ECE-592/492-S

NC STATE

Soft Electronics:
Organic Electronics & LCDs

Lecture 10

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http://courses.ncsu.edu/ece592s/

Agenda

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- OLED Applications and Markets
  - Displays: AMOLED & PMOLED
  - Flexible/Foldable
  - Lighting
- Materials Research
- Overcoming Problems
- Manufacture & Printing
- Cutting-Edge Research

Web Resources

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Universal Display Corporation
http://www.universaldisplay.com/default.asp?contentID=612

LEDs Magazine
http://www.ledsmagazine.com/magazine/pdf/0706

Kodak OLED
http://www.kodak.com/eknec/PageQuerier.jhtml?pq-path=1473/1683&pq-locale=en_US

OLED Display.net
http://www.oled-display.net/how-works-the-oled-technology

OLED Lighting Overview
http://www.idtechex.com/printedelectronicsworld/articles/who_is_winning_with_oled_lighting_00000605.asp

DuPont OLED Materials
http://www2.dupont.com/Displays/en_US/products_services/oled/oled_materials/index.html

How OLEDs Work
http://electronics.howstuffworks.com/oled.htm

OLED Overview

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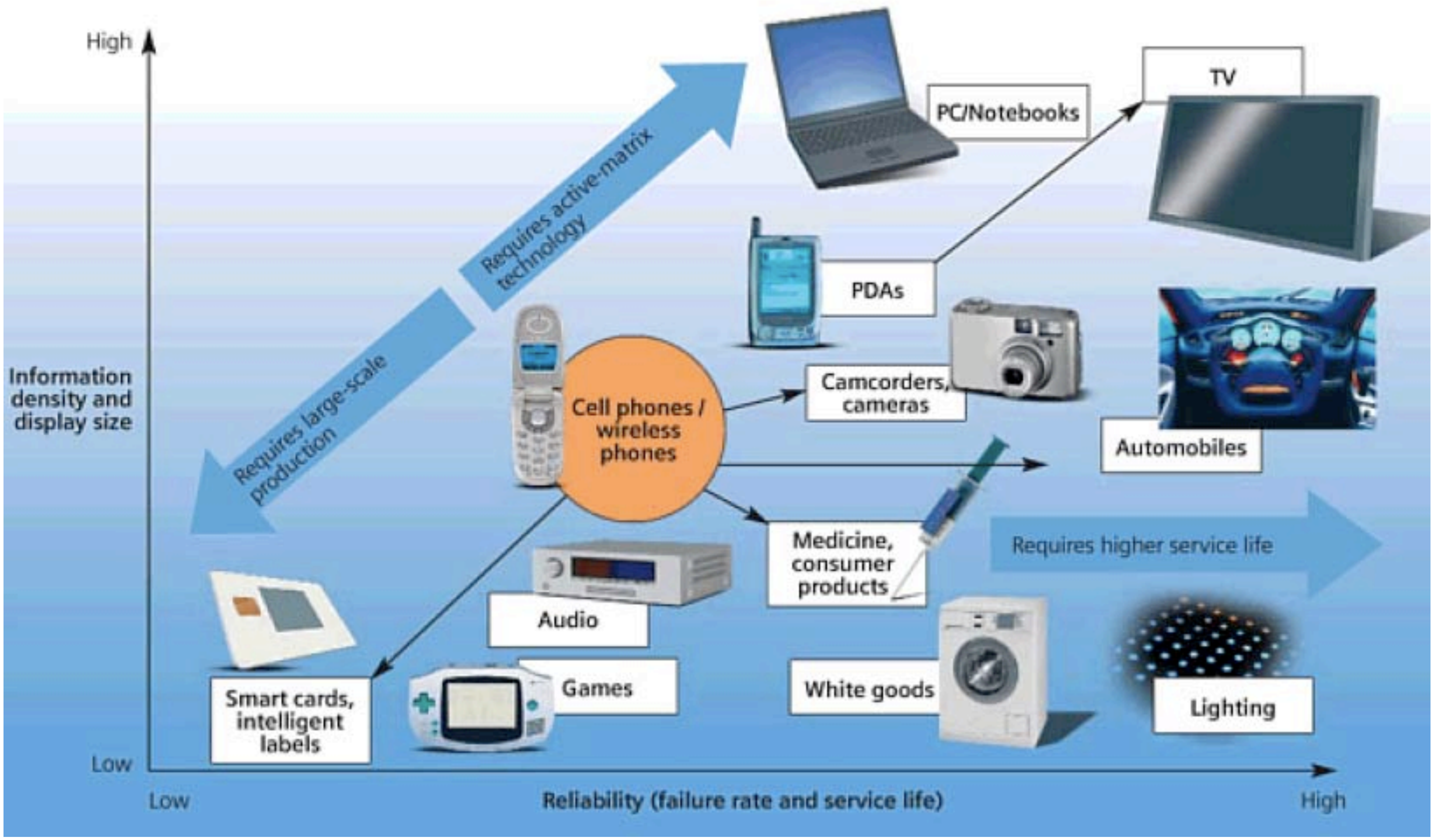
Technical map: OLEDs



OLED Market

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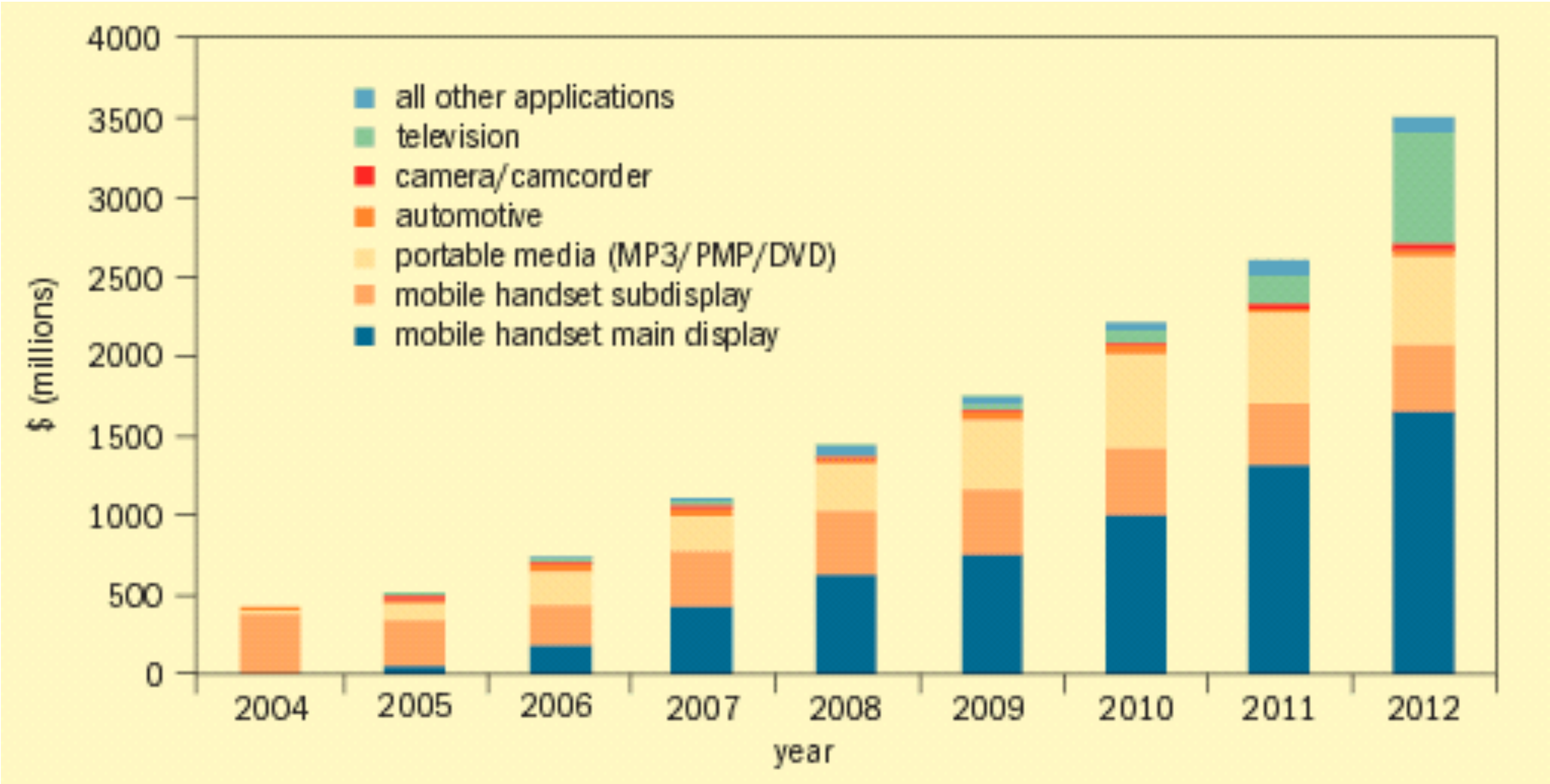
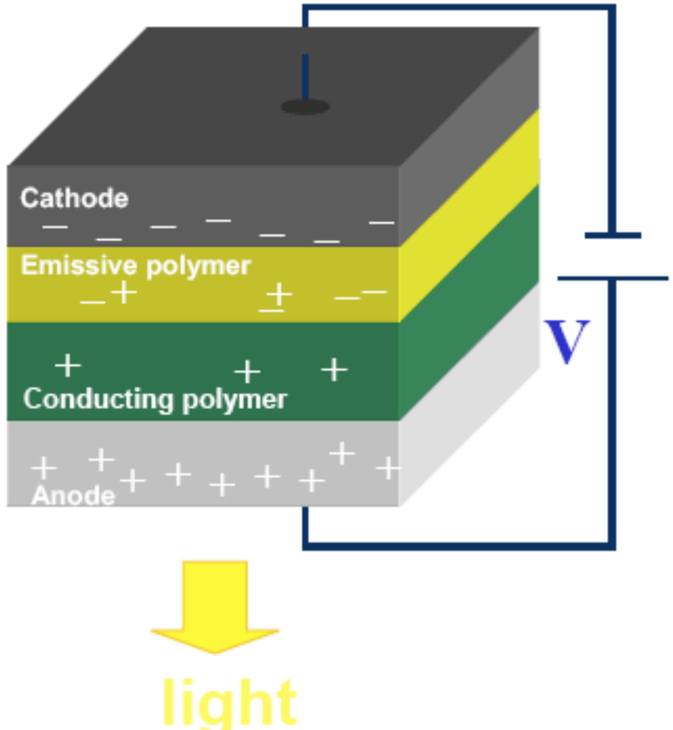


Optics.org 2006

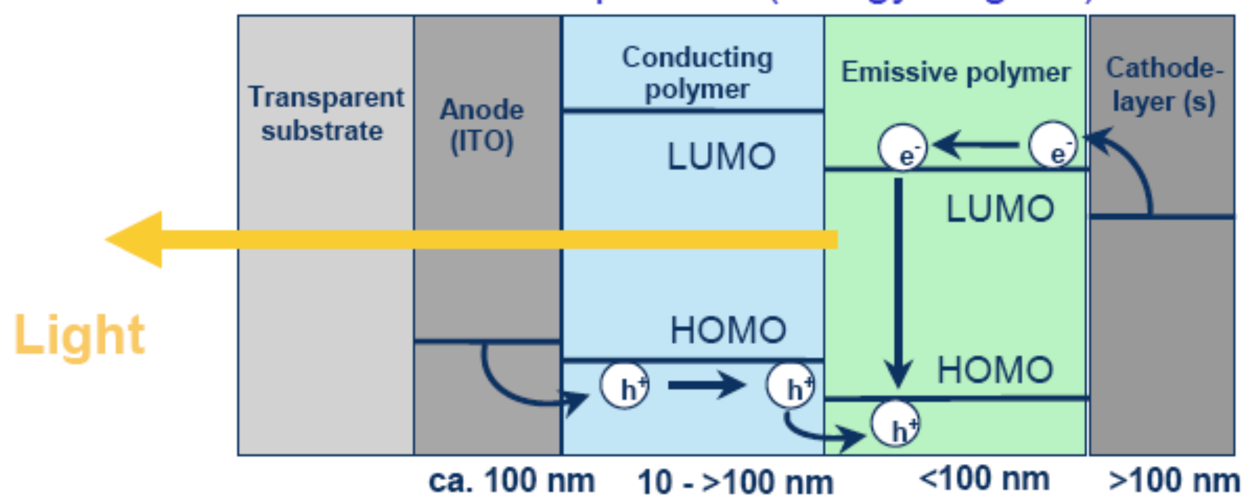
OLED Device Operation Principles



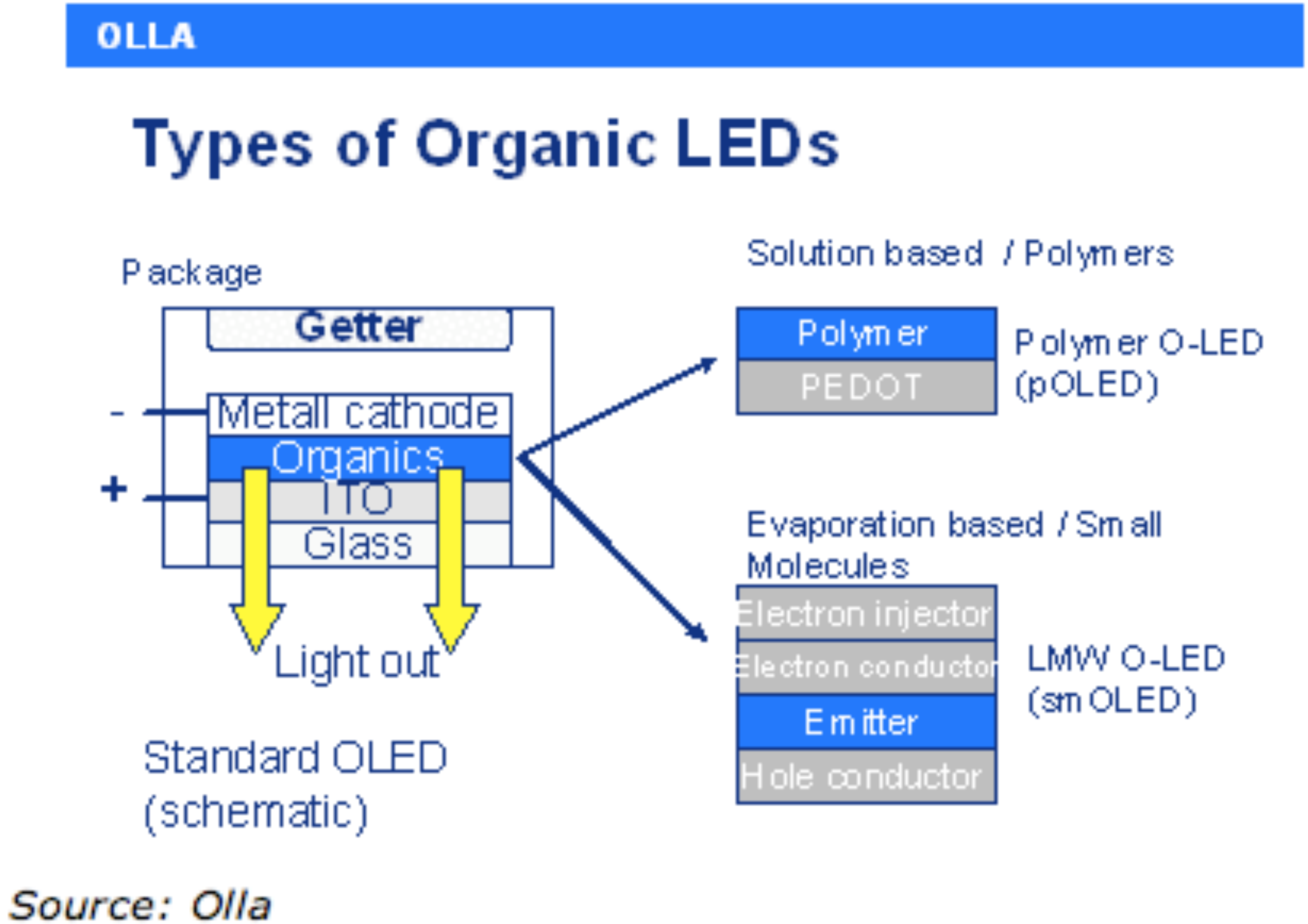
OLEDs rely on organic materials (polymers or small molecules) that give off light when tweaked with an electrical current

