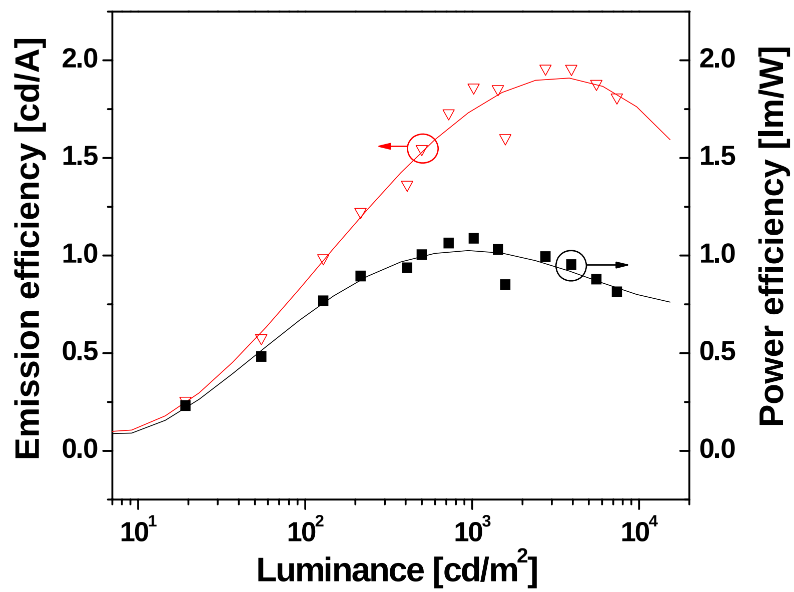
Y. Hong and **J. Kanicki**, *Rev. Sci. Instruments*, vol. 74, 2003

