

Flexible Displays/Electronic Paper and Related Materials

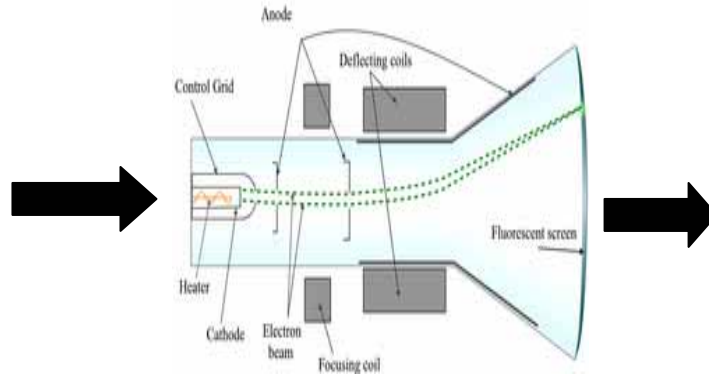
R.C. Liang 梁榮昌

- Trillion Science, Mountain View, CA
- Delta Electronics, Taiwan

Outline

- Overview of the flexible display market
- Recent developments in flexible displays and e-paper
- Technical challenges and opportunities in flexible & roll-able displays
- Conclusions

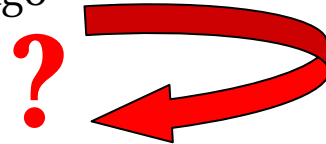
From Books, CRT to Flexible Displays & Format Flexible ePaper



~1000 years ago

~100 years ago

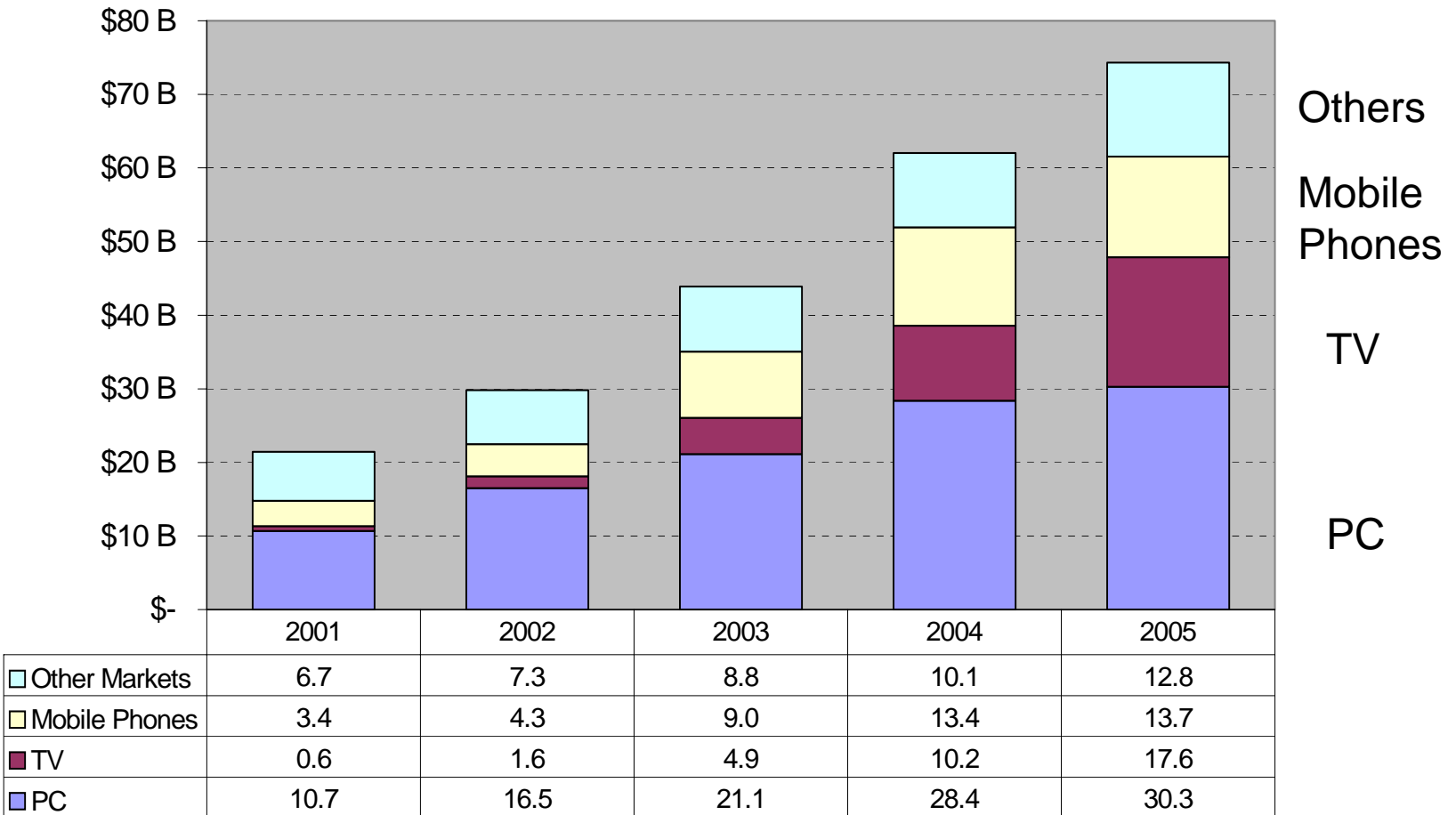
~30 years ago



an ?



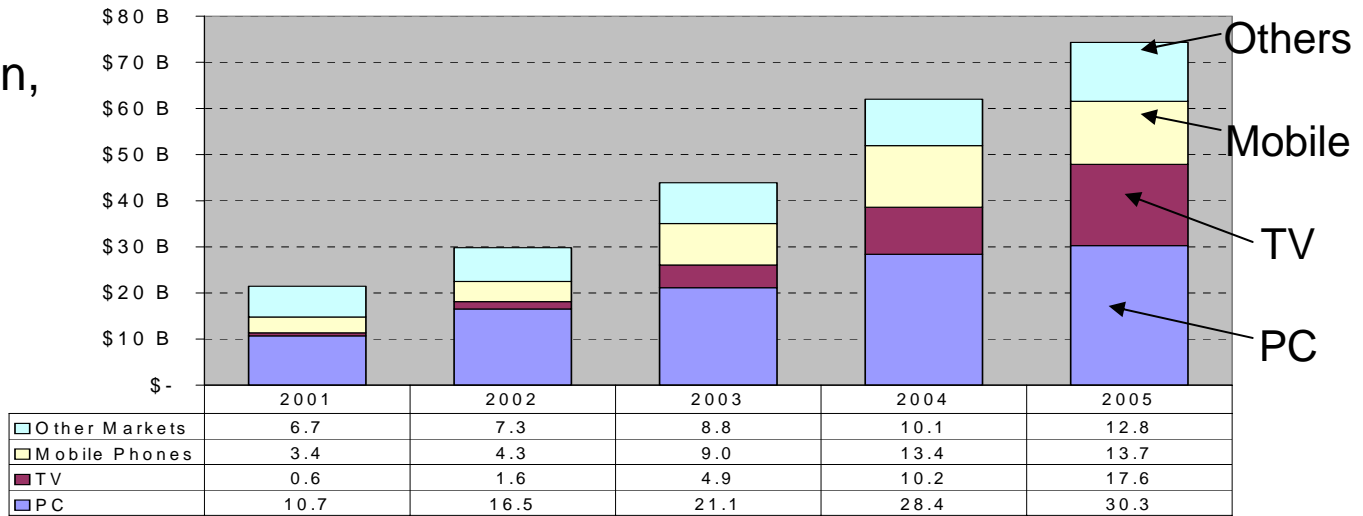
USDC Worldwide FPD Market Report (by Application, 2006)



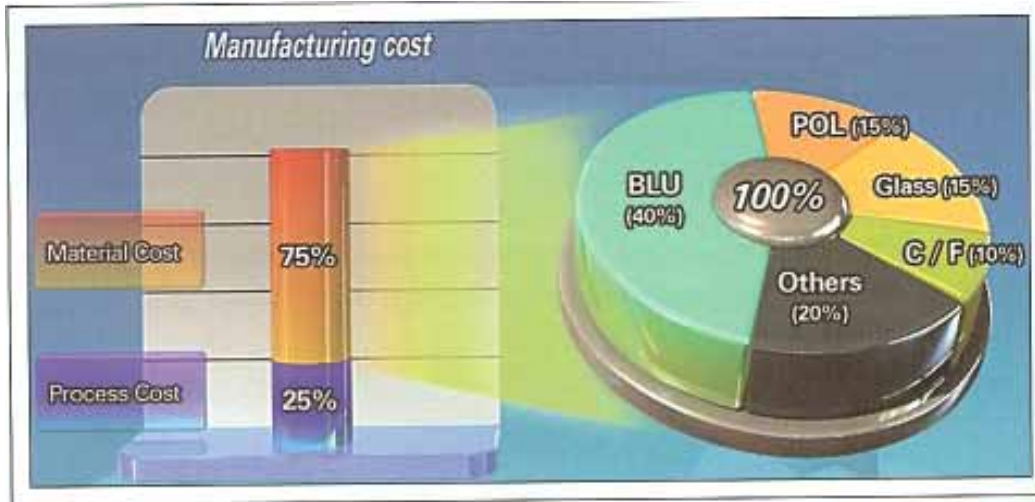
USDC Worldwide FPD Market Report

2006
@\$85B

(by Application,
2006)



