Flexible and Roll-able Displays/Electronic Paper

A Brief Technology Overview

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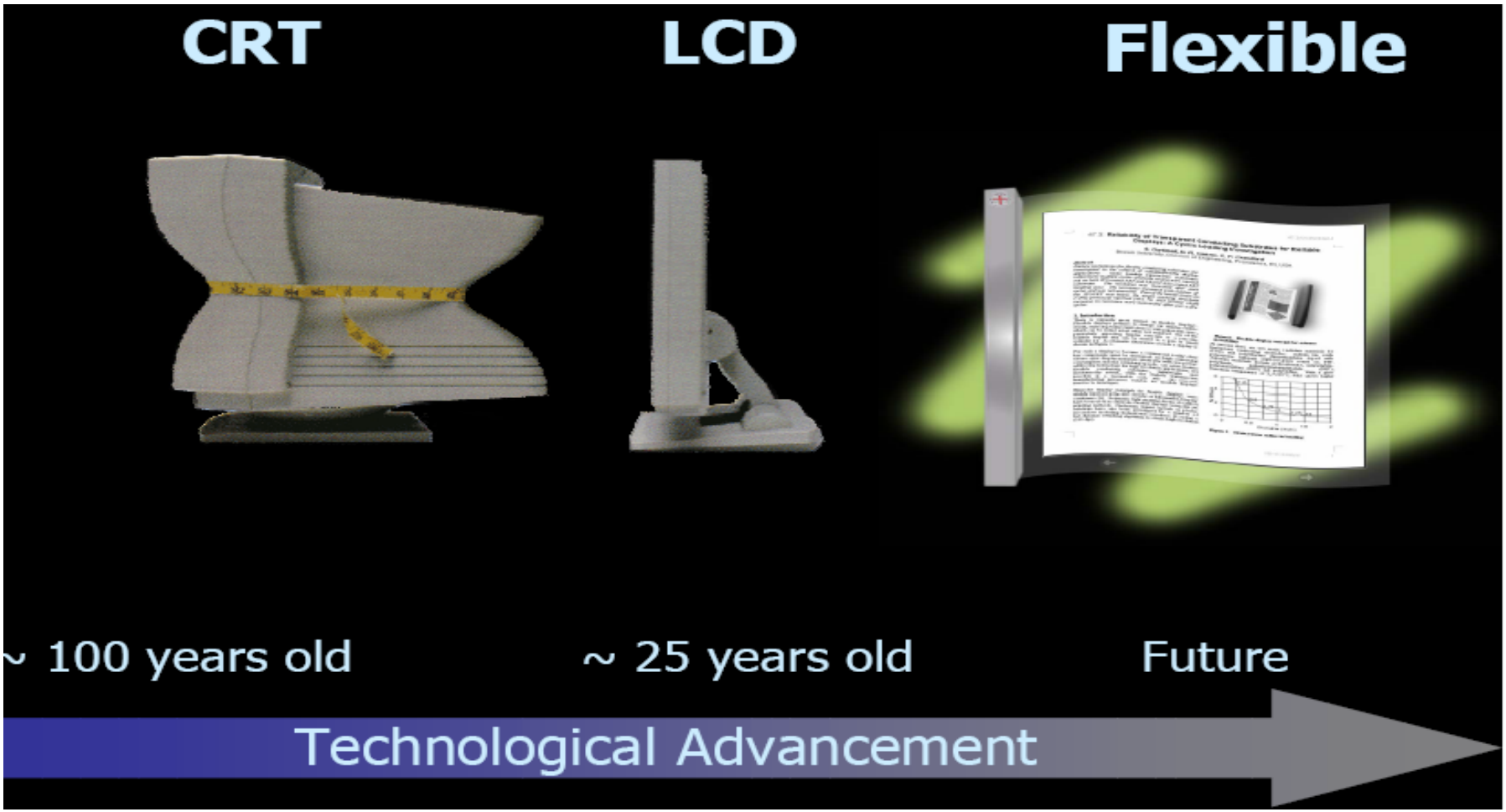
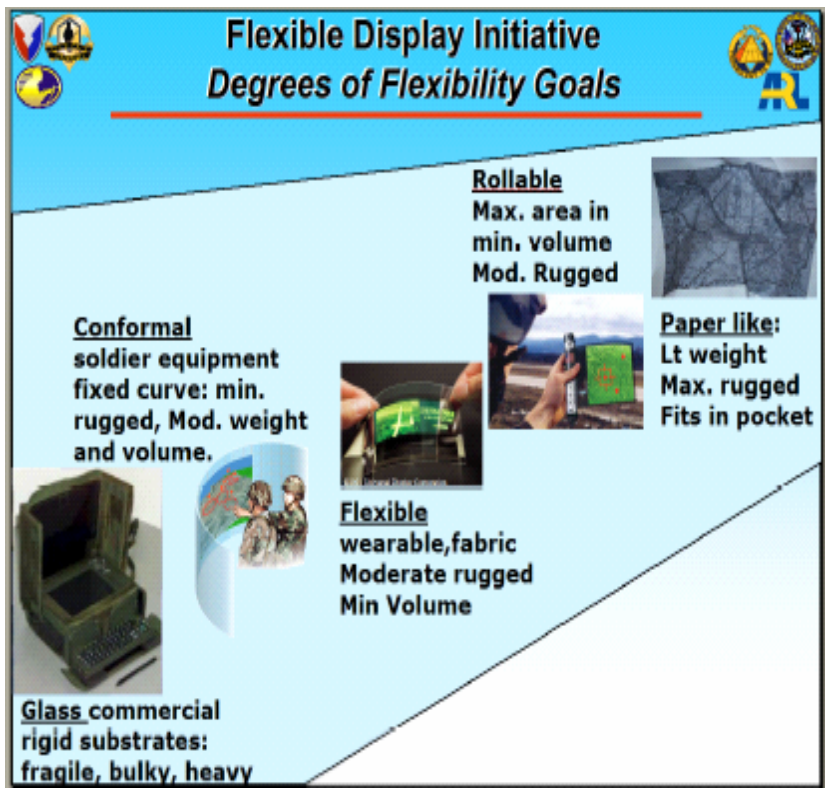
Toward Flexible & Rollable Displays/Electronic Paper



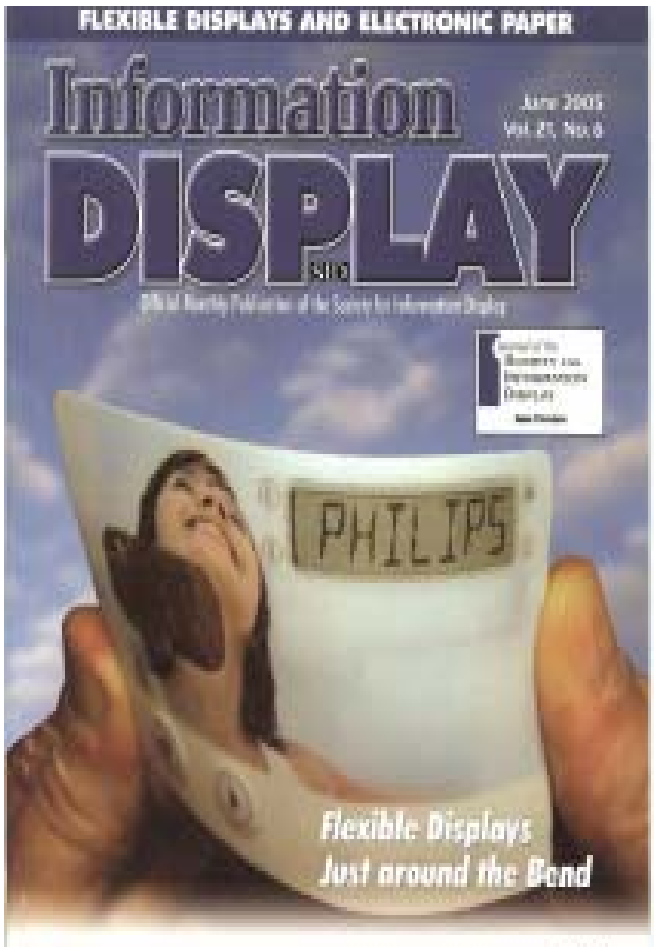
The US DoD Flexible Display Initiative

Source: D. Hopper (Air Force Research Lab.)



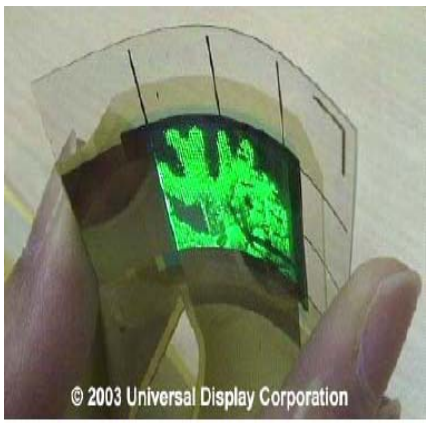
Source: J. Pellegrino (Army Research Lab.)

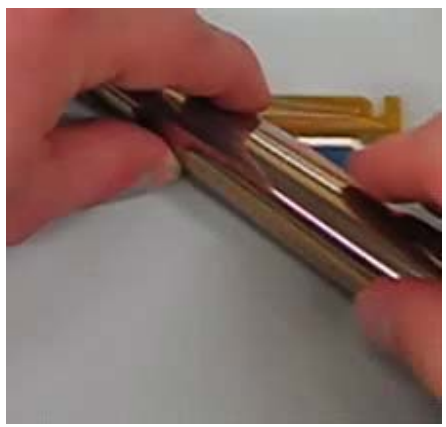
Recent Developments



Hitachi ePaper 07/05 400x440

Conformal, Wearable, and Rollable Displays demonstrated recently





Definition of Electronic Paper

A display with the basic characteristics of printed media:

- Compatibility with flexible substrates
- No power required to maintain an image (bistability)
- Wide viewing angle
- Insensitive to ambient lighting and various humidity/temperature conditions.

And preferably,

- Low manufacturing cost
- Low Operating cost
- Format Flexibility
- Easy Converting

Paper vs. Displays

Dot density required in printed media to match the resolution of a 200 ppi display with 24-bit color (IBM)

Consideration/Condition	"Equivalent" Print
Nature images with binary halftone	~200 lpi
Smallest reliable spot, minimum linewidth	~133 lpi screen; ~600 dpi
Smallest area with full grey scale (4 bit dots)	~800 dpi
Equivalent bit areal density	~ 690 dpi

- 400 dpi ⇔ typical 100 ppi of current electronic displays.
- inexpensive 2400 dpi printers are now available for home and office uses.

