
Opportunities for Chemists in Organic LEDs and Other Display Technologies

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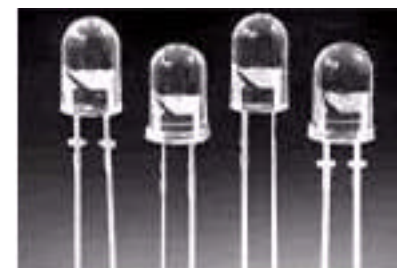
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ACS National Meeting, San Diego, April 1, 2001

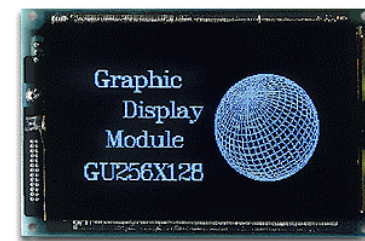


Lighting and Displays

LIGHTING:



DISPLAYS:



GU256X128-300



Kodak – Sanyo Demo Displays



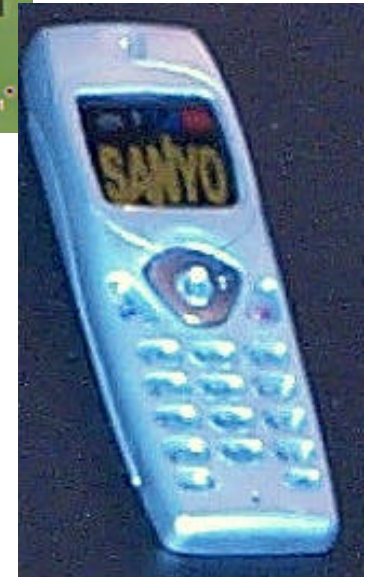
Full color
Active matrix
5.5" and 2.4" diagonal

Incorporated into
Kodak Smart
Picture frame



Multicolor
Passive matrix
1.3" diagonal

As cell phone
mock-up



Why OLEDs ?

ATTRIBUTES

- ◆ Bright
- ◆ Colorful
- ◆ Very wide viewing angle
- ◆ High contrast
- ◆ Monochrome, area color, or full color
- ◆ Low power
- ◆ Thin
- ◆ Competitive cost



Common Display Technologies: Market Sizes and Forecast (\$B)

	2000	2006	Growth Rate
CRT	\$24	\$27	2%
LCD – Active matrix	16	36	15%
LCD – Passive matrix	5	7	4%
Plasma Display	1	8	40%
Inorganic LED	0.5	0.4	-4%
Organic LED	0.03	2	100%
Projectors	11	18	9%
Other	0.9	0.9	0%
Total	\$58	\$99	10%

Other consists mainly of VFD, EL, and FED

Sources: Stanford Resources2000-01 and Eastman Kodak



Two approaches for chemists looking for opportunities

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Look where the money is



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Look where the money is

Look where the growth is



Opportunities for OLED Display Improvements

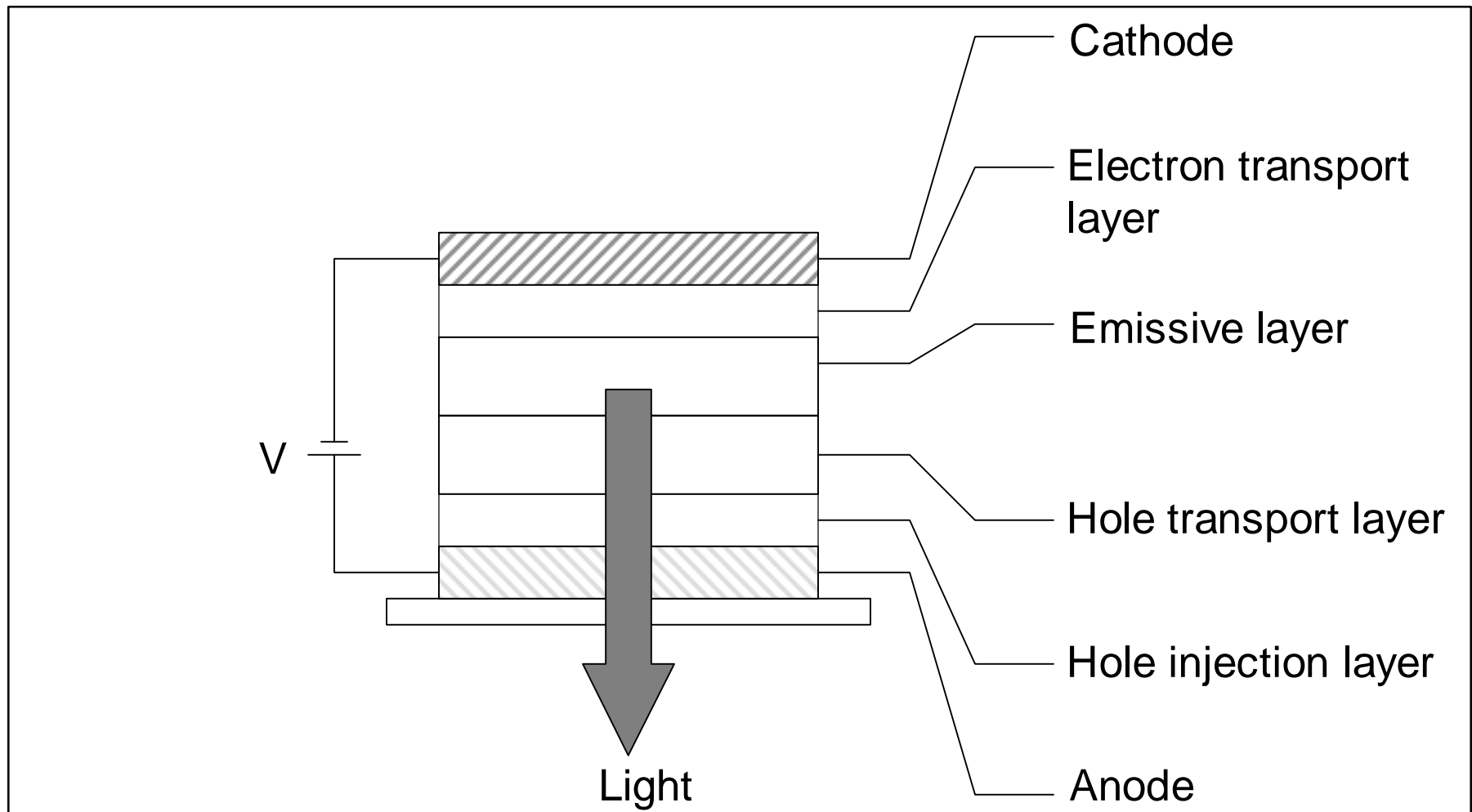
- ◆ Light emitting materials
 - efficiency
 - lifetime
 - color variety and purity
- ◆ Manufacturing technology
 - coating methodology (vacuum, spin, inkjet, roll-to-roll, self-assembling)
 - color patterning
 - factory automation and robotics
- ◆ Device structures
 - layer thicknesses and formulations
 - encapsulation
 - flexible substrates
- ◆ Drive electronics
 - thin film silicon transistor arrays
 - organic semiconductors and transistors



