平面顯示技術概論

Introduction to OLED Devices and Displays

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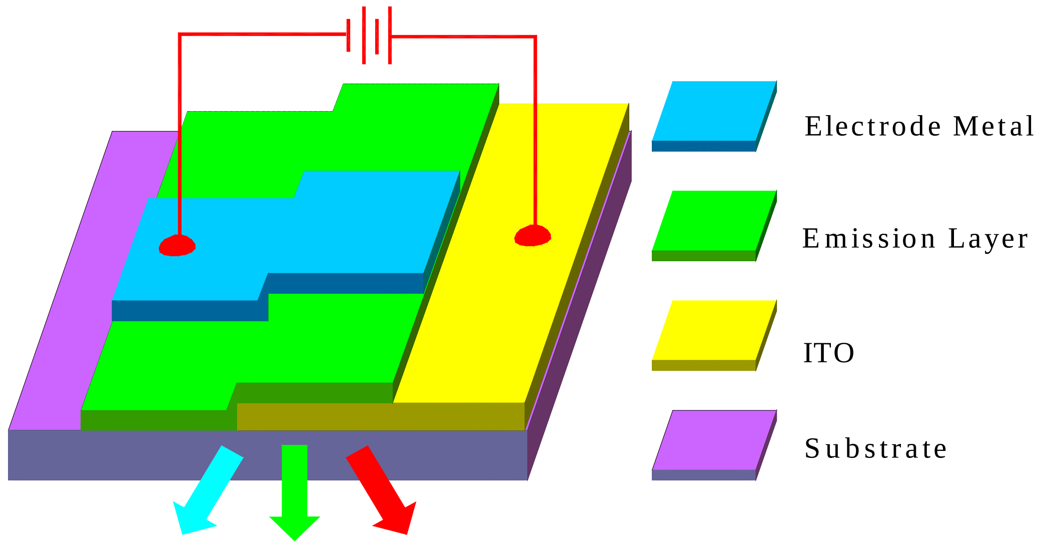
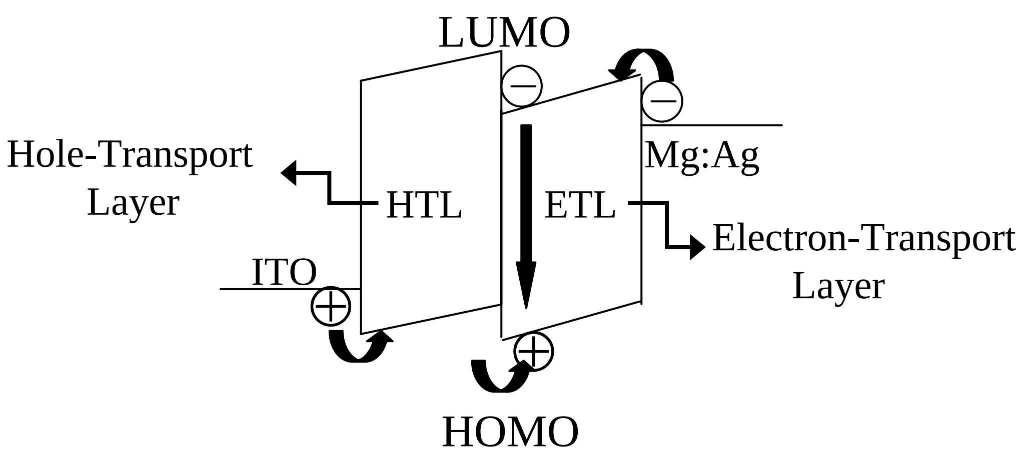
Outline

- Introduction
- OLED Device
- OLED Processing
- OLED Displays

Organic Light-Emitting Diodes (OLEDs)



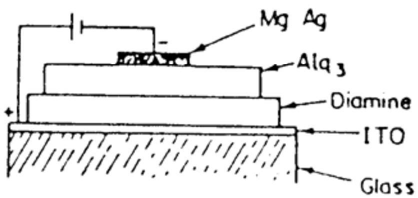


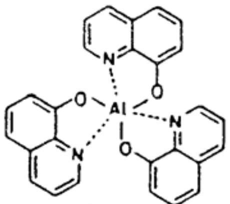
- Carrier injection, transport, recombination, emission

Pope et al., J. Chem. Phys., 1963; C. W. Tang et al., APL, 1987

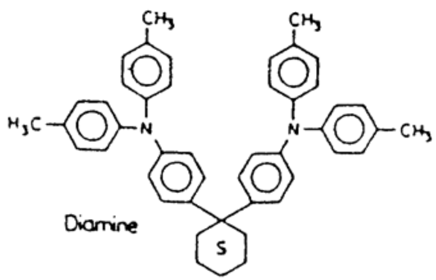
Kodak, 1987
- vacuum evaporation
- small molecules

Cambridge, 1990
- spin-coating
- polymer

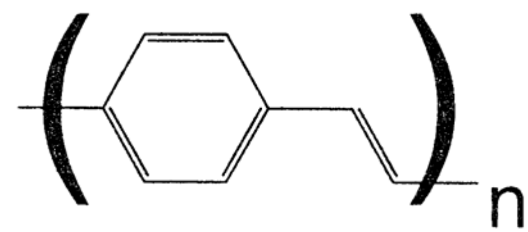




Alq3



Diamine



PPV

Features of OLEDs for Displays

- Low-T process, versatile in substrates
- No epitaxy, large area
- Flexible
- Fast response time (<us)
- Self-emissive (viewing angle not an issue)
- RGBW, full color available
- low voltage (<10V)
- High brightness (>100000 cd/m2)
- High efficiency (tens of lm/W)
- Less components

Technology/Application Evolution

1980's

Pioneer

Pioneer

1997-2000

Pioneer

Kodak

2000-2003

IBM/CMO 20”

Sony 24”

Pioneer

Future

Passive Matrix

Active Matrix

Companies

台灣：

錸寶、光磊、悠景、東元激光、聯宗光電、勝園、翰立光電

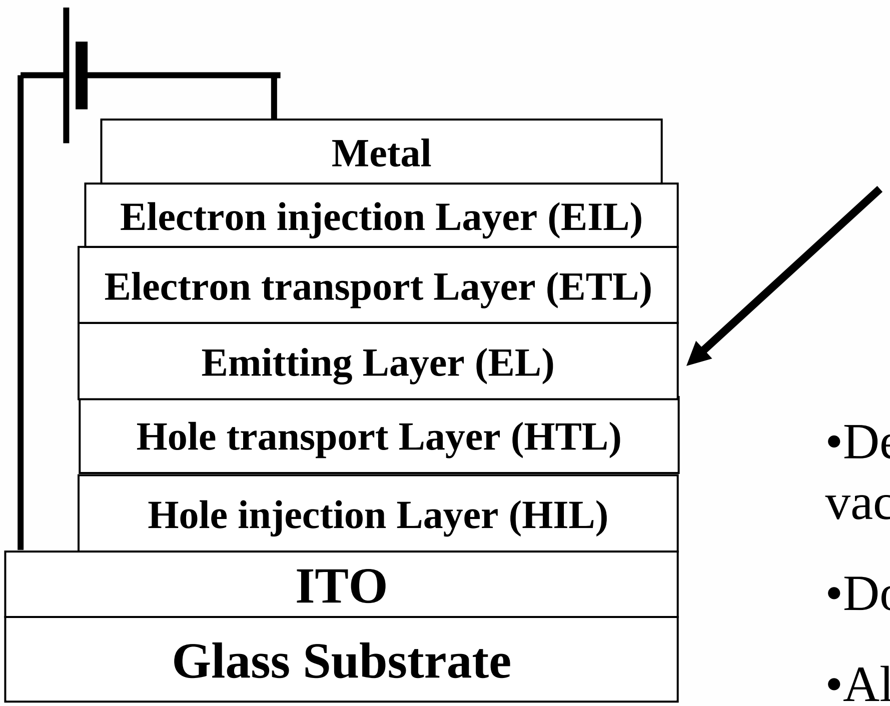
友達、奇美、統寶、華映

永信、昱鐳光電

國外：

Samsung、LG、Pioneer、Sony、Sanyo/Kodak、Toshiba、Seiko-Epson、NEC、Idemistsu、Philips、Osram、DuPont、Dow、UDC、CDT etc.

