

# Microcup<sup>®</sup> Electronic Paper

By

## Roll-to-Roll Manufacturing Processes

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Sr. Director of polymer and imaging technologies

**SiPix** Imaging, Inc.

R&D: 1075 Montague Expressway. Milpitas, CA 95035

Manufacturing: 47485 Seabridge Dr., Fremont, CA 94538

# E-Paper/E-Books



## Readability:

High Whiteness  
Good Contrast Ratio  
Wide View Angle  
Ambient & Sun Light  
Readable

## Portability:

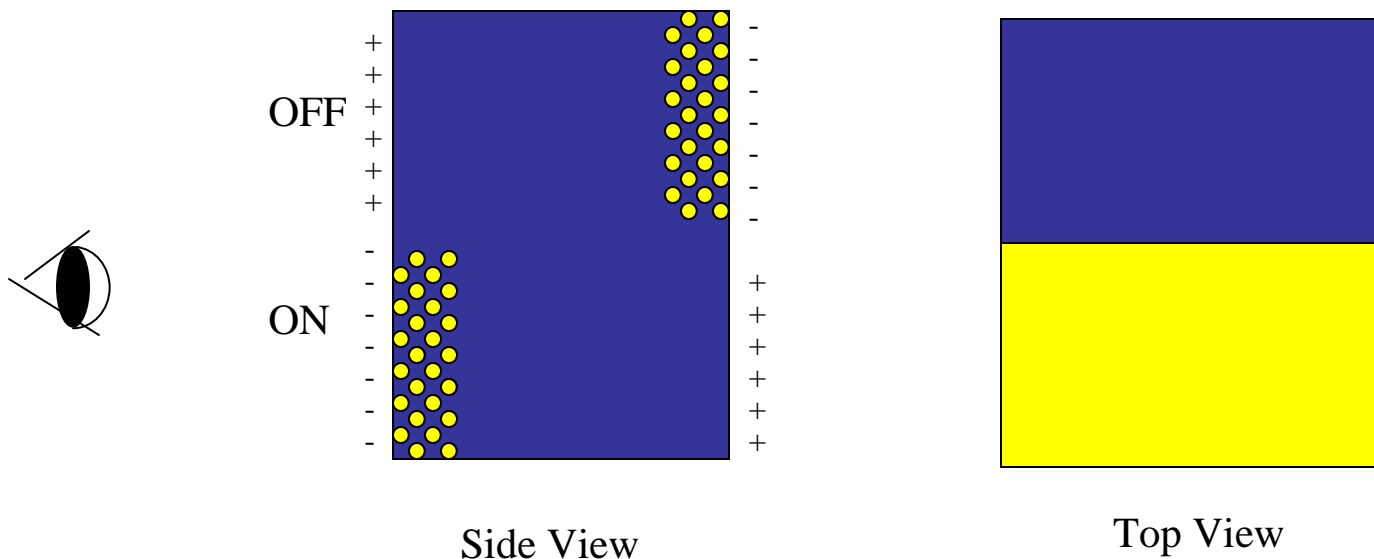
Light Weight  
Thin & Flexible  
Durable  
Writtable/Printable  
Format Flexible

## Affordability:

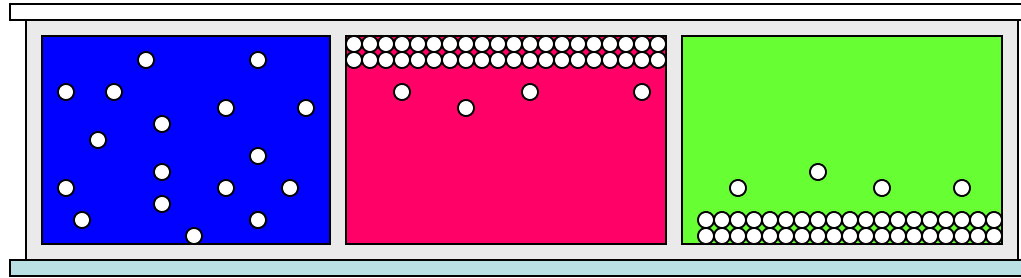
Low Material Cost  
Easy Manufacturing  
Environmental Friendly  
No Power

# SiPix Electrophoretic Displays (SiPix EPDs)

- Field-induced migration of charged particles in a dielectric fluid to create contrast. (First Disclosed in 1969)
- Advantages: Power consumption, bi-stability, view angle, contrast ratio (reflective), manufacturing cost.
- Disadvantages: Shelf-life, switching rate.



# SiPix Microcup<sup>®</sup> EPDs



**- High Speed Roll-to-roll, Format Flexible manufacturing processes:**

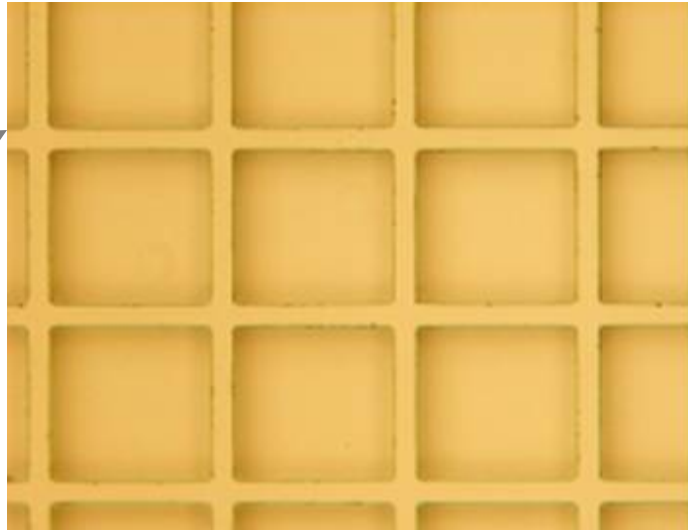
- High speed microembossing processes
- Seamless filling and sealing processes

- Submicron, stable, density-matched particles
- Passive and Active Matrix EPDS

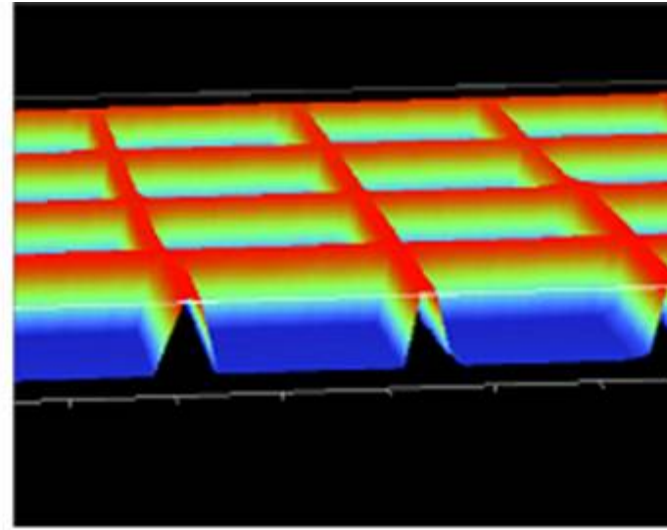
**- Proprietary driving mechanisms**

# SiPix Microcups<sup>®</sup>

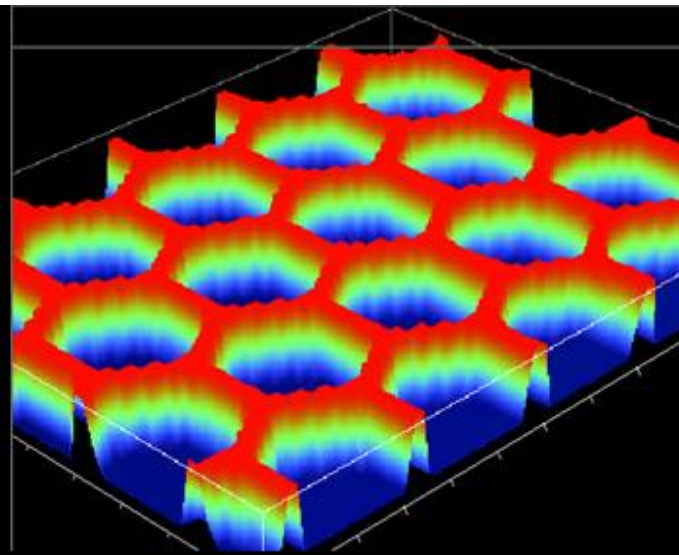
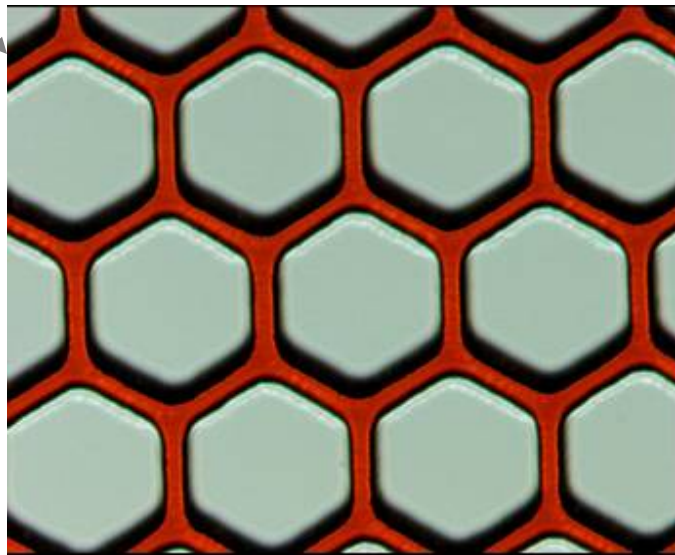
60~180  $\mu\text{m}$