- Electrons injected from cathode
- Holes injected from anode
- Transport and radiative recombination of electron hole pairs at the emissive polymer

OLED device operation (energy diagram)



OLED Types


OLLA
Types of Organic LEDs
Package
Getter
Metall cathode
Organics
ITO
Glass
-
+
Light out
Standard OLED
(schematic)
Solution based / Polymers
Polymer
PEDOT
Polymer O-LED
(pOLED)
Evaporation based / Small
Molecules
Electron injector
Electron conductor
Emitter
Hole conductor
LMW O-LED
(smOLED)
Source: Olla

OLED Advantages & Challenges

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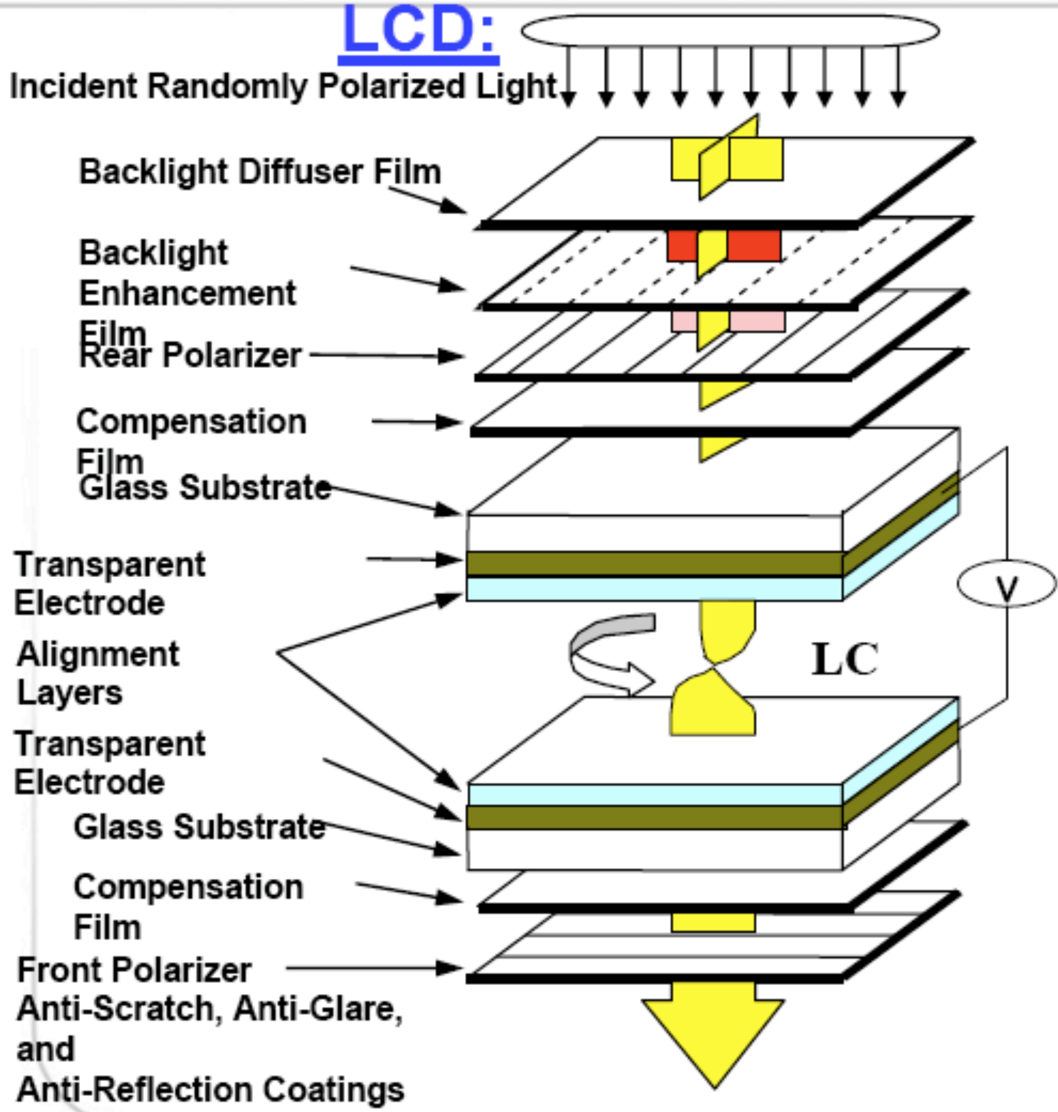
- No Backlight => Thin and Low Power
- Power Only Given to ON Pixel => Efficient
- Faster (100x Faster than LCDs)
- Simple, Cheap Processing

- Current Driven => More complex drive circuitry
- Short Lifetime
- Color Drift
- Size
- Price

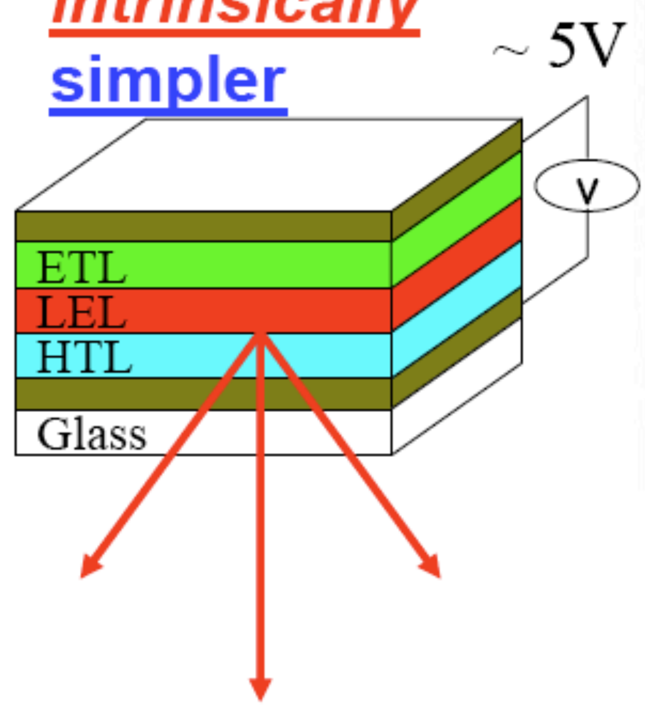
OLED Display *vs.* Liquid Crystal Display

LCD:

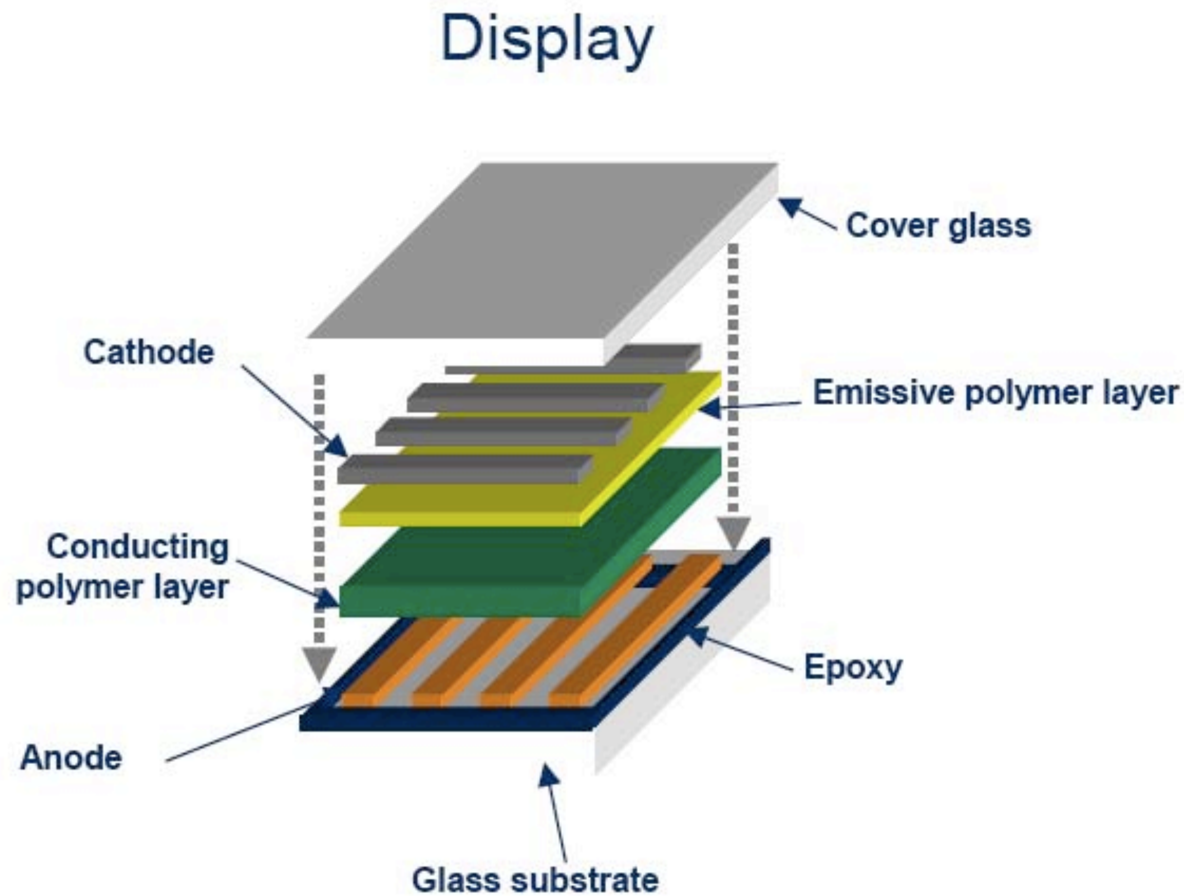


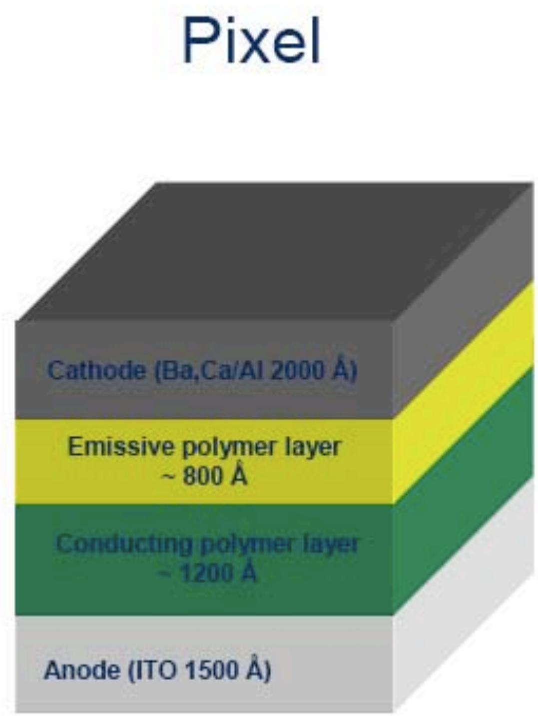
OLED:

Its structure is *intrinsically* simpler



OLED Pixel vs. Display



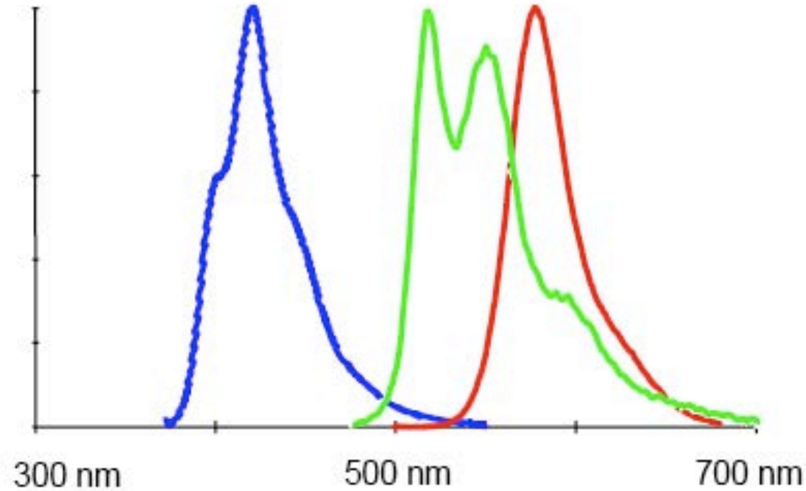


Single pixel structure

Human hair is 200X the thickness of the OLED layers

Multiple emission colors achieved by Covion

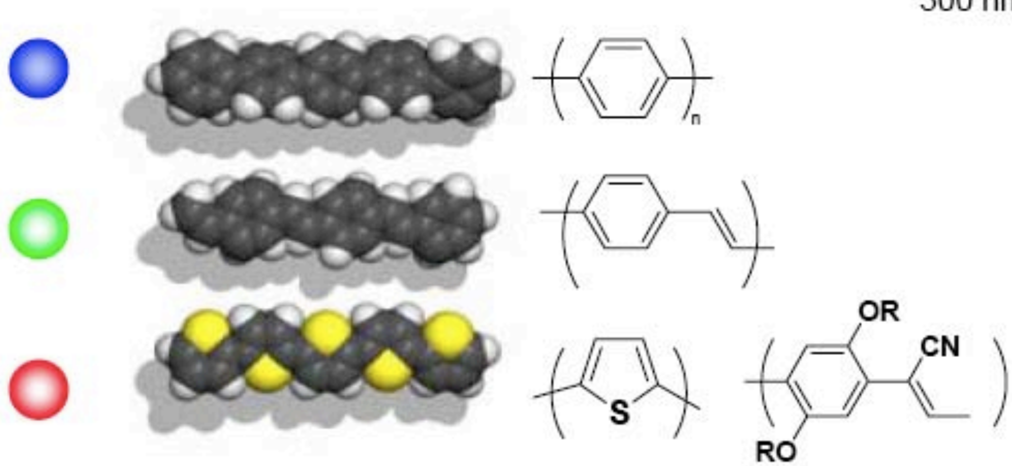
Different emission colors can be obtained with a variety of chemical structures