State-of-Art Heterostructure OLEDs



Host and Dopant

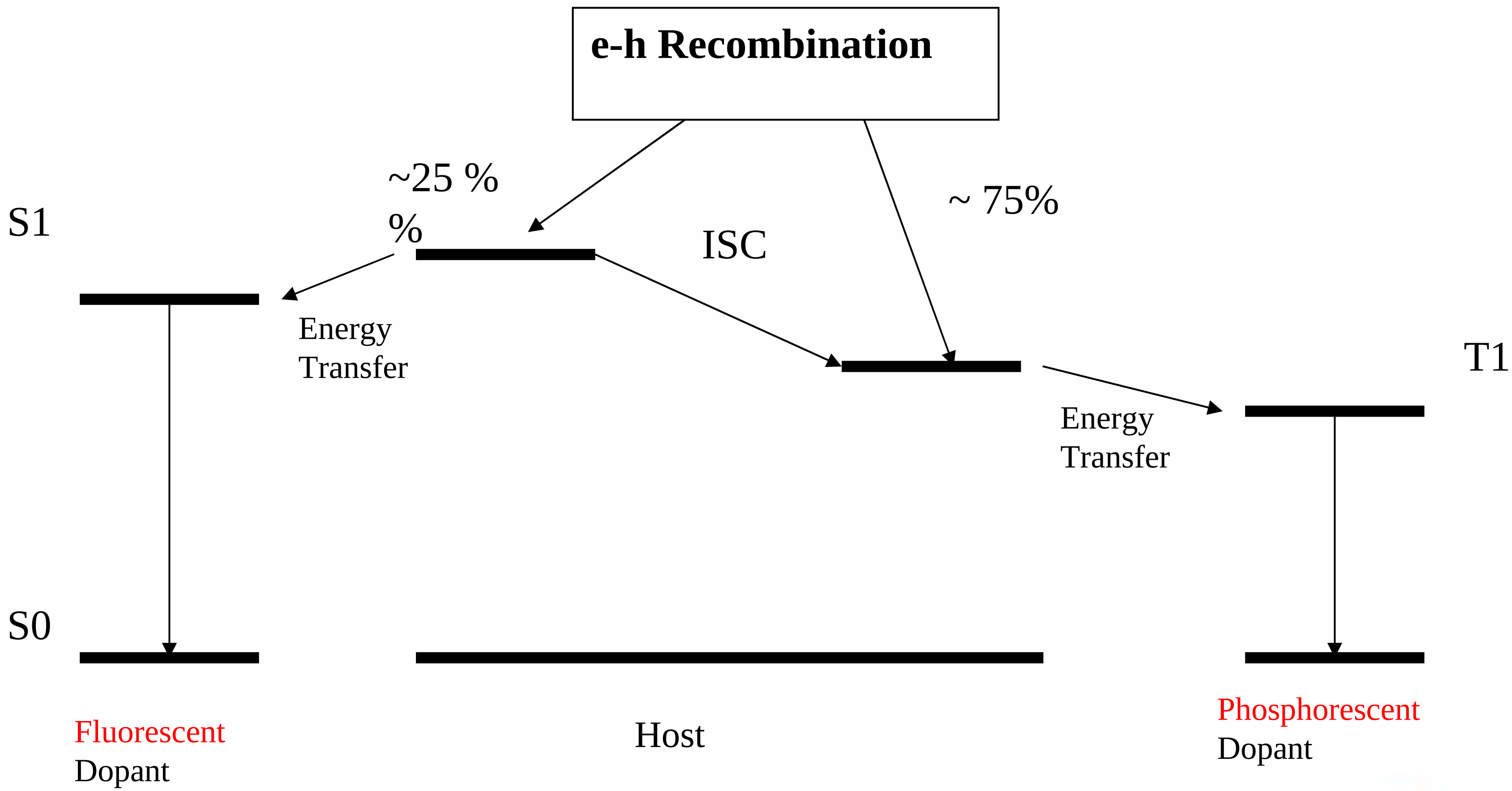
- Fluorescent
  (singlet emitter)
- Phosphorescent
  (triplet emitter)

•Deposition by multiple-source vacuum system < 10^{-6} torr

•Doping by co-deposition

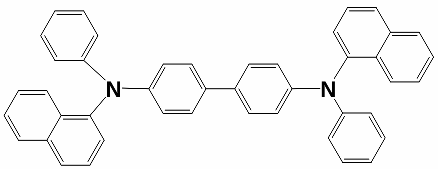
•All in one pump-down

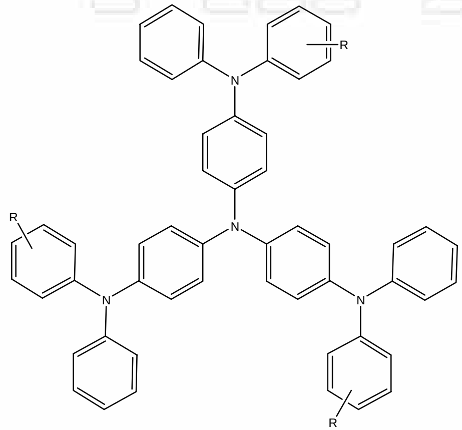
Emissive Doping and Materials Systems



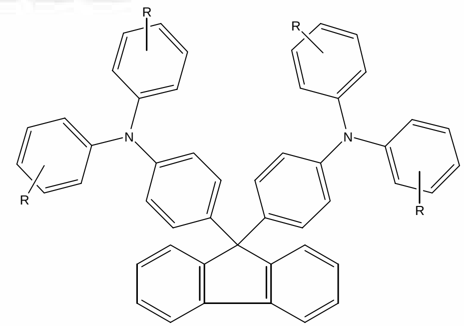
Emissive dopant: (i) to enhance emission efficiency, (ii) to tune color

Hole-Transport Materials



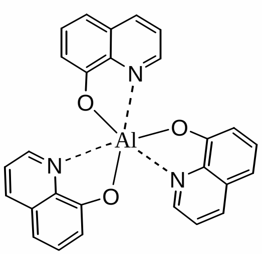


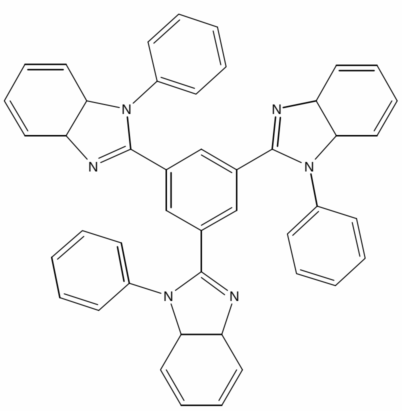
TDATA



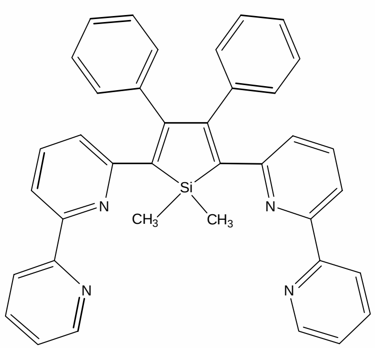
FTPD

Electron-Transport Materials

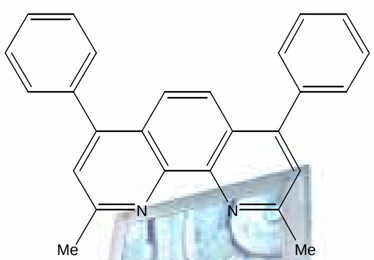




TPBI

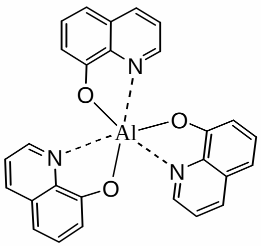


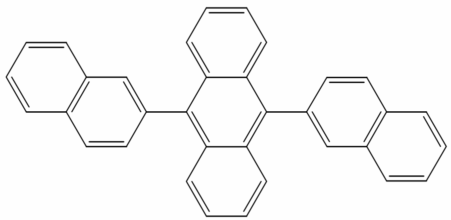
PyPySPyPy

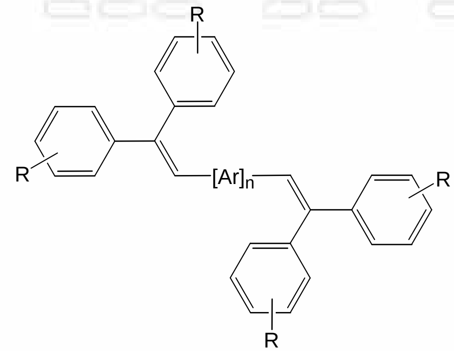


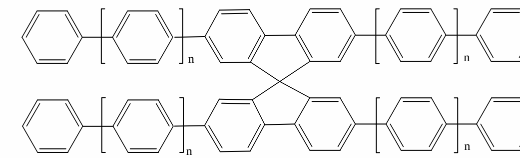
BCP

Host Materials

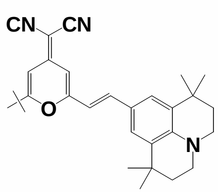


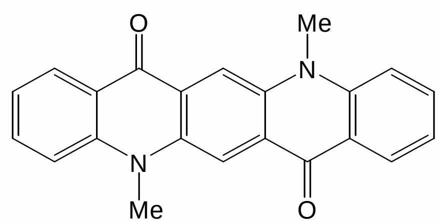




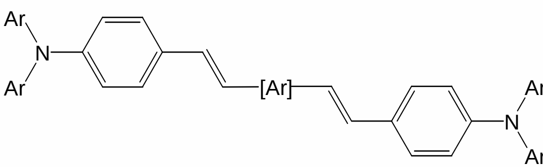


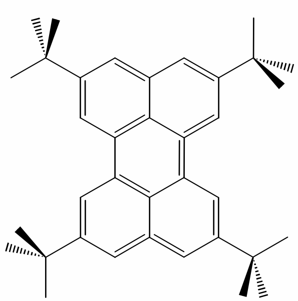
Dopant Materials

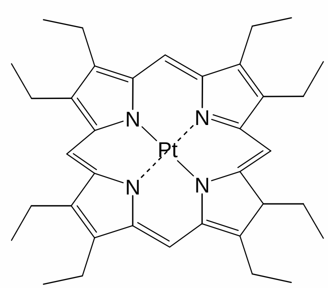


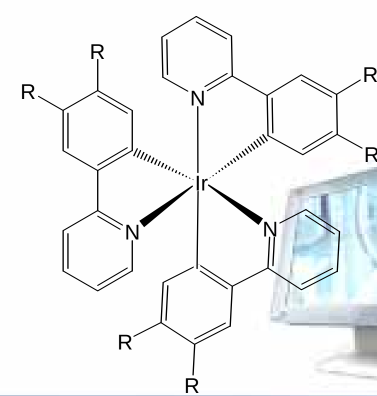


Quinacridone









OLED Parameters

A device area
J current density (mA/cm2)
V voltage (V)
P optical power (W) ⇔ ***F*** flux (lumen) ⇔ ***B*** Brightness (cd/m2)
(radiometry) (photometry) **B = F/πA**