As of today, printed Media is still of much higher resolution and low cost

Technical Challenges

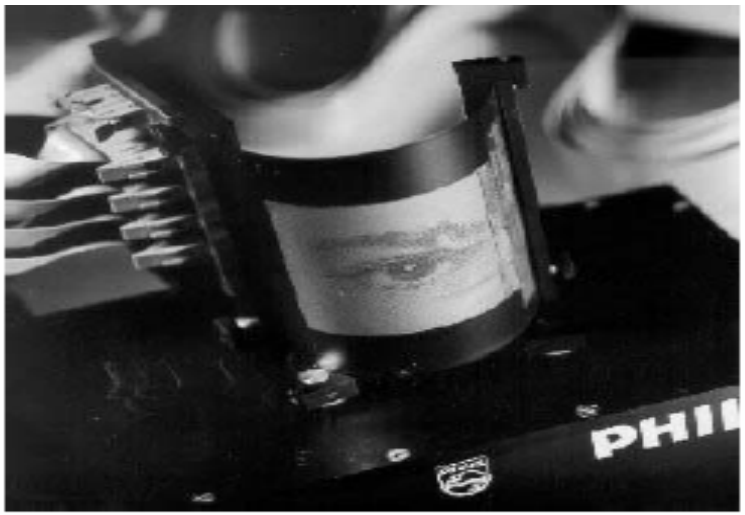
General issues:

- Barrier properties, surface roughness and temperature resistance of substrate
- Mismatch of thermal expansion coefficients
- Flexure resistance of the electrodes
- Flexible Battery

For LCDs:

- Cell gap control during bending/rolling
- Viewing angle
- Thickness & Light Management

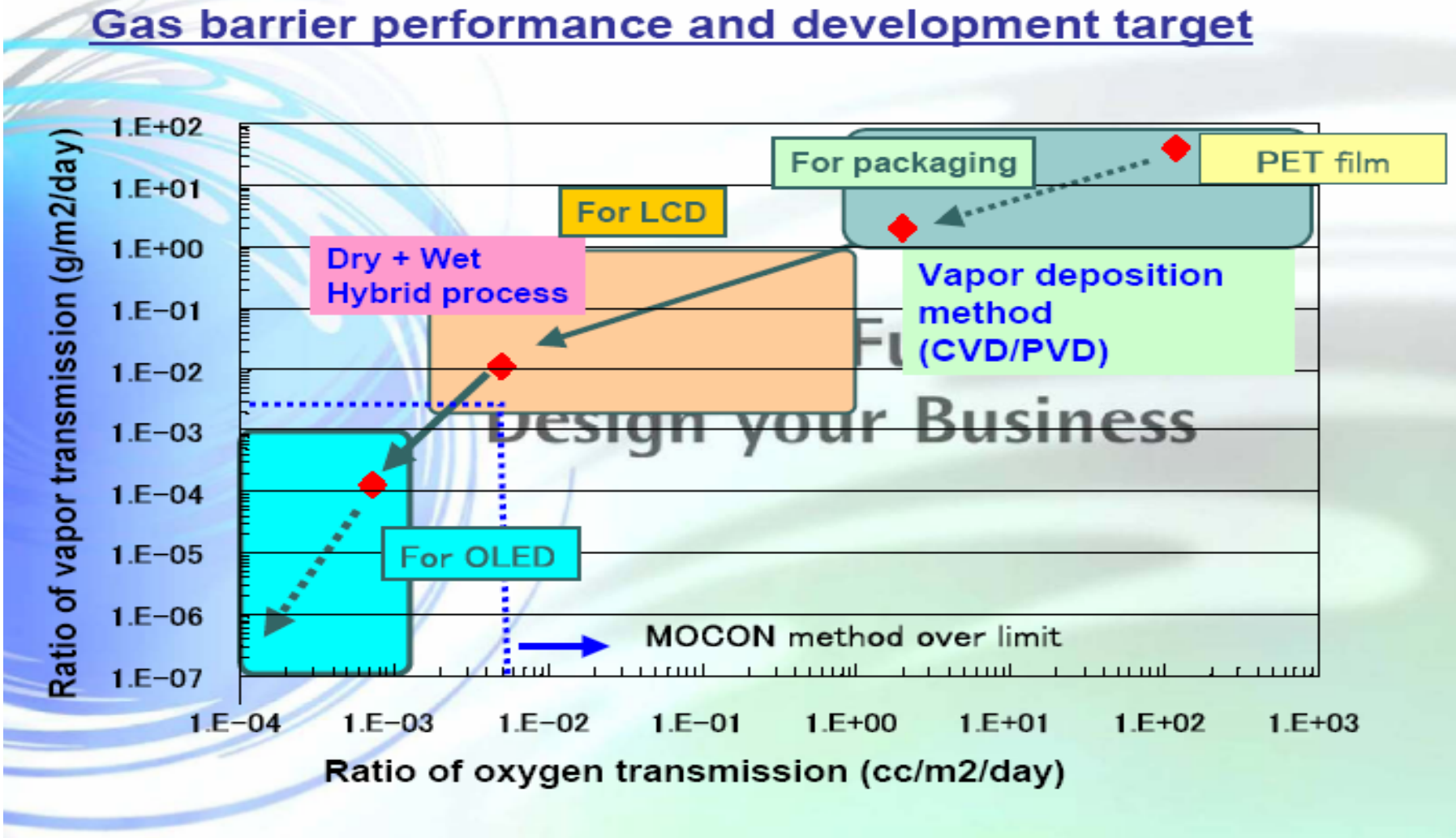
Contrast During Bending/Rolling



- Changes of cell gap during bending may be controlled to about 50 nm by using spacers in fixed positions that are aligned with the ITO lines.

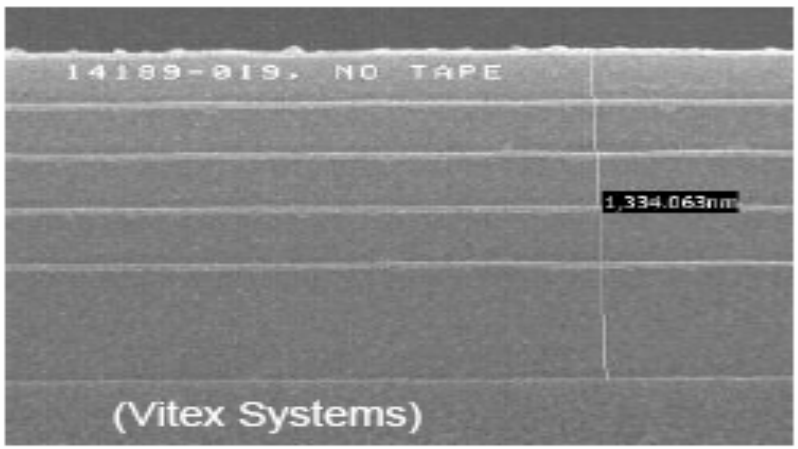
- Fixing cell gap by microcup structure is a potential solution for roll-to-roll manufacturing of flexible displays with or without polarizers.

Barrier Properties

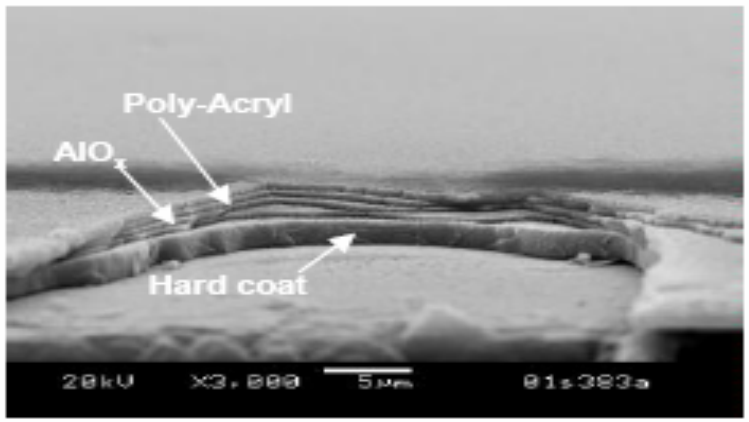


Polymeric substrate & barrier coatings

- Multilayer (inorganic / organic) coated Polymer
- Or: Single layer inorganic barrier films



- Hard coat film plus 4 to 8 barrier layers

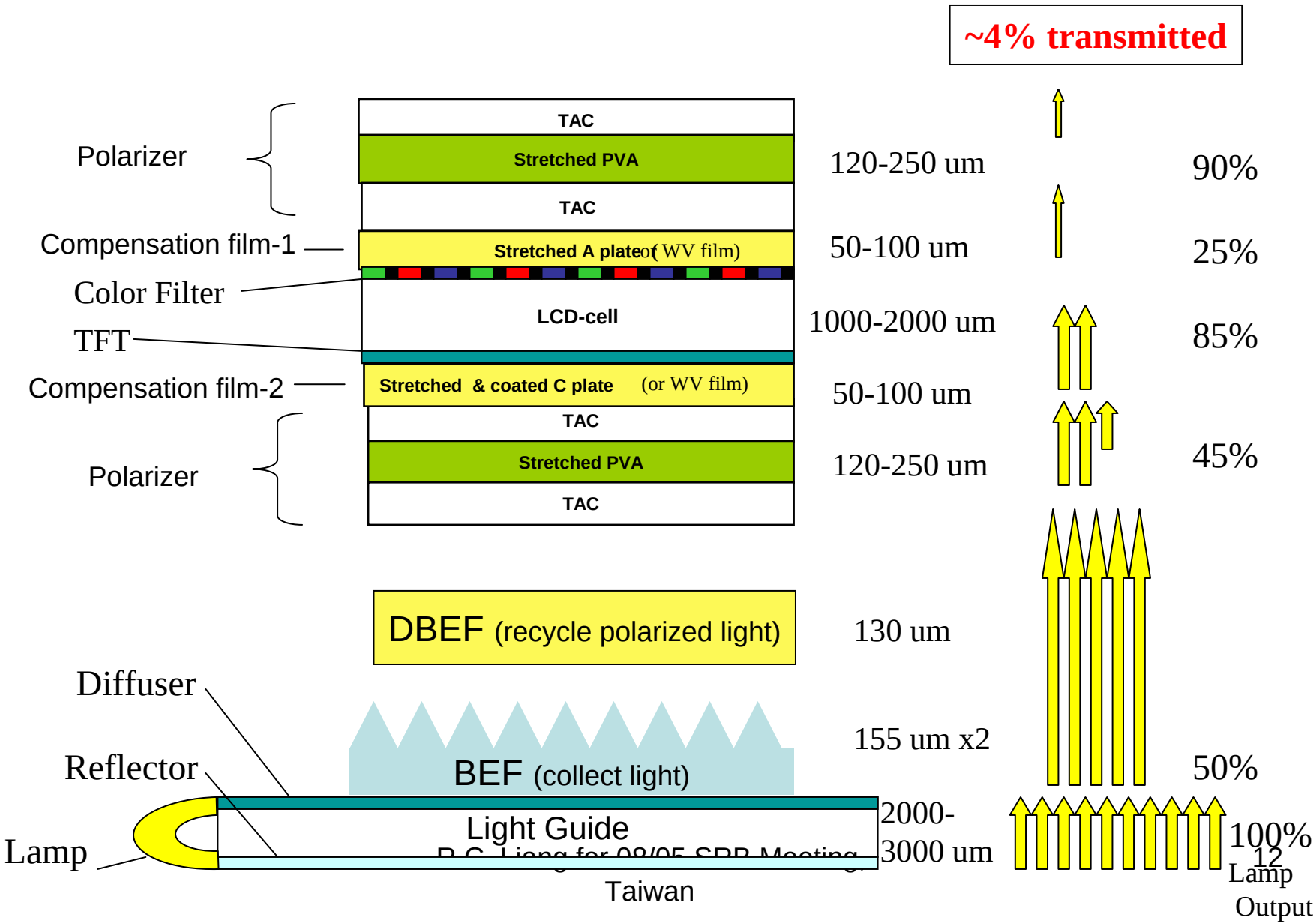


- polymer / AlO_x multilayer compensates coating defects
- permeation rates below the detection limits of commercial equipment

