OLED Activity and Technology Development

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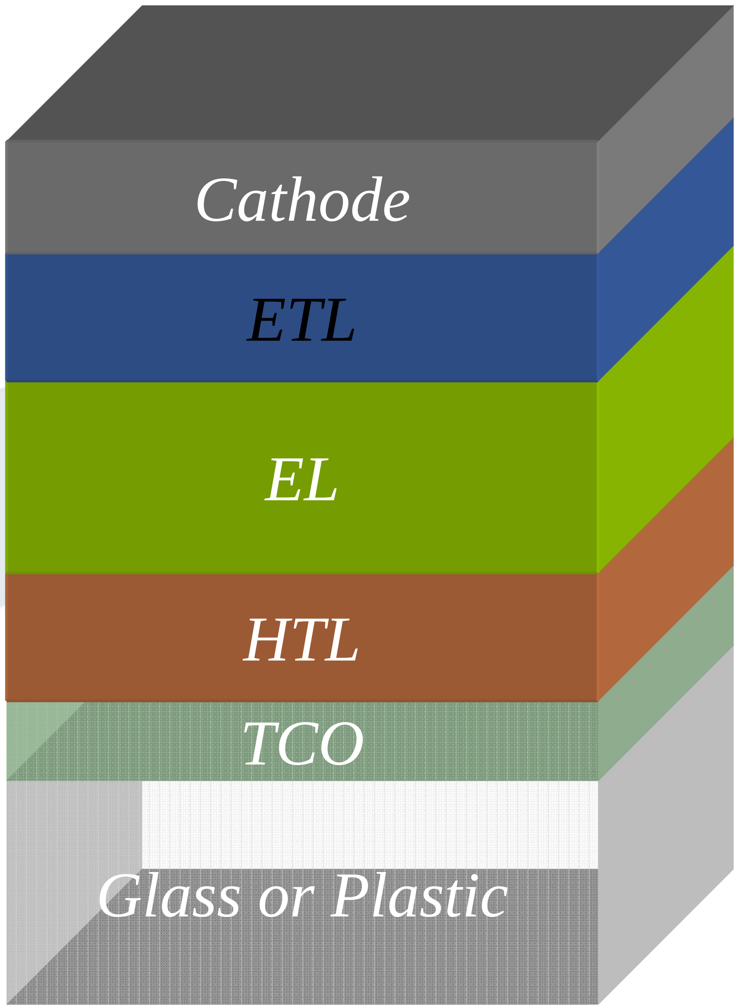
Outline

- What is an OLED?
- What is the Promise of OLED?
- OLED Applications and Market Share
- Progress with OLED Performance
- Advances in OLED Panel Technologies
- Solution Printing Technologies
- OLED Opportunities & Challenges

What is an OLED?

- OLED = Organic Light-Emitting Diode
- OLEDs are semiconductor devices
- Construction of OLED
  - Substrate
  - TCO film (anode)
  - Hole transport layer
  - Emissive layer
  - Electron transport layer
  - Metal film (cathode)



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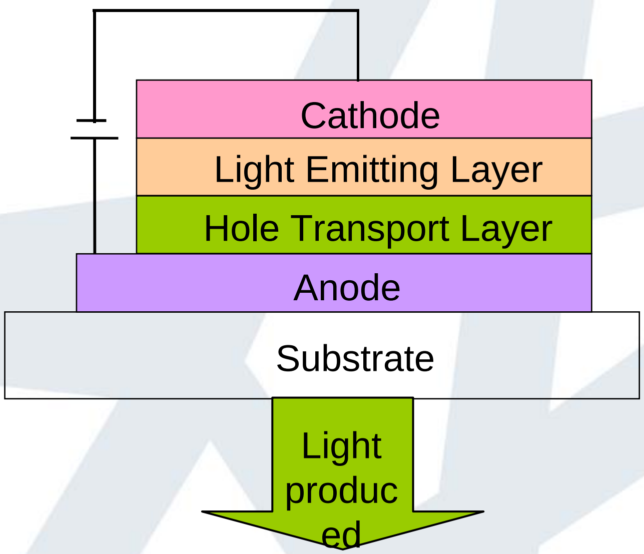
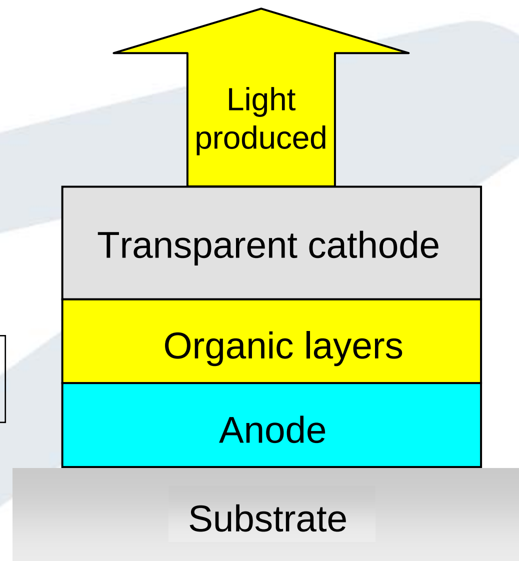
Principle – How does it work?

Holes and electrons, injected from anode and cathode, combine to release energy thereby producing light.



Conventional OLED



TOLED

Examples of materials

Cathode:

Ca/Ag, Li:Al, Mg:Ag, etc.

Emitter:

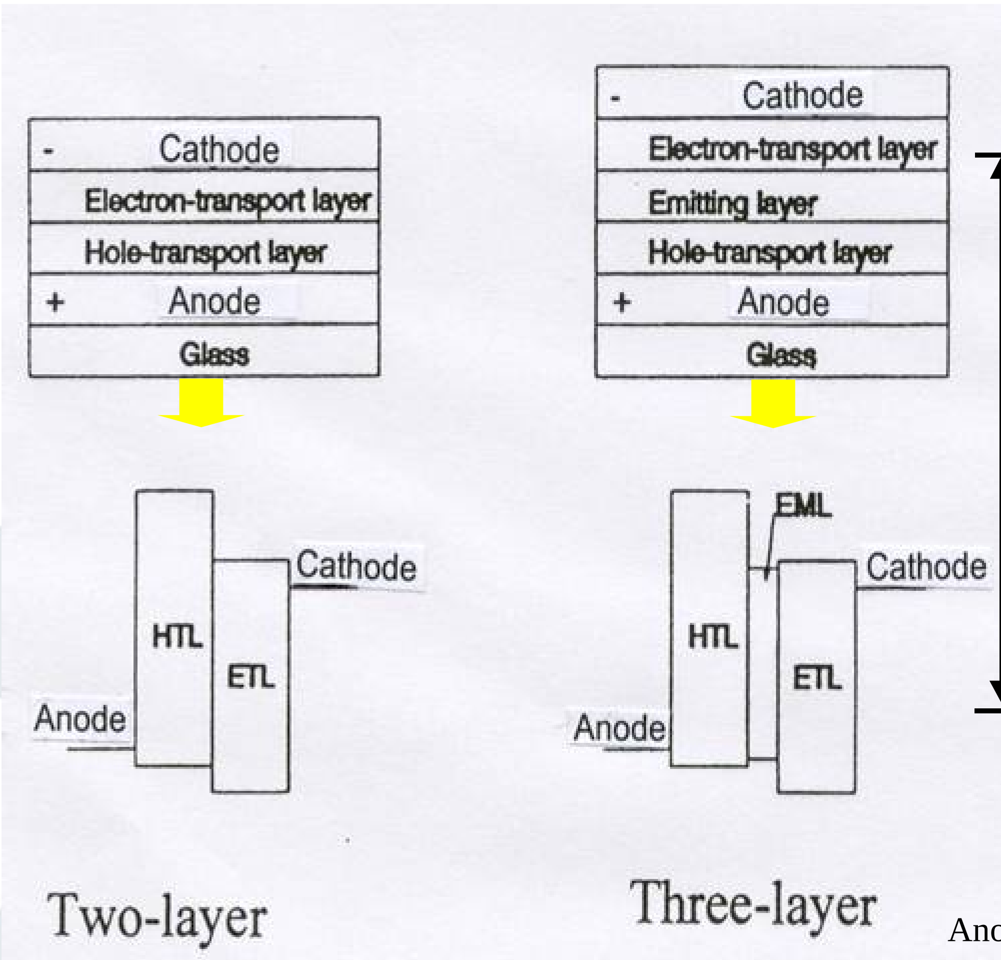
EL organic, Alq_3, etc.

