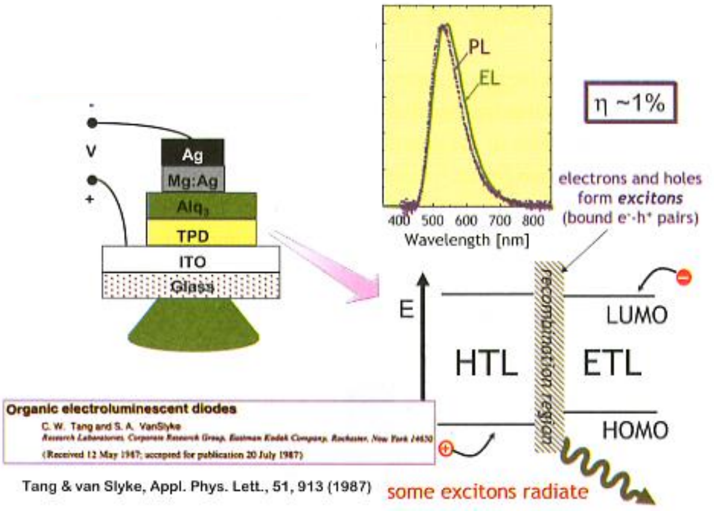
Organic and Printed Electronics

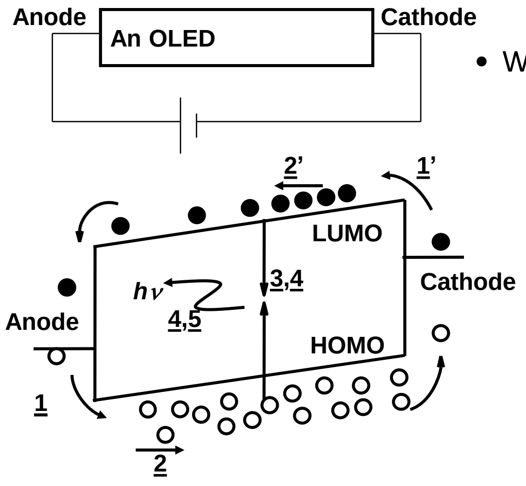
LESSON 6 – OLEDS

Prof. Vivek Subramanian

The first efficient OLED – Tang (Kodak)

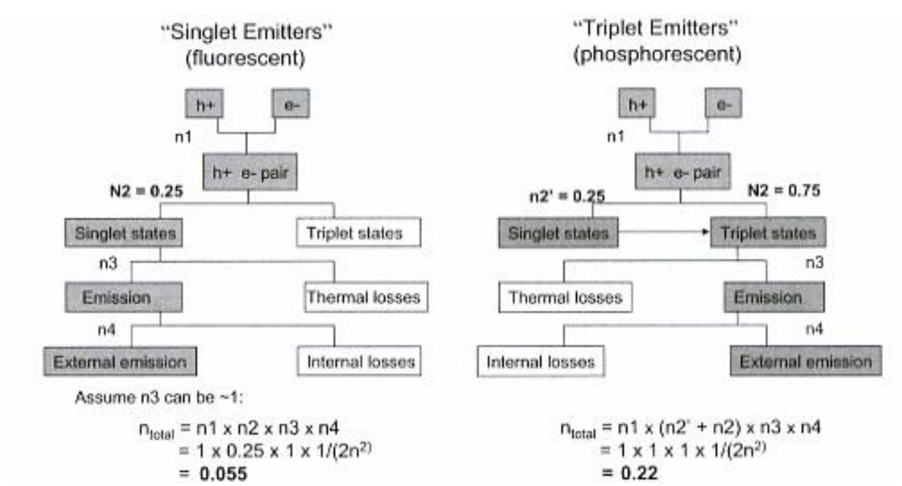


OLED Functioning – Electroluminescence

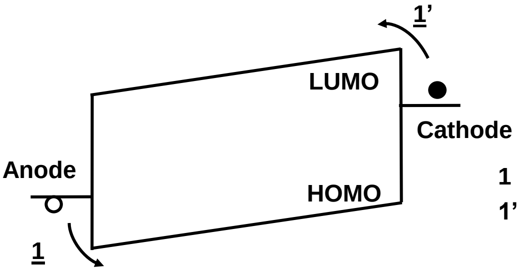


- When device is forward biased
  - 1,1' Charge Injection
  - 2,2' Charge Transport
  - 3 Exciton Formation
  - 4 Radiative Recombination
  - 5 Coupling Light to Outside