Light Emitting Materials



Typical Multilayer OLED Structure

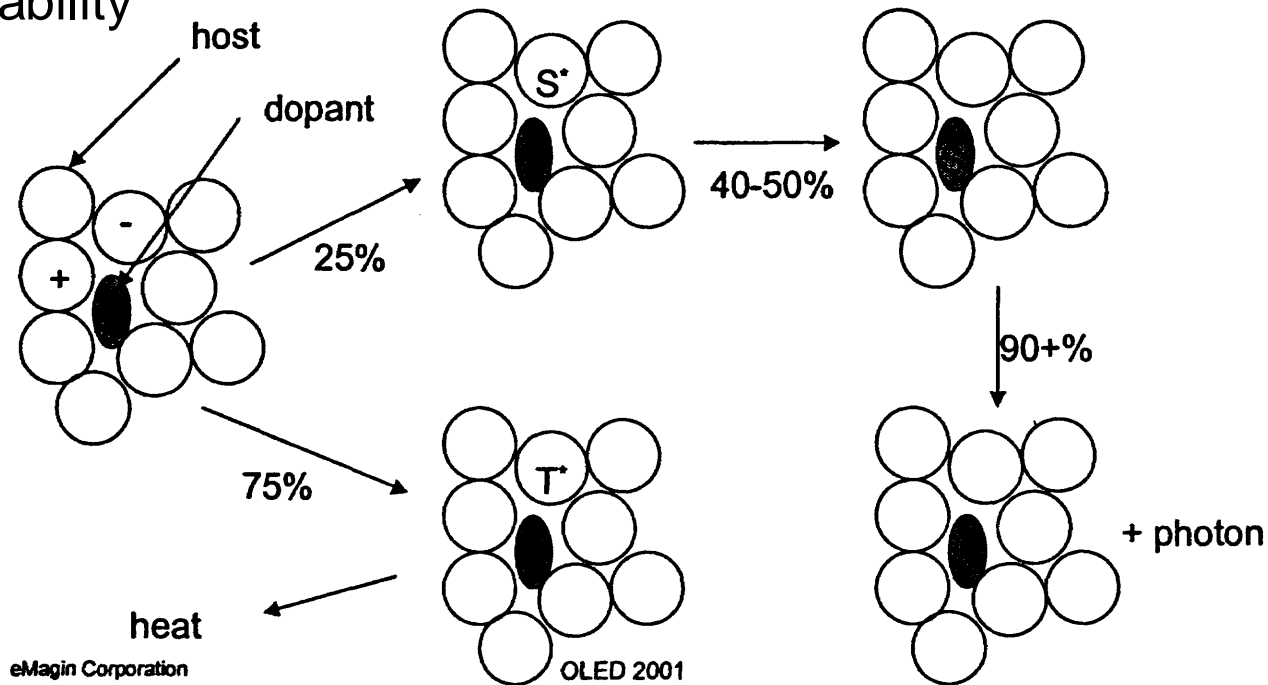


Doped Emitters

Quantum mechanics meets flat panel displays

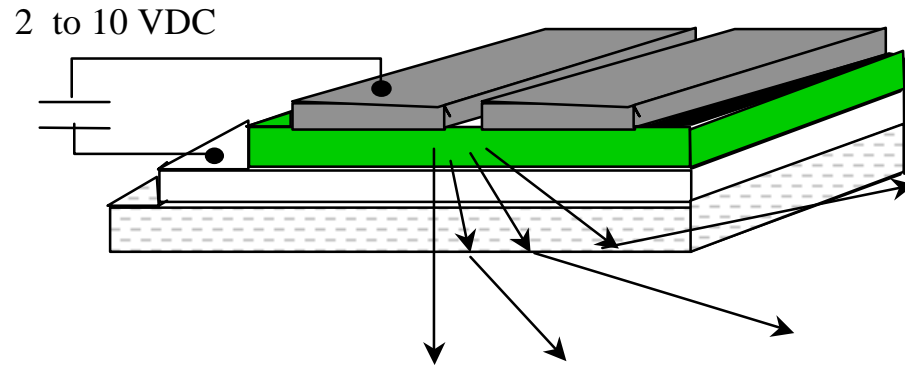
Advantages:

- Luminescent solid films
- Improved EL efficiency
- Improved EL stability
- Color tuning



Device Efficiency

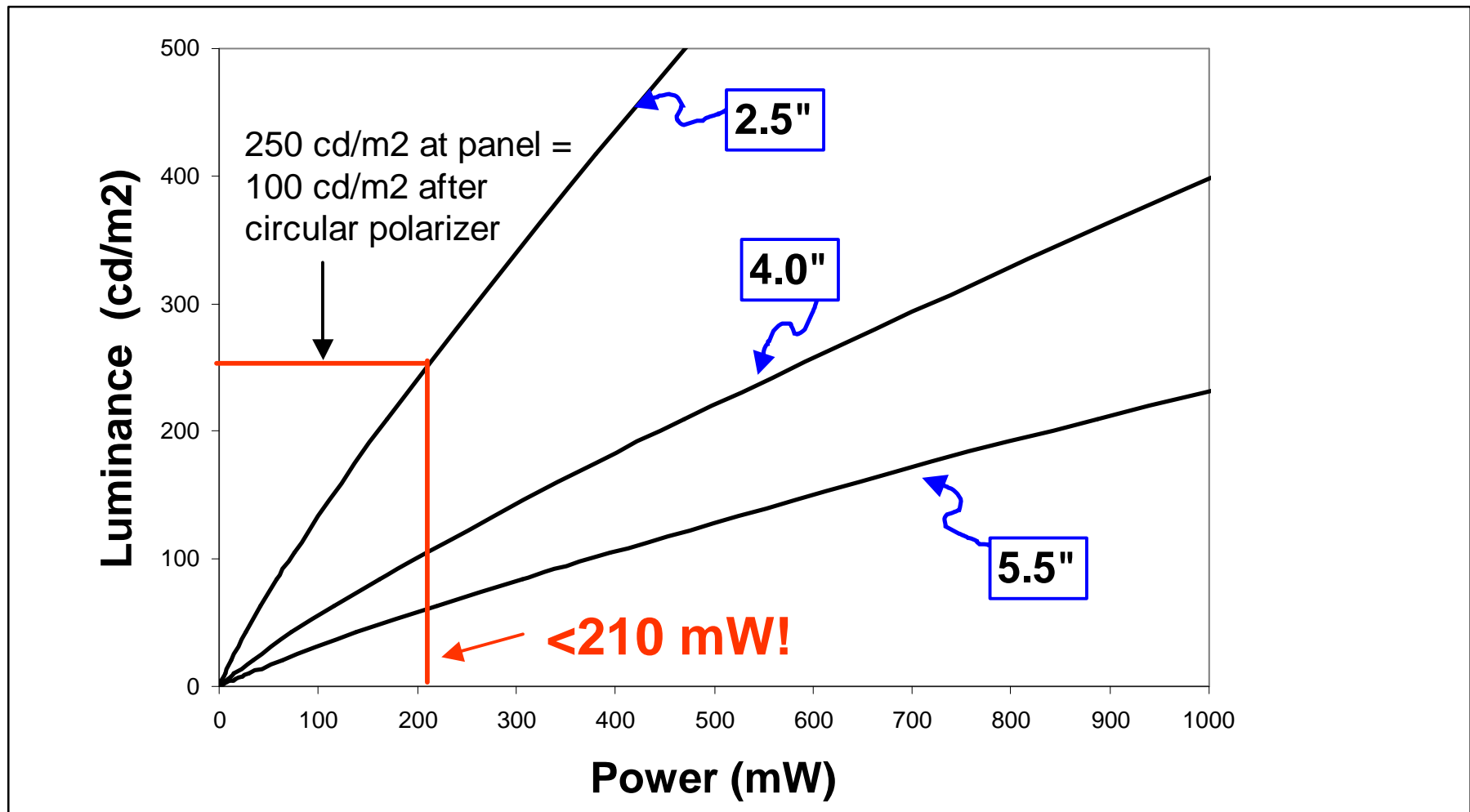
- ◆ Internal quantum efficiency of the device $\eta_{\text{int}} = \gamma f_s q$ where
 - γ is the fraction of injected electron-hole pairs forming excitons.
 - f_s is the fraction of excitons forming as singlets.
 - q is the radiative decay efficiency of the excitons.
- ◆ The fraction of internally generated light that radiates in the forward direction from the device $\sim 1/2n^2$, where
 - n = index of refraction of the substrate