- **External Quantum Efficiency** (photon/electron, %) ⇔ cd/A

$$\eta ext = (P/h\nu)/(AJ/e)$$ (photometry)

- **Power Efficiency** *(%)*

$$\eta p = P/(AJV) \propto \eta ext/V$$

- **Luminous Efficiency** *(lumen/watt, lm/W)*

$$\eta L = F/(AJV) \propto \eta ext/V$$

External Quantum Efficiency

$$\eta_{ext} = \eta_r \chi \eta_{em} \eta_{opt}$$

η_r : fraction of electrons and holes that form e-h pairs

χ : fraction of e-h pairs resulting in desired excited states (singlet or triplet)

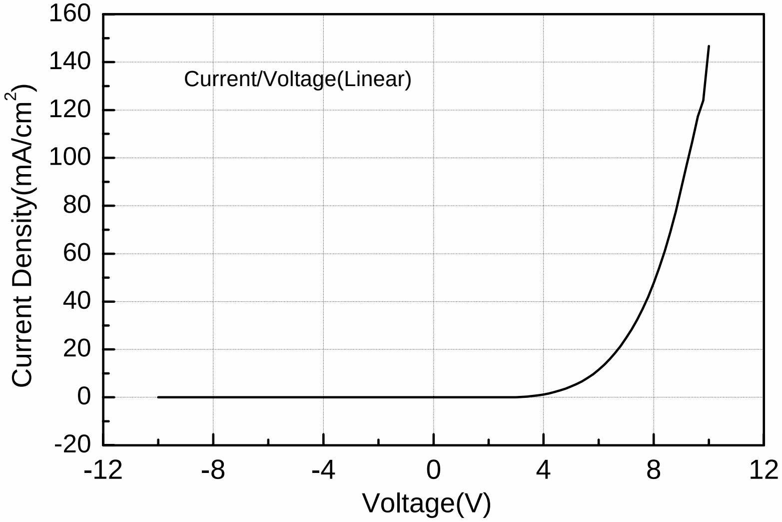
η_{em} : emission efficiency of molecular excited states

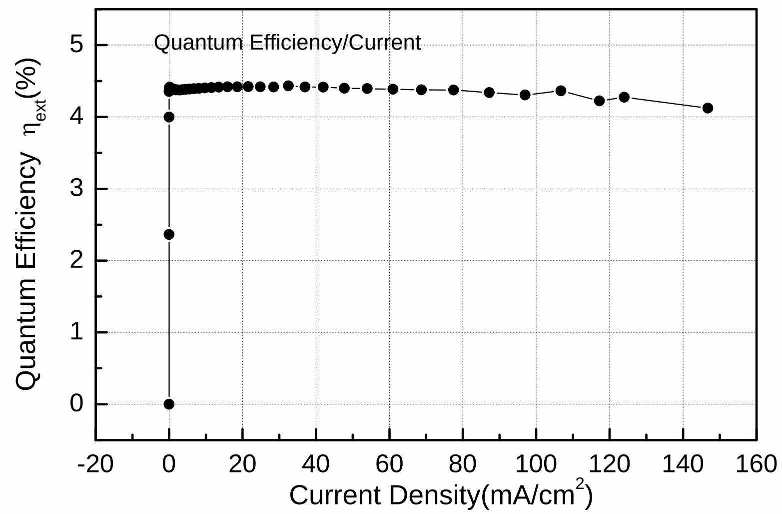
η_{opt} : fraction of emitted photons coupled out of devices

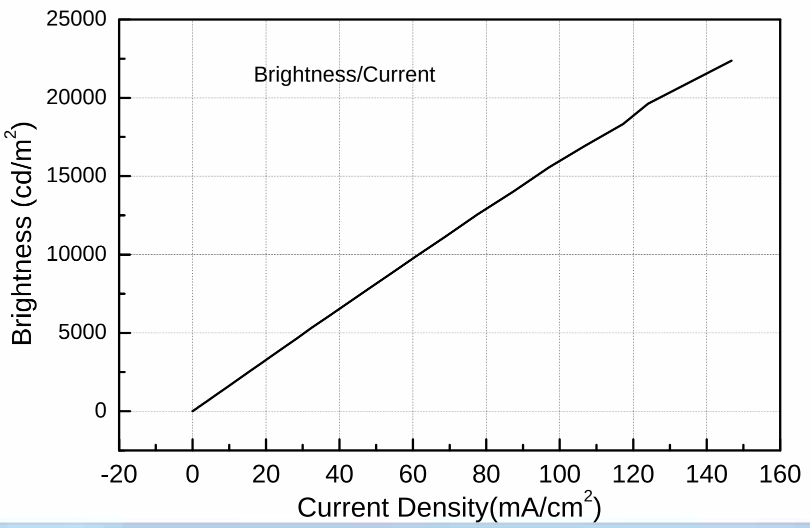
- **Fluorescence** : $\eta_{ext} \leq 1 \times (1/4) \times 1 \times (1/2n2) \sim 6\%$
- **Phosphorescence**: $\eta_{ext} \leq 1 \times (1) \times 1 \times (1/2n2) \sim 20\%$

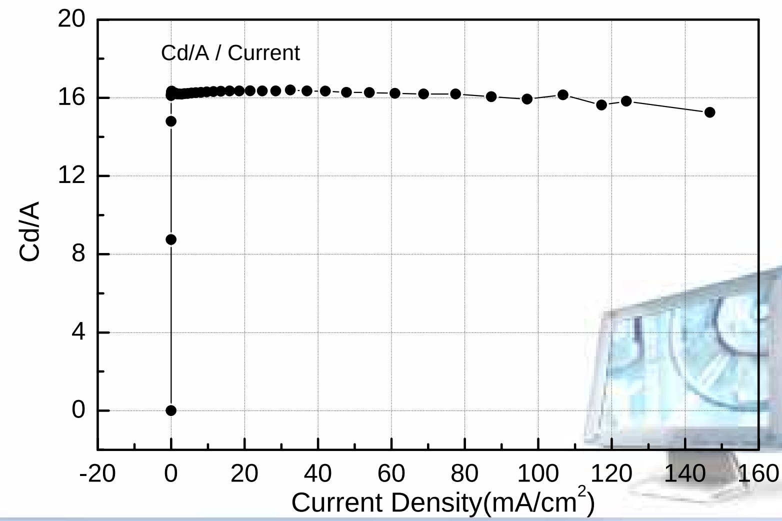
(n : refractive index of organics ~1.6-1.9)

OLED Characteristics (fluorescent, green)





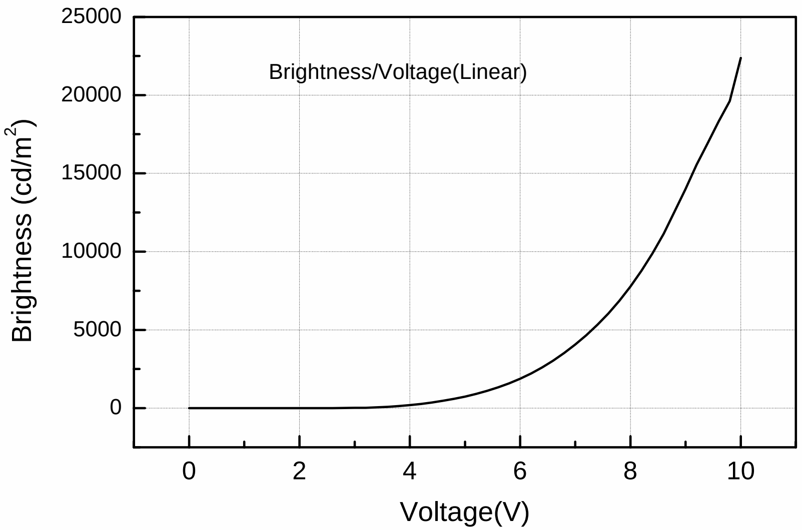


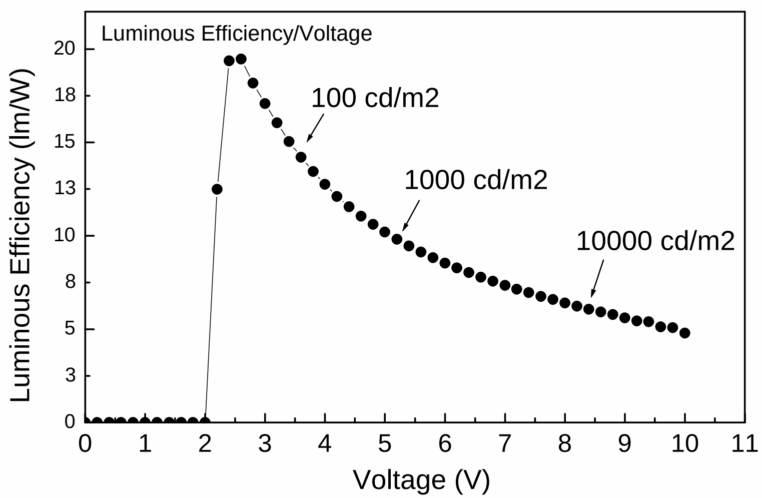


Operation Voltage & Power Efficiency

Ex. Green OLEDs (Fluorescent)

ηext = 5%, B = 100 cd/m2, 0.5 mA/cm2, 4V, ηL~ 15 lm/W





- Low conductivity of OLED materials

  ⇒V increases with J and B quite significantly

  ⇒ ηL decreases with J and B quite significantly

Contrast

- **Contrast Ratio (N:1)**

$$\frac{B_{ON}}{B_{OFF}} = \frac{B_{OLED} + B_{OFF}}{B_{OFF}}$$

- **Reflective metal cathode of OLED**

⇒ require contrast enhancement component

e.g. Neutral density filter, Circular polarizer etc.

