Organic light-emitting diodes

OLED Displays and Device manufacture

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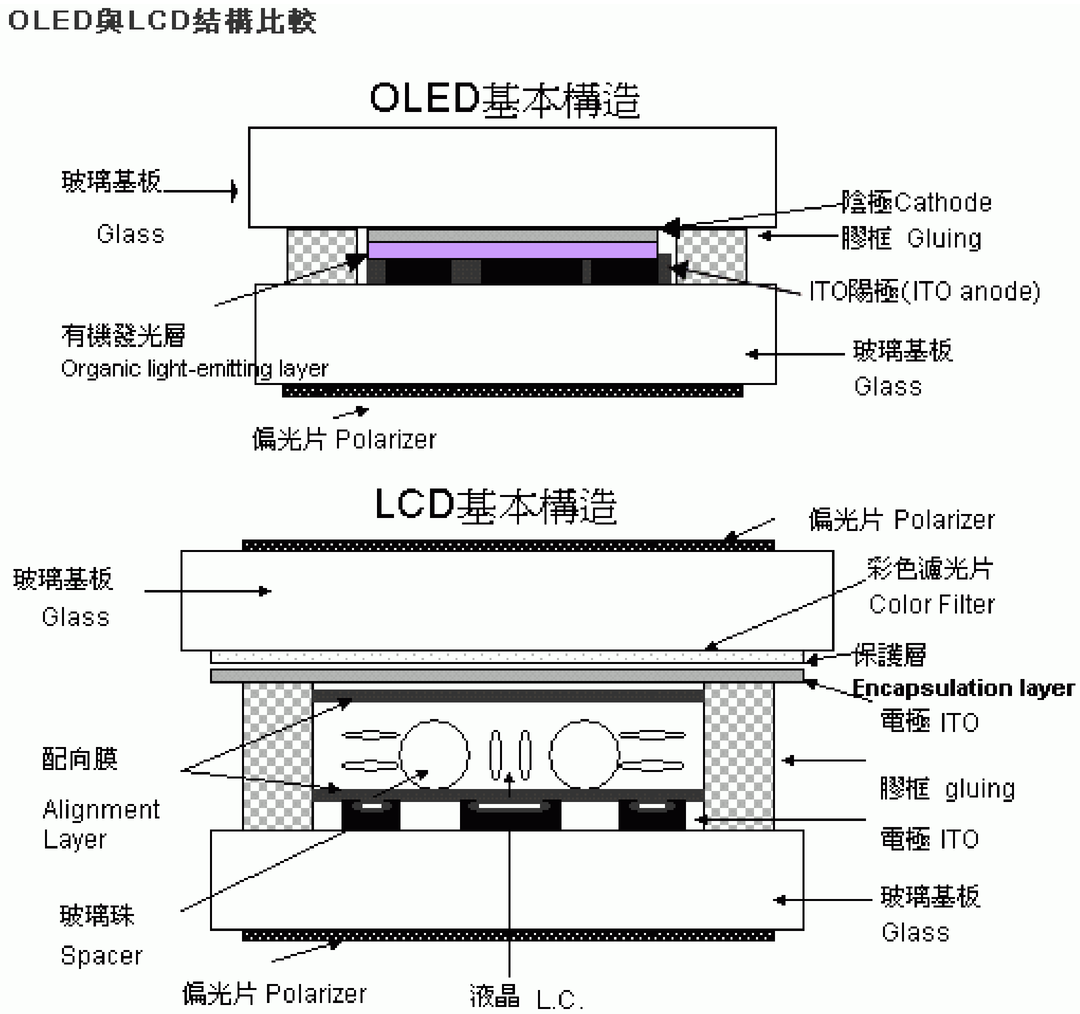
Device Structures : OLEDs vs LCDs



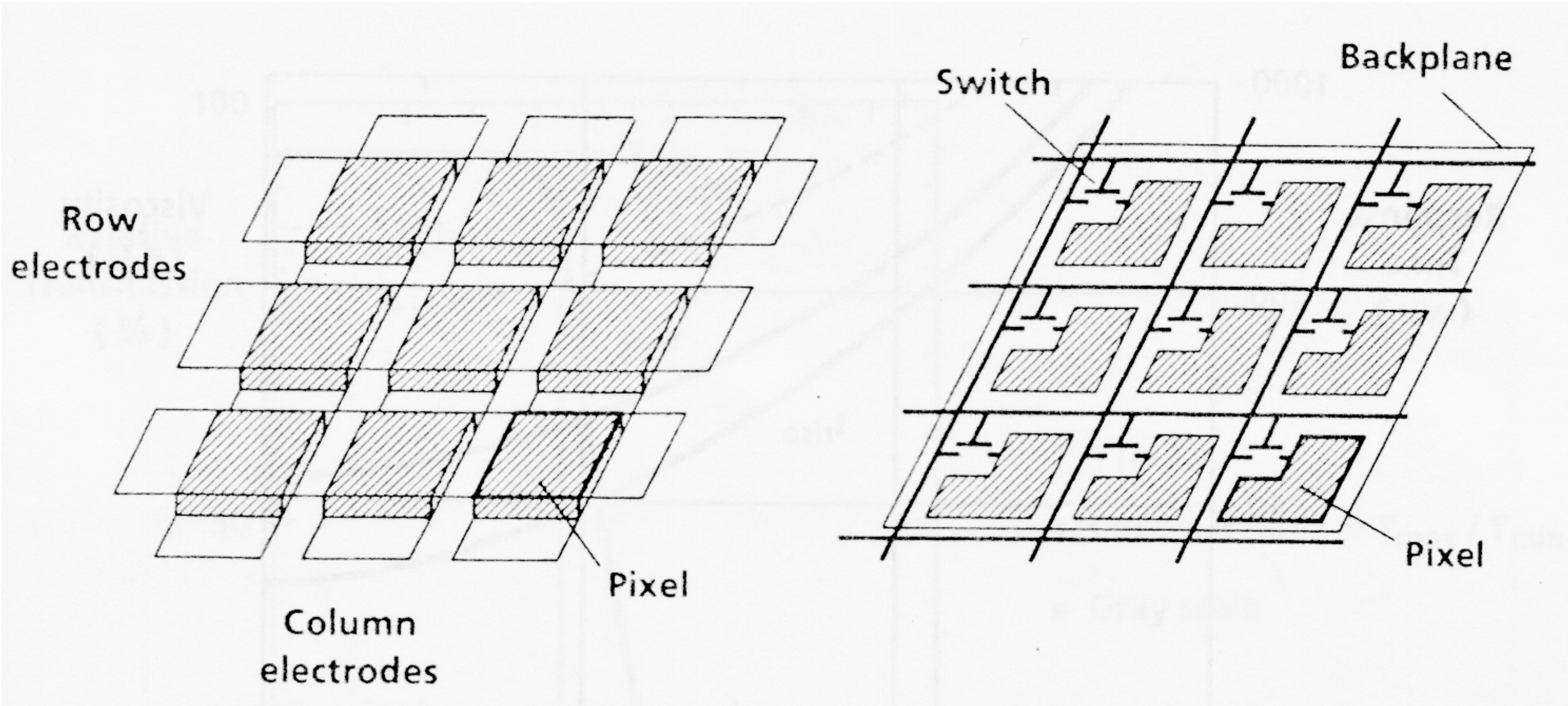
Pixel Addressing Modes

Passive Matrix

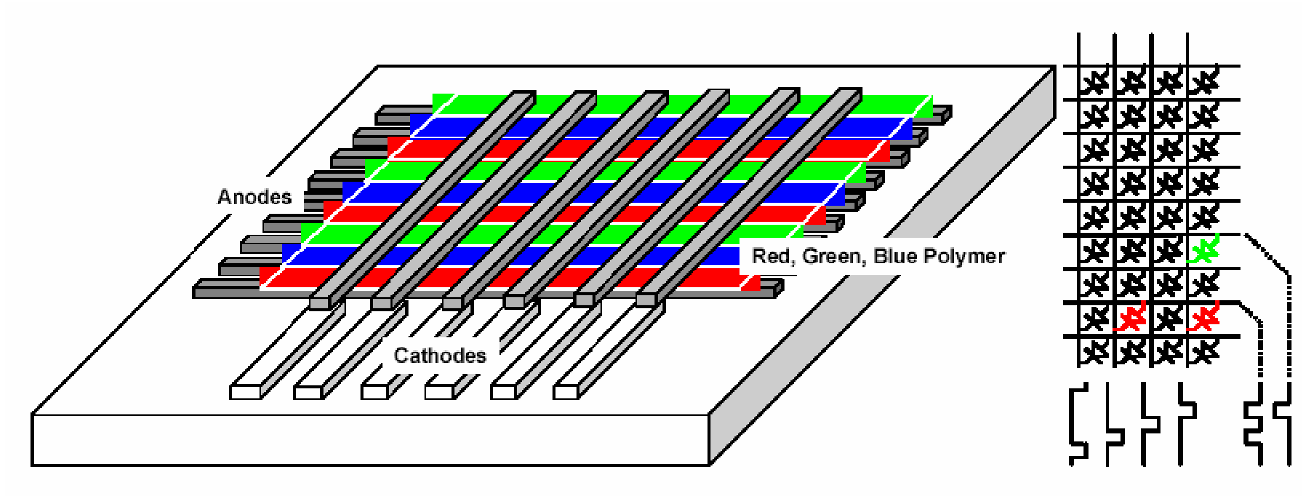
- Stripes of conductor on opposing glass plates
- Pixels defined by intersection of electrodes

Active Matrix

- Array of pixel electrodes on one glass plate, common electrode on opposing glass plate
- Switch at each pixel for isolation