Efficiency Calculations



Charge Injection

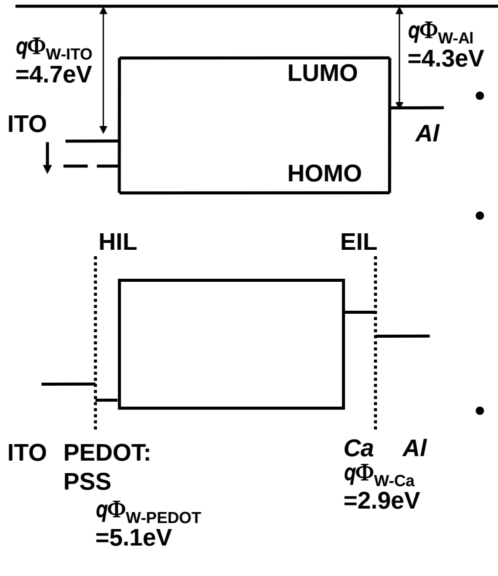


1 Holes injected from anode

1' Electrons injected from cathode

- **Anode – should allow easy hole injection**
  - **Indium Tin Oxide (ITO); Transparent, Φ_W=4.7 eV**
- **Cathode – should allow easy electron injection**
  - ***Ag* (Φw = 5.1 eV) or *Al* (Φw = 4.3 eV)**

Improving Charge Injection

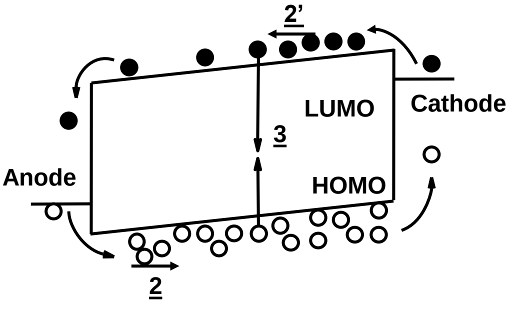


- **Increase ITO work-function**
  - **Ozonization**
  - **Oxygen Plasma treatment**
- **Introduce Hole Injection Layer**
  - **PEDOT:PSS**

    Poly (3,4) diethyledioxythiphine:

    Poly Styrene sulphonic acid
- **Introduce Electron Injection Layer**
  - **Calcium to form *Ca-Al* contact**
  - **Layer of *LiF***