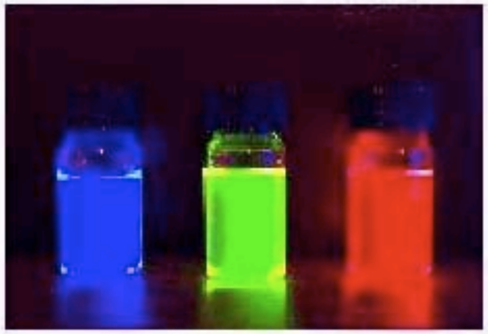
PPP

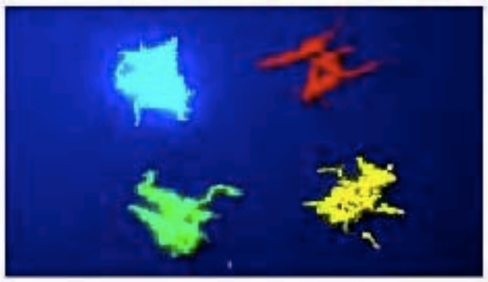
PPV

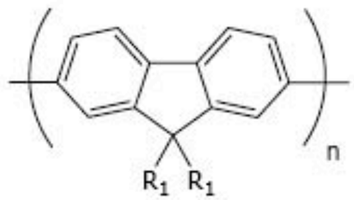
PT or CN-PPV



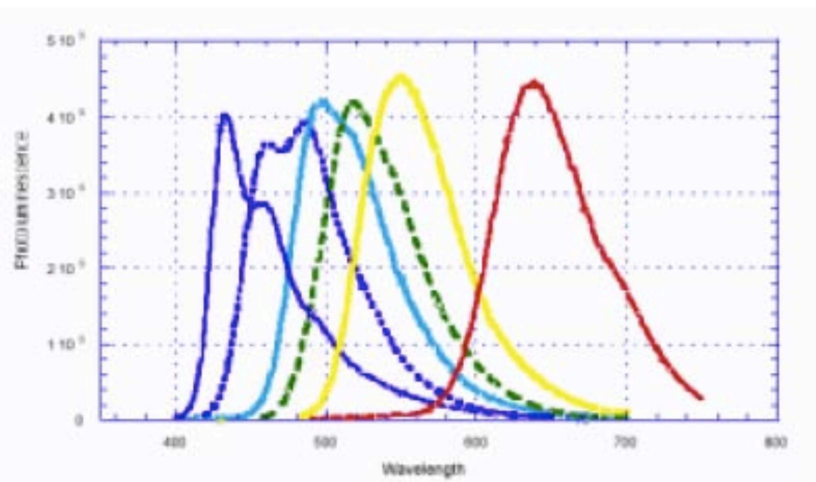
Multiple emission colors achieved by Dow Chemical

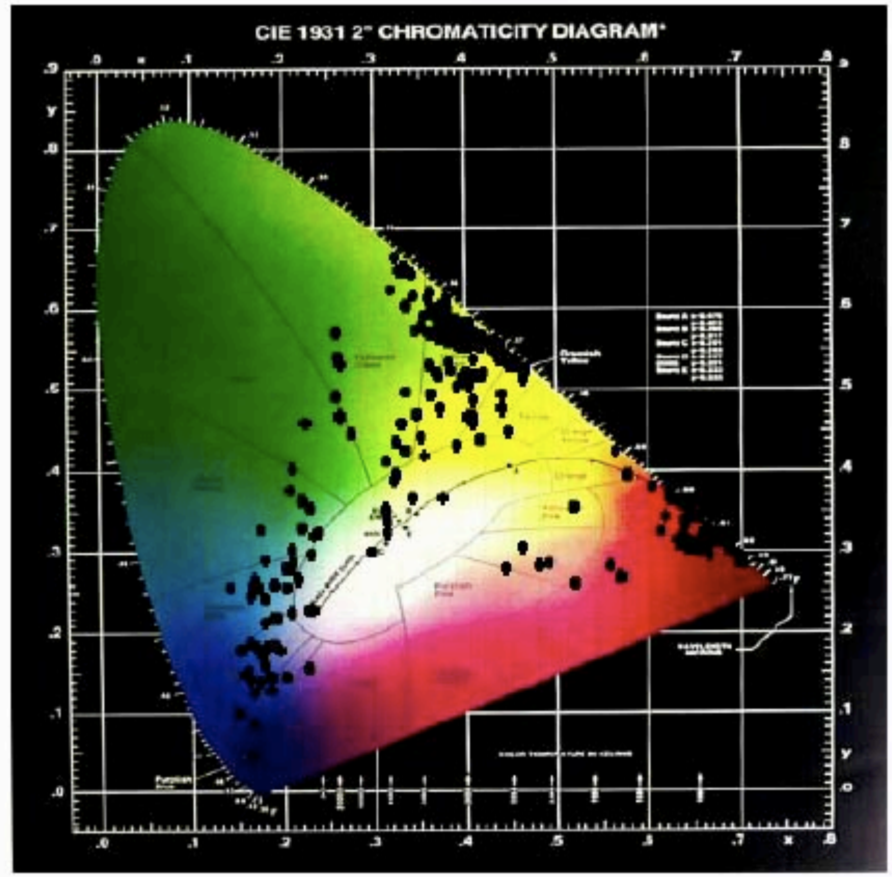






PF





lumation

Dow

Opto Semiconductors OSRAM

OLED Display Advantages

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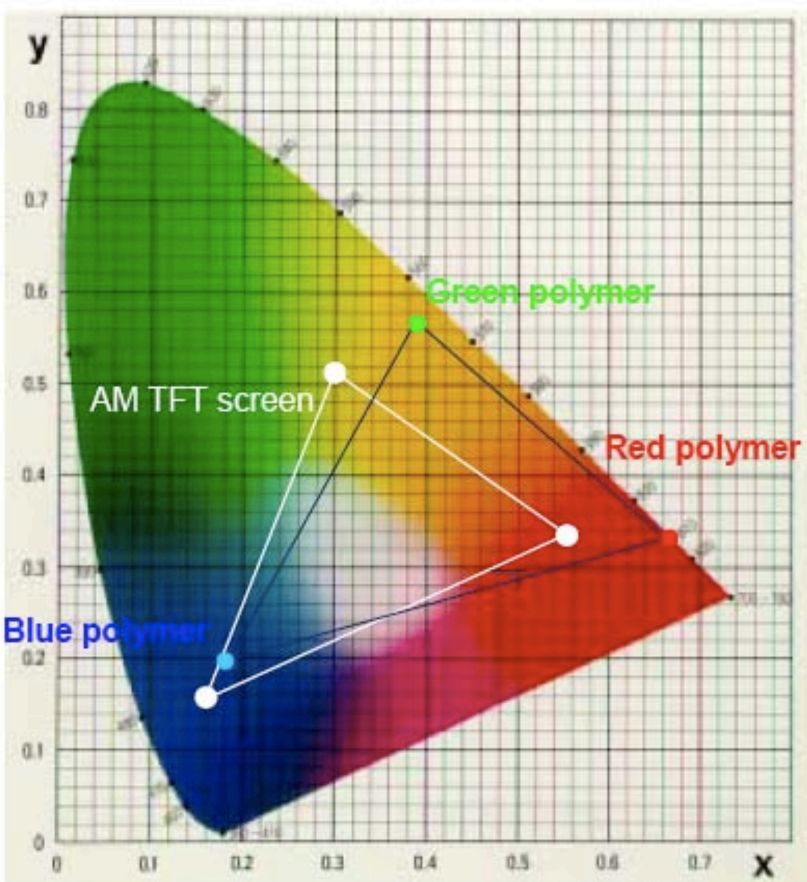
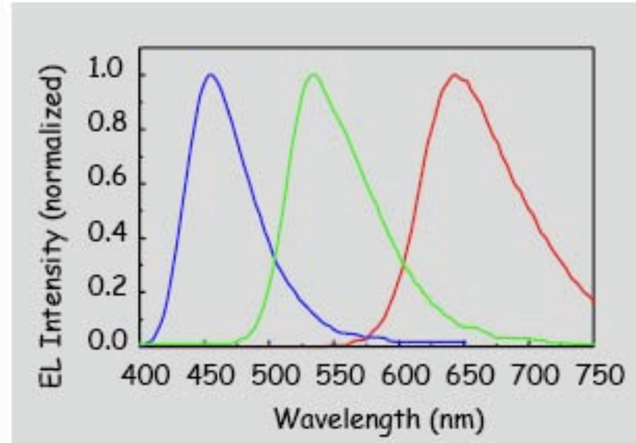
- Wide Color Gamut
- High Contrast
- High Viewing Angle
- Rapid Response Time
- Low Cost (Fabrication)

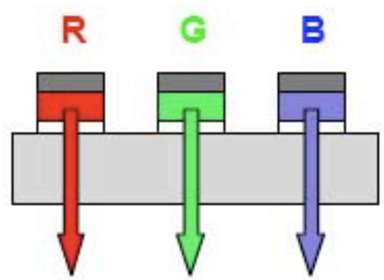
Obtaining a Full Color OLED Display

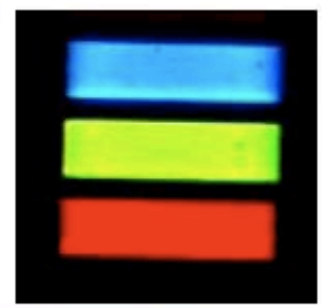




Ink Jet printing **of R,G,B emissive polymers defines the R,G,B subpixels**

(x_R, y_R) (x_G, y_G) (x_B, y_B)

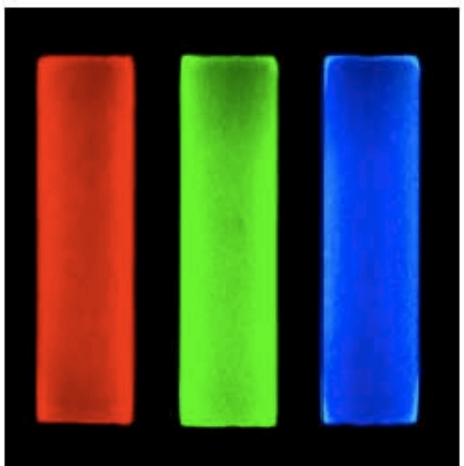




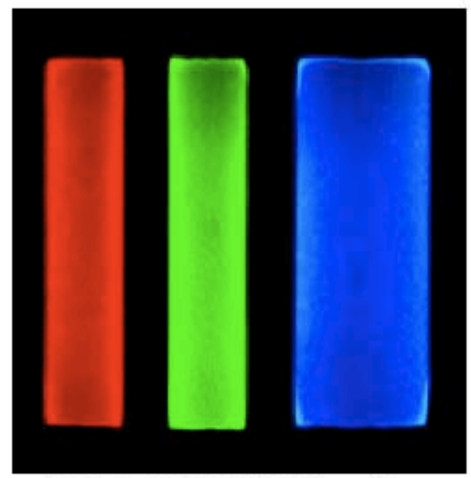
Single pixel

Pixel area scaling

- The performance differences between OLED colours can be balanced by scaling the relative aperture ratios (ARs) of the three colours.
- Pixel area scaling can, in particular, address two areas:
  - System lifetime
    - The relative area of the blue OLED can be increased to increase the system lifetime
  - System efficiency
    - For example, adjusting areas to balance drive voltage can, in particular for passive matrices, reduce the driver power consumption



1:1:1 RGB ratio



0.8:0.8:1.4 RGB ratio

OLED Televisions

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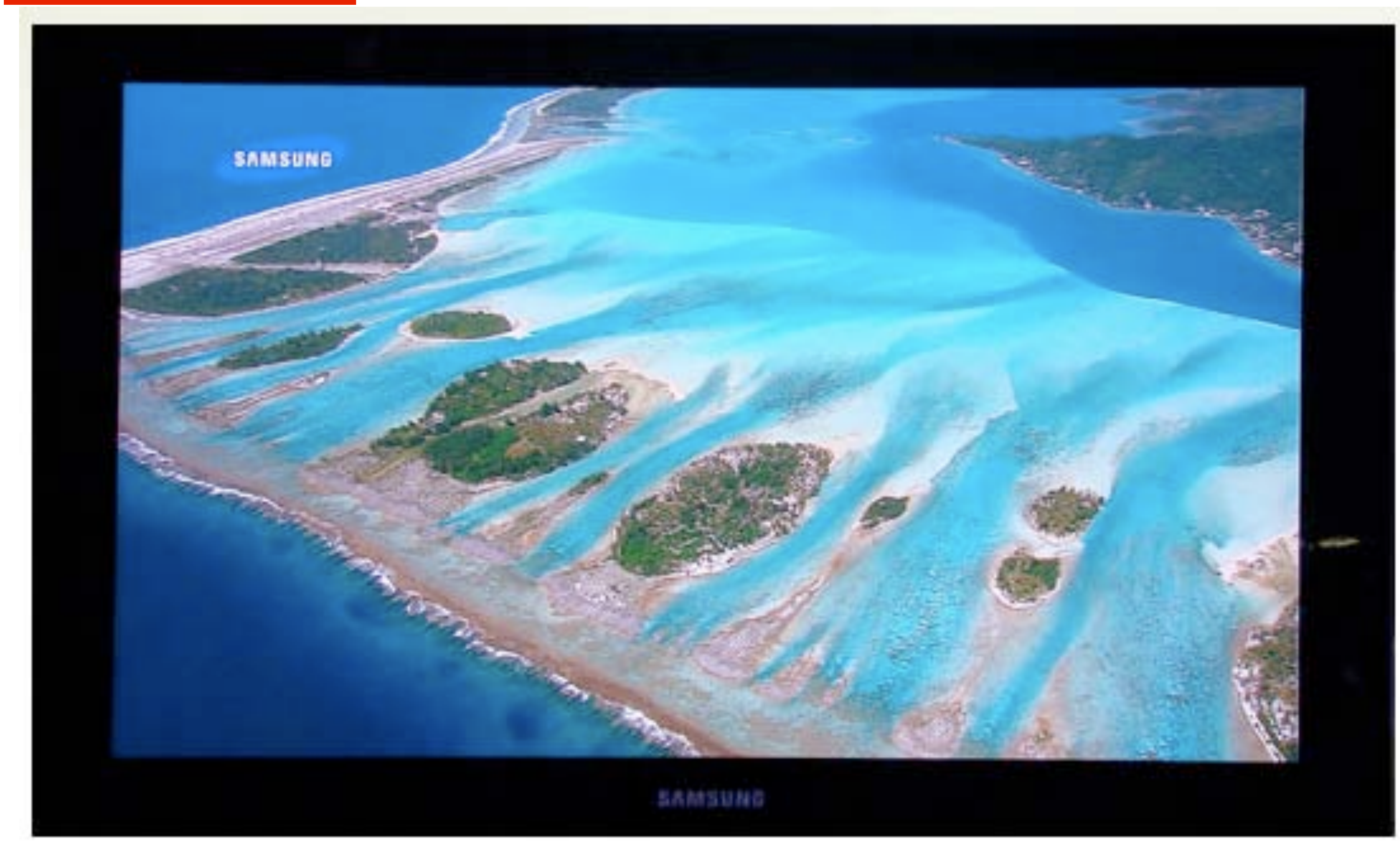
- Uses less power than regular TV
  - LCD Halves the power of CRT
  - OLED can reduce 40% more
- Super thin (less than 3cm)
- Can appear “three-dimensional”