5~25  $\mu\text{m}$

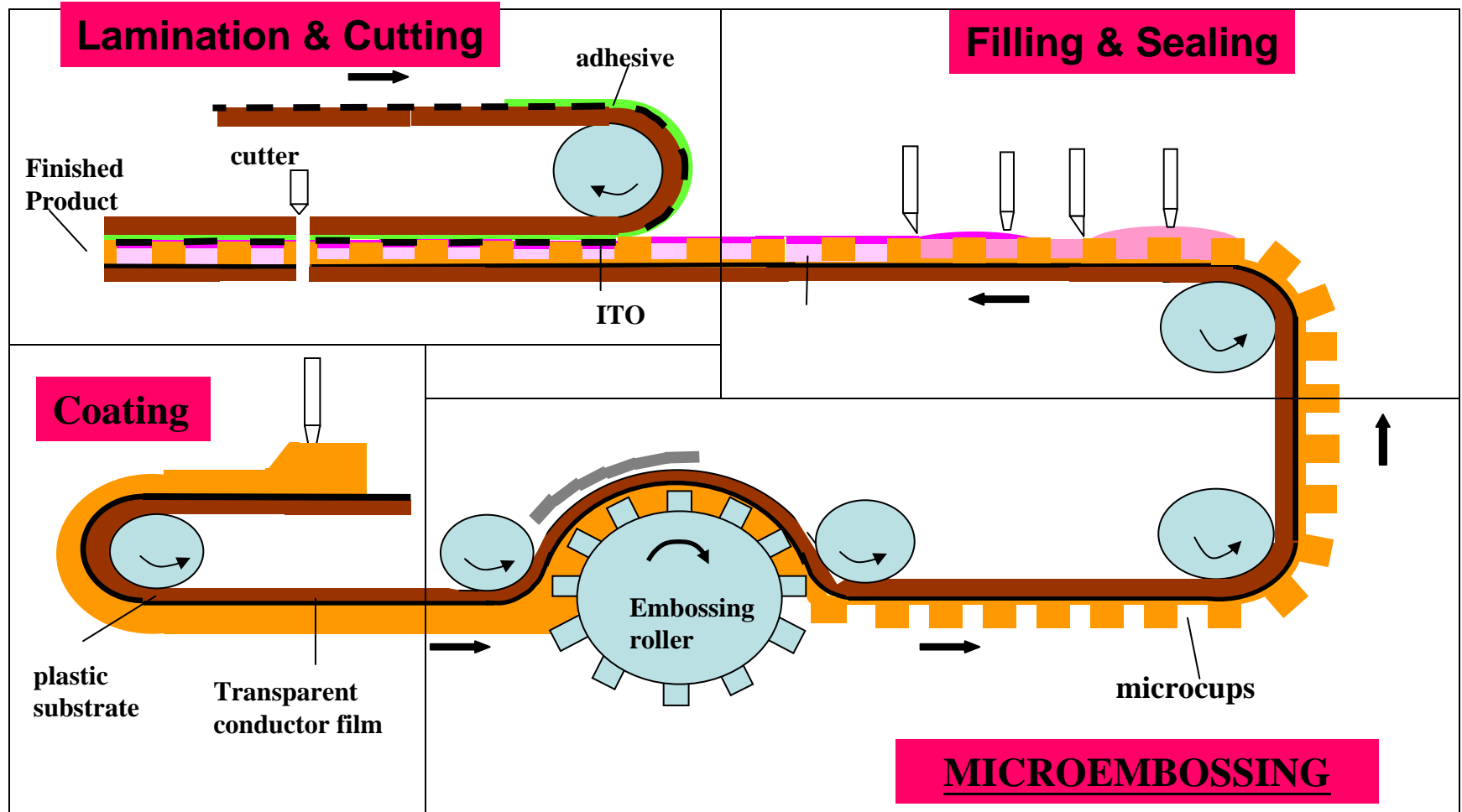


12~40  $\mu\text{m}$



# SiPix Roll-to-Roll Manufacturing

(Current Throughput  $\geq 10$  ft/min)

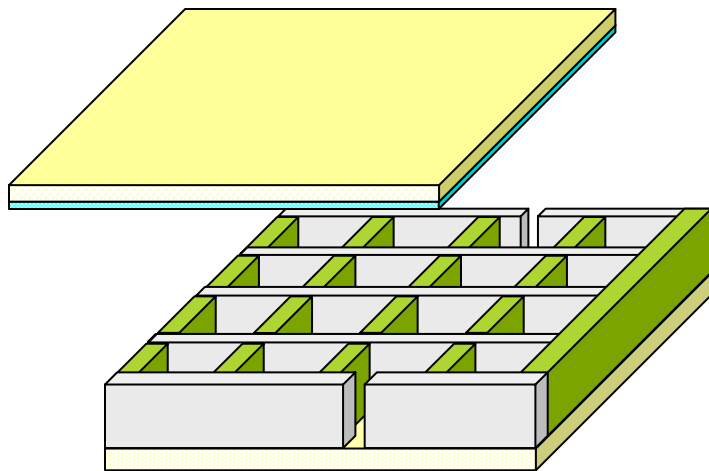


Each step must be accomplished within seconds

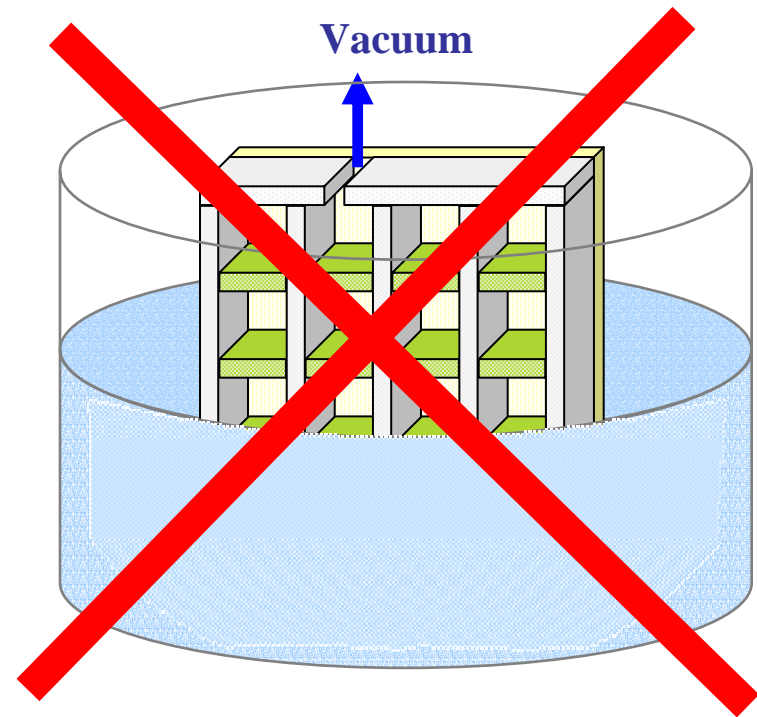
# Schematic Edge-Sealing and Vacuum Filling

**Not applicable for SiPix Microcup® EPDs**

**Edge Sealing**

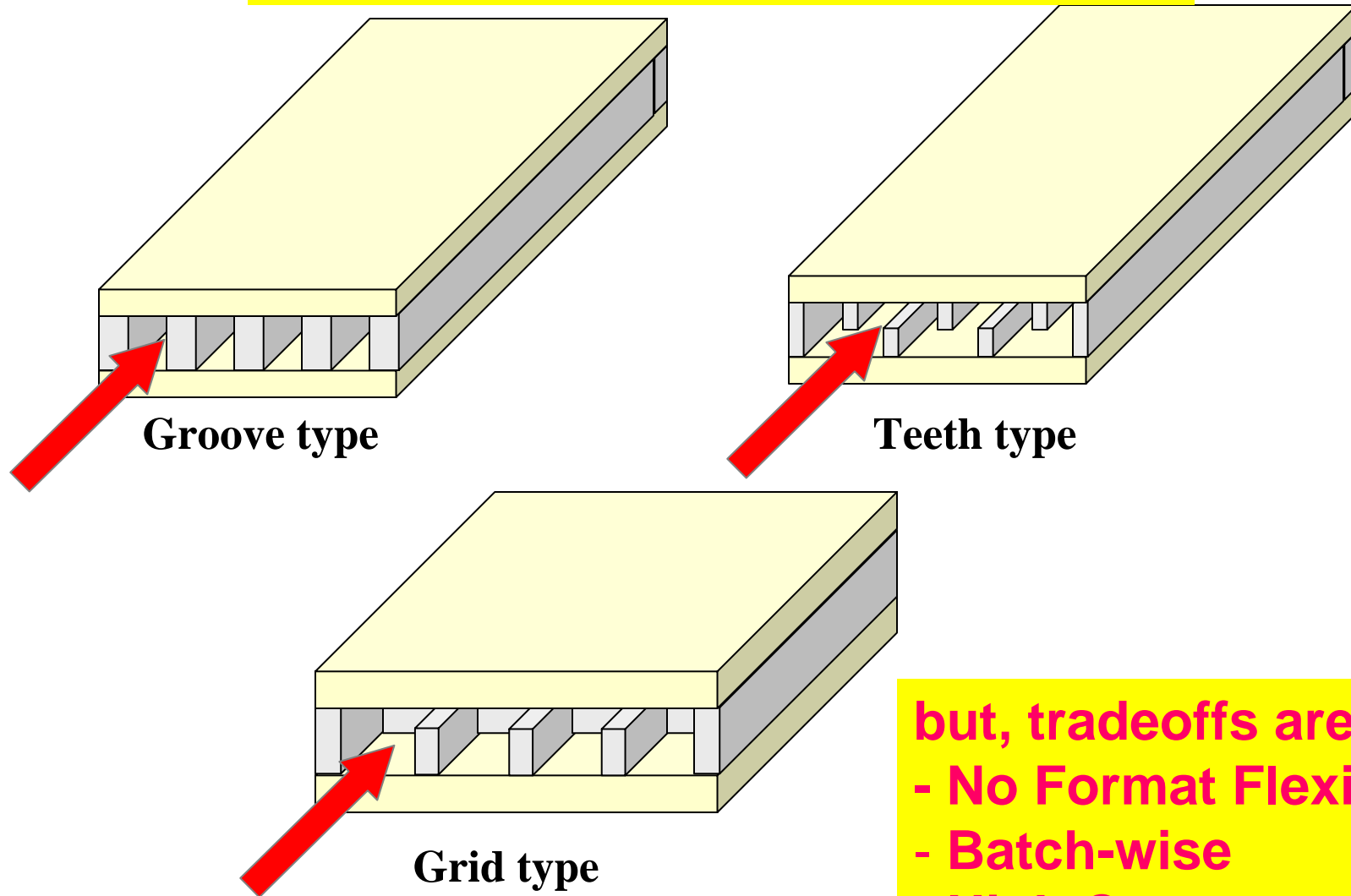


**Vacuum filling**



# Alternative Partition Structures

Vacuum filling/sealing is OK...