7

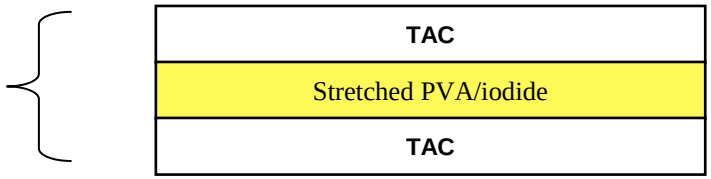
- Vitex System Multilayer AlOx/Acrylic system
- Pioneer: SiON passivation layer

Light/Power/Thickness Management



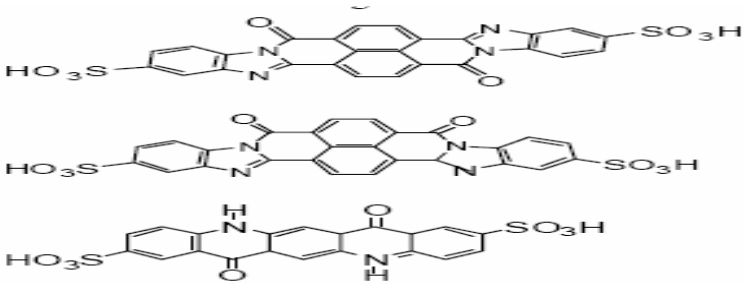
Polarizers by Coating

Polarizer

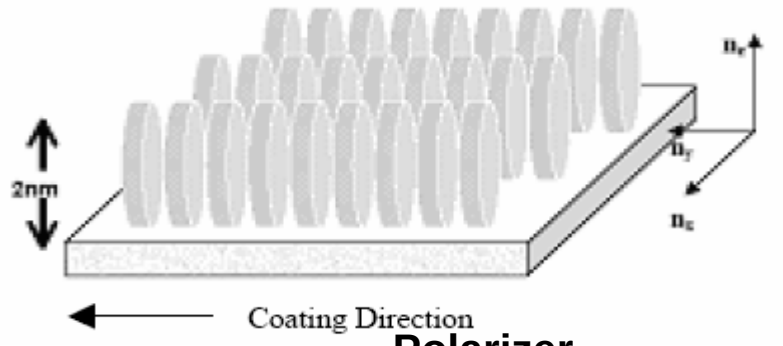


(not to scale)

Optiva



	Mayer Rod Coating	Slot Die Coating
Uniformity of Transmittance (T~39%)	< +/- 3%	< +/- 1%
Contrast Ratio (T ~ 39%)	CR>25	CR>34
Polarizing Efficiency (T~39%)	E~96%	E~97.5%
Uniformity of Polarization	Low	High
Off-angle coating	Done	Need Additional development
Cost of equipment	Cheaper (Simple coating mechanism)	Expensive (High precision required)
Target product	TN/STN LCDs	C-STN/TFT LCDs



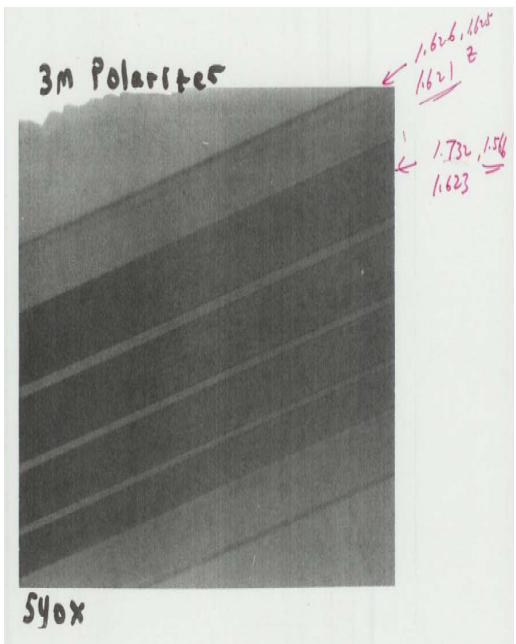
Polarizer

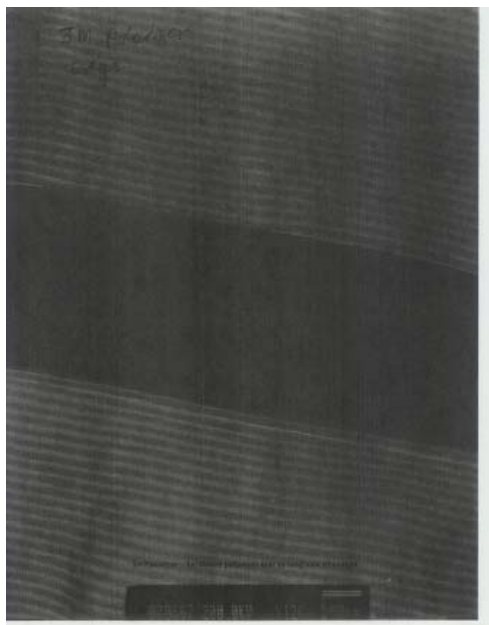
Next move?

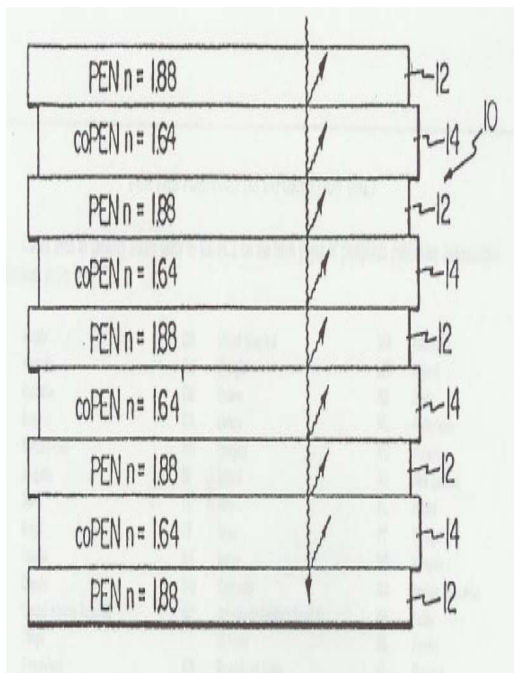
- Improve orientation
- Improve environmental stability (w/o protective films)
- In-cell coating

3M DBEF Stacks

Structure of a brightness-enhancing film
Source: 3M's DBEF-D document

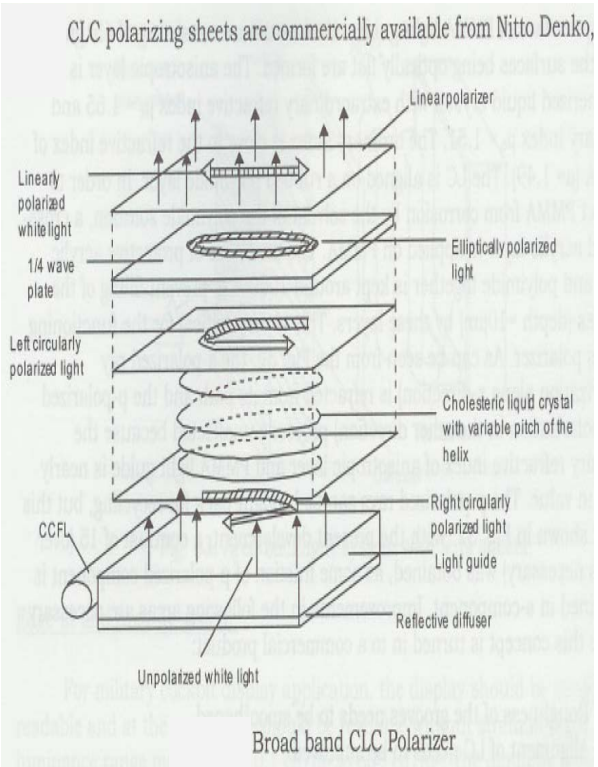




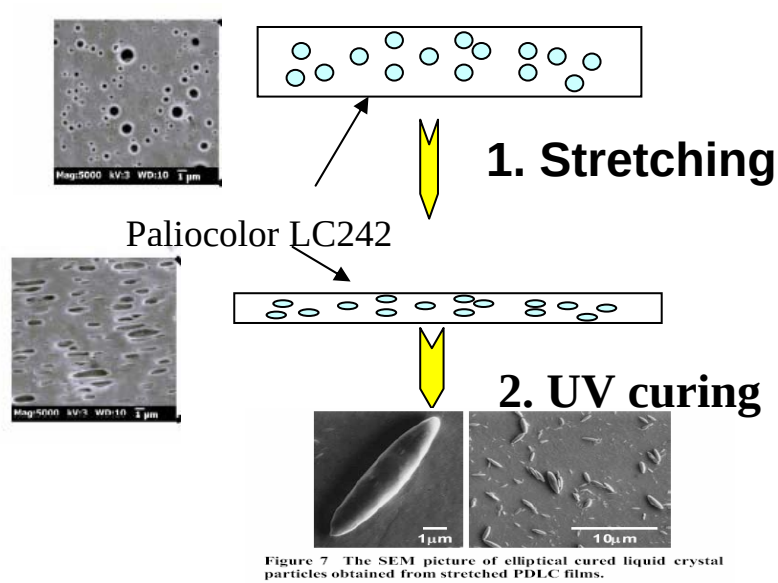


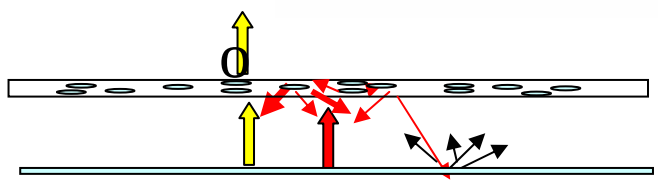
Alternative Brightness Enhancement Films

Nitto, Philips, Reveo,BASF, ROLIC, Charmica



Polaroid, Honeywell, Brown Univ.