- ◆ Device external quantum efficiency $\eta_{\text{ext}} \sim (1/2n^2) \gamma f_s q$



Low power consumption of OLEDs fits portable applications



Material Requirements

- ◆ High luminescence efficiency
- ◆ Adequate conductivity
- ◆ Good oxidative stability (water, oxygen)
- ◆ Good radical cation/anion stability
- ◆ Good temperature stability (Tg)

- ◆ Coatability (thin films with no pinhole defects or impurities)
 - PLED: Good film formation from solution
No side reactions with solvents
 - OLED: Does not degrade during sublimation
No catastrophic film crystallization
- ◆ Color saturation/purity

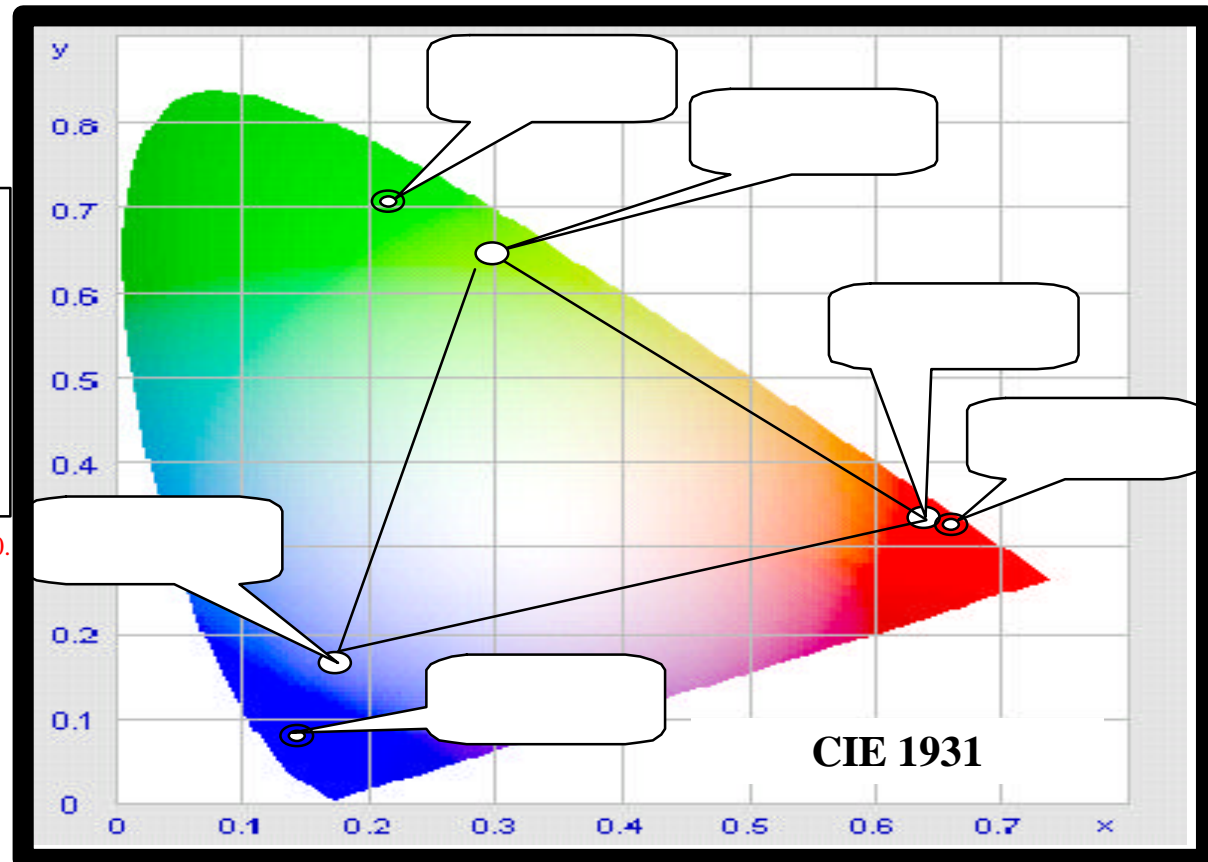


Material Requirements

Typical OLED CIE characteristics and color/efficiency requirements for video applications

Color	Eff.cd/A
Red	1.0
Green	10.0
Blue	2.5

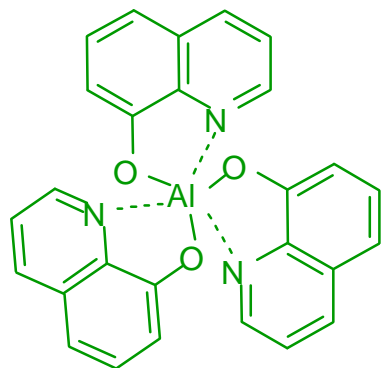
G.Rajeswaran. SID 5/17/00.



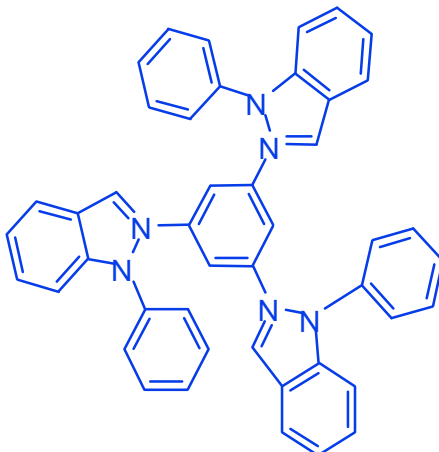
Typical Materials Used for OLEDs

Electron-transporting/host materials:

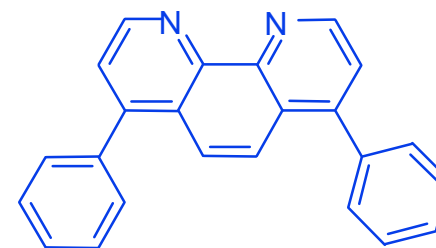
Alq₃



TPBI

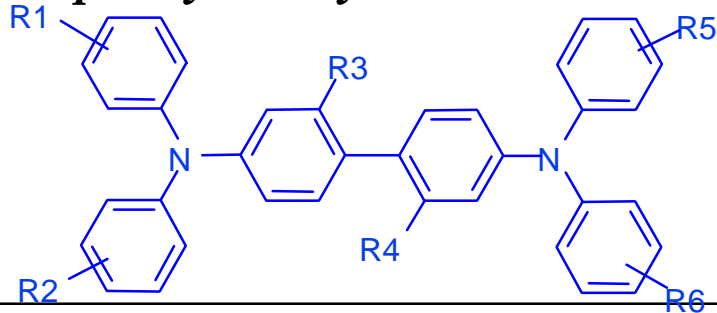


BCP



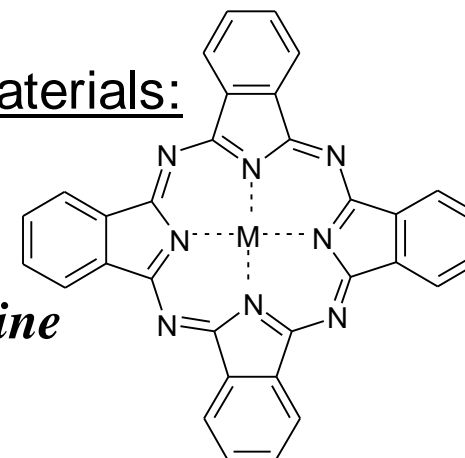
Hole-transporting materials:

• *Biphenyl-triaryl amine derivatives*



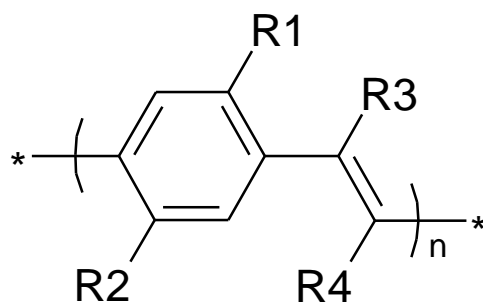
Hole injection materials:

Phthalocyanine derivatives



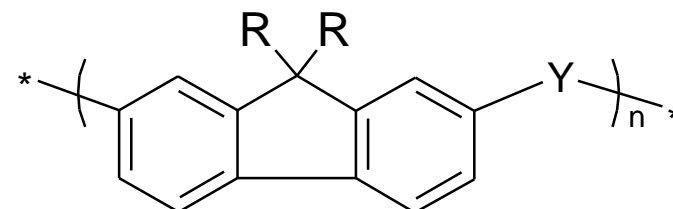
Typical Materials Used for PLEDs

- ◆ The emissive layers for PLEDs tend to be based on *poly(phenylene vinylene) derivatives* and *poly(fluorene) derivatives*



Hole-transporting: R1,2 = H, OR, C6H6, F

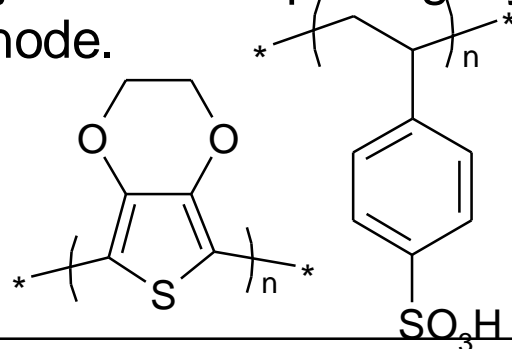
Electron-transporting: R3,4 = CN



Y = triphenyl amines

Y = cyano-PPV, triazole deriv.

- ◆ An additional hole injection/transporting layer is often also used for PLEDs at the ITO anode.

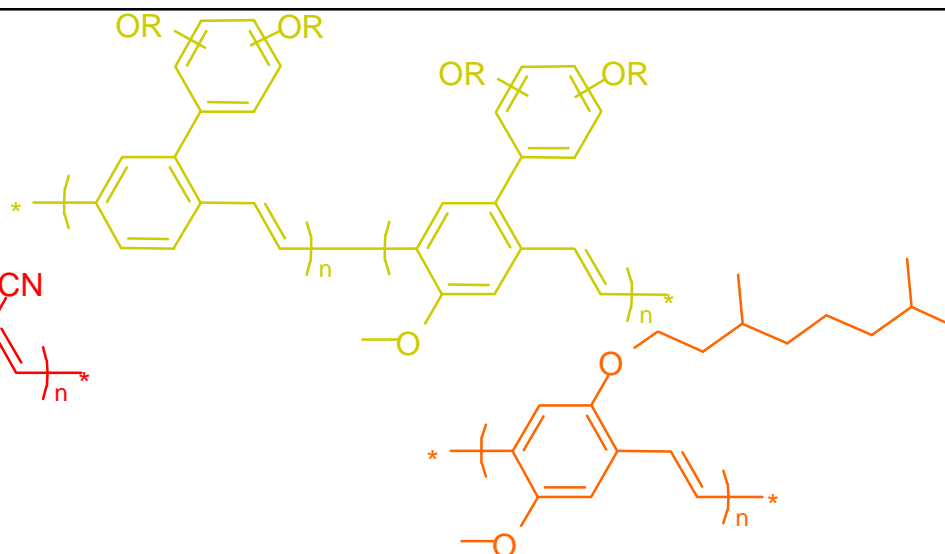
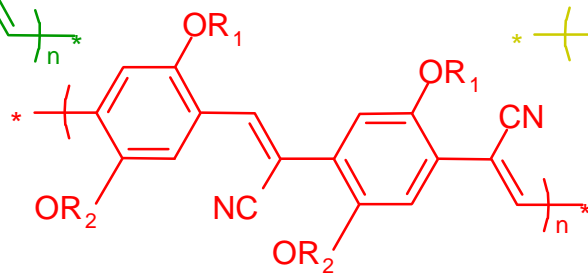
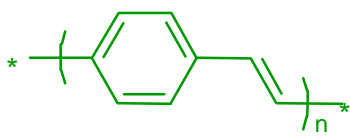


PEDOT/PSS

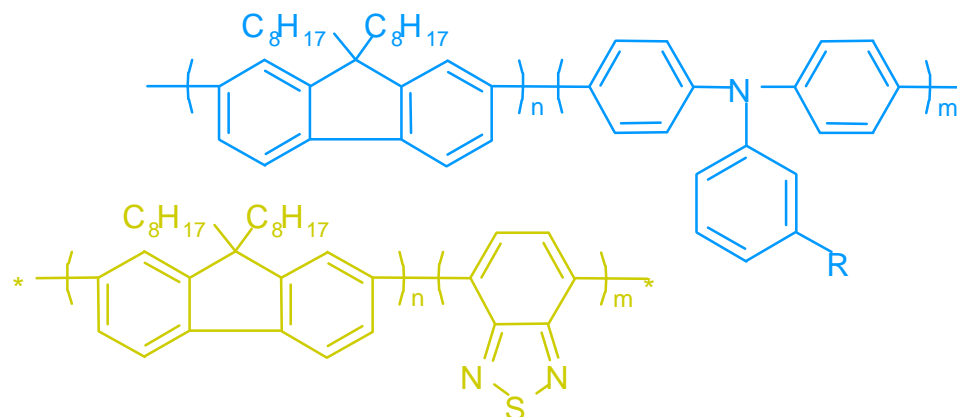
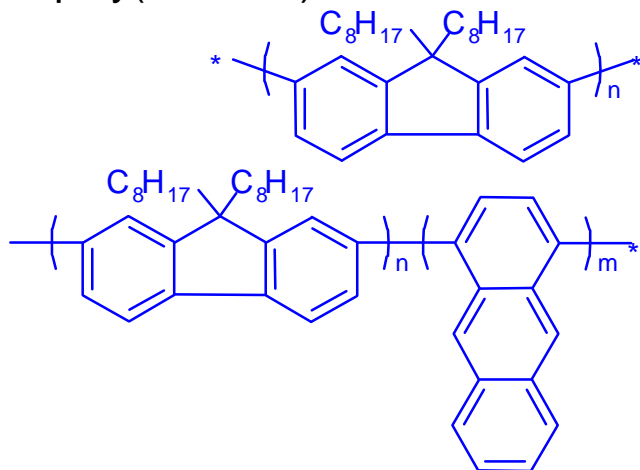


Color Tuning of Electroluminescent Polymers

◆ poly(p-phenylene vinylene)