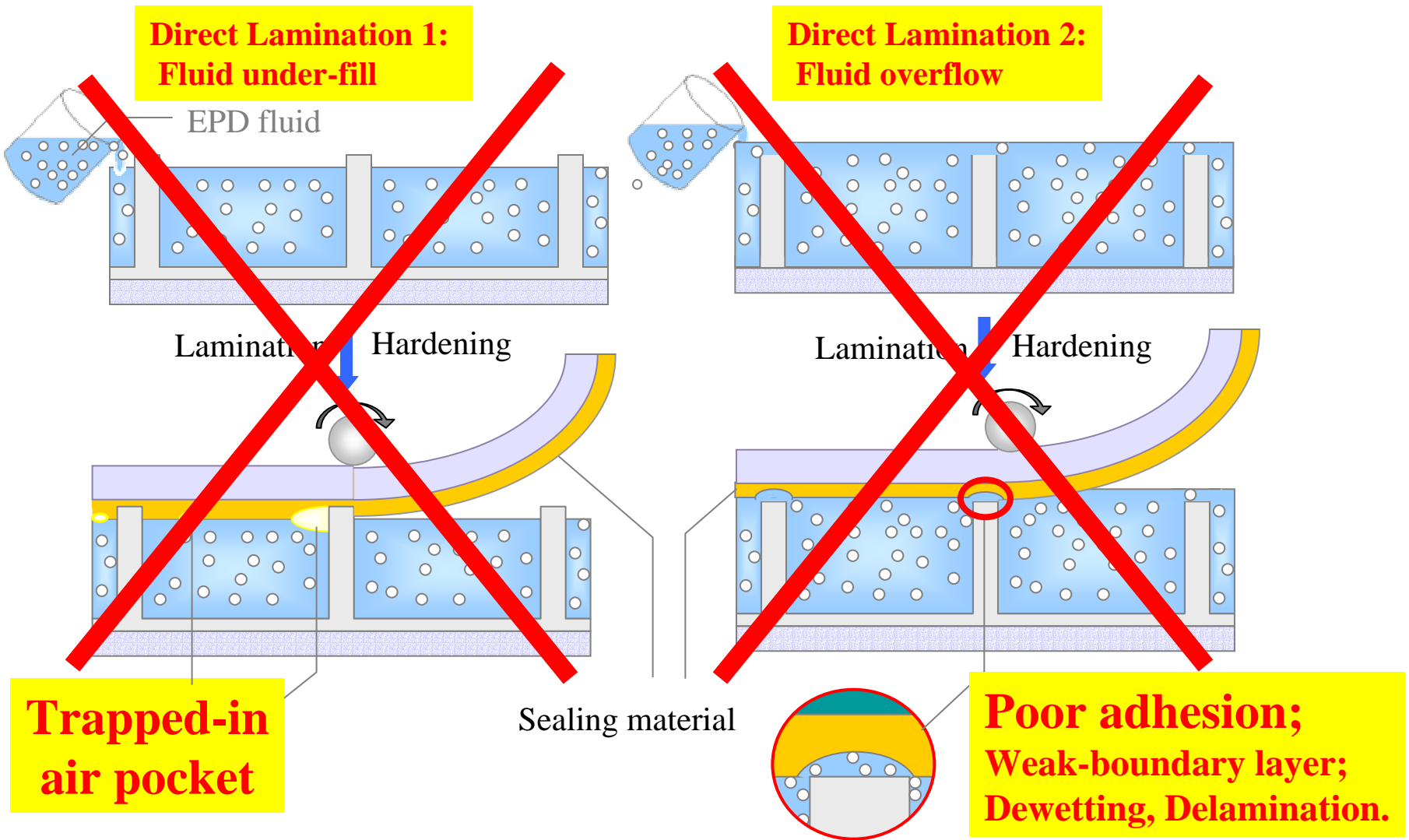


but, tradeoffs are:

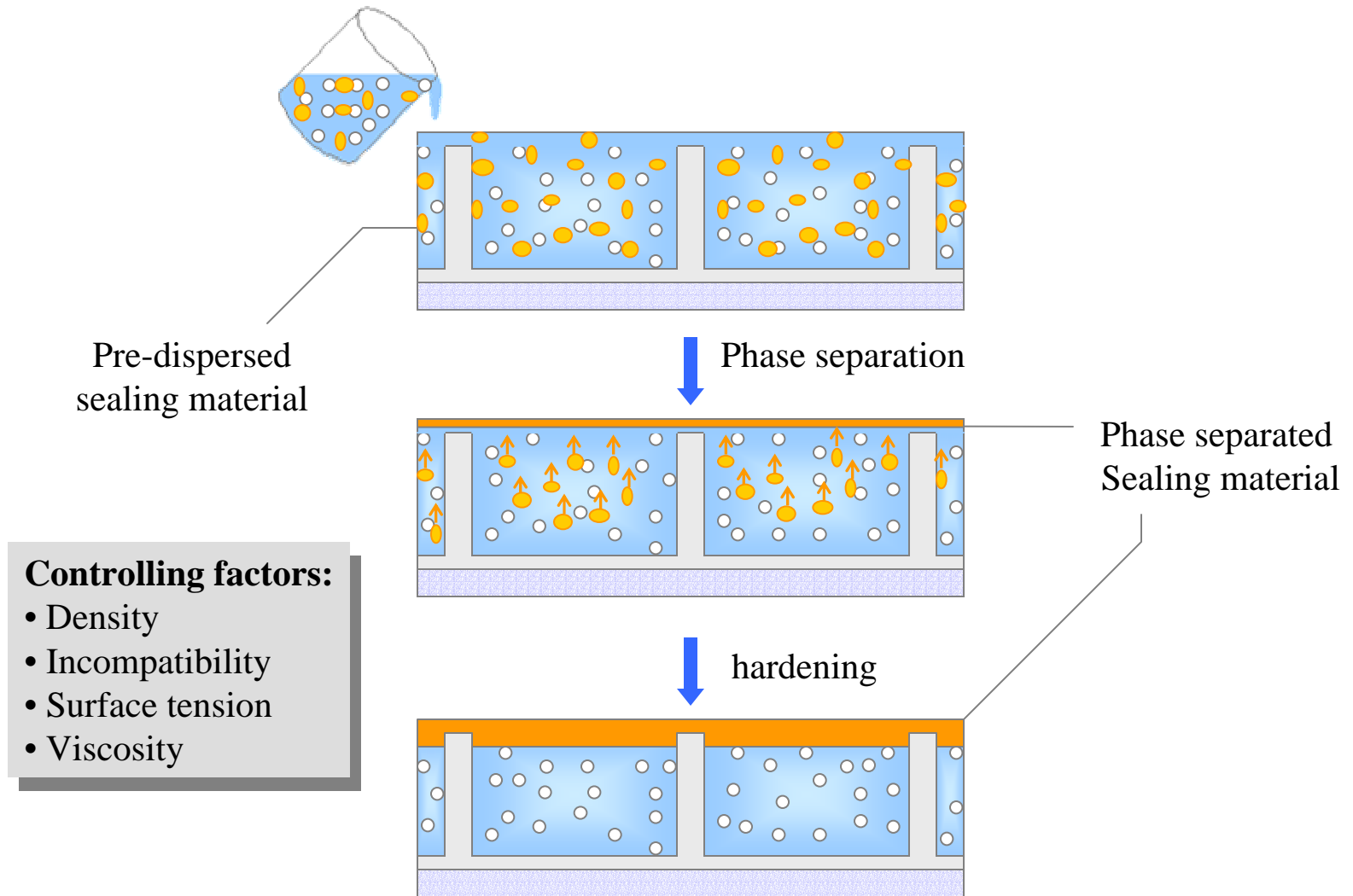
- No Format Flexibility
- Batch-wise
- High Cost
- Monochrome

