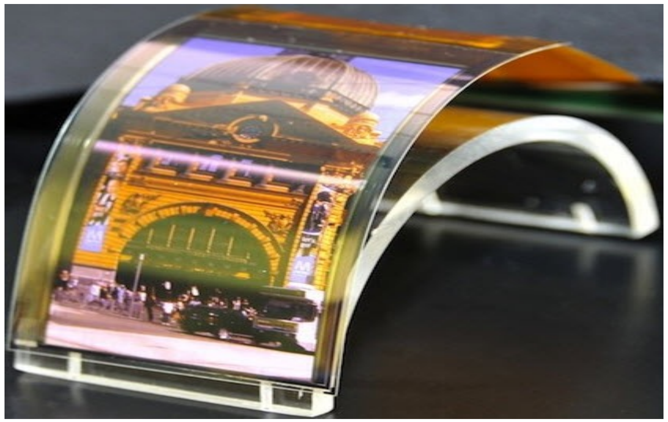
SECTION 8

OLED TECHNOLOGY

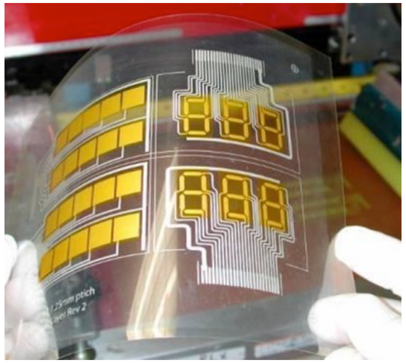
HANDBOOK OF VISUAL DISPLAY TECHNOLOGY 2ND EDITION (2016)

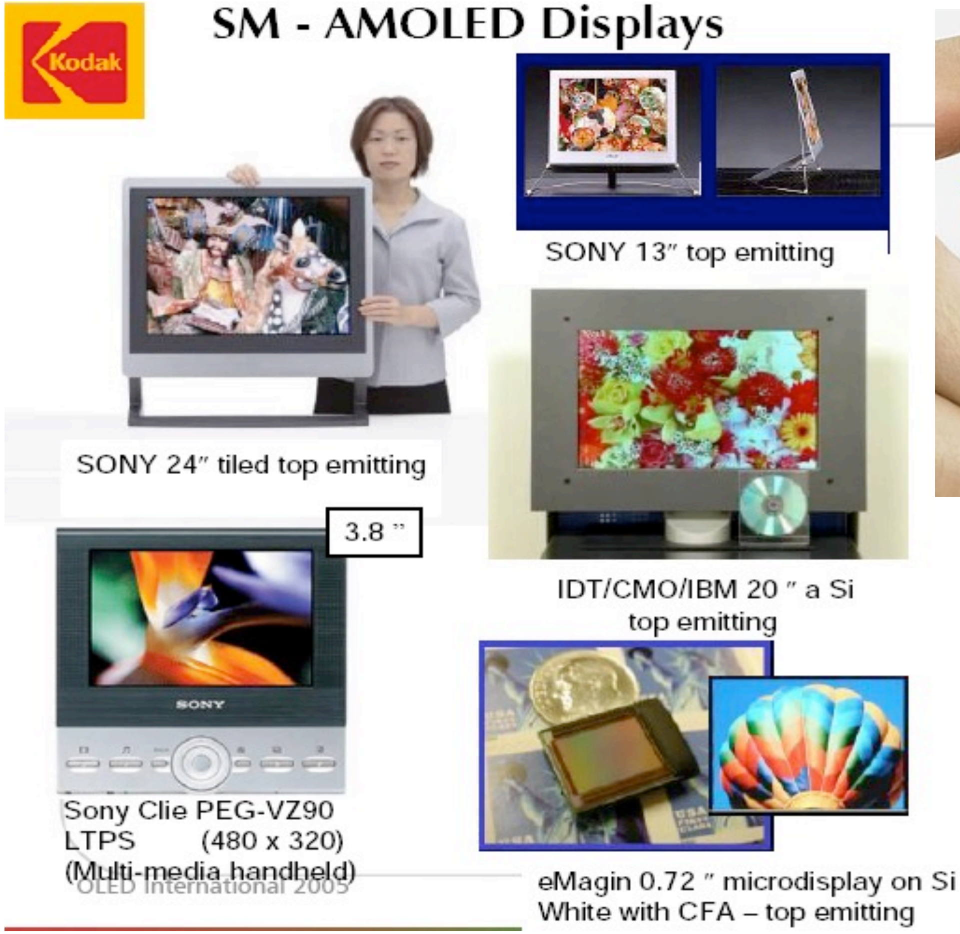
AMOLED Manufacture
Glory K. J. Chen, Janglin Chen
Pages 1779-1797

Organic Light-Emitting Diodes (OLEDs)
Ruiqing Ma
Pages 1799-1820



Applications of OLEDs - Historical





AUO / UDC 4" a Si bottom emission

Organic LED Device Classification

MATERIAL FAMILY

Small molecule | Polymer long chain

LIGHT EMISSION

Fluorescent | Phosphoresecent

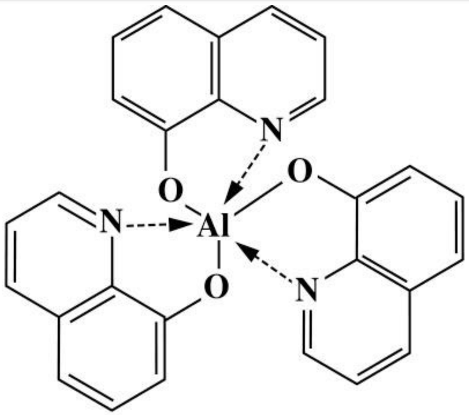
MANUFACTURING

Vacuum process | Solution process

"I think you'll find it's a little bit more complicated than that"

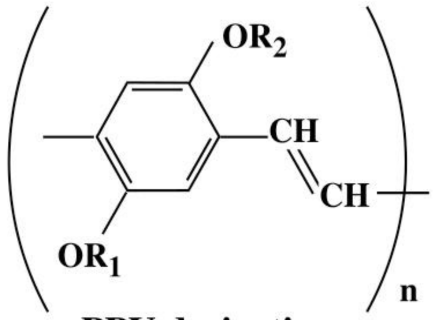
Two Main families of materials

Tris(8-hydroxyquinolino)aluminium

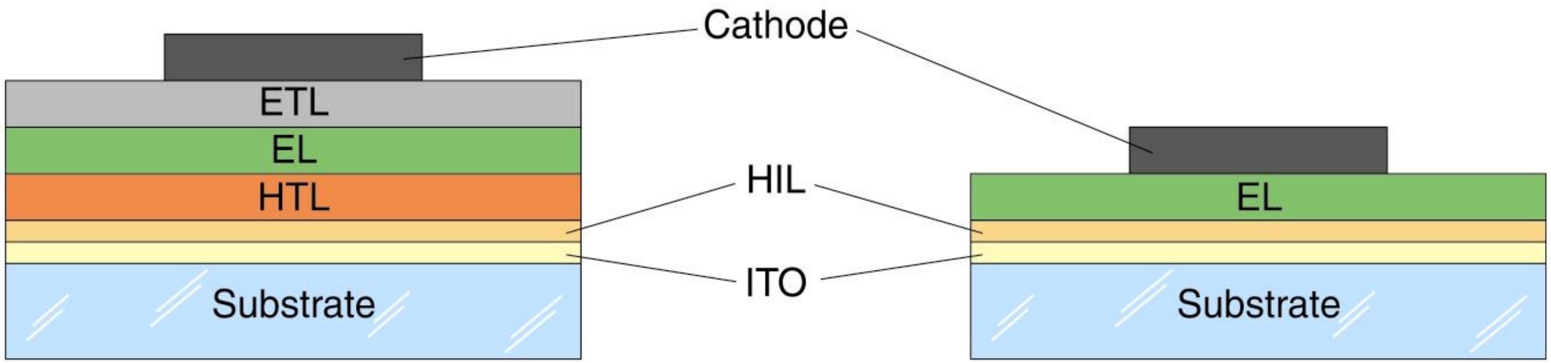


Alq3

Polyparaphenylenevinylene (PPV)



PPV derivatives



Evaporated molecule based OLED

Polymer based OLED

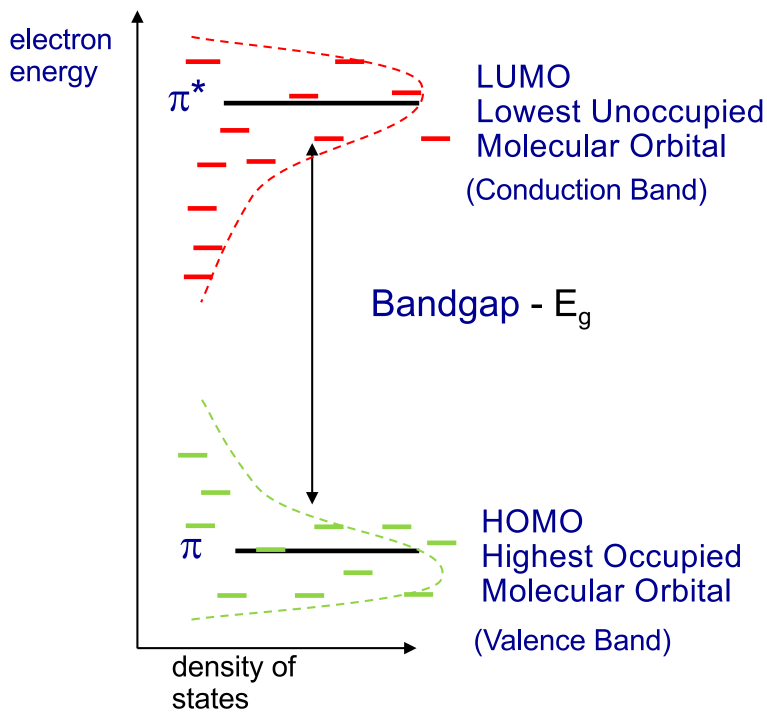
Electronic structure

The bonding state (π) forms the HOMO level, while the anti-bonding state (π^*) forms the LUMO level.