Cost Structure of a 40" Display

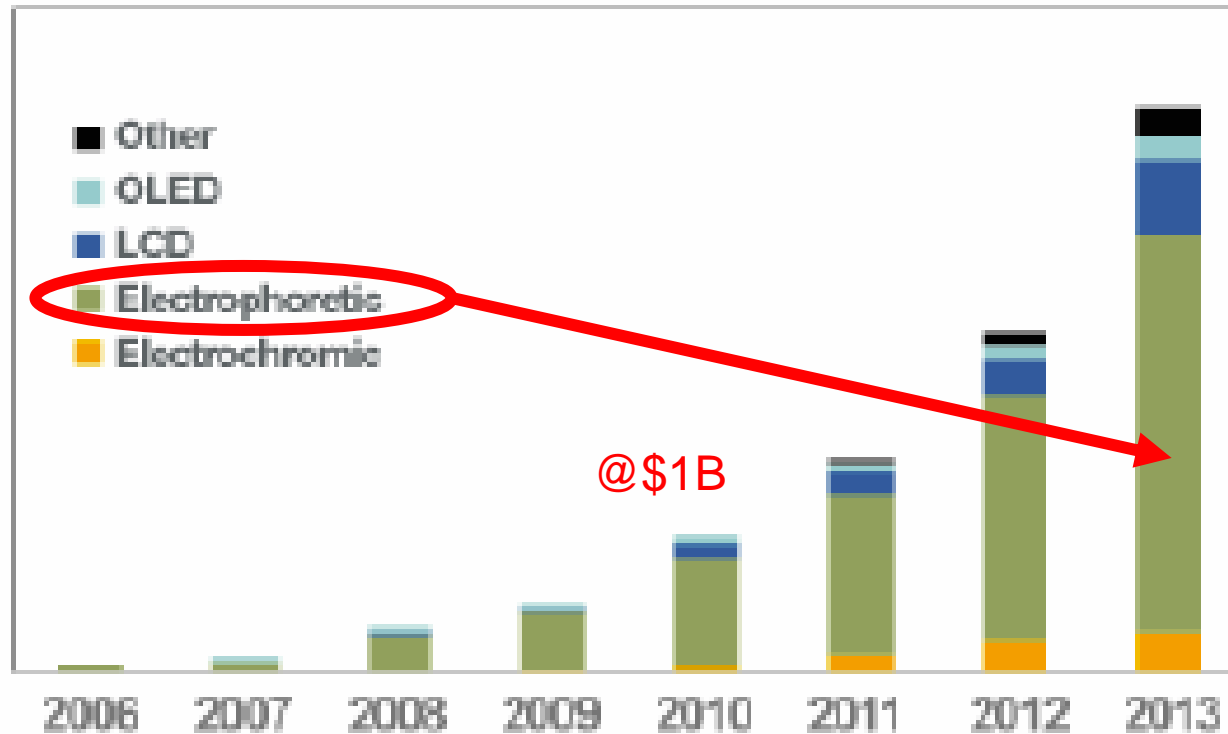


The material cost accounts for **75%** of the total manufacturing cost. ---Information Display, 22(2), p 12 (2006)---

Samsung Electronics Co.

Flexible Display Market to Grow 83.5%/yr

Flexible Displays Market Value by Technology
(Millions of US Dollars)



Recent Developments in Flexible Displays/E-Paper

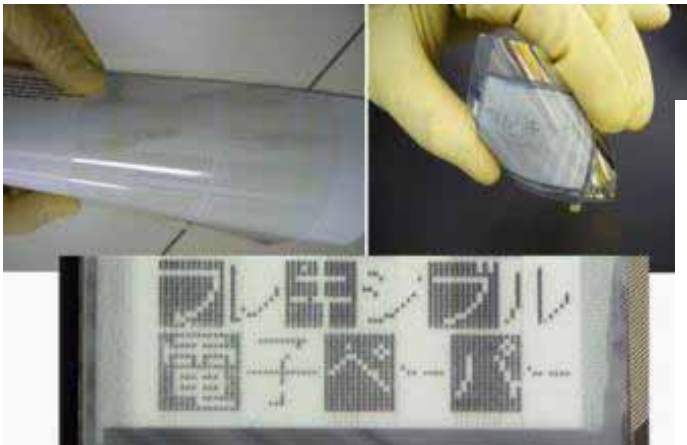
- Electrophoretic displays
e-ink, SiPix, Bridgestone
- Electrowetting
Liquvista (Philips)
- Cholesteric LC
Kodak, Kent Display, Fujitsu
- Electrochromic
Siemens, N'Tera Ltd., and Uppsala Univ.
- MEMS
Qualcom
- OLED/PLED
Kodak, UDC, Xerox, DNP...etc

E-Ink



PlasticLogic
01/06;
10", 100 p/in²

A Flexible Display
Paper-Like Electronic Displays Near Market
By Tracy Staedter, *Discovery News* 01/2006



Specifications

Display Size	42.2 mm x 31.7 mm
Number of Pixels	320x240 (QVGA)
Pixel Pitch	132 μ m (192 ppi)
Contrast Ratio	More than 10
Frame frequency	6.7 Hz
Voltage	3.3V / 8V
Number of Terminals	20
Total Thickness	95 μm
Device Weight	0.24g

0.14g for paper of the same size

Toppan/Tokyo Inst. Tech, room temperature processable amorphous oxide (a-InGaZnO) TFT on plastic

Epson LTPS by SUFTLA

LG Philips Flexible eBooks

a-Si:H TFT on a stainless steel foil w a multi-barrier structure



14" flexible e-book display at the SID'06. over one megapixel and can be viewed from any angle.



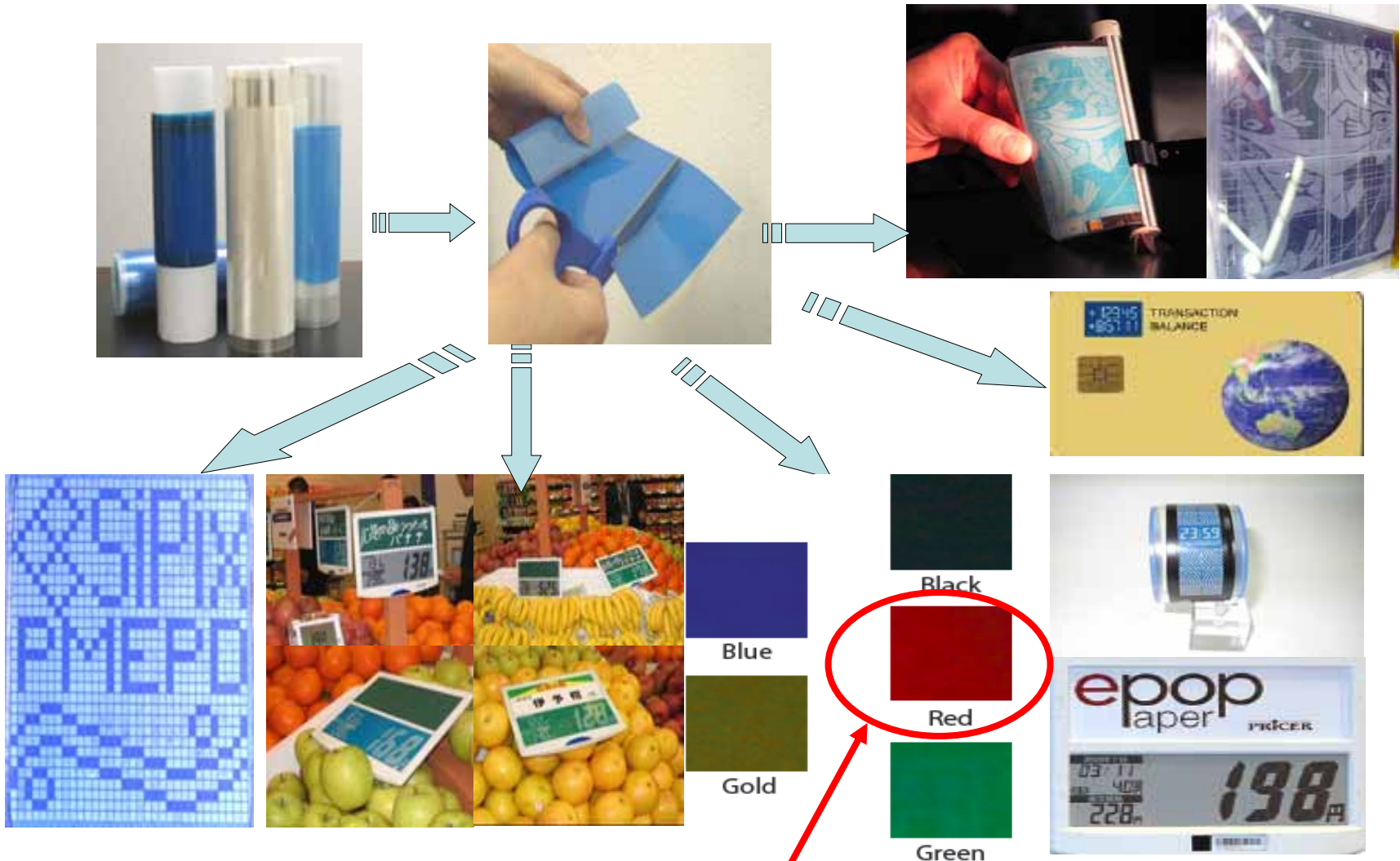
10" SVGA flexible E-ink display
Information Display (6/2006)
CR>10:1; 4 gray levels; 15V
Total thickness: 0.3 mm

SID
Best product award
of 2005

Smart Card by
SmartDisplayer
based on
SiPix
Microcup
EPD

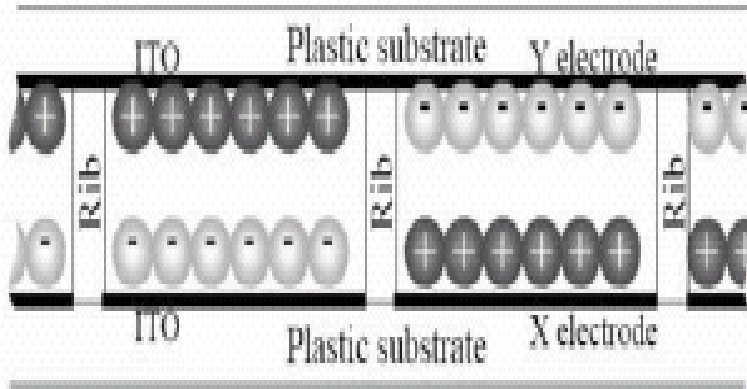


SiPix Microcup EPDs

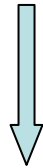


(special dyes jointly developed with BASF)