# Other Traditional Filling & Sealing

## **Failure** of Direct Lamination Process

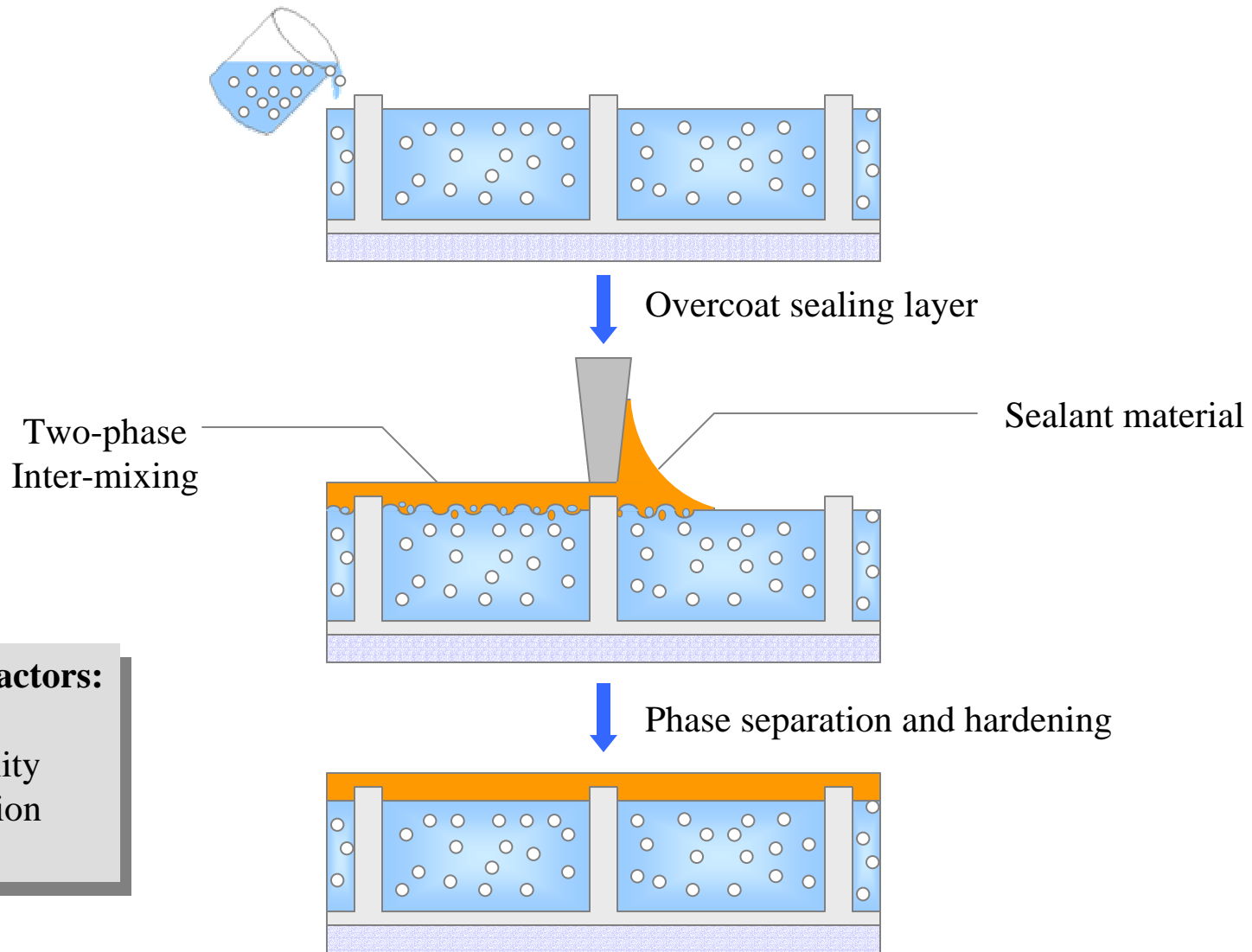


# **SiPix** One-Pass Filling & Sealing Process



**Seamless sealing may be accomplished in seconds.**

# SiPix Two-Pass Filling & Sealing Process



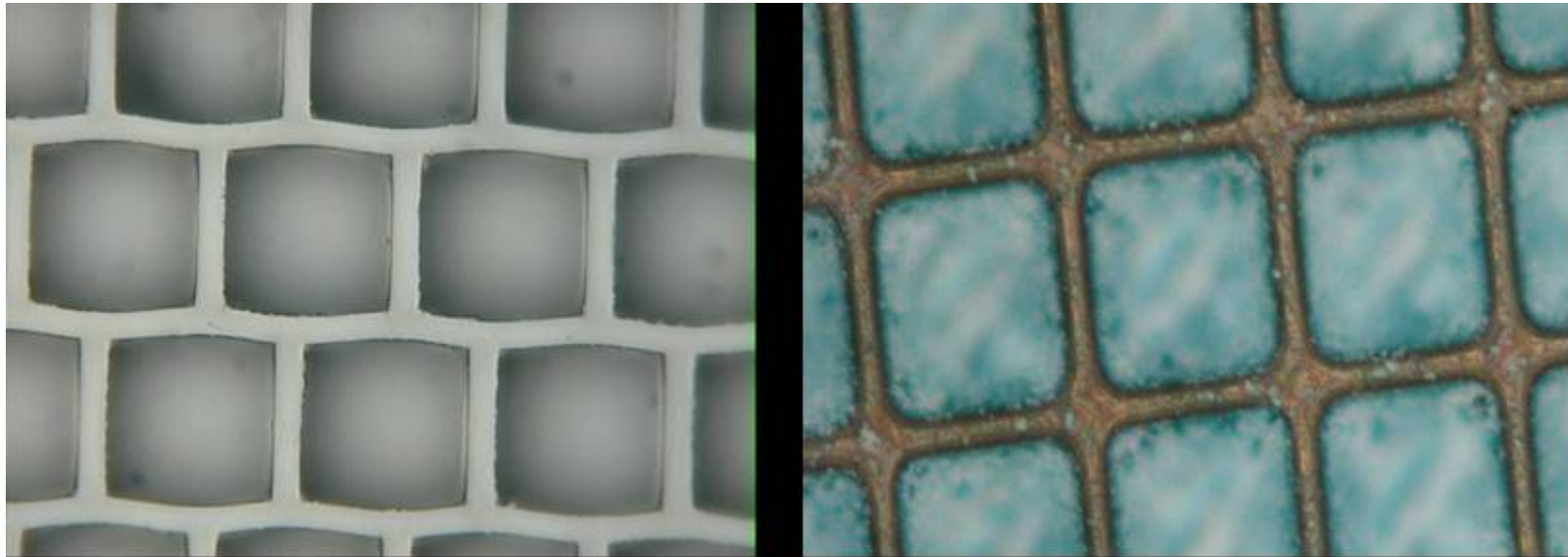
## Controlling factors:

- Density
- Incompatibility
- Surface tension
- Viscosity

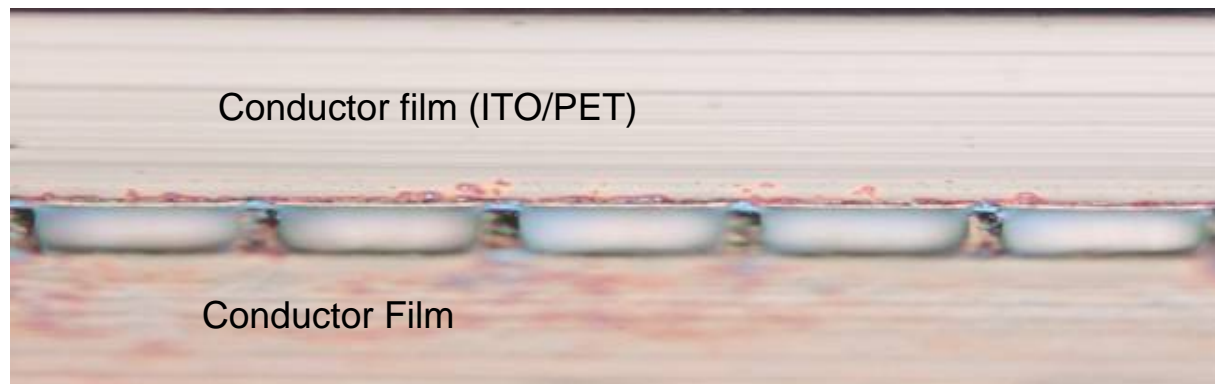
**Seamless sealing may be accomplished in seconds.**

# SiPix Seamlessly Sealed Microcups<sup>®</sup>

Negligible weight loss after 5 days in 80°C oven



Cell gap:  
15~30  $\mu\text{m}$ .

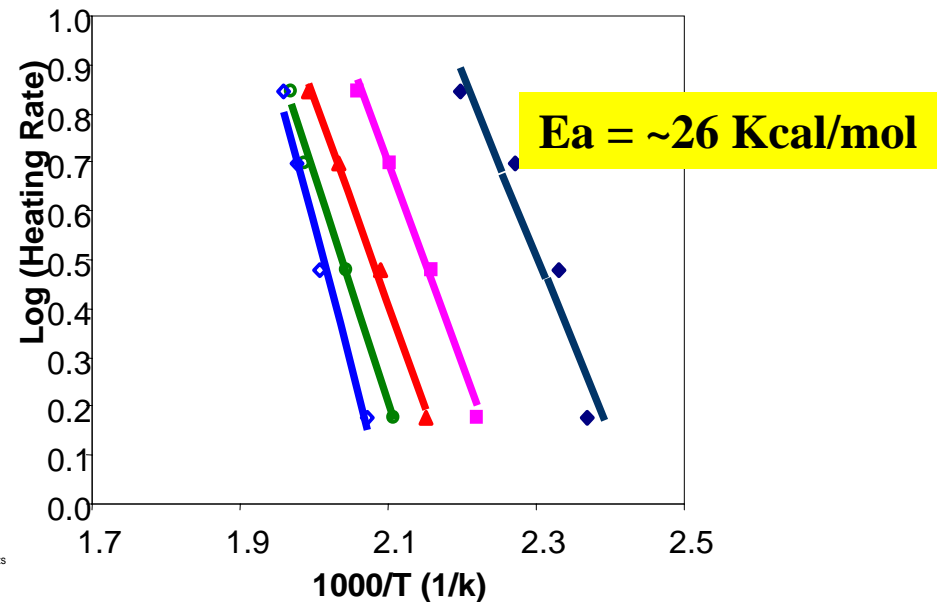
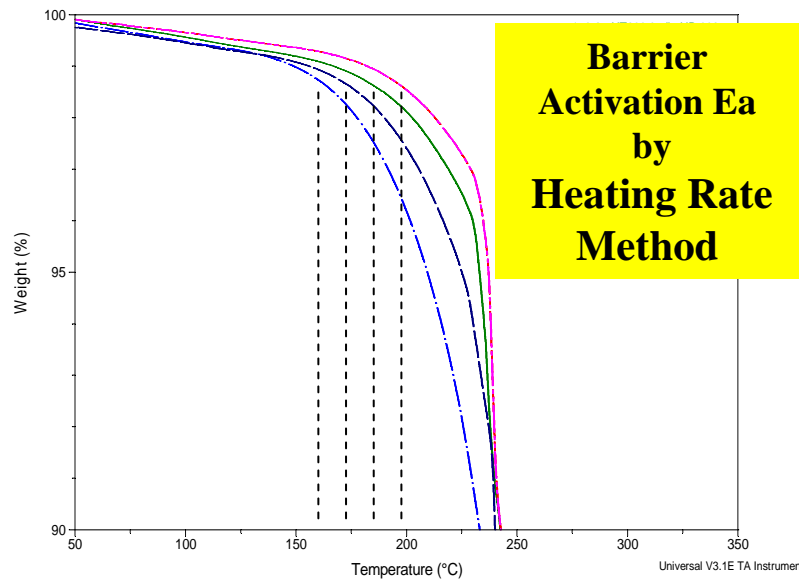
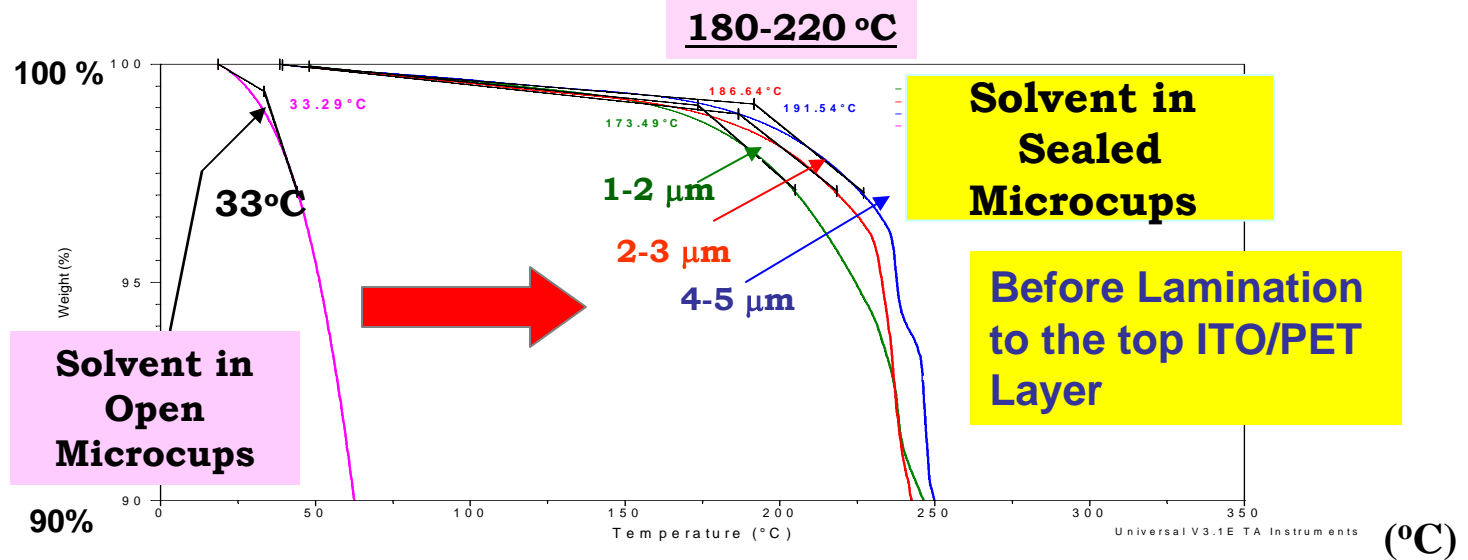