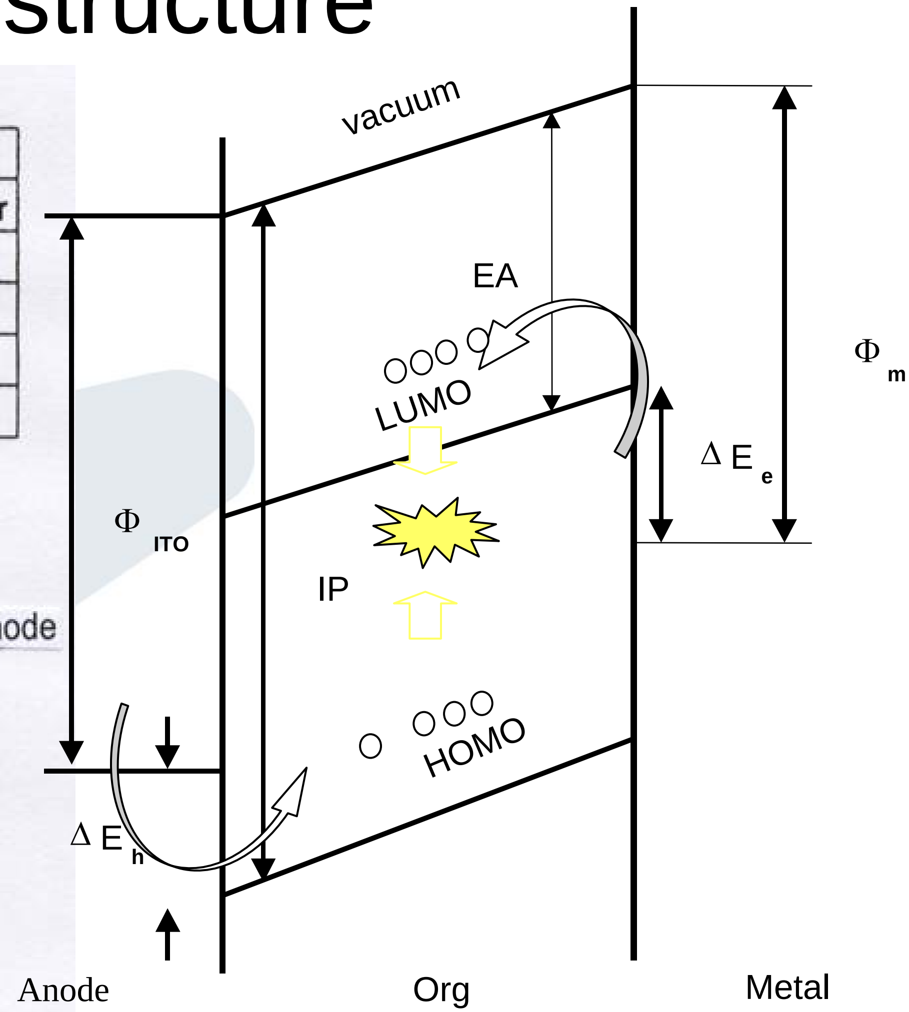
HTL and EHL

Anode: ITO, IZO,

Substrate: Rigid & flexible

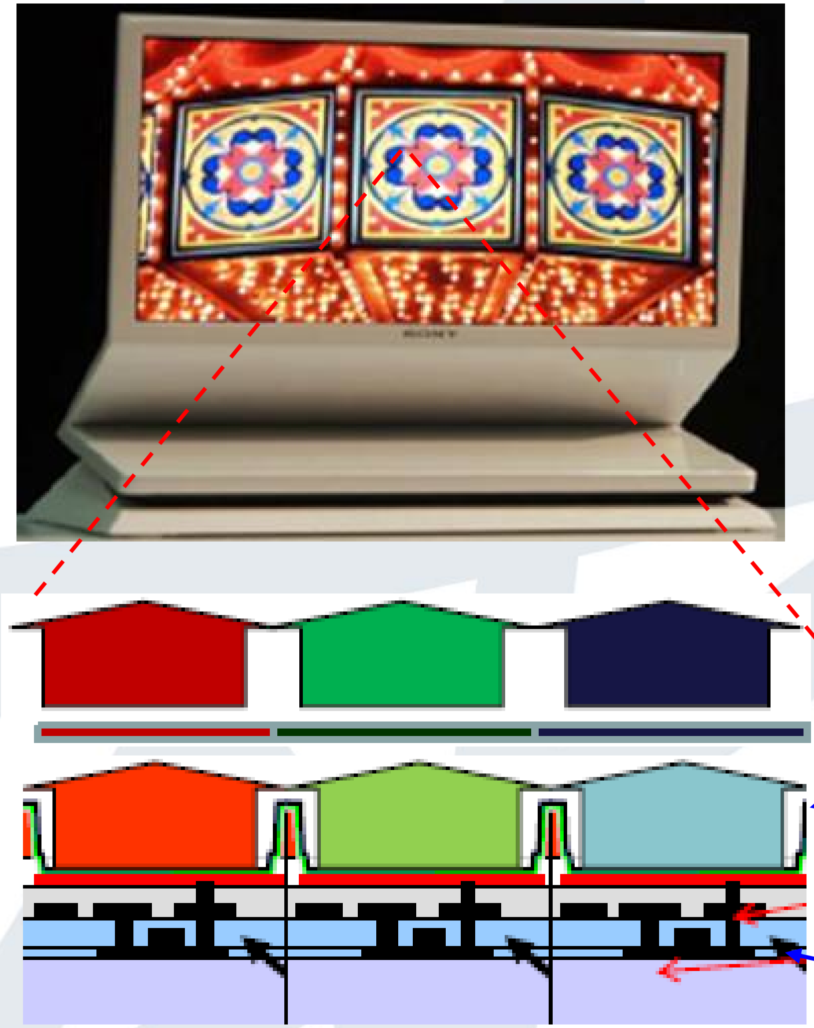
Schematics of OLED structure



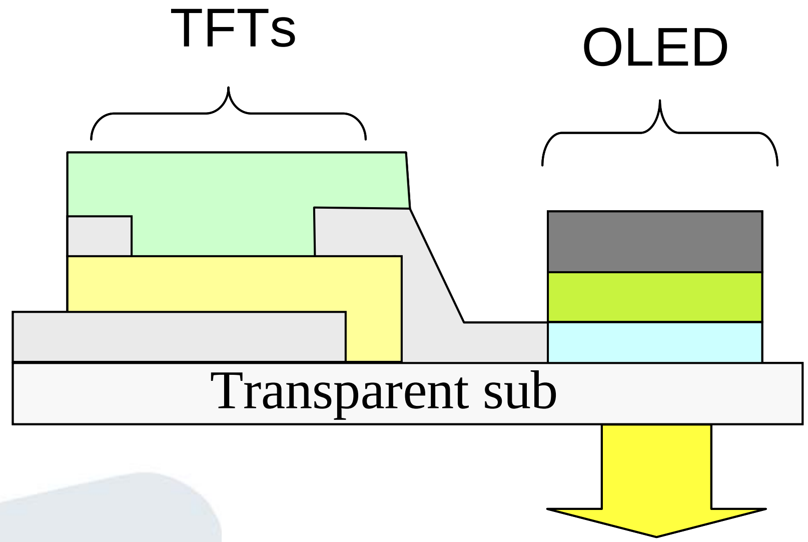


Balancing of electron and hole currents

Top-emitting OLED



Sony 11" TV uses TOLED cavity tuning + Color Filter



Conventional bottom emission OLED displays

- Color filter to improve the gamut
- Cavity structure for color tuning
- TOLED structure with a large aperture
- LTPS backplane for AMOLED displays

What is the Promise of OLED?

- Contrast ratio > 10,000:1
- Response time < 0.1 ms
- Wider viewing angle > 170^{O}
- Total display thickness < 1.5mm
- Low power consumption < 50% of LCD

- The most important attribute has become the simple device structure that can significantly reduce manufacturing cost

- As LCDs continue to improve, it is clear that OLEDs must deliver a significant cost advantage to become mainstream

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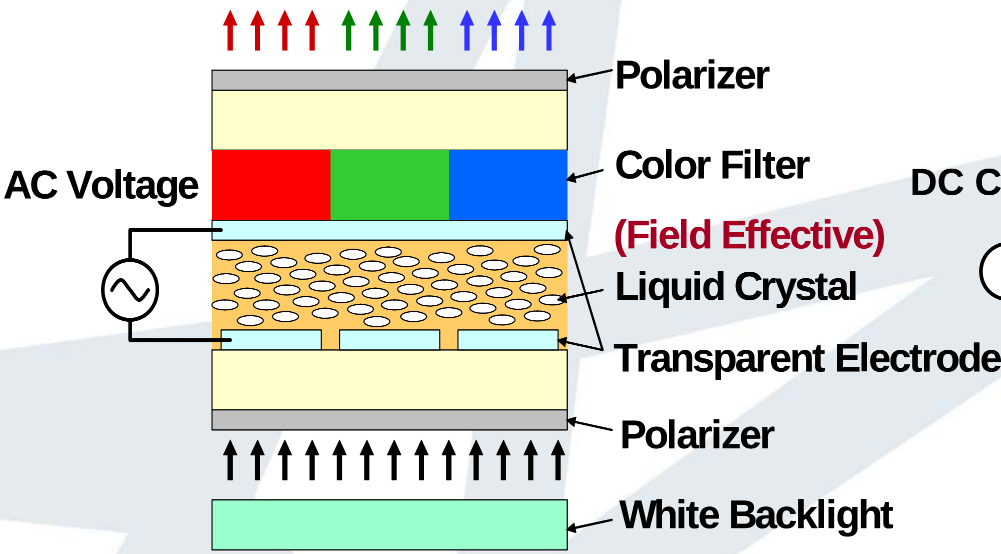
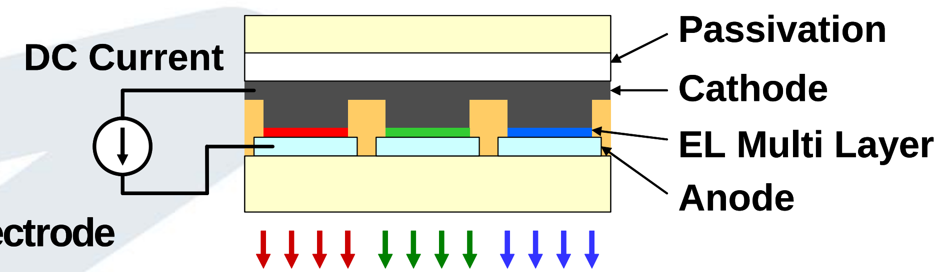
OLED's simpler structure leads to low cost