Passive Matrix OLED Displays



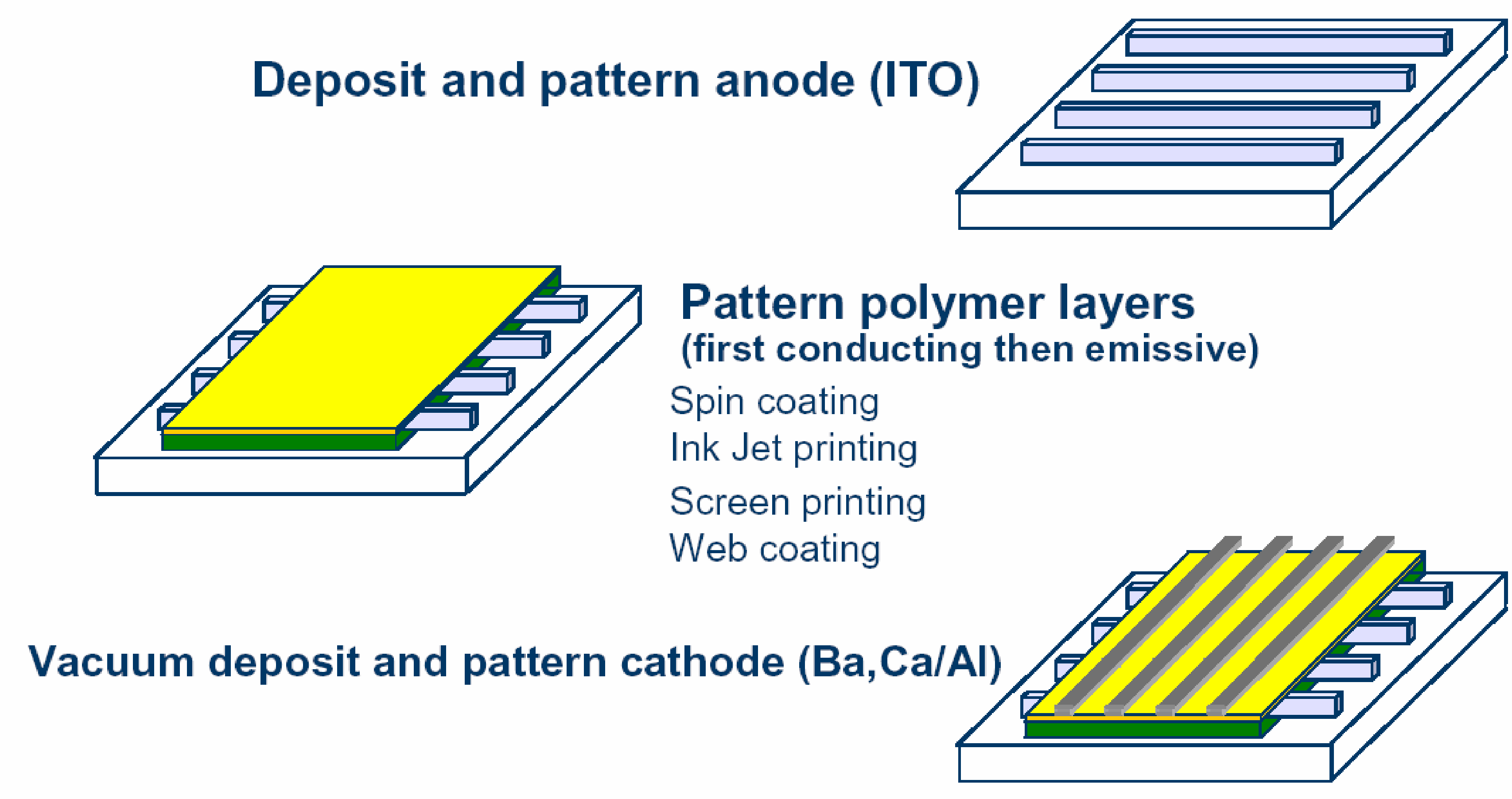
Advantages

Simple structure
Easy to fabricate
Low cost

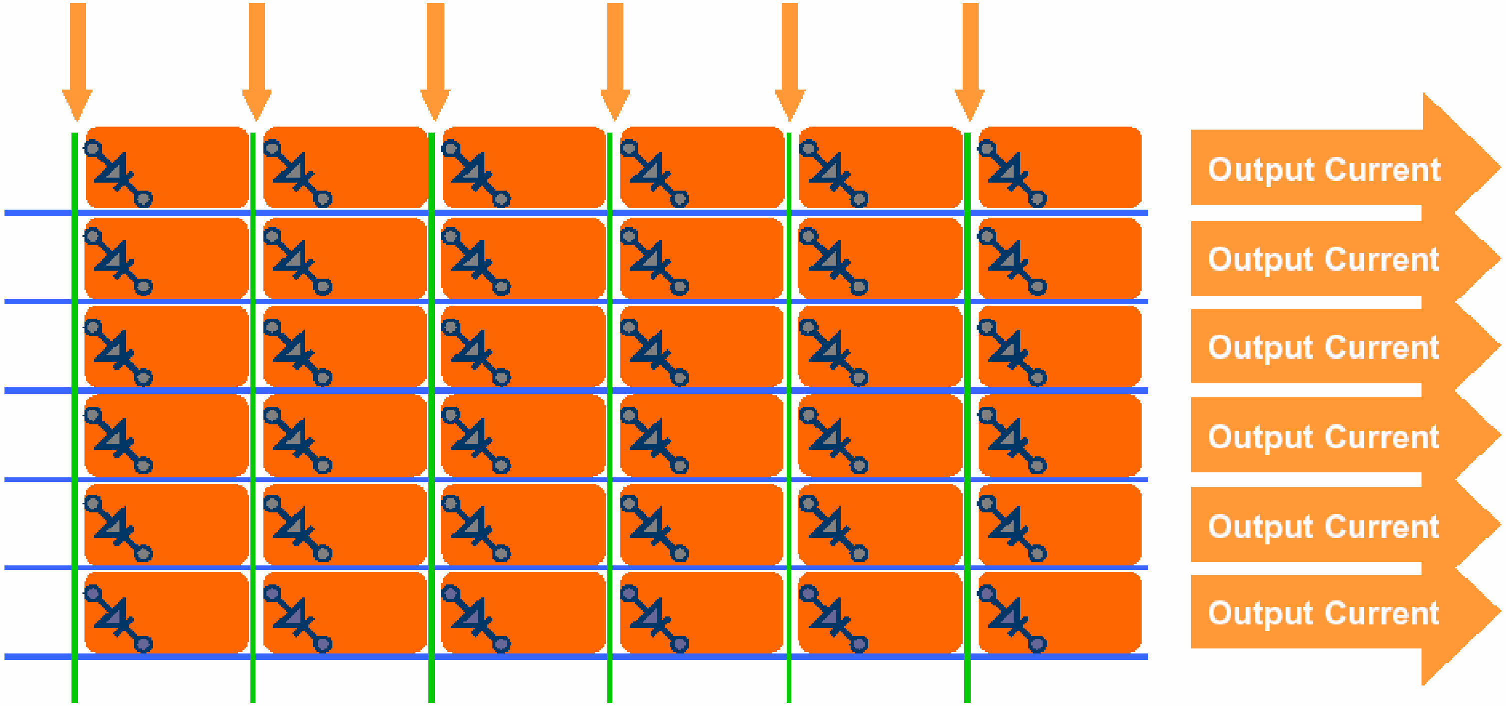
Disadvantages

Limit life time
More power consumption
(LED, Capacitive, Resistive)

Fabrication of PM-OLED Displays



Passive Matrix OLED Displays



- Line by line multiplex scanning
- Duration of addressing is 1/mux rate
- Pixel pulsed luminance = mux rate times average luminance
  - if 64 rows then pixel L=6400 nits for an average of 100 nits
- Limited addressed lines

Why Active Matrix OLED Displays?

Lower power consumption

Longer lifetime

Higher contrast ratio

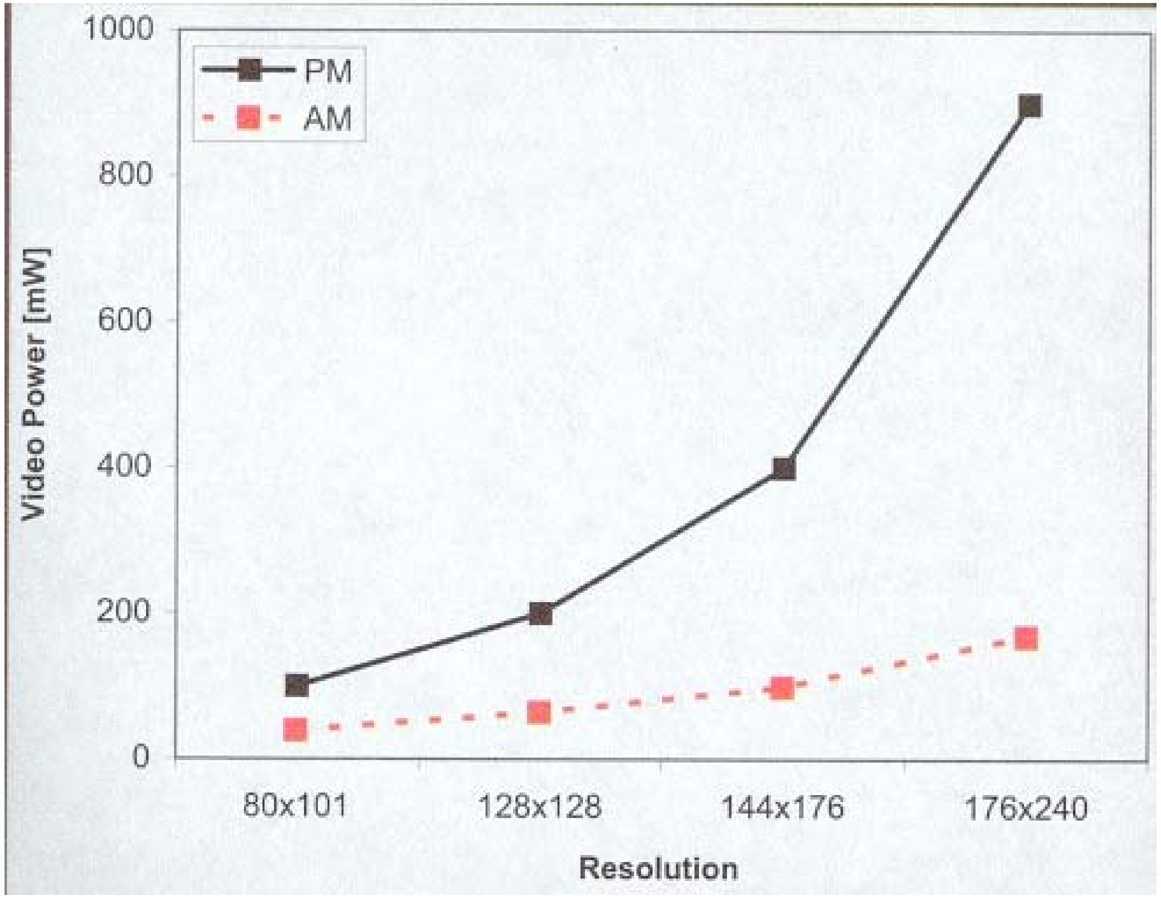
Higher yield

Monochrome, PMOLEDs : 15 cd/A, 0.1 mm^2, 100 cd/m^2

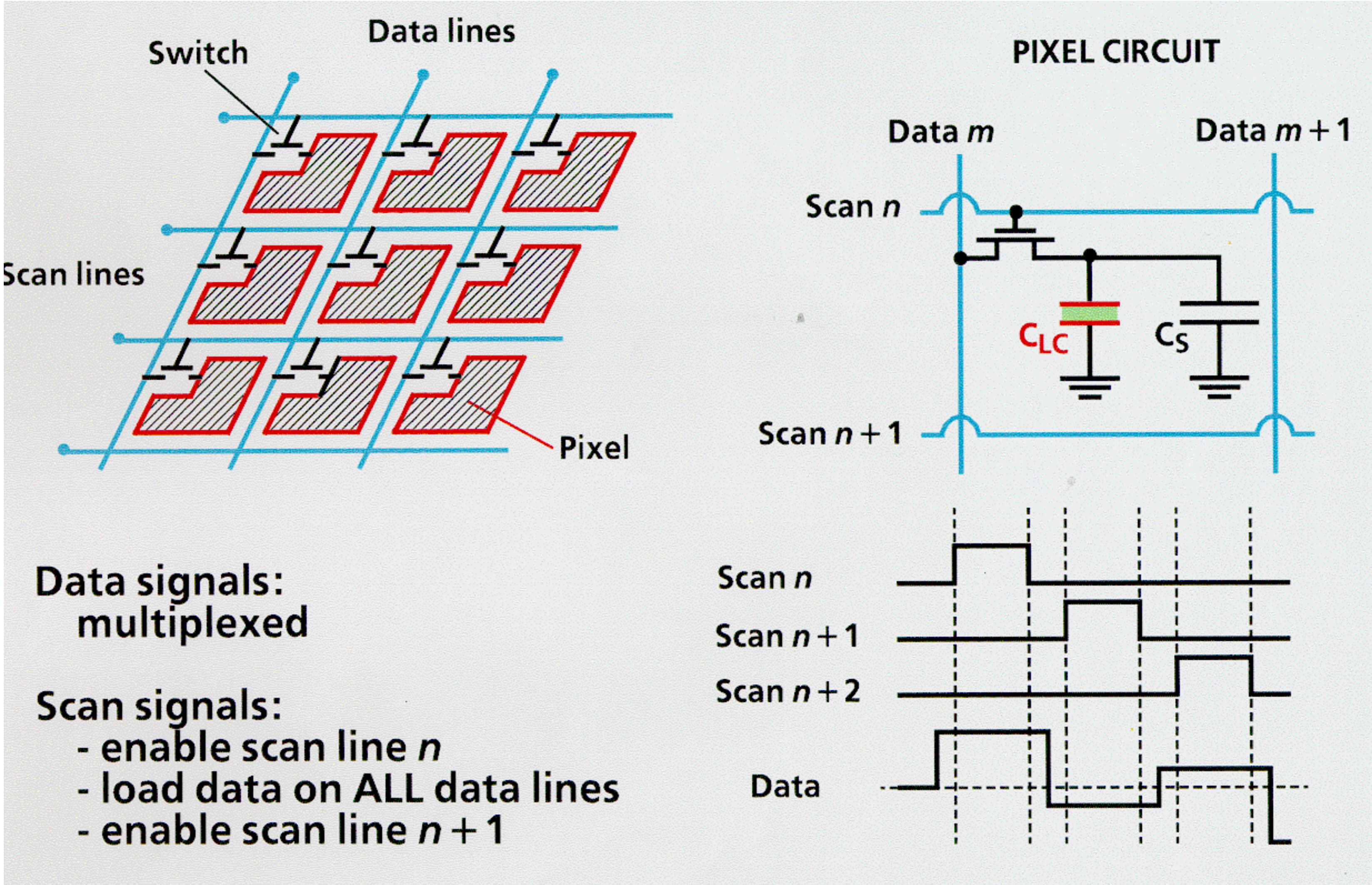
Power consumption of displays of different sizes and resolutions

Resolution (column/row)	Diagonal (inch)	P_{LED} (mW)	P_{CAP} (mW)	P_{RES} (mW)	P_{TOTAL} (mW)	Efficacy (lm/W)
80 × 60	1.2	15	10	1	26	5.3
160 × 120	2.4	80	110	10	200	2.8
320 × 240	5	400	1300	300	2000	1.1
640 × 480	10	2000	18 000	8000	28 000	0.3