Sealing/Adhesive

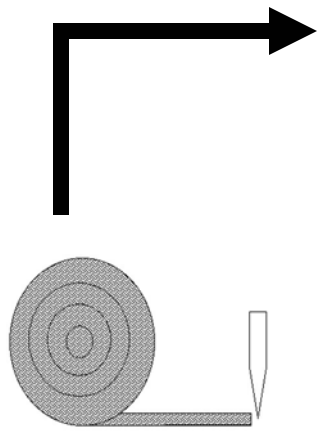
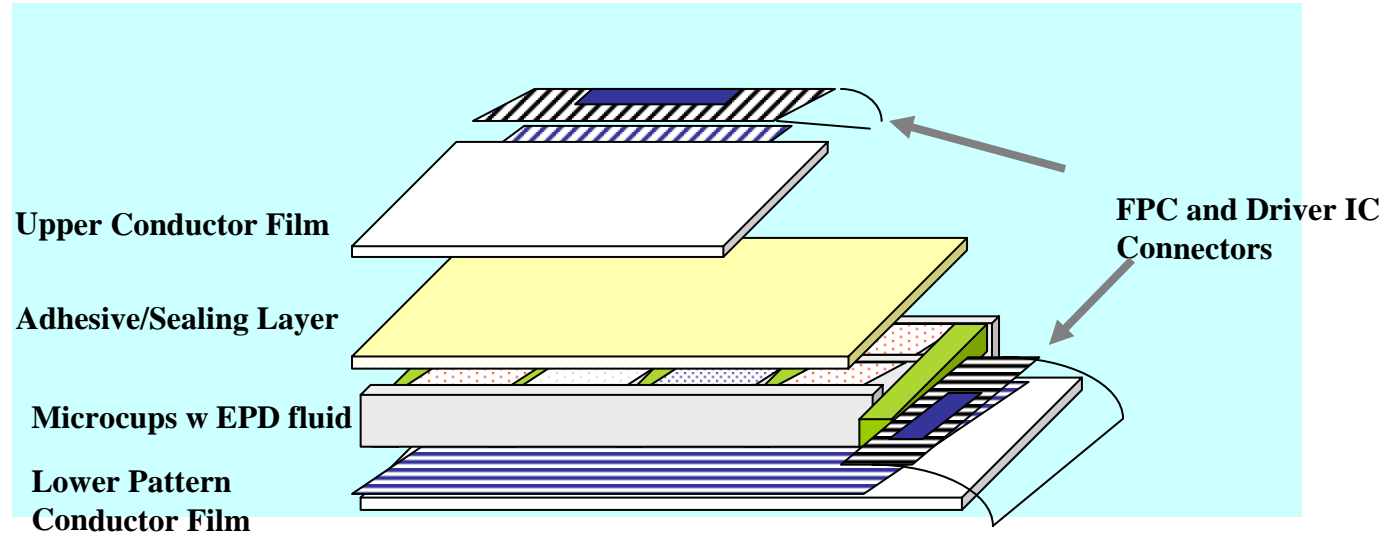
Microcup Partition

# Barrier Property of the SiPix Seamless Sealing Layer

TGA

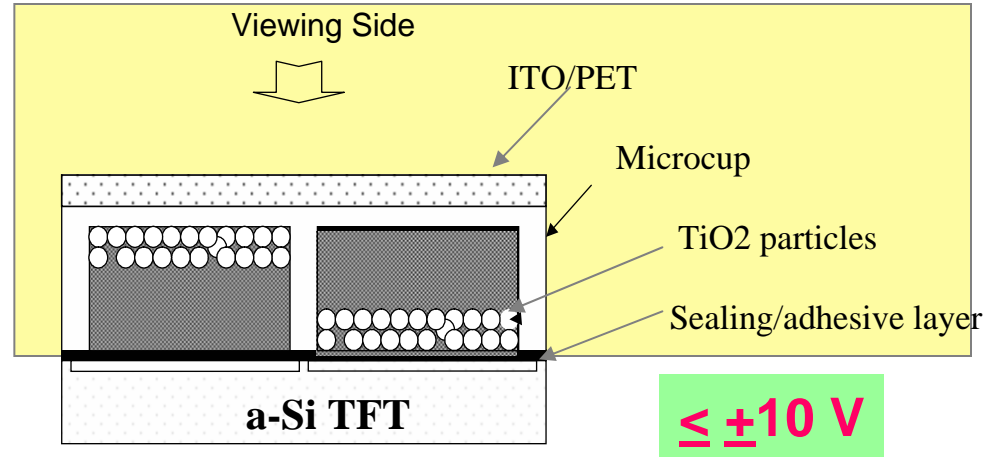
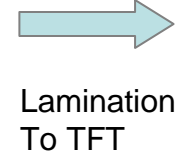
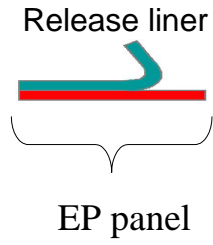
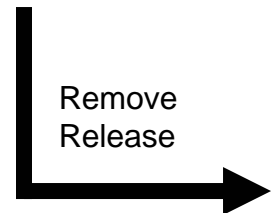


# SiPix Microcup<sup>®</sup> PMEPDs



EPD Roll

# SiPix Microcup<sup>®</sup> AMEPDs



# SiPix Displays

- Easy to Carry

Ultra thin, ultra light, durable and flexible

- Easy to Read

Reflective/Transflective, high contrast ratio, wide viewing angle, sun light readable

- Low Operation Cost

Bi-stable, low power consumption, Low operation voltage

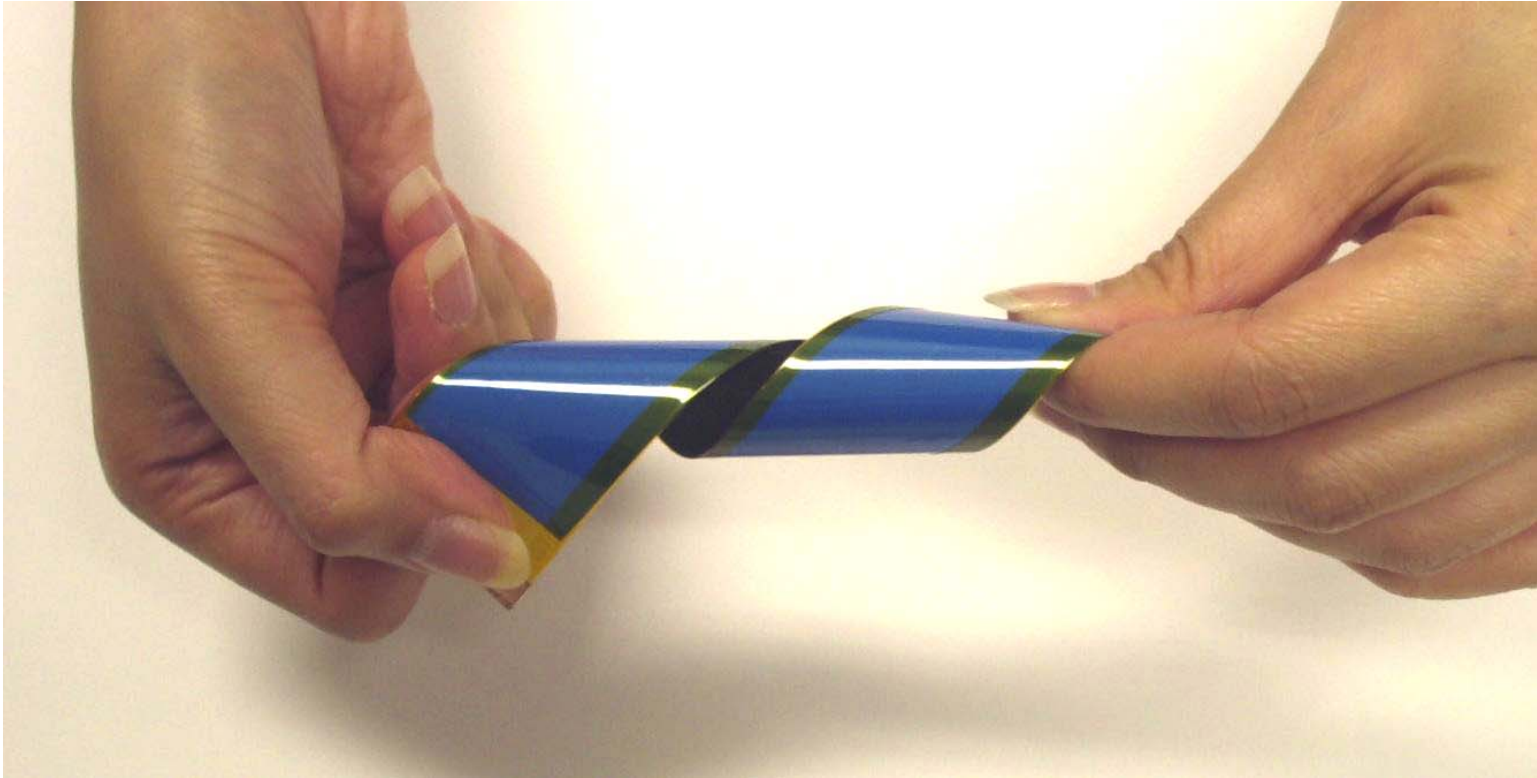
- Very Low Manufacturing Cost

Roll-to-roll, format & size flexible manufacturing process, very high yield, extremely low material cost