Opto-electrical Properties

Current – Voltage - Luminance



Efficiency - Luminance

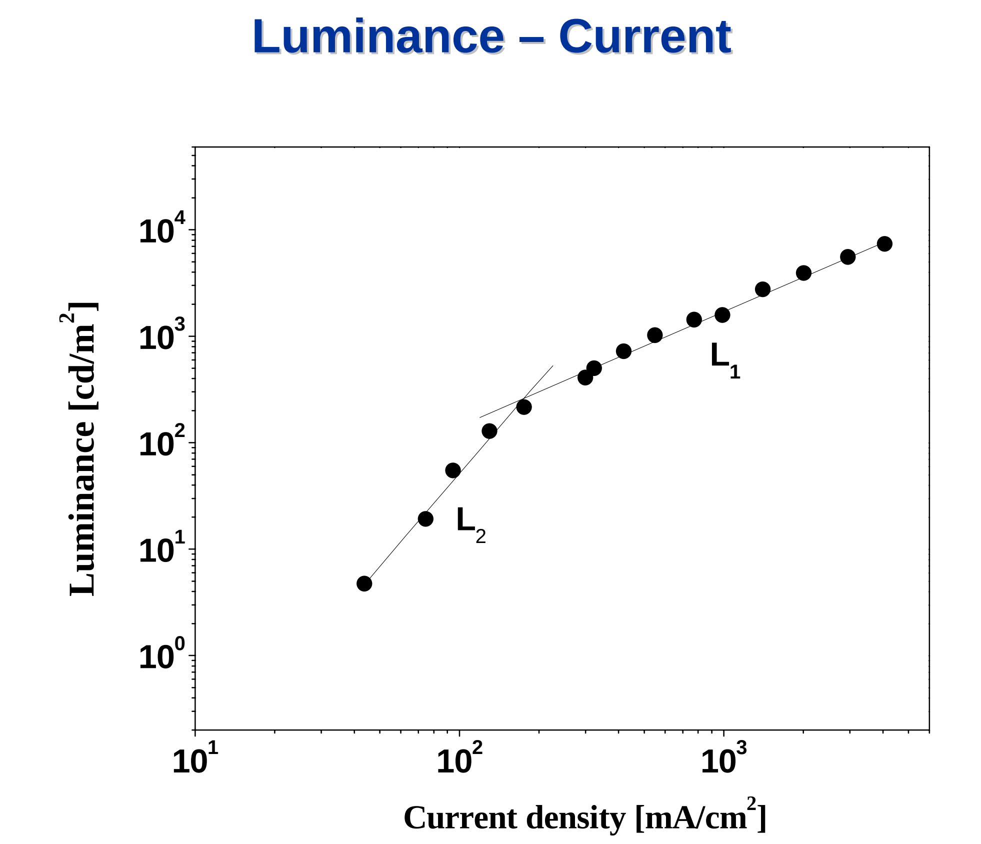


- Turn-on voltage = ~ 5.6 V
- L_{max} = ~ 7400 cd/m²

$$EE = L / J, \quad PE = \frac{\Phi}{IV} = \frac{\pi L}{JAV} = \frac{\pi EE}{AV}$$