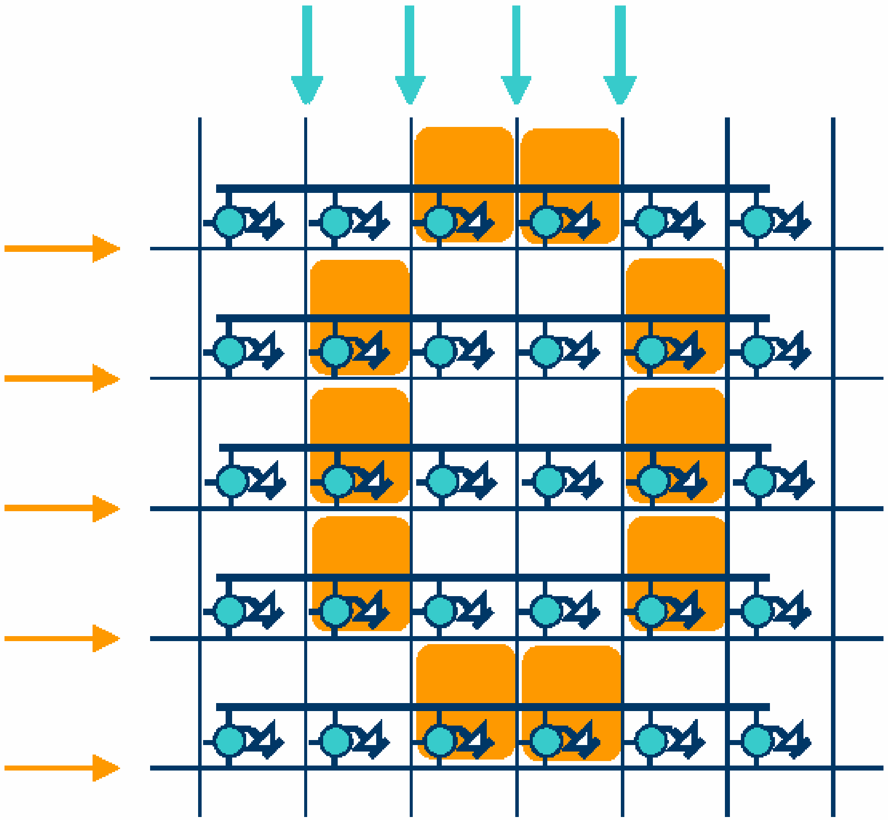
Active vs Passive : Power Consumption

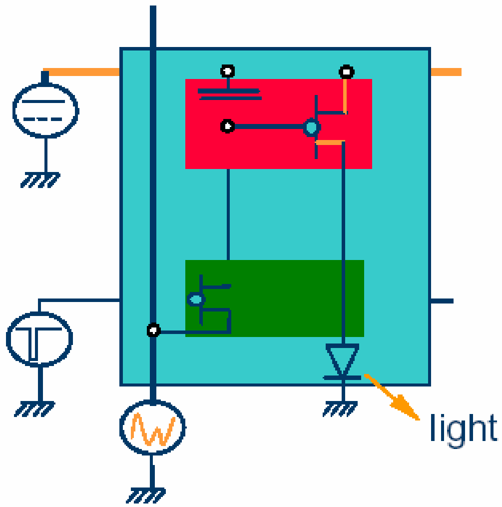


Active Matrix LCD Operation



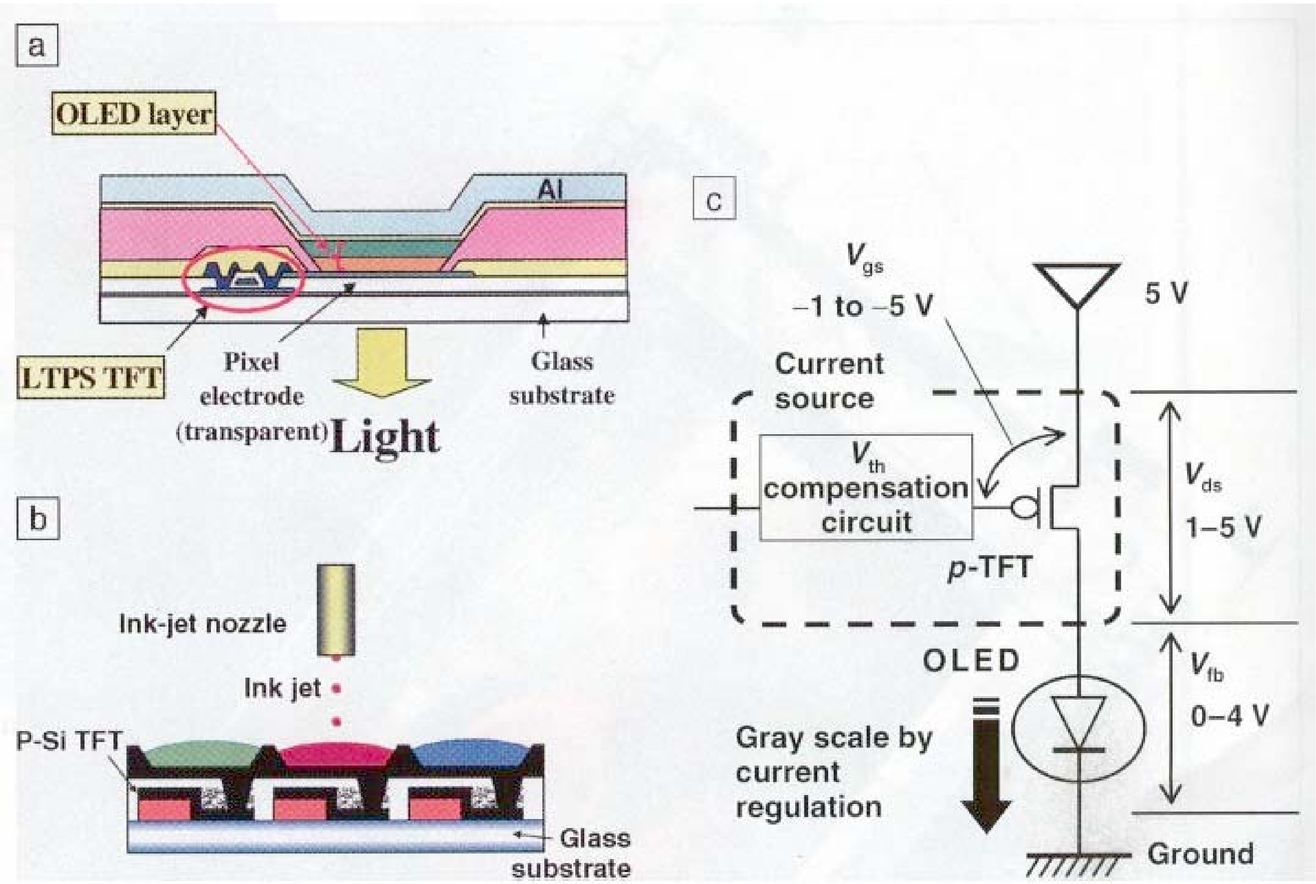
Active Matrix OLED Displays





- Place a switching TFT at each pixel
- Selected pixel stays on until next refresh cycle (pixels are switched and shine continuously)
- Common cathode
- Unlimited addressed lines

Active Matrix OLED Displays



OLED Pixel TFT Performance Requirements

- Ability to supply current to OLED (>10 mA/cm^2)

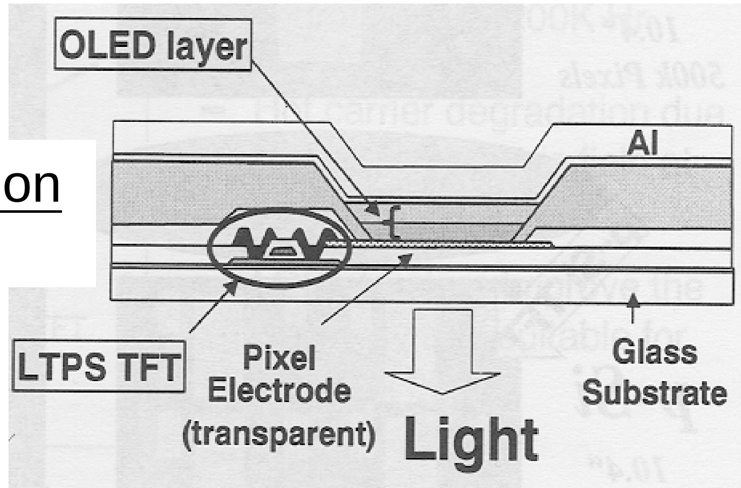
→ I_{ON} = 5 - 10 μA (V_{GS} < 10 V, V_{DS} < 5 V)

→ mobility > 10 cm^2/V•s

→ **Poly-Si TFT technology is needed!**

Note : Phosphorescent OLEDs are not considered yet.

Schematic cross-section of AM-OLED pixel:

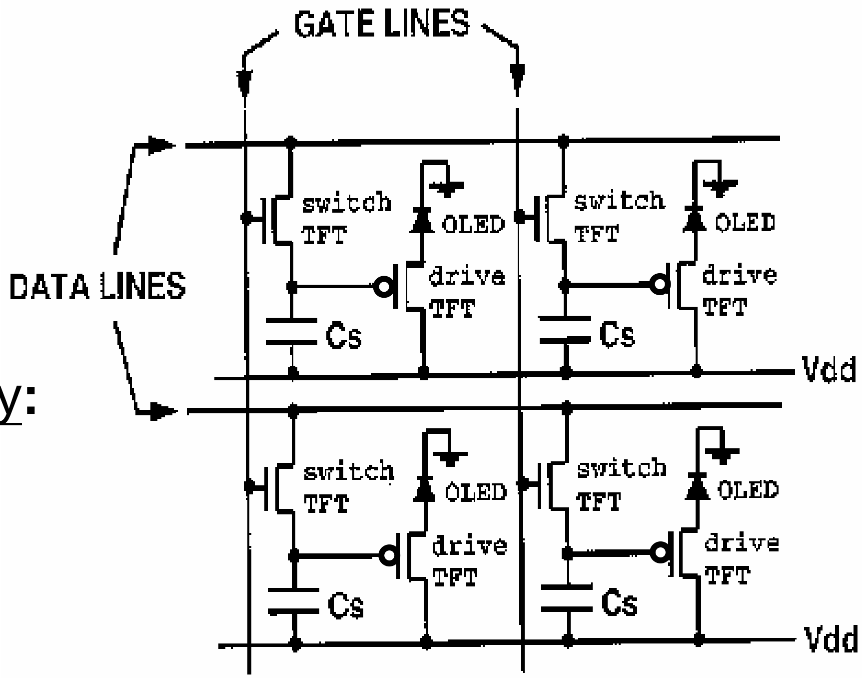


OLED Pixel TFT Requirements (cont'd)

- Low leakage to maintain charge

  → I_{OFF} < 1 pA   (V_{GS}=0 V; V_{DS} = 10 V)

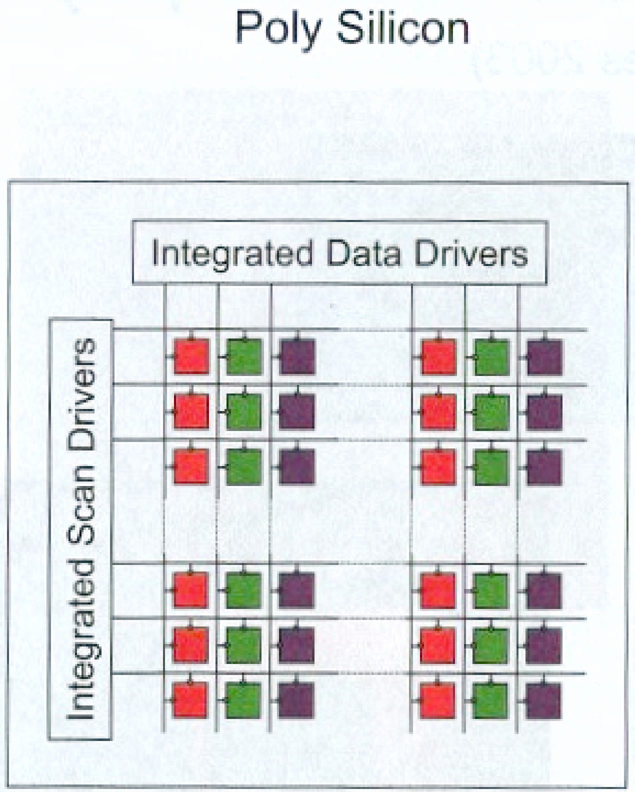
Circuit Diagram for Active-Matrix OLED Display:



❖ **Poly-Si TFT technology meets these requirements!**

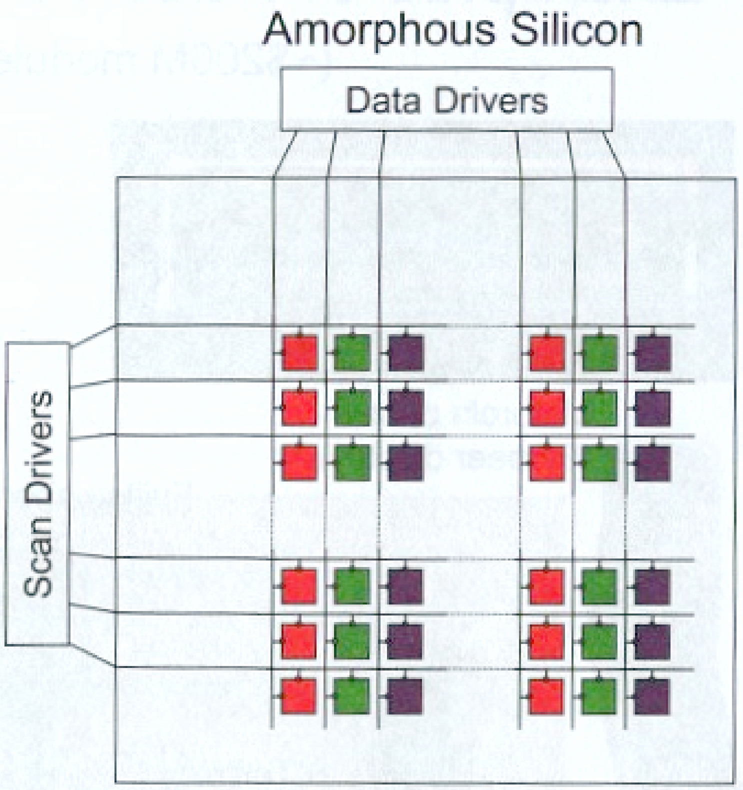
- **Uniformity of I_{ON} is a challenge, however.**

Poly and Amorphous Silicon OLED Displays



- High mobility p-Si enables integrated drivers
- Minimal connections to glass edge (video, timing)
- Integrated drivers = reduced display module size
- Less uniform

G. Rajeswaran et al., Proc. of SID, p. 974 (2000)

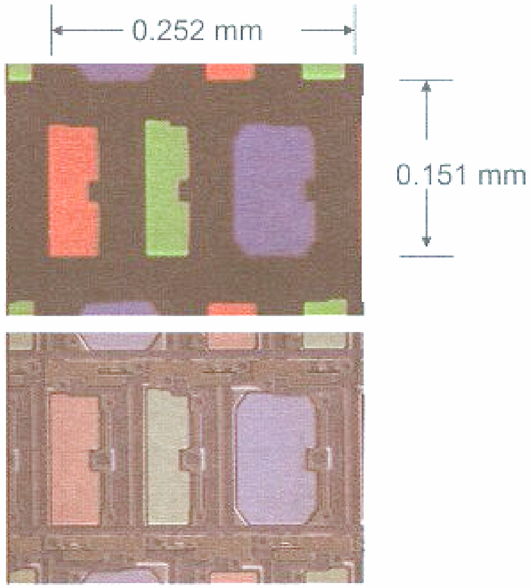


- Low mobility a-Si insufficient for integrated drivers
- Many connections to glass edge (rows + columns)
- External drivers = increases display module size
- Enabled by high-efficiency emitters (triplets)
- More uniform