Conduction through OLED



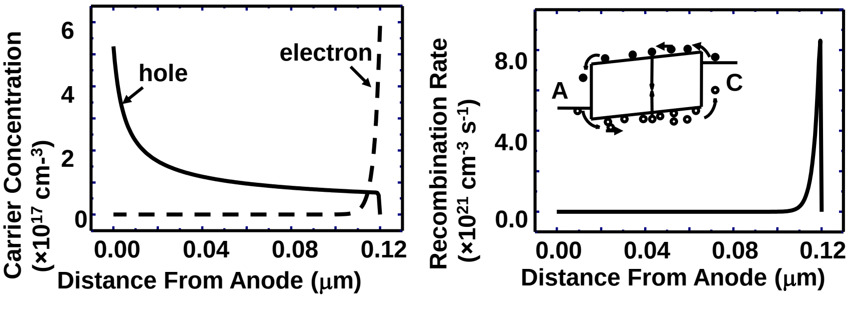
2 Holes flow towards cathode

2' Electrons flow towards anode

3 Electron-hole pair form exciton

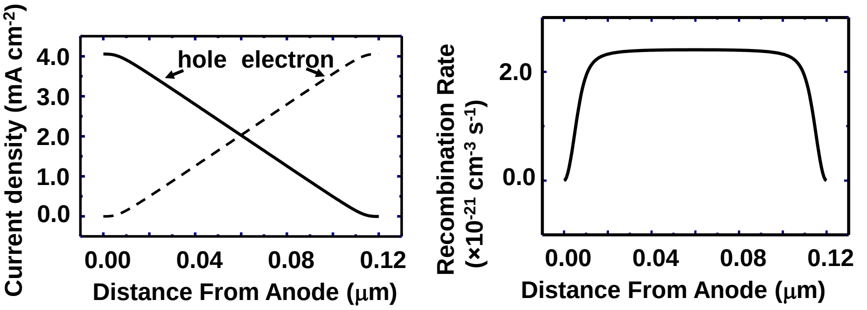
- Usually $\mu_{hole} >> \mu_{electron}$
  - Disbalance of mobilities is of many orders of magnitude
- Excess holes flow to cathode
- Location of formation of exciton important

Carrier Profile in Single Layer OLED



- Many holes flow through without forming excitons
- Excitons formed near cathode which is not desirable

Ideal Situation



- **Want similar concentration and mobility of electrons and holes**
- **Would prefer exciton formation away from the contacts**

Transport Equations

holes
$$\frac{\partial p}{\partial t} = \frac{\partial}{\partial z}\left[\mu_p pE - \mu_p \frac{k_B T}{e}\frac{\partial p}{\partial z}\right] - \frac{np}{\varepsilon}(\mu_n + \mu_p)$$

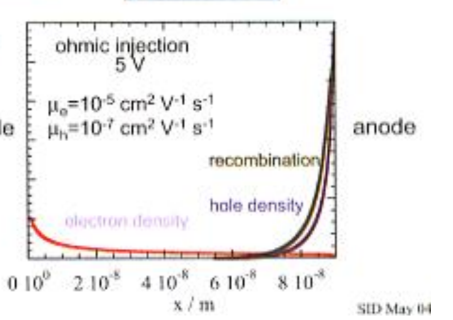
electrons
$$\frac{\partial n}{\partial t} = -\frac{\partial}{\partial z}\left[\mu_n nE + \mu_n \frac{k_B T}{e}\frac{\partial n}{\partial z}\right] - \frac{np}{\varepsilon}(\mu_n + \mu_p)$$