- EE_{max} = ~ 2.0 cd/A, PE_{max} = ~ 1.1 lm/W

PLED Opto-electrical Properties



- **At high luminance:**

$$L_1 \propto J^{\alpha}$$

$$(\alpha = 1.07 \pm 0.01)$$

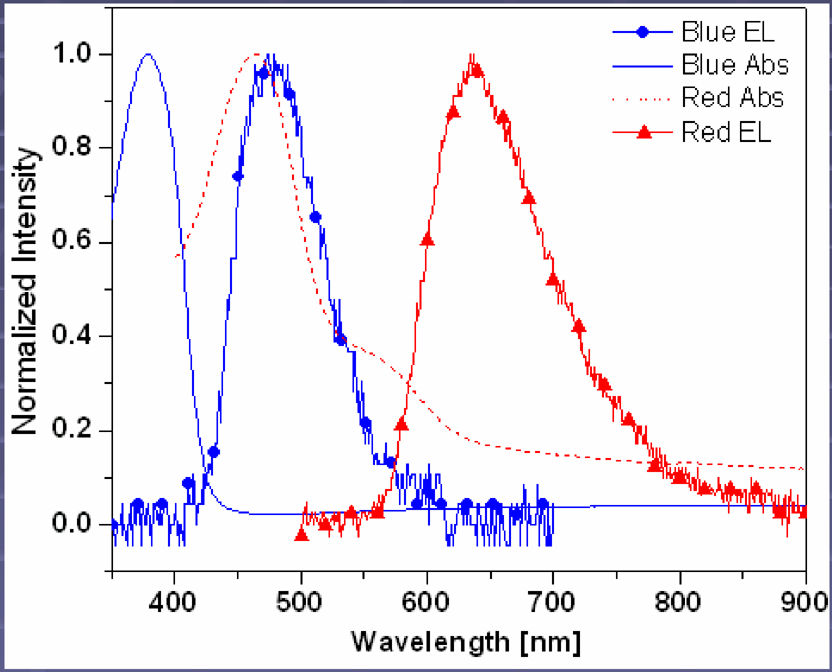
- **At low luminance:**

$$L_2 \propto (-7.48 + 0.17J)^{\alpha}$$

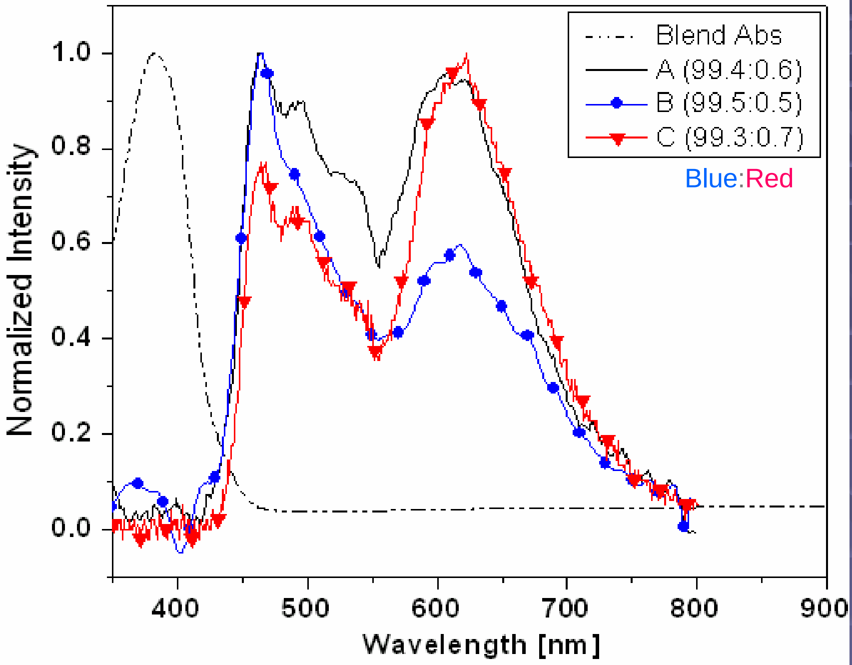
$$(\alpha = 1.82 \pm 0.19)$$

PLED Electroluminescence Spectra

Blue-Red Single Layer

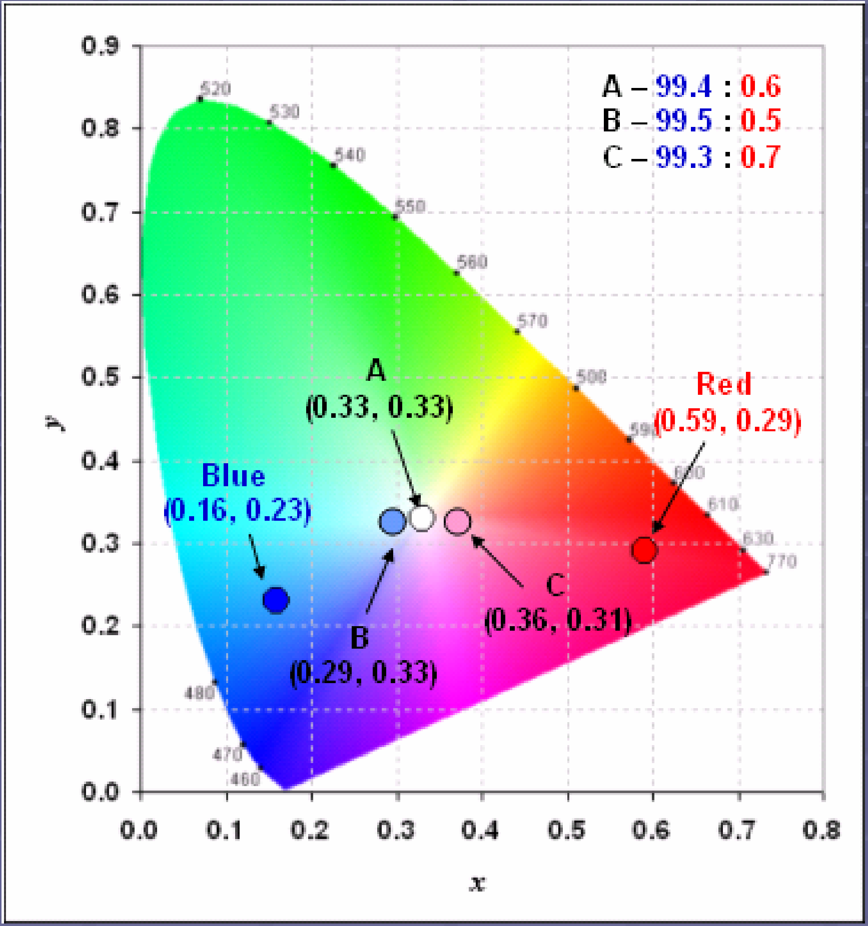


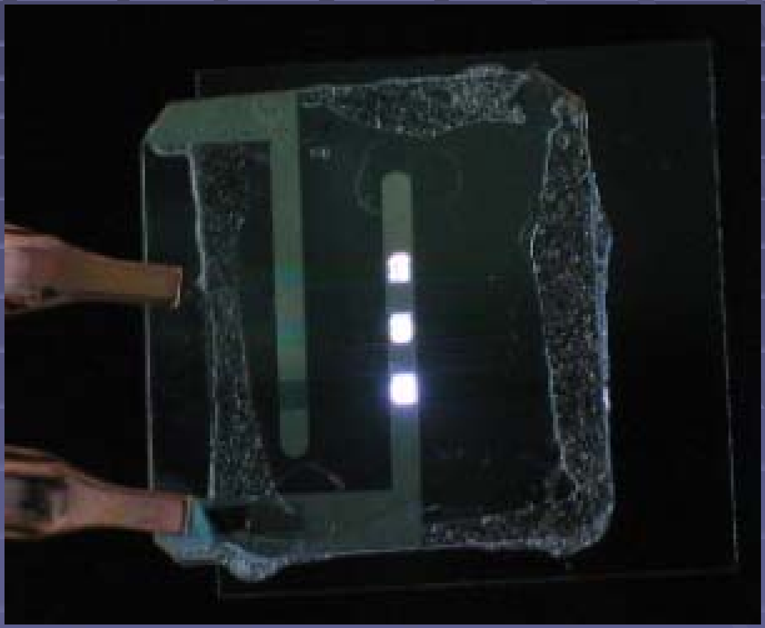
Blue:Red Polymer Blend



- EL peaks from polymer blend : blue (~ 464 nm), red (~ 622 nm)
  - → Red polymer absorbs EL spectrum from blue polymer
  - → PL emission from red polymer
- Details / shape of EL spectra is very sensitive to polymer blend ratio

CIE Coordinates : White Light Emission





◆ Optimal weight blending ratio for "pure" white light is 99.4:0.6 (Blue: Red)

→ It corresponds to the intensity ratio of 77.3:22.7 (Blue: Red) from simulation

Conclusion

PLED on plastic	White	Red	Blue
Voltage (V @ 1 cd/m^2)	~ 5.6	~ 2.8	~ 4.8
Current (mA/cm^2 @ 1 cd/m^2)	~ 42.7	~3705*	~14128*
Voltage (@ 300 cd/m^2)	~ 8.3	~ 5.1	~ 7.0
EEmax (cd/A)	~ 1.96	~ 0.27	~ 0.69
PEmax (lm/W)	~ 1.09	~ 0.23	~ 0.33
Lmax (cd/m^2)	~ 7366	~ 1410	~ 2652
CIE coordinate	(0.33, 0.33)	(0.59, 0.29)	(0.16, 0.23)