Li et al., Proc. of SID, p. 14 (2003)

- **Manufacturing started**
  - Pioneer 1997
  - TDK (Alpine, 2001)
  - Samsung-NEC Mobile Display (SNMD) (2002)
  - RiTdisplay (2003)
  - Sanyo-Kodak (2003)
- **R, G, B colors available**
  - limited lifetimes for blue
- **Shadow masking allows easy patterning for area color**
  - presents challenges with scalability and high volume manufacturing
- **Shadow masking challenging for full color**
  - high throughput and scalability is a challenge

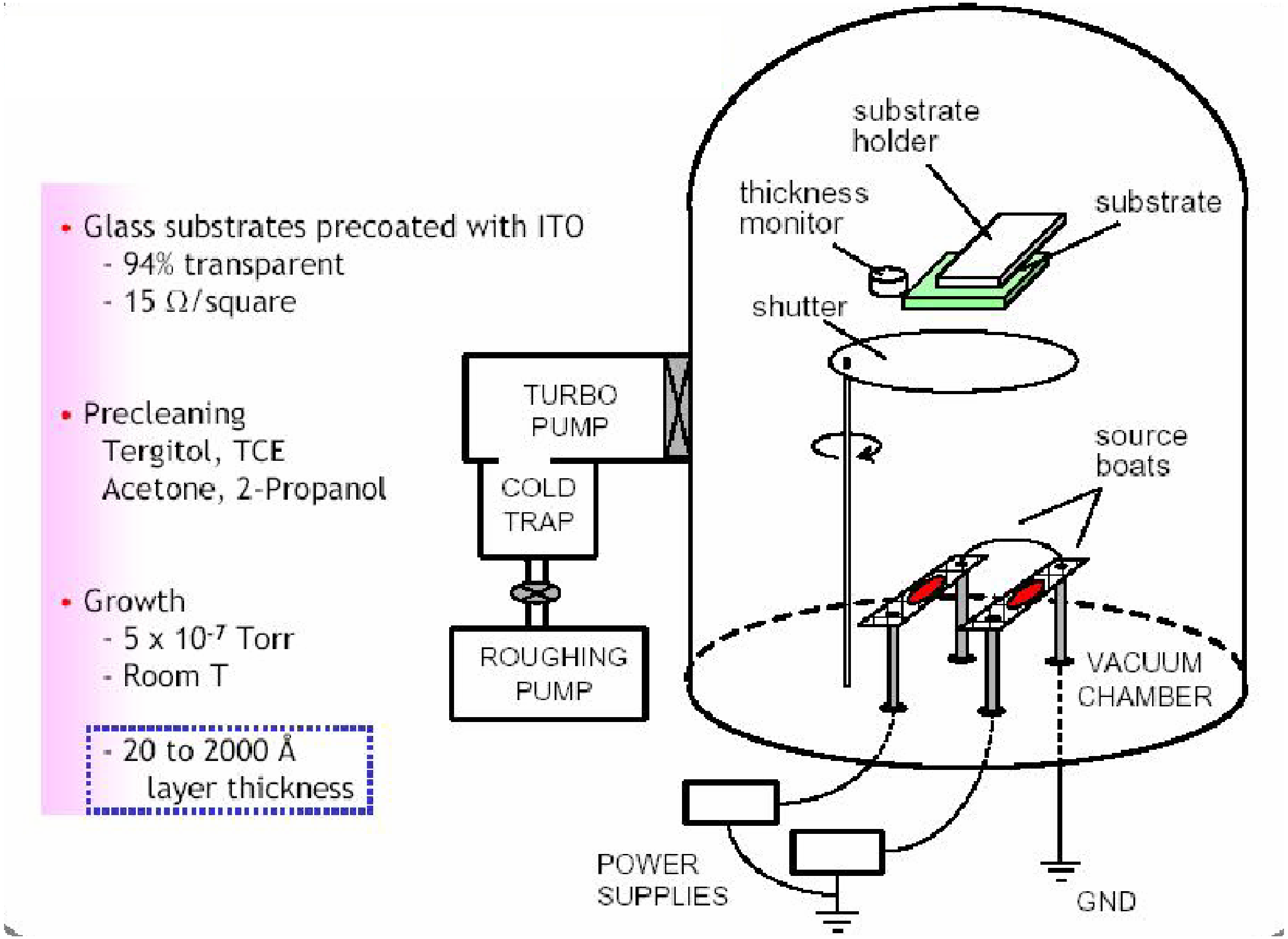
Full-Color AMOLED Display Product
KODAK LS633 Digital Camera



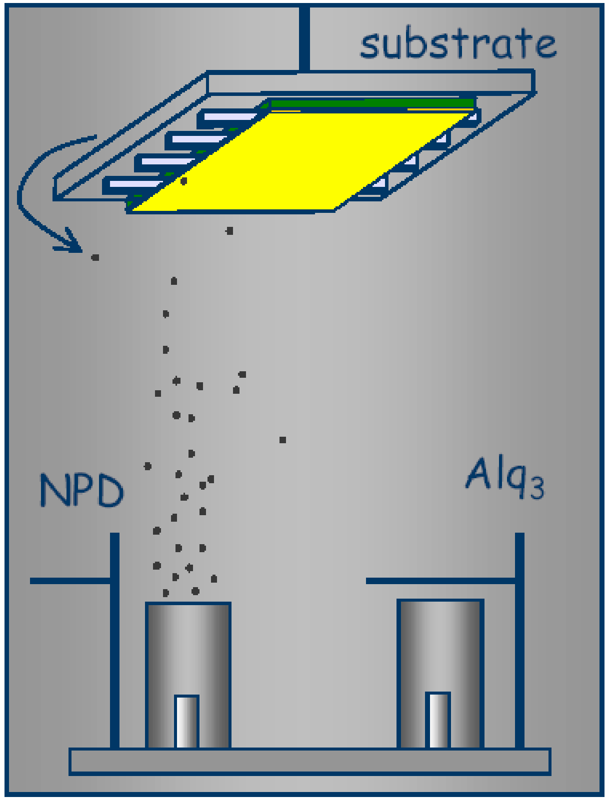
2.16” diagonal
521 x 218
LTPS

(Photographs from commercial sample)

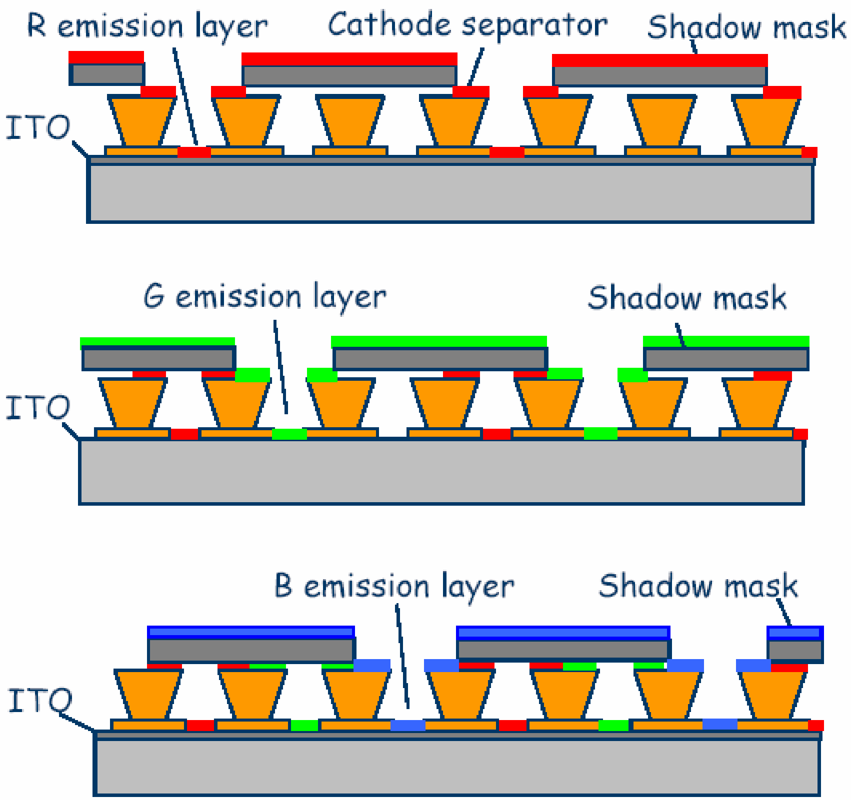
Point source of conventional OLED manufracture



Full color pattering with small molecular

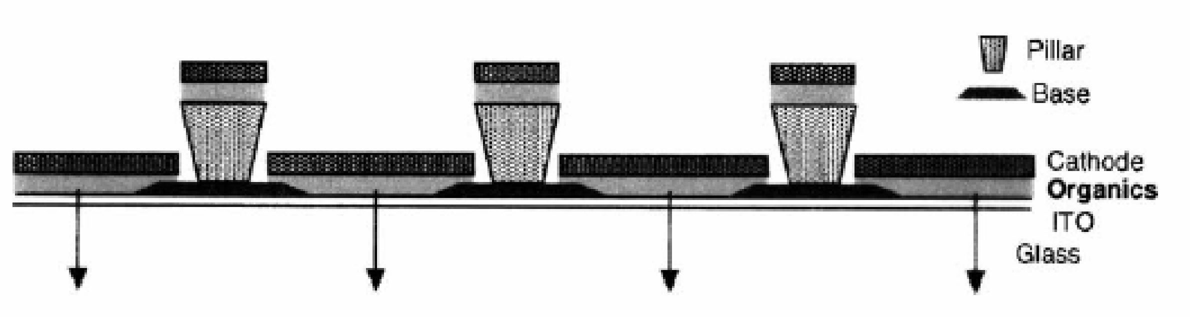


Small molecules are thermally evaporated in vacuum



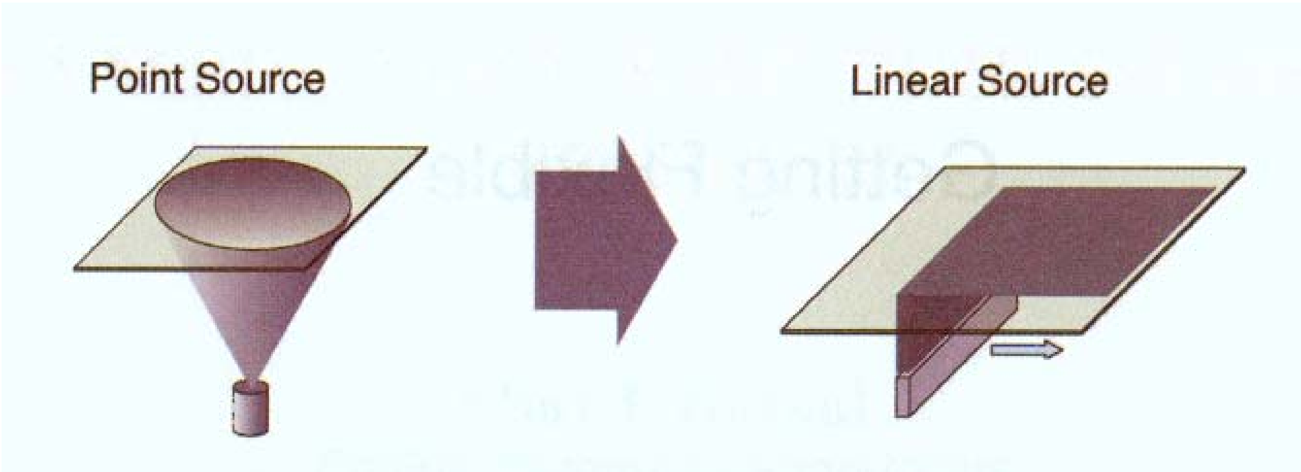
R, G, B pattering is defined by shadow masking in vacuum

Full color pattering with small molecular



- Photoresist is used for both the bases and the pillars.
- Pillars : separators for automatic organic and cathode pattern
- Bases : insulators to prevent shorting between the cathode and anode layers.