- **Environmental friendly**

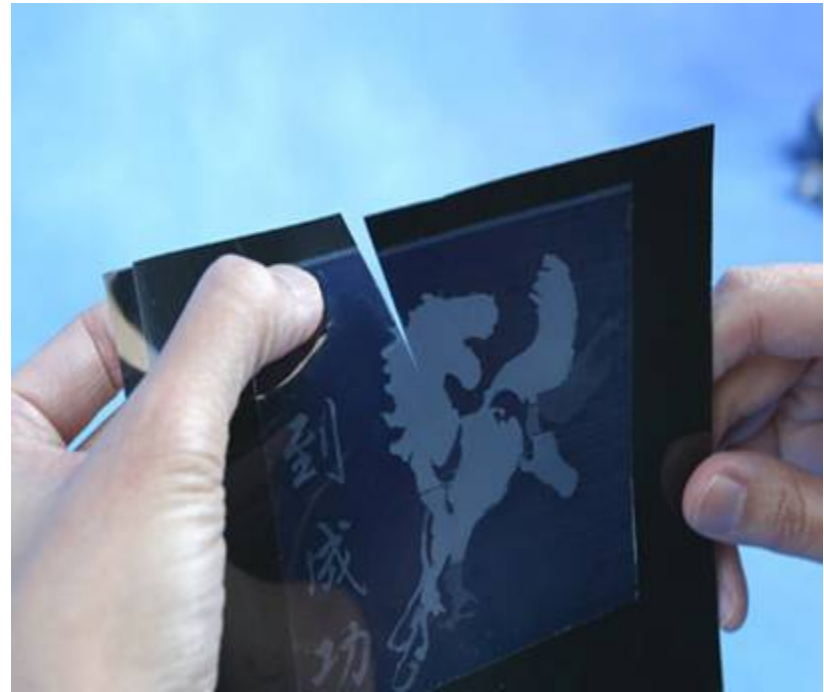
# SiPix Revolution

## Flexibility & Durability

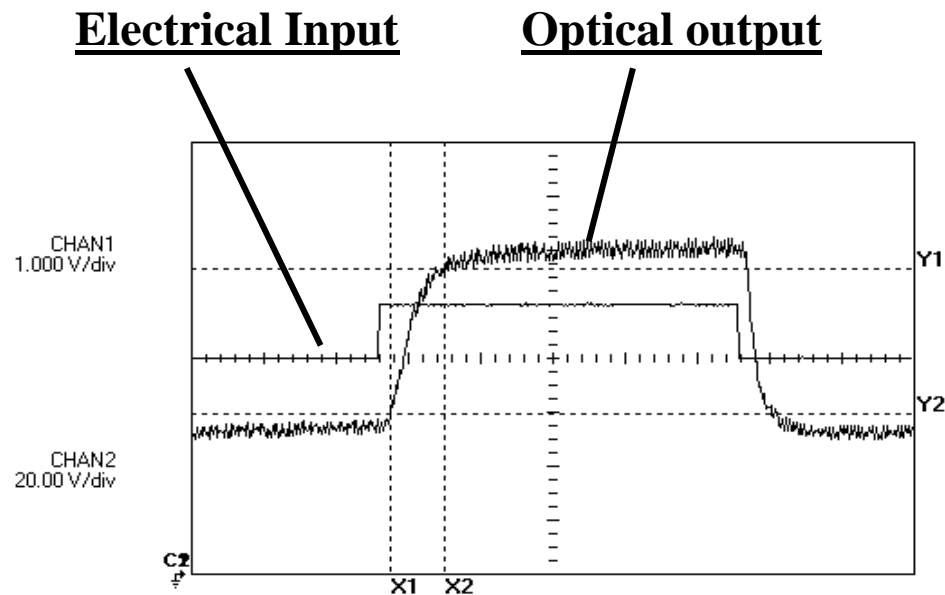


# SiPix Revolution

Format flexibility & Durability



# SiPix Microcup® AMEPD



**Electro-optical response curves of the 1<sup>st</sup> generation a-Si TFT Microcup® AMEPD driven at +10 V.**

**$t_{on} \simeq 400$  msec, CR  $\sim 10$ .**



# SiPix Microcup® EPDs

## SiPix Microcup® EPDs



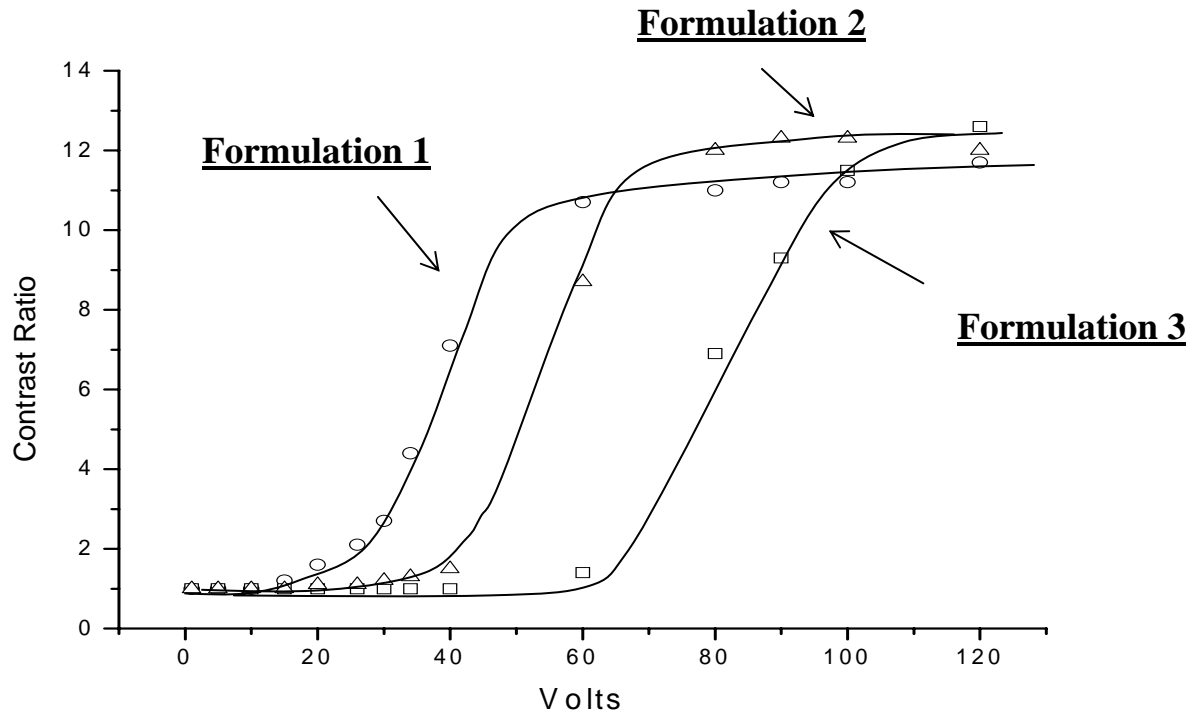
Smart Card



Price Tag/ E-sign/ Digital clock

# SiPix Microcup<sup>®</sup> PMEPDs

The World's First Plastic PMEPD by Roll-to-Roll Manufacturing



Optimized  
EP fluid &  
Microcup<sup>®</sup>

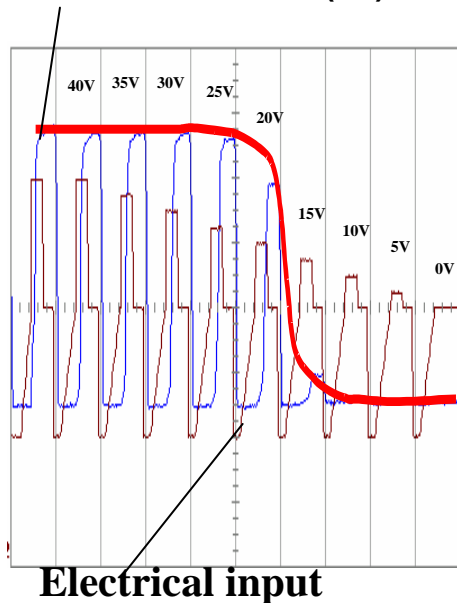


- Contrast ratio  $\geq 10$
- Threshold Voltage = 10~55 V  
for various applications
- High Mobility & Bistability

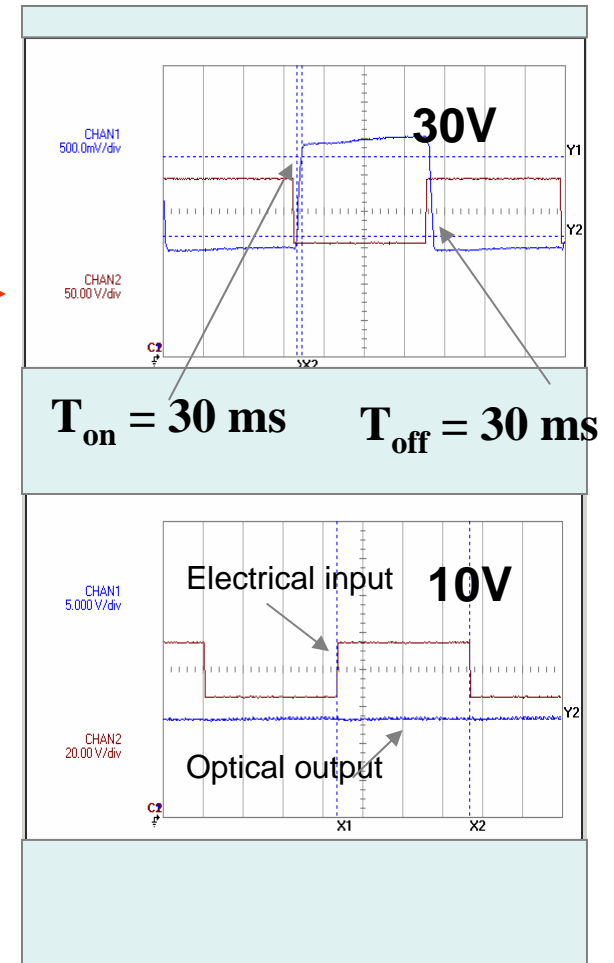
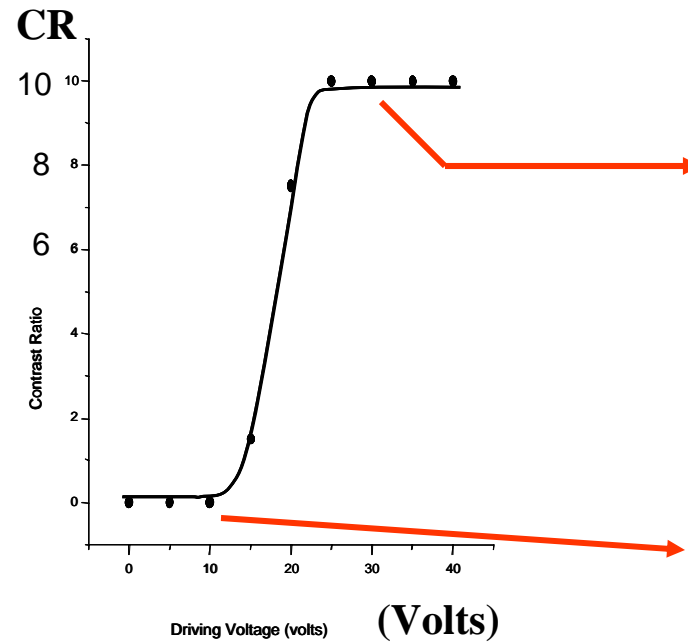
# SiPix Microcup<sup>®</sup> PMEPDs

Threshold Voltage  $\geq 10V$ ; Operation:  $\geq 25V$ ; Sharp Gamma  
(for e-board/bulletin applications)

Optical output (7A)



(7B)



**Figure 7** Electro-optical response (15A) and contrast ratio-voltage (15B) curves of the 1<sup>st</sup> generation Microcup<sup>®</sup> PMEPPD.