Samsung 31” AMOLED TV

NC STATE

Launched at 2008 CES



Inhabitat.com 2008

Sony 11” AMOLED TV

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- First available in US ($2500)
- 3mm Thick
- Contrast Ratio 1,000,000:1

Sony OLED @ CES ‘08

http://link.brightcove.com/services/link/bcpid1381642463/bclid1381640499/bctid1379594969

Physorg.com 2008

Oled-info.com 2008

Other AMOLED Devices

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Samsung AMOLED Phone Display

- <1mm thick [Current are 2-3mm]
- 2 screens create a 1.61mm phone [Current is 6.9mm LCD]

Mobilementalism.com 2008

Canon Migrating to All Products

- Focus on Brightness, Color Accuracy, Low Power
- For Cameras, Camcorders, and InkJet Printers

Canon.com 2008

http://www.oled-display.net/what-is-amoled

AMOLED

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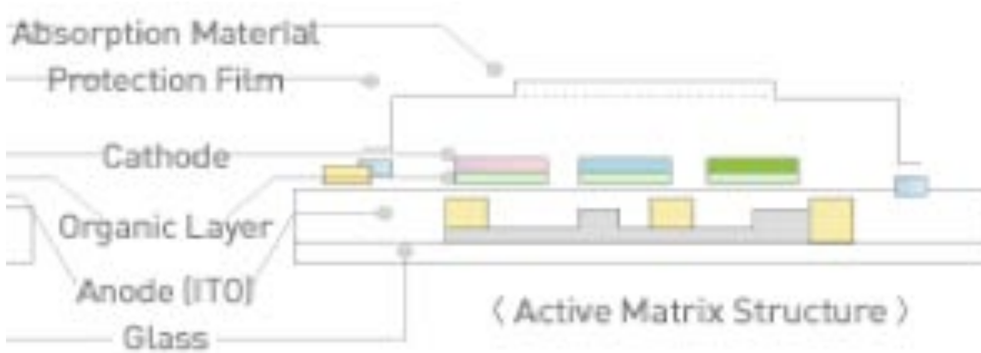
- Stack Cathode, Organic, and Anode Layers on the Circuitry Layer
- Pixels defined by a continuous dot pattern and activated directly via TFT backplane (poly-Si or a-Si -- preferred but Vt shift)
- Pixels turned on and off 3x faster than speed of motion picture -- ideal for fluid, full-motion video
- Bright
- Thin
- Self-Illuminating
- Wide Viewing Angle
- Less circuitry=Packaging can be thinner
- High cost, for now



Oled-display.net 2008

AMOLED

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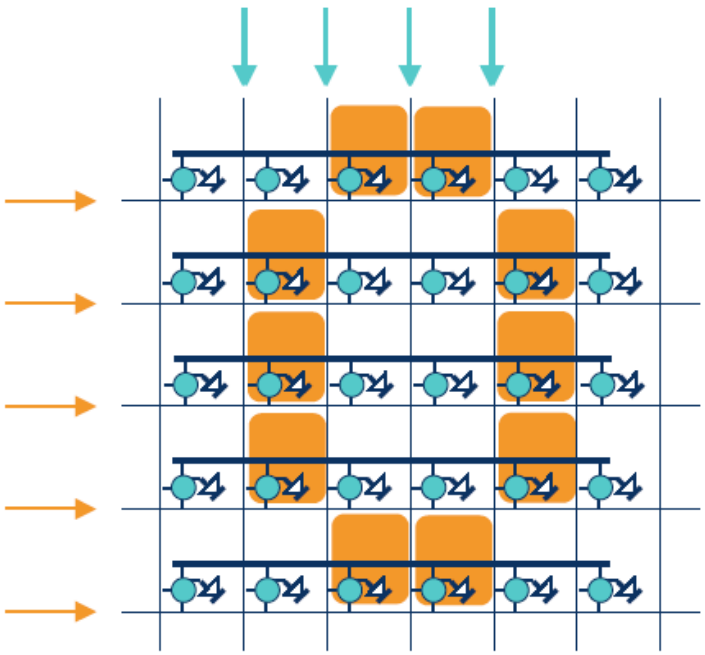
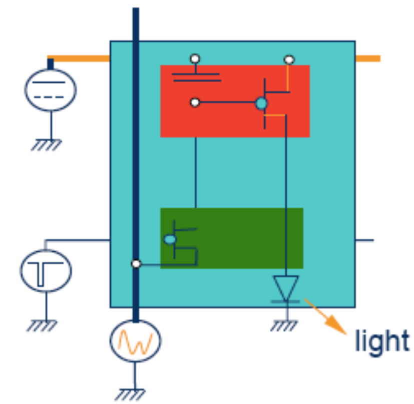
Active Matrix Addressing

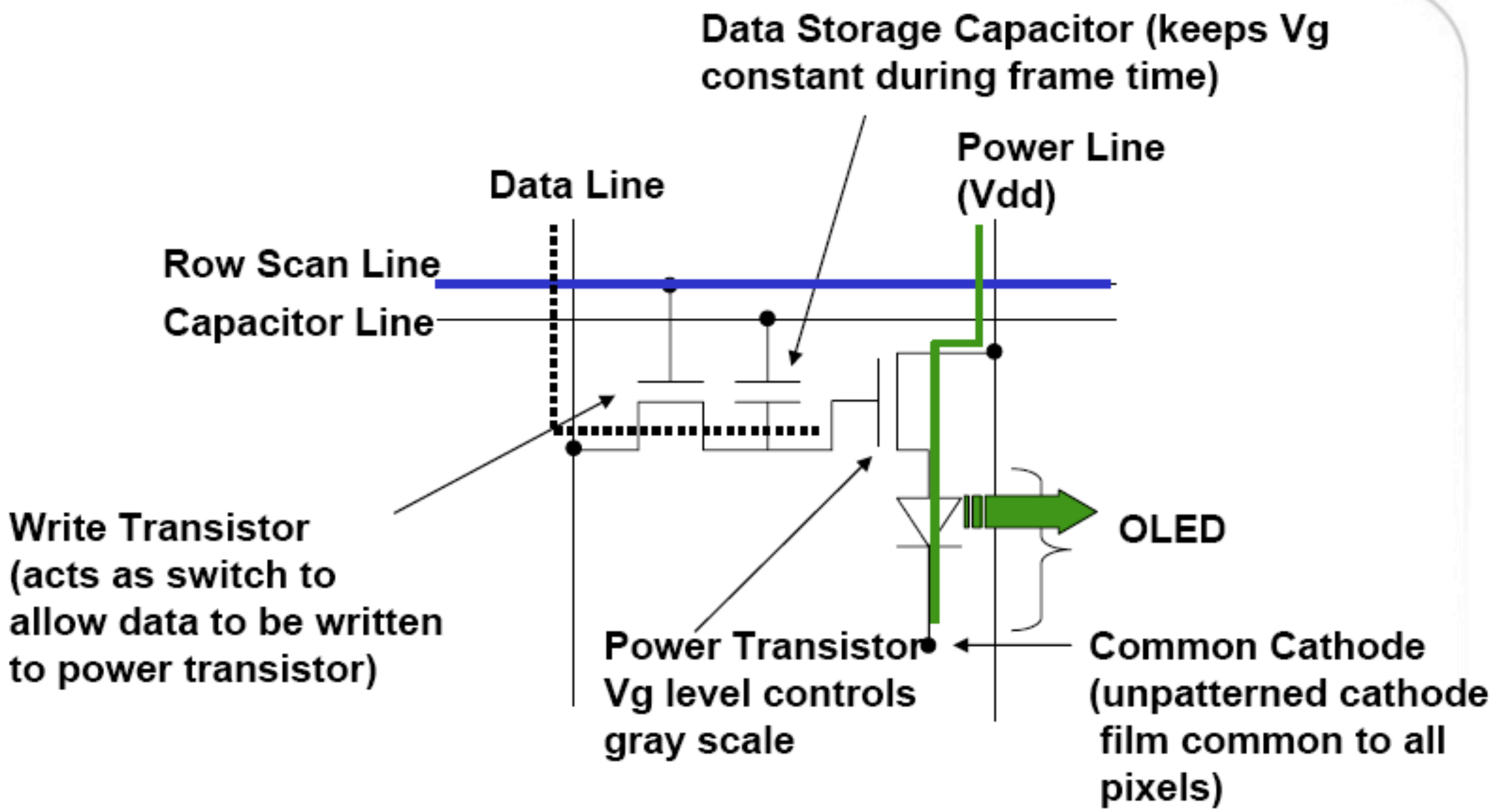




- Place a switching TFT at each pixel
- Selected pixel stays on until next refresh cycle (pixels are switched and shine continuously)
- Common cathode
- Unlimited addressed lines

AMOLED

Two-Transistor AMOLED Design

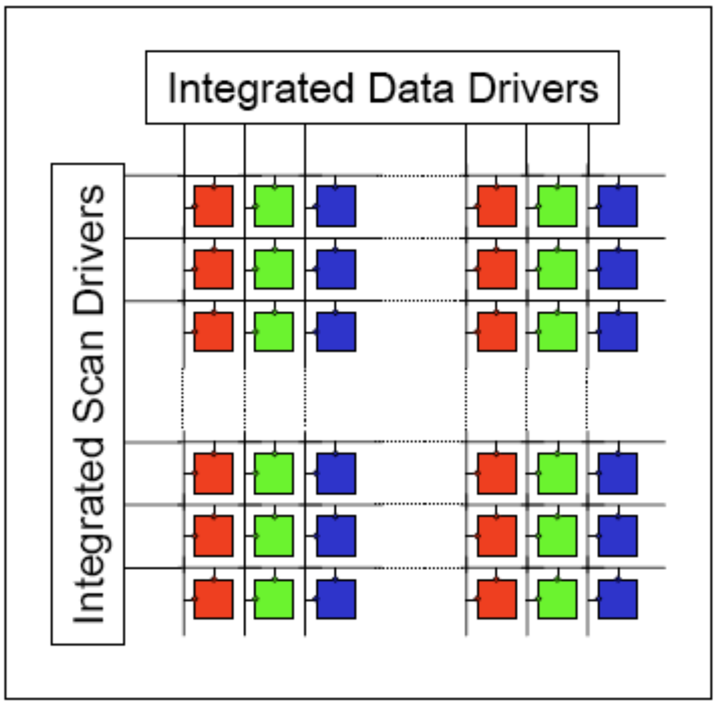


Data Line (applies voltage to power transistor gate)

AMOLED

Typical AMOLED Display Designs – Amorphous and Poly-Silicon

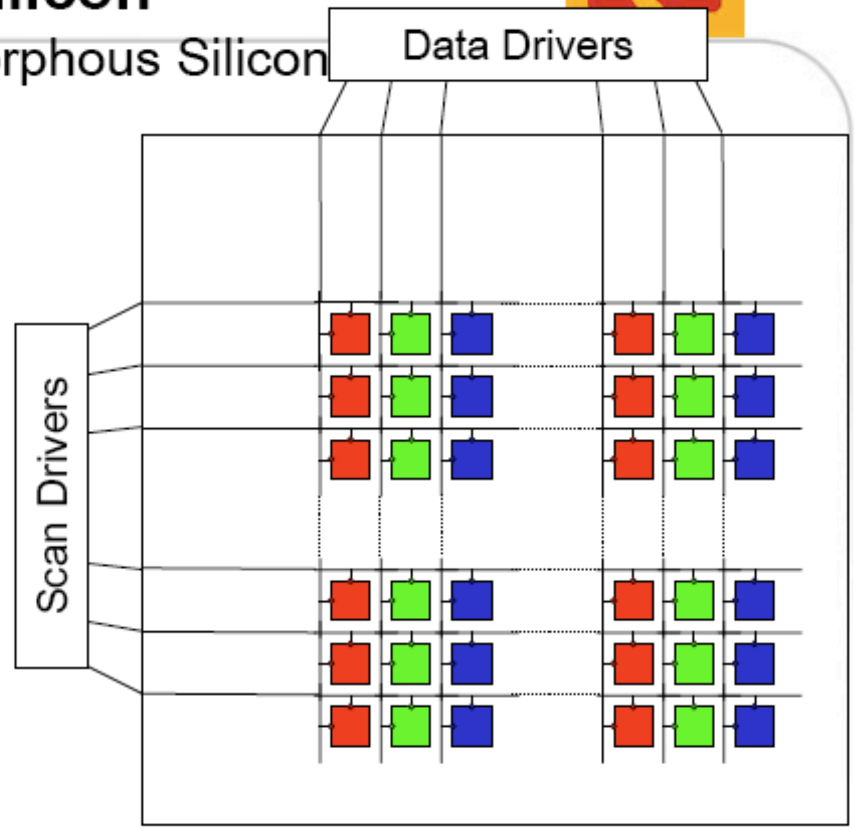
Poly Silicon



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

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

Amorphous Silicon



- Low mobility a-Si insufficient for integrated drivers
- Many connections to glass edge (Rows + Columns)
- External drivers = increases display module size
- More uniform (good short range order for a-Si)
- Enabled by high-efficiency emitters (Triplets)

- *Li et al, Proc. Of SID, p. 14 (2003)*

PMOLED

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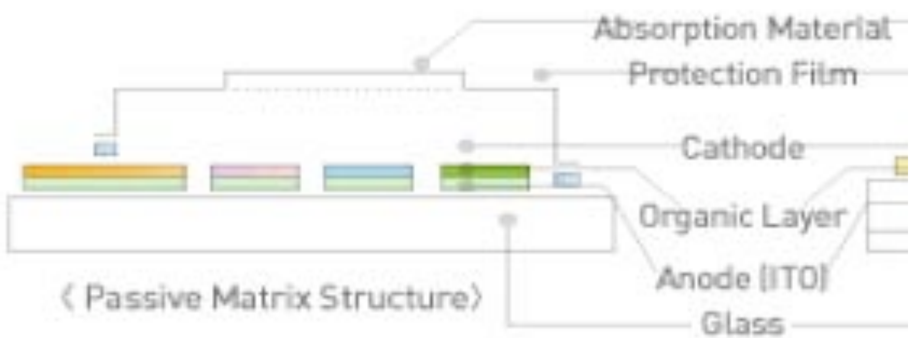
- Grid: Columns of Organic and Cathode Materials / Rows of Anode Materials
- Pixels defined by intersection of rows and columns
- Easier and Cheaper to Manufacture
- BUT
  - Expensive, current-sourced drive electronics
  - Power Consumption much higher than a comparable AMOLED
- Most practical in 2”-3” Diagonal or 100 Rows (Cell Phones, MP3, etc)