T (%) = Transmittance

⇒ optical loss

- (or black cathode, low-reflection OLED etc., still optical loss)

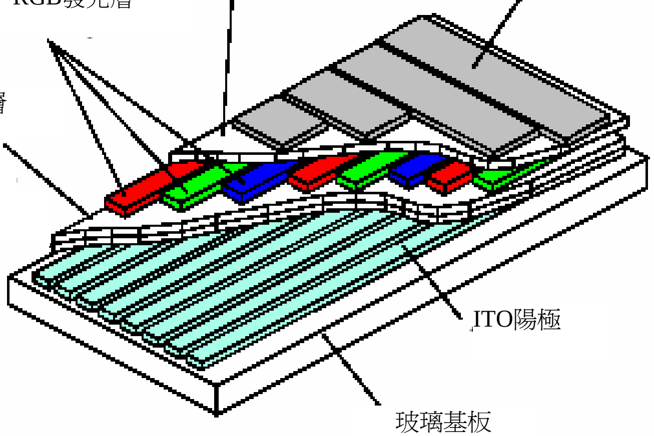
Key Issues in OLED Display Development

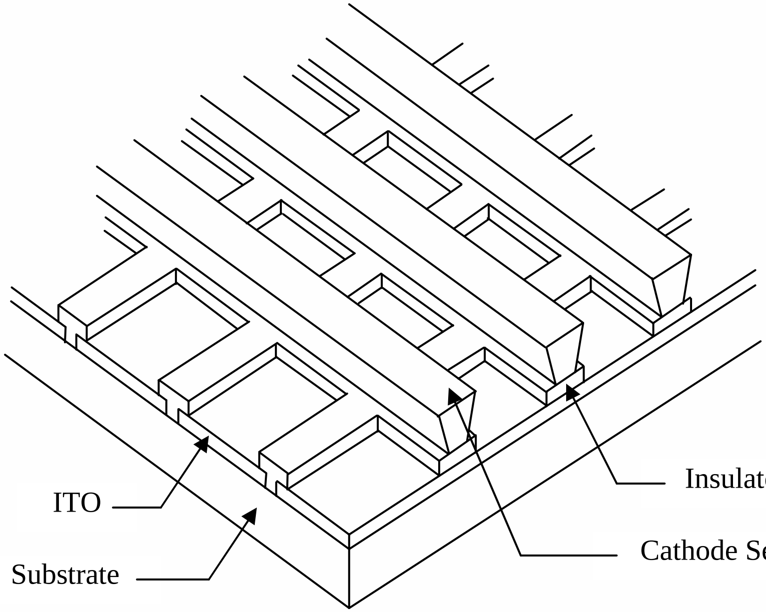
- **Pixel patterning**
  - cathode electrode patterning
  - color sub-pixel patterning

- Driving schemes
  - passive matrix
  - active matrix

- (Sealing and packaging too, of course!)