These are roughly analogous to the valence and conduction band in inorganic semiconductors

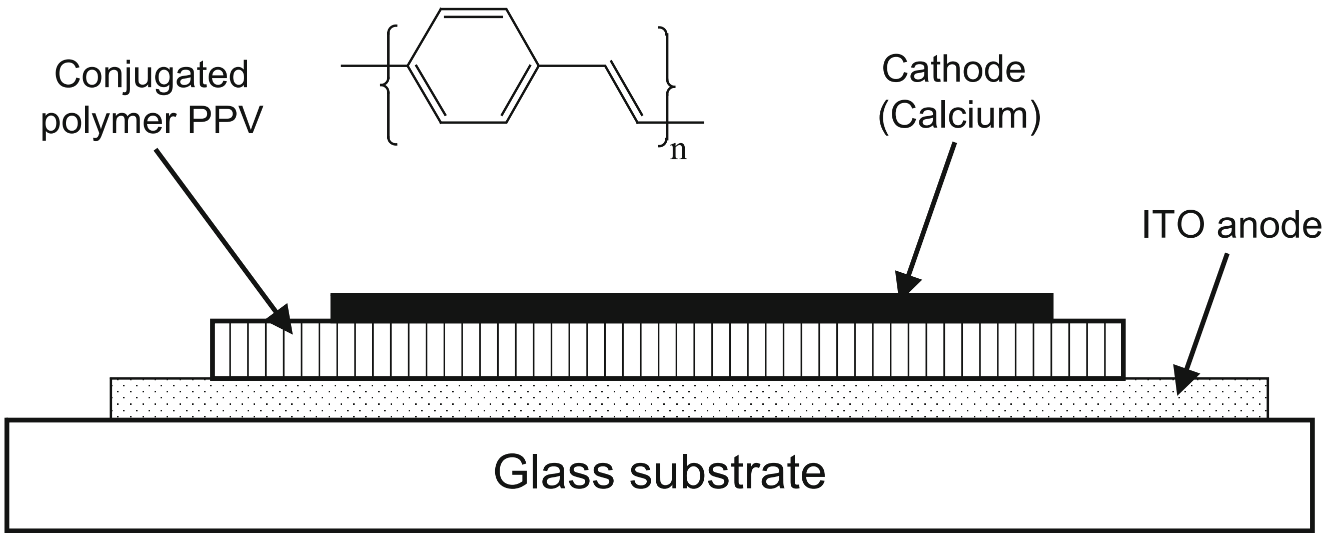
Due to disorder, charges are localised within the conjugation length

- several repeat units long



Broad distribution of energy levels

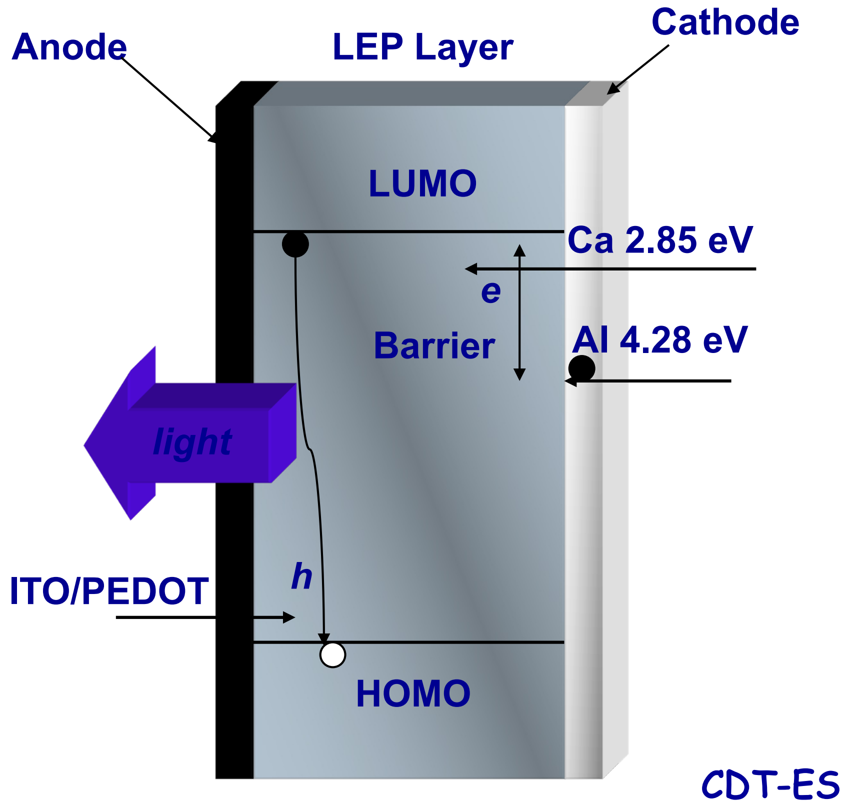
Simple Polymer OLED



Burroughes JH, Bradley DDC, Brown AR, Marks RN, Mackay K, Friend RH, Burn PL, Holmes AB (1990) Light-emitting diodes based on conjugated polymers. Nature 347:539–541

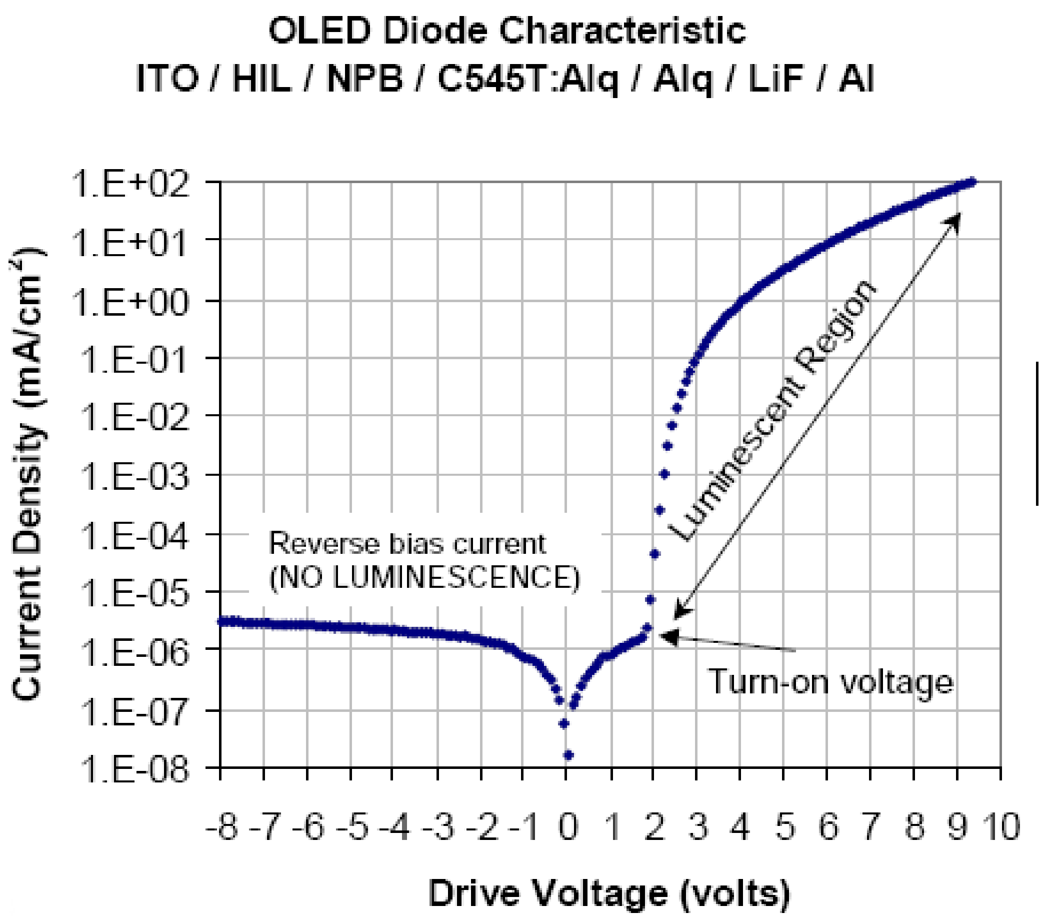
OLED – principle of operation

- Low work function cathode to assist electron injection
- High work function anode to assist hole injection
- High mobility to reduce voltage and increase recombination probability
- Colour of emission is determined by HOMO-LUMO energy gap