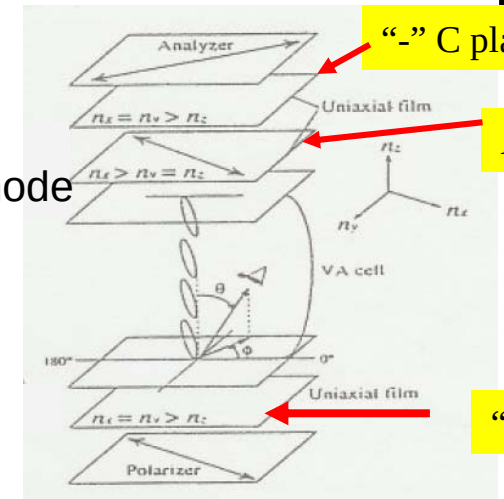


o e Reflector/diffuser depolarize light

Next move? Direct integration/coating on the back light unit.

Compensation Films

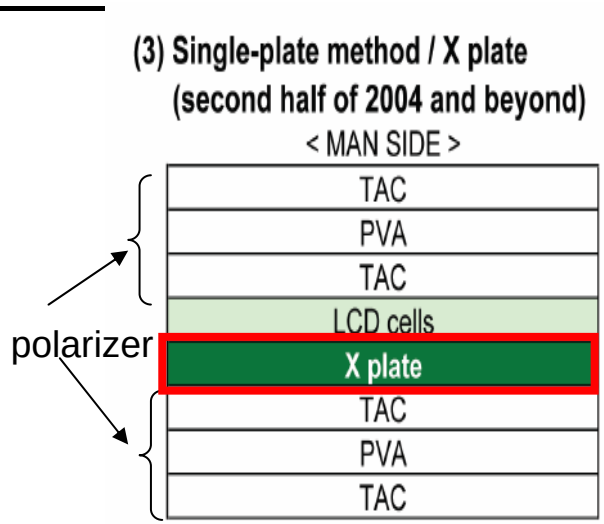
For MVA mode



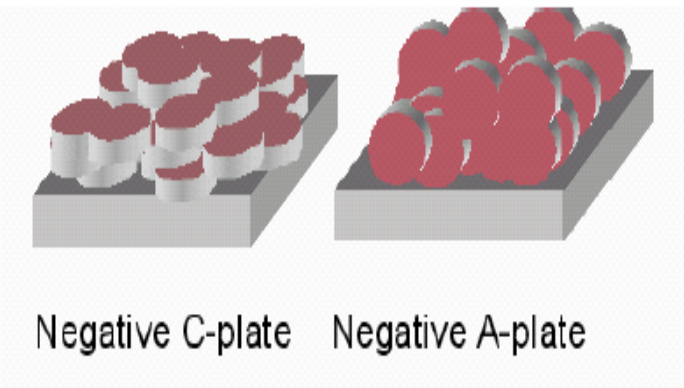
"-" C plate

A plate

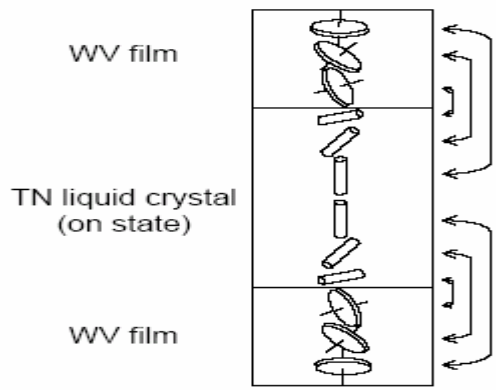
"-" C plate



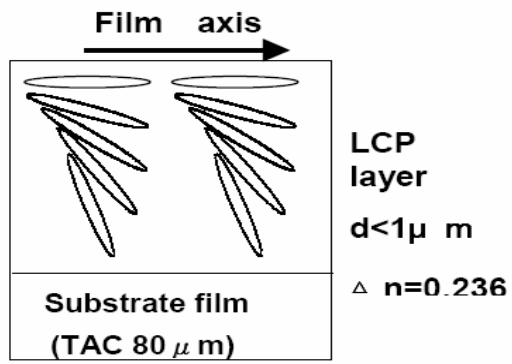
Optiva



Fuji Photofilm



Nippon Oil NH Film



Next Move??

1. Coated compensation films on polarizer
2. Coated compensation films in LCD cell

Active Matrix TFT Choices for Flexible Substrates

1. Transfer high performance silicon devices onto plastic substrates
   - Very low temperature processing
   - Not compatible with low-cost objectives
2. Amorphous Silicon (a-Si) TFT:
   - Work horse of the well established AM LCD Industry
   - Low Mobility ~ 1 cm^2/V.Sec
   - Typical deposition temperature ~ 300°C
   - Low temperature (~ 150°C) a-Si TFT process feasible
3. Low-Temperature Poly-Silicon (LTPS) TFT:
   - High TFT Mobility ~ 100 Cm2/V.Sec.
   - Both NMOS and PMOS TFTs available
   - Typical process temperature ~ 450 to 600° C
   - Ultra low temperature (~ 100° C) Poly-Si (ULTPS) process is being developed
4. Organic TFTs
   - Mobility ~ 3 cm^2/V.Sec
   - Very low temperature processing (~ 100° C)
   - Technology is being developed

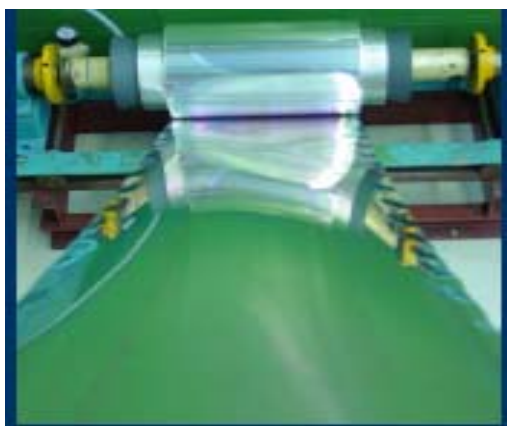
ECD Roll-to-Roll Flexible Solar Cell

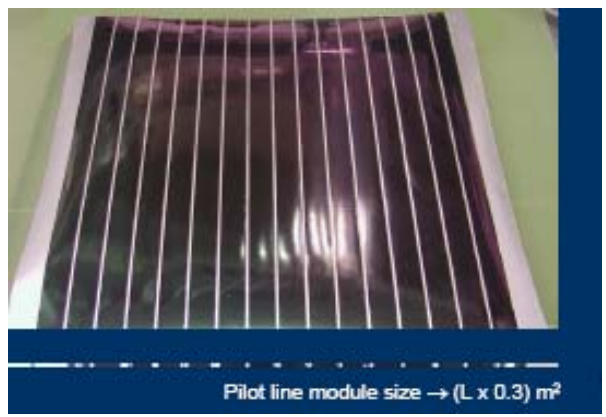
Akzo Nobel Roll-to-Roll Flexible Solar Cell

Temporary Al foil

⇩

Plastic film



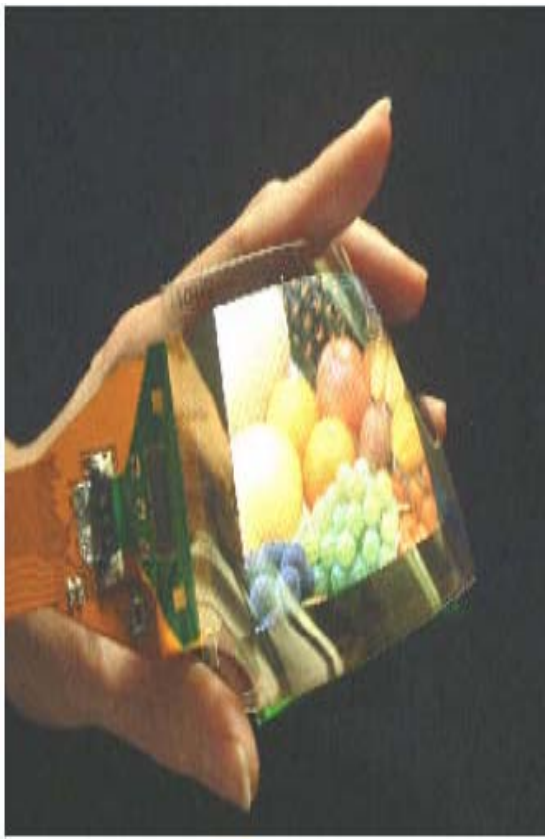


Flexible Display/Electronic Paper Technologies

1. Light Emitting Diode technologies:
   - OLED/PLED/PHOLED, CCM, ECL, and their hybrids

2. Reflective, Bistable Display technologies
   - **cholesteric LC, electrophoretic, gyroelectric, electrochromic, electrodeposition, conducting particles, and liquid powder.**

Recent Flexible PM OLEDs/PLEDs



Pioneer in SID’03.
3”, 8 bits grey scale 160xRGBx120
SiON passivation layers

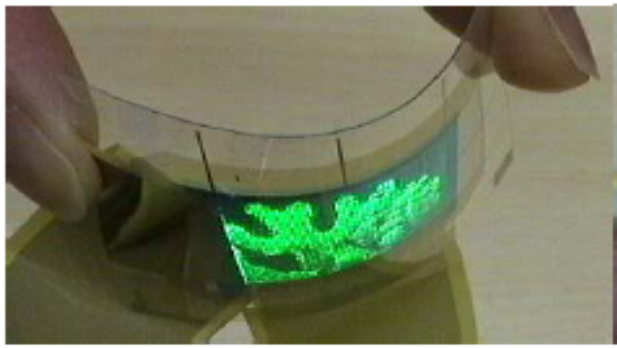
Pioneer in IDW’03.