Passive Matrix OLED as Example





Glass清洗

↓

陽極電極製作
- ITO濺鍍
- 光阻塗佈
- 曝光、顯影
- 蝕刻
- 光阻剝離

↓

絕緣層製作
- 沈積
- 曝光、顯影
- 蝕刻

↓

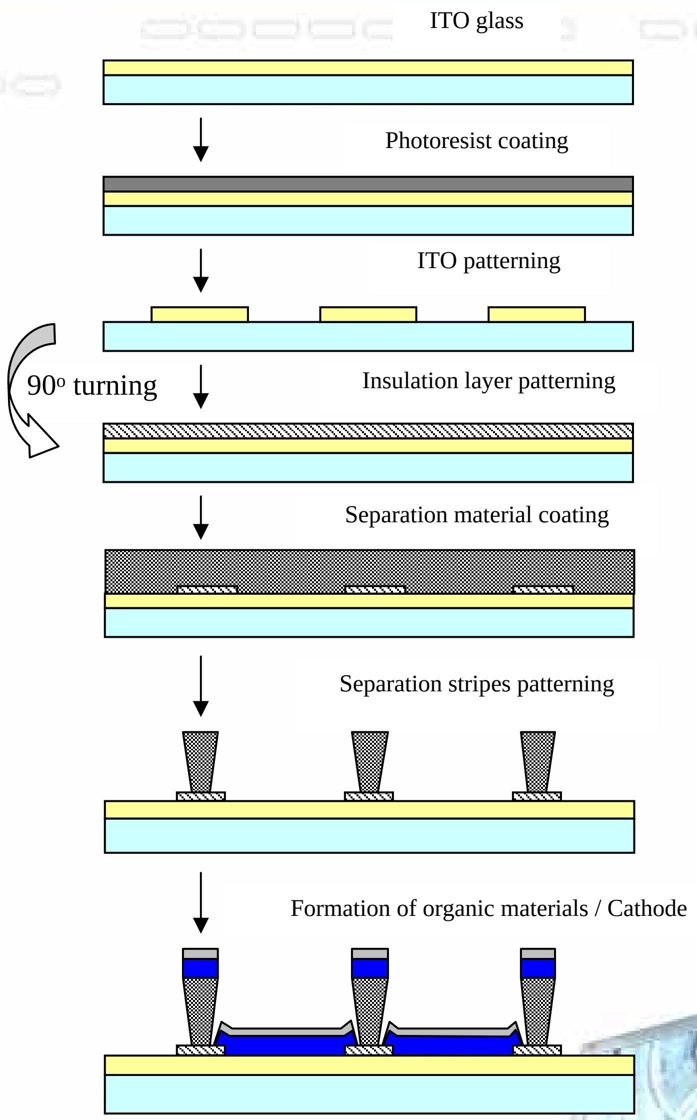
陰極分隔線製作
- 沈積
- 曝光、顯影
- 蝕刻

↓

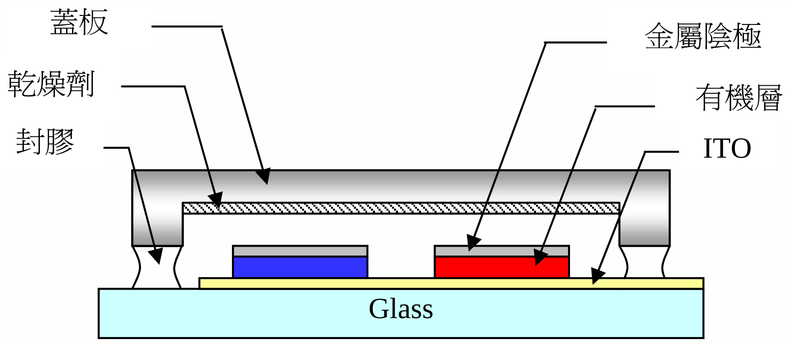
有機材料蒸鍍
- 電洞傳導層
- 發光層
- 電子傳導層等

↓

陰極電極

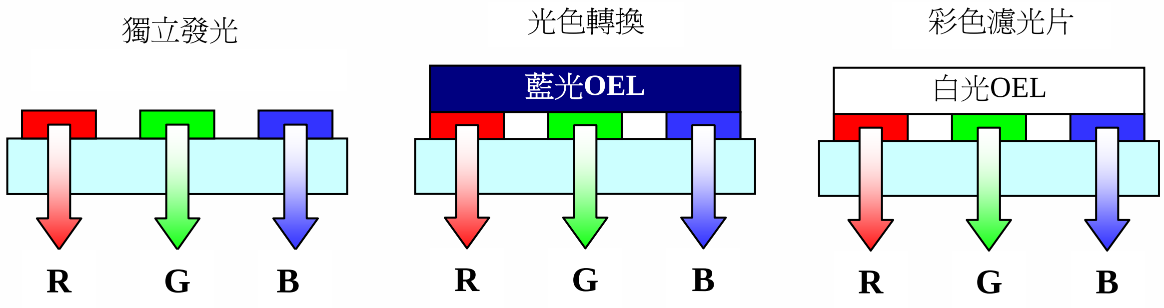


Encapsulation



Full Color Schemes

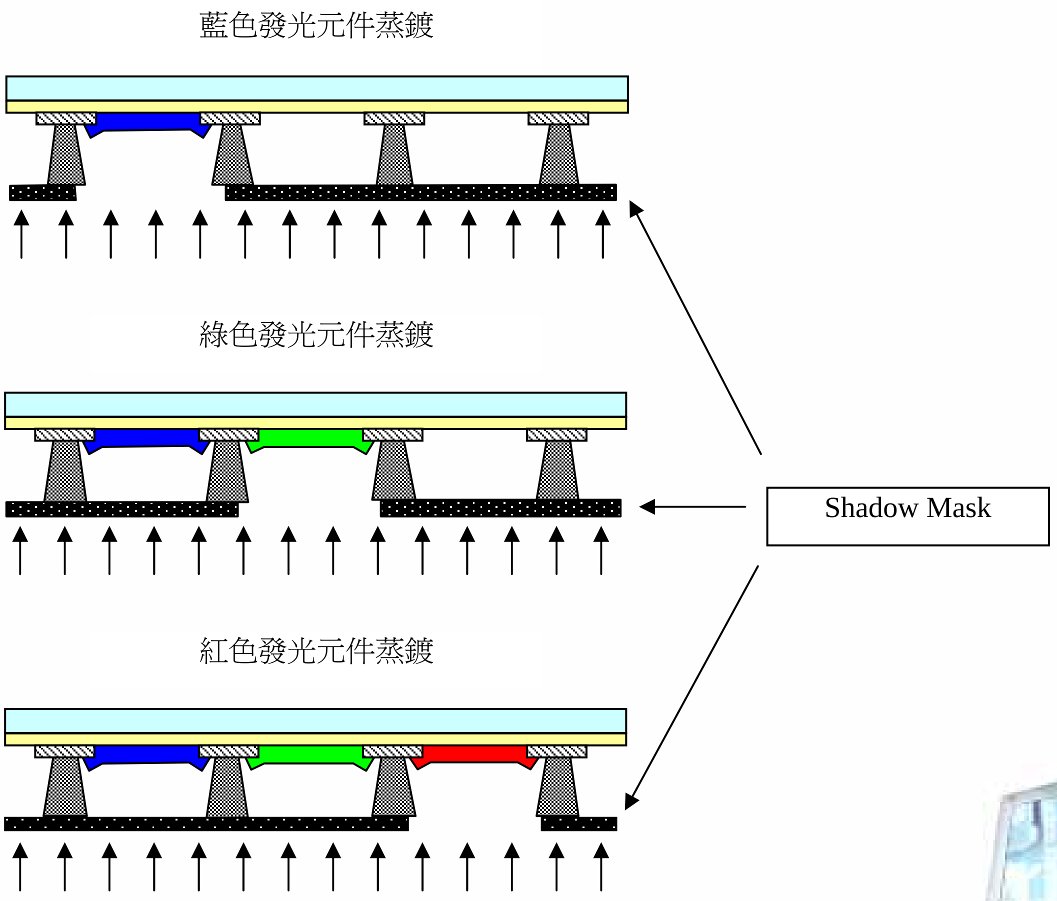
Color Pixels



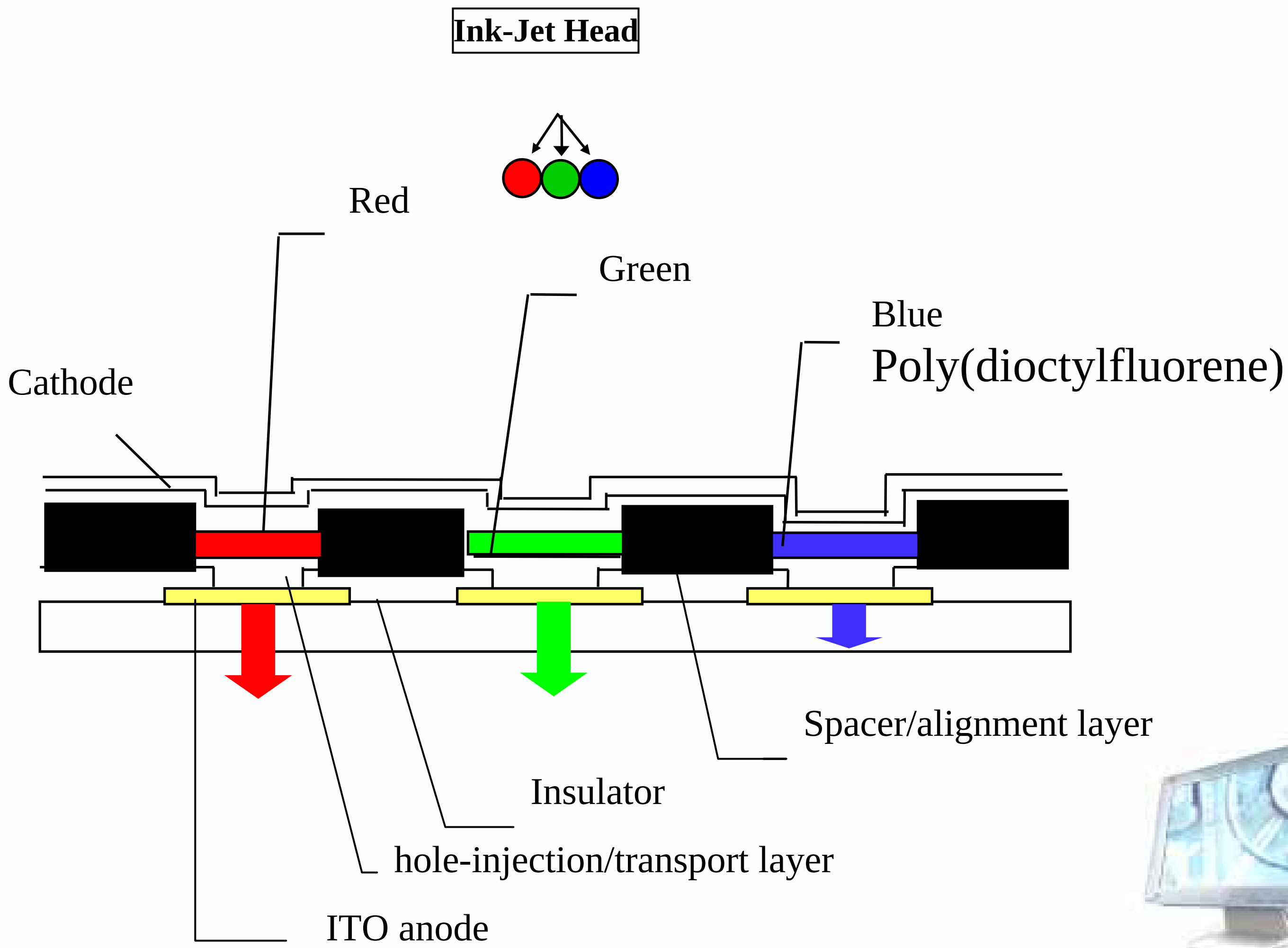
- **Patterned RGB OLEDs**
  - Sequential growth of RGB OLEDs
  - RGB patterning by printing (mostly polymer LEDs)

- **Single Emitter + Color Control Array**
  - White OLED + color filter
  - Blue/UV OLED + color conversion

Precision Shadow Masking



Ink-Jet Printing



Issues in Full-Color Schemes

- **Separate RGB Emitters**
  - complexity
  - difficulty in scaling up
  - production issues

- **White+Filter**
  - >2/3 light wasted
  - efficiency of white OLEDs

- **Blue/UV+Down-conversion**
  - color bleeding, contrast issues
  - conversion efficiency

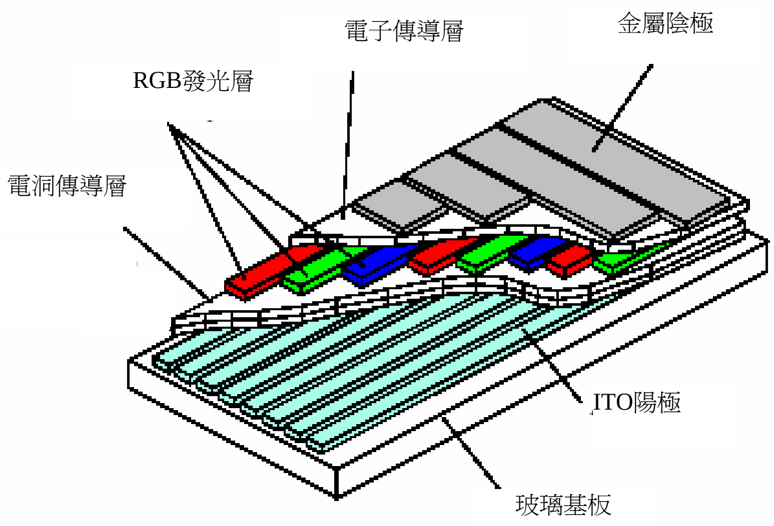
Key Issues in OLED Display Development

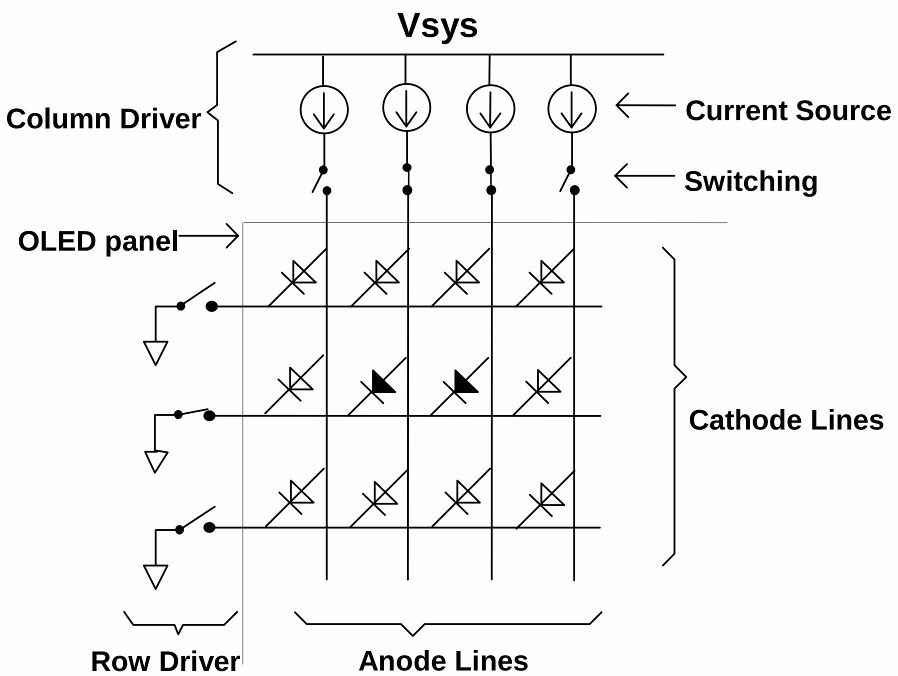
- Pixel patterning
  - cathode electrode patterning
  - color sub-pixel patterning

- **Driving schemes**
  - passive matrix
  - active matrix

- (Sealing and packaging too, of course!)