Evaporation Sources



Small Area

Low Materials Usage

Large Area

High Materials Usage

Developed by ULVAC

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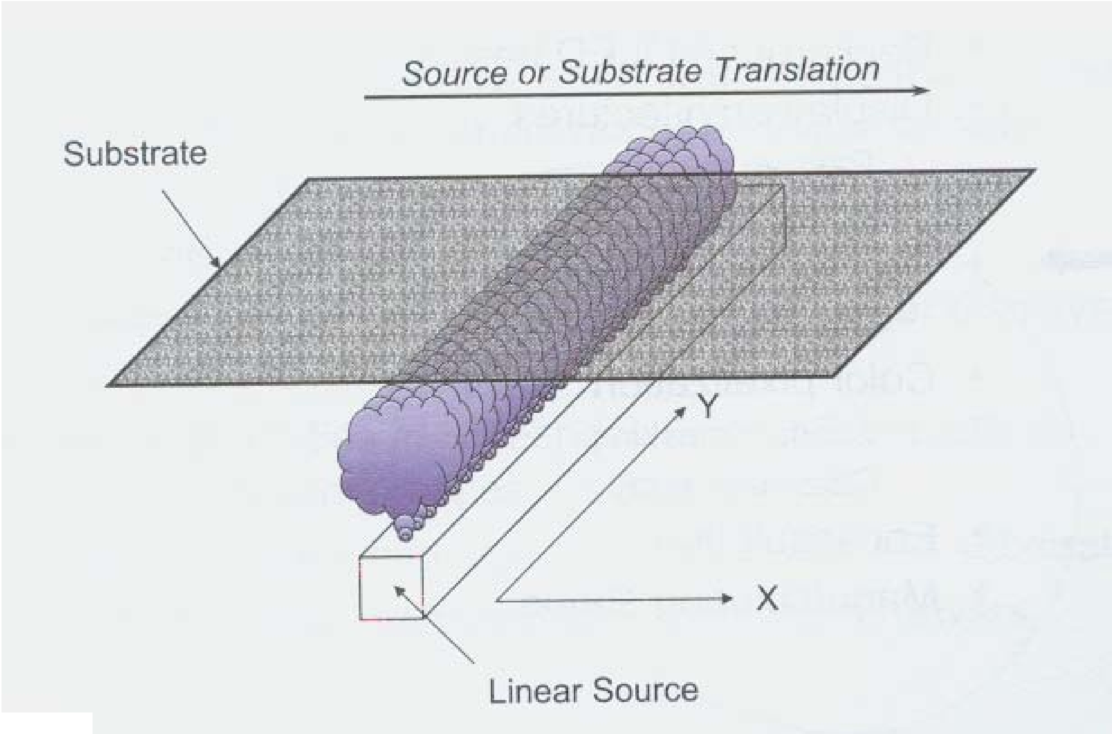
Linear source and substrate



Van Slyke et al., Proc. Of SID, p 886 (2002)
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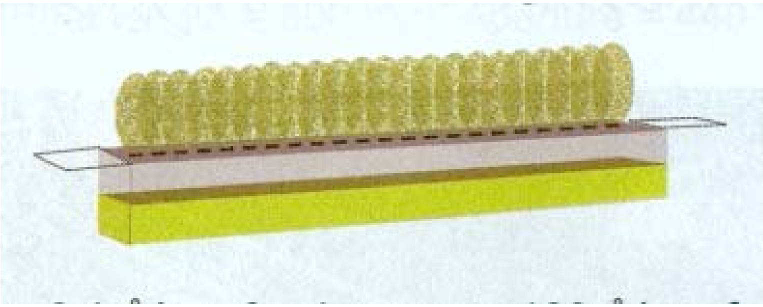
Point and Linear source considerations

Point Sources

Production design must make tradeoffs between uniformity, source-to-substrate distant and off-axis location, effective material utilization, deposition rates, productivity and operating ratio

Linear Sources

Improved deposition rate is due to reduced source-to-substrate distance, Same or better uniformity than point sources, and better material utilization



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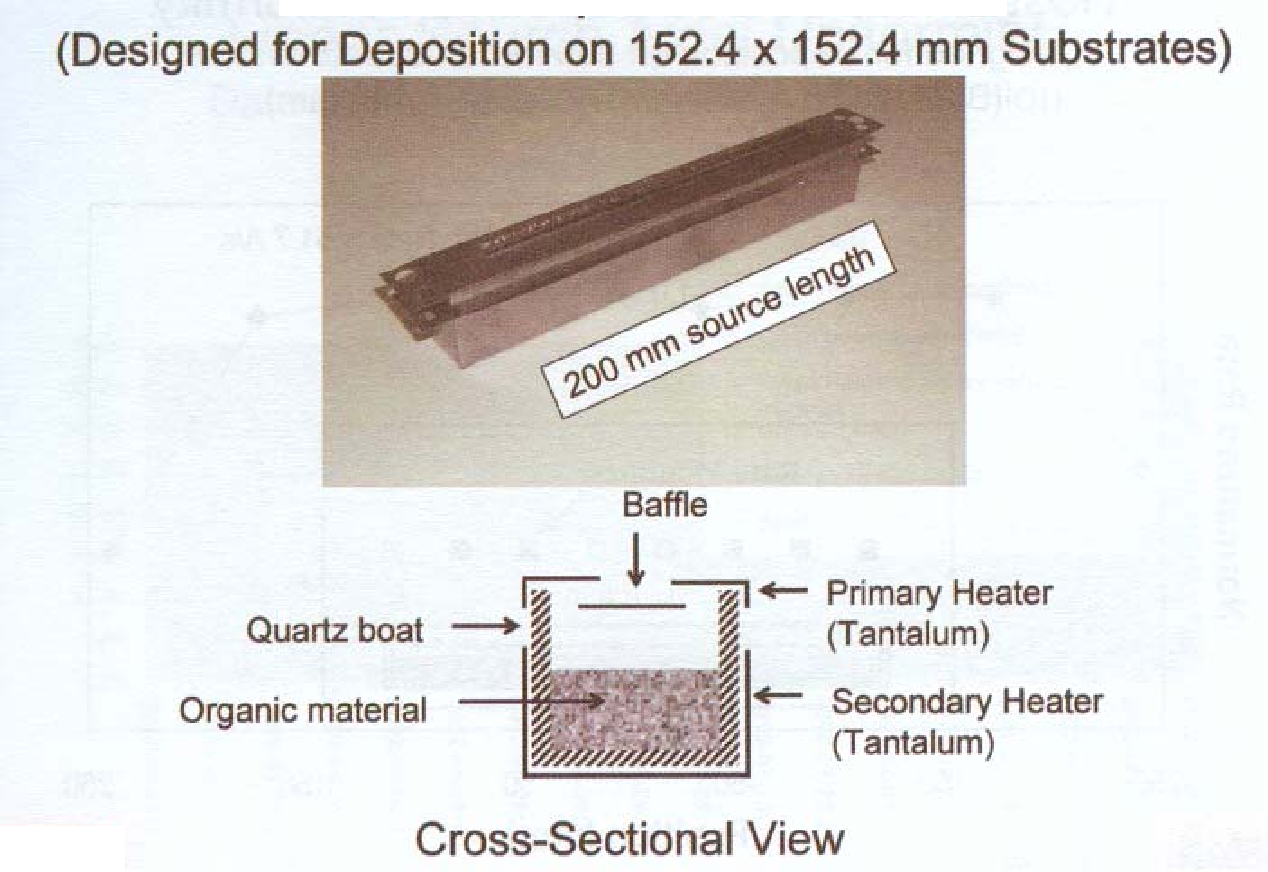
Linear source requirements

- Rates from 0.1 Å/sec for dopants to 100 Å/sec for hosts
- Storage of operating material for many days – protect this material from heat until needed
- Uniformity within +/-5% of aim across width of substrate
- Easy to remove, clean, load, and replace
- Stable operation over many days – no clogging, easy to control

Linear Evaporation Source



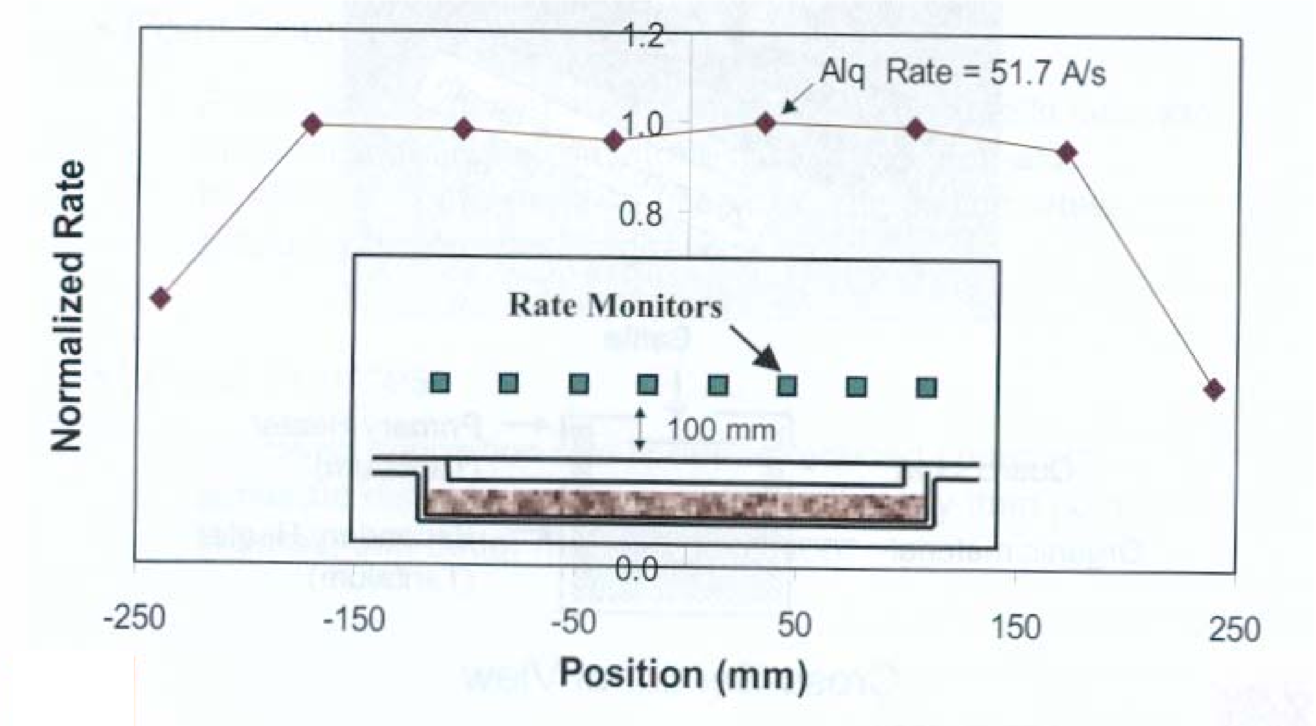
US Patent 6,237,529

Production Source

Designed for Deposition on 300 x 400 mm Substrates

Host linear source deposition uniformity

Designed for Deposition on 300 mm Substrates Widths
(Boat length = 500 mm, Aperture = 440 nm)



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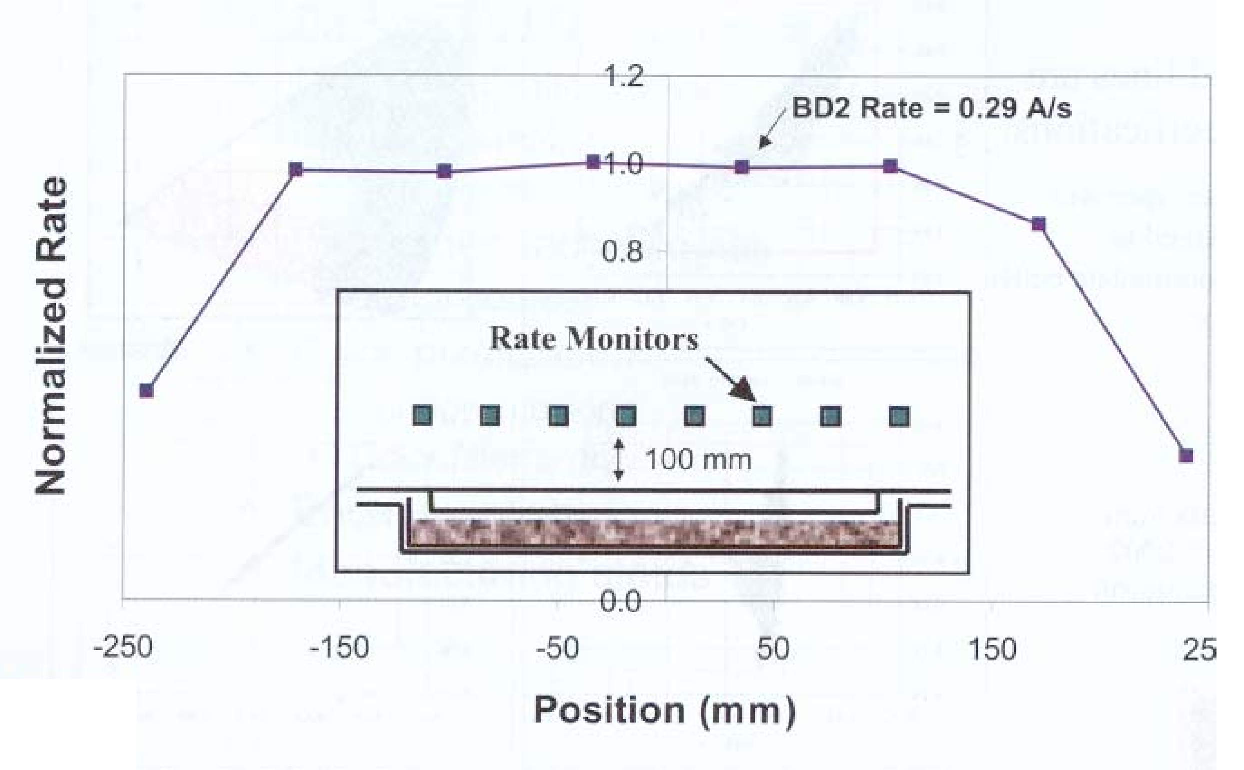
Dopant linear source deposition uniformity