Drift — Diffusion — Langevin Recombination

$$\frac{\partial E}{\partial z} = \frac{(p-n)e}{\varepsilon}$$

Example

cathode



anode

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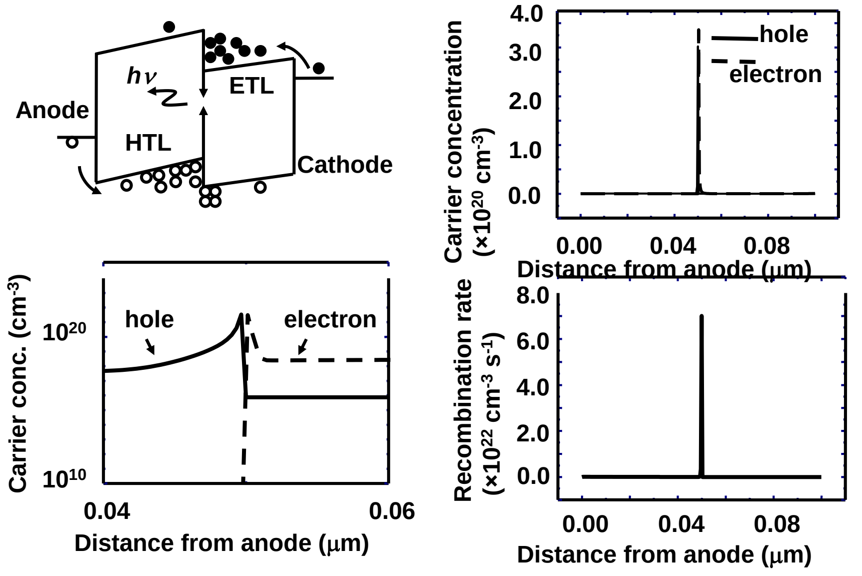
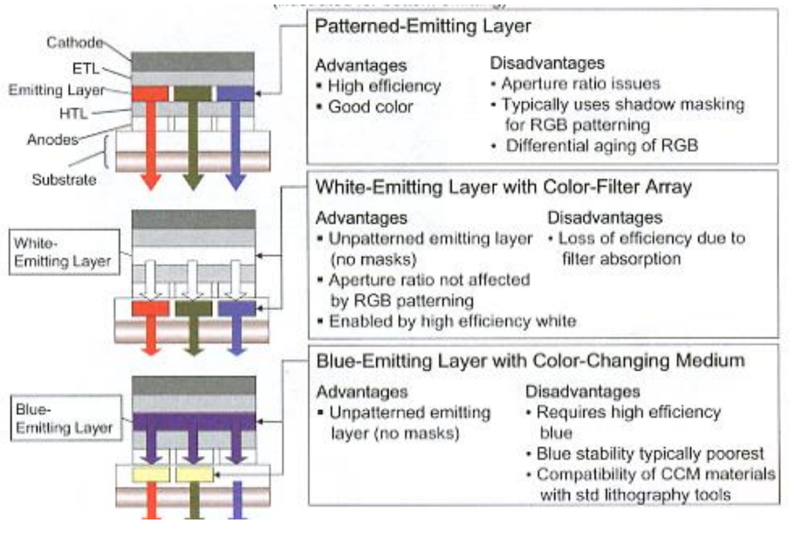
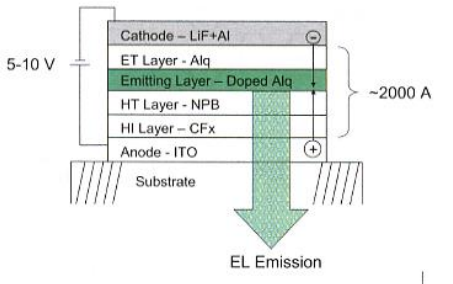
Hetero-junction OLED



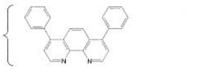
Color Control in OLEDs



A typical OLED structure

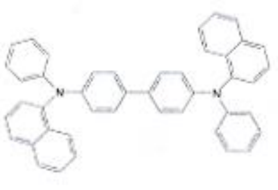


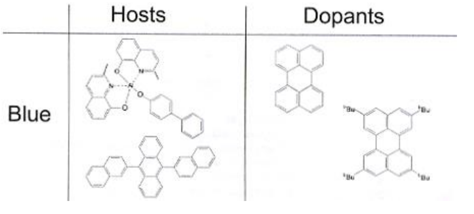
Alq (u ~ 10^{-6} – 10^{-7} cm^2/V-s)

Bphen 

Li:Alq (Li increases mobility)

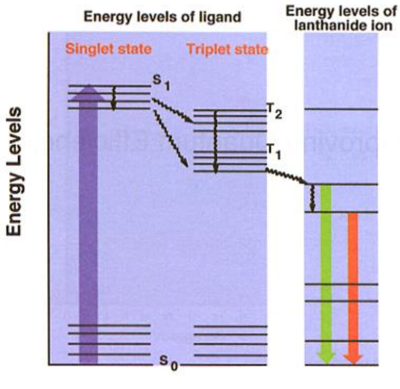
NPB (NPD)