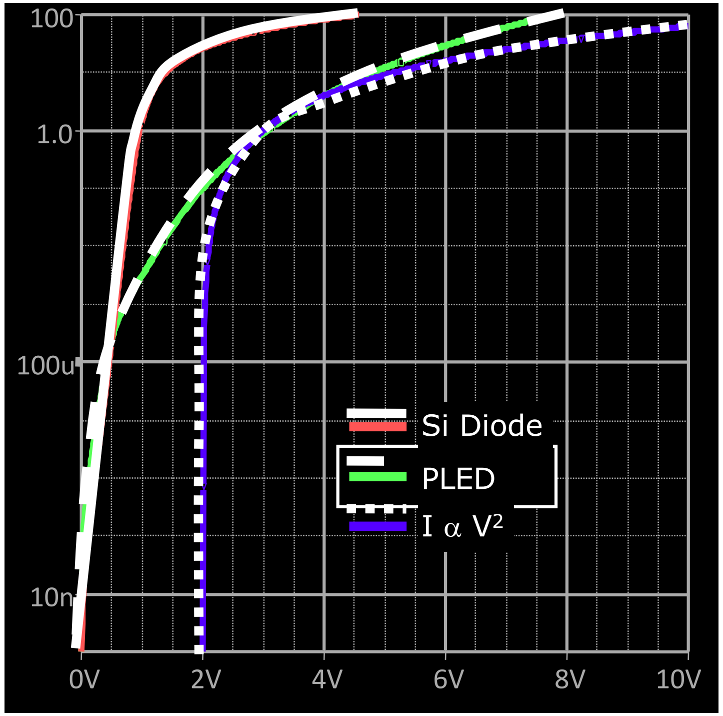


Viewgraph courtesy CDT

Typical IV Characteristic



Device Operation – IV characteristic



Log-linear plot of IV characteristics

The chart left shows the I-V characteristics of a silicon diode and a PLED

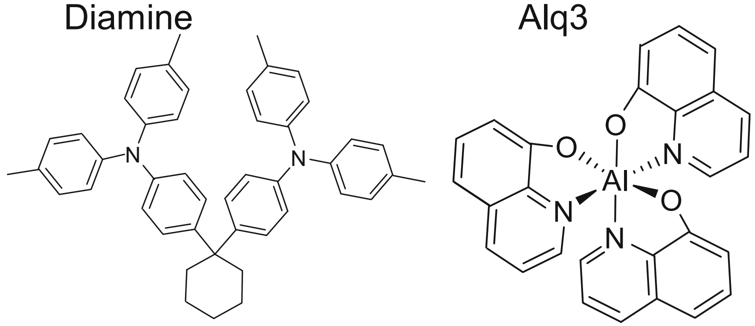
The silicon diode shows an exponential I-V curve, and is therefore injection limited

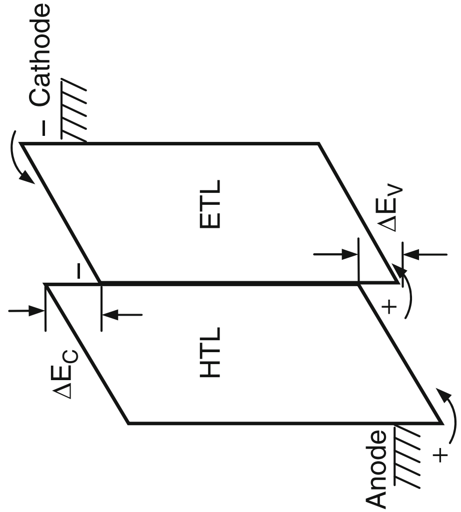
The PLED lies between the exponential and quadratic

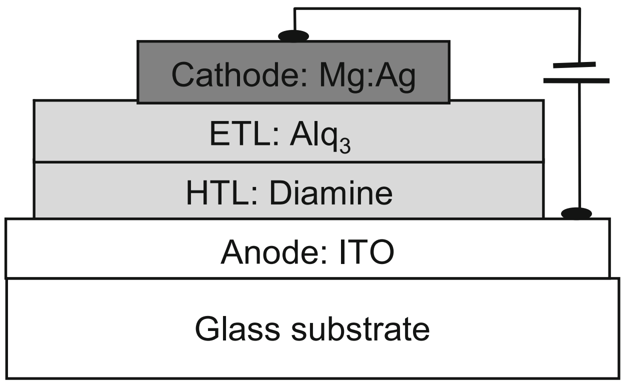
The PLED is space-charge limited, however a field dependent carrier mobility increases the power relationship with field

Simple Bilayer OLED Device

Cross Section and
Energy Band diagram
Reproduced from Tang and VanSlyke (1987)

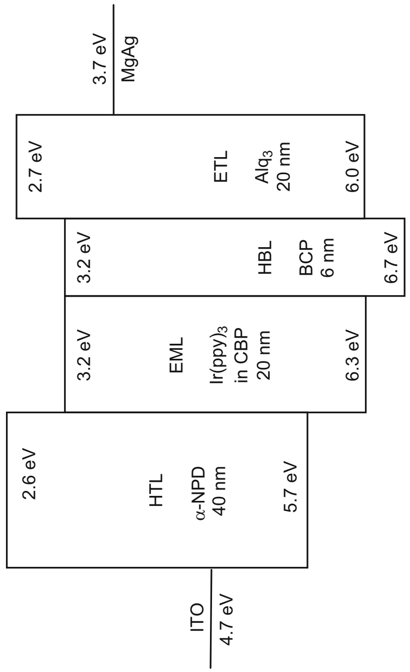


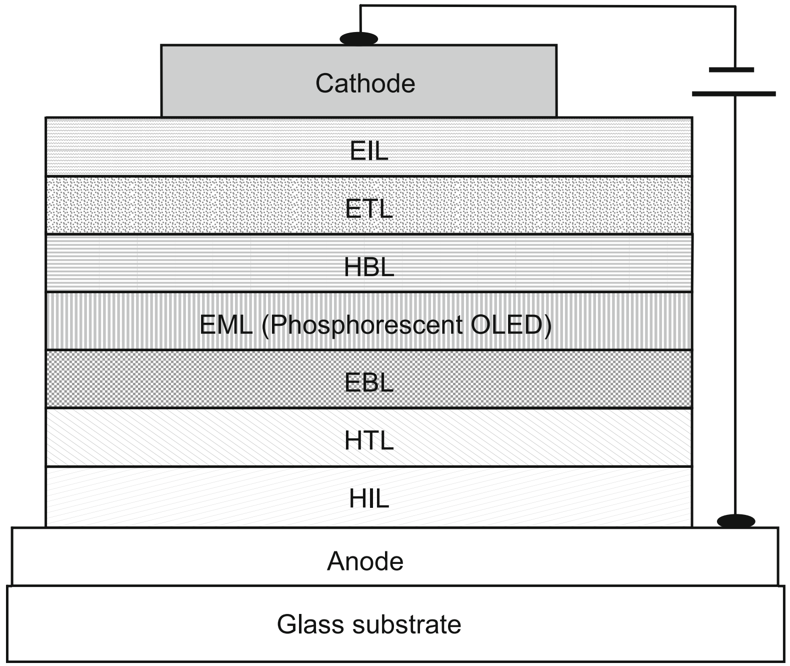




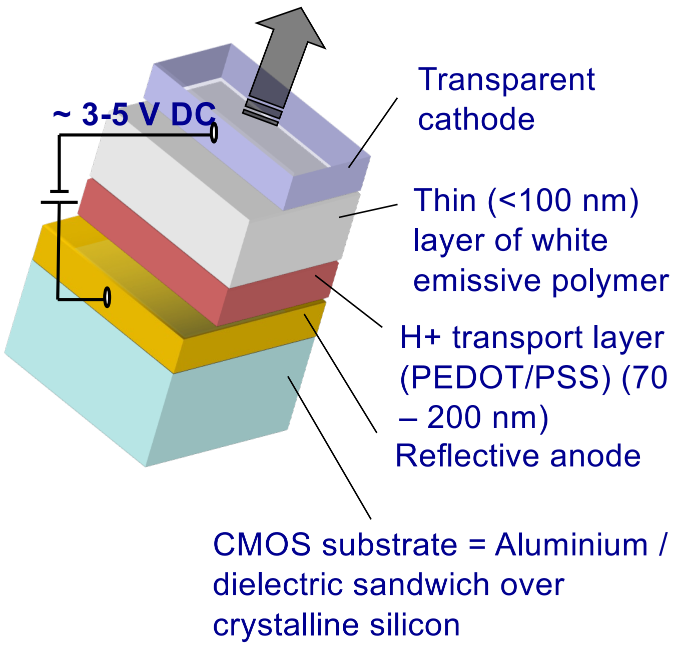
Advanced high-efficiency OLED Device

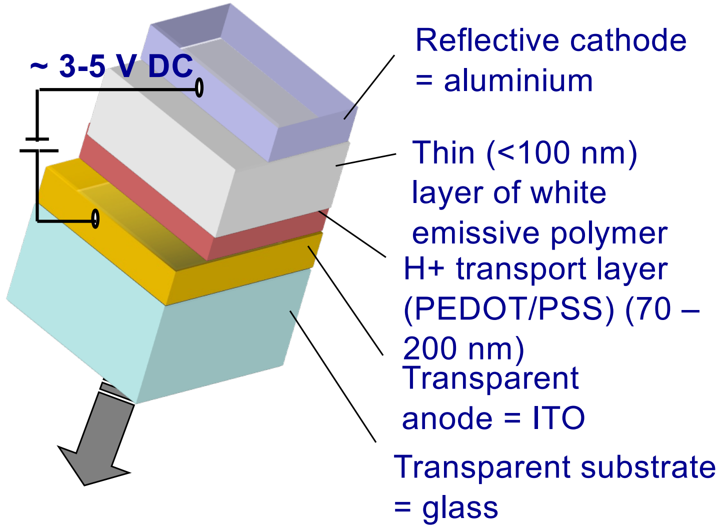
Energy level diagram of a phosphorescent OLED device with ITO anode; Mg:Ag cathode; HTL, EML, HBL, and ETL organic layers