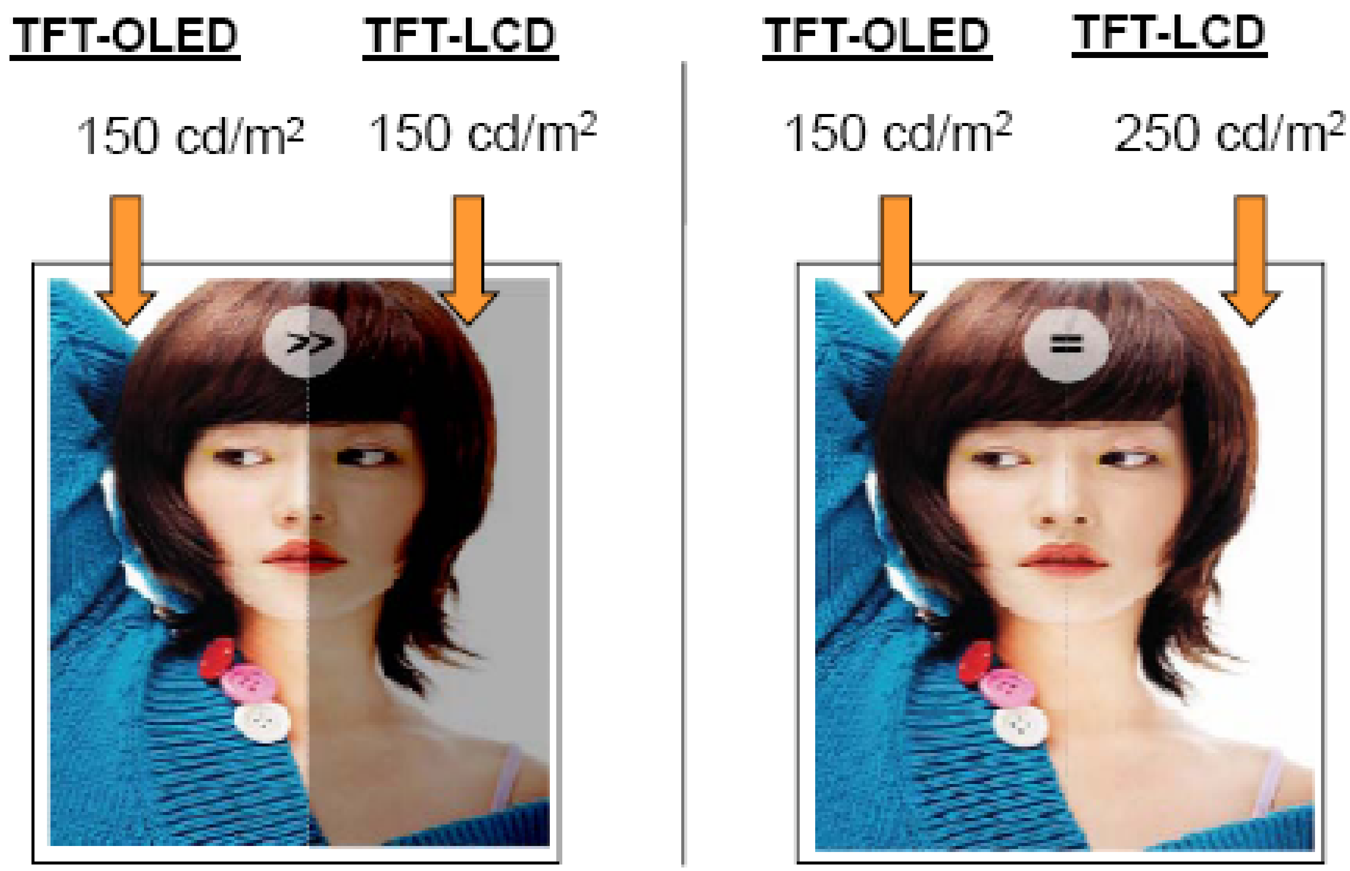




LCD is a gray scale shutter for light

OLED is primary a color light source

Power Efficiency:
Less power better picture



SOURCE: Samsung SDI Stand, FPD Yokohama, October 2006

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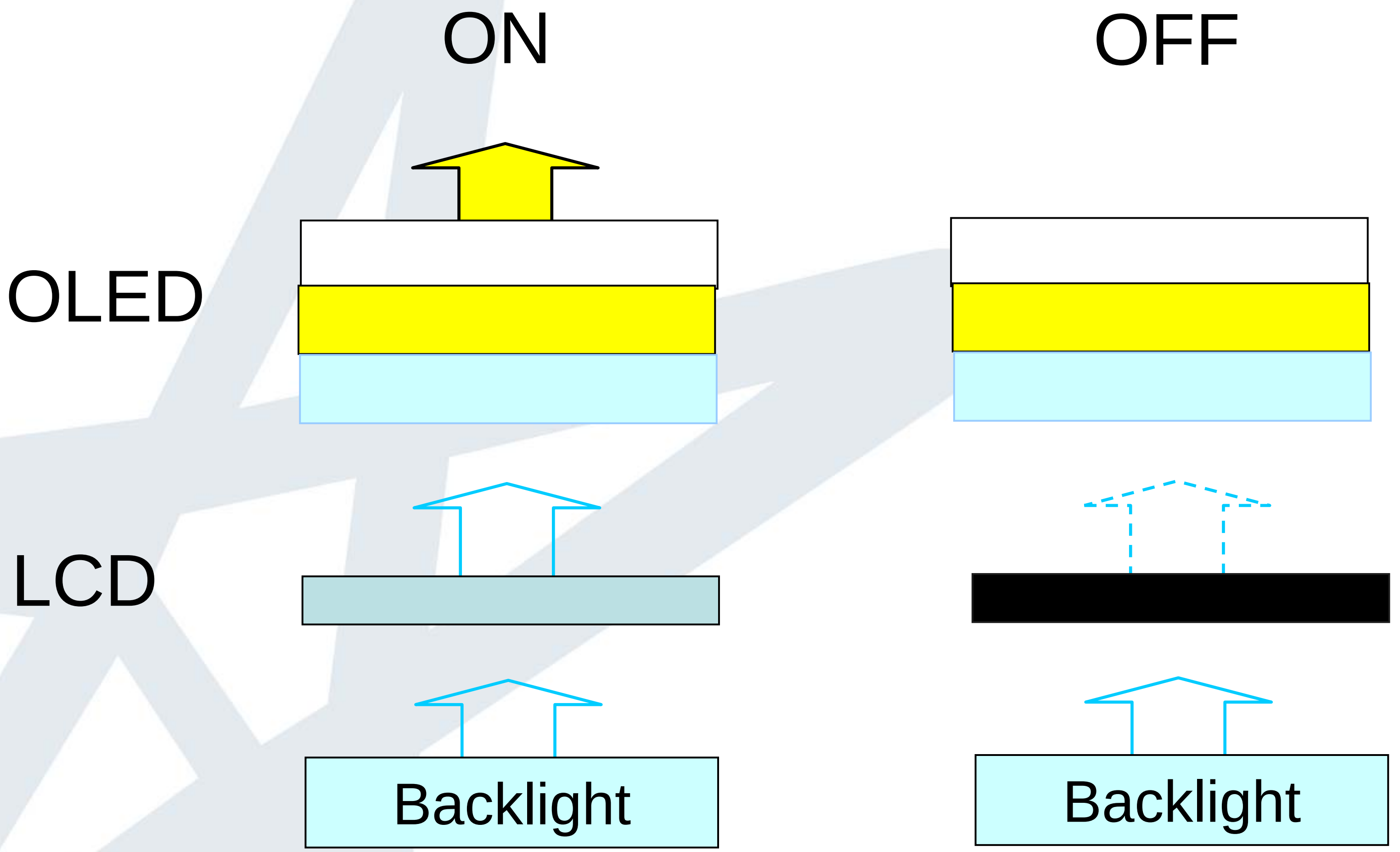
“Black” is black



Power consumption in AMOLED & AMLCD

Panel	Active Area (cm^2)	L_{peak} (nits)	P_{max} (Watt)	P1 (W) Cartoon	P2 (W) Action film	P3(W) Mystery
8" AMLCD DVD Player (LTA0808332A)	175	135	3.89	3.89	3.89	3.89
7" AMLCD DVD Player (LB070W02)	132	106	2.54	2.54	2.54	2.54
7" AMOLED	146	150 (with circular polarizer)	2.81	1.00	0.71	0.52

Best fit with battery-powered applications

Source: DuPont Displays

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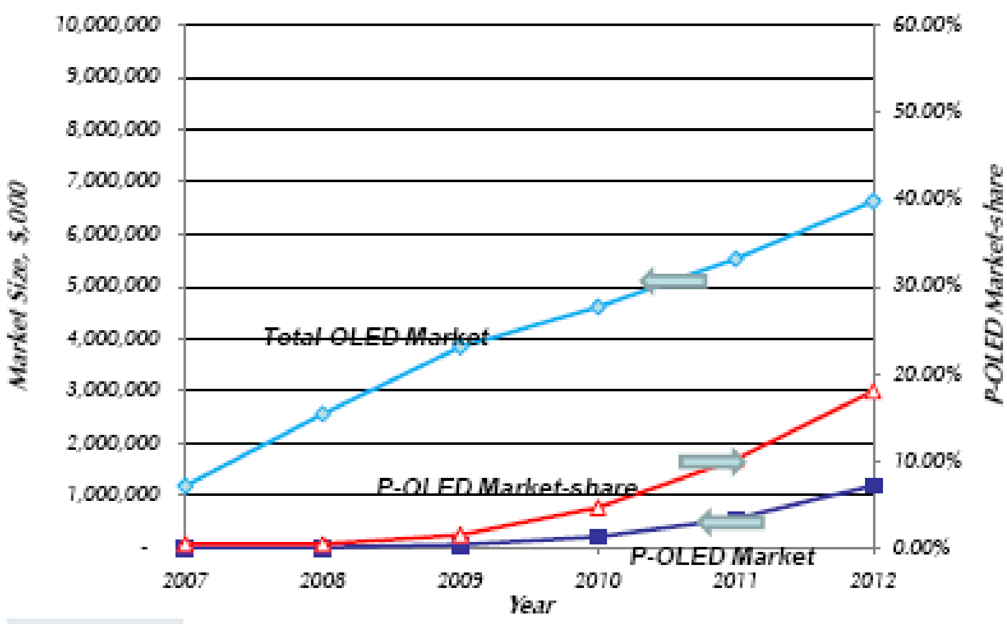
OLED development

- 1989 OLED was discovered in a useful form, Kodak
- 1991 University research, Cambridge
- 1994 Launch of industrial R&D
- 1998 First OLED product on the marketplace
- Today New OLED industry