NHK in IDW’03.
3.6”, 64xRGBx64

PHOLED (Universal Display)

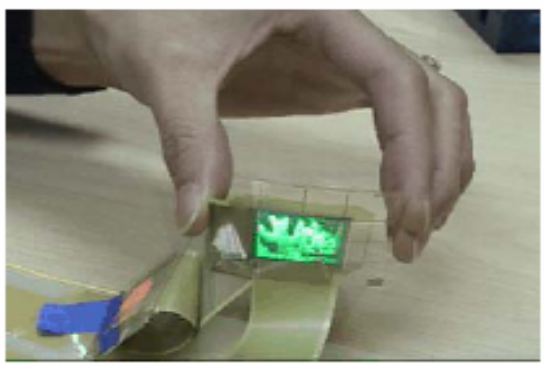
Thin Film Encapsulated Display on Plastic

Display under compression



Display under tension

In action:

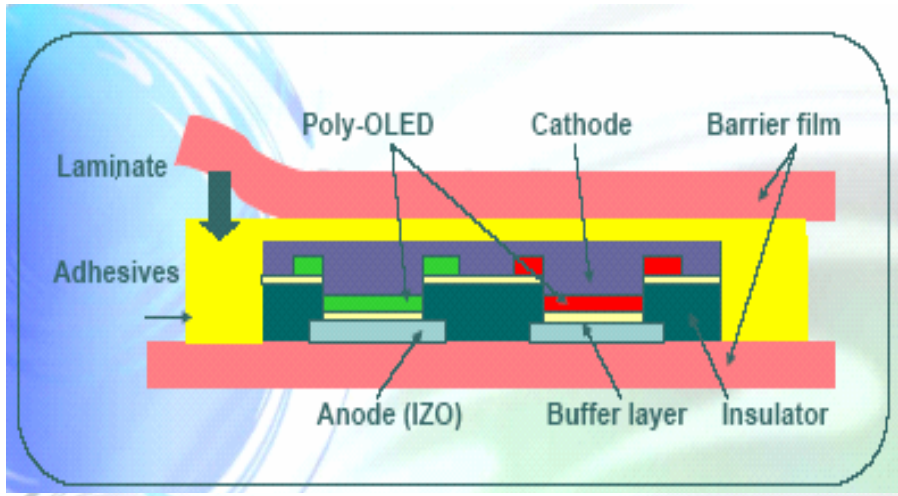


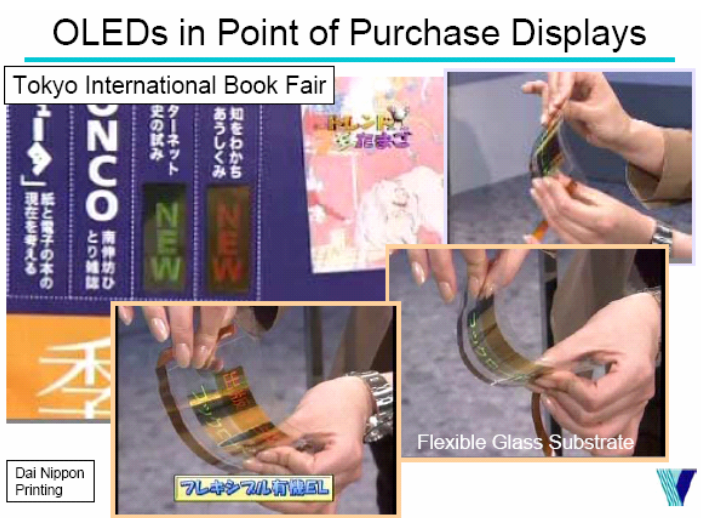
- 64x64 passive matrix
- small molecule phosphorescent
- 80 dpi resolution
- video rate
- 178 μm barrier coated PET
- 5-7 μm thick encapsulant

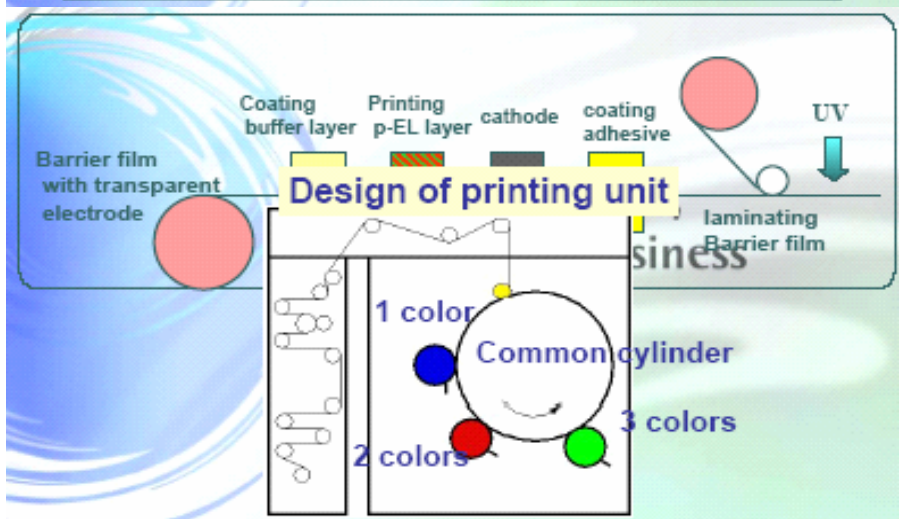
In collaboration with Vitex Systems

UNIVERSAL DISPLAY CORPORATION™

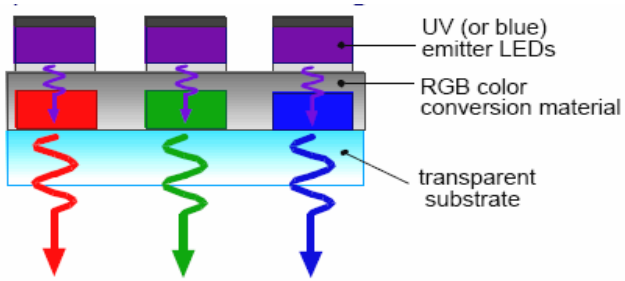
Printed PLED by DNP



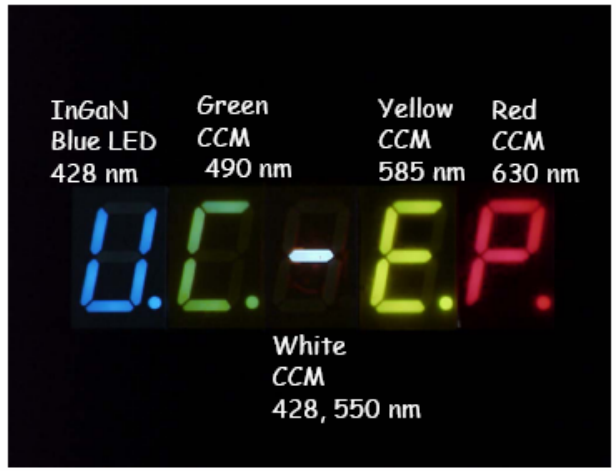


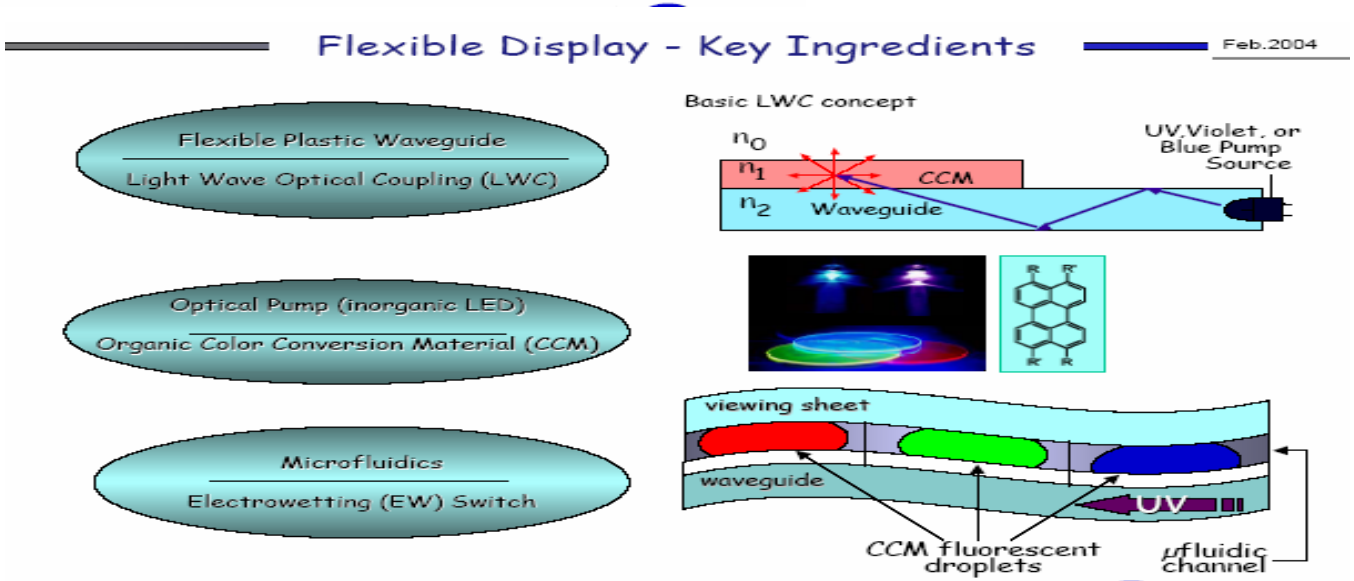


CCM by Univ. of Cinn.

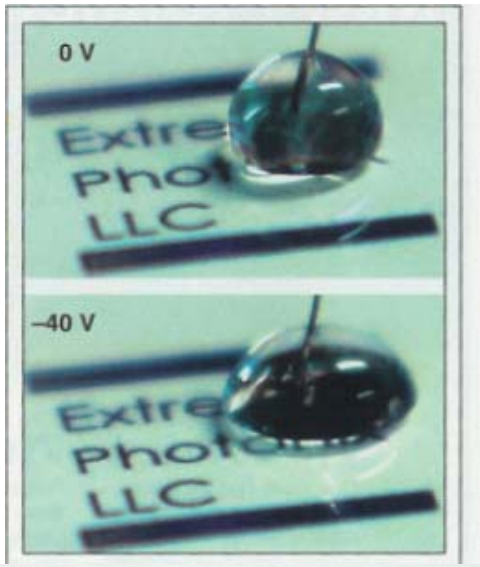


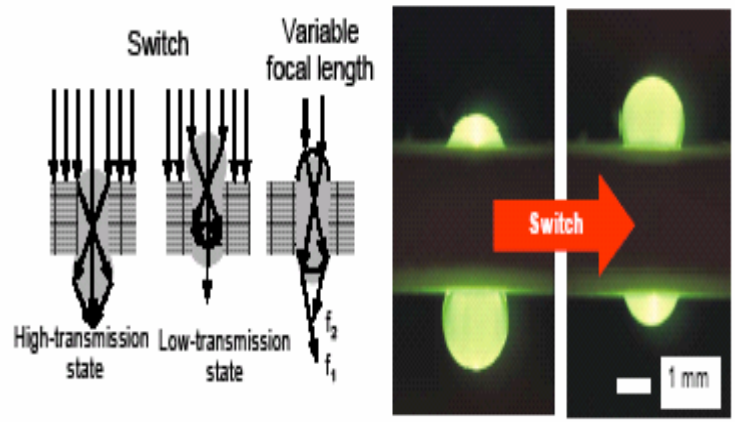
- Single Inorganic Material High Efficiency LED - (Al,Ga,In)N
- Organic Material - "Passive" layer :
  - Very high luminescence efficiency
  - No current flow ⇨ No contacts ⇨ Simple process
    ⇨ No current-related degradation
  - Single organic layer/LED
  - 3-color integration
    - Vacuum evaporation - shadow mask in single pumpdown
    - Ink jet printing, Screen printing