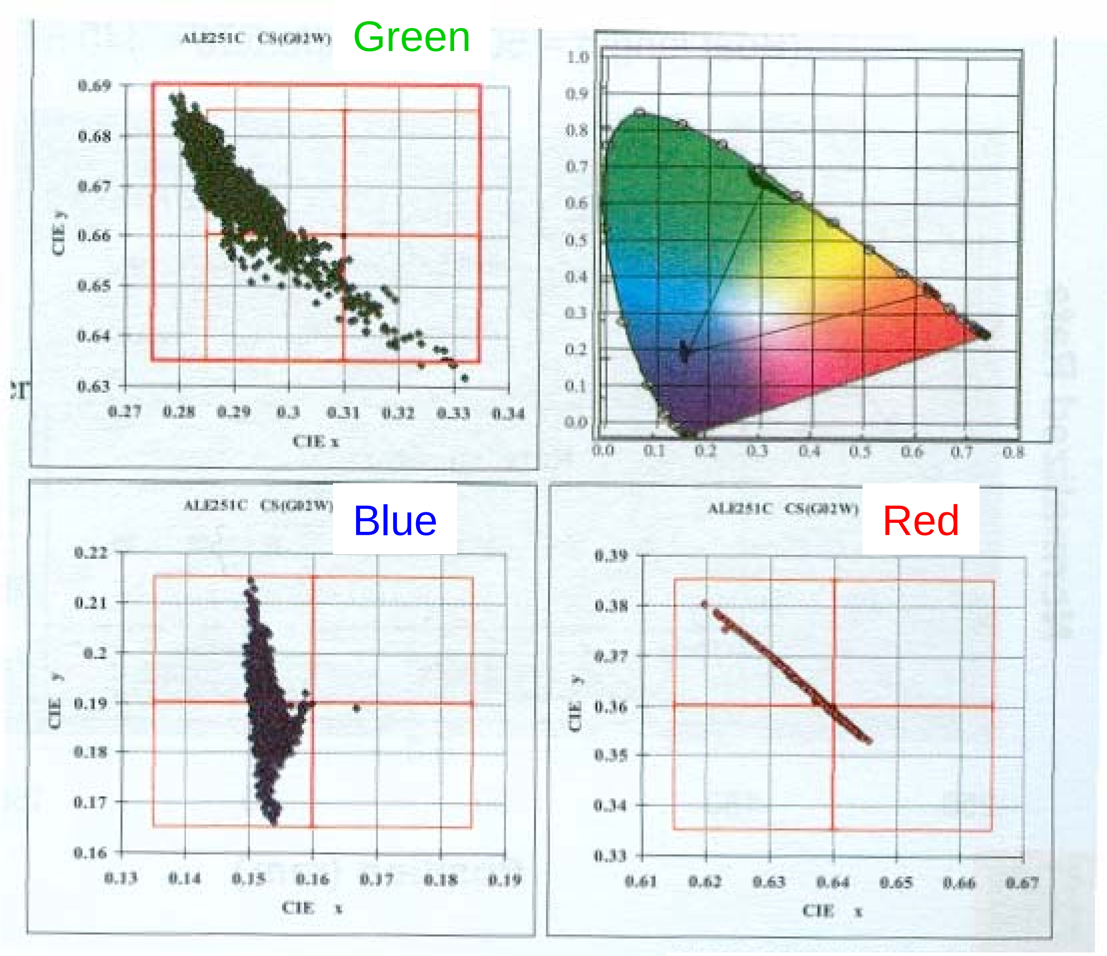
Designed for Deposition on 300 mm Substrates Widths
(Boat length = 500 mm, Aperture = 440 nm)



Linear source results

(300 x 400 mm substrates)

Red lines are specifications



Data from SK
Oct. 2002 Production

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Mass Production of AMOLED Full Color Display

Fabrication Using Linear Source Deposition of Organic Layers

A. SK Display has developed two models
a) 2.2” cell phone display
b) 2.2” camera display
c) More models under development

B. Sample shipments were made throughout 2002 to key customers, in support of product development

Kodak markets EasyShare LS633 DSC with 2.2” AMOLED
In March 2003

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Manufacturing Status

- October 2001: Zelda 450 pilot line commissioned
- 2002: Sample shipments to Sanyo & Kodak
- October 2002: Mass Production started
- March 2003: Kodak introduces LS633 DSC with OLED display
- July 2003: Capacity expansion
- October 2003: Sanyo showcases many OLED display models for DSC & cell phone applications
- January 2004: Zelda 650 full production line commissioned

Zelda 450 Photos

Linear source deposition

ULVAC Zelda 450 300 x 400 mm substrate

ULVAC Zelda 650 335 x 550 mm substrate

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OLED Products on the Digital Carera

Kodak LS633

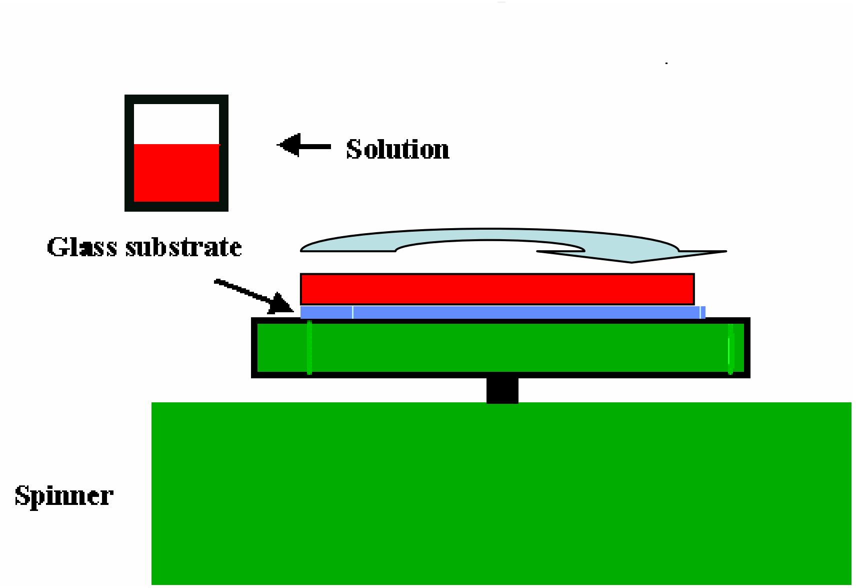
LTPS (Sanyo)+OLED(Kodak)
(SK Display)

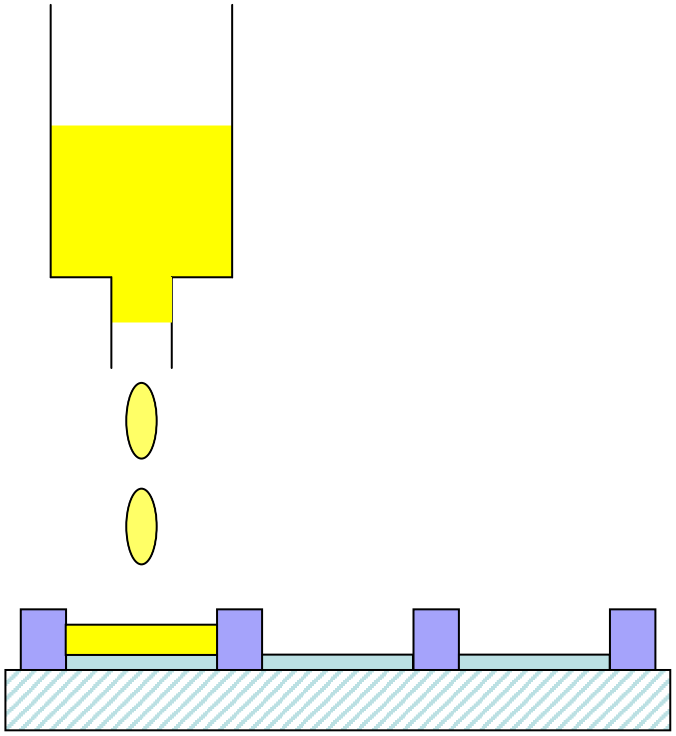
Resolution : 2140x1560 pixels

Display : 2.2 inch OLED

Manufacture of PLEDs

Spin-coating or ink-jet printing



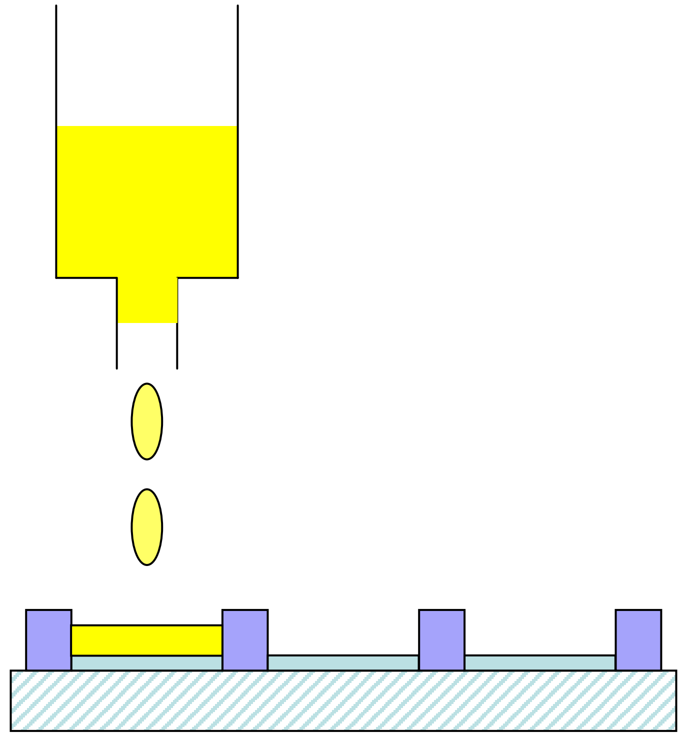


Inkjet Printing

Photolithographic barriers for definition

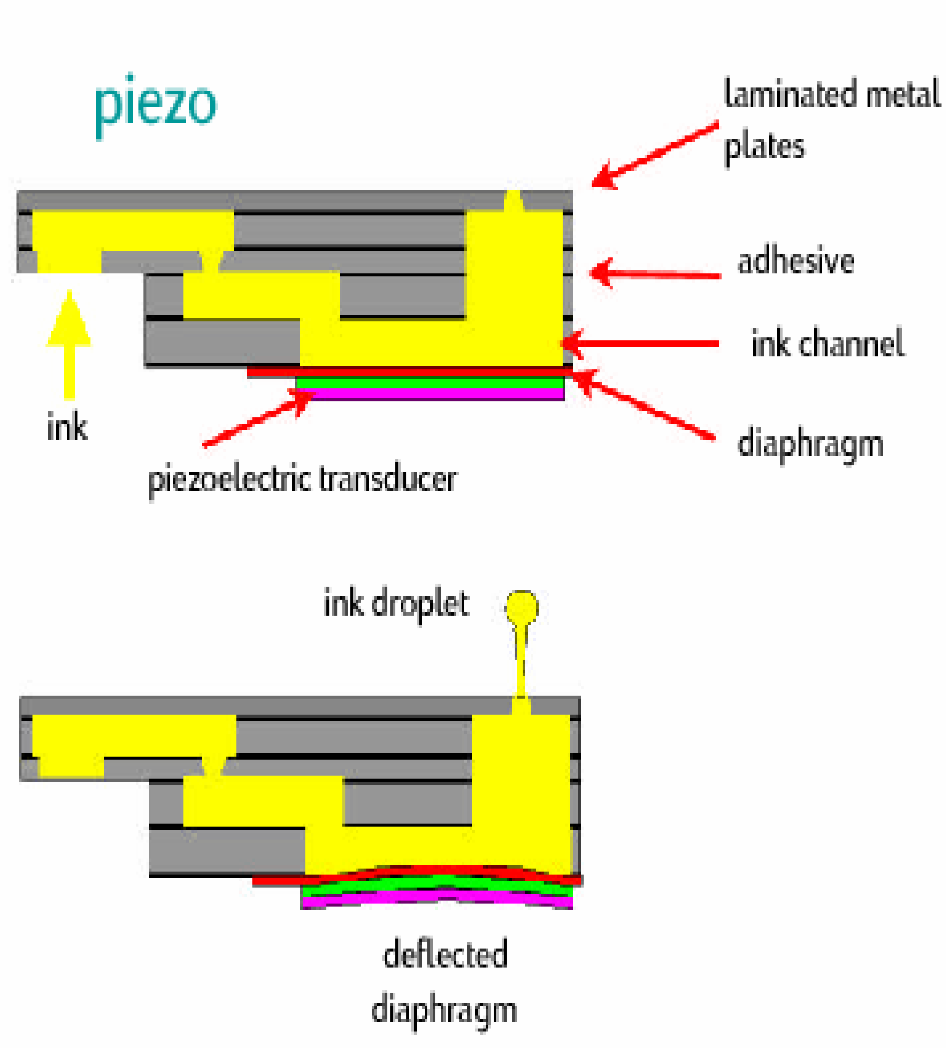
Printing PEDOT & drying

Printing polymer & drying



Principle of Piezoelectric Inkjet-printing

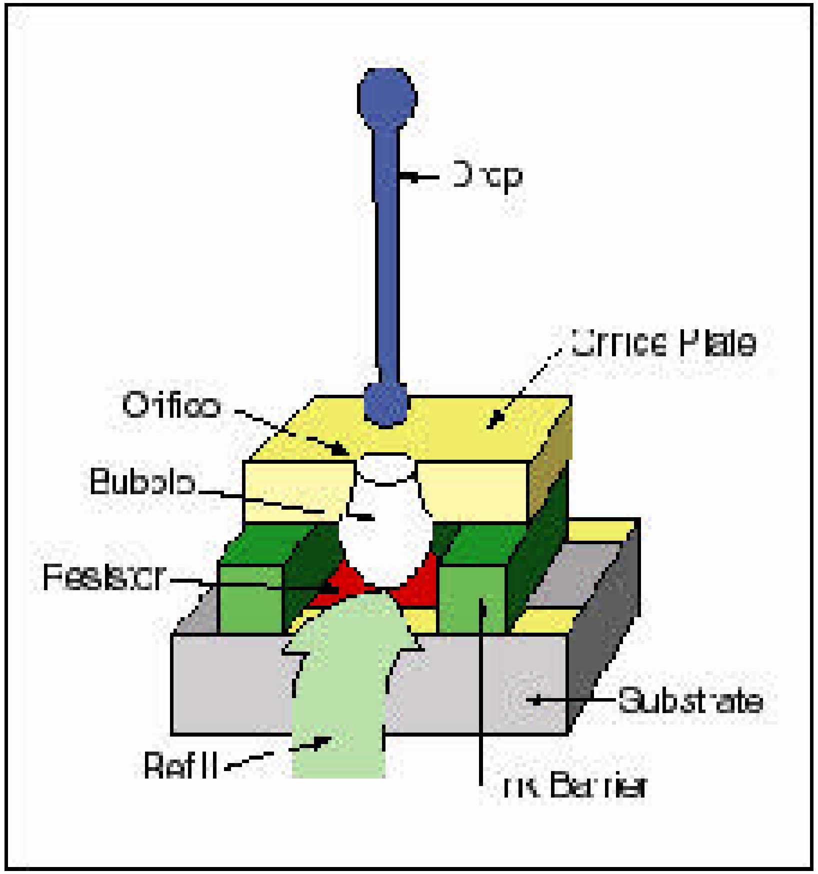
- uses a piezoelectric crystal to push and pull a diaphragm adjacent to the firing chamber
- creates a physical displacement that ejects the ink - difficult to control for printing small drops - results in imprecise placement of broken drop of ink
- mechanically moves the mass of diaphragm and the ink- available force determines the frequency of operation
- mechanical manufacturing processes make miniaturization more difficult to achieve - typically have lower nozzle density