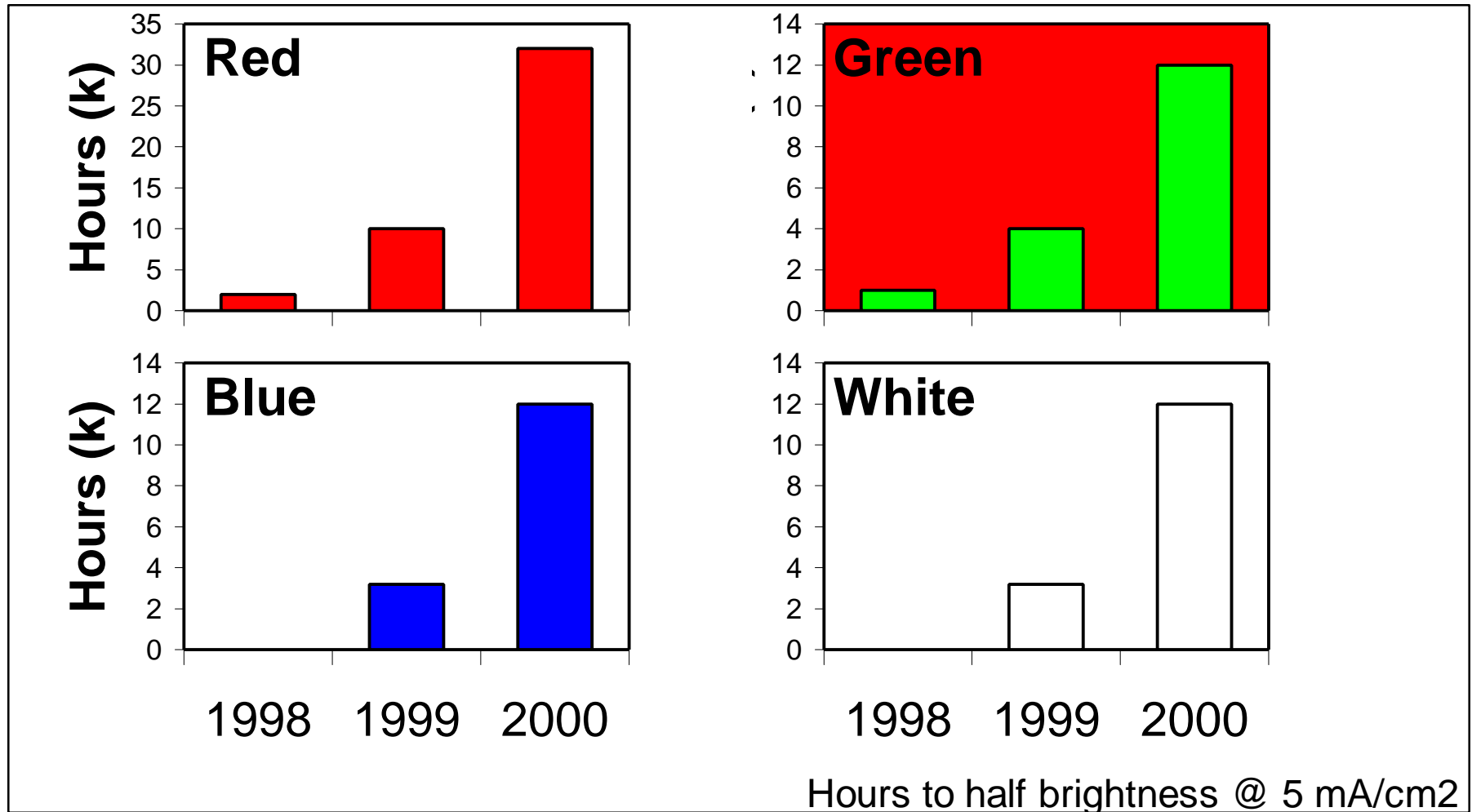


◆ poly(fluorene)



Lifetimes Continue to Improve

(Current Kodak color set)



Relative advantages of small molecule and polymer OLEDs

Small molecule OLEDs:

- ◆ Fabrication of efficient multilayered device geometry is more straightforward (vacuum evaporation vs solvent casting).
- ◆ Easier to exclude water, oxygen and impurities with vacuum deposition than solvent-based processing.
- ◆ Fabrication of patterned, device-quality layers with no defects, adequate layer uniformity is more straightforward with vacuum processing (shadow mask patterning vs. inkjet deposition).

Polymer OLEDs:

- ◆ Potentially better operational stability at higher temperatures, due to higher $T_g > 180\text{ }^\circ\text{C}$.
- ◆ Potentially lower cost for deposition (only high-vacuum step is cathode deposition; can get high throughput on roll to roll coatings).