OLED – bottom and top emitting



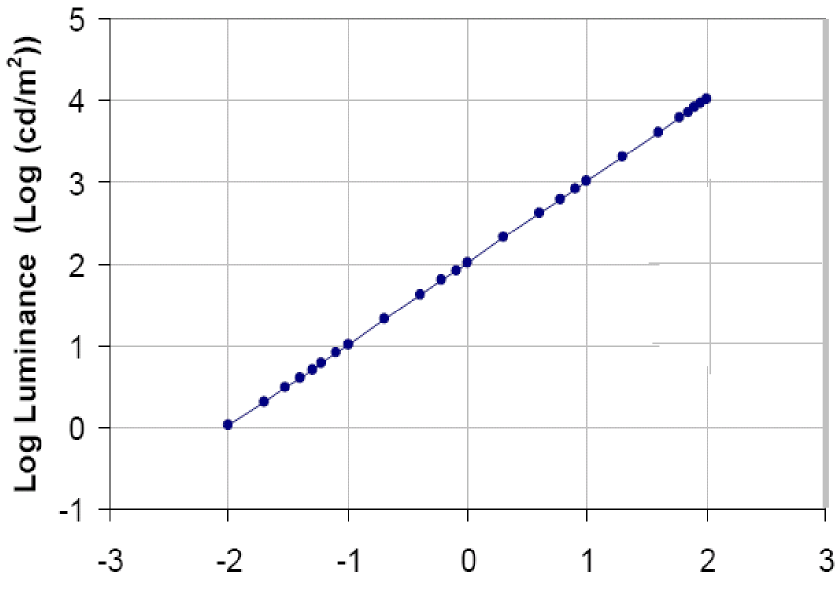


Adopted from an original by CDT

OLED Optical response

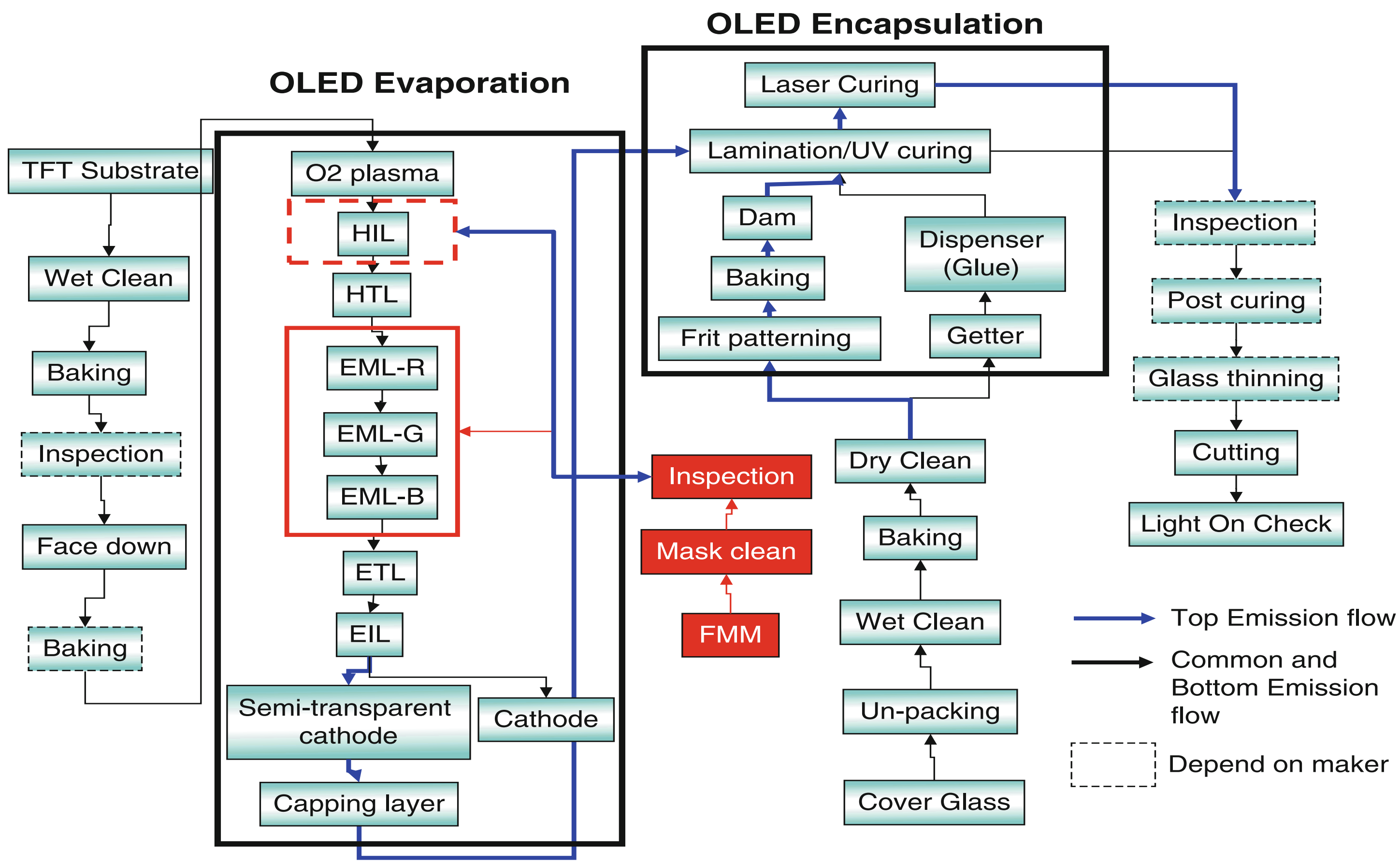
OLED response is highly linear

Luminance proportional to current density over many decades of dynamic range

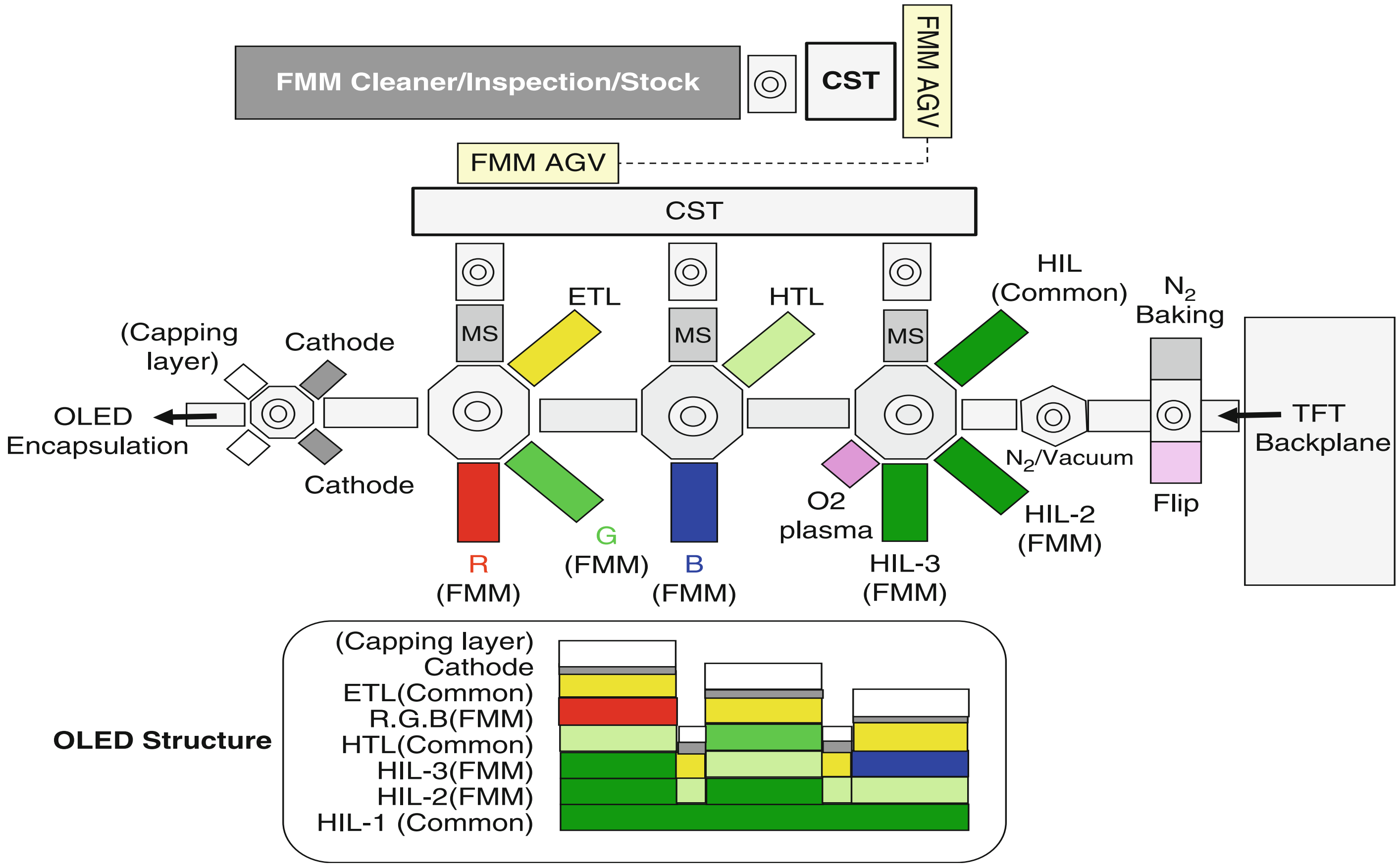


CDT-ES

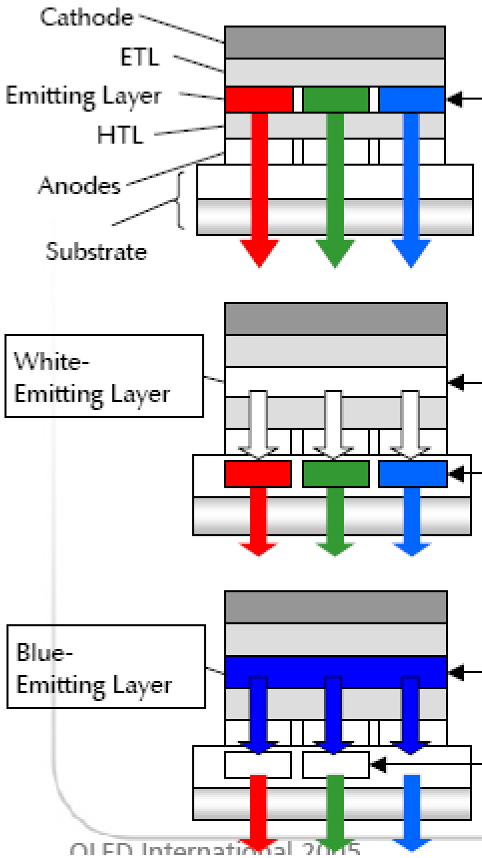
OLED Manufacturing Process Flow



OLED Manufacturing Equipment Schematic



Creating RGB Colour in OLEDs



Patterned-Emitting Layer

Advantages
- High efficiency
- Good color

Disadvantages
- Aperture ratio issues
- Typically uses shadow masking for RGB patterning
- Differential aging of RGB