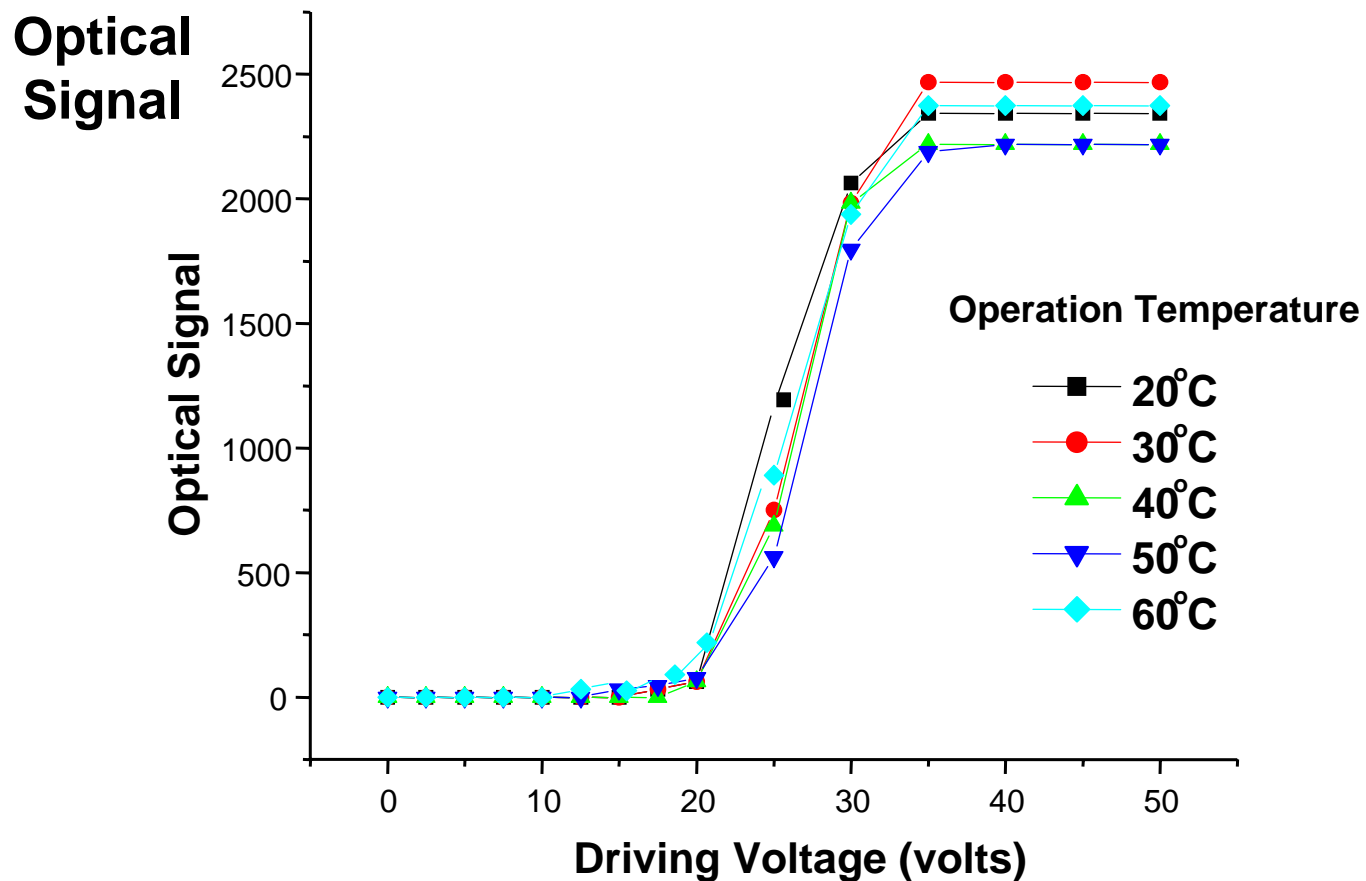
**Today,  $T_{on} = 20\text{ msec}$**



# Microcup<sup>®</sup> PMPED

## Operation Temperature Latitude

**Threshold remains almost unchanged between 20~60°C**



# SiPix Grayscale Bi-stability

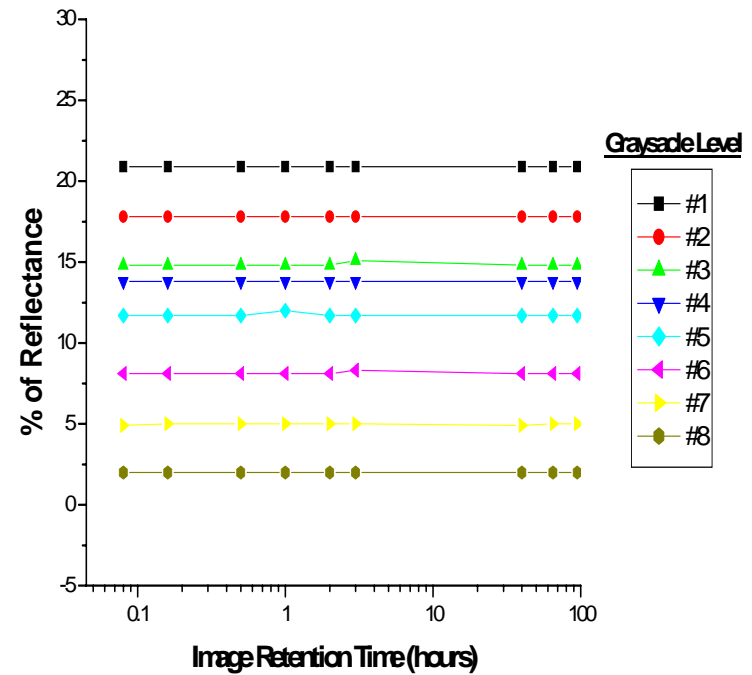


E-sign

(1A)



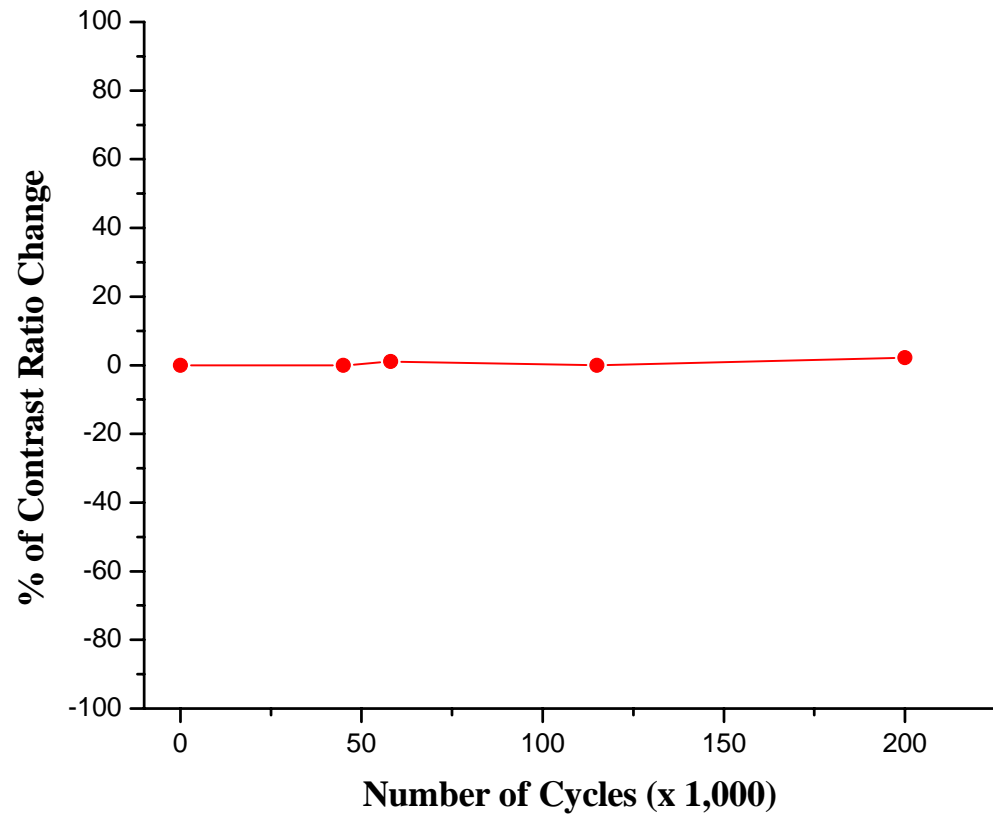
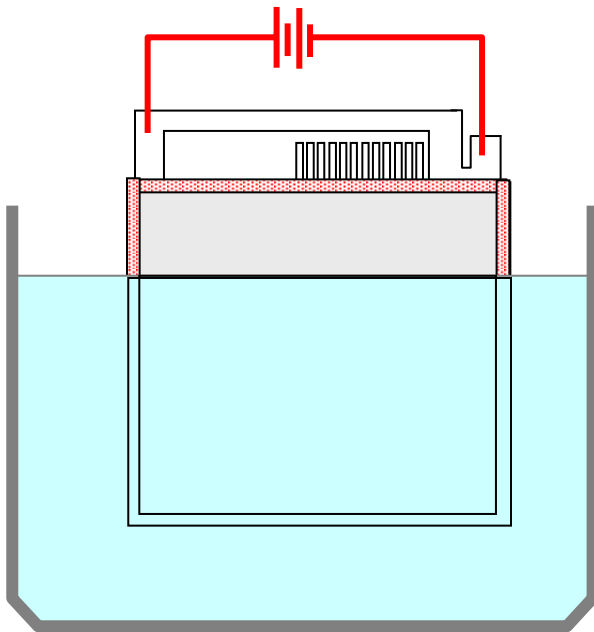
(1B)



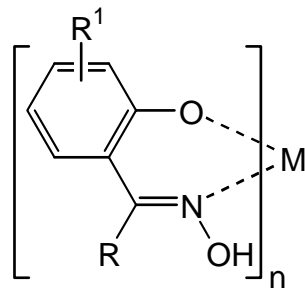
Today,  $\geq 12$  levels of grayscale have been demonstrated.

