Development of Electro-Osmotic Color E-paper

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SID 2013 Vancouver

IGM
Institut für Grossflächige Mikroelektronik

IRX INNOVATIONS

Outline

- EPD status
- Overview current color technologies
- Layered color displays
  - E-osmotic principle and properties
- Required parameters / challenges
  - Aperture (white state)
  - Electrode coverage (colored state)
  - Speed and saturation
- Implemented improvements
  - Anti-reflection metal
  - ITO transmission
  - SU-8 pixel walls
- The demonstrator(s)
  - Passive, 8 colors on separate regions
  - Active (8 colors dithered, later greyscale, in preparation)
- Conclusion

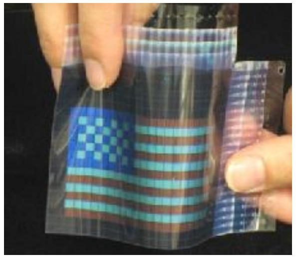
EPD status 2013

- Greyscale devices maturing
  - Display quality compares to good quality newspaper
  - Moderate contrast (~10:1)
- Color e-paper devices have hardly hit the market
  - Several display effects for color EPD investigated
  - No completely satisfying technology is proven for information displays yet
  - Target: a color image that meets the performance of a color photograph

IRX INNOVATIONS

Current reflective color solutions

- Additive color mixing (RGB (+W))
  - Shown by many using EPD
  - RGB – lack of brightness
  - RGBW – brighter white state but - lower reflectance of saturated colors / limited color gamut



- 3-layer RGB (Cholesteric / Flepia)
  - Shown by KDI / Fujitsu
  - Not satisfactory.. (yet?); PM – faint colors; AM – difficult – high voltage

- 2- or 3-layer CMY(K) – subtractive color mix
  - e.g. in-plane electrophoretics by Philips, electrowetting, electrofluidic by LiquaVista & Gamma Dynamics and electrochromic displays by Ricoh
  - Not proven yet (in information displays)

Current reflective color solutions

- Further attempts:
  - HP's "electrokinetic" display
    - hybrid vertical and horizontal (in-plane) electrophoretic display
    - CMY-stacked AM; speed: <300msec@15V

  - Fuji Xerox - SID 2012 - field dependent switching electrophoretic display
    - Cyan – Red prototype shown
    - Difficult to apply to 3 different particle system?

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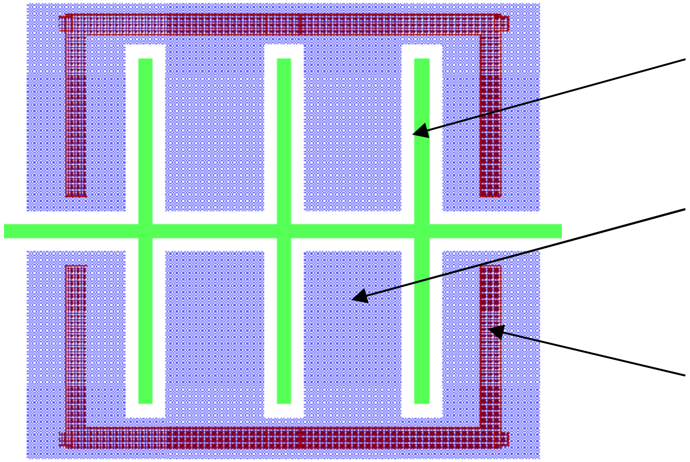
Electro-Osmotic principle

- Make use of liquid flow – rapidly transport colored particles through display pixel
- Hold particles electrostatically in desired places



Pixel design example

- Suitable pixel design to create a “pumping region” in certain parts of the pixel electrode – providing pumping action across the entire pixel electrode area

Pixel layout - properties

- Particles must be hidden from view in the transparent state
- The electrodes must create homogenous field across the cavity
- Particles must distribute evenly over the cavity in the colored state
- Aperture must be maximized

➡ E-Osmosis display technology could fulfill these requirements outperforming pure in-plane electrophoresis with much faster and more reliable switching