White-Emitting Layer with Color-Filter Array

Advantages
- Unpatterned emitting layer (no masks)
- Aperture ratio not affected by RGB patterning
- Enabled by high efficiency white

Disadvantages
- Loss of efficiency due to filter absorption

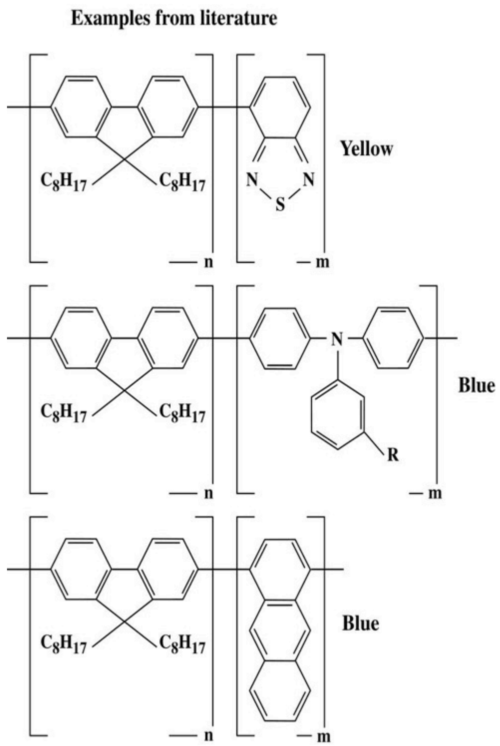
Blue-Emitting Layer with Color-Change Medium

Advantages
- Unpatterned emitting layer (no masks)

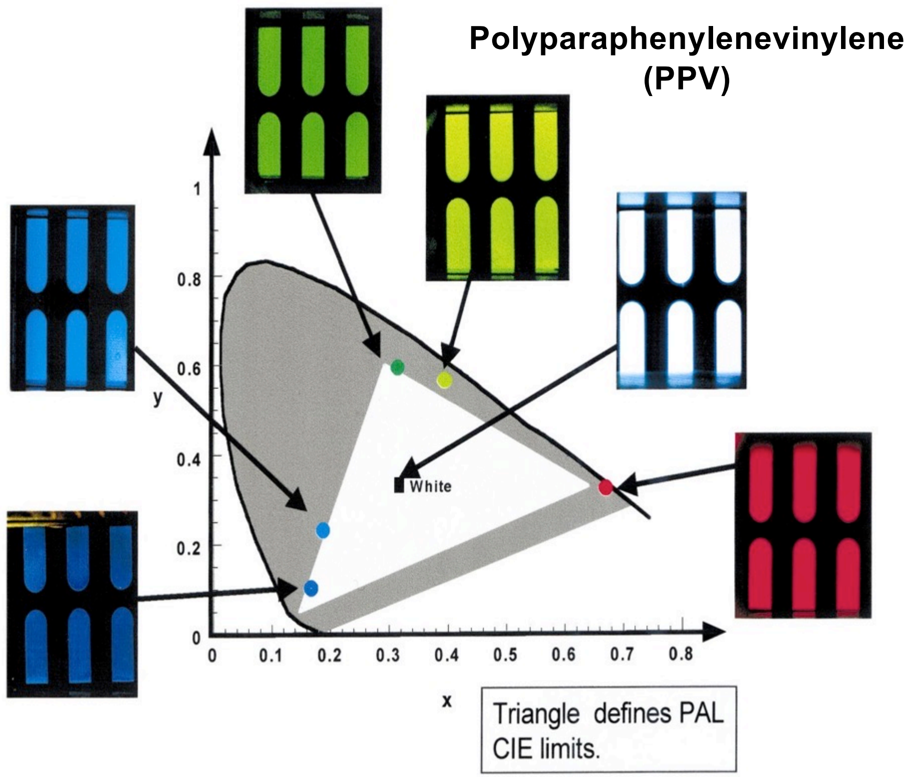
Disadvantages
- Requires high efficiency blue
- Blue stability typically poorest
- Compatibility of CCM materials with std lithography tools

OLED International 2005

Colour tuning by chemical modification

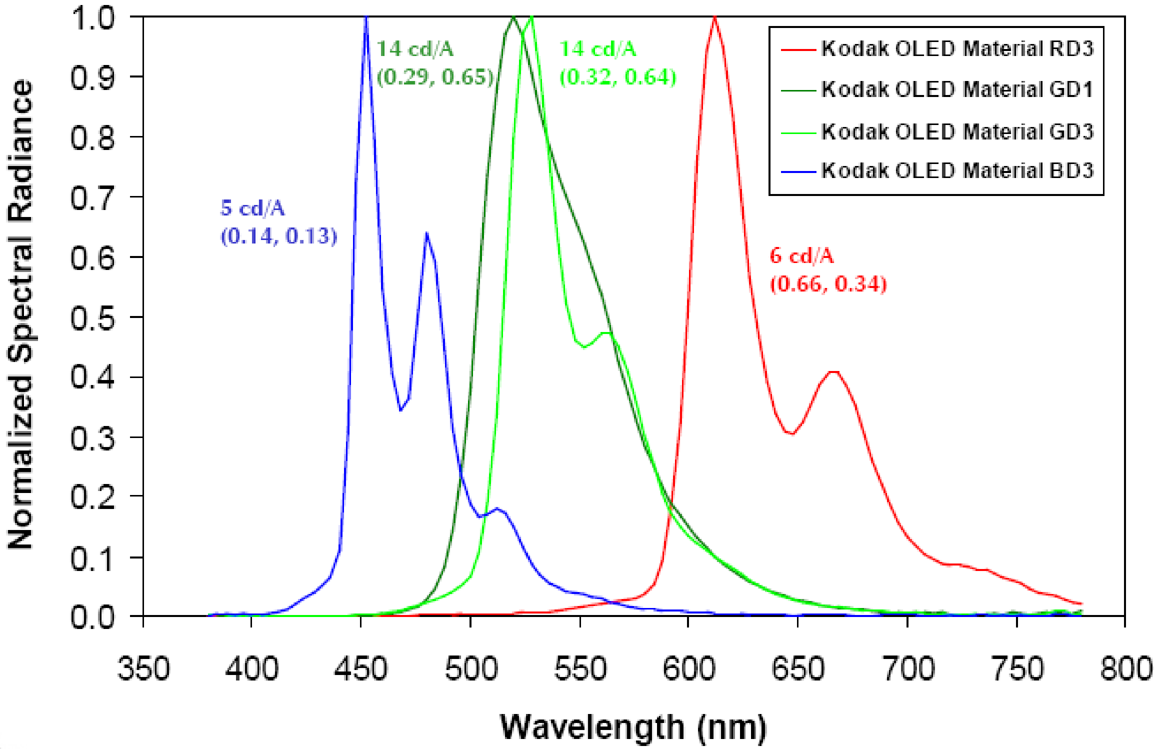


Polydialkylfluorène



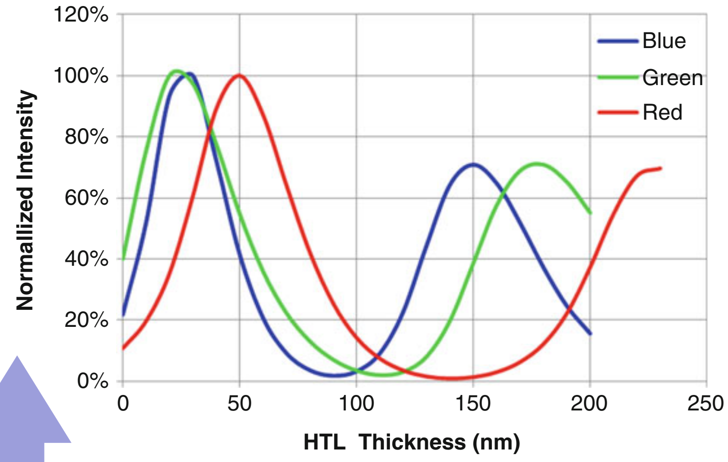
Colour from OLEDs

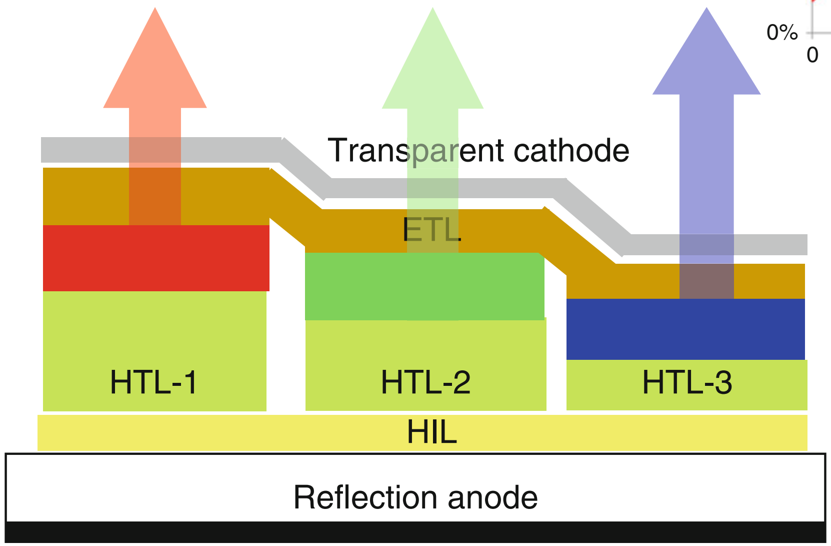
Typical Electroluminescent Spectra



Colour tuning

The "cavity" in which the OLED is located affects the colour efficiency





Properties for Different Colors

Colour	Efficiency @100cd/m² (lm/W)	Voltage @100cd/m² (V)	Luminous intensity @5.5V (cd/m²)	Time to half luminous intensity at room temp.
Red	2.3	2.4	2,000	>40,000
Green	11	2.7	20,000	>25,000
Blue	2.5	3.5	2,000	>6,500
Yellow	7 18	3 2.1	2,000 100,000	60,000 ~14,000
White	1.5	4.3	400	>10,000