Passive-Matrix OLED (PMOLED)





- one line on at a time
- pulsed operation of OLEDs
- current driving more popular for data (column) driver
- Grayscale by (1)current pulse amplitude (analog), (2) pulse width (digital), (3) combination of both

Issues in PMOLED

One line on at a time

⇒peak pixel brightness ∝ no. of lines

ex. 100 lines → ~ a few times of 10000 cd/m2

320 lines → > 100000 cd/m2

⇒ high peak current and voltage

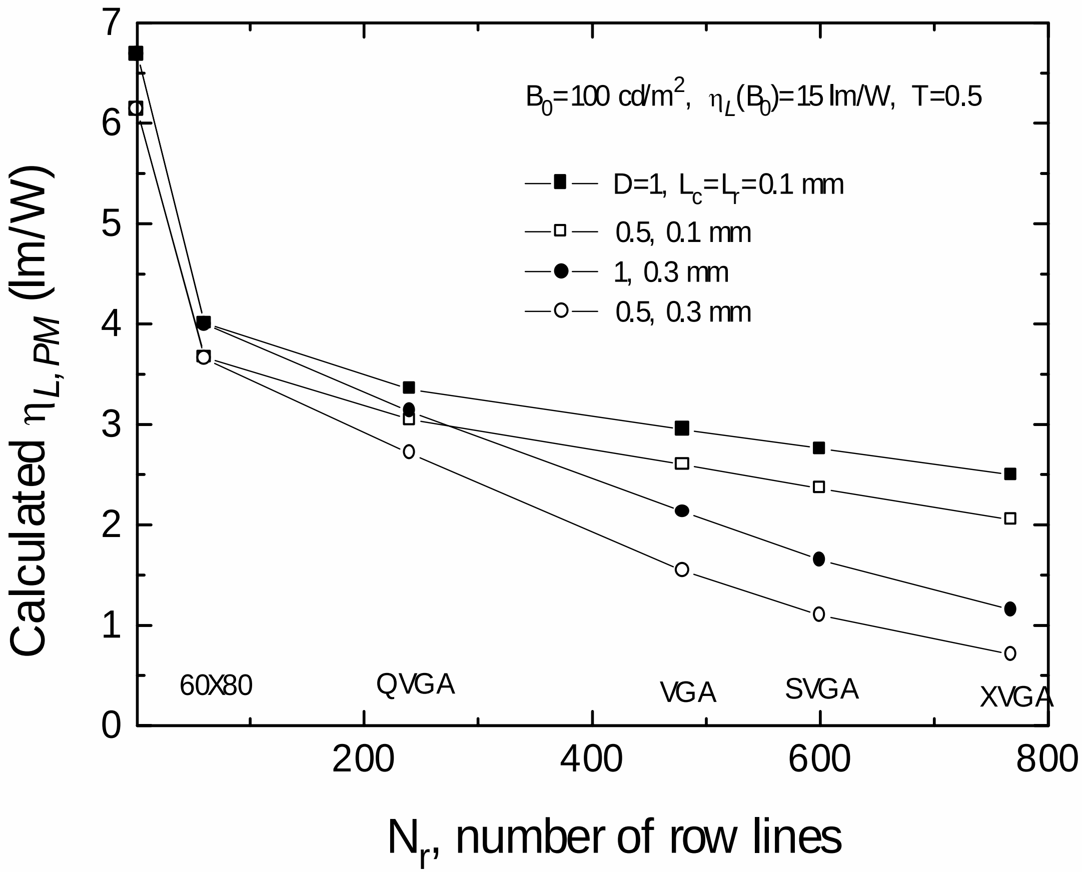
⇒ (1) lower luminous efficiency

(2) substantial voltage drop on electrode lines

(3) troubles in driving electronics

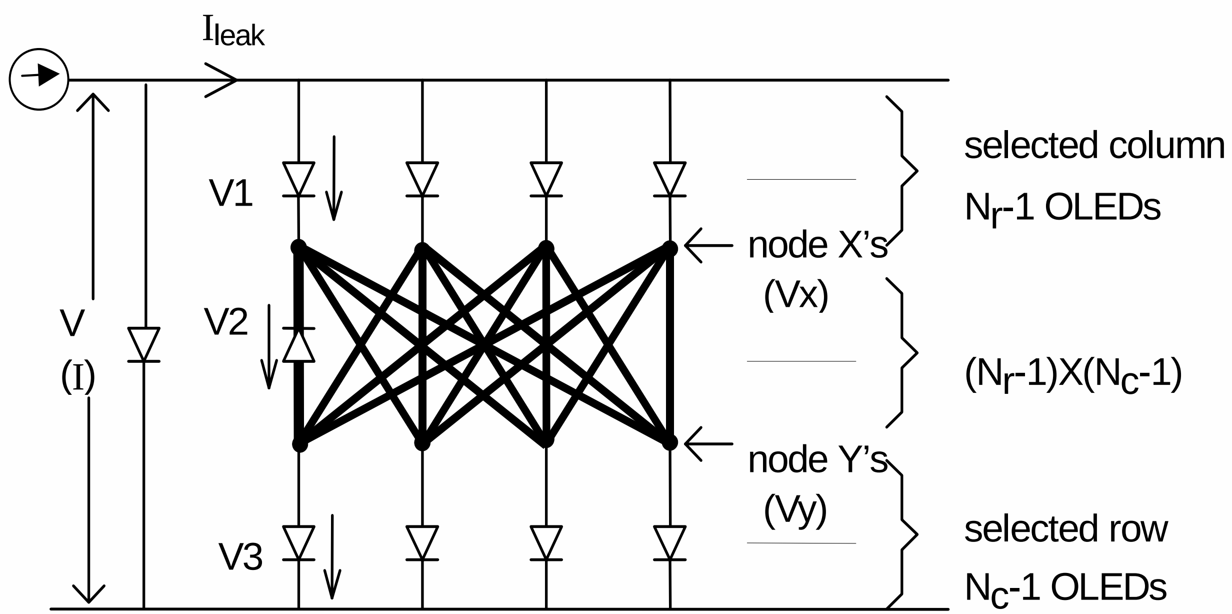
(4) OLED reliability issues

Performance of PMOLEDs



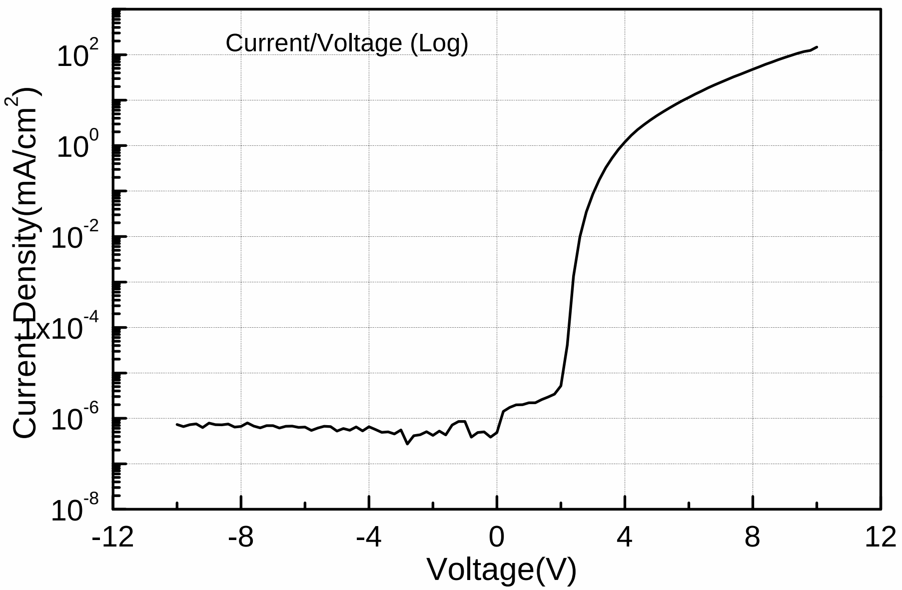
- Such performance and previous issues limit resolution of PMOLED to at most ~200 scan lines (usually)

Crosstalk Issue in PMOLED



- Leakage current, defective devices
- Cross-talk
- High rectification essential for PMOLED