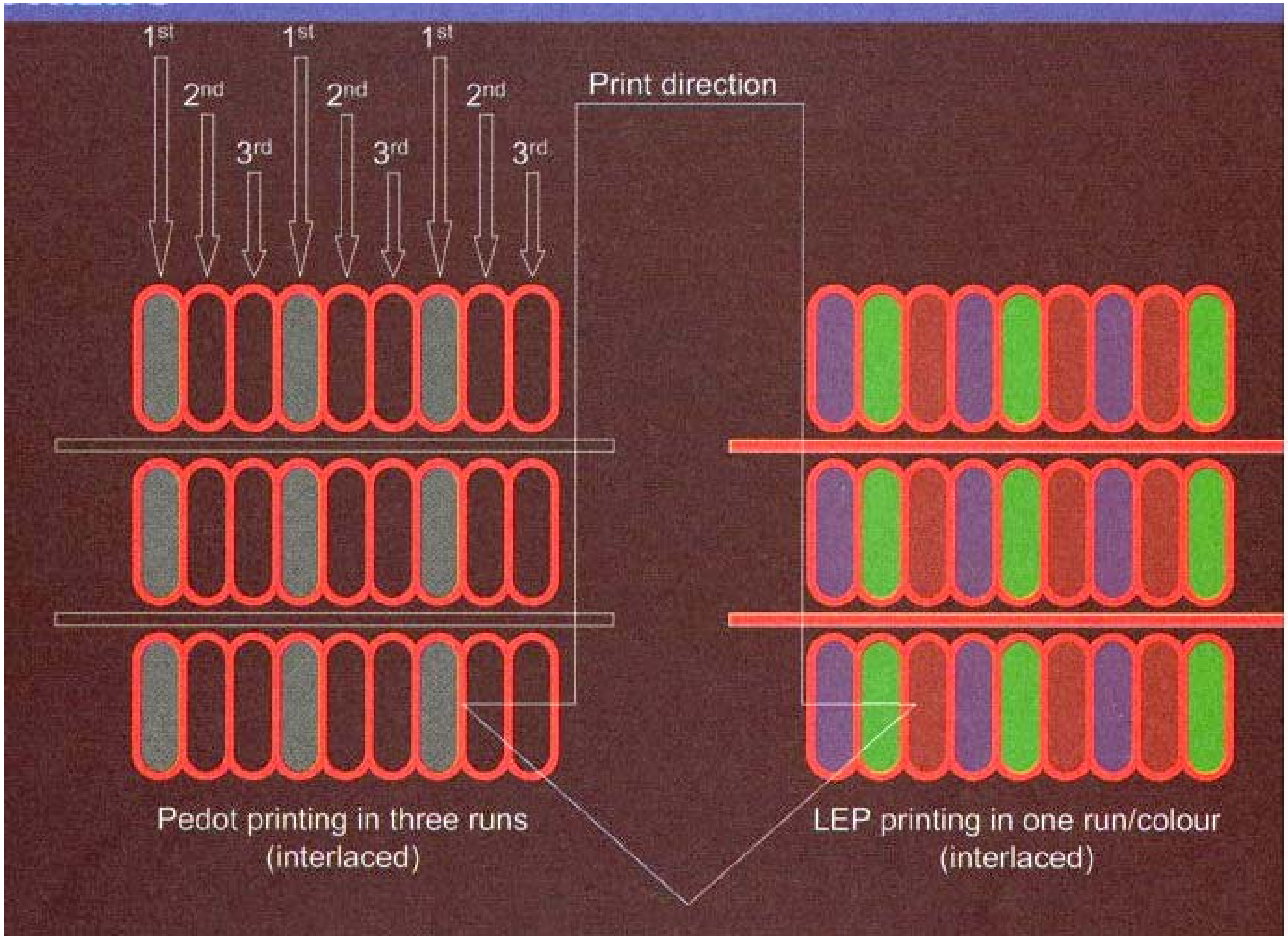


Principle of thermal bubble Inkjet-printing

- thin film resistor is located in the center of each firing chamber floor. This resistor is a tiny electrical heater that gets extremely hot when we pass electricity through it

- each resistor is 60 microns (millionths of a meter) or smaller on each side - but power density on its surface is 1.28 billion watts per square meter - more than on the surface of the sun!





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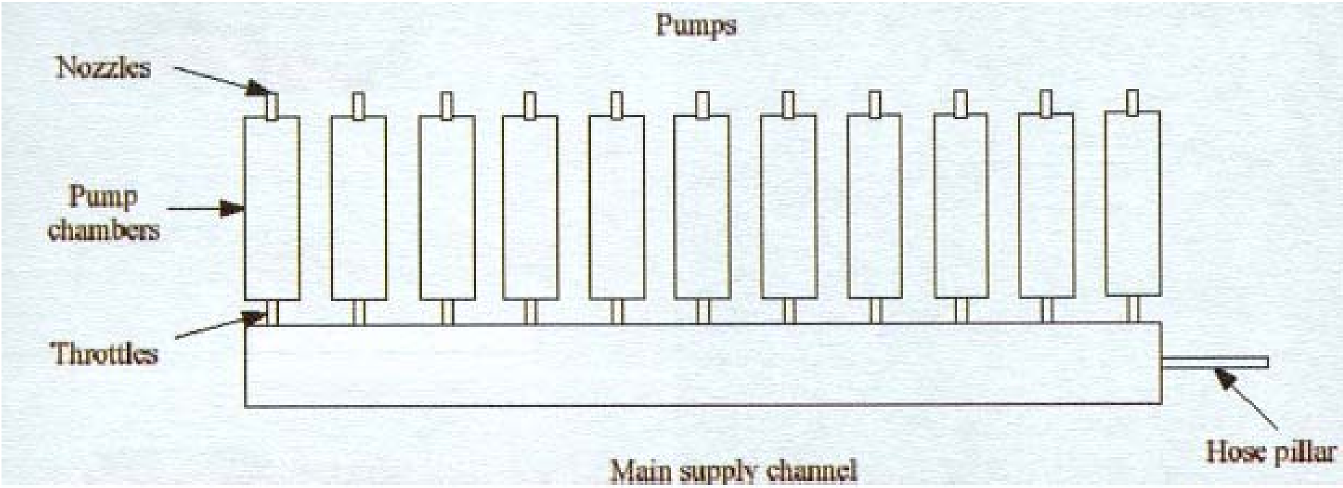
Scheme of an ink Jet head



Ink jet printing on the substrate

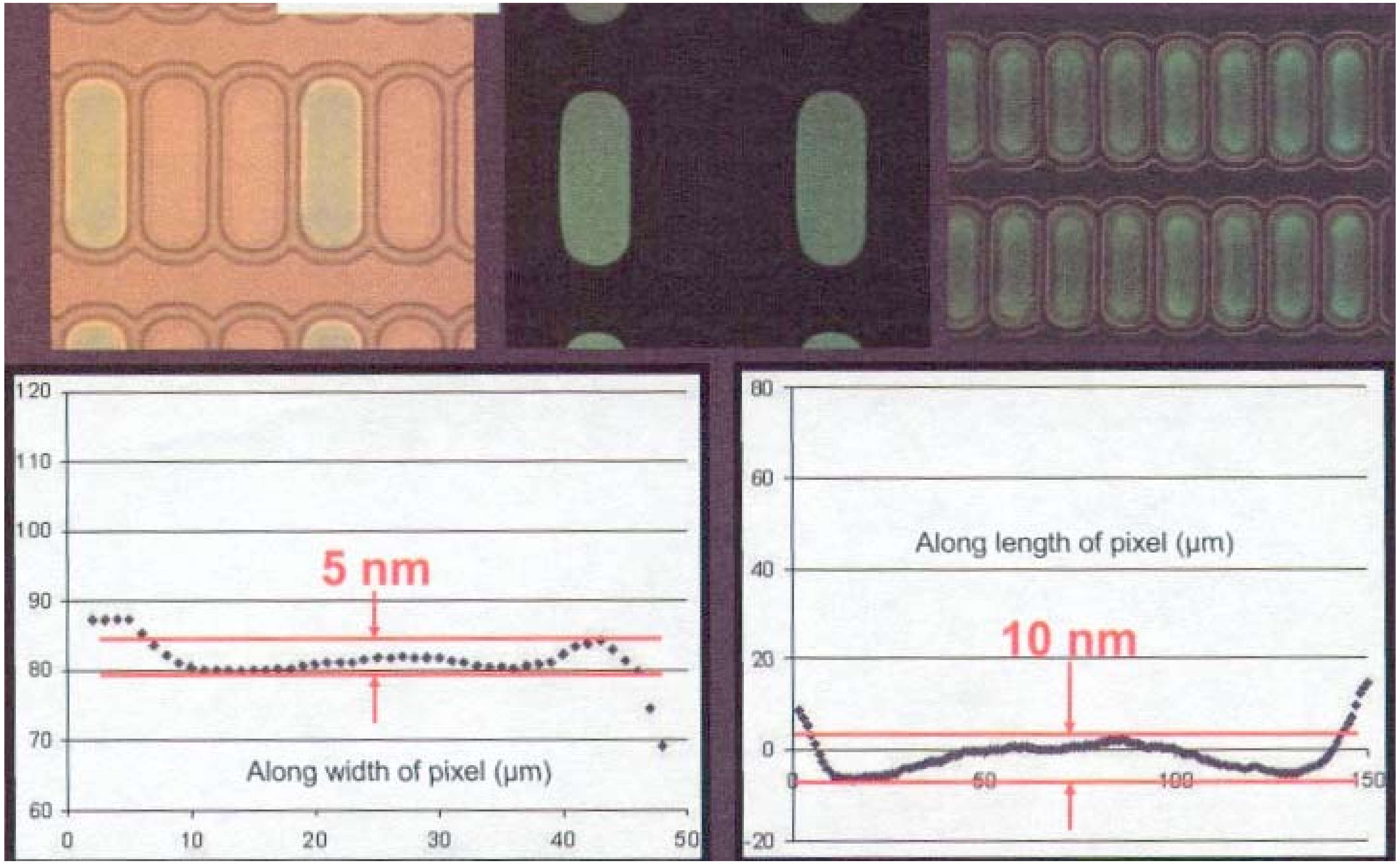
- Drop must hit the surface and fill the active area.
- The dried layer must form a flat film.
- Structures on the substrate are used to confine the fluid in subpixels.
- These structures are pretreated to avoid overflow between subpixels.