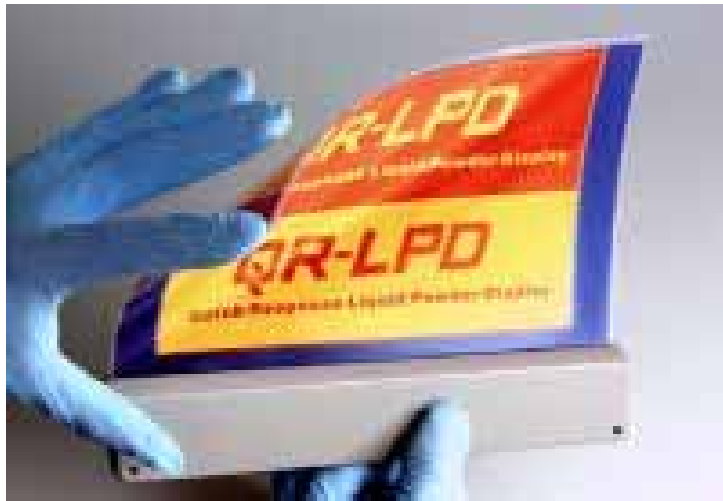
BridgeStone Liquid Powder



2003-04
@10 um
particles



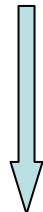
2005-06
@3~4 um
particles



2-color display by color liquid powder
0.29mm, all plastic (06/2006)



Hitachi ePaper 07/2005 400x440



?



Hitachi, 13.1", 512x384
4096 color, RGBW, Color filter (2006)

Electrowetting (by Philips, Cornell Univ, RPI)

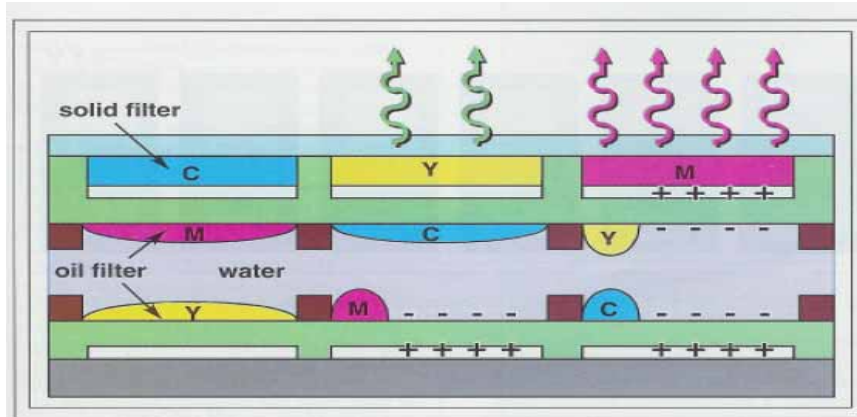
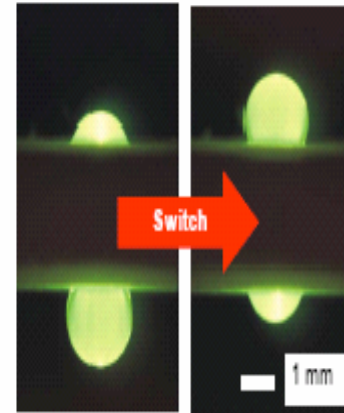
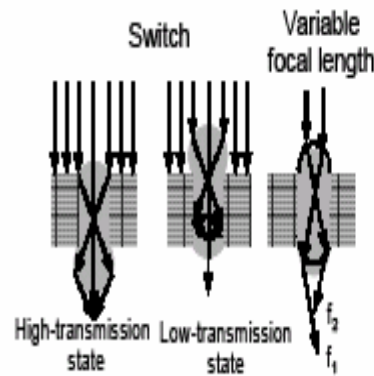
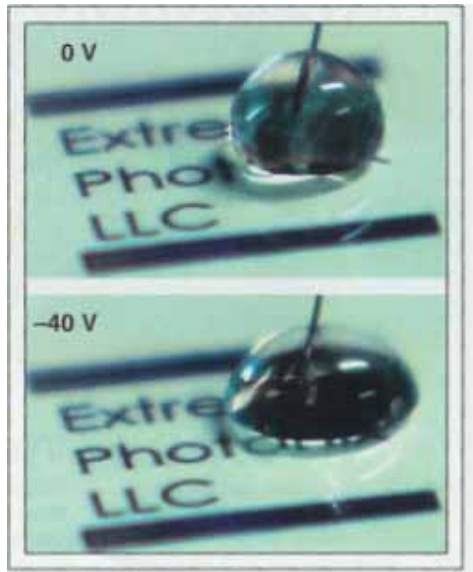


Fig. 5: Shown is a possible subpixel layout for reflective or transmissive CMY ELVs. One subpixel consisting of two differently colored oil layers can produce several colors. The center subpixel, for example, which has cyan and magenta oil layers and a solid-yellow filter, can produce black, green, red, and yellow, depending upon which of the two oil films is displaced.

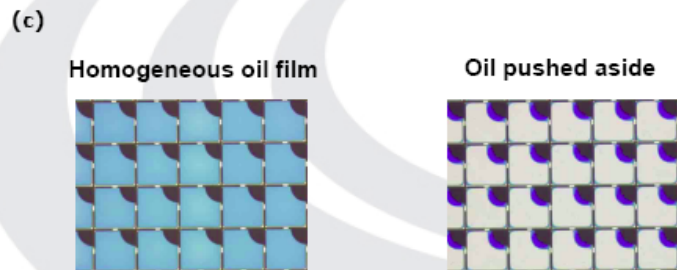
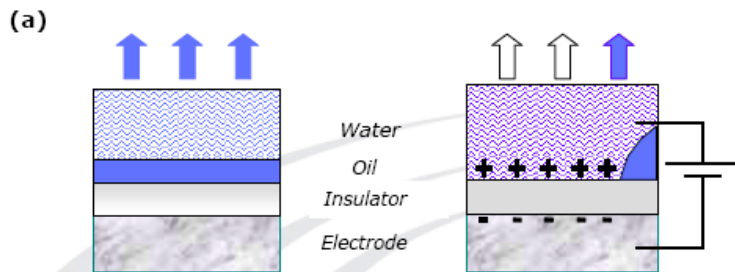
Very high color saturation
C, M, Y colors in all pixels

Liquavista, Electrowetting



- Fast switching rate
- High brightness
- High color saturation

Flexible? Roll-able?
R2R Manufacturing?



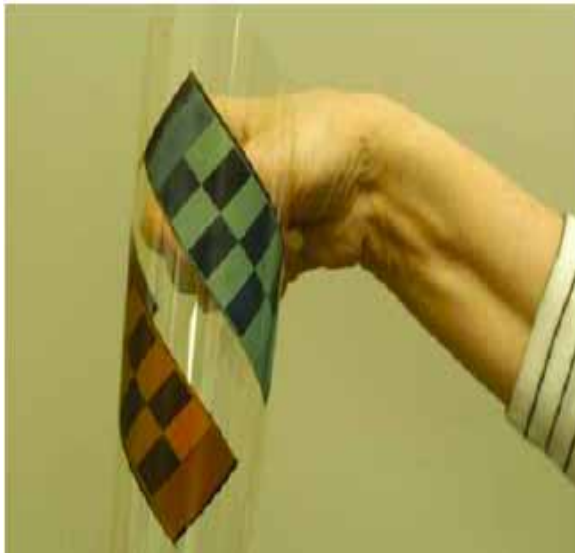
(b)

(d)

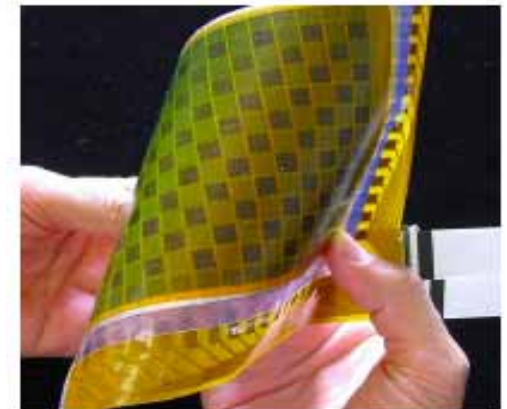
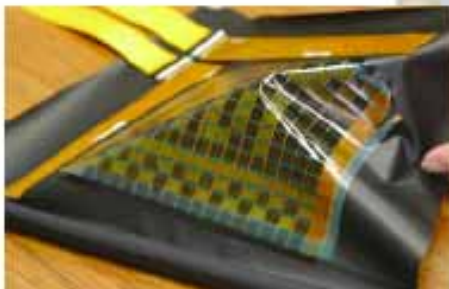
Technology	B/W Reflectivity	Color Conversion	Contrast	Viewing angle	Switching speed (ms)
Reflective LC	50	33	15	Limited	15
CTLC	30	100	10	Limited	50
Electrophoretic	55	33	12	Good	150
MEMS	50	33	12	Limited	<10
Electrowetting*	60	100	15	Good	<10
Paper	70	100	15	Good	-

* optical properties: in-pixel x 0.90 (accounting for losses at walls)

Cholesteric LCD (Kent, Kodak, Fujitsu)

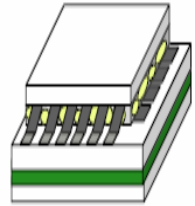


Example of the color rendering in Fujitsu's bendable e-paper with image memory.