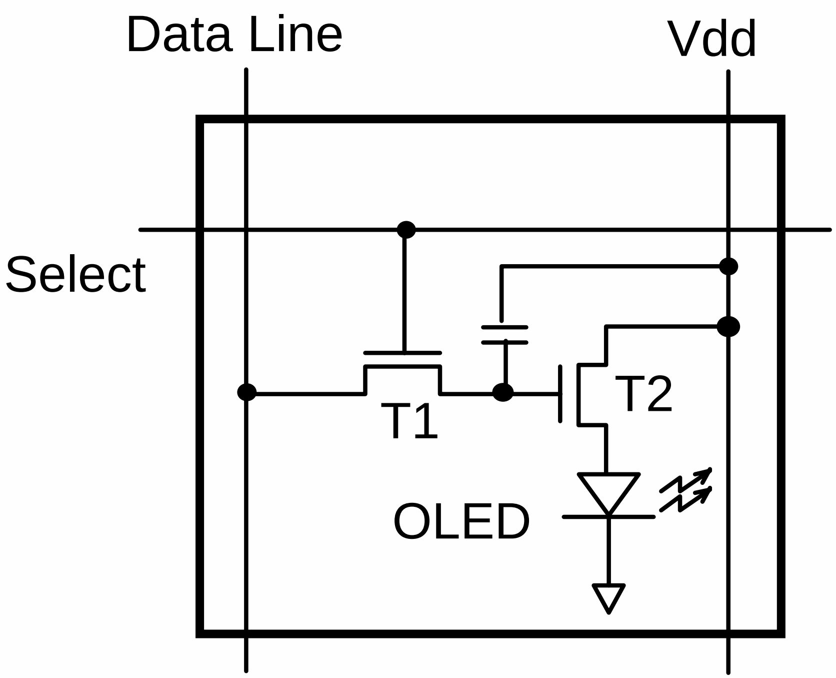
Highly Rectified OLED



- Rectification ratio > 10^8 achievable with OLED
- Reasonable large PMOLED array achievable

Active Matrix OLED Display (AMOLED)

- Each pixel has separate Vdd and ground connection
- Grayscale by controlling TFT current



TFT REQUIREMENT

T1: sample and hold

-low leakage to maintain charge

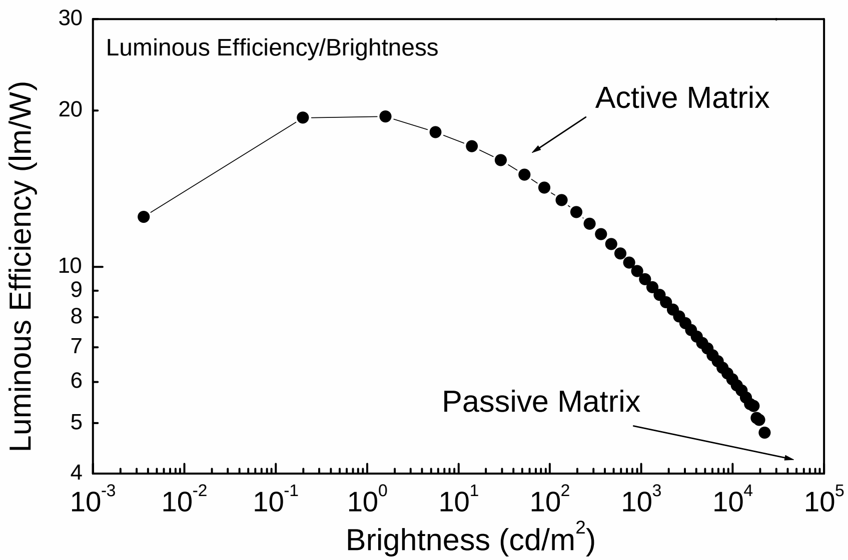
T2: drive OLED

- ability to drive OLED

Active-matrix

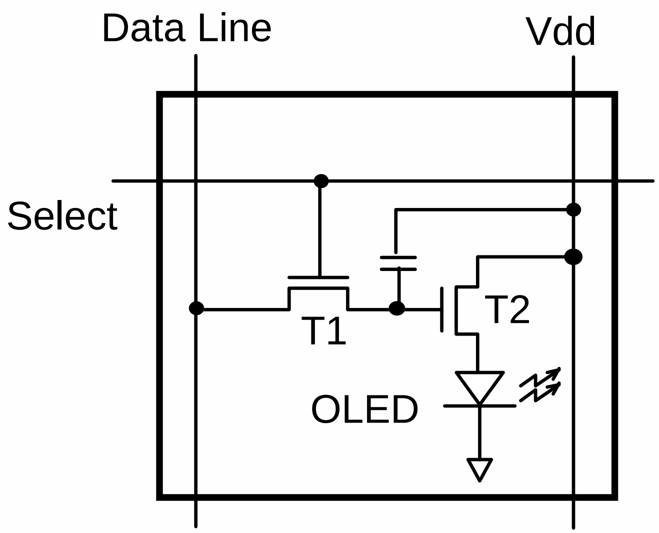
- Higher brightness
- Higher resolution
- Better grayscale control
- Higher power efficiencies

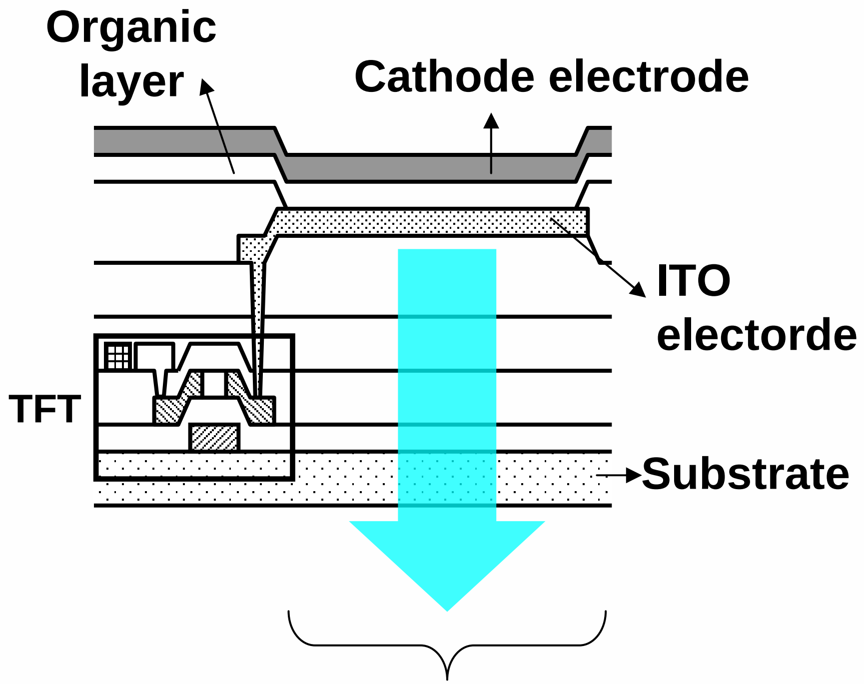
OLED Operation Mode: AM vs. PM



- $B\uparrow \Rightarrow V\uparrow \Rightarrow \eta L\downarrow$

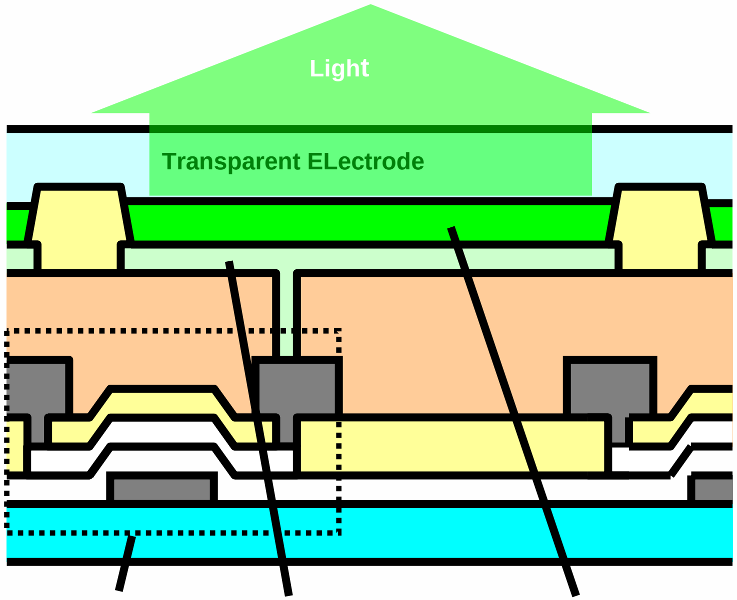
AMOLED Structure





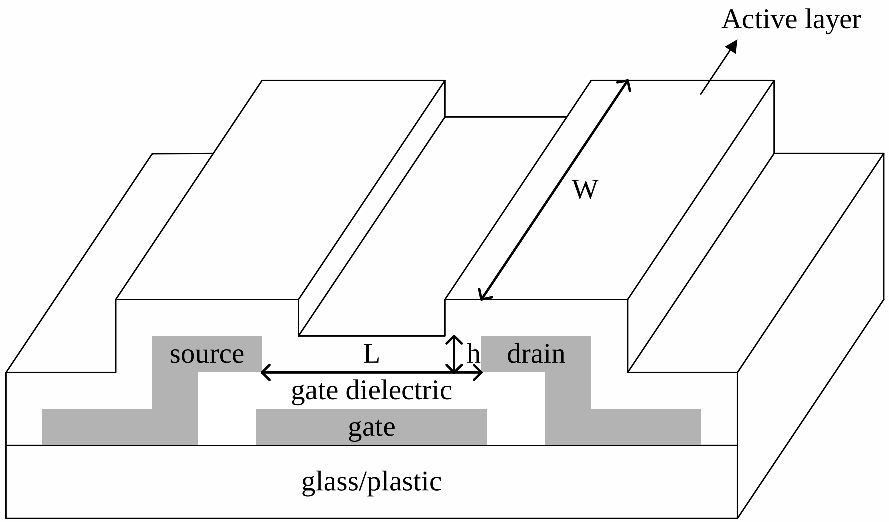
OLED Fill Factor

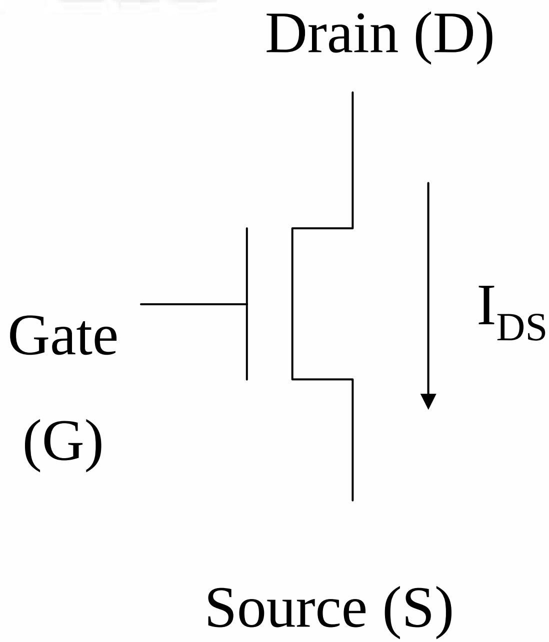
Top-Emitting AMOLED



To improve pixel OLED fill factor

Thin-Film Transistors (TFTs)