HOMO (eV)	-5.9	-5.85	-5.8
LUMO (eV)	-2.1	-3.12	-2.1

* High current values for red and blue single polymer devices are due to current bumps in I-V characterstics which have been previously reported by other groups

* **S. Berleb et al**, *Synth. Met.*, 1999

Comparison

Parameters	Small molecule based devices on glass				Polymer based devices on glass			
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Year	1995	1999	2002	2004	1995	1996	2004	2004
Voltage (V @ 1 cd/m^2)	~ 6	n/a	~ 8	~ 10	~ 8	n/a	~ 5	n/a
EE_{max} (cd/A)	n/a	n/a	n/a	~ 2.5	n/a	n/a	~ 4.3	~ 1.6
PE_{max} (lm/W)	n/a	~ 0.35	n/a	n/a	n/a	n/a	~ 1.0	n/a
L_{max} (cd/m^2)	~ 2200	~ 13500	~ 150	~ 15000	~ 4100	n/a	~ 12000	~ 3000
Voltage (V @ L_{max})	~ 16	~ 18	~ 14	~ 13	~ 20	n/a	~ 17	~ 10
CIE coordinate	n/a	(0.33, 0.33)	(0.34, 0.38)	(0.29, 0.33)	(0.34, 0.38)	(0.34,0.32)	(0.32, 0.33)	(0.34, 0.34)

[1] J. Kido et al, *Science, 1995*.

[2] R. S. Deshpande et al, *Appl. Phys .Lett., 1999*.

[3] M. Mazzeo et al, *Physica E, 2002*.

[4] Y. Shao et al, *Appl. Phys. Lett.*, ***2005*.**

[5] J. Kido et al, *Appl. Phys. Lett.*, ***1995*.**

[6] M. Granström et al, *Appl. Phys. Lett.*, ***1996*.**

[7] X. Gong et al, *Adv. Mater.*, ***2004*.**

[8] G. Ho et al, *Appl. Phys. Lett.*, ***2004*.**