OLED Market forecast to reach $6B by 2121

OLED Market size from DisplaySearch 2007

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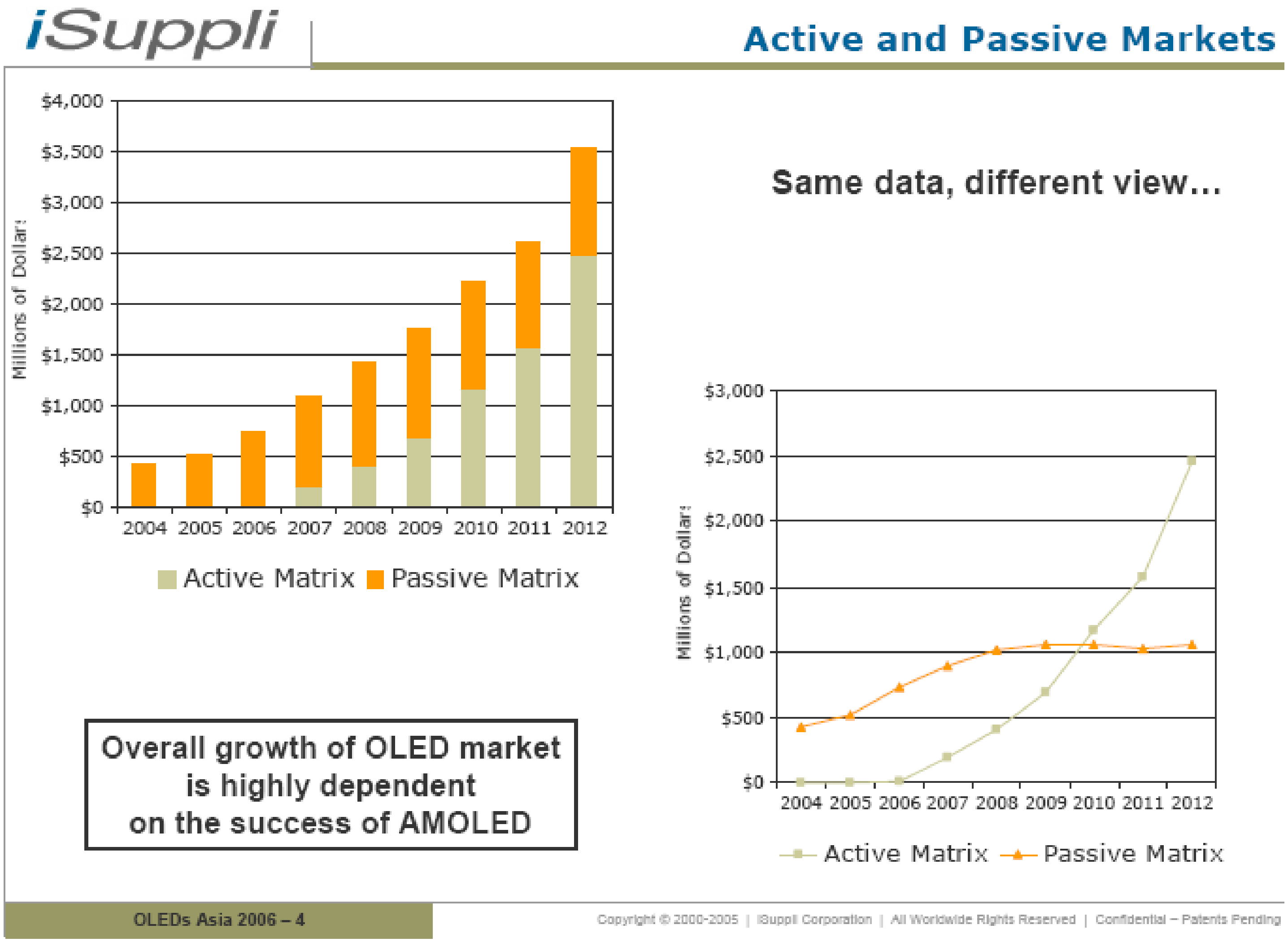
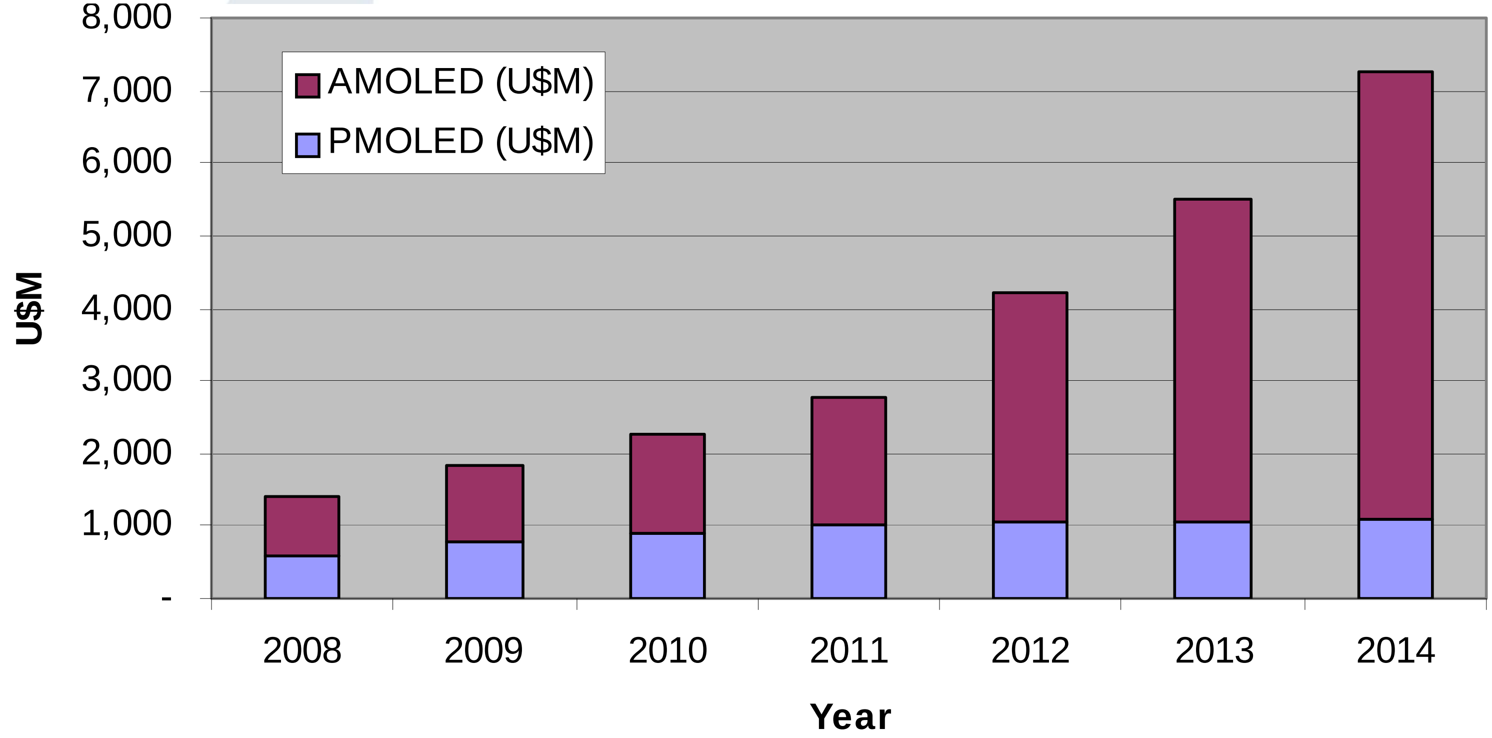
OLED display market forecast



OLED display market forecast



	2008	2009	2010	2011	2012	2013	2014
OLED Market (U$M)	1,400	1,840	2,252	2,758	4,214	5,499	7,276
PMOLED (U$M)	600	800	900	1,000	1,050	1,070	1,075
AMOLED (U$M)	800	1,040	1,352	1,758	3,164	4,429	6,201

Source: DisplaySearch, isupply

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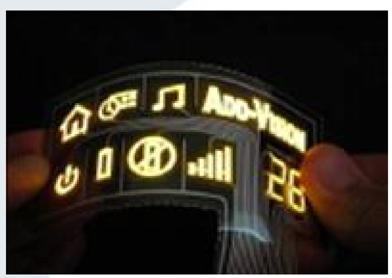
OLED Applications _ Displays

Samsung SDI AM-OLED mobile phone displays

Creative MP3

AUO: BenQ-Siemens

eMagine



low-cost simple displays and lighting panels, signage, merchandising, keypad lighting, toys etc

Samsung Electronics:40” AM-OLED Demonstrator in 2005/6: White EL on C/F

OLED Applications _ AMOLED TVs

SONY

- Started to sell 11" OLED TV

SAMSUNG

- 2 million 2" panel in Q4 2007
- 21" (2009), 42" (2010)

CMEL

- 32" (2010) w/ UDC's PHOLED material

Sumitomo Chemical

- Acquired CDT(2007), P-OLED TV (2009)

Toshiba

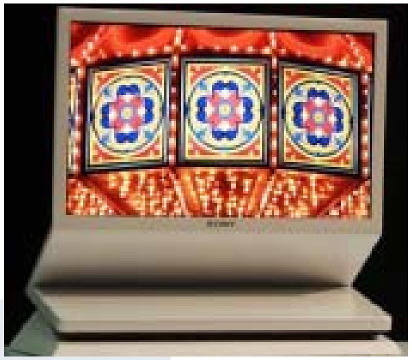
- 20" TV (2009) w/ TMD panel

LG Philips LCD

- 3" and 2.2" AMOLED, OLED TV(2008)

Epson

- 2" and 7" w/ small molecule (2009)



Sony 11" OLED TV

Feature	Specification
Screen size	11"
Number of pixels	1,024(H)×600(V) (W-SVGA)
Contrast ratio	>1,000,000:1
Brightness	All white: 200 cd/m^2 Peak: > 600 cd/m^2
Numbers of colors	16.7 million colors (8 bits/color, >100% NTSC)
Device structure	'Super' top emission structure

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OLED Applications _ Lighting

RIOE
Research Institute for Organic Electronics

Large size white OLED panel: 30cmx30cm

NEC OLED lighting 15cm x15cm

Matsushita Electric

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OLED Applications _ Lighting

Current Status:

- Novaled: 35 lm/W, lifetime100K@1000 cd/m^2
- UDC: ~ 40 lm/W
- Eastman Kodak: 50 lm/W (2008)

Future Target:

- 100-150 lumens/W for OLED lighting in the long run

Potential Manufacturers:

- Osram Opto Electronics
- Philips
- GE
- Matsushita Electric
- NEC
- …

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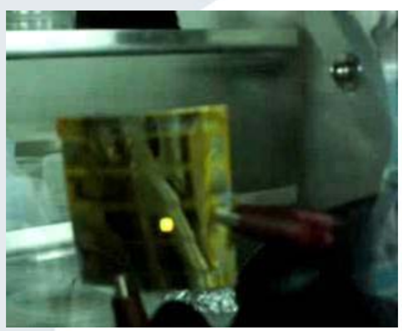
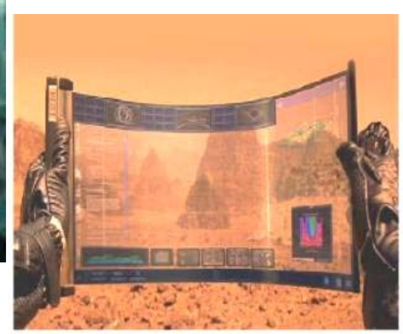
OLED Applications _ Flexible displays

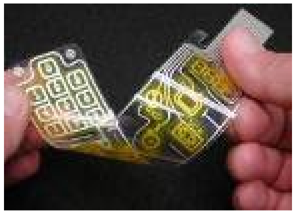
- **Potential benefits:**
  - New product design opportunities
  - Portable devices with large, storable displays
  - Lightweight and robust
  - Lower production costs through R2R manufacture