Printing Polymer (specifications)

- **Uniform droplet volumn**
- **Straightness to less than ±10mrad (10μm deviation at 1mm distance)**
- **Uniform droplet speed (3-8 m/s)**

  -- For predicting landing position

Layer Uniformity



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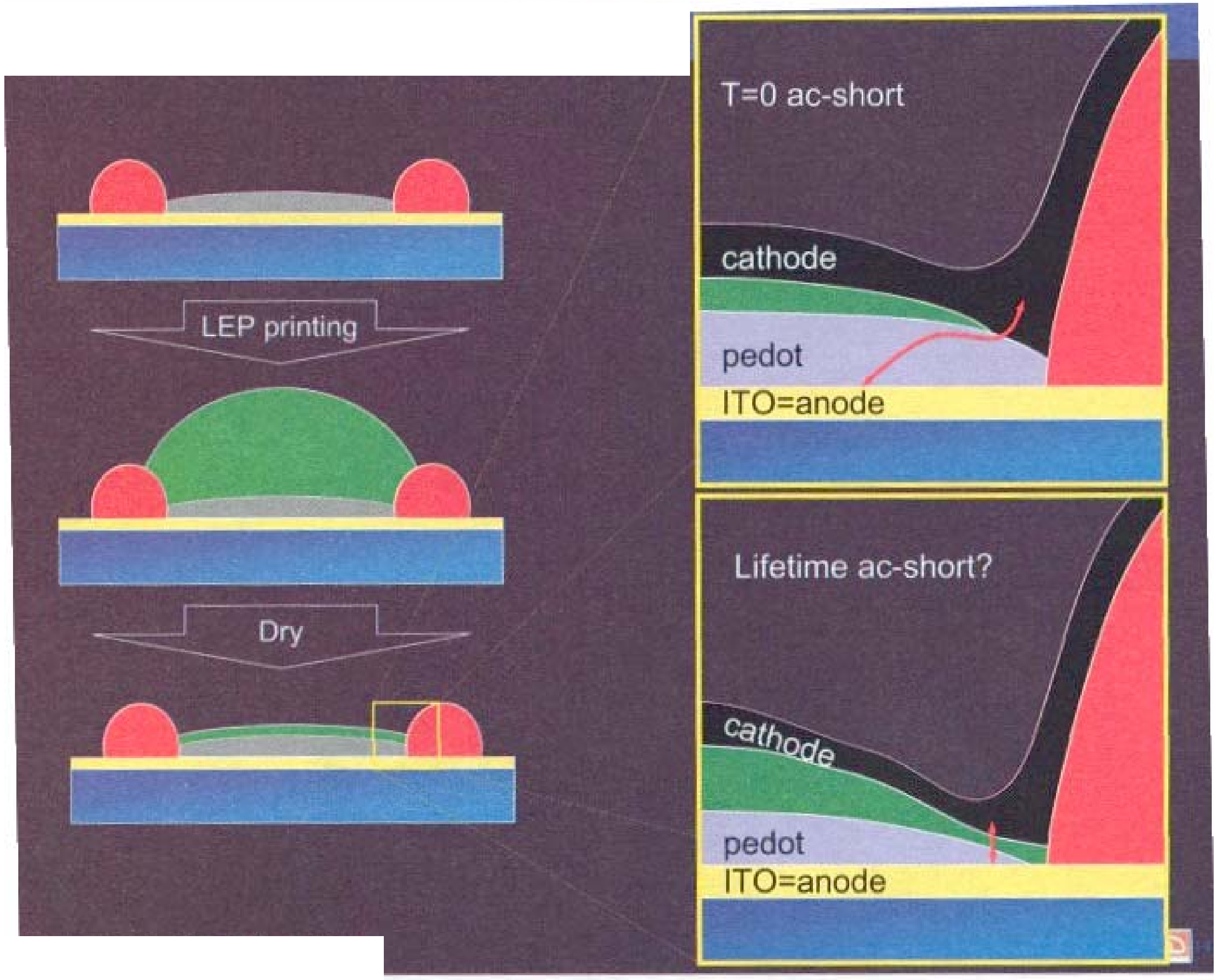
Layer Uniformity



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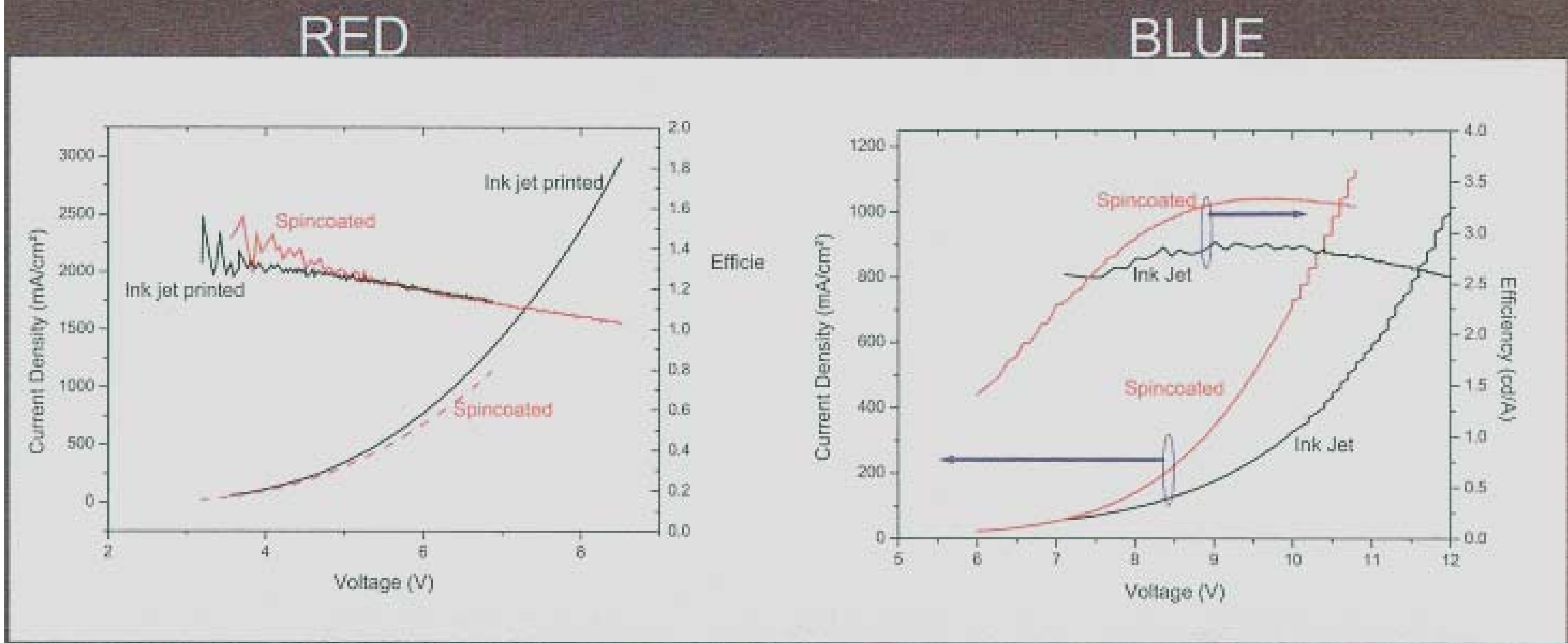
Ink jet vs. spincoated device



Red 80°C/50% RH	Lifetime (h)
Spin-coating (354 cd/m²)	143
Inkjet printing (416 cd/m²)	299

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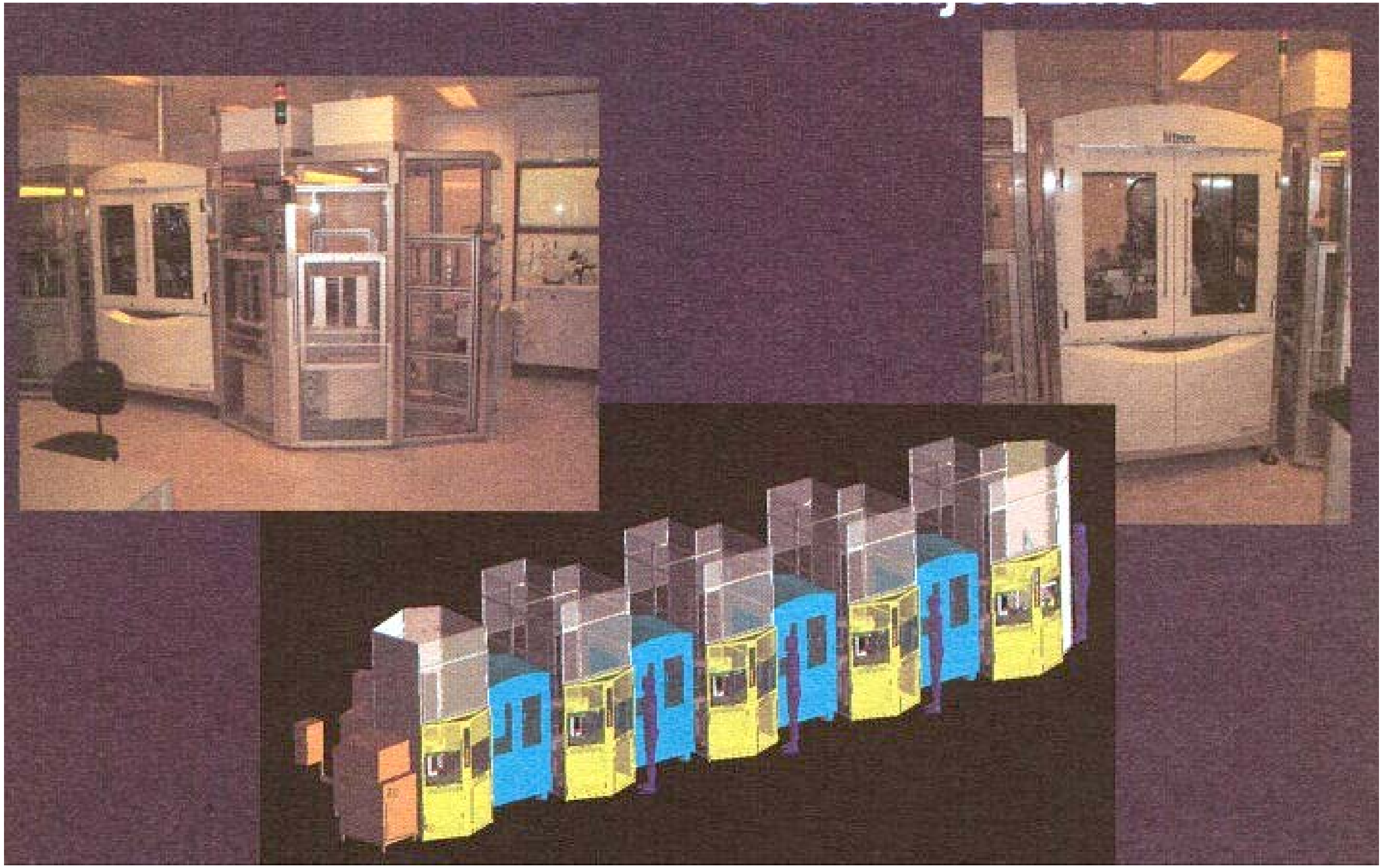
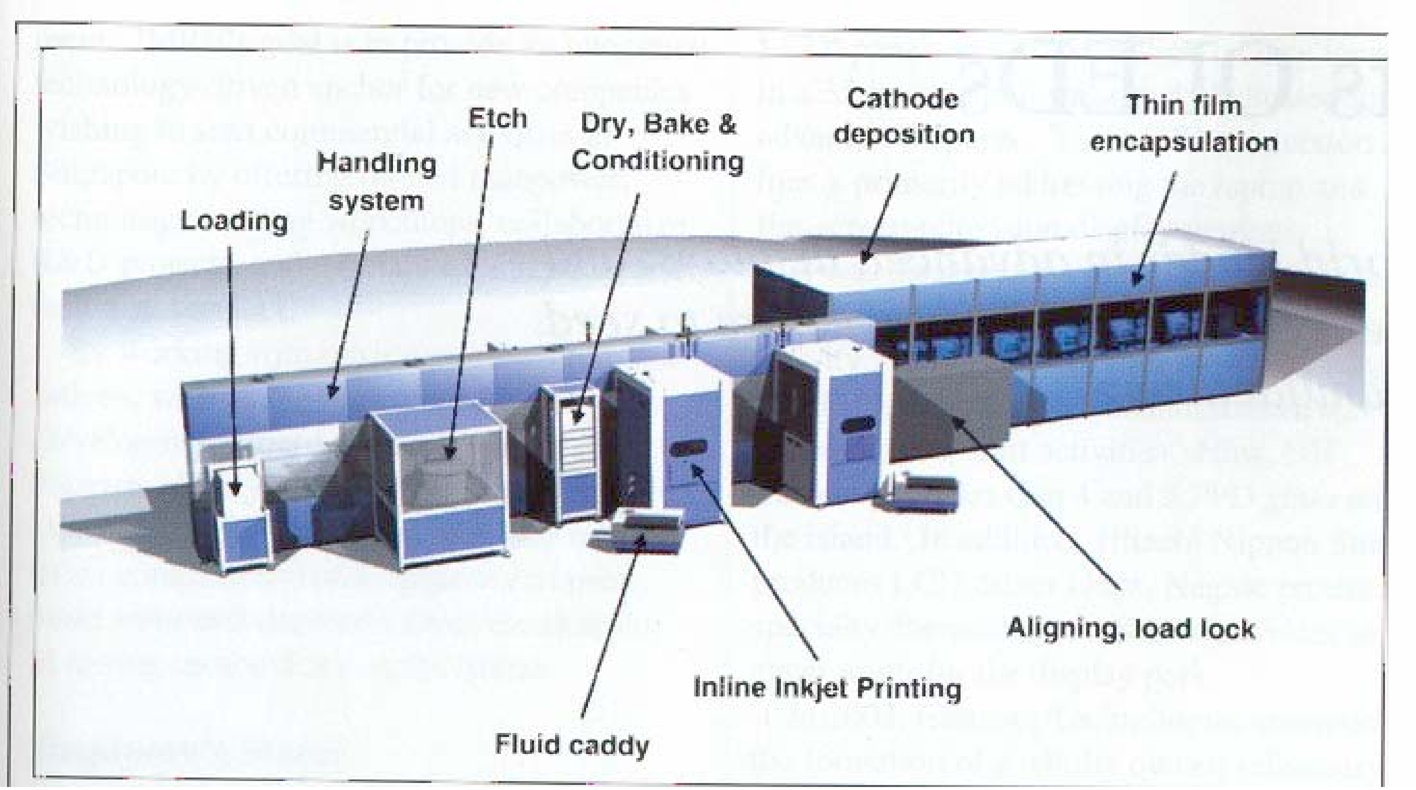
Litrex RGB inkjet line



RGB inkjet line



Innoled/OTB/CDT fully integrated in-line system
Clean room is NOT required

Gen 7 ink-jet-printing system is under development (Litrex Corp.)

J. Halls, Information Display, 21, (2), p15