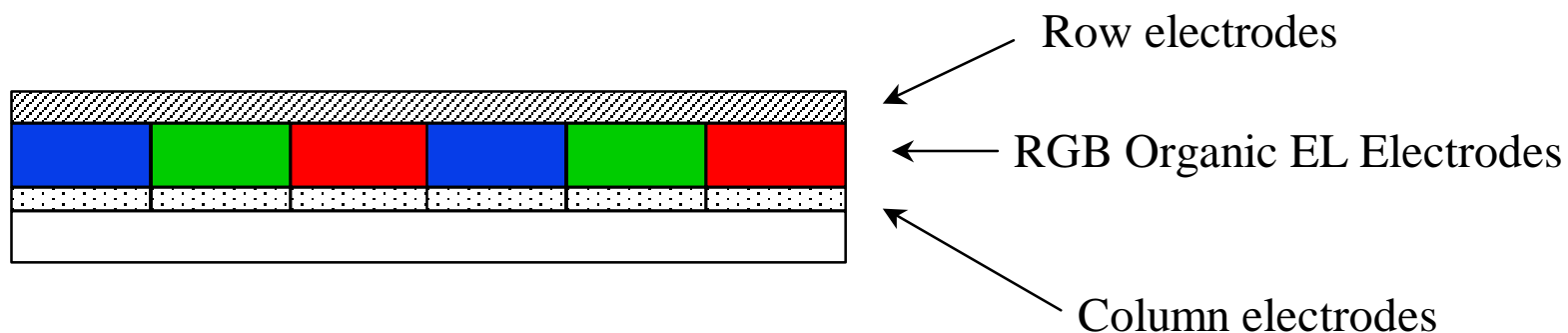
Manufacturing Technology

- ◆ Color Patterning
- ◆ Coating Methods



Full Color Displays

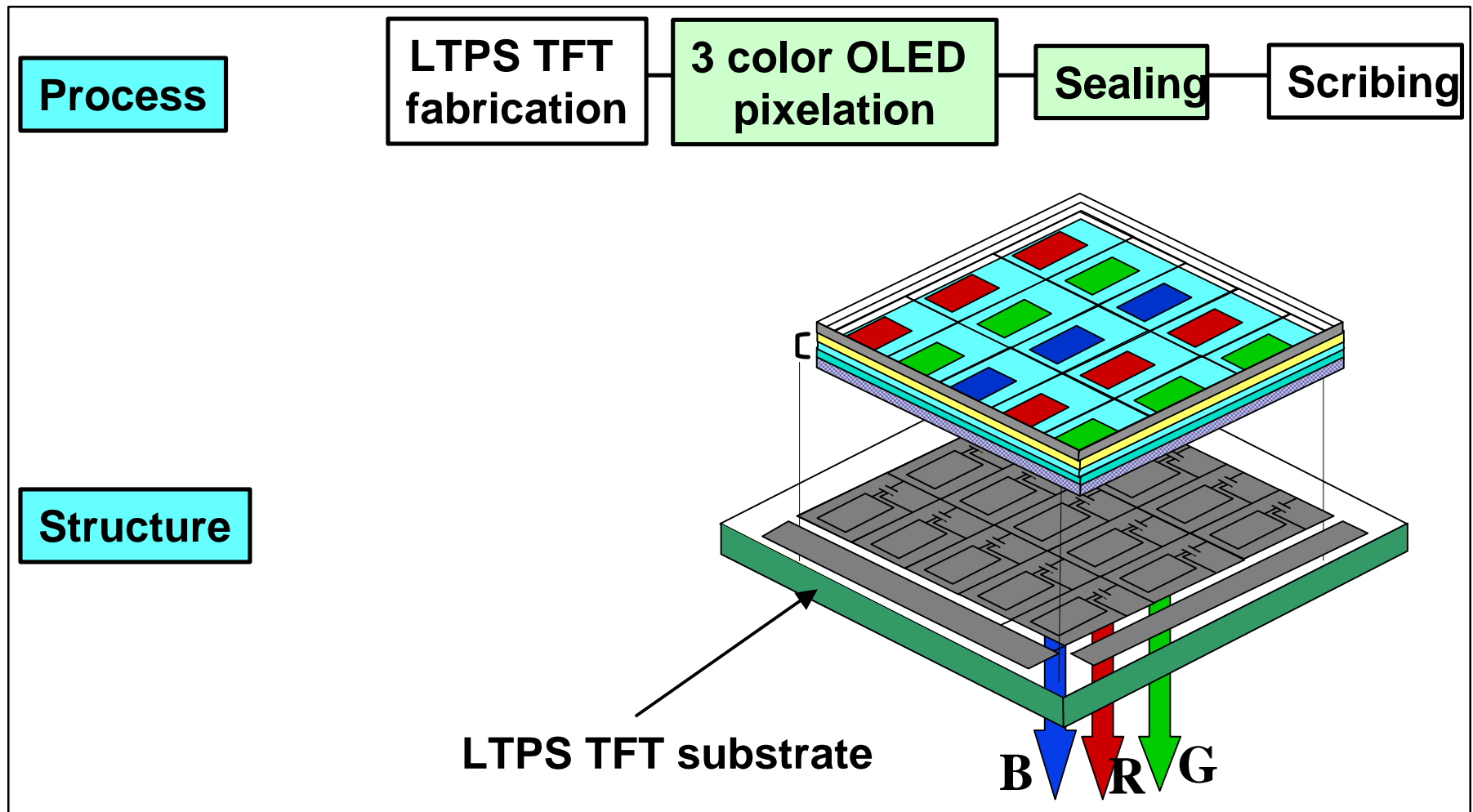
- ◆ Color pixelation method--patterned organic EL layer



- ◆ Advantages: high luminous efficiency
- ◆ Disadvantages: need for critical patterning method for high-resolution panels
 - OLED: physical evaporation through a shadow mask
 - PLED: inkjet deposition, photolithographic patterning



Kodak AM-OLED Manufacturing Process

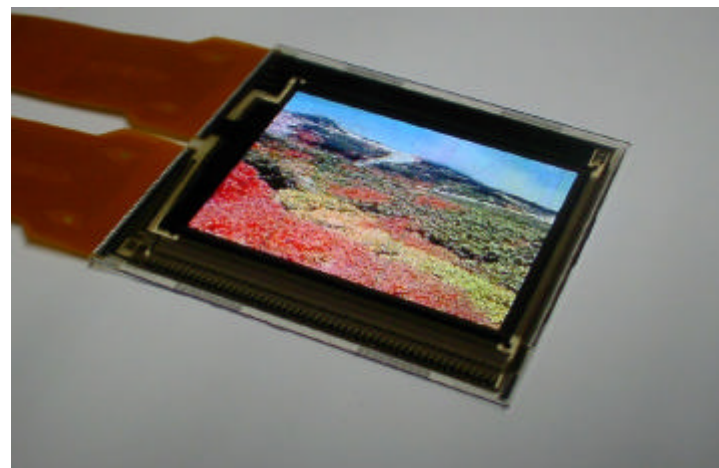


Methods of patterning color



**Small molecule OLED on polysilicon
prototype patterned by vacuum
sublimation through a shadow mask**
Kodak and Sanyo

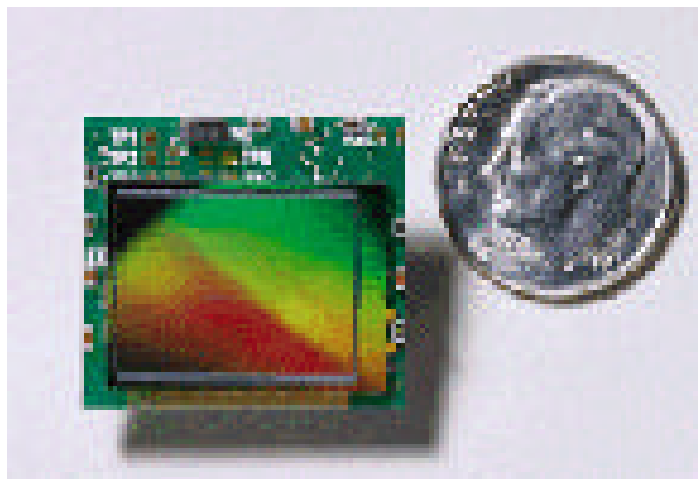
**Polymer OLED on polysilicon
prototype patterned by inkjet printing**
Cambridge Display Technology and Seiko
Epson



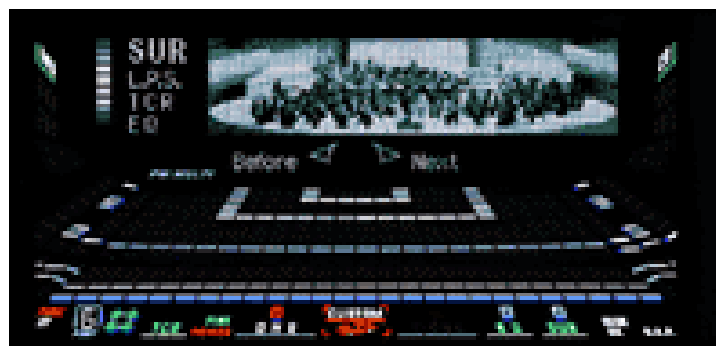
Another path to color: **White OLED + color filters**

R, G, B Filter Array
White OLED
Substrate

eMagin OLED microdisplay



TDK OLED car stereo display



Device Structures Flexible Substrates



Flexible Substrates

- ◆ **Vision:**
(courtesy of Universal Display Corporation)



- ◆ **Prototype** polymer OLED on thin glass (May 2000)



Requirements for Flexible Substrates Used with OLED/PLED Technology

- ◆ Most important: *barrier properties* to water and oxygen
 - Estimated to be $< 1 \mu\text{g H}_2\text{O/ m}^2\cdot\text{day @ } 38^\circ\text{C, } 90\% \text{ RH; } < 10^{-3} \text{ cc O}_2/\text{m}^2\cdot\text{day}\cdot\text{atm}$
- ◆ Other important parameters include:
 - Coating compatibility/good adhesion for ITO, SiO_2 .
 - Good transparency.
 - Uniform thickness and flat surface.
 - Chemical resistance (for photolithography, polymer deposition).
 - Heat resistance/thermal expansion (for photolithography, laser scribing).
 - Abrasion resistance.
 - Refractive index and birefringence (for coupling light out of device).
 - Environmental stability.
 - Flex resistance.
 - etc.....