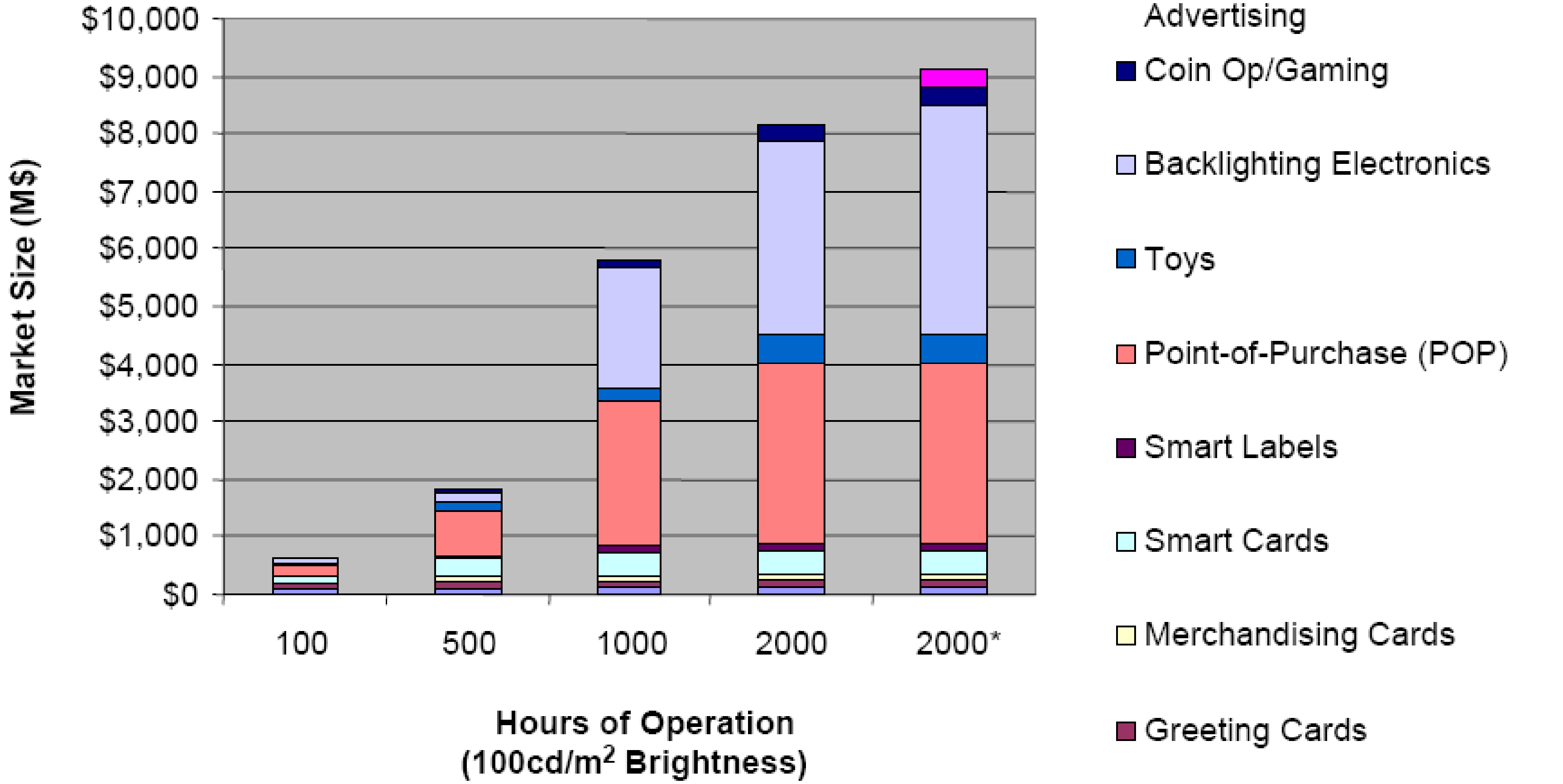


Glass displays have limitations…,

Serviceable Market vs. Display Lifetime



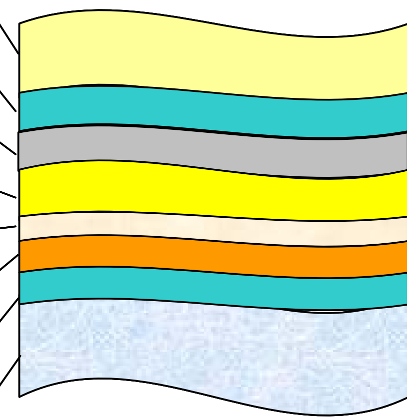
ADD-VISION, INC.
WWW.ADD-VISION.COM



*** High Brightness***

Flexible OLED Challenges

- Encapsulation film
  Transparent, robust
- Barrier
  Transparent, reduced permeability to O_2, H_2O
- Cathode (e.g., Ba,Ca,Al)
  Transparent for top emission , high conductivity
- Organic layer stack
  HTL, Interlayer, LEP
- Anode (e.g., ITO)
  Transparent for bottom emission, high conductivity
- Backplane
  TFTs, tracks, vias and planarisation
- Barrier
  Transparent, reduced permeability to O_2, H_2O
- Substrate
  Transparent, Robust, thermally stable



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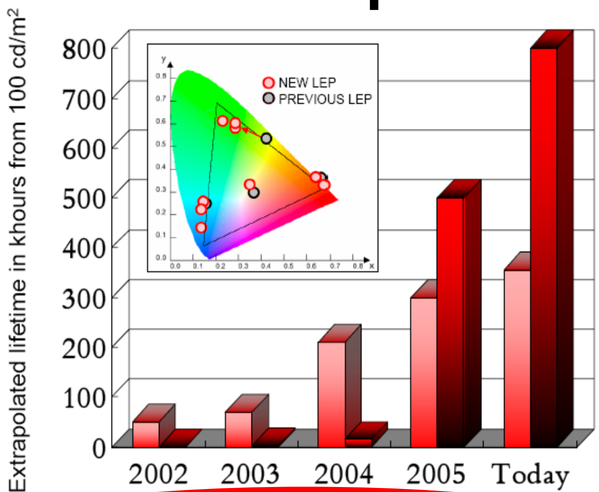
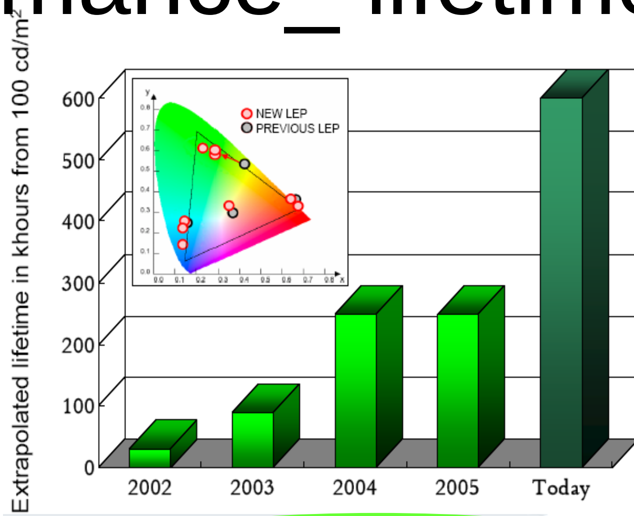
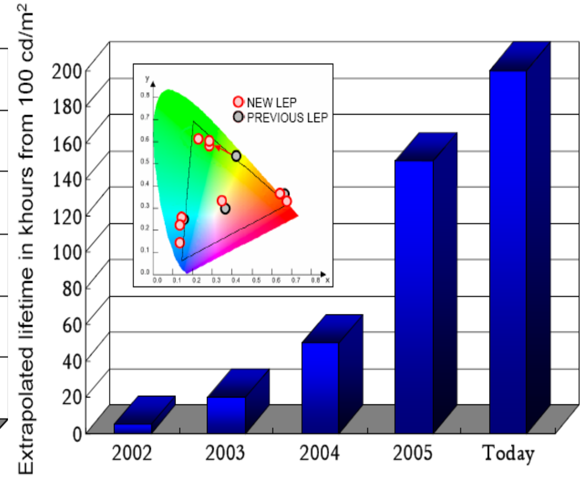
OLED performance_ lifetime issue



Efficiency: 11cd/A

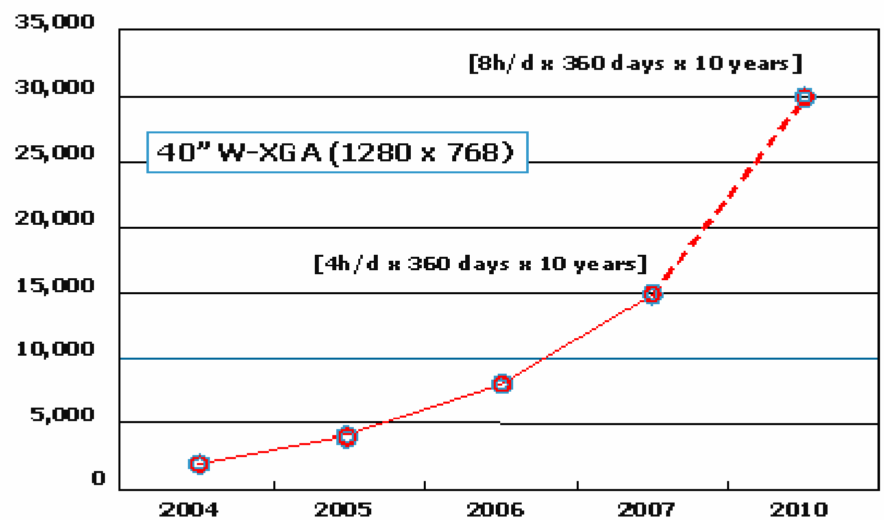


Efficiency: 16cd/A



Efficiency: 9cd/A

T50 (1000 cd/m²)	Performance Data			
	Red (phosphorescent)	Green	Blue	White
Efficiency (cd/A)	10	16	9	7
Colour (at 100 cd/m²)	x= 0.67 y= 0.32	x= 0.29 y= 0.64	x= 0.14 y= 0.21	x= 0.33 y= 0.31
Lifetime (spin) (hrs)	24k	35k	10k	5.2k
Equivalent lifetime at 400 cd/m² (hrs)	150k	198k	62k	27k
Equivalent lifetime at 100 cd/m² (hrs)	~ 2.4m	~ 2.8m	~ 1m	~ 330k



Sumation: 11th April 2007-MRS 2007 San Francisco

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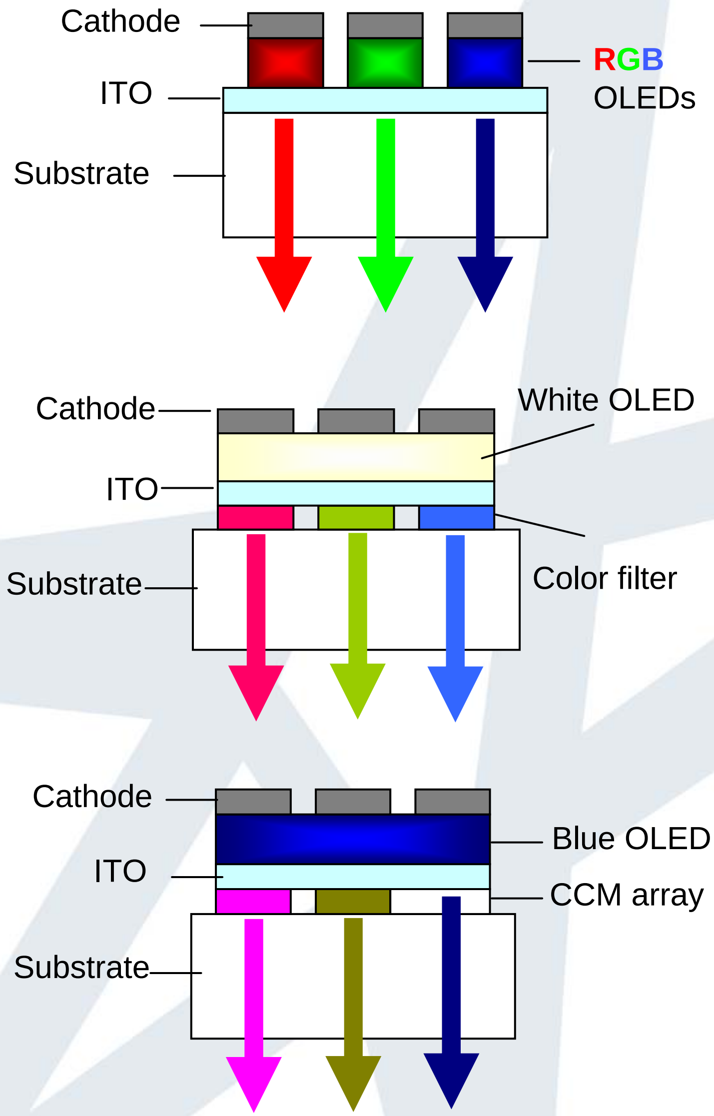
OLED performance_ lifetime issue