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CMY(K) / in-plane challenges

- Stacking
  - 3 panels combined
- Aperture
  - May be an issue with TFT backplanes?
  - How small can the total obstruction be made?
- Transmission / Reflectance
  - Multiple substrates, residual absorption by ITO, dye
- Unwanted reflections off electrodes
  - Provide dark electrode
- Speed and Saturation
- Parallax
  - Maximum spacing?
  - Use plastic foil / thin glass

Stacking

- Multi-layer systems not mainstream technology yet
  - Systems are expensive
- Multi-layer systems means higher complexity in device building
  - Two or three active matrix panels instead of one
  - Alignment of panels / optical losses
- Additive color solutions are an (economical) option as far as exact color reproduction is not a major requirement of the device
- Key to subtractive color solution at market
  - Task of display makers: Control the cost of multilayer systems
  - High yields + easy processing (make use of existing LCD infra-structure)
  - Should be possible to make an 10” triple panel display for around $100 material cost

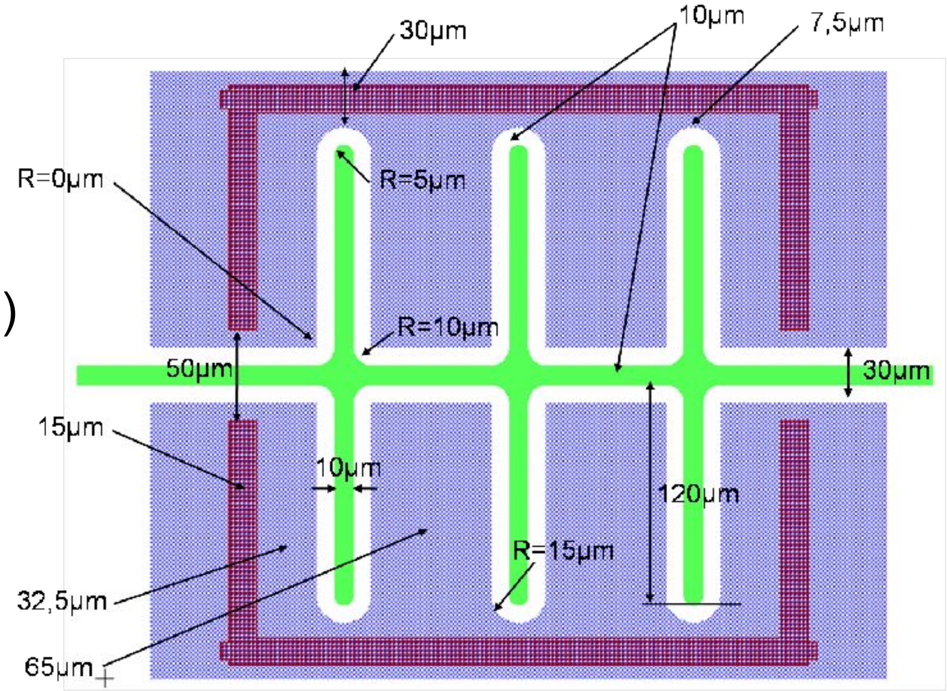
Aperture - PM

Maximize open pixel area !

<u>Calculated example:</u>

- Pixel: 300 x 300 µm
  - 90000µm²
- opaque electrode (green)
  - 10000µm²
- transparent electrode (blue)
  - ~60800µm²
- space between electrodes
  - ~19200µm²
- spacer walls
  - 8600µm²