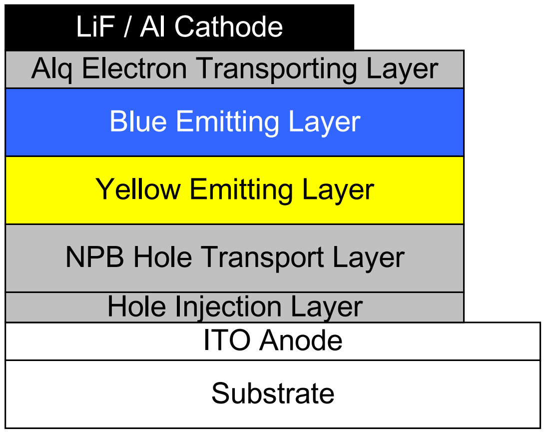
NB. Beware that this data improves rapidly
Check independently for up-to-date figures

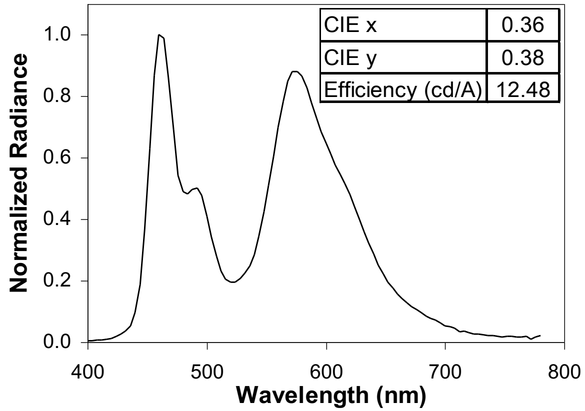
CDT-ES

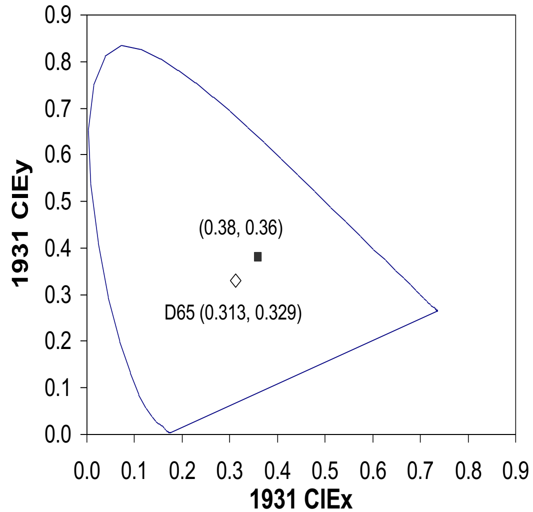
STATE OF THE ART

2019
LG's 88in Signature OLED TV is only 2.5mm thick

White emitting OLED (1) for lighting

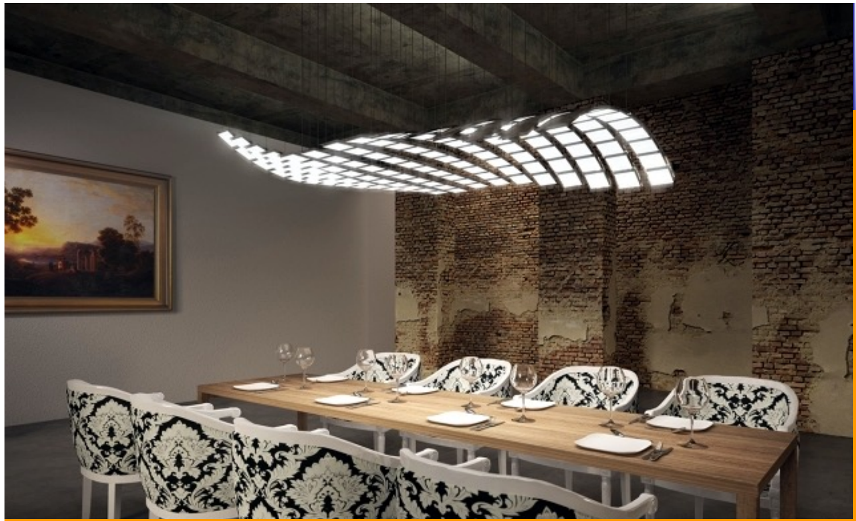






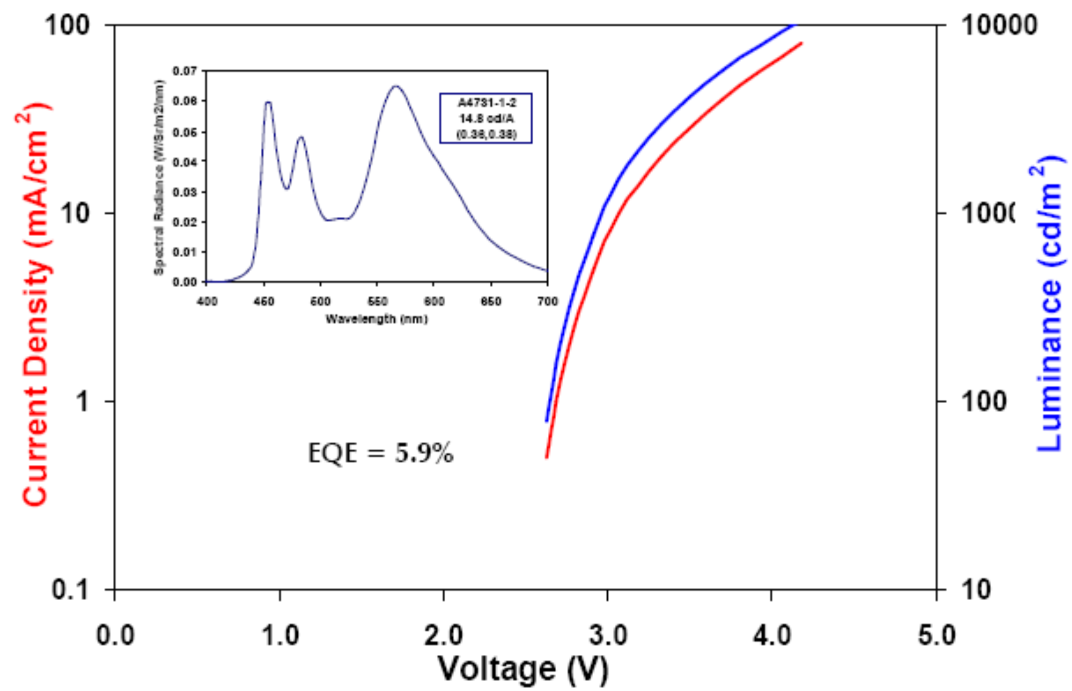
Note: Better power efficiency results if white point of emitter = D65

OLED Lighting

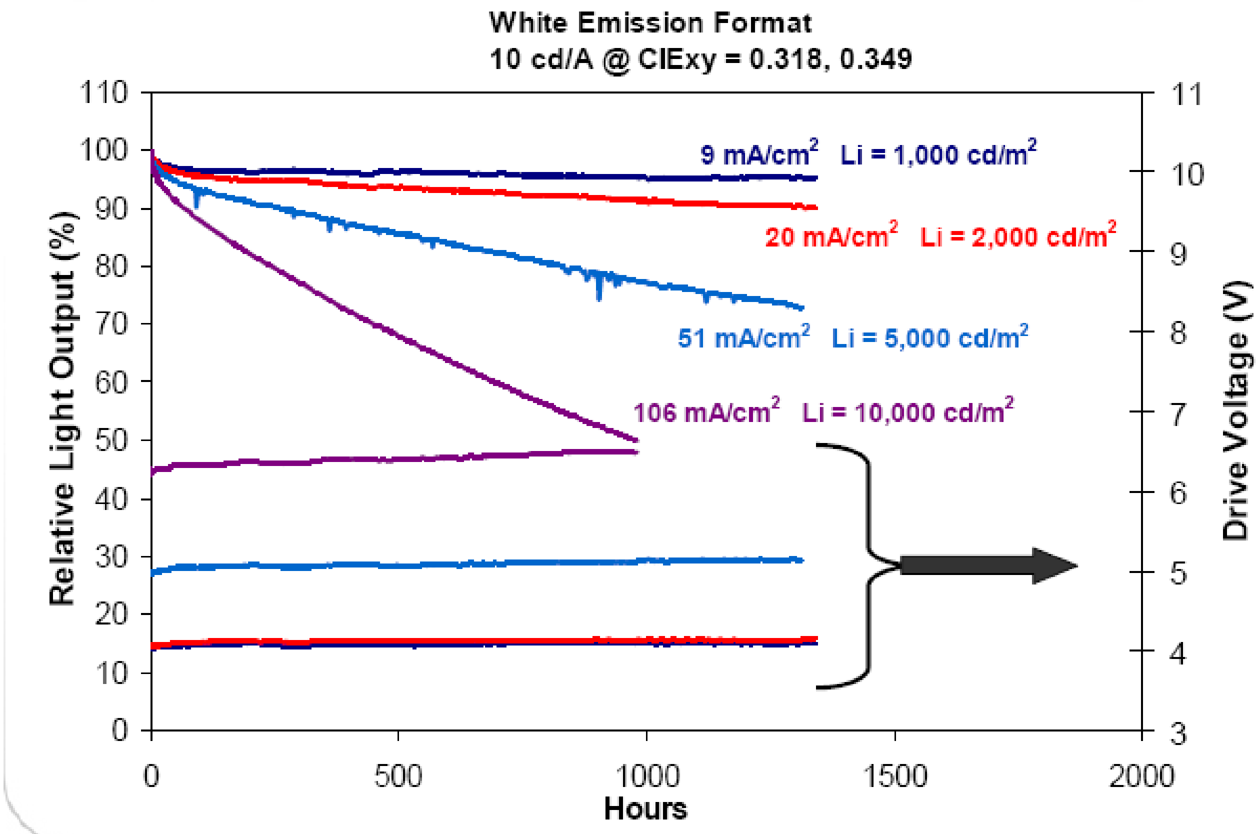


White emitting OLED (2) for display

Low Voltage OLED (white)