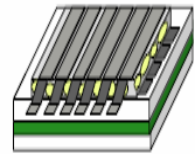


ChLCD on solar cell

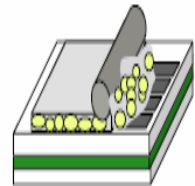
Cholesteric LCD (Kodak/Kent)



5. Coating top clear polymer film



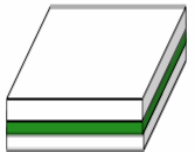
4. Printing top conducting polymer electrode



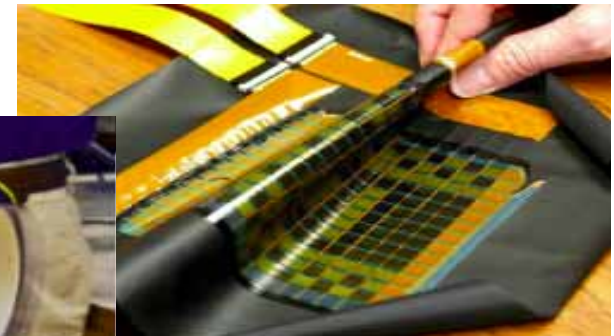
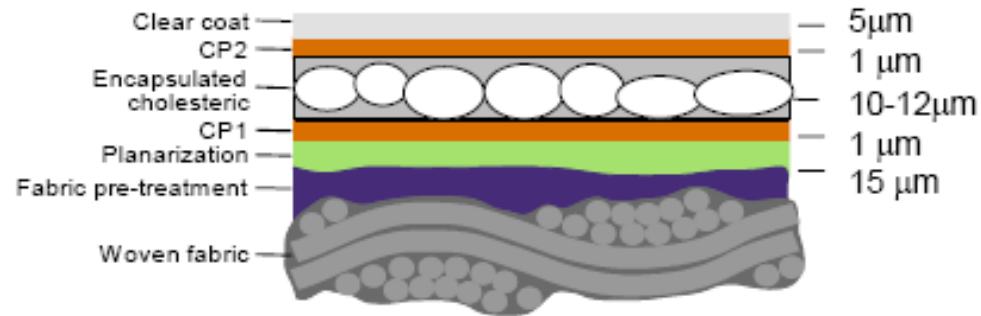
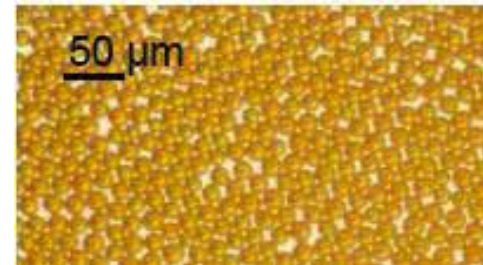
3. Emulsion coating



2. Printing bottom conducting polymer electrode

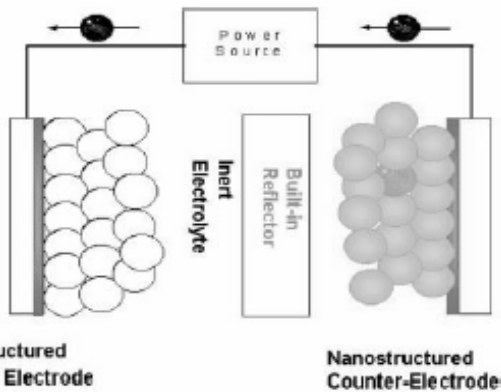


1. Substrate preparation
12 μ m PET/PSA/Release Liner

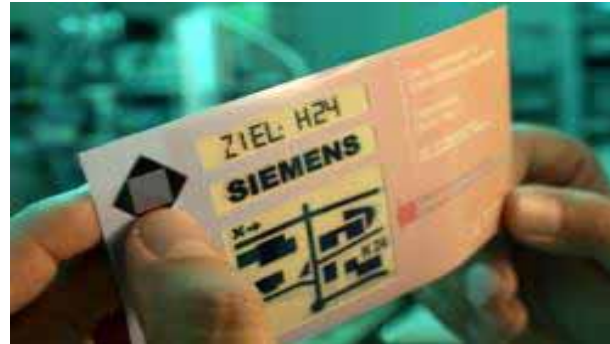


ElectroChromic Displays

(Siemens, N'Tera Ltd., Ireland and Uppsala Univ, Sweden)



(To be launched in 2007)



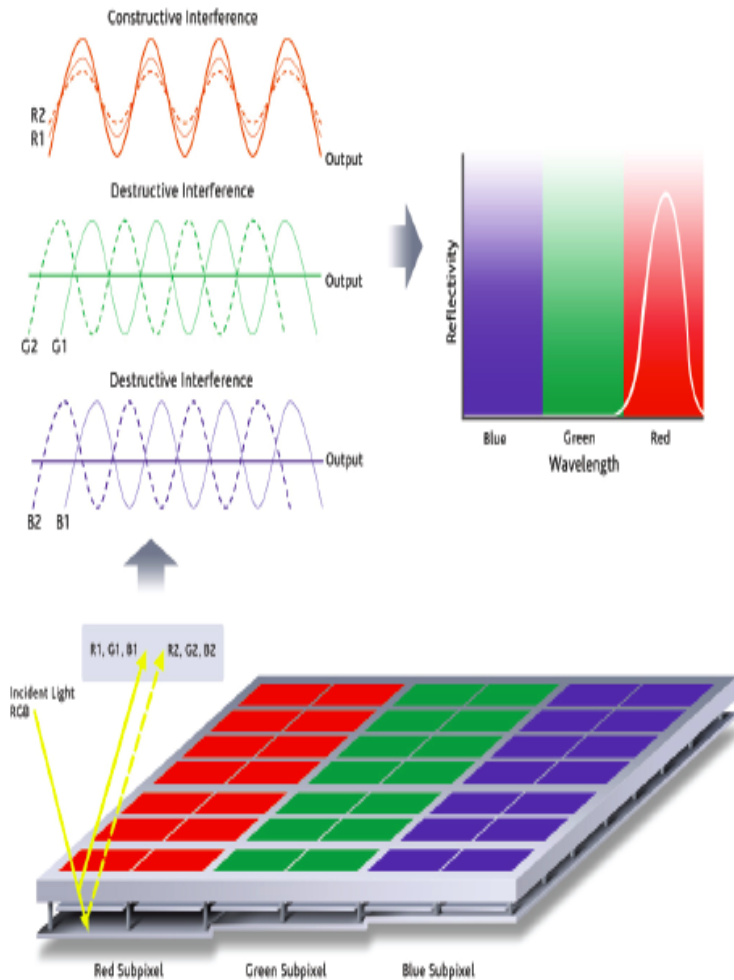
- High Sintering T
- Stainless steel substrate
- Stability of dyes @ high V for High switching rate
- Limited colors shown
- 2-week bistability



<1 Euro for a 3" Label?

Qualcom (Iridigm) Digital Paper

(A MEMS Based Display)



- High switching rate/V
- Low color saturation
- Expensive process
- Large area?
- Flexible?

Flexible OLED/PLED



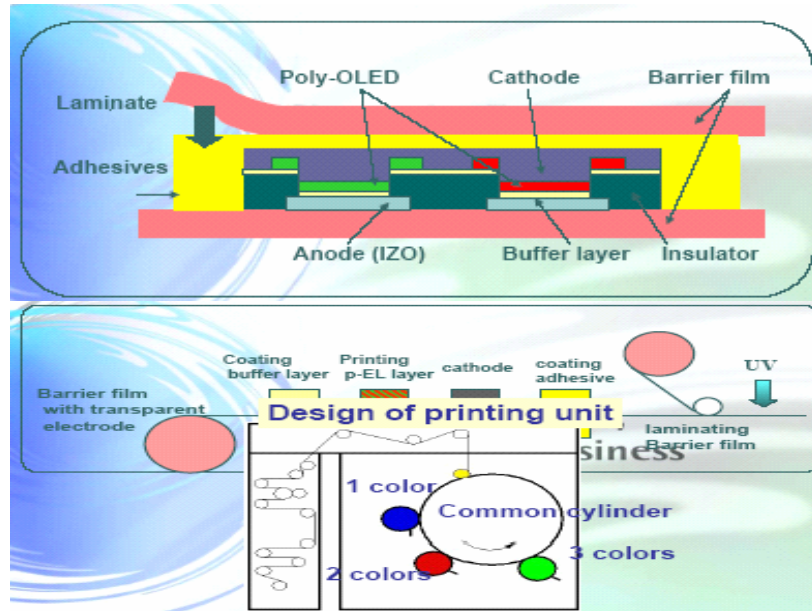
Pioneer

OLEDs in Point of Purchase Displays

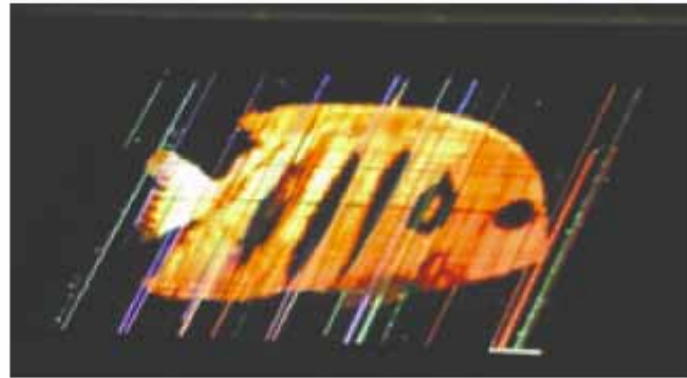
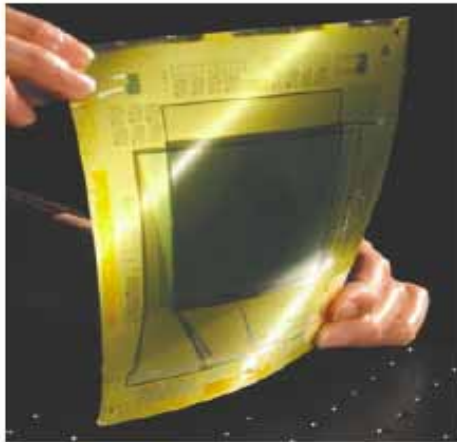
Tokyo International Book Fair