- Dialog semiconductor has SmartXtend -new family of display drivers- used in mobile devices - PMOLED based - lower cost, same video quality and performace - will extend lifetime - reduces peak current up to 30% and power consumption by 30% compared to conventional PM (oled-info.com 2008)



Oled-display.net 2008

PMOLED

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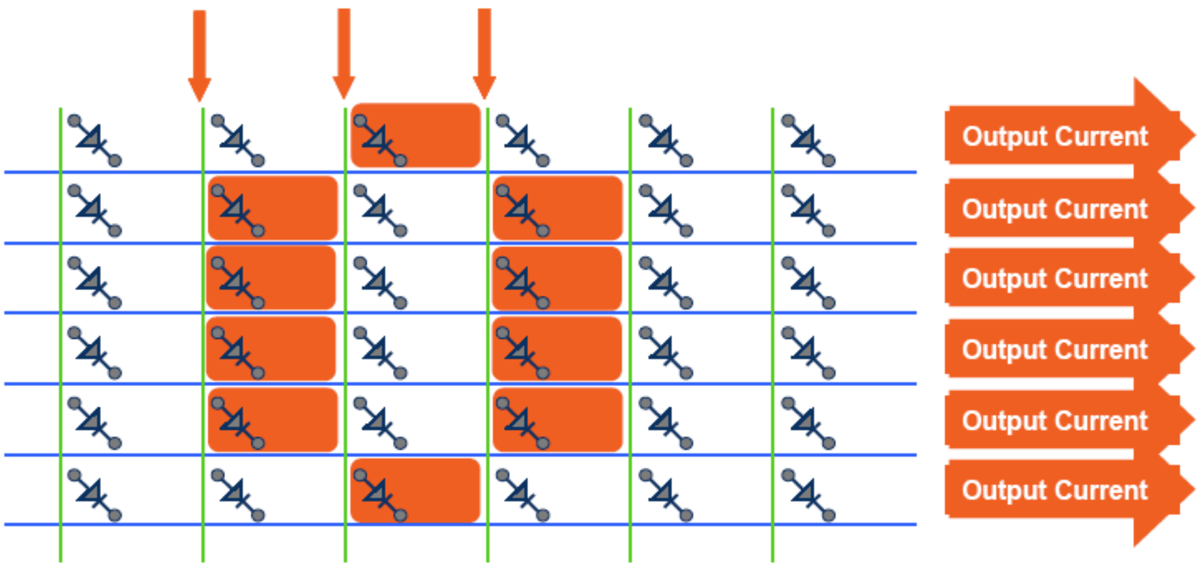
Passive Matrix Addressing



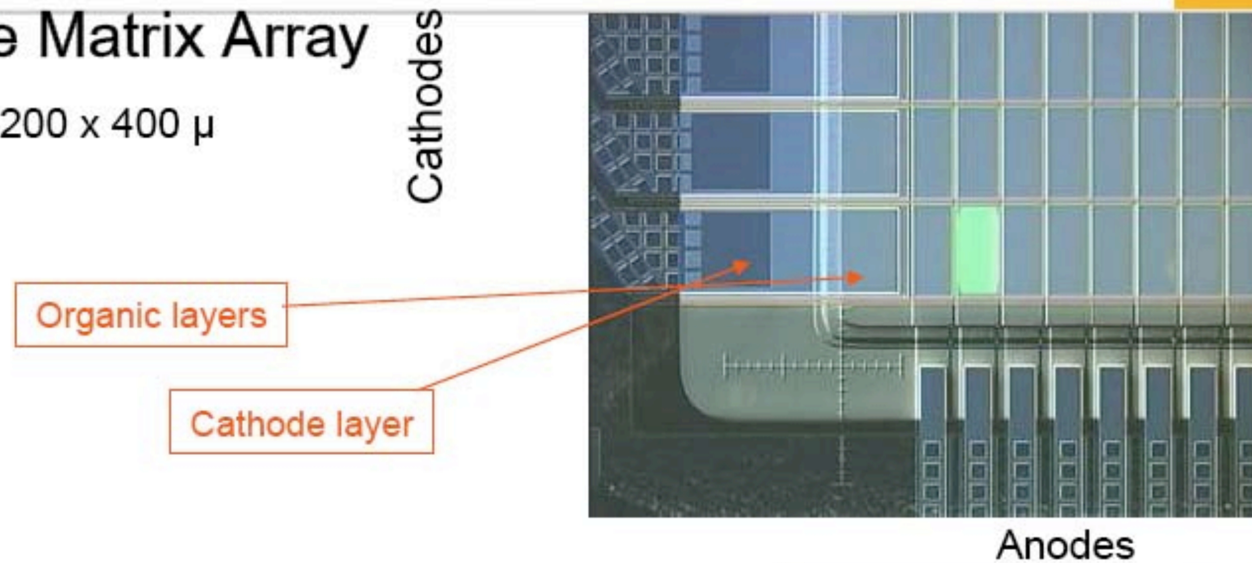
Courtesy of Philips Electronics

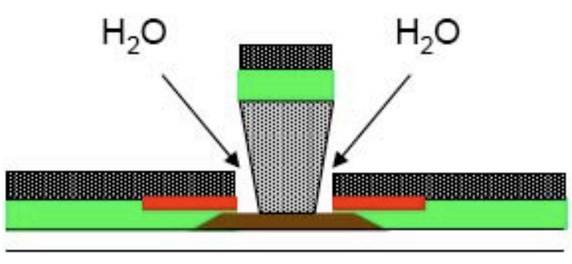
- Line by line multiplex scanning
- Duration of addressing is 1/mux rate
- Pixel pulsed luminance = mux rate times average luminance
  - if 64 rows then pixel L=6400 nits for an average of 100 nits
- Limited addressed lines

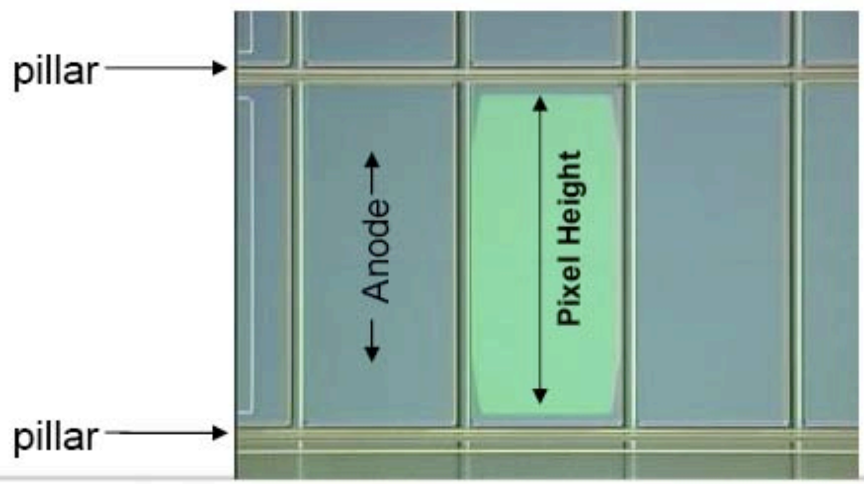
PMOLED

Passive Matrix Array

Pixel size: 200 x 400 µ







OLED Display Market

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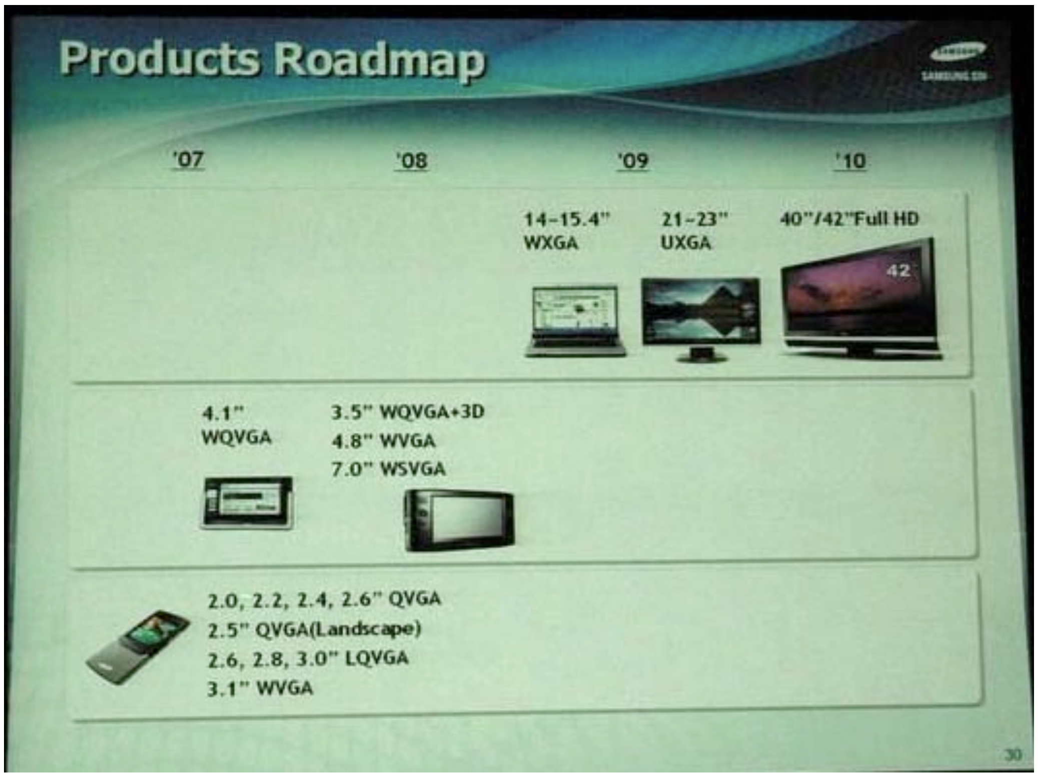
Samsung's View (Oct 07)



- OLED Panel Market grows to $3.7 Billion in 2010
- Will output 3 Million 2" Units per Month in 2008 (currently 2 Mil)
- 4.1" Panels in Ultra-Mobile PCs
- 14"-21" Panels in 2009
- 40"-42" HD Panels in 2010
- Light Emitting Efficiency is Doubling Every Year
- Currently 50 lm/W
- Currently 20k Hours before Luminance Halves (LCDs 60k)
- Renders > 80 colors

Nikkei Business Publications, Inc. 2007

OLED Display Market

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Other Views (07 - 08)

- Flat Panel Industry -- $57 Billion in 2006 (TFT-LCD 75%)
- OLED Panel Industry earned $475 Million in 2006 (4%)
- Market will reach $1.4 Billion by 2013 (Frost & Sullivan - Mktng)

•Sony does not see rapid growth in production of OLED TVs in the near future (Jan 31 2008, CFO Oneda)

•Panasonic says we won't see retail OLED TVs for a few years yet, 2012, need special facility for large sizes (Jan 30 2008, President Sakamoto)

•Other companies cranking out the prototypes (TMDisplay 20.8", Sony 27")

•Toshiba mass production in 2009/2010

OLED Display Market

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What can Prevent OLED Growth?

- Declining Prices of LCD Panels (Frost & Sullivan)
- Must Increase Yield & Decrease Cost of AMOLED
- Must Enhance Efficiency & Product Life

OLED Display Challenges

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- Product Life Expectancy
  - –TVs & Monitors 50,000 hrs or more (20+ yrs)
  - –OLEDS much less
- Large Display Size
  - –Amorphous-Si…Less stable; Low mobility…BUT
  - –Poly-Si…Great mobility; Vt shifts…BUT

Flexible Displays

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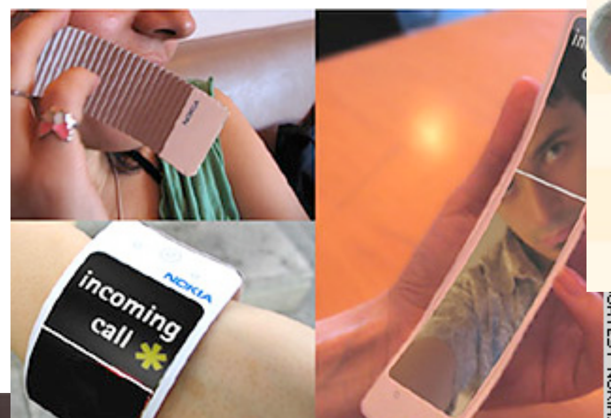

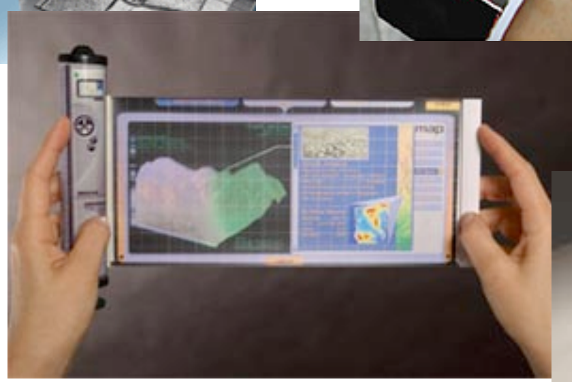

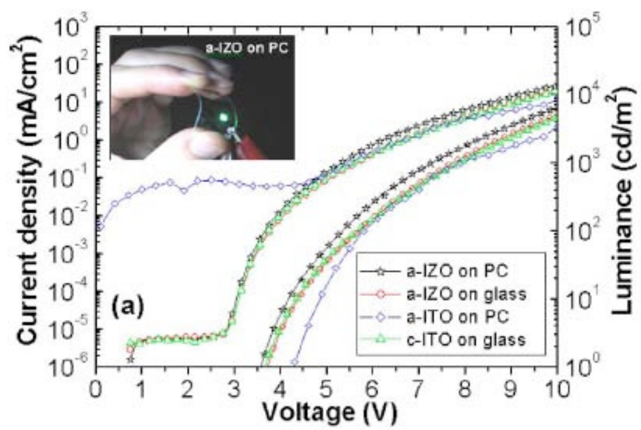

Kang 2007

Flexible Displays

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- Wrist-mounted, featherweight, rugged PDAs
- Wearable, form-fitting, electronic displays
- Conformed, high-contrast automotive instrument and windshield displays
- Heads-up instrumentation for aircraft and automobiles
- Roll-up, electronic, daily-refreshable newspapers
- Ultra-lightweight, wall-size television monitors
- Office windows, walls and partitions that double as computer screens
- Color-changing lighting panels and light walls for home and office
- Computer-controlled, electronic shelf pricing for supermarkets and retail stores