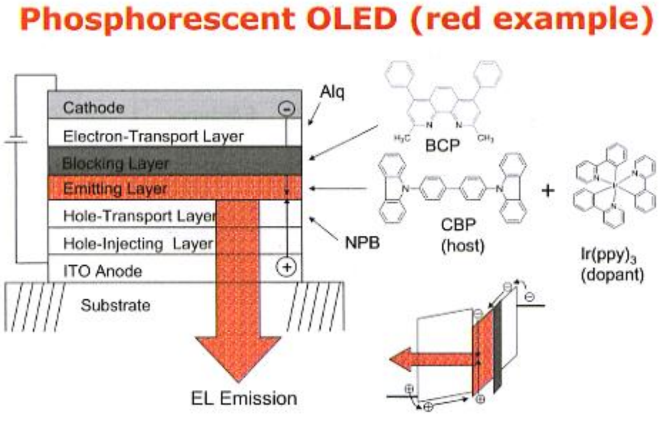
Phosphorescence – breaking the 25% barrier

- **Since triplet states do not produce much radiative recombination, they typically represent a loss mechanism**
- **By adding a phosphorescent dye, the triplet energy can be transferred and subsequently radiatively emit**

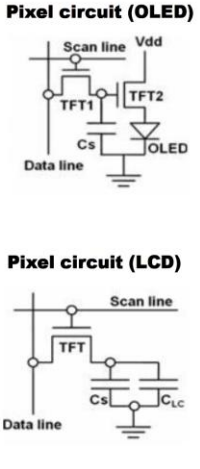


Typical PhOLED

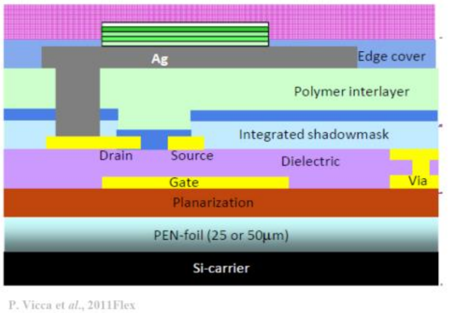
- **Usually, phosphorescent OLEDs make use of metal-containing dye molecules**



Driving OLEDs

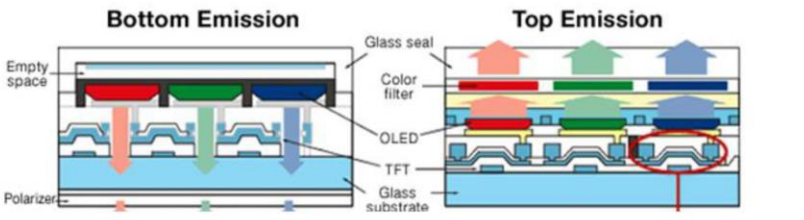


- **LCDs are Voltage driven**
- **OLEDs are current driven**
  - **Well-controlled current needed (2TFTs)**

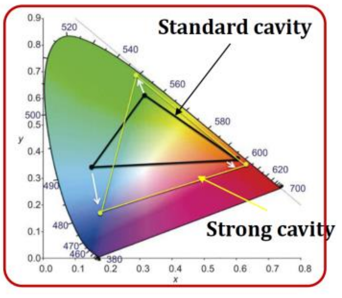


P. Vicca et al., 2011Flex

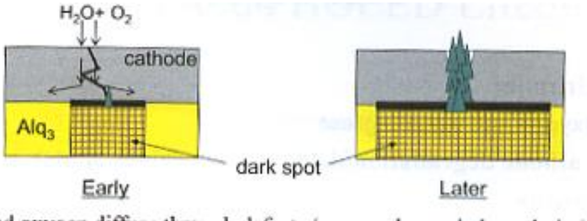
Top Emission



- **Higher aperture ratio**
  - **→ More efficient**
  - **→ More stable**
- **Processing on Si / Metal, etc.**
- **Larger color gamuth**



Degradation mechanisms in OLEDs



- Water and oxygen diffuse through defects (*e.g.* cracks, grain boundaries)
- Insulating interface is formed between the cathode and the Alq_3 film
  - oxidation of Mg, could be followed by hydration of MgO
  - oxidation of Alq_3^+ at cathode/Alq_3 interface
  - process results in open circuit in dark spot
  - oxidation processes are field independent, *I.e.* similar dark spot growth with and without bias
- Humidity induces crystallization of Alq_3 (Aziz, *et. al.*, *APL* (1998)), leading to feature growth at the surface in later stages of degradation