Printed PLED (DNP)

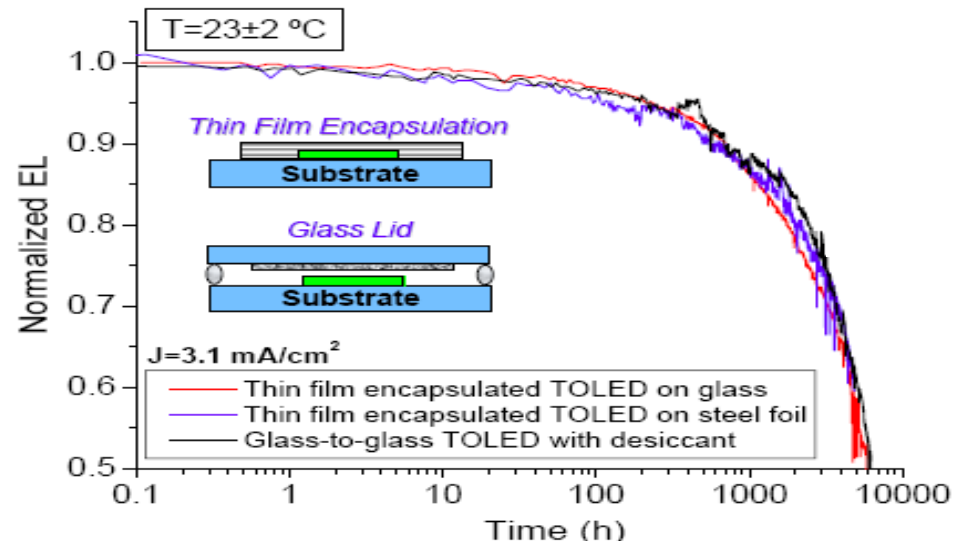


AM-OLED (UDC/Xerox/Vitex)



6"x6" QVGA Xerox Poly-Si TFT on Steel, UDC PHOLED, Vitex barrier

- 320x3x240
- 60 Hz refresh rate
- 64 grayscale levels
- Full color, RGB stripes
- 100 dpi (85 um sub-pixel pitch)
- Top emission
- Phosphorescent R and G, fluorescent B
- Multilayer thin film encapsulation



Technical Challenges & Opportunities

for Rollable Displays & e-Paper

For LCDs:

- Thickness & Light Management
- In-cell polarizers/retarders
- Cell gap control during bending/rolling
- Viewing angle

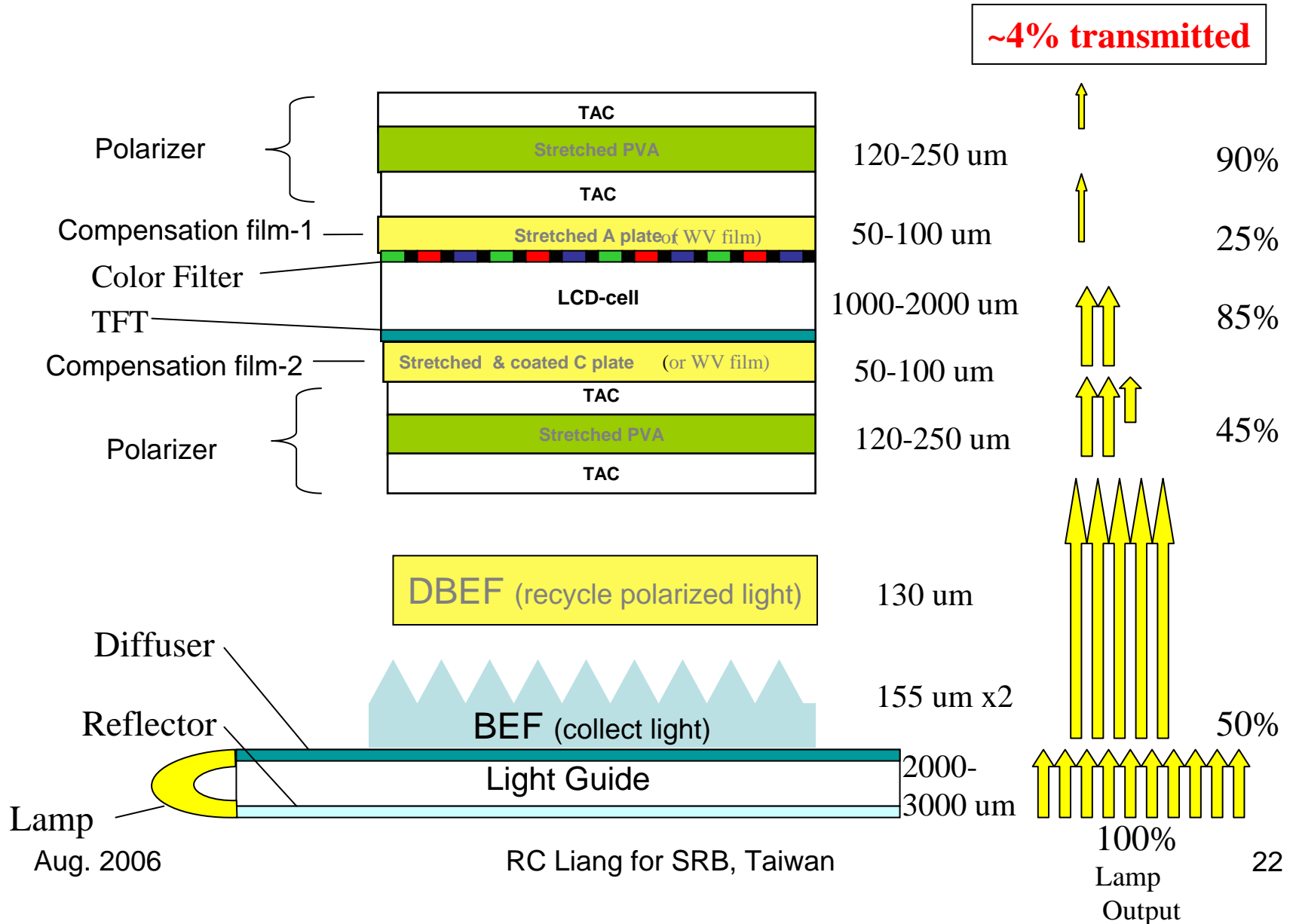
General Process Issues:

- Not all technologies are printable
- Resolution/registration of printing & converting

General Material issues:

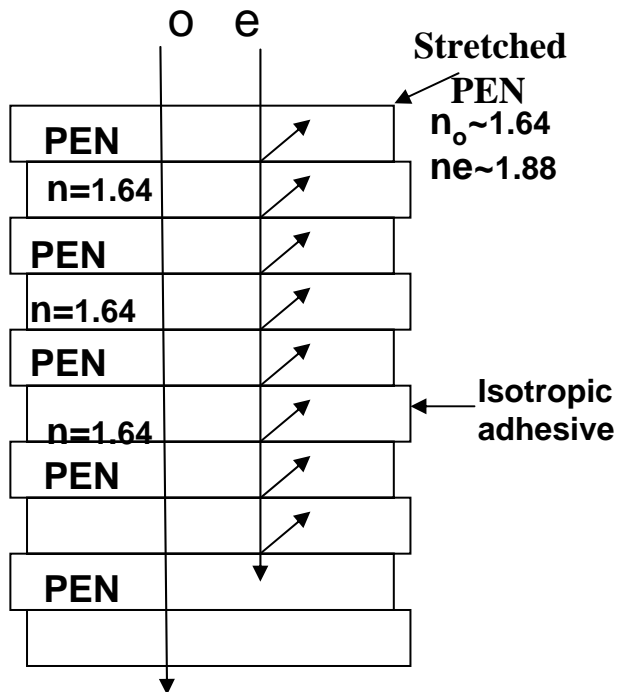
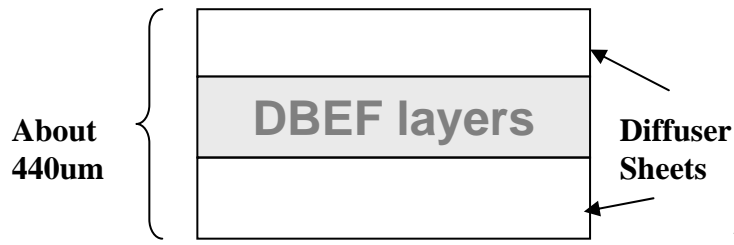
- Barrier properties, surface roughness and temperature resistance of substrate
- Mismatch of thermal expansion coefficients
- Flexure resistance of the electrodes
- Flexible Battery
- Fine pitch connection & packaging materials (Trillion Science)

Light/Power/Thickness Management

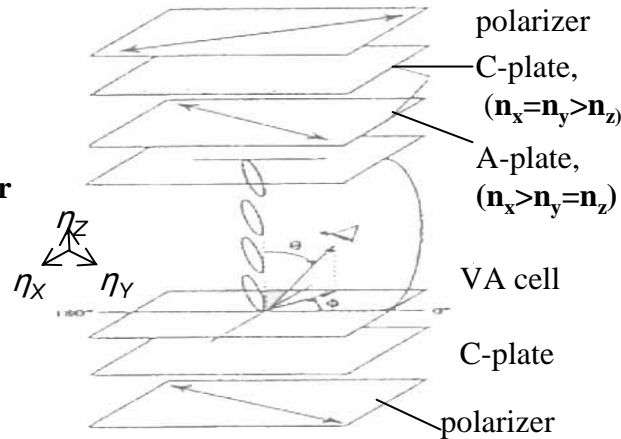


Optical Films Currently Used in LCDs

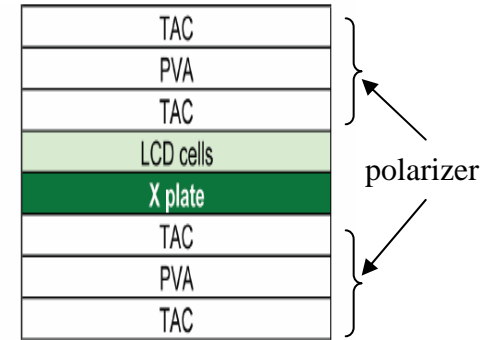
(A) 3M DBEF Film



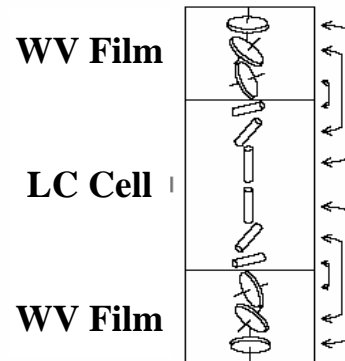
(B) A & C plates (for MVA Mode)