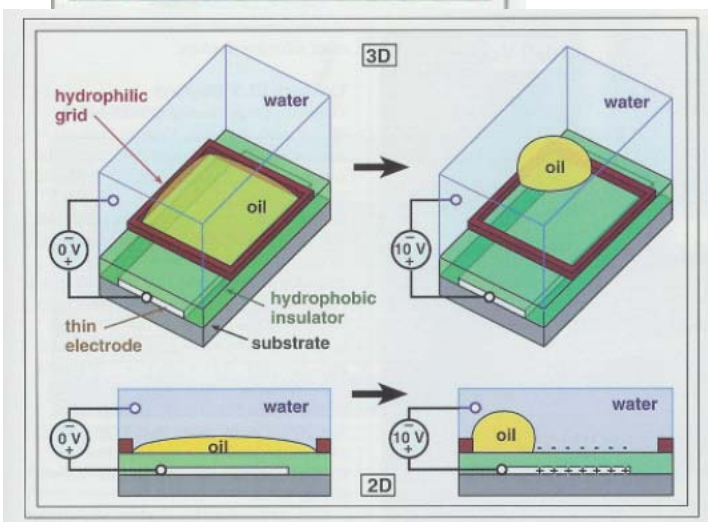




Electrowetting (by Philips, Cornell Univ, RPI)







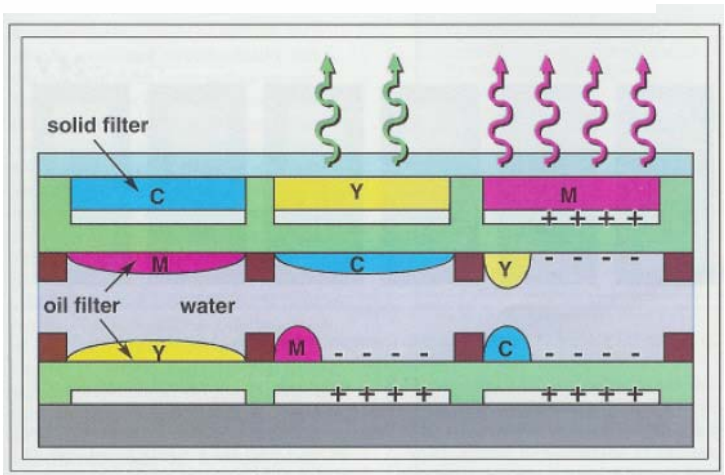
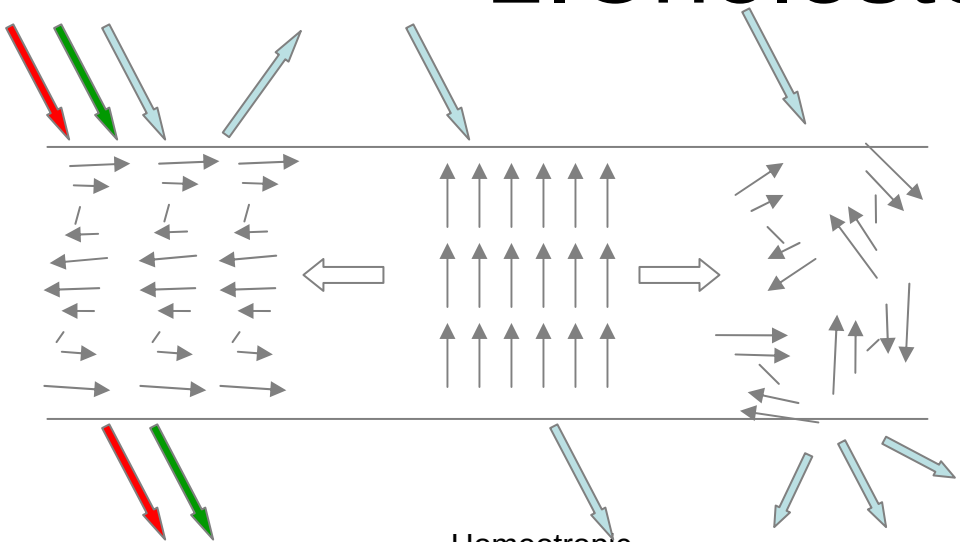


Fig. 5: Shown is a possible subpixel layout for reflective or transmissive CMY ELVs. One subpixel consisting of two differently colored oil layers can produce several colors. The center subpixel, for example, which has cyan and magenta oil layers and a solid-yellow filter, can produce black, green, red,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

Reflective Displays

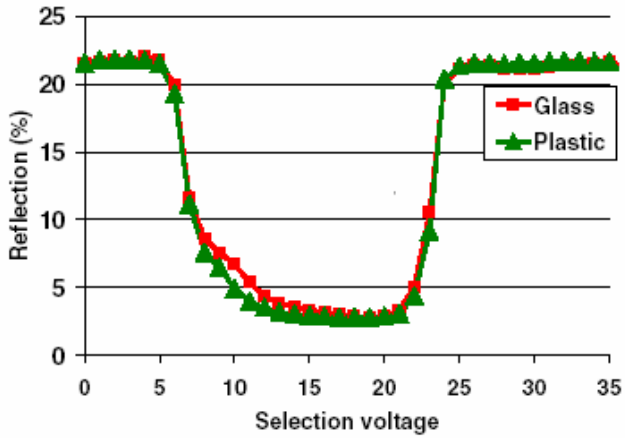
1.Cholesteric LC

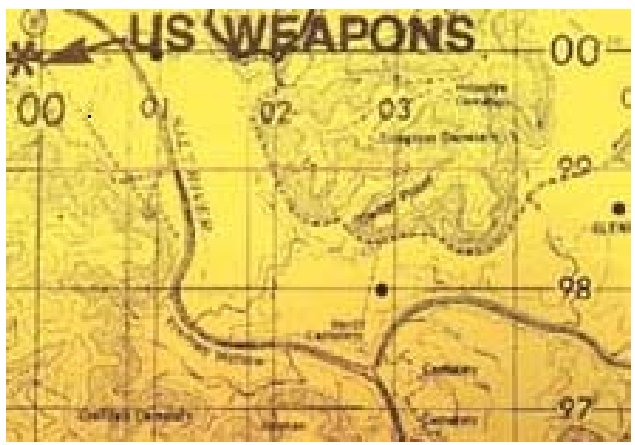


Planar
(Bragg Reflecting)

Homeotropic
(transparent)

Focal Conic
Weakly Scattering



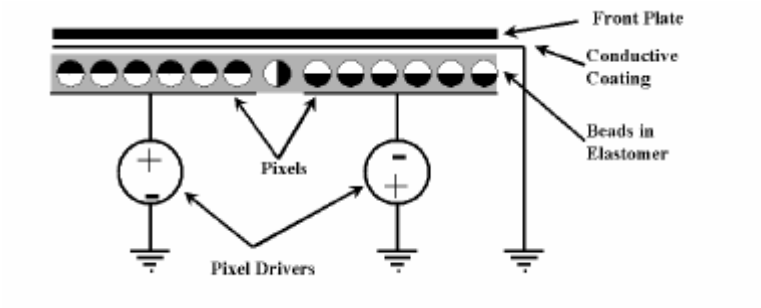


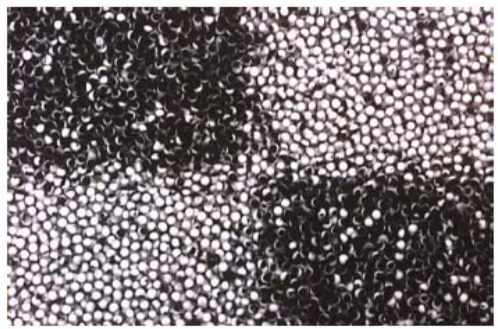
Kent Display

Flexible Full-Color VGA 6.3 inch
Cholesteric Reflective Display on Plastic Substrates

Source: Bill Doane (Kent Displays)

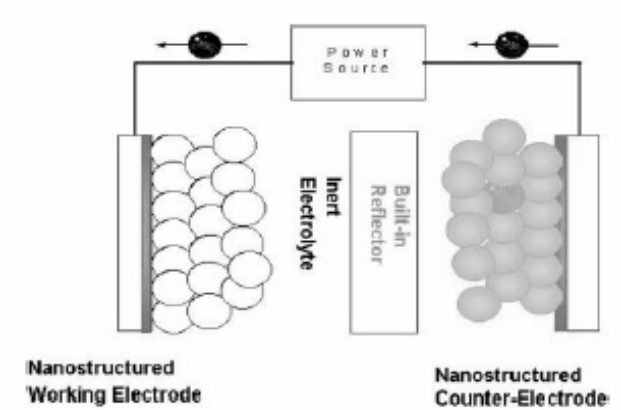
2. Rotating Balls (Gyricon Media)

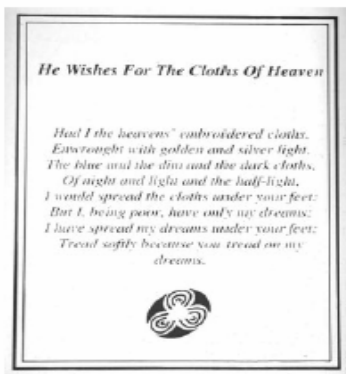




3. ElectroChromic Displays

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



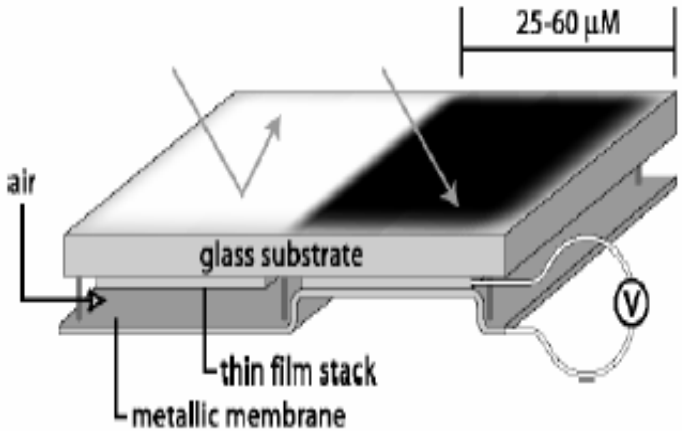


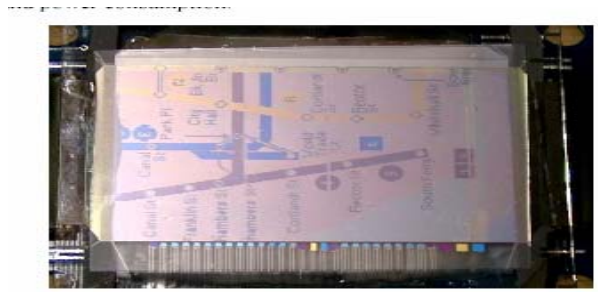
He Wishes For The Cloths Of Heaven

Had I the heavens' embroidered cloths,
Enwrought with golden and silver light,
The blue and the dim and the dark cloths,
Of night and light and the half-light,
I would spread the cloths under your feet:
But I, being poor, have only my dreams;
I have spread my dreams under your feet;
Tread softly because you tread on my dreams.