Why flexible substrates?

- ◆ **Thinness** – a few tenths of a millimeter matter in consumer electronics
- ◆ **Weight** – every gram saved is an advertisable difference
- ◆ **Impact resistance**
- ◆ **New display modalities** – molded/sculpted/conformable displays on nonplanar surfaces
- ◆ **Flexibility** – roll up screen ?
- ◆ **Lower cost manufacturing** – roll to roll coating methods eventually?
- ◆ **Because it's cool ?**

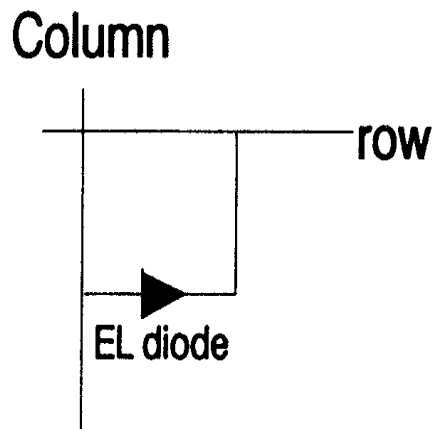


Drive Electronics



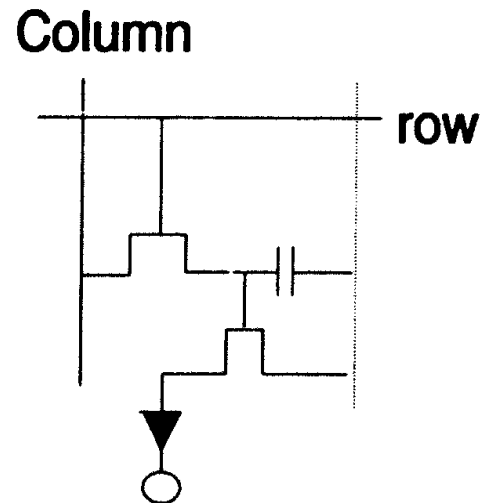
Passive and Active OLEDs

Passive-matrix



- Simple process steps
- Low cost
- Limited size and resolution

Active-matrix

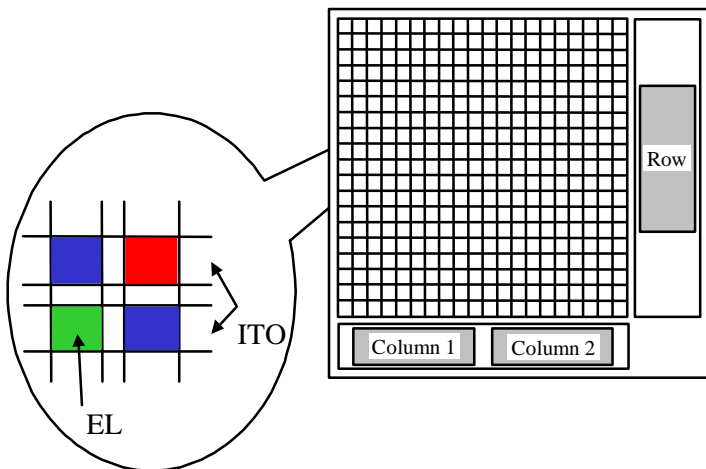


- Very high resolution
- Large panel size
- Low voltage and current
- Integrated drivers
- Robust design



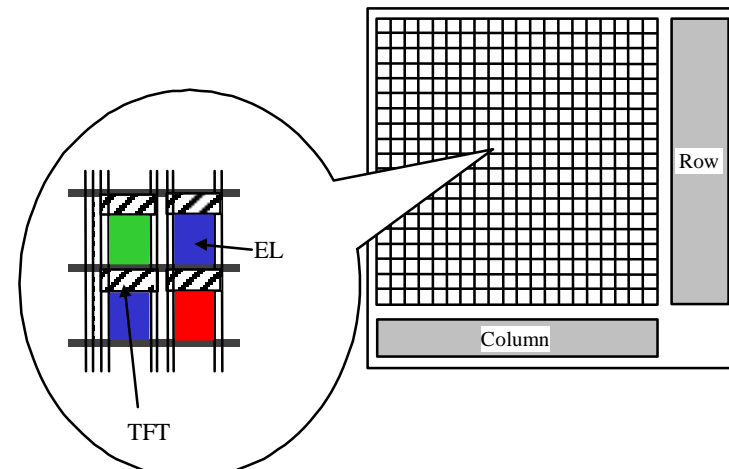
Passive vs Active Matrix Displays

Passive Matrix



- Matrixed pixels (crossed anode and cathode).
- Line-by-line scanning.
- Discrete ASIC drivers.

Active Matrix



- Each pixel has switching TFT.
- Selected pixel stays on until next refresh cycle.
- Integrated drivers.

G.Rajeswaran. SID 5/17/00.

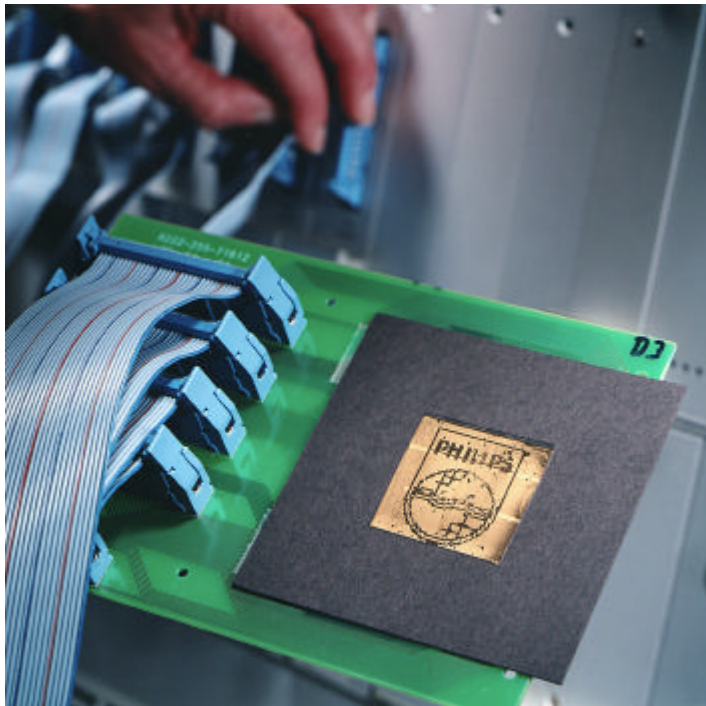


Semiconductors for Active Matrix OLEDs (and LCDs)

Silicon Type for TFTs	Electron Mobility (cm ² /V-s)	Motherglass Size	Display Size (inches)	Compatible Circuit Types
Organic semiconductors	0.01 to 0.1	lab prototypes are a few inches	a few inches	None
Amorphous Si (a-Si)	0.5 to 2	300x400 mm to 730x920 mm	1.8 – 30"	None
Low-temperature polycrystalline silicon (LTPS)	50 to 200	300x400 mm to 620x750 mm	0.55 to 15"	Integrated Drivers
High-temperature polycrystalline silicon (HTPS)	100 to 200	8 to 12 inch wafer size	0.55 to 1.8"	Integrated Drivers
Continuous grain-boundary silicon (CGS)	~300	8 to 12 inch and 300x400 mm	0.5 to 7"	Integrated Drivers
Crystalline silicon (x-Si)	~500	8 to 12 inch wafer	0.2 to 2"	Integrated Drivers, Signal Processors