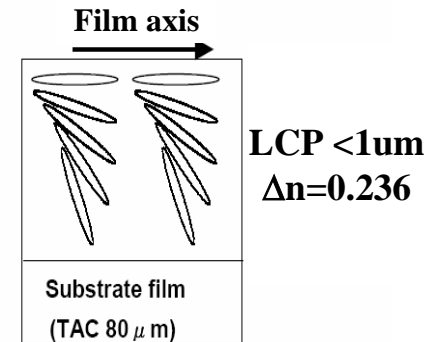
(C) X-Plate



(D) Fuji Photo WV film



(E) Nippon Oil NH Film



Brightness Enhancement Film by Coating

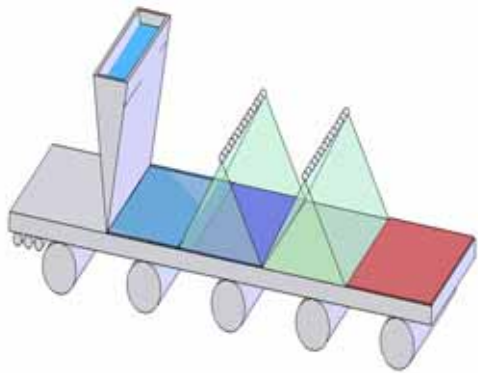
(Nitto, 3M, Polaroid, ROLIC, OCLI, Reveo, BASF, Honeywell, Brown Univ., ITRI...)

(5A)

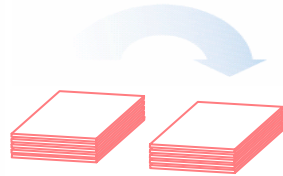
LC
Coating

Drying

UV
Curing



Converting



**LC film on carrier;
Transfer
Lamination or
overcoating, if
needed.**

(5B)

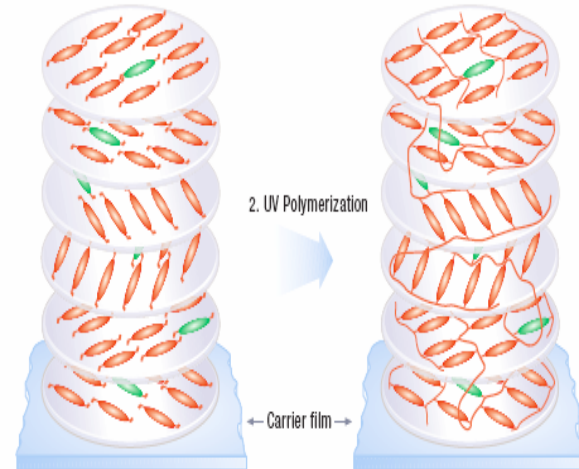
Paliocolor®LC 242
Nematic LC



Paliocolor®LC 756
Chiral dopant



1. Coating on
substrate

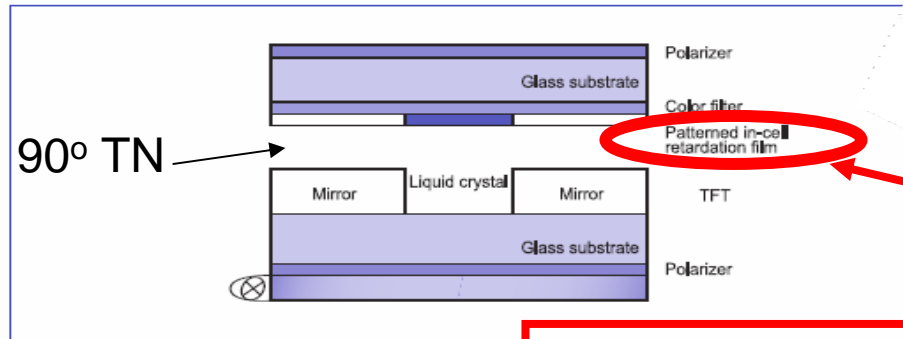


Next moves:

- Coated $\frac{1}{4}$ plate
- Oblique angle alignment or stretching
- Single-pass broad-band brightness enhancement

In-Cell Polarizer/Retardation Film-1 (Philips/BASF)

The white area is a 1/4-wavelength film, and the black area is where there is no retardation film material. Source: Philips Research (Netherlands).



Transflective & Reflective LCDs

- Broad-band 1/4 wave coating
- PI alignment layer
- 2-step exposure
- post thermal curing

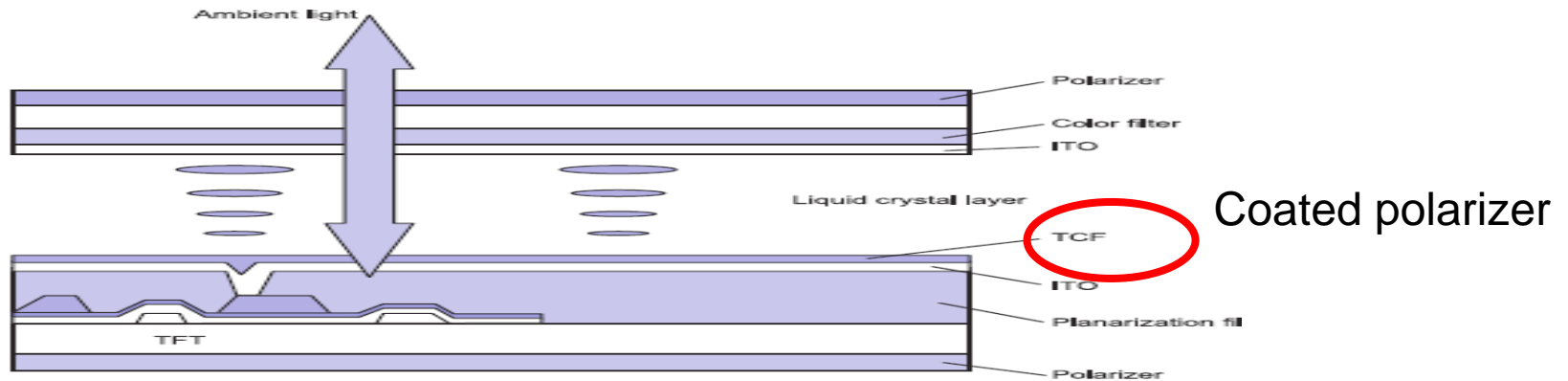
The dark area indicates zero phase shift, and other areas indicate regions with a 1/4-wavelength phase shift. Source: Philips Research (Netherlands).



- Thinner
- Brighter
- Wider viewing angle
- Lower V

Image displayed on the semi-transparent LCD panel utilizing a patterned in-cell retardation film

In-Cell Polarizer/Retarder-2 (SONY)

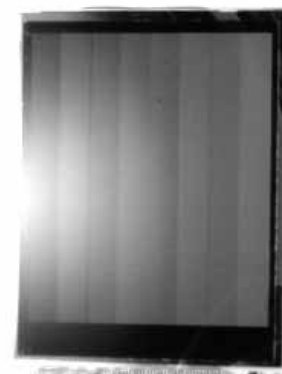


Source: Sony.

Type of liquid crystal panel	Existing transmission type	TCF panel
Transmission rate (%)	7.5	6.7
Contrast ratio [dark]	≥ 200	≥ 200
Contrast ratio [under 20,000 lux of outside light]	5	10
Color reproduction range [NTSC ratio, dark state] (%)	50	50
Color reproduction range [NTSC ratio under 20,000 lux of outside light] (%)	17	25



(a) Without TCF



(b) With TCF

- Polaroid 1980's: H-polarizer for in-cell applications

- Chemical resistance, alignment and polarization efficiency need to be significantly improved