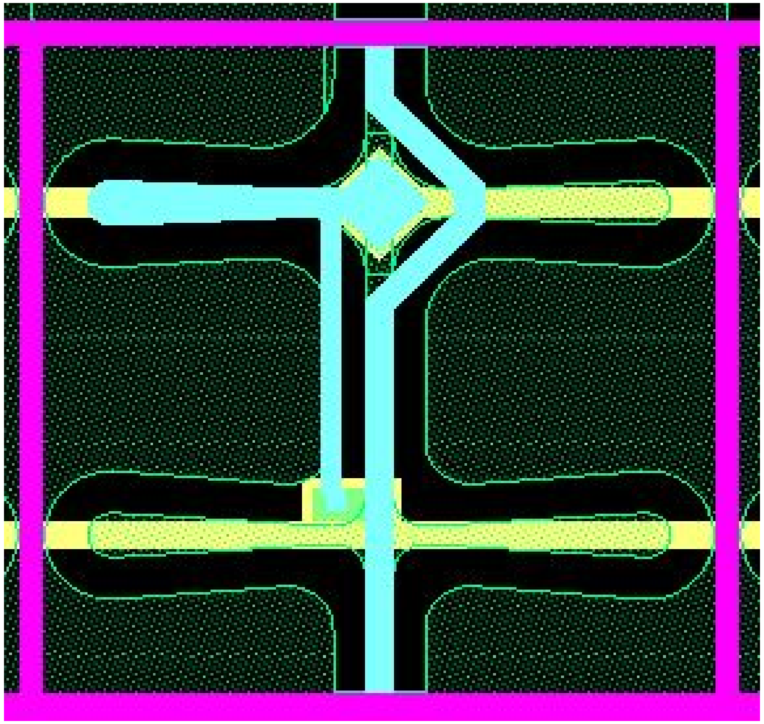
- ~11% covered area
- aperture: ~89%



Aperture - AM

Actual design:

- Pixel: 168 x 168 µm
  - 28224µm²
- Metal tracks: 3 x 5 x 168 µm
  - 2520µm²
- TFT: 20 x 50 µm
  - 1000µm²
- Pixel electrodes: 3 x 5 x 150 µm
  - 2250µm²
- Pixel contact: 30 x 30 µm
  - 900µm²
- Capacitor overlapping gate line

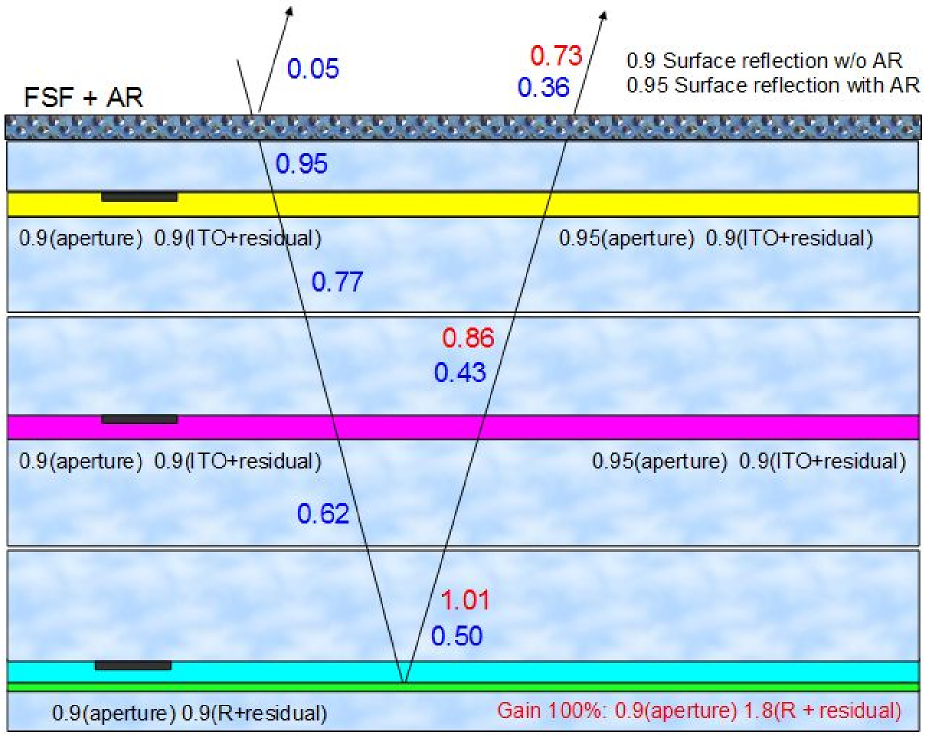


- 7420µm² covered area but most structural patterns burried beneath pixel electrodes, leading to ~3500µm² opaque area