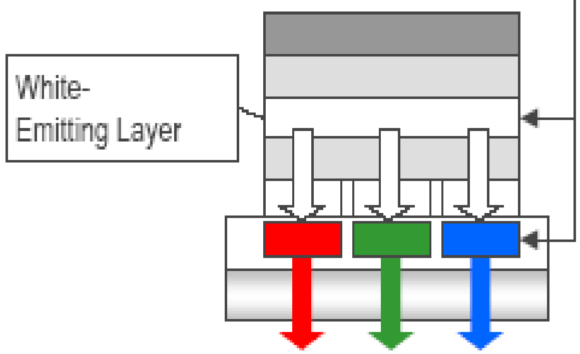
	Colour	CIE (x,y)	Cd/A	T50 LT/k hrs @ 1000nits	Reference
DuPont	Blue	0.14, 0.14	4	10	SID 2007
UDC	Blue	0.16, 0.27	11 (Lm/W)	6 (at 500cd/m2)	
Idemitsu	Blue	0.14,0.16	11	20	Finetech 2007
Sumation	Blue	0.14, 0.19	9	10	OEC-07
DuPont	Red	0.66, 0.34	21	46	SID 2007
UDC	Red	0.64, 0.36	20	330	SID 2007
Idemitsu	Red	0.67, 0.33	11	160	SID 2007
Sumation	Red	0.67, 0.32	10	67	OEC-07
DuPont	Green	0.29, 0.65	24	230	SID 2007
UDC	Green	0.38, 0.59	67 (Lm/W)	250	SID 2007
Idemitsu	Green	0.33, 0.63	36	64	Finetech 2007
Sumation	Green	0.29, 0.64	16	78	OEC-07
Kodak	White	0.32, 0.34	13	50	OledAsia 2006
Sumation	White	0.33, 0.31	8	8	OEC-07

Method of Color Patterning

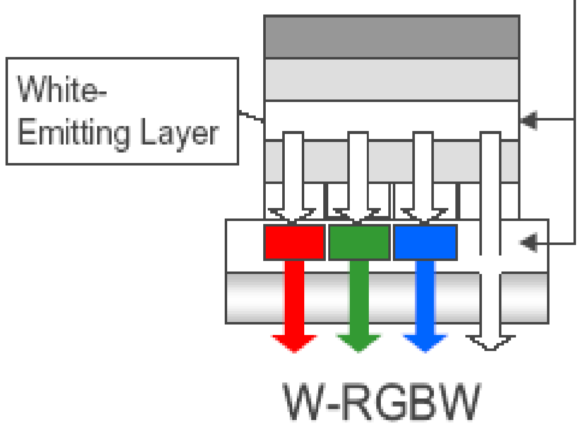


Patterned-Emitting Layer (RGB)	
(Advantages)	**(Disadvantages)**
-High Efficiency -Good color	- Aperture ratio issues -Shadow masking for RGB patterning
White-Emitting Layer with Color-Filter Array	
-No mask (Un-patterned emitting layer) -Aperture ratio not affected by RGB patterning -Enabled by high-efficiency white	-Loss efficiency due to filter absorption
Blue-Emitting Layer with Color Changing medium	
- Un-patterned emitting layer (no mask)	- Request high eff. blue - Blue stability is lowest - CCM materials with std. lithography tools

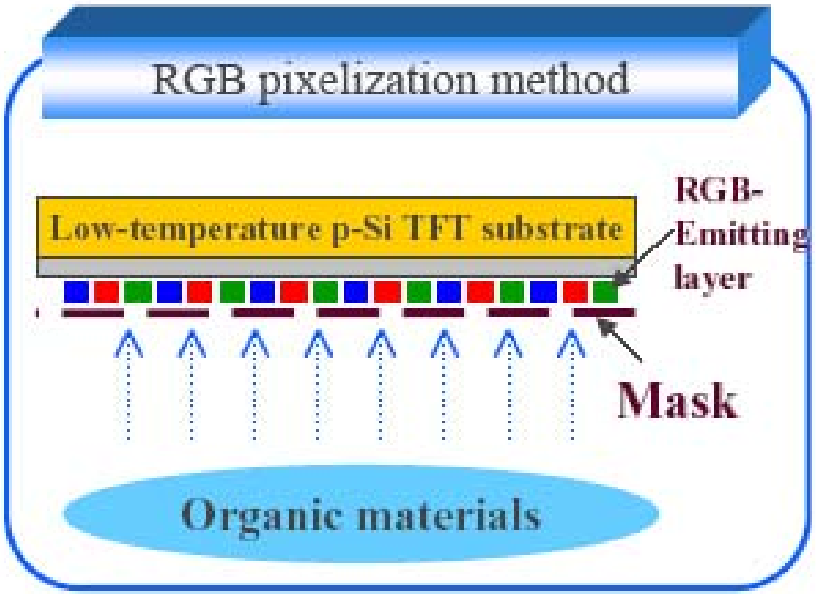
W- RGB vs. W - RGBW

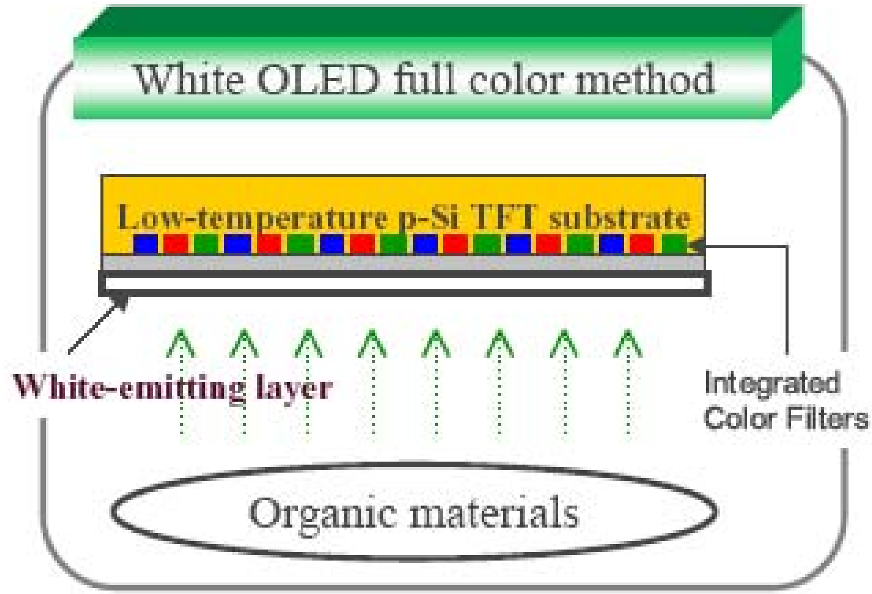


White-Emitting Layer with RGB Color-Filter Array (W-RGB)	
(Advantages)	**(Disadvantages)**
-No mask (un-patterned EL layer) -Enabled by high-efficiency white -Fewer OLED processing step -Reduced deferential aging	- Efficiency loss due to filter absorption - Gamut controlled by white spectrum
White-Emitting Layer with W- RGB Color-Filter Array (W- RGBW)	
-No mask (un-patterned EL layer) -High efficiency white sub-pixel results **<u>significantly power reduction</u>** (a large portion of image content contains white) -Enabled by high-efficiency white	- Efficiency loss due to filter absorption



RGB vs. White OLED + Color Filter





One mask process for each RGB – Total 3 contacts

No mask process

1. Maskless and scaleable technology
2. Simplified process

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RGB vs RGBW

- Displays from Kodak

Model	Size	Example Application	Technology	Dot Count	Color Arrangement
ALE251	2.2	DSC	RGB+PSM[2]	521x218	RGB Delta
ALE247	2.2	Cell Phone	RGB+PSM	528x220	RGB Stripe
ALE257	2.2	Cell Phone	W+CFA[3]	528x220	RGB Stripe
ALE258	2.2	DSC	W+CFA	521x218	RGB Stripe
ALE269	2.5	Cell Phone	W+CFA	720x320	RGB Stripe
ALE269W	2.5	Cell Phone	W+CFA - RGBW[4]	720x320	RGBW Stripe
ALE255	1.9	DSC	W+CFA	521x218	RGB Delta
ALE334	3.5	PDA	W+CFA - RGBW	968x322	RGBW Stripe
ALE293[1]	2.2	DSC	W+CFA - RGBW	862x240	RGBW Delta
ALE294[1]	2.5	DSC	RGB+PSM	720x240	RGB Delta

Product: Kodak LS633 DSC (2003)

Product: Sanyo Xacti DVC (2006)

Kodak's AM635LX (2005)

Kodak:

RGB and RGBW technologies

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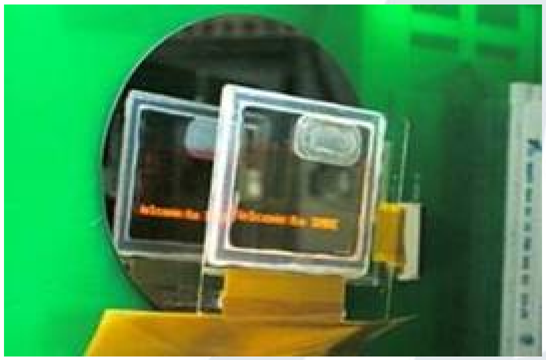
PMOLED and AMOLED

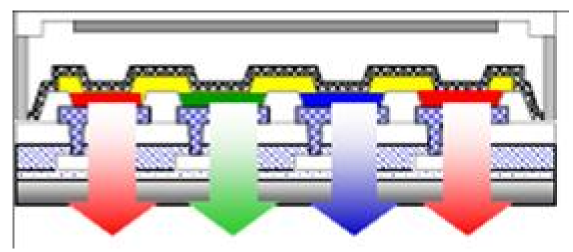


Source: IMRE

PM vs AM	PMOLED	AMOLED
Emission Period	Line Time	Frame Time
Driving Current	High	Low
OLED Driving Voltage	High (>12V)	Low (~8V)
Life Time	Short	Long
Power Dissipation	Probably High	Probably Low*
Limitation of size	Small	Larger

Source: UDC

AMOLED



AMOLED for high density and large size displays

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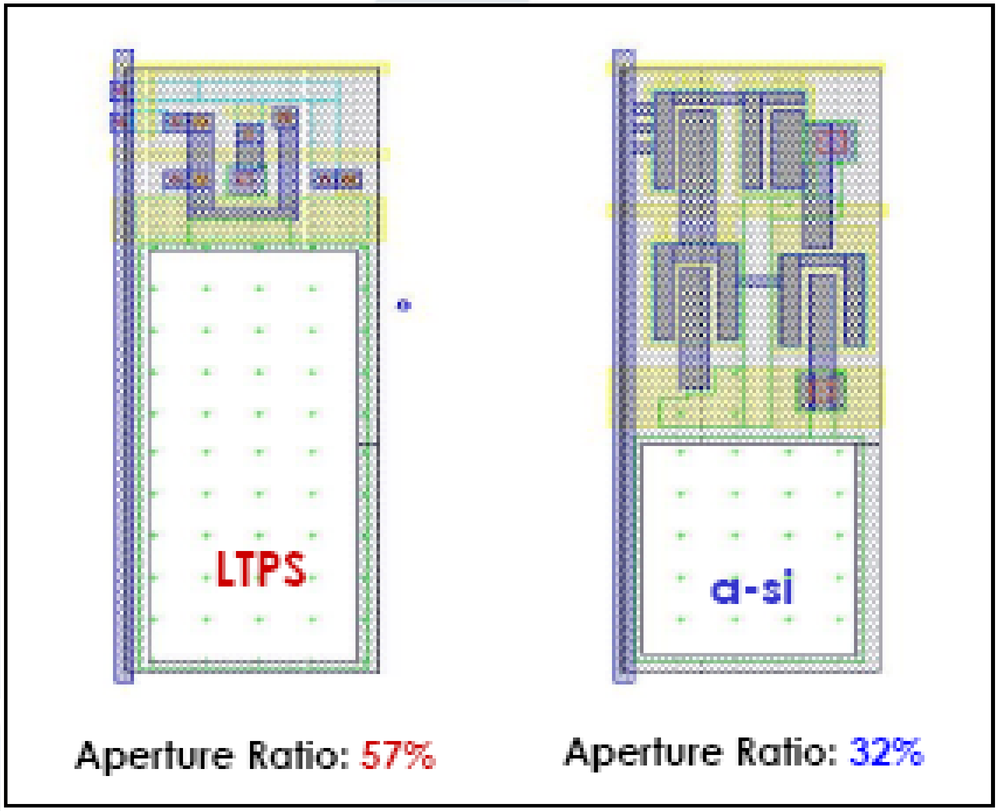
TFT-AMOLEDs: Benefits from LTPS