Reduction in output with use

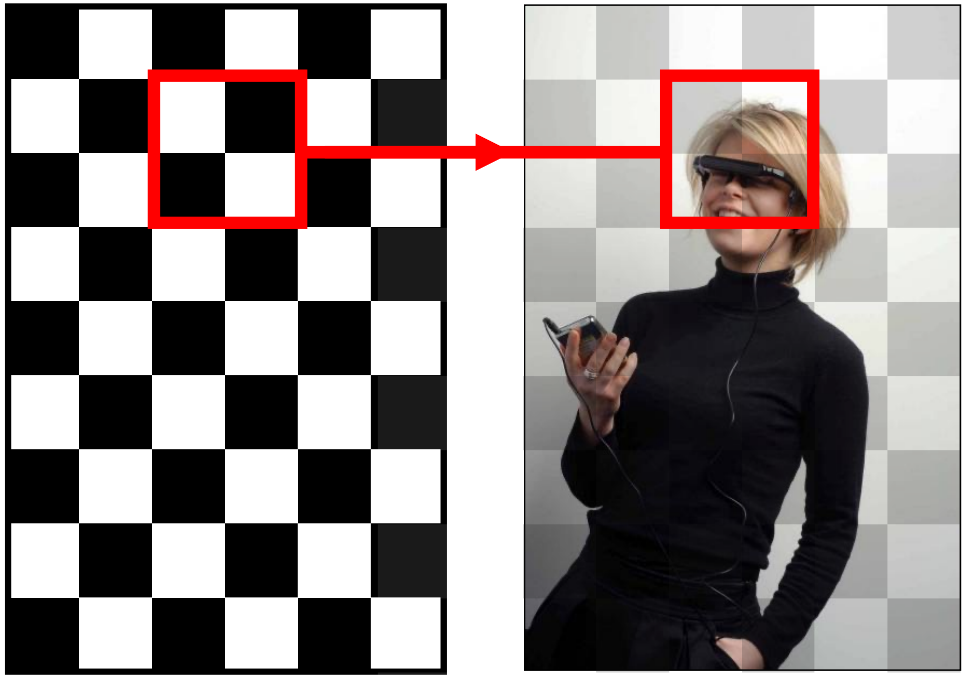


Consequences of OLED Lifetime

Image sticking

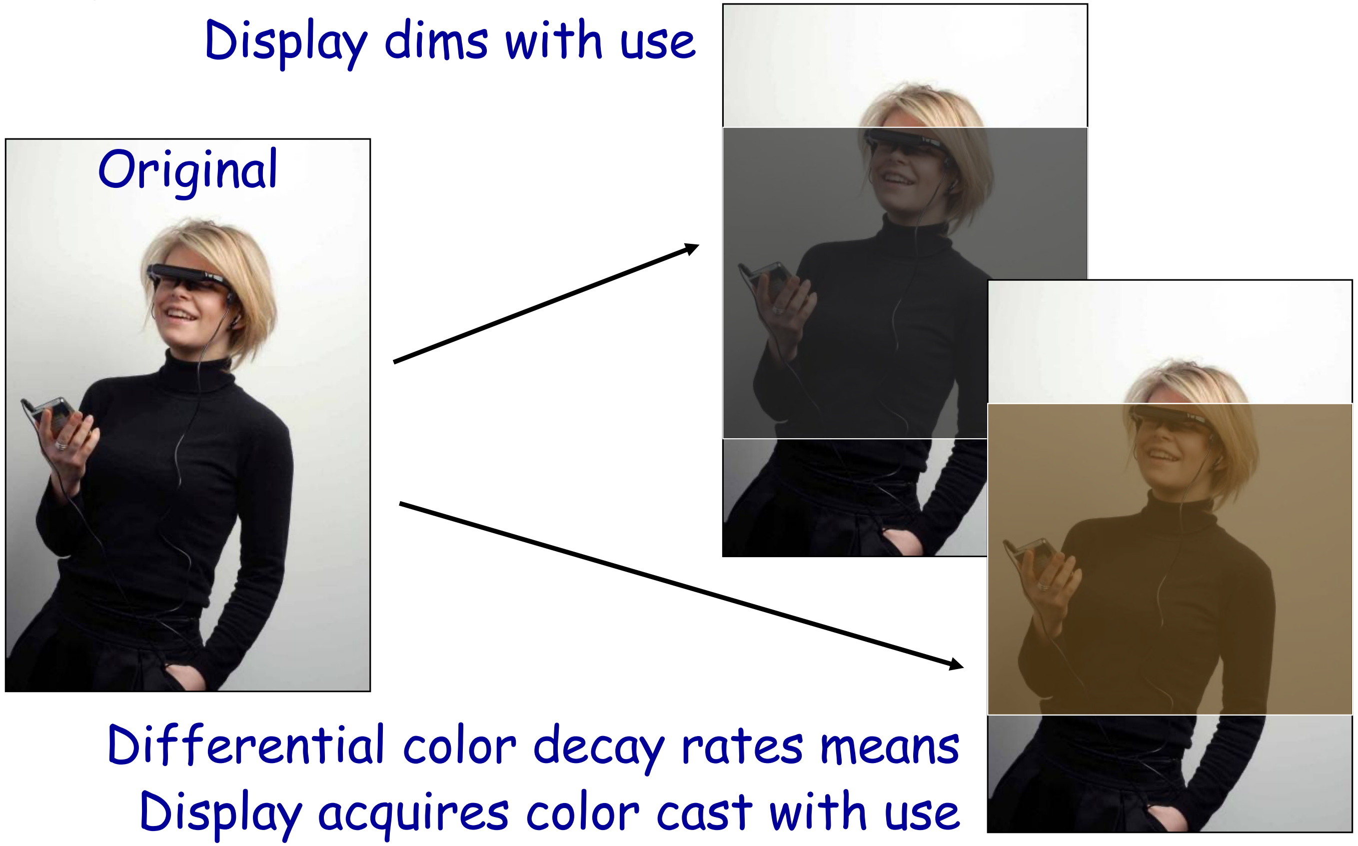
Caused by Differential pixel ageing

Pixels used more become dimmer sooner



Effect of OLED Luminance Characteristics

Display “lifetime” is related to material / device lifetime



Example of image sticking (burn-in) on PLASMA

Additional Slides

OLEDs - List of Abbreviations

AMOLED	Active-matrix OLED
AR	Antireflection
BE	Bottom emission
ELA	Excimer laser annealing
EML	Emission layer
ETL	Electron transport layer
FPD	Flat panel display
FMM	Fine metal mask
HIL	Hole injection layer
HTL	Hole transport layer
LTPS	Low temperature polysilicon
NTSC	National Television System Committee
RPL	Redundant pixel line
SBS	Side-by-side
TE	Top emission
VAS	Vacuum assembly system
WOLED	White organic light-emitting diode

Charge injection

Work-function does not line up with HOMO, LUMO

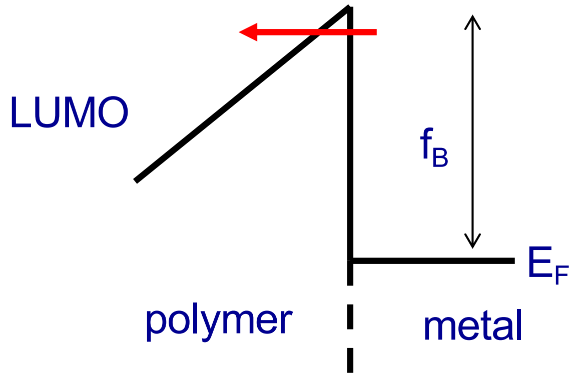
- potential barriers at the interfaces between electrodes and semiconductors

Thermionic emission

$$J = AT^2 \exp(V_{app} - q\varphi_B)/kT$$

Tunnelling

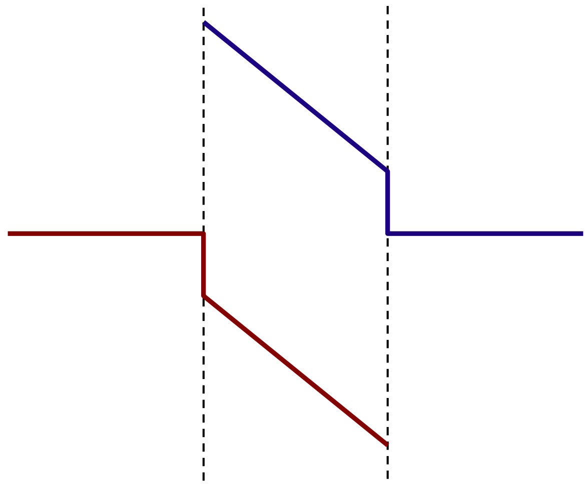
$$J = CE^2 \exp(-E_0 / E)$$



At low bias and high barriers current limited by injection

better engineering of the barrier heights (interfacial chemistry) leads to improvement in performance (low threshold voltages)

Device Operation – zero bias



Polymer OLED zero bias condition

Left is an OLED device under zero bias

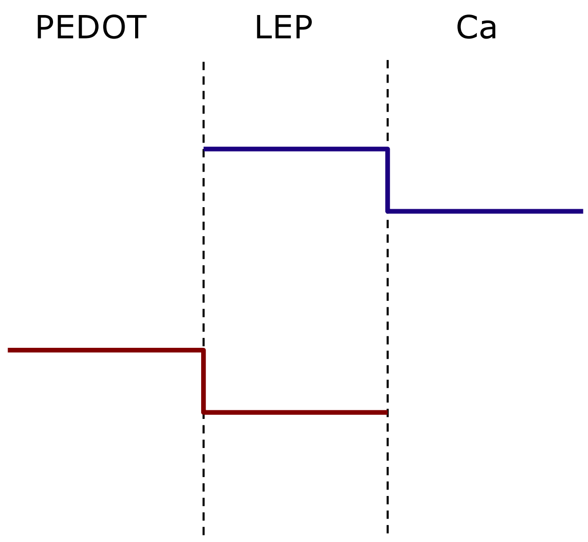
The carrier mobility in both the anode and cathode is much greater than in the LEP

- All the built-in field falls across the LEP

A (very) small current can flow due to dissociation of photo-excited excitons.