Flexible OLEDs

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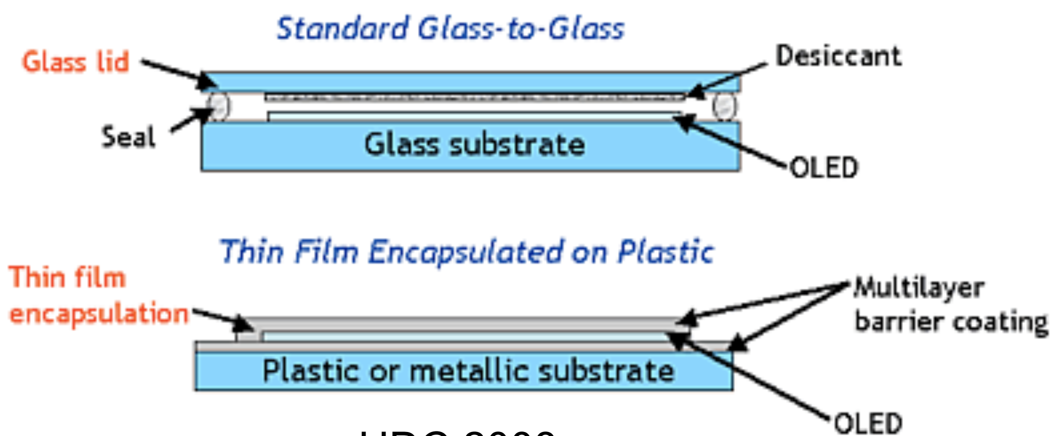
FOLEDS:

- Robust Flexible Substrates
- Conductive Transparent Oxides / Polymers
- Electro-Optic and Reflecting Materials
- Inorganic and Organic Electronics
- Packaging / Barrier Layers
- Processing / Fabrication



UDC 2008

http://www.oled-display.net/flexible-oled

FOLED

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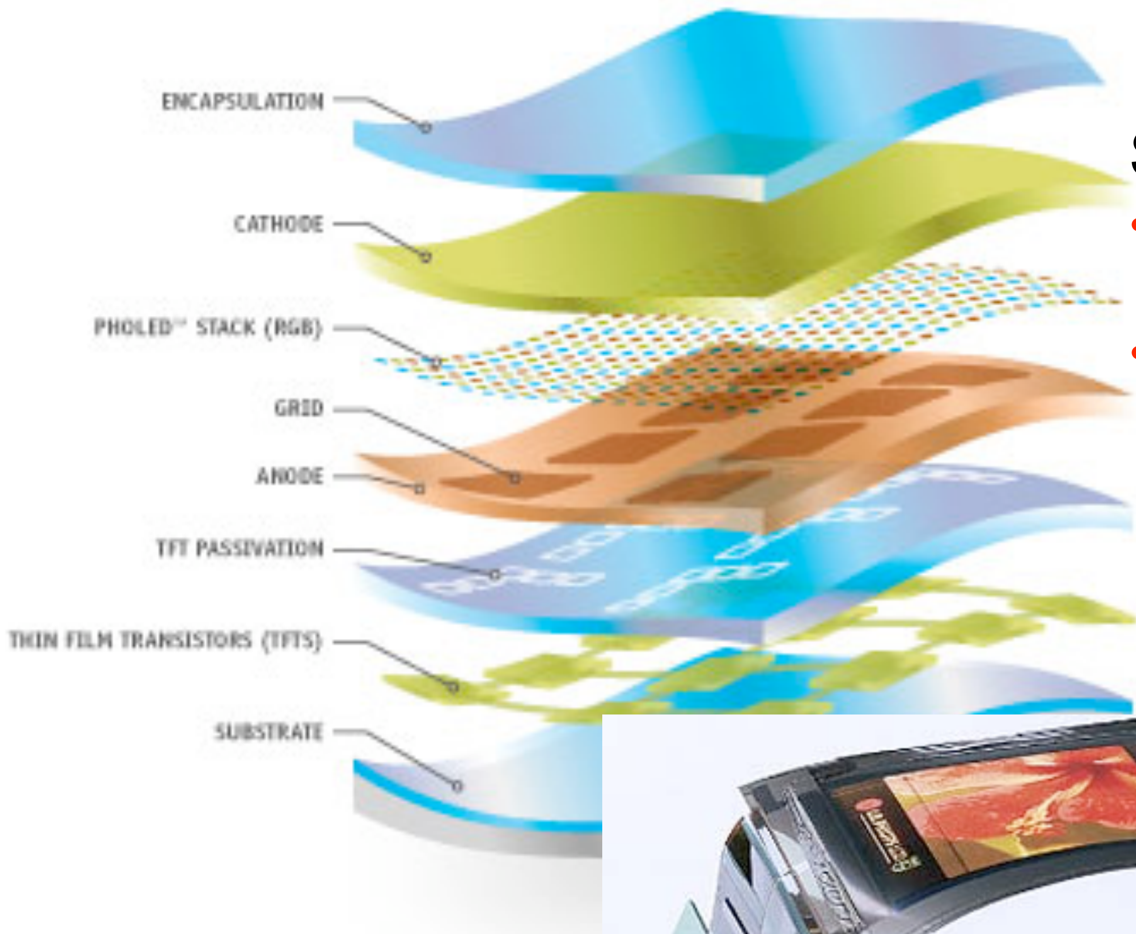

UDC 2008

Some Issues "Overcome"
- Substrate
  (Plastics & Metallic Foils)
- Encapsulation
  (Coatings & Laminations)

F/OLED Device Degradation

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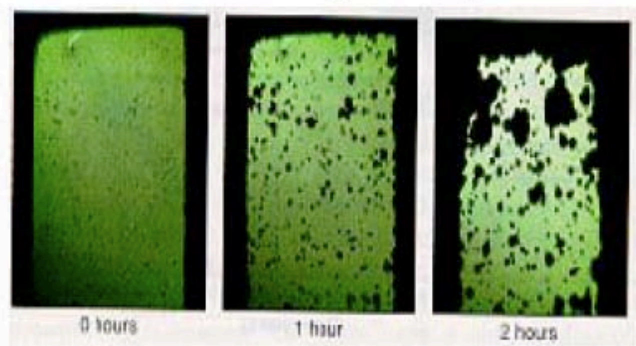
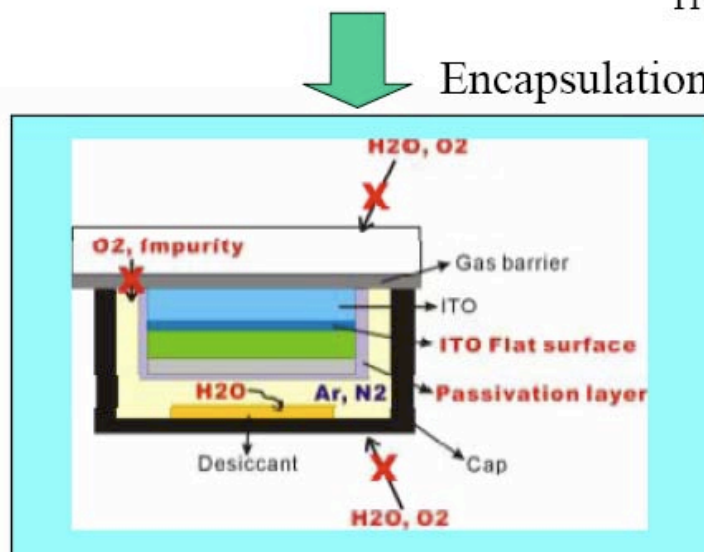
Change of Electroluminescence depending on time under humid atmosphere

OLED devices



ITO/TPD/Alq3+Quinacridone/Mg

Encapsulation



- **Water Vapor** creates nonconductive regions on electrodes through hydrolysis
- Packaging must keep permeation rate to $<10^{-6}$ g/m^2
- **Oxygen** will oxidize (rust) the cathode,…
- Packaging should keep oxygen transmission rate ideally $<10^{-5}$cm^3/m^2/day/atm

Flexible AMOLED

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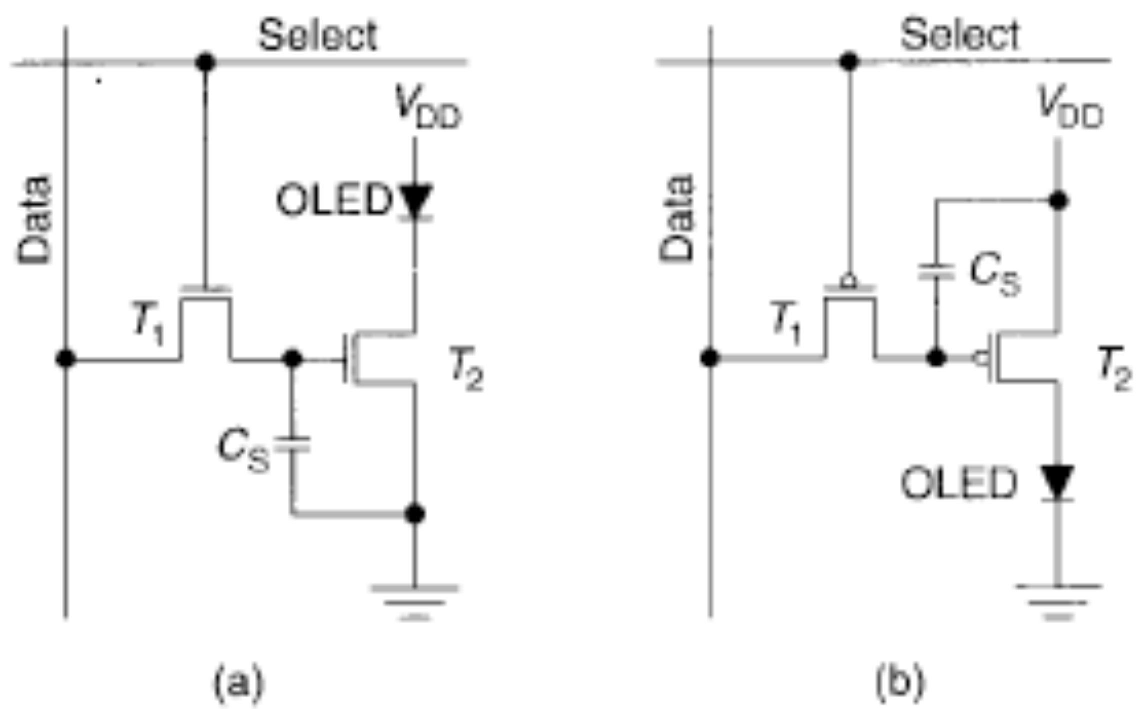
- On a *transparent flexible* surface, *ITO and TFT circuitry* must be patterned
- **TFT Circuit must** continuously run an OLED pixel throughout the frame period with uniform emission across the whole display for a given signal level
- **Minimum of 2 TFTs needed for each pixel:** Select , Drive



Crawford 2005

Flexible AMOLED Issues

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- Want to bias T_2 in saturation where it will act as a constant current source:

$$I_D = \mu_{FET} C_d \frac{W}{2L}(V_{GS} - V_t)^2$$

- Nonuniform Illumanance arises if variations in pixel-to-pixel mobility or threshold voltage

- Other issues include *minimum mobility requirements, low leakage in T_1 to prevent drop in C_s, etc.*

Flexible ITO Issues

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- ITO layer can become brittle and crack
- ITO life can be elongated by
  - *reducing the thickness*
  - *using a high modulus but nonbrittle undercoat*
  - *introduce compressive stress in the ITO layer*

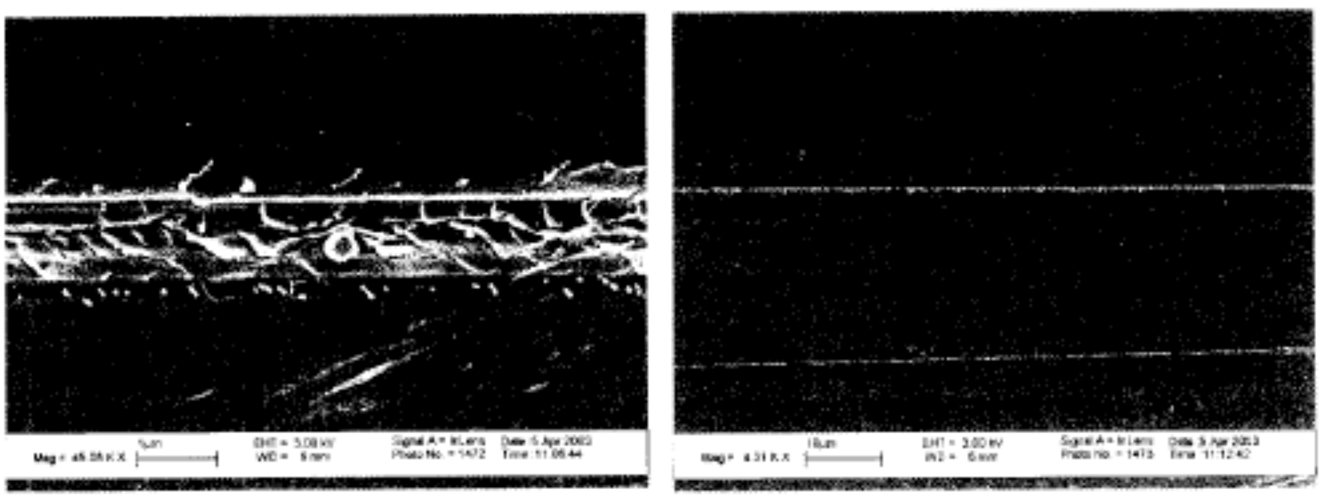

Figure 9.10 Scanning electron micrograph of ITO-coated PET substrate showing parallel cracks created after 100 000 cycles of fatigue test. Resolution 1 μm (left), 10 μm (right)

Crawford 2005

OLED Lighting

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- ➢Incandescent ~ 15 lm/W
- ➢Fluorescent ~ 50 lm/W

Source: Philips & Merck Lighting

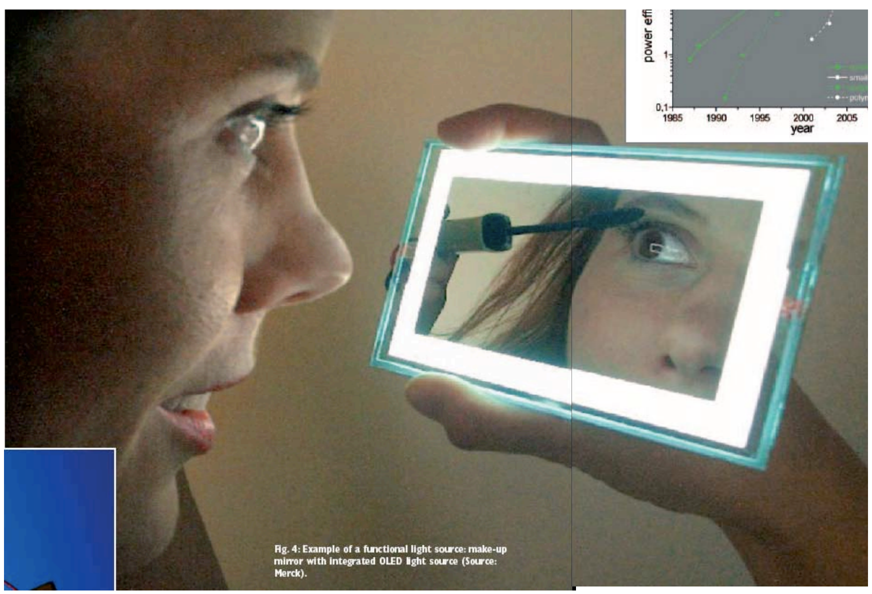


Fig. 4: Example of a functional light source: make-up mirror with integrated OLED light source (Source: Merck).