*Based on 15" 1024x768 XGA (84ppi)

- AR increased → Current density reduced → Lifetime improved

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PMOLED vs AMOLED

PMOLED	AMOLED
Requires cathode patterning	Each pixels can ON for entire frame time (not pulsed as PMOLED)-
High-pulsed drive currents	Better operation stability
Number of rows limited to <240	Short defects result unlit pixels. AM circuits prevents cross-talk
Shorted pixels result in cross-talk or line defect	Lower current pulses and lower capacitances allows much larger display
Significant capacitance issue	Non-uniformities in LTPS backplanes results in display non-uniformities
Simple structure/fabrication	High manufacturing cost associated with AM substrate
Much lower manufacturing cost compare to AMOLED. However, PMOLEDs command much lower price compare to AMOLED	

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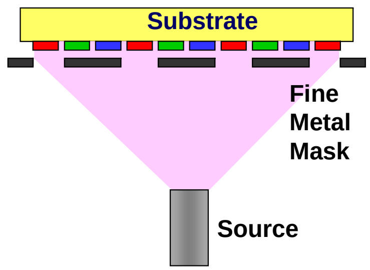
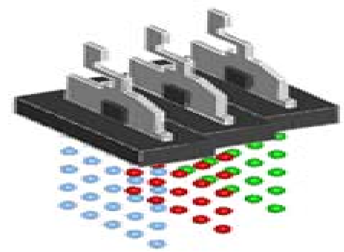
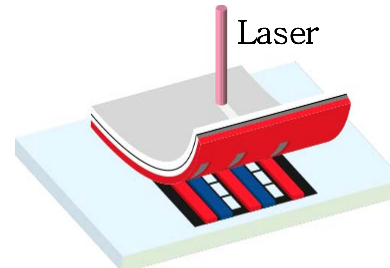
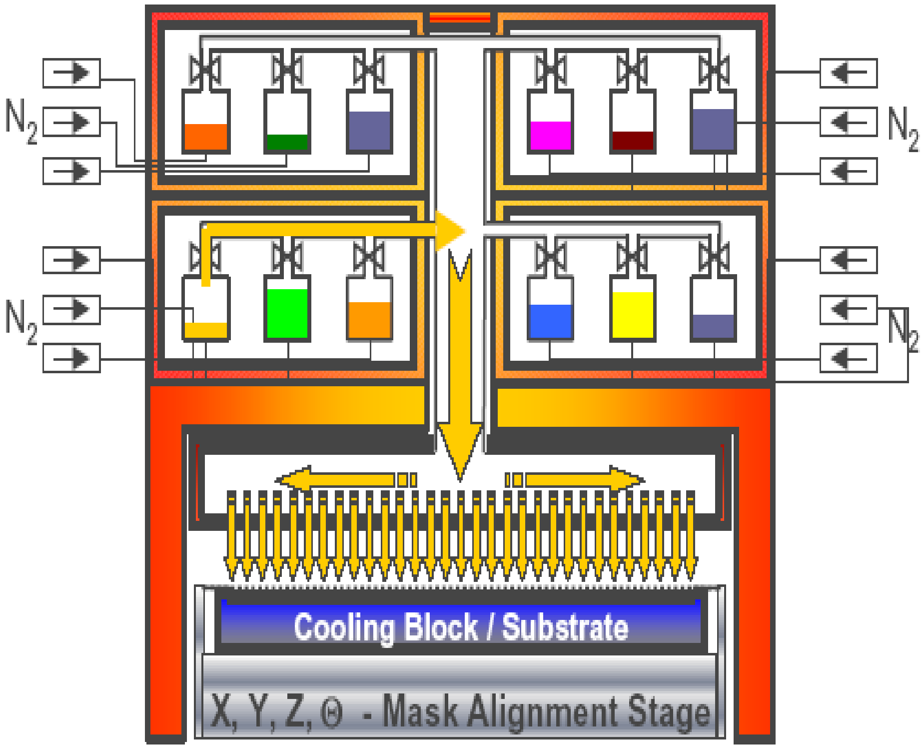
OLED process technologies

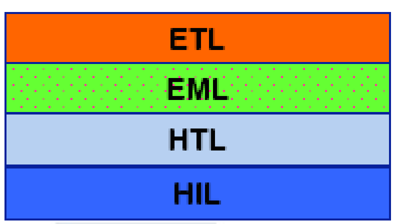
Items	Evaporation (Shadow Mask)	Ink-Jet Printing	LITI
			
Materials	Small Molecule (SM)	Polymer (LEP)	LEP, SM, Hybrid
Position Accuracy	± 15㎛	± 10㎛	± 3.5㎛
Resolution	~200ppi	~200ppi	~400ppi
Aperture Ratio (Top Emission)	30~50%	40~50%	40~60%
Remarks	• M/P: Gen. 2 • Develop: Gen. 4 - Glass handle limit - Mask align limit	• Size: >2m • Simple/Economic process • Material development issue	• Size: >4G • Dry Patterning /multi-stacking • Donor film required

Source: *Hye-Dung Kim, SDI, 2006*

New Technologies_ OVPD

Organic Physical Vapor Deposition (OPVD)





Key advantage of OVPD

Scalability: Large area Deposition

- Close Coupled Showerhead
(Uniform, efficient, no increase the source temperature)

- Throughput
(High deposition rate)

- Yield
(Fast layer switching valve, precise deposition control by mass flow controller, simple contamination control and particle control)

-Reduced running cost
(materials consumption, uptime, investment and facilities cost)

-Full color OLED

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Large area OLEDs made by OPVD

Source: Kodak

FPD technologies

A paradigm shift in future display technologies

-High cost, new materials, large substrate, fabrication tech

Photolithography Process

Vacuum Process

High Cleanness Process

→ **Low cost:** material & process →

Solution Technology

Non-vacuum Process

Ambient Environment

↓

Solution processable:

IJP, R2R, Imprinting,…

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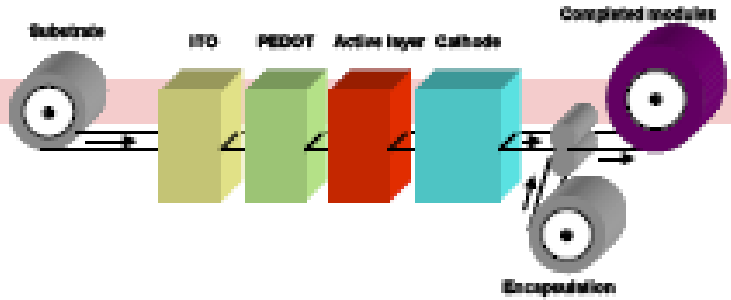
Solution printing technologies

Roll-to-roll printing

TOPPAN

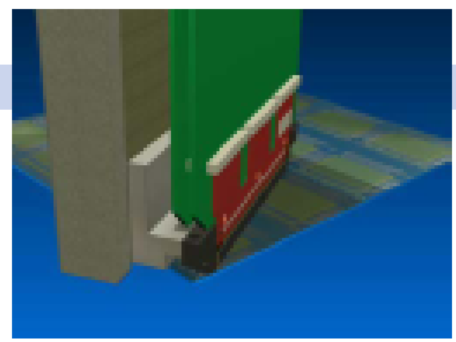


Screen Printing

ADD-VISION

Ink jet printing

litrex Corporation PHILIPS EPSON



Ink jet printing is currently the key to efficient, scaleable display manufacture

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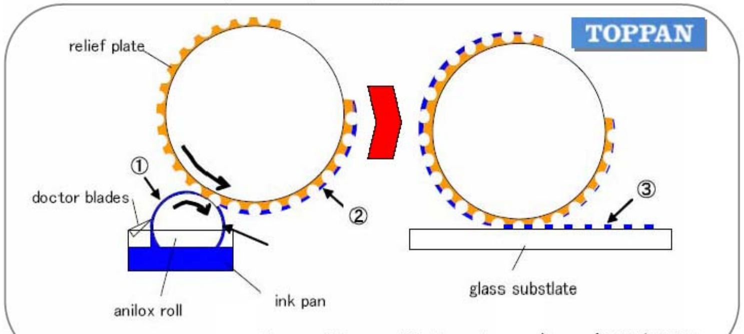
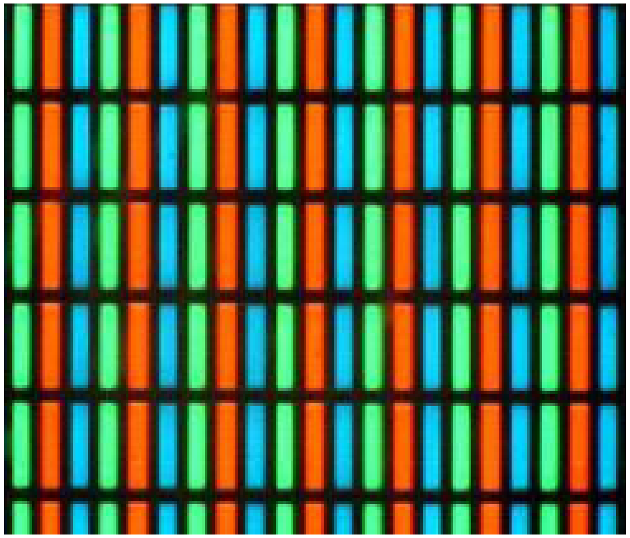
Solution process_ R2R printing

- 5″ displays demonstrated by Toppan
  - 70 ppi resolution (>200 ppi is feasible)
  - 360 µm pixel pitch
  - Thickness variation ~4%, luminance
  - **No need any patterning**
  - **Save cost and processing time**