Under reverse bias small leakage currents will dominate

Device Operation – threshold



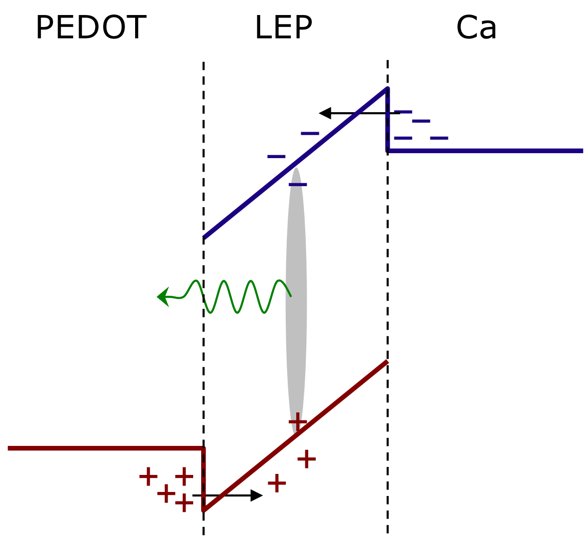
Polymer OLED in flat-band condition

Left is an OLED device at turn-on threshold ("flat-band" condition)

Thermionic emission allows carriers over the barriers to injection

- Temperature dependent

Device Operation – carrier injection



LEP in forward bias ("on")

Left is an OLED under forward bias

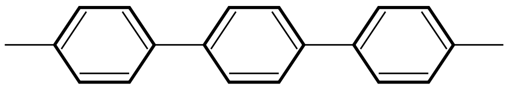
The current passing through any diode will be limited by either

- Carrier injection
- Space-charge

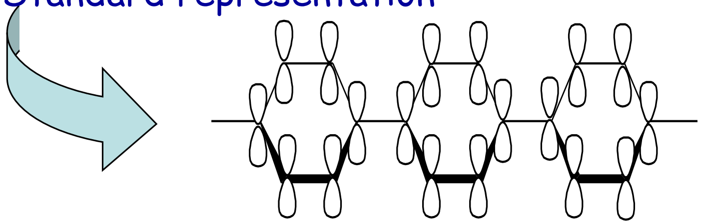
An injection limited device will be characterised by an exponential current-voltage relationship

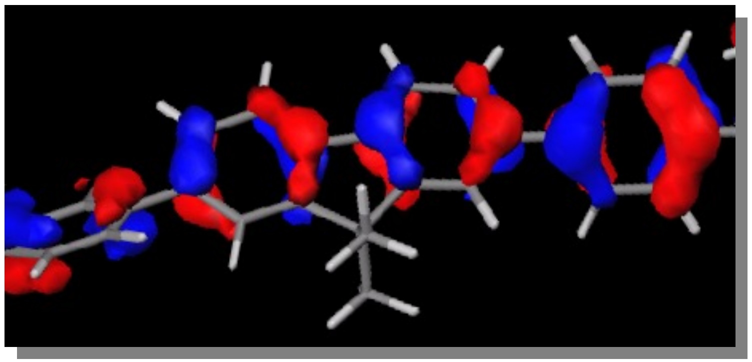
A space-charge limited device will have a quadratic current-voltage relationship

Conjugated polymers



Standard representation





HOMO level of a polyfluorene

The outer valence electrons can form two types covalent bonds - p and s bonds.

An s bond is the overlap of orbitals of two atoms, and is localised around the axis joining the two atoms.

A p orbital is formed between the un-hybridised p orbitals perpendicular to the axis of the s bond.

Continuous sections of molecules with p bonds are *conjugated*, in this case the p electrons are delocalised along the length of the conjugation.

Electrical conduction in conjugated polymers

Conduction is very different from metals or typical inorganic semiconductors:

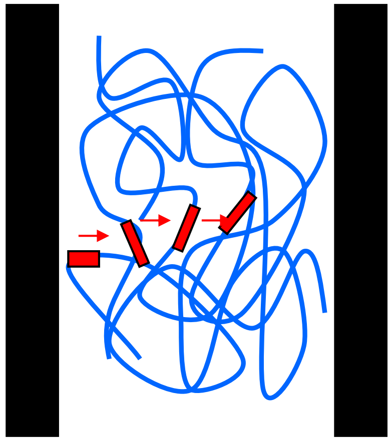
Conjugation breaks present energy barriers to free charge flow. In this type of situation conduction proceeds via *hopping*.

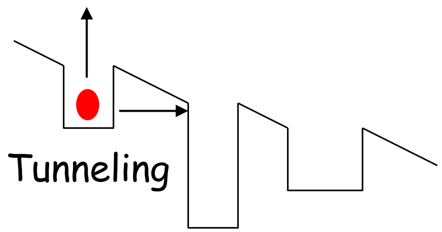
Charge Mobility μ is used to characterise conduction: $v = \mu E$

Mobility is very low compared to inorganic semiconductors

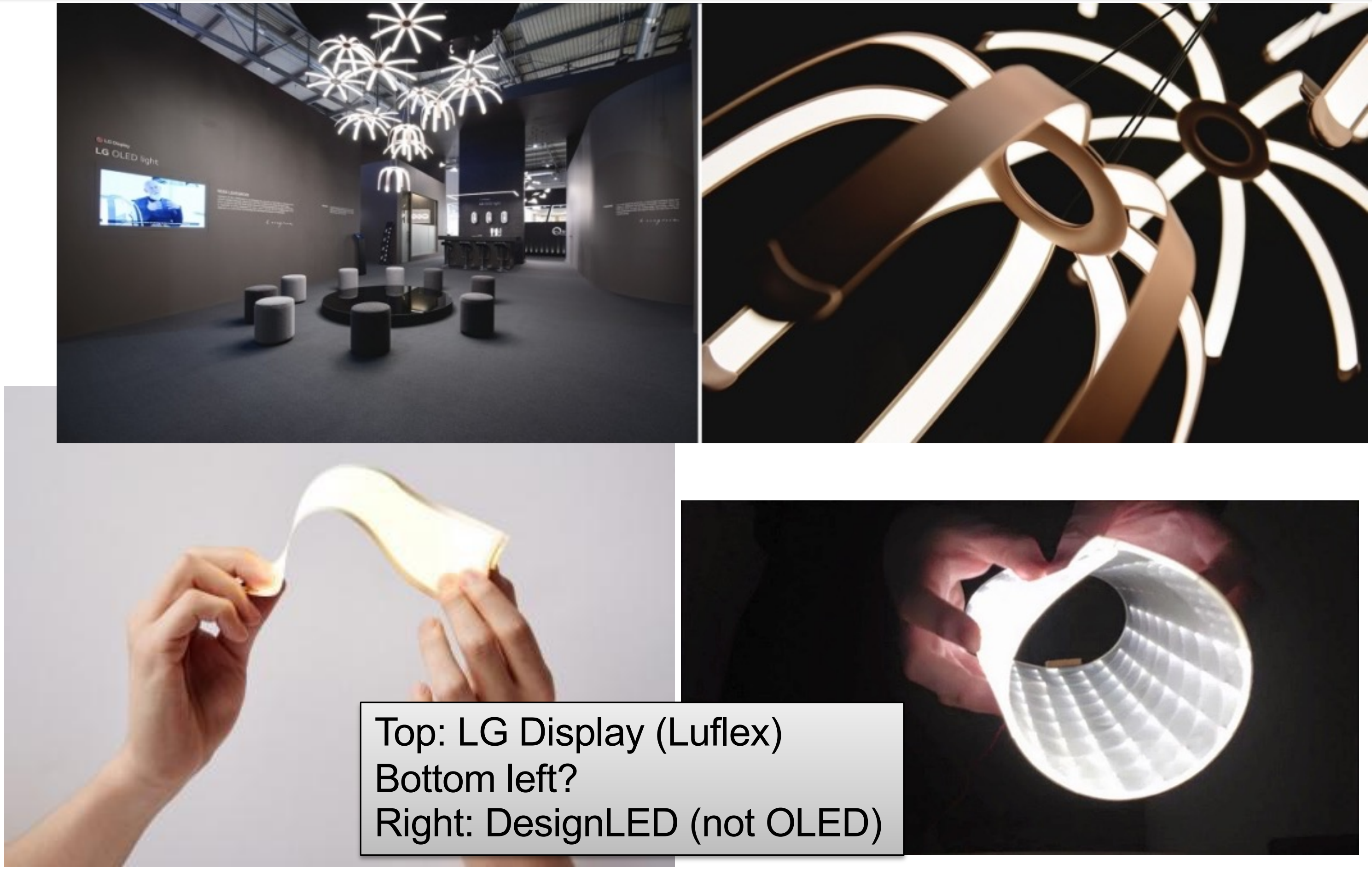
(<10^{-3} cm2/Vs)

Mobility depends on the electric field





State of the Art



Top: LG Display (Luflex)
Bottom left?
Right: DesignLED (not OLED)

Applications of OLEDs - Lighting