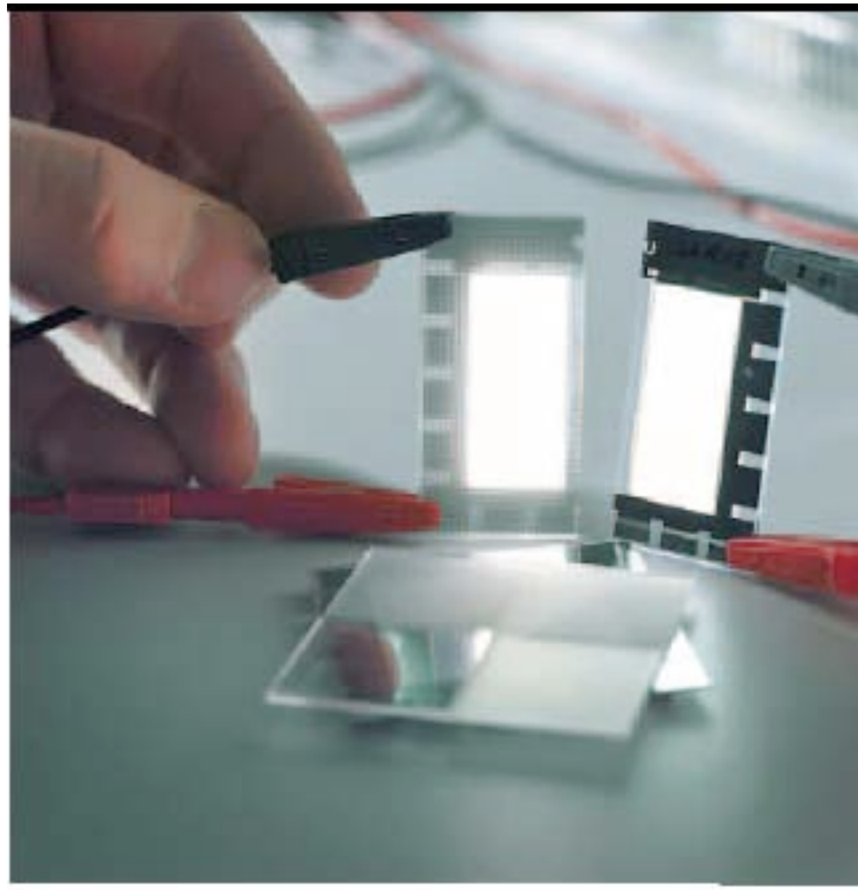
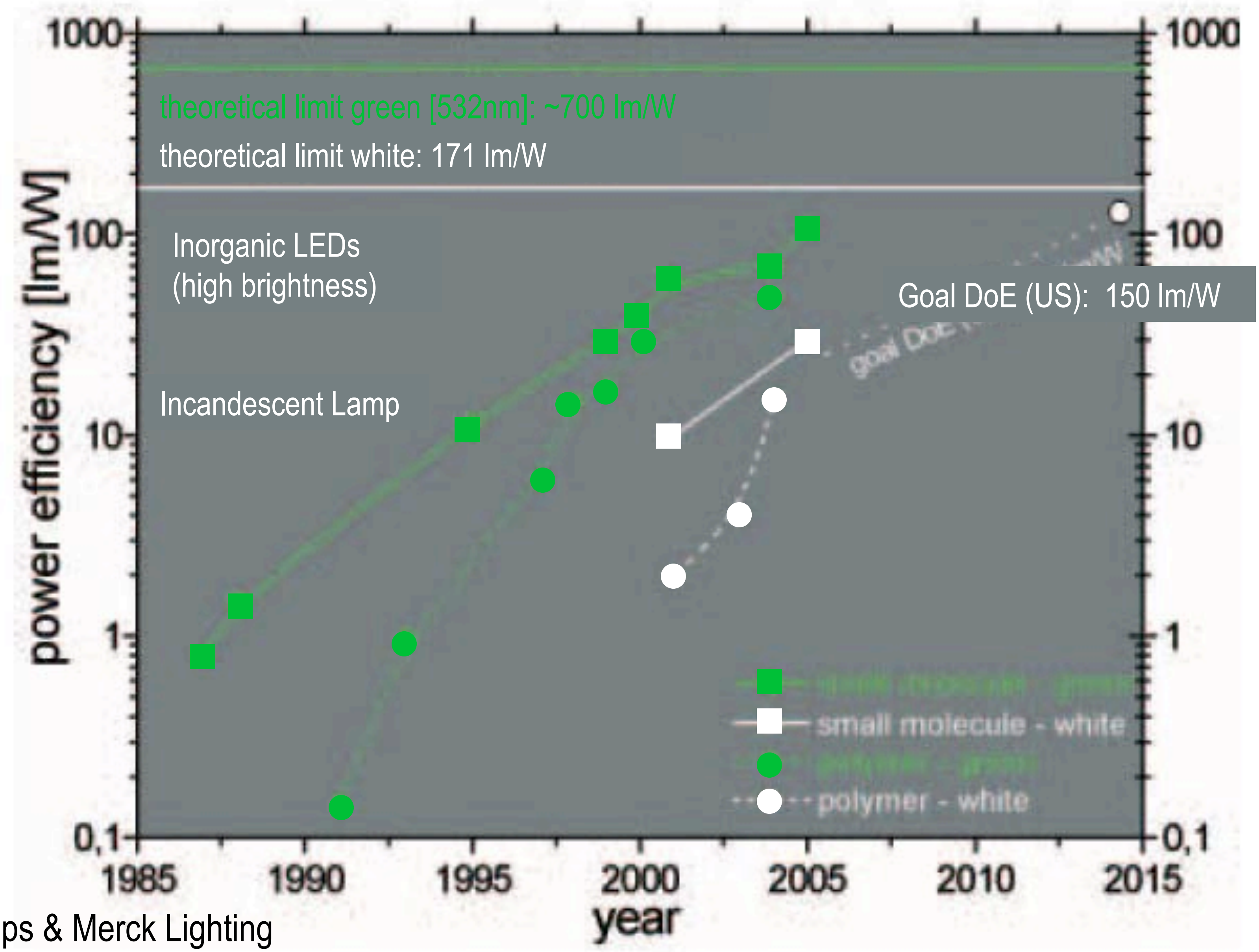


Fig. 3: Additional light outcoupling structures make OLEDs up to two times more efficient.
(Source: Philips Lighting)

OLED Lighting

NC ST



Source: Philips & Merck Lighting

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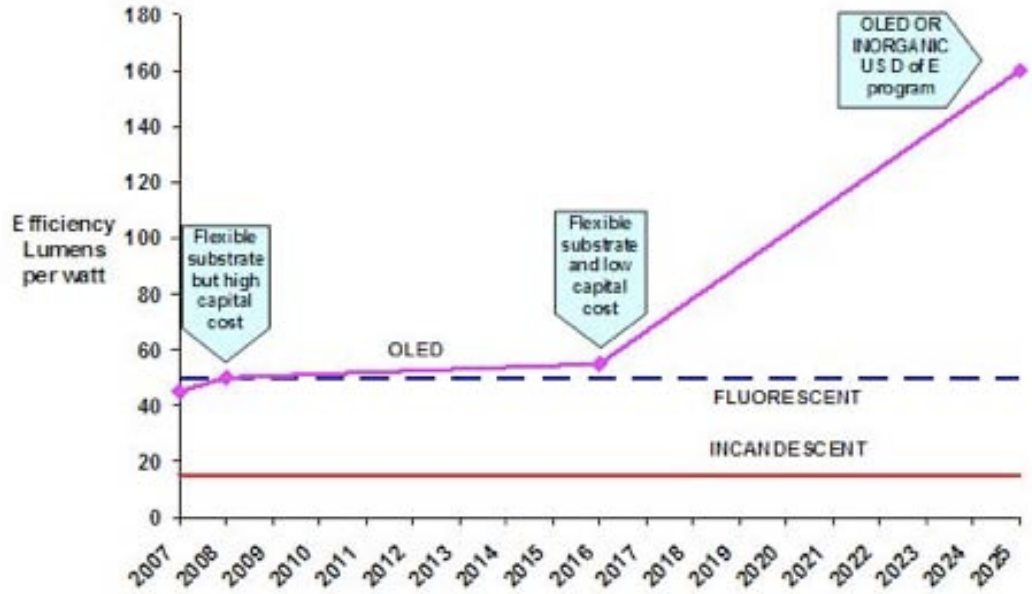
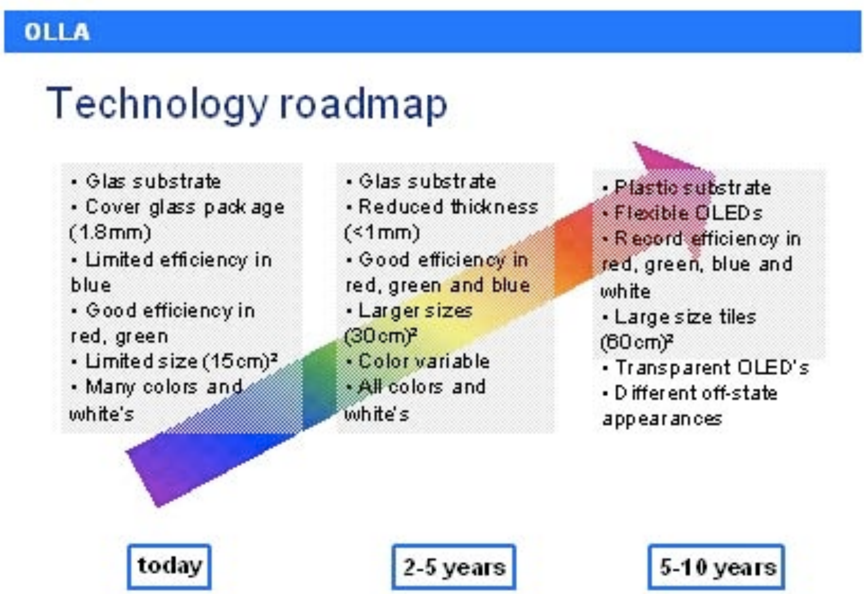


Figure: Roadmap 2007-2015 for improvement in efficiency of OLEDs for lighting and signage and the target of the US Department of Energy programs for OLED and inorganic lighting in general use. Source IDTechEx



Market	Brightness (cd/m^2)	Size (cm^2)	Lifetime (h)	Efficiency (lm/W)
Decorative lighting	50-500	10-100	10.000	10-15
Automotive applications	50-2000	5-50	10.000	10-20
LCD backlighting	2.000-4.000	10-200	10.000	25-50
Emergency lighting	300-500	300	25.000	25-35
Large area illumination	1.000	>1000	10.000	35-50
General illumination	5.000	5000	10.000	50-100

Source: Olla

OLED State of the Art

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- Companies and Researchers achieve white by mixing phosphors and fluorescent materials and enhance luminous efficacy with backreflectors
- Research in individual colors claim as high as 110 lm/W
- 2007: Philips/Novaled 35 lm/W @ 1000 cd/m^2 for 100k Hours with optical enhancement
- 2007: Universal Display Corp. 45 lm/W with optical enhancement
- 2007: Konica-Minolta 64 lm/W @ 1000 cd/m^2 for 10k Hours with optical enhancement
- 2007: Yamagata Univ. 48 lm/W @ 1000 cd/m^2 without optical enhancement

Philips 2006; Oled-info.com 2008; IDTechEx 2008

OLED Lighting

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OSRAM 2008

OLED Lighting Panels
- Transparent On / Off
- 20 lm/W at 1000 cd/m^2
- Can provide ‘directional’ and diffuse lighting
- Phosphors can be added for color

OLED Lighting

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OLLA

Other OLLA demonstrator areas

Automotive

Signalling

LCD backlighting

Signage

Source: Olla

OLED lights 150 mm X 150 mm have been made.