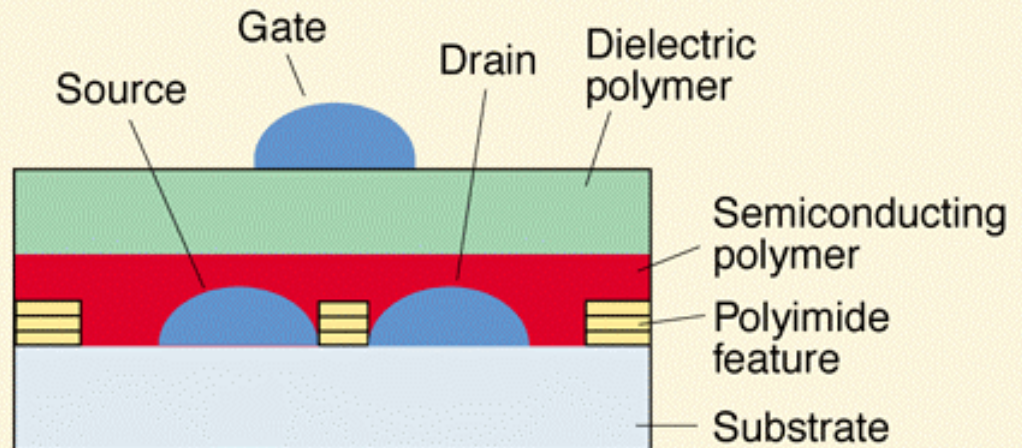
TFTs based on organic semiconductors



Polymer-based active-matrix thin-film transistor array used to drive a 64 x 64-pixel LCD (Philips Research)

Cavendish Laboratory
C&EN January 1, 2001

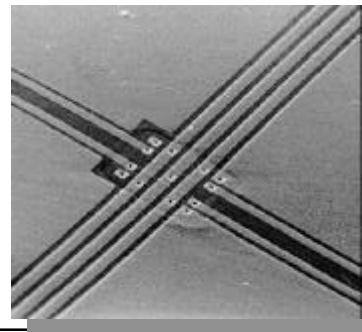
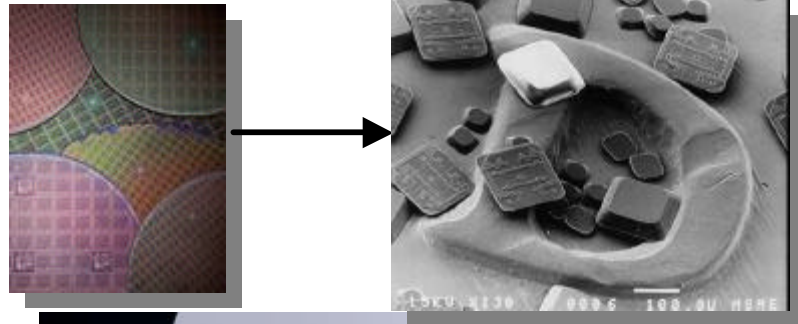
Ink-jet-printed transistor consists of four polymers



Self assembly of display drive electronics ?

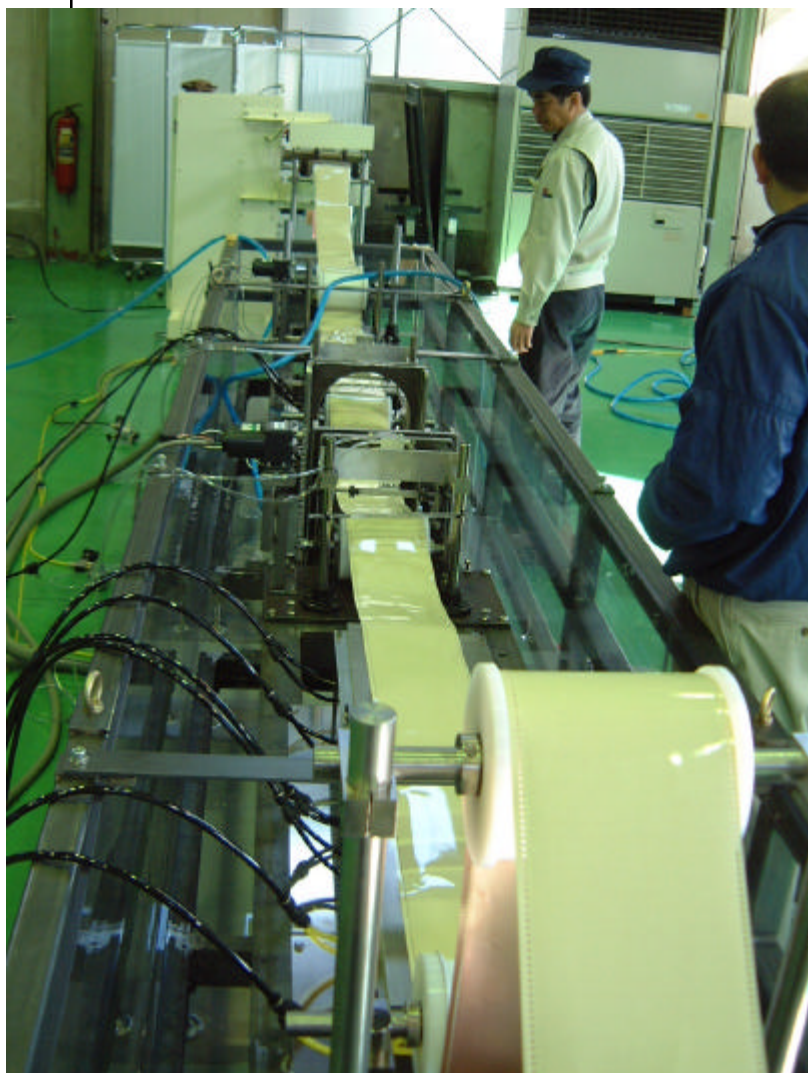
(Used with permission from Alien Technology, Morgan Hill, California)

- Micromachine NanoBlock™ IC's from foundry wafers
- Fluidic Self Assembly to place NanoBlock™ IC's onto a glass or plastic substrate
- Deposit and etch conductor to interconnect circuits

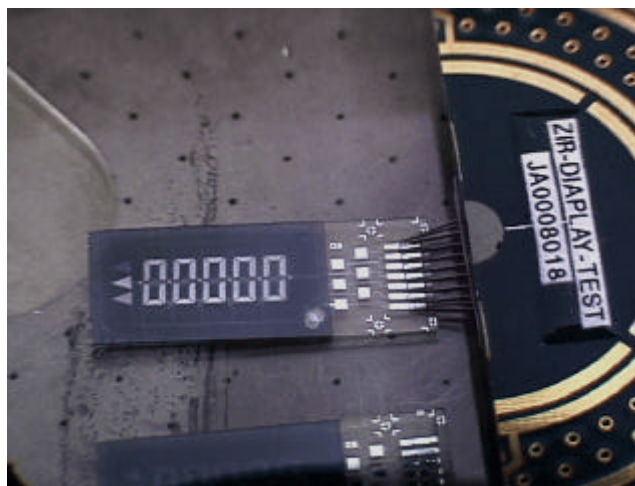


Self assembly of display drive electronics ?

(Part 2, with permission from Alien Technology, Morgan Hill, California)



Roll-to-Roll FSA Machine and an LCD prototype



Skills Chemists Need

(besides chemistry)

- ◆ Electrical engineering
- ◆ Optics
- ◆ Image and color science
- ◆ Device physics
- ◆ Manufacturing technology
- ◆ Japanese language
- ◆ Marketing