4. Iridigm Digital Paper

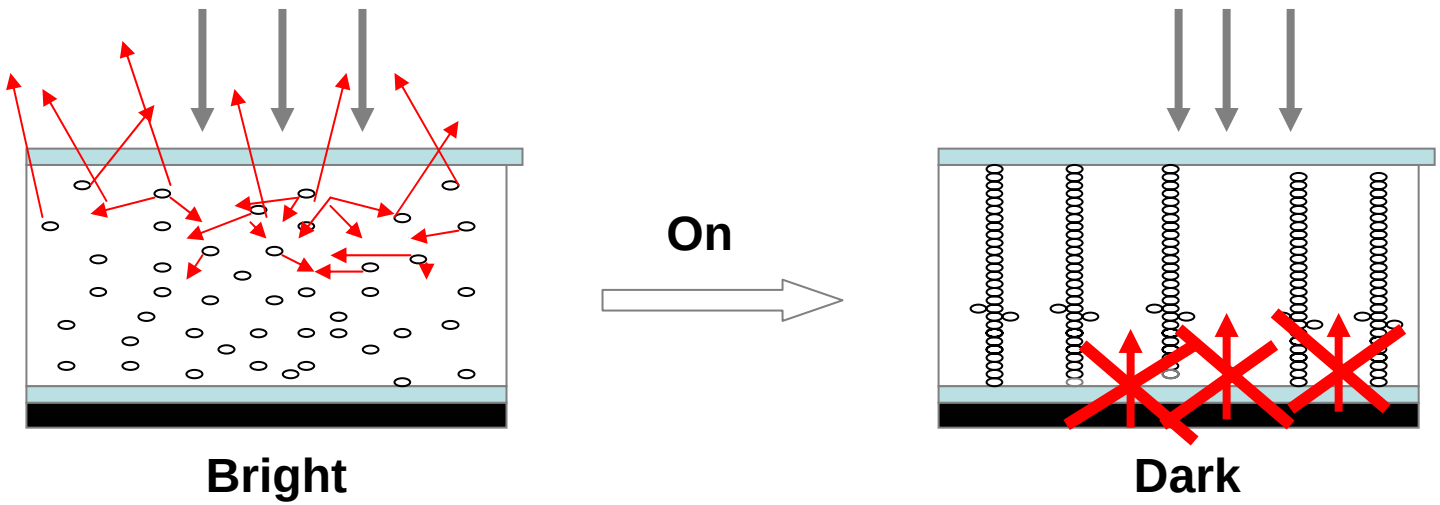
(A MEMS Based Display)



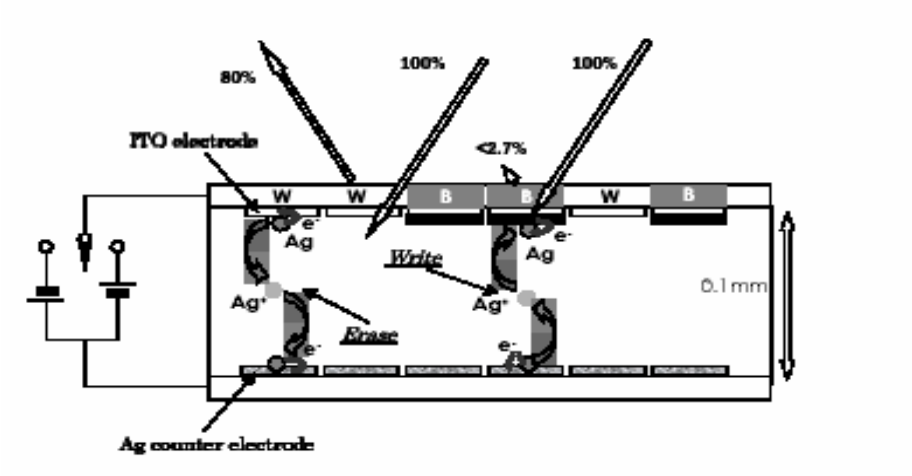


5. Conducting Particles (Citala)

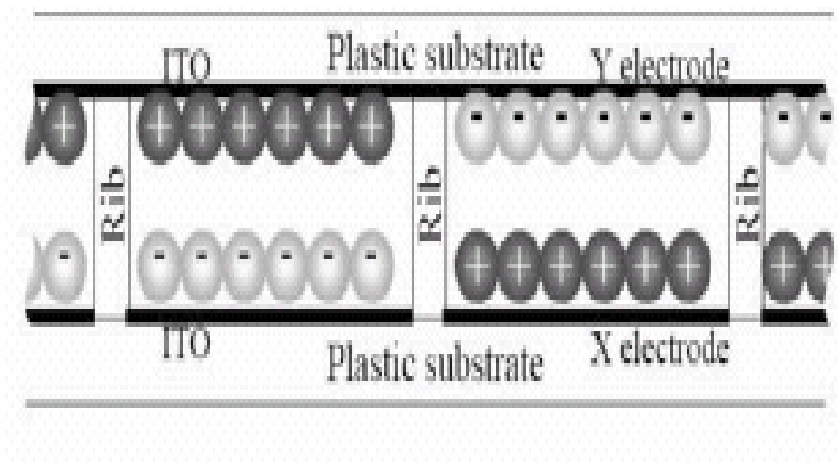
White or light scattering particles



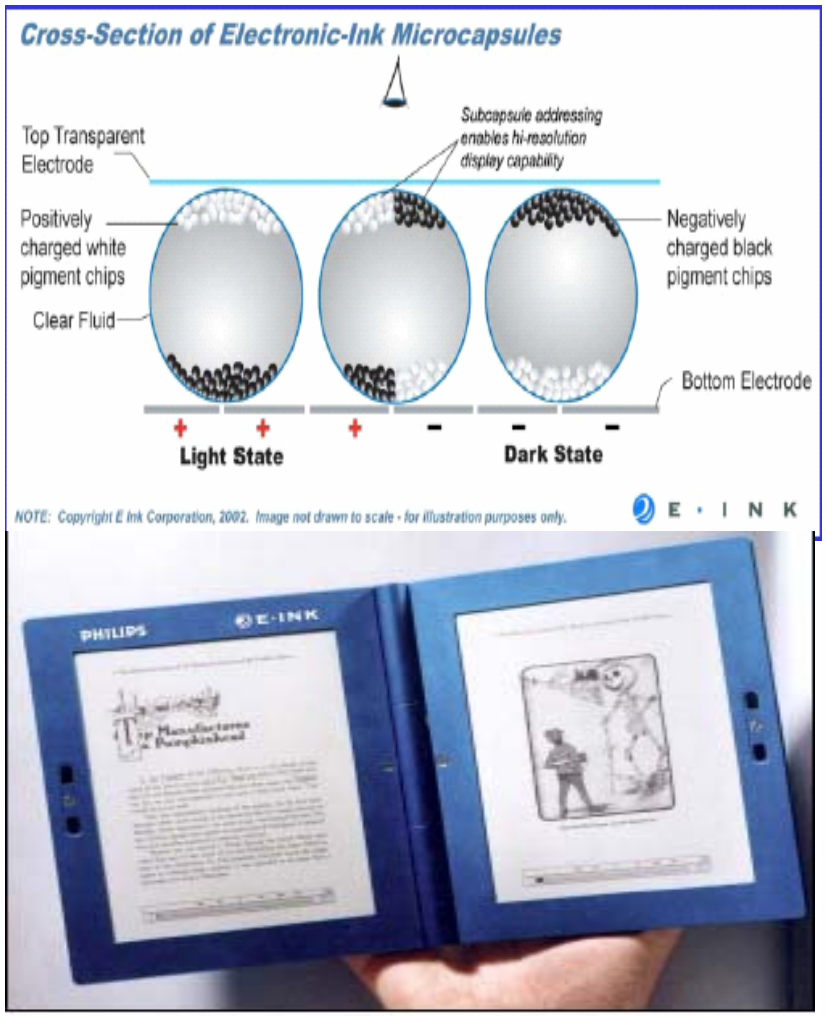
6. Electrodeposition Displays (Sony)