Aperture: 87%

Transmission / Reflectance

- Transmission difficult to influence
- ~ 5% of incident light reflected at each substrate to air interface
- ~5-10% absorption per electrode
- 3 displays in stack containing 6 substrates and 3 transparent electrodes
- Optical bonding of single panels to avoid inter-panel reflections
- Make pixel electrode as transparent as possible
- ~ 90% transmission per pixel electrode should be feasable
- 3-layer color display: ~35-70% reflectance depending on paral-lax and reflector



Speed and Saturation

- Speed
- In plane switching, larger distances to overcome than for out of plane switching
- switching over entire pixel – higher switching speeds needed
- e-osmosis display effect predicts solution
- segmented pixel design – shortens path (and aperture)

- Saturation
- Saturation matter of dye performance / dye concentration / cell gap / homogeneous field distribution
- Concentration high enough to provide sufficient extinction and low enough to still permit easy/fast switching

Parallax

- If pixels are aligned perfectly, no additional losses for perpendicular viewing / illumination
- With finite layer distance, illumination and viewing are off-axis, leading to loss of reflectance.
  - Worst case loss = 0.5* aperture loss per additional layer,
  - Larger distance does not lead to larger loss, but leads to larger “color bleeding”
- Typical layer distance between front- and rear pixel in multi-layer stack should be no larger than pixel size
- Practical:
  - Display with 200 µm pixel
  - 3 displays using 50 µm substrate thickness
  - Distance top to bottom pixel is 4 x 50 µm
  - Viewing at grazing incidence leads to 42 deg. light path inclination.
  - Apparent displacement < 1 pixel
- Challenge at pixel sizes below 200µm
  - Thin glass / plastic foils can offer solution

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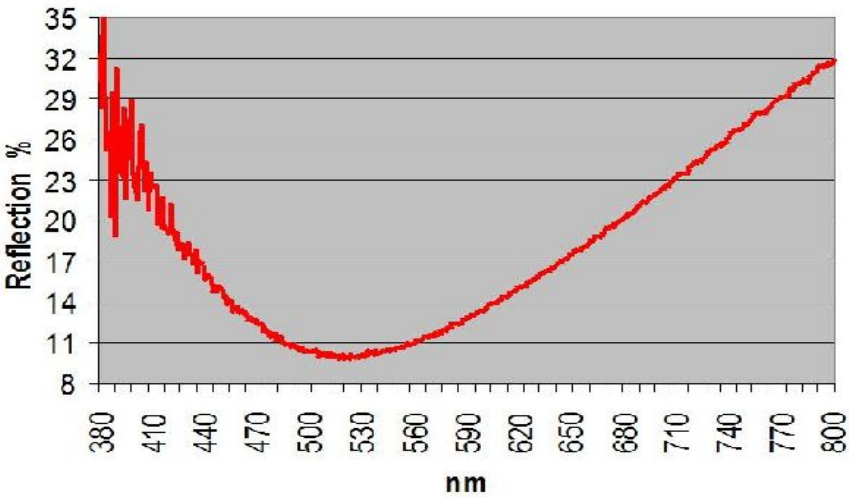
Black Matrix (BM)

- Absorb unwanted reflection of opaque metal electrode
- Molybdenum Tantalum (MoTa) + metal oxide interference layer