Source: Olla

http://www.oled-display.net/oled-lighting

OLED Lighting Advantages

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- Large area diffuse light source
- Thin, flat, lightweight
- Form freedom in design
- Fast switch-on; fully dimmable
- Many colors, incl. whites
- Robust source (no wires inside)
- Transparent, mirror-like, black or white appearance
- Low voltage technology
- Potentially high efficiency
- "Green" product (energy efficient, recyclable)
- Potentially cheap fabrication

OLED Lighting Challenges

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- High Luminance: Lighting applications needs at least 1,000 cd/m^2 brightness
- Long Lifetime: Long operation and shelf lifetime is necessary
- High Efficiency: At least 30 lm/W in WHITE
- Good Homogeneity: Especially on large areas applications
- High CRI at high brightness: > 80 for direct lighting applications
- Very low costs

Fabrication Processes

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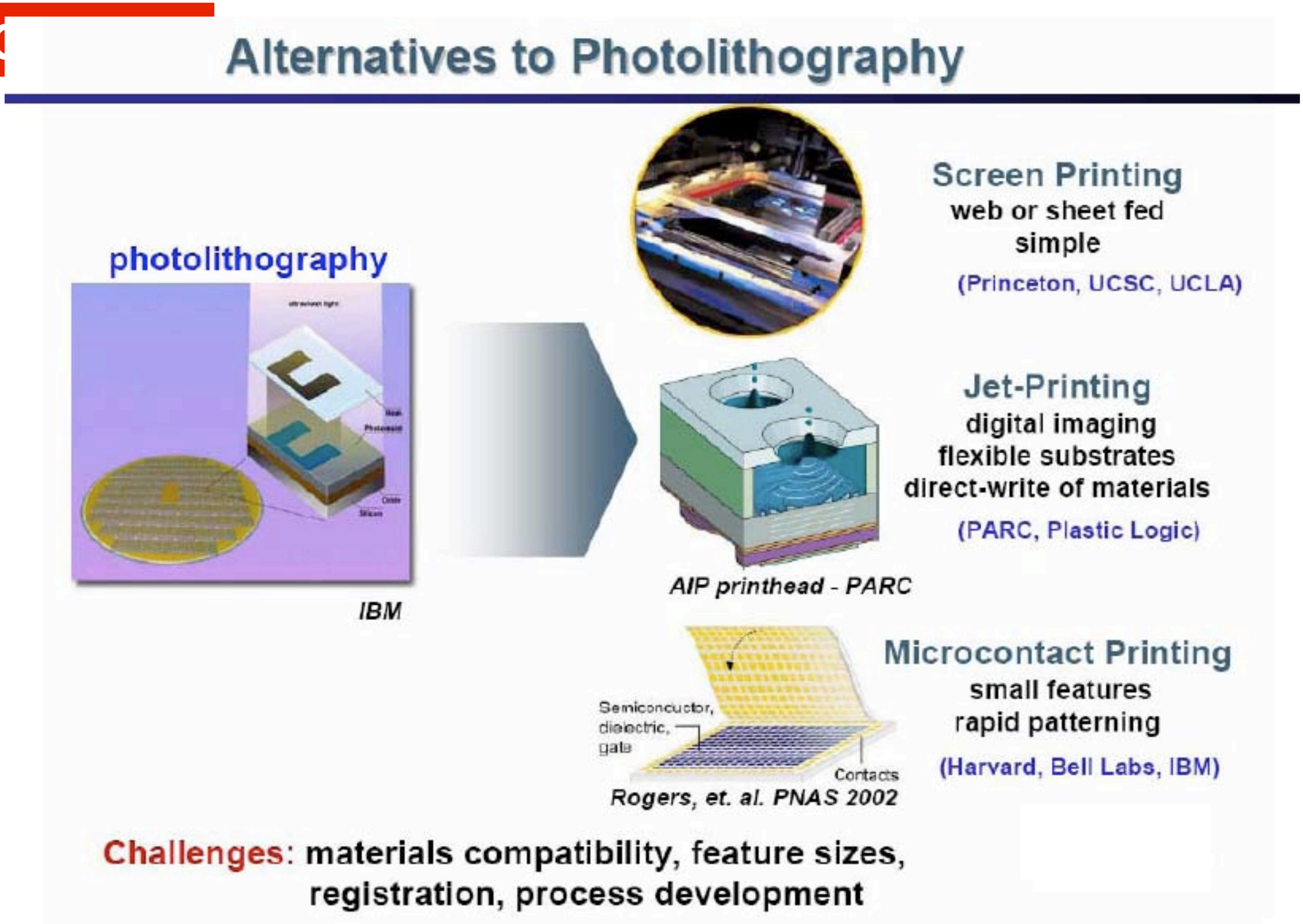


Coating Technologies:

NC STATE

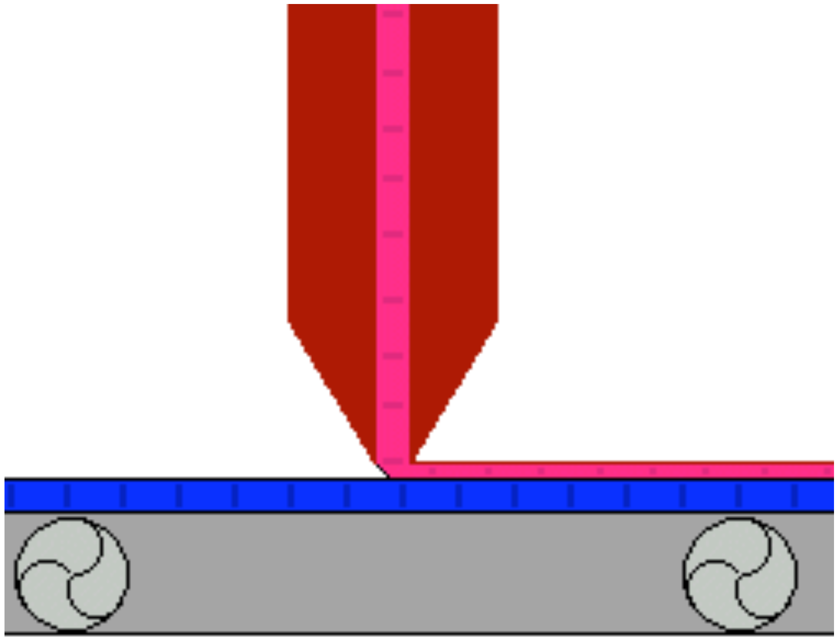
- Spin-coating (rotating rigid substrate)

Coating Technologies:

NC STATE

from http://www.tciinc.com

- Slot- or Die-coating
- For flexible substrates

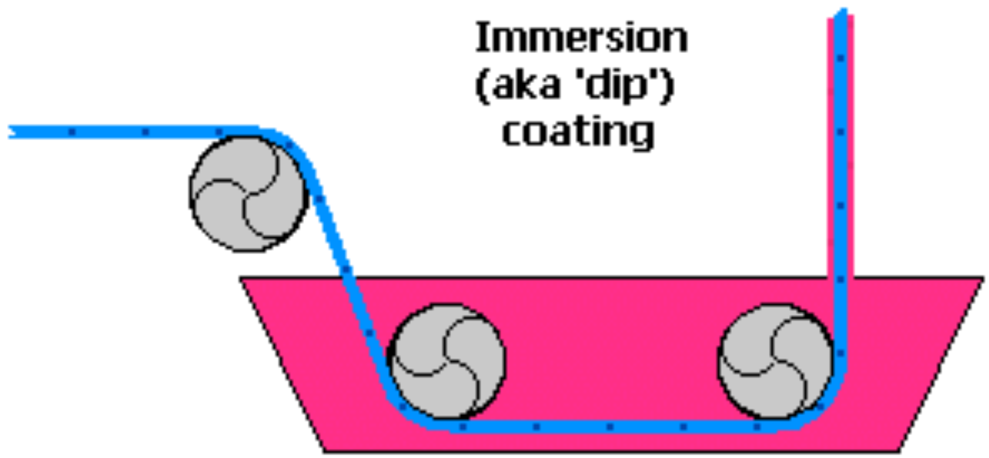


Coating Technologies:

NC STATE

from http://www.tciinc.com

- Dip-coating
- For flexible substrates



Coating Technologies:

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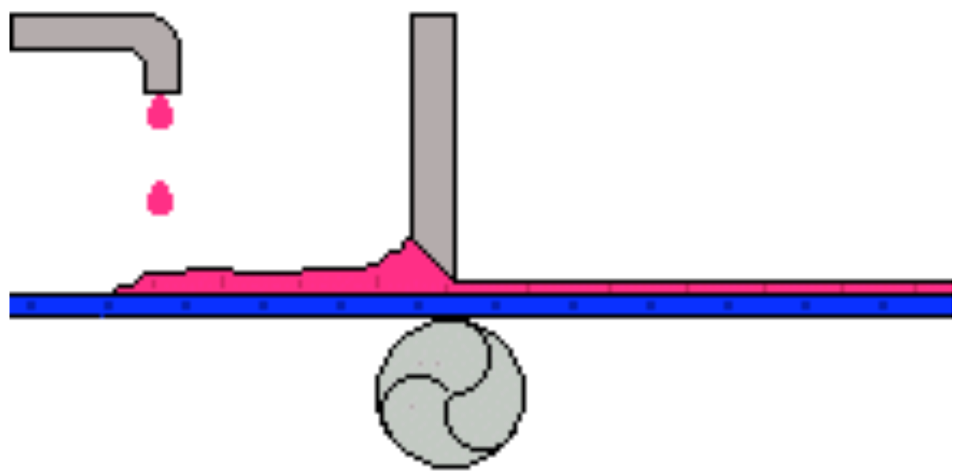
from http://www.tciinc.com

- Knife-edge or doctorblade-coating
- For flexible and rigid substrates



Doctorblade

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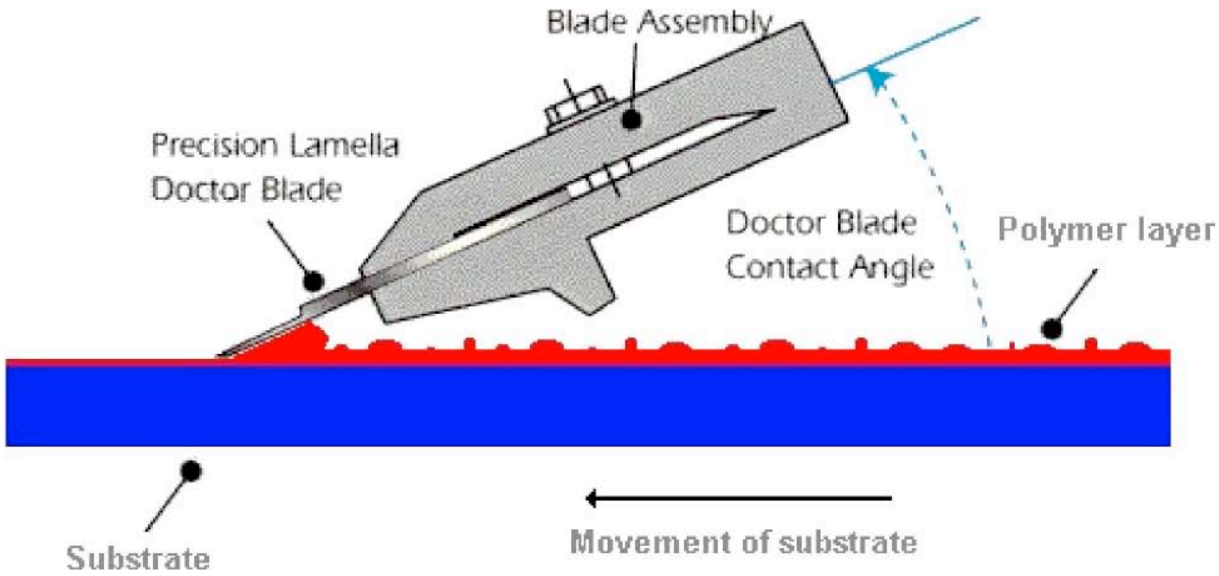


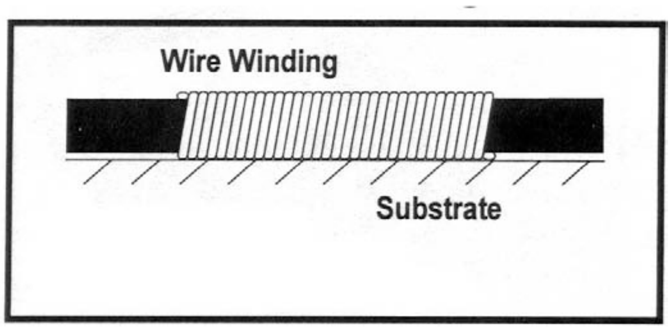
Figure 2.6: Scheme of the working principle of the coating done by doctor blading. On the substrate (blue) the solution (red) is placed in front of the blade. The blade is moved over the substrate with a defined slit height and blading speed. Picture after [44]

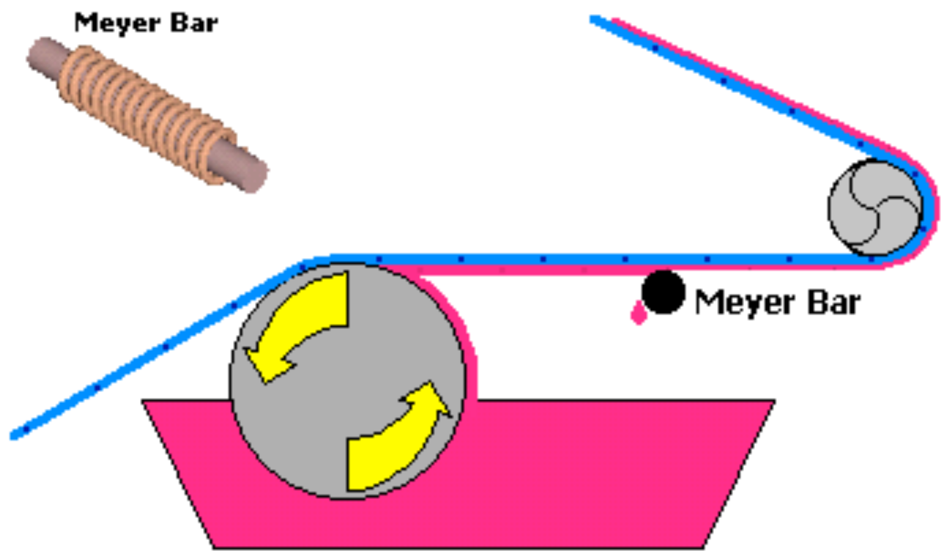
Coating Technologies:

NC STATE

from http://www.tciinc.com
and http://www.webcoatingblog.com/blog/2005/07/mayer_rod_coate.html

- Meyer-rod or Mayer-rod coating
- For flexible and rigid substrates



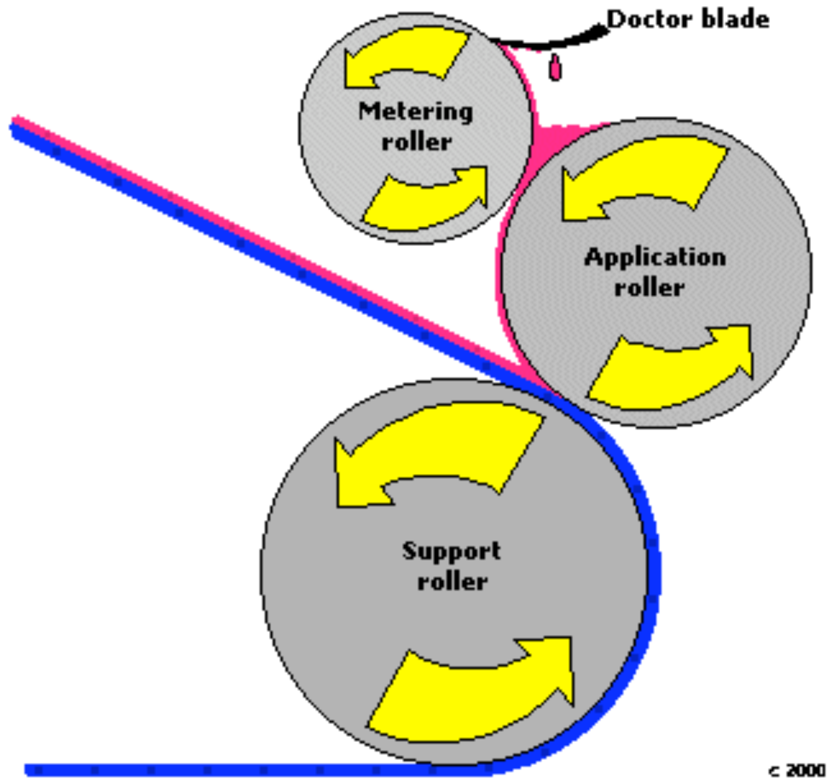


Coating Technologies:

NC STATE

from http://www.tciinc.com

- Reverse-roll-coating
- For flexible substrates



Coating Technologies:

NC STATE

- Inkjet printing