7. BridgeStone Liquid Powder

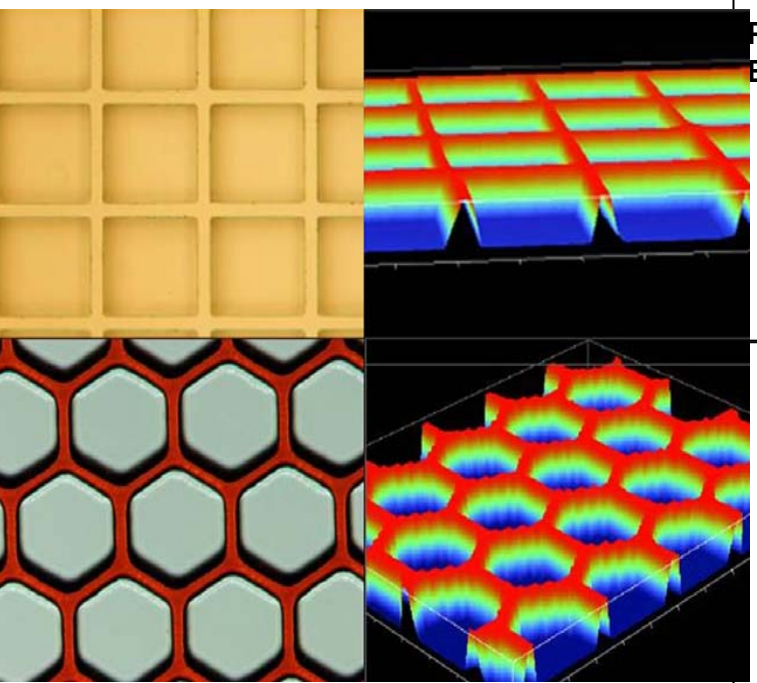


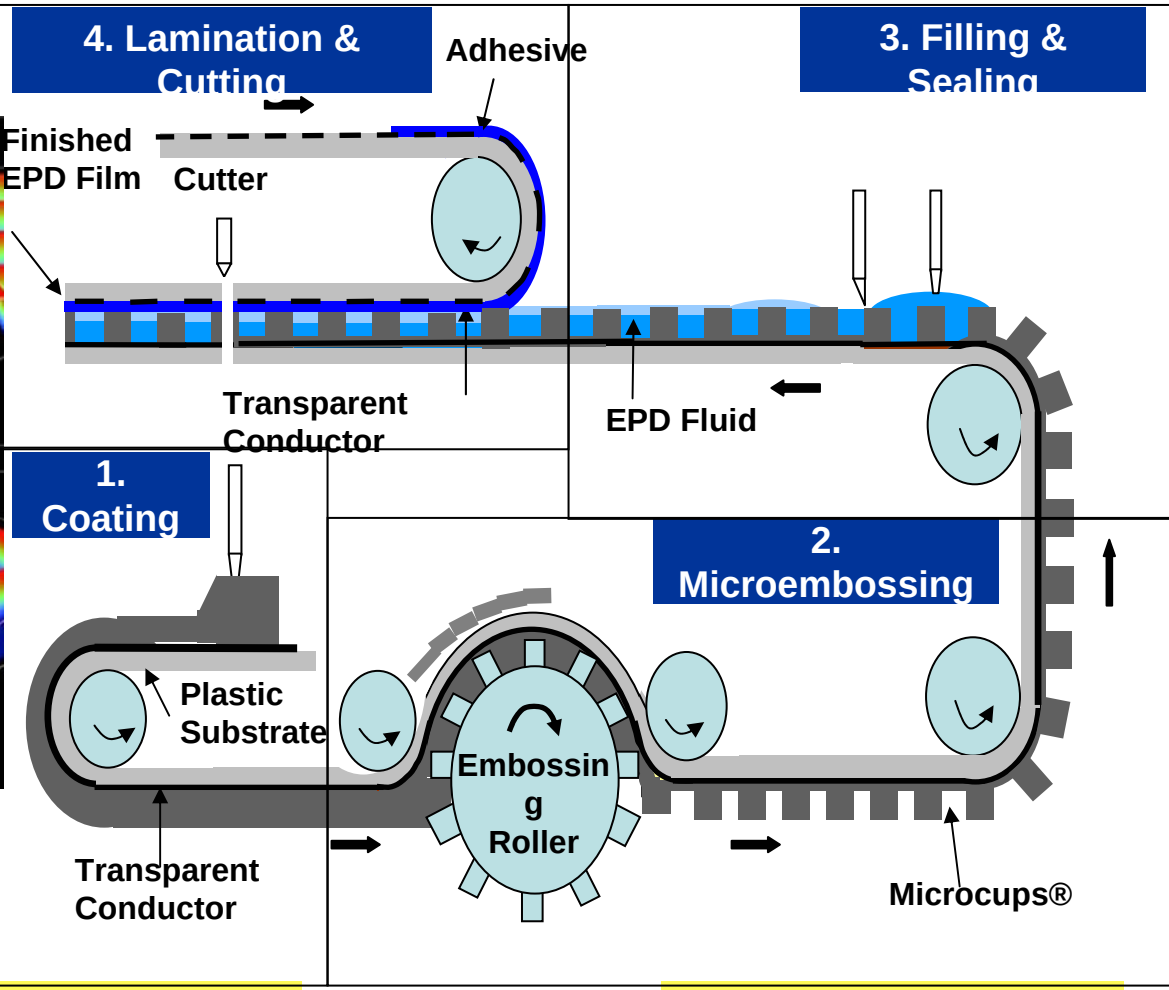
8. E-ink EPDs


Cross-Section of Electronic-Ink Microcapsules
Top Transparent Electrode
Subcapsule addressing enables hi-resolution display capability
Positively charged white pigment chips
Negatively charged black pigment chips
Clear Fluid
Bottom Electrode
Light State
Dark State
NOTE: Copyright E Ink Corporation, 2002. Image not drawn to scale - for illustration purposes only.
E INK
PHILIPS
E-INK


Enter Hamlet.
Ham. To be, or not to
Whether 'tis Nobler in the
The Slings and Arrowes of outra
Or to take Armes against a Sea of
And by opposing end them: to dye, to
No more; and by a sleepe, to say we
The Heart-ake,
That Flesh is
SALE!
SALE!

SiPix Microcup® EPDs





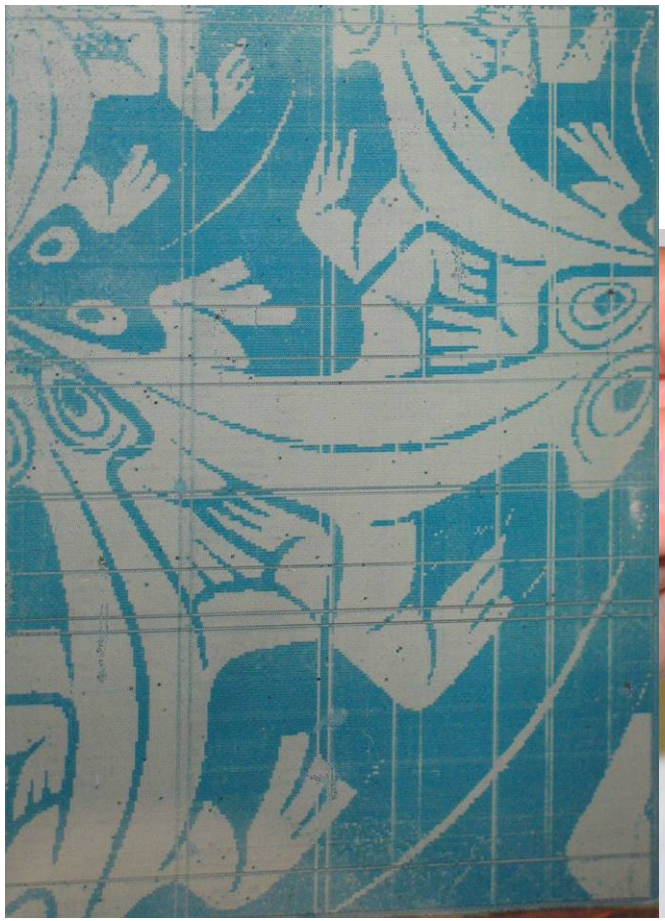
The world's first roll-to-roll line in production

Each step must be accomplished within seconds

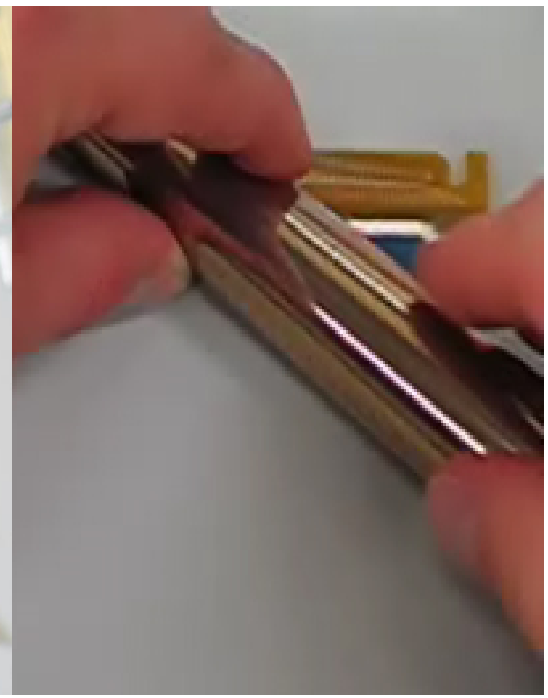
SiPix Microcup®Electronic Paper

Rollable Active Matrix EPD

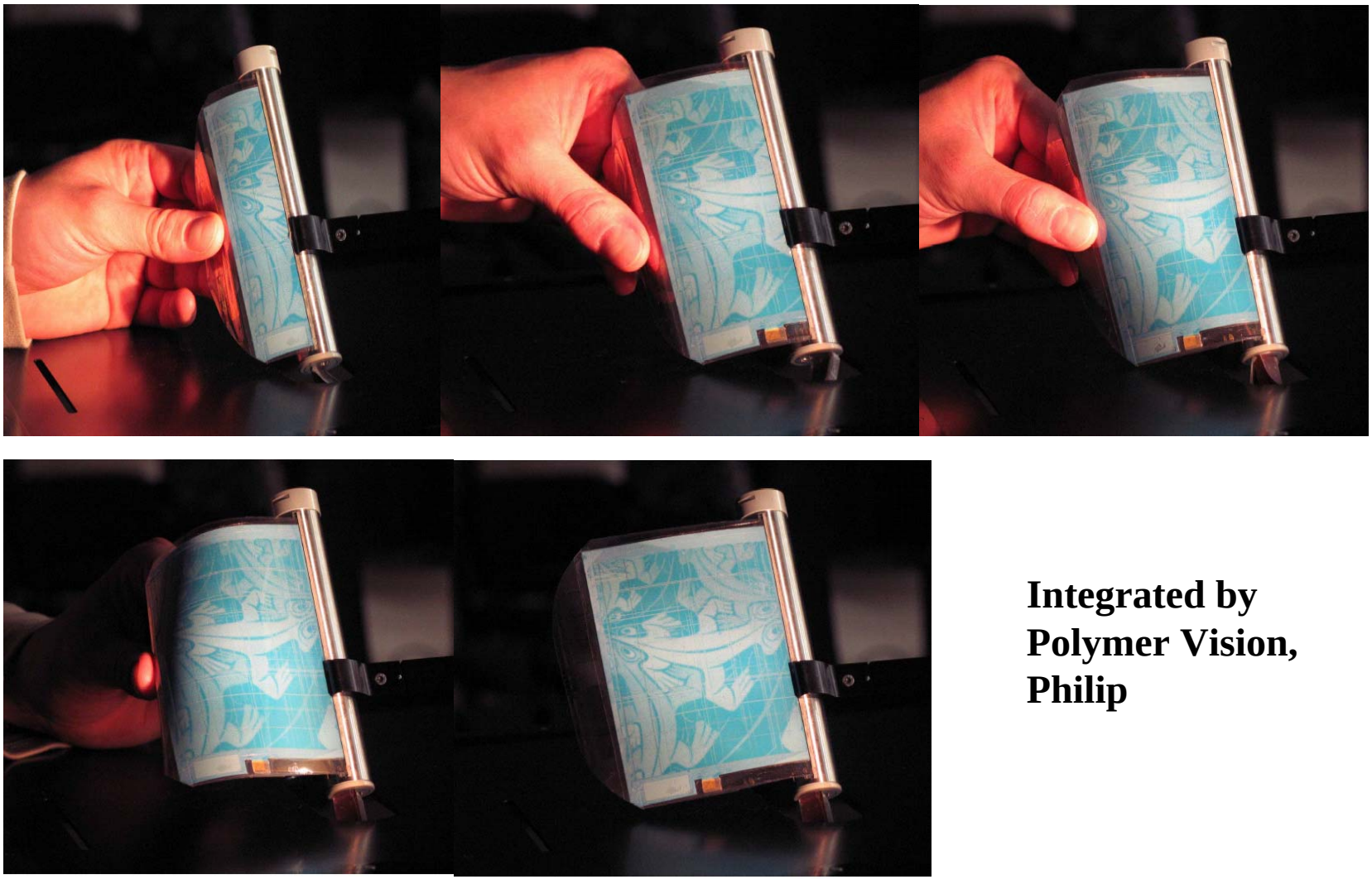
Back plane supplied by Philips



Thickness: ~ 125 μm
Bending radius < 1cm !!!!



Rollable Microcup® EPDs



Integrated by Polymer Vision, Philip

Conclusions

- Technical challenges exist in barrier, substrate, cell gap control, flexure resistance of electrodes, viewing angle, light and thickness management management, and manufacturing processes.

- As of today, Electrophoretic (EPD) is one of the most encouraging for Rollable Displays/**Electronic Paper** applications for their

  - Reflective, wide viewing angle
  - Bistability
  - Low operation voltage & negligible current demand
  - Ultra thin, ultra light weight
  - Compatibility with roll-to-roll manufacturing & converting processes
  - Format flexibility
  - Both PM and AM driving
  - Full color with high color saturation (to be demonstrated)
  - Physicomechanical & environmental durability (Microcup® EPDs)