Toward Roll-to-Roll Manufacturing

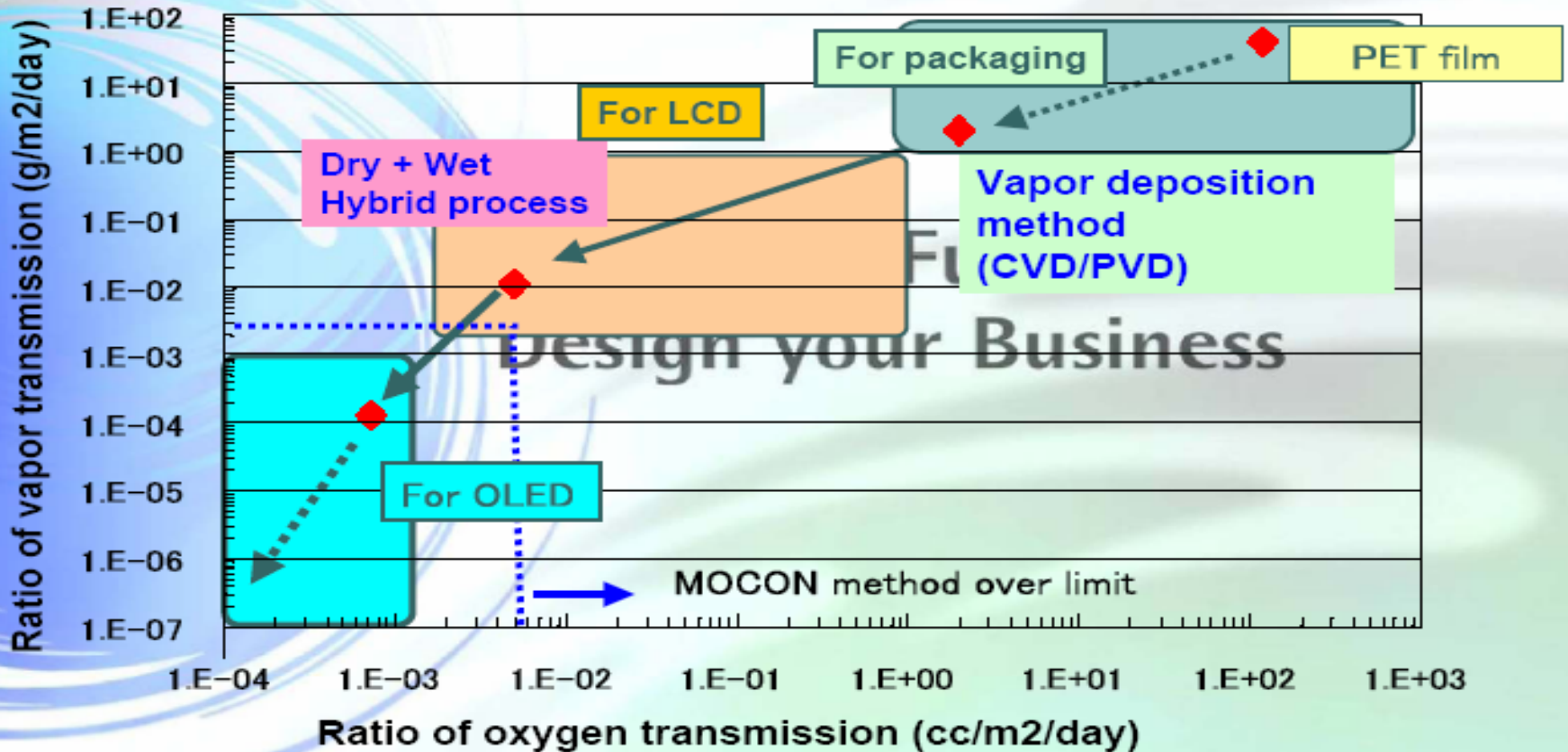
Patterning Processes

Process Technology State of the Art Development Phase

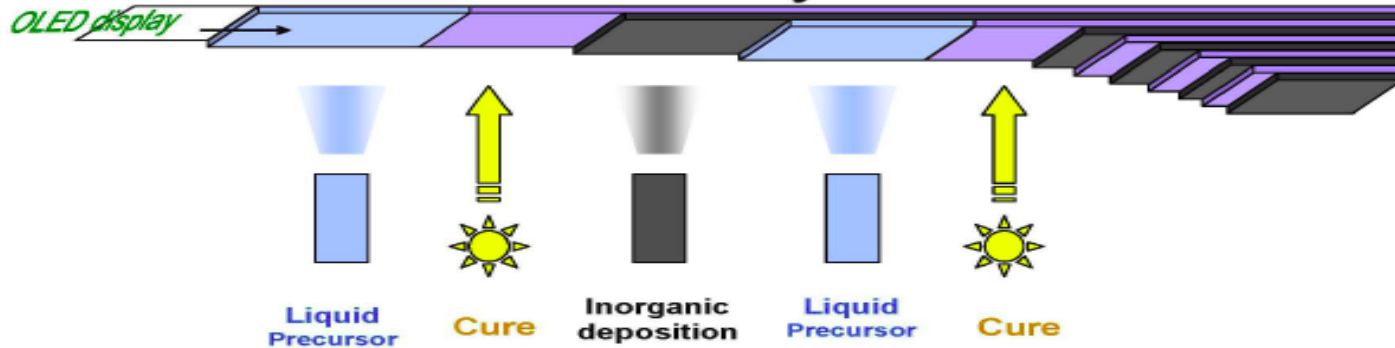
	Line Width	Register	Productivity	Players
Photolithography	2.5 μm	<1 μm		Philips Infineon
Direct Inkjet	40 μm	5 μm	9 m^2/hr	Litrex PARC
Surface Energy +Inkjet	5 μm	1 μm	9 m^2/hr	Plastic Logic
Laser Transfer	5 μm	3 μm	60 m^2/hr	
Traditional Print	50 μm	20 μm	Low at this registration !	Anitra Mann
Soft Lithography	50 nm	250 nm	0.04 m^2/hr (25-100 mm substrates)	MII, Abducat Nanonex, EV, Suss

Barrier Properties

Gas barrier performance and development target



Barix™ Multilayer Process



Vitex

•Inorganic:

- Aluminum oxide deposited by DC reactive sputtering
- Thickness 30-100 nm

•Organic:

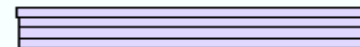
- Monomer mixture deposited in vacuum
- Non-conformal deposition: Liquid-Vapor-Liquid- (UV curing)-Solid
- Thickness 0.25 – several μm

•4-5 polymer / inorganic pairs (dyads) for encapsulation

Sigma Technologies

1. Clear Ultra High Barrier Film Based On Lamination of a High Quality Single Clear Barrier Film Produced at Speeds of 7-10m/sec
2. Clear Desiccant Film Placed Both In front and Behind the Device, Designed to Extend the Life of the Final Package
3. Heat Sealable Aluminum Foil Barrier Layer Placed on the Back Side of the Device – Also Functions as A Ground Plane

Clear Laminate Barrier Film



Clear Desiccant Film

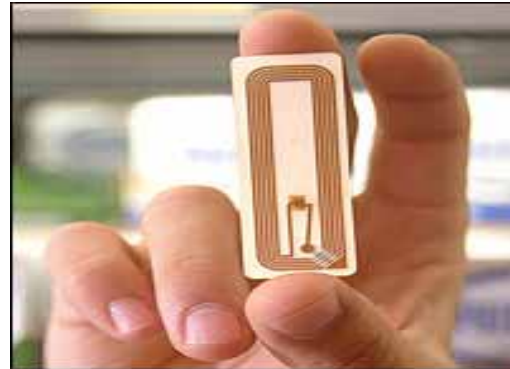


Aluminum Foil Barrier Layer



Aug. 1

NEC Organic Radical Battery (ORB)



Gel battery boost for
radio tags

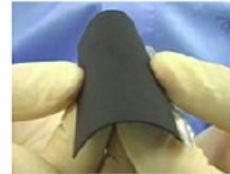
(12/2005)

- <1 mm thick and can be recharged in 30 sec.
- no harmful chemicals typically used in rechargeable batteries
- about 300 um gel polymer layer

Target Applications:

- Smart cards
- RFID
- Wearable computers
- E-paper

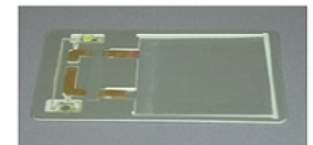
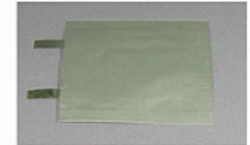
フレキシブル電極



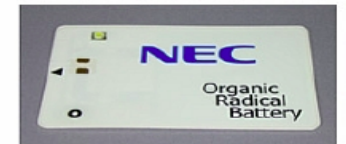
フレキシブル電池



薄型フレキシブル電池



薄型フレキシブル電池内蔵カード



Flexible Batteries

Solicore Li Battery



Li Polymer, MnO_2/Li

- 3V, 10-30 mAh,
- <1%/month self-discharge
- Operation T: -20~60°C
- ≥ 0.35 mm

Aug. 2006

Enfucell Paper Battery



- Metal is oxidized at one side of paper and MnO_2 is reduced at another side of the paper when the battery is connected.
- A paper-containing electrolyte as the separator.
- M = Zn, Al, Ni...; 1.5V if Zn and MnO_2 are used.