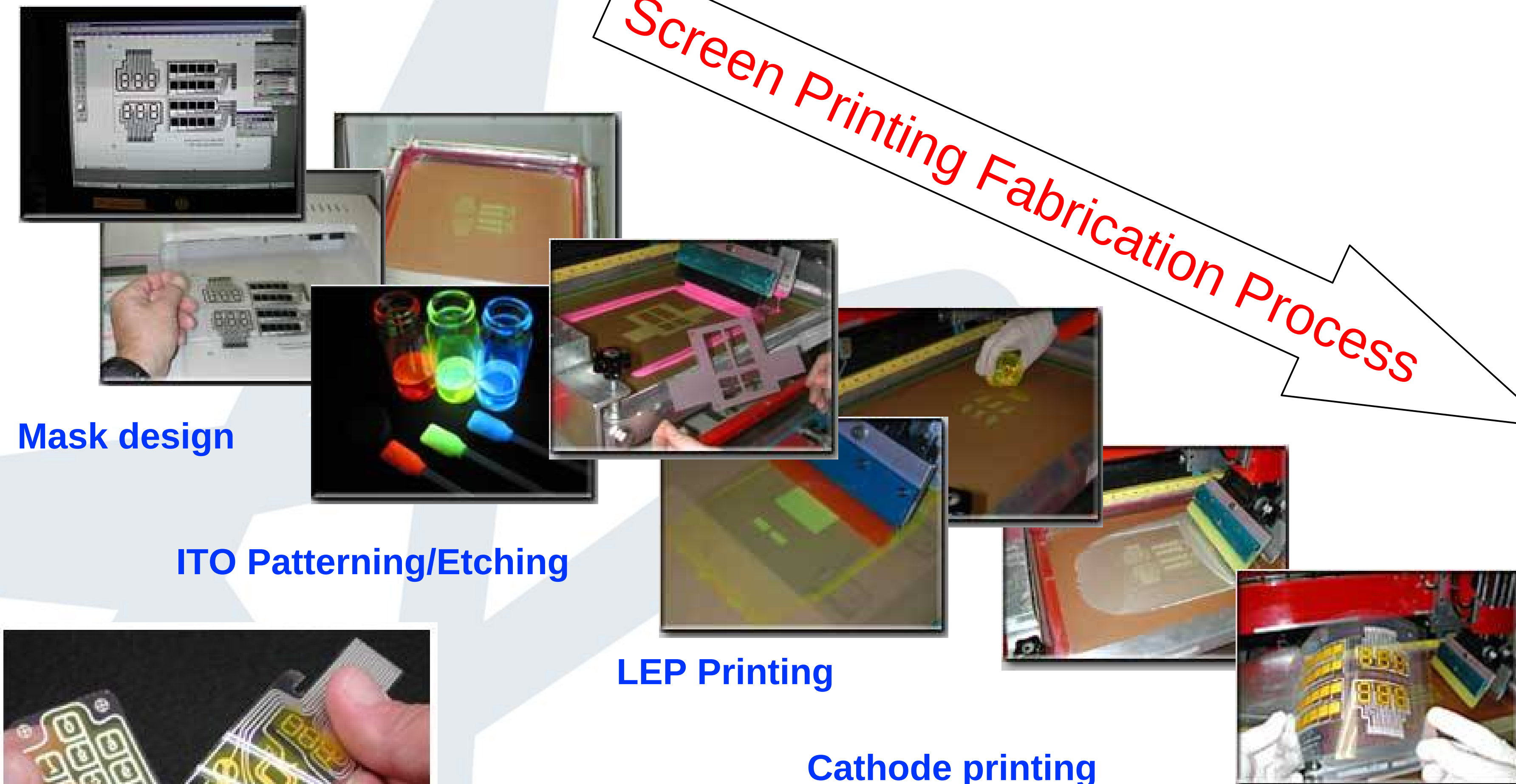
Source: Toppan Printing , Proceedings of IDW/AD 06



Source: Toppan Printing, Proceedings of IDW/AD 06

Solution process _ screen printing

Screen Printing Fabrication Process

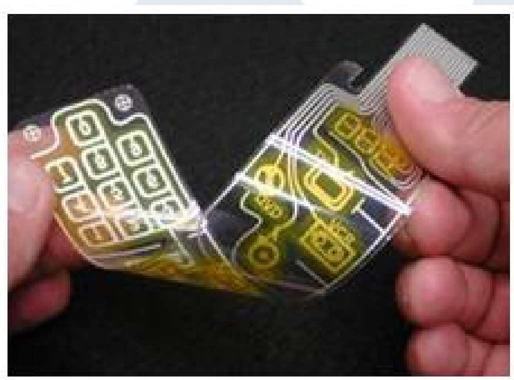


Mask design

ITO Patterning/Etching

LEP Printing

Cathode printing



Source: Add-Vision

Target market: Low-cost simple display and lighting panel

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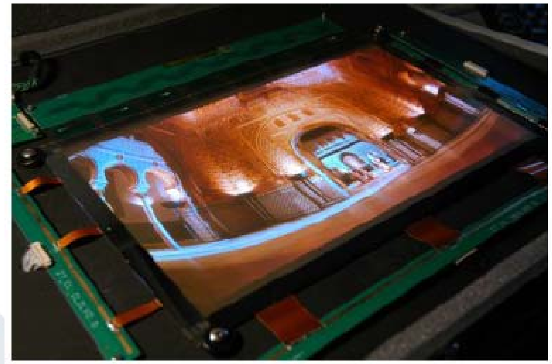
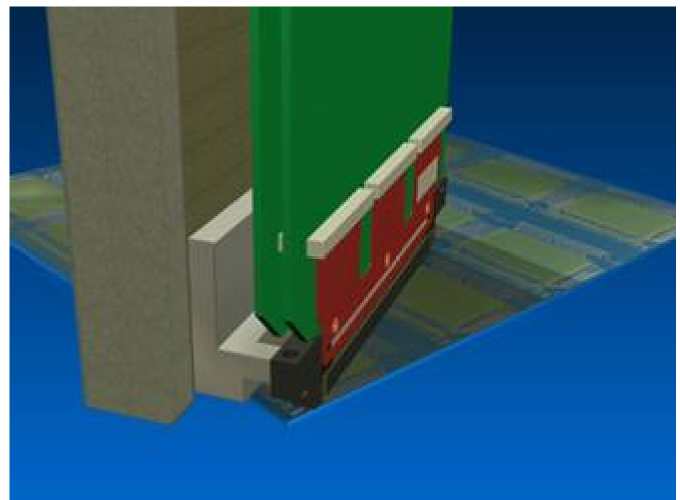
Solution process_ inkjet printing

Seiko Epson: IJP 40" OLED TV



CDT: IJP 14" OLED TV



CDT is leading IJP technologies:

- High scalability using multi-nozzles
- Very complex and relatively slow

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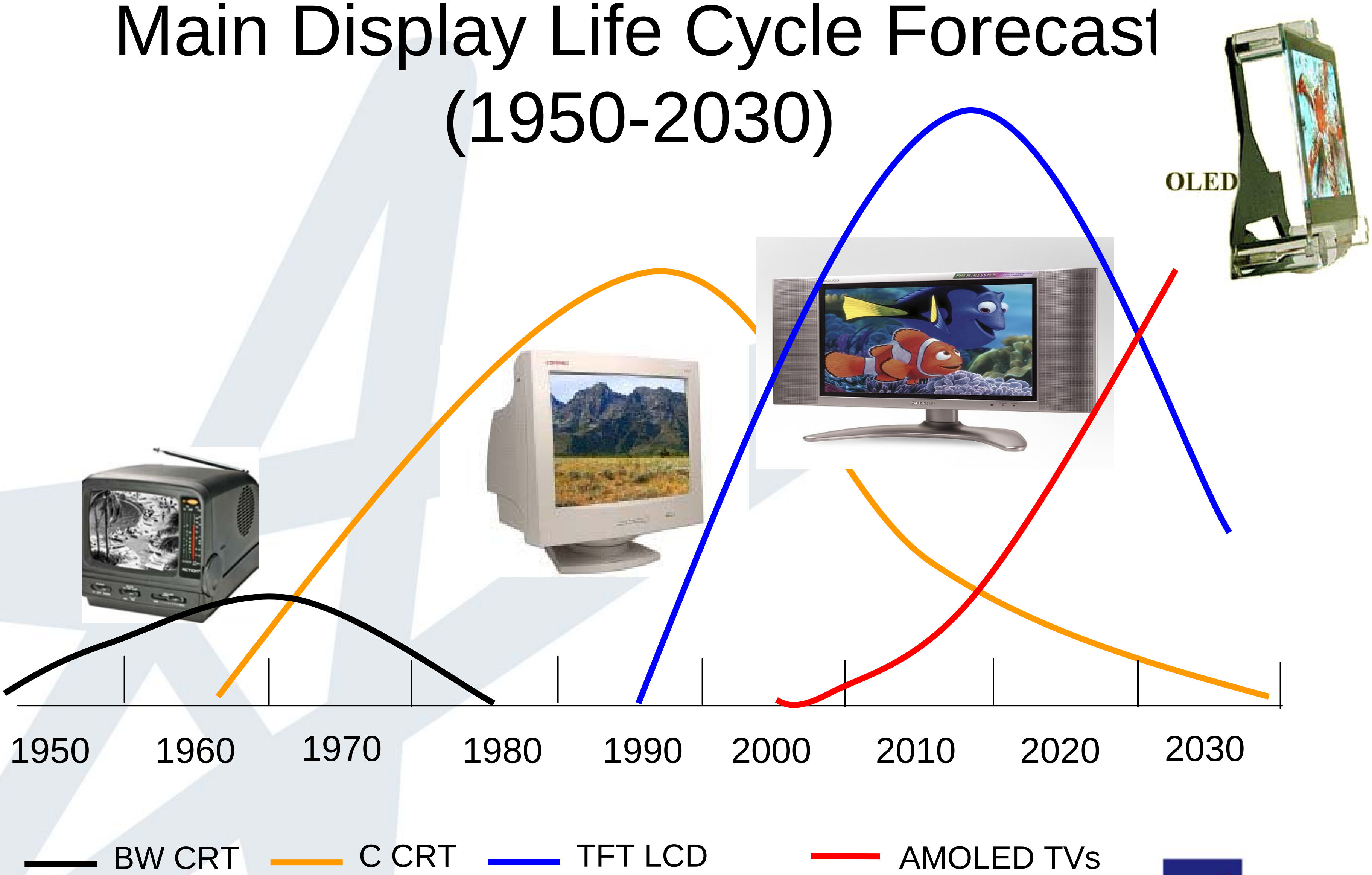
Challenges and Opportunities

- **Materials**: blue & white EL, low-cost ITO alternatives
- **Process**: scalable, cost, high yield
- **TFT Backplane**: compatible with existing LCD technology and infrastructure
- **Encapsulation**: low cost, design flexibility, OLED lifetime must be improved to meet commercial specifications
- **A Killer Application:** flexible or preformed OLED displays, WOLED lighting or backlight…
- **OLED Industry:** still in the early stage of development
- **OLED Market Image:** slow but steady market penetration

Challenges and Opportunities

- **OLED Displays** will have more market share for portable applications (display quality, thickness, light weight etc)
- **PMOLED**: tech is matured & recognized by the market
- **AMOLED**: TFT backplane technology is the key with promising progresses, top-emission is crucial
- **Driving Tech** for AMOLED is still under development
- **Color-by-White** is promising (one device stack, higher yield, & more reproducible, high performance WOLED is needed)
- **Solution Printing** tech is viable for large size and low cost
- **FOLED** will be very attractive for application in conformal, fordable or even flexible lighting and displays

Main Display Life Cycle Forecast (1950-2030)



Source: Display Bank

More news on OLED TVs: http://www.blogcatalog.com/blogs/oled-displays/posts/tag/oled-tv/

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Thank you

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