- L: channel length, W: channel width
- Active layer (semiconductor layer)
  - Amorphous Si (a-Si): a-Si TFT
  - Polycrystalline Si (p-Si): p-Si TFT
  - Low-Temperature p-Si (LTPS): LTPS TFT
  - Organic: OTFT

Thin-Film Transistors

$$I_D = \frac{1}{2}\mu_{FE} C_g \frac{W}{L}(V_{GS} - V_T)^2 \qquad V_{DS} \geq V_{GS} - V_T$$

μ_{FE}: Field effect mobility

V_T: threshold voltage

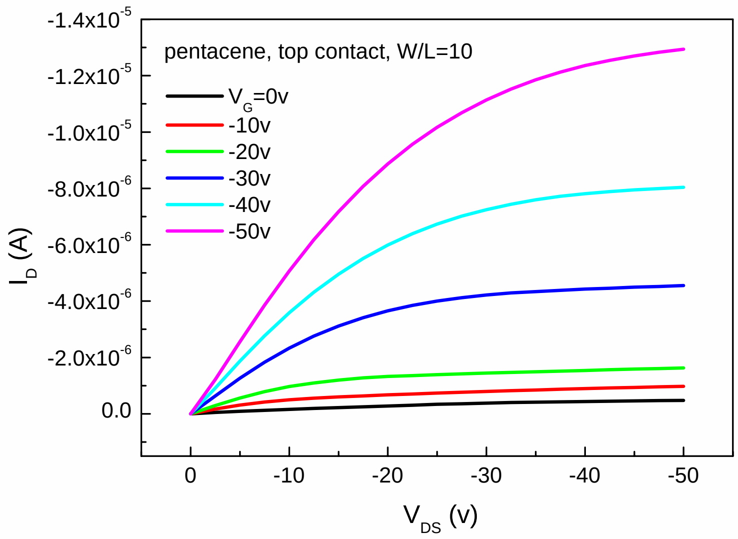
V_{GS}: gate to source voltage

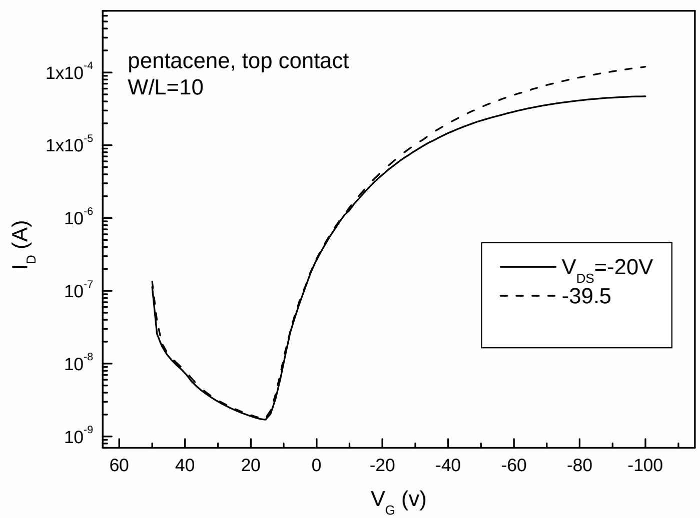
C_g: the gate capacitance per unit area

W and L: the channel width and length

$$V_{DS} \geq (V_{GS} - V_T)_{max.} = \sqrt{\frac{2J(B_0)L_c L_r}{C_g \mu_{FE} \frac{W}{L}}}$$

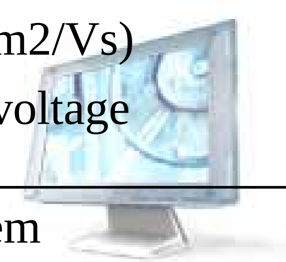
TFT Characteristics



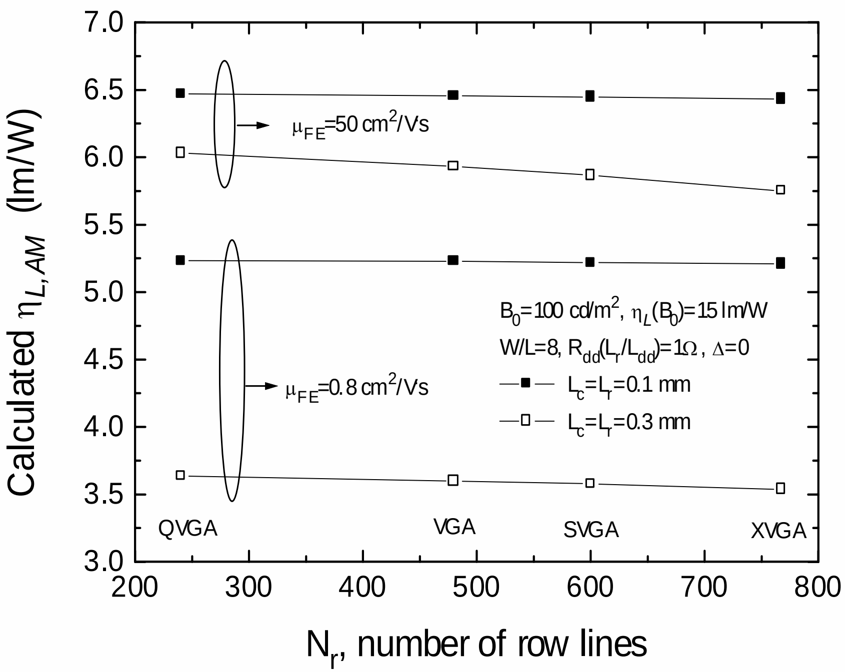


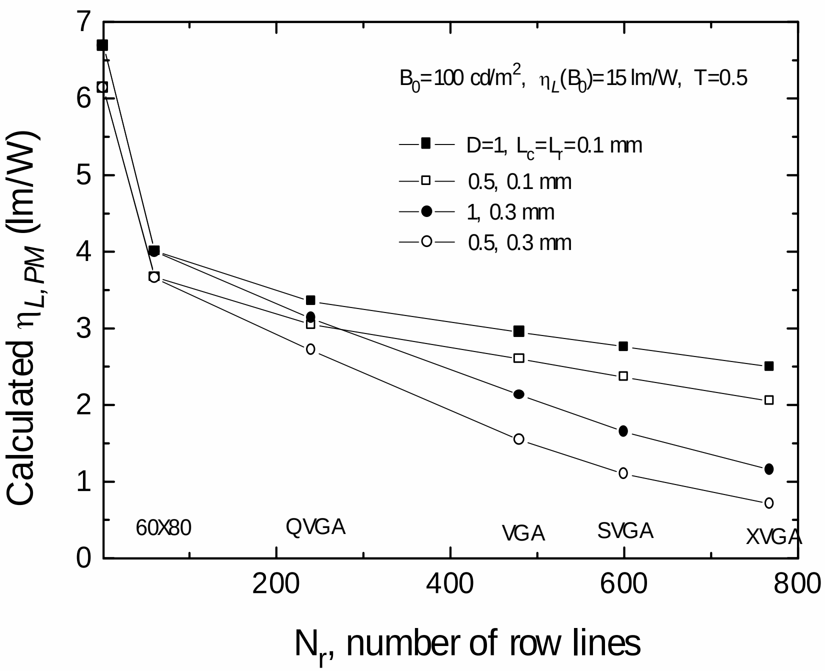
Comparison of TFT Characteristics

	a-Si TFT	LTPS TFT	OTFT
Technology maturity	mature	Less mature	developing
Large-area scalability	yes	Less mature	developing
Uniformity	yes	Less uniform	developing
Performance	lower mobility (0.5 cm2/Vs) Higher voltage	High mobility (50-300 cm2/Vs) Low voltage	Lower mobility (0.5 cm2/Vs) High voltage
Reliability	problem	OK	problem



AMOLED vs. PMOLED





AM	**PM**
- continuous excitation	- high peak pixel brightness
- higher power efficiency	- high peak current, voltage

AMOLED vs. PMOLED

- Continuous top electrode
  - eliminate fine patterning of top electrodes
- Full duty-cycle OLED operation
  - high brightness, high resolution
- More accurate and easier grayscale control
- No pixel cross-talk
  - eliminate line defects
- Higher power efficiencies
- Integrated drivers (more robust packaging)

** with much higher cost than PMOLED, of course.