Others: Polaroid

RC Liang for SRB, Taiwan

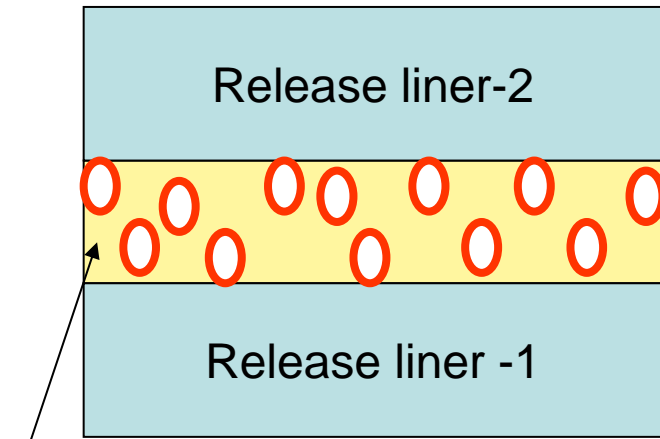
Fuji Electric System



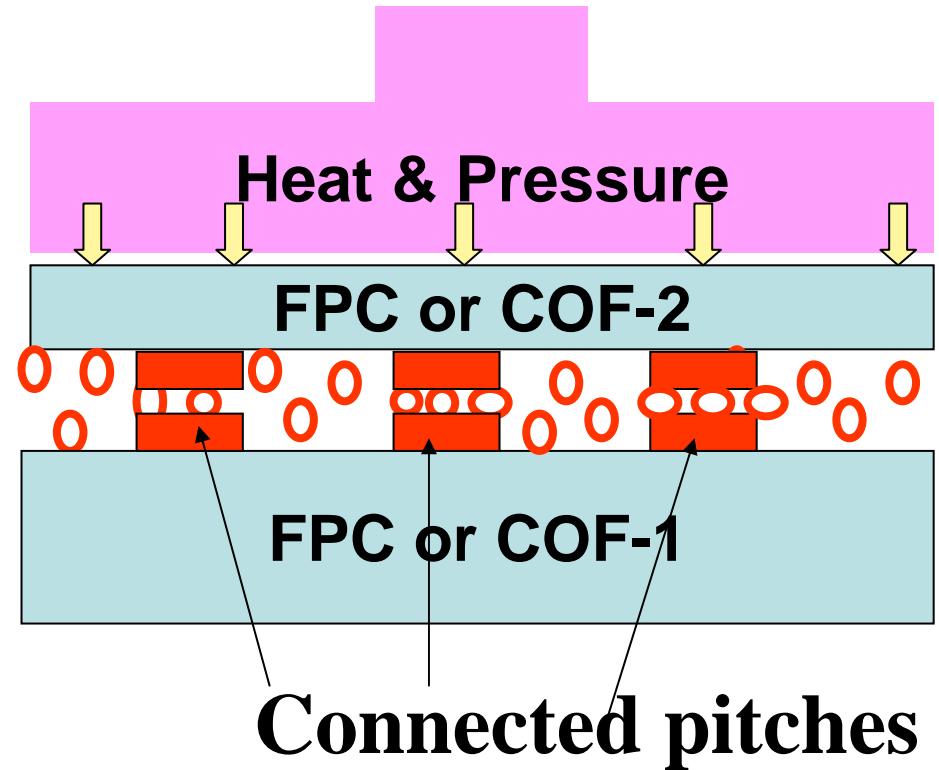
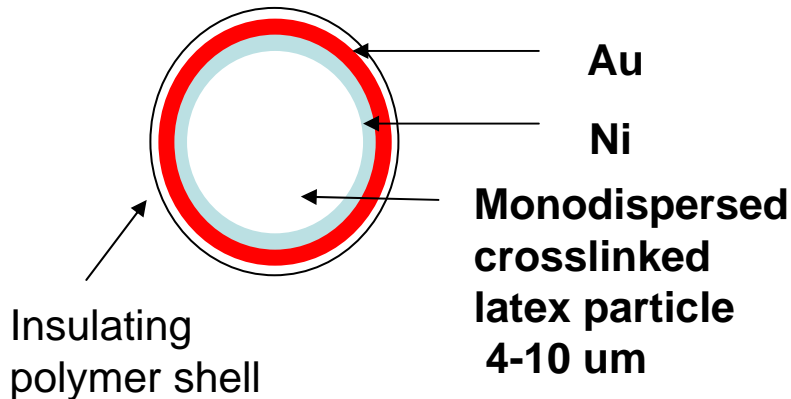
- Roll-to-roll flexible, tandem junction (SiGe/a-Si) solar cell on polyimide
- Jointly developed with Kumamoto University and the Kumamoto Techno Industrial Foundation.
- 30MW by 2009

Other flexible Solar cell companies:
ECD, Akzo Nobel, Konarka...etc

Anisotropic Conductive Film (ACF)



Low T Curable Epoxy Adhesive

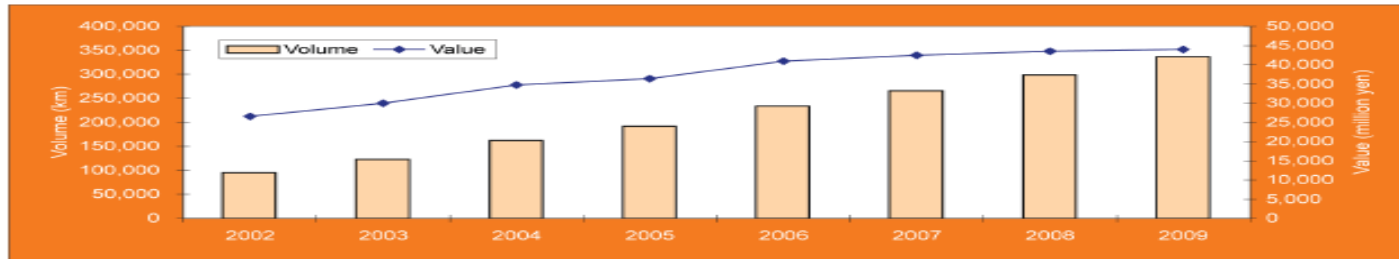


- ACF is critical for bonding fine pitch display or chip to substrate, e.g. FPC, COF.

- As of today, a pitch size of 40-50 um appears to be the resolution limit of ACF.

World-wide Market and Applications of ACFs

About US\$400M in 2005 @ 13% AGR (30% increase in volume)



FY	Unit	Actual		Estimate	Forecast				
		2002	2003	2004	2005	2006	2007	2008	2009
Volume (km)		95,000	123,000	162,000	192,000	234,000	266,000	299,000	337,000
% change from previous year		-	129.5	131.7	118.5	121.9	113.7	112.4	112.7
Value (million yen)		26,600	30,000	34,800	36,400	41,000	42,500	43,500	44,000
% change from previous year		-	112.8	116.0	104.6	112.6	103.7	102.4	101.1
Average unit price (yen/m)		280	244	215	190	175	160	145	131

Estimated by Fuji Chimera Research Institute, Inc.

FPC to FPC bonding



Chip-to-glass (COG) or chip-on-film (COF)

ACF



Display to FPC or PWB



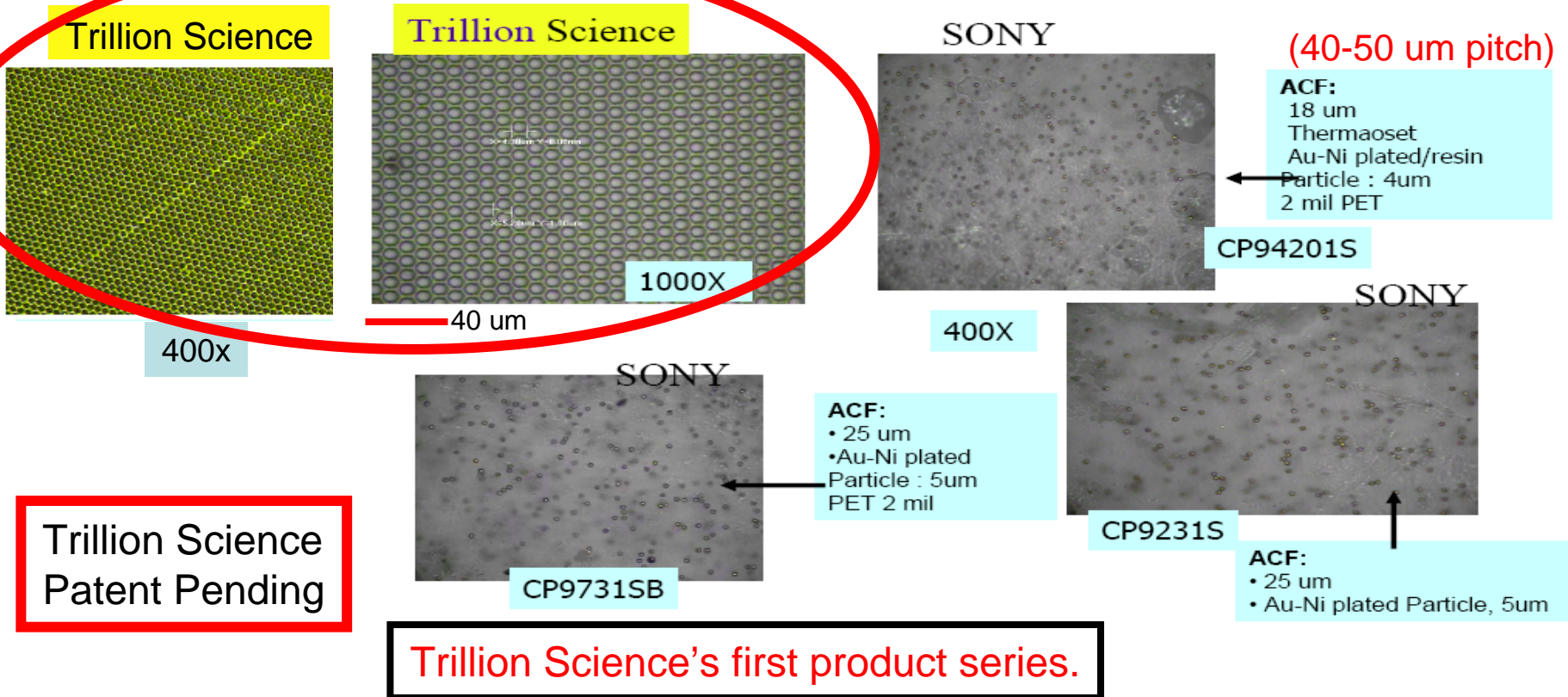
Flip Chip Bonding



Two Major Suppliers: SONY and Hitachi, pitch size: ~40-50 um

For high-end portable & roll-able displays, a finer pitch ACF is needed.

Trillion Science Vs. SONY & HITACHI



Trillion's Fixed Array ACFs compared with SONY and Hitachi's:

- **Ultra fine pitch (<20 um, the world's record?)** achieved by the fixed array structure
- **Higher conductivity** in electrode areas
- Comparable resistivity in the non-electrode area
- Comparable curing kinetics and performance of bonding adhesive
- **Significantly lower particle loading (very low material cost)**
- **Significantly simpler roll-to-roll process (significantly lower Manufacturing cost)**

Scale-up and Reliability tests underway

Conclusions

- Flexible displays and e-paper are gaining more and more visibility with a very impressive growth in market share.
- Technical challenges and opportunities exist in almost all areas, particularly in
 - New display/imaging technologies
 - Substrate & Barriers
 - Optical films, particularly in coated and in-cell applications
 - Batteries
 - Connection and packaging materials
 - Patterning & Manufacturing processes
- Taiwan has great potential to become the key leader in both technology and manufacturing in this huge and fast growing industry.