# Effect of Under-Water Operating on Contrast Ratio of Microcup<sup>®</sup> EPD

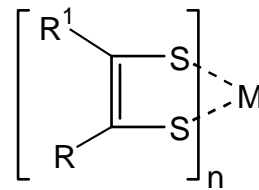
## Under Water Test Setup



# Metal-containing quenchers for the photostability of the EPD fluid



$Q_1$



$Q_2$

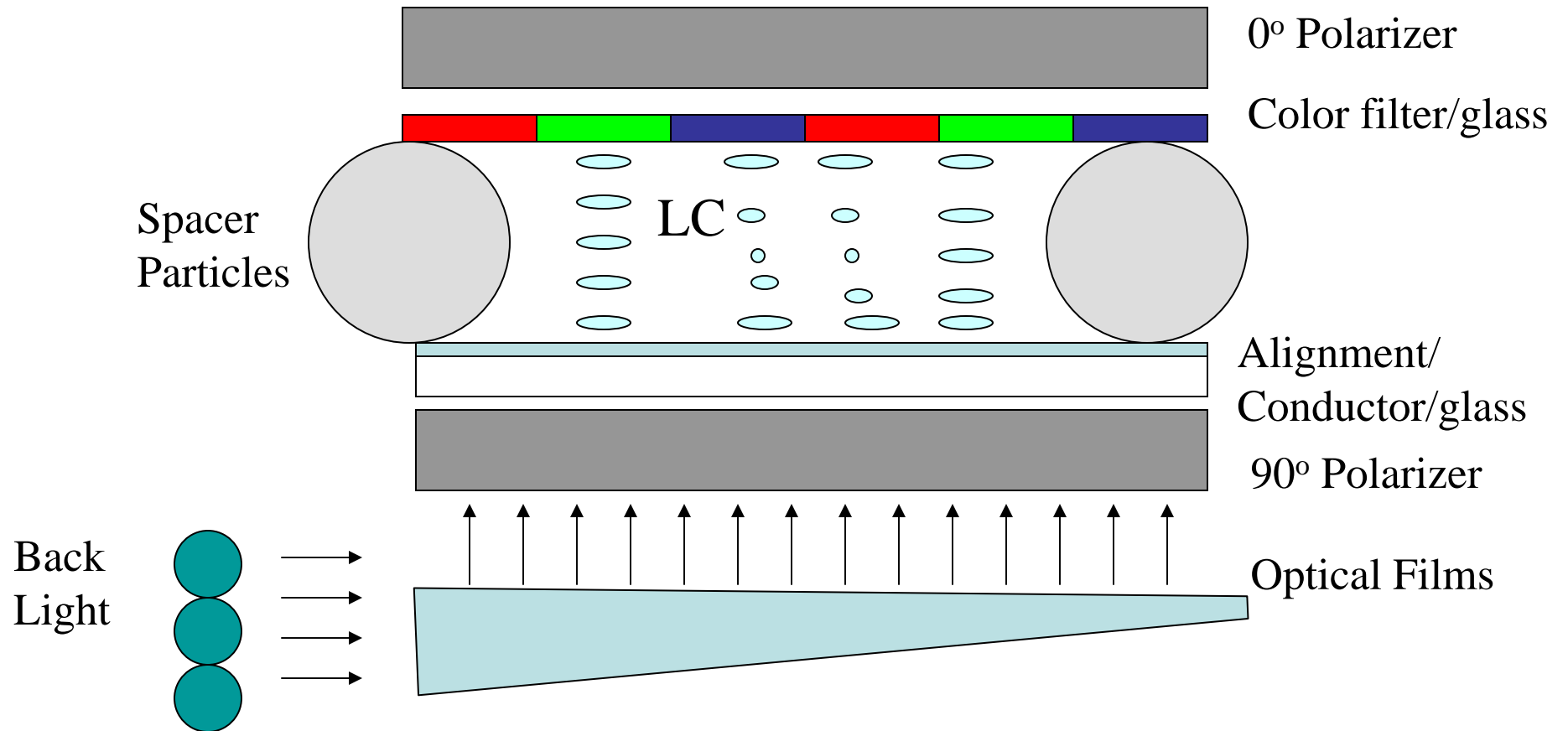
## The effect of Metal-containing quencher Q1-1 on the photostabilization of EPD fluid

	Concentration of Q <sub>1</sub> -1 (ppm in EPD fluid)	OD <sub>620nm</sub> loss after 2 hrs under a collimated 150W Xe-Arc lamp*	White light Exposure (hrs)	Normalized % decrease in display reflectance at the D <sub>min</sub> state @ 40V	Display contrast ratio at 40V, 0.2 Hz
1A	100	0%	0	6.9%	7.1
1B	100	-	17	2.3%	7.6
2A	0	11%	0	0.0%	7.4
2B	0	-	17	86.0%	1.1

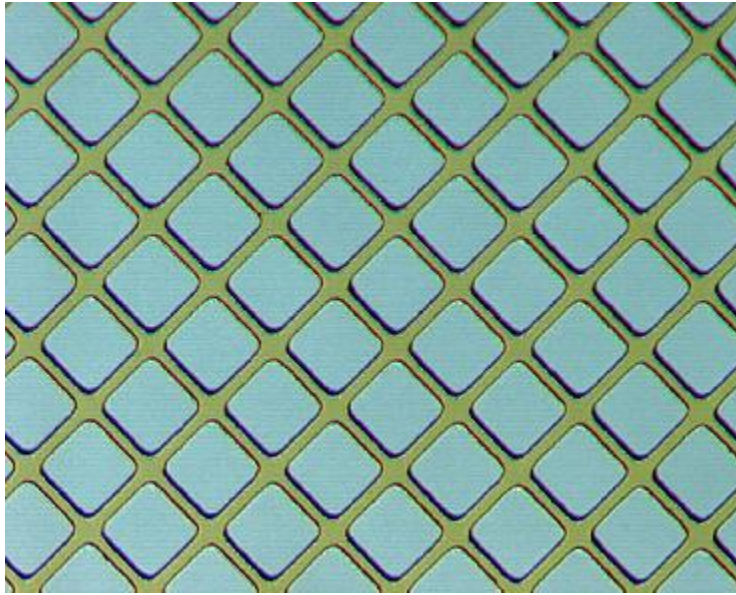
\*Optical density loss of the dye solution

# Comparison: LCDs

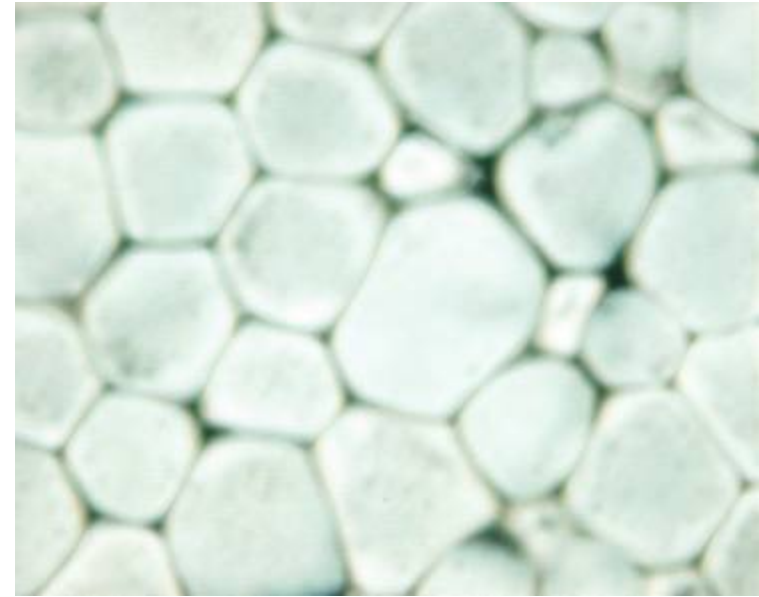
Performance extremely sensitive to surface roughness & birefringence



# SiPix Microcup<sup>®</sup> vs. Microcapsule EPDs

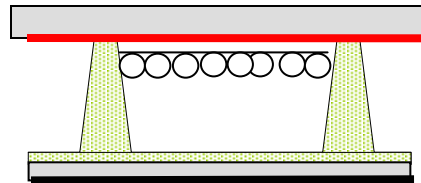


**Microcup<sup>®</sup> EPD Example**



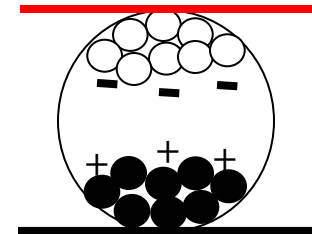
**Microcapsule EPD Example**

Cell gap:  
15-30  $\mu\text{m}$



High  
Payload

- Super mechanical properties
- Dry Embossing and Non-Aqueous Sealing Processes
- Color Separation is possible
- Microcup<sup>®</sup> and fluid may be optimized independently

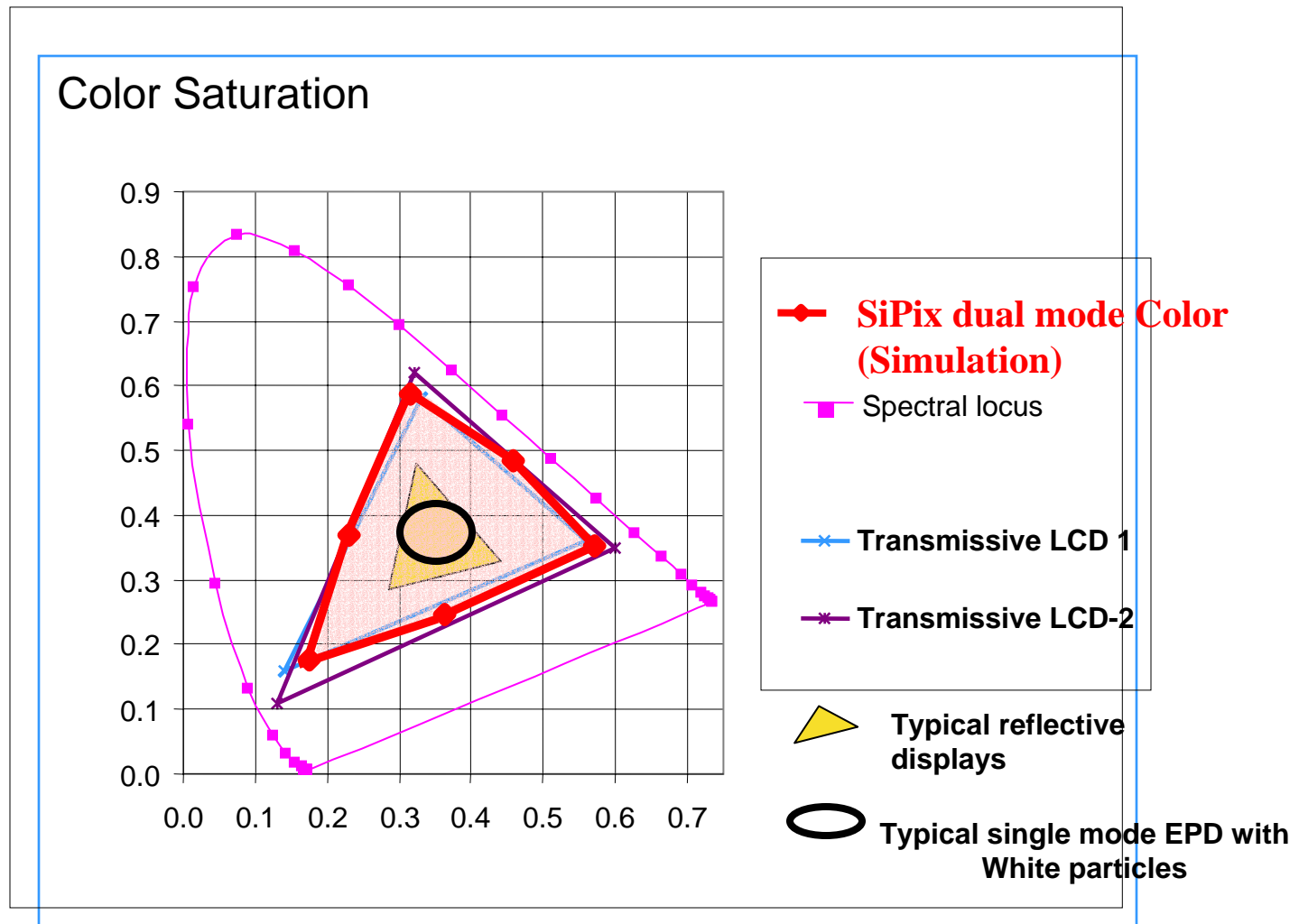


Cell gap:  
30-70  $\mu\text{m}$

# SiPix Dual Mode Color EPDs

v.s. Transmissive LCDs

**(Simulation)**



# Acknowledgement

- **SiPix Imaging Inc. for providing the great career opportunities in the exciting e-paper technologies.**
- **Center for Photochemical Sciences at BGSU**
- **Dr. D. C. Neckers for his continuous encouragement and world-class trainings in Photochemical Sciences during my PhD study**
- **Haiyan Gu and Fei Wang for their support in e-paper related development**