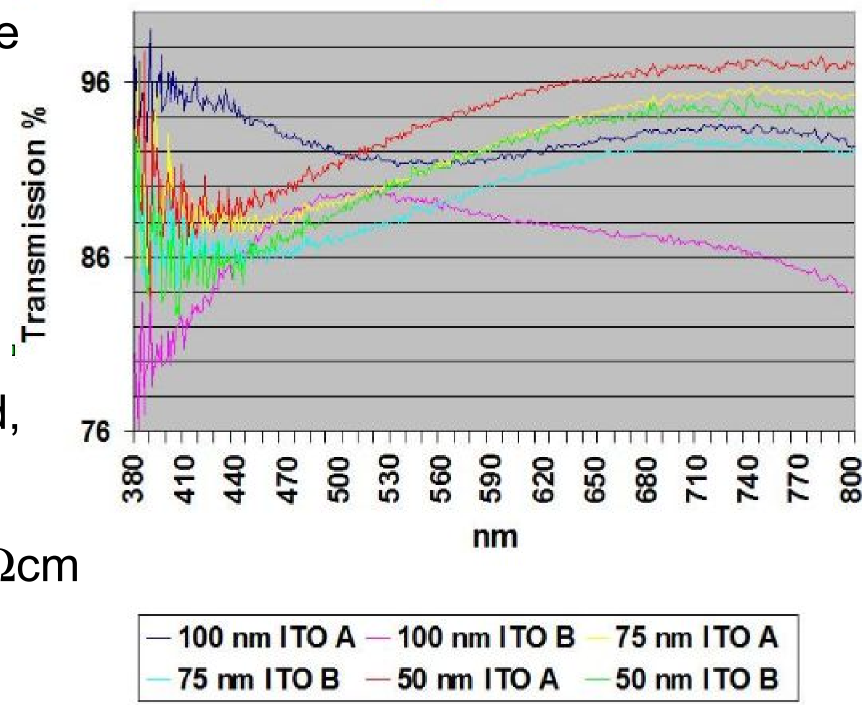


Relative reflection of BM double layer

- BM reduces reflectance of opaque finger electrodes to between 70-90% compared to single MoTa layer

Pixel ITO

- Transparent electrode made of ITO
- 3-layer stack – increase transmission to max. value
- 2 different sputter and wet etch processes investigated, 3 thicknesses
- ITO A, B d=50nm, ρ=200μΩcm
  -> 90-95% transmission
  -> sufficient for application

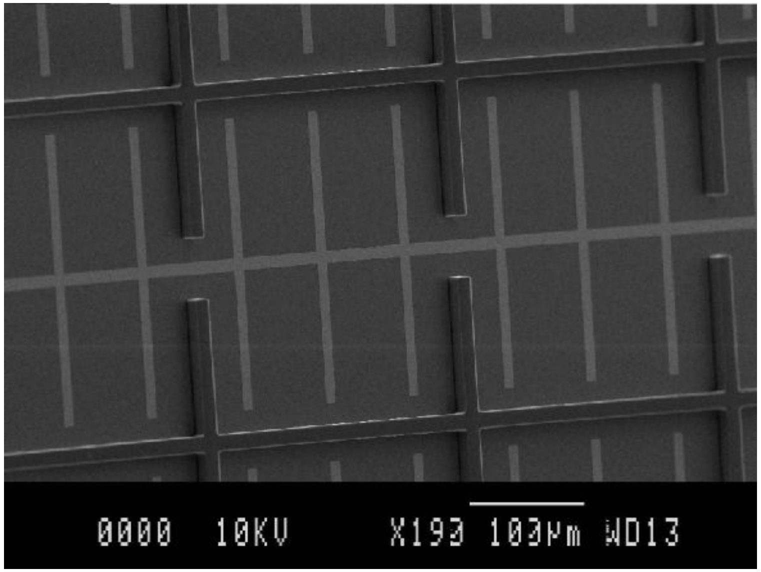


Relative transmission of sputterd ITO

Pixel walls

- first trial: cell gap definition with spherical plastic spacers
  - Crosstalk between neighboring pixels
  - Movement of spacers during capillary cell filling
  - (Negative ?) influence on switching behaviour

- use of photolithographic patternable spacers
  - SU-8 negative epoxy resist
  - Aspect ratio 1:1 for passive display – 15µm height + width (3:1 for active matrix)
  - Several spacer wall designs tested
  - Positive influence of pixel walls on switching
  - Open pixel walls for capillary filling, later closed design for ODF



SEM image of SU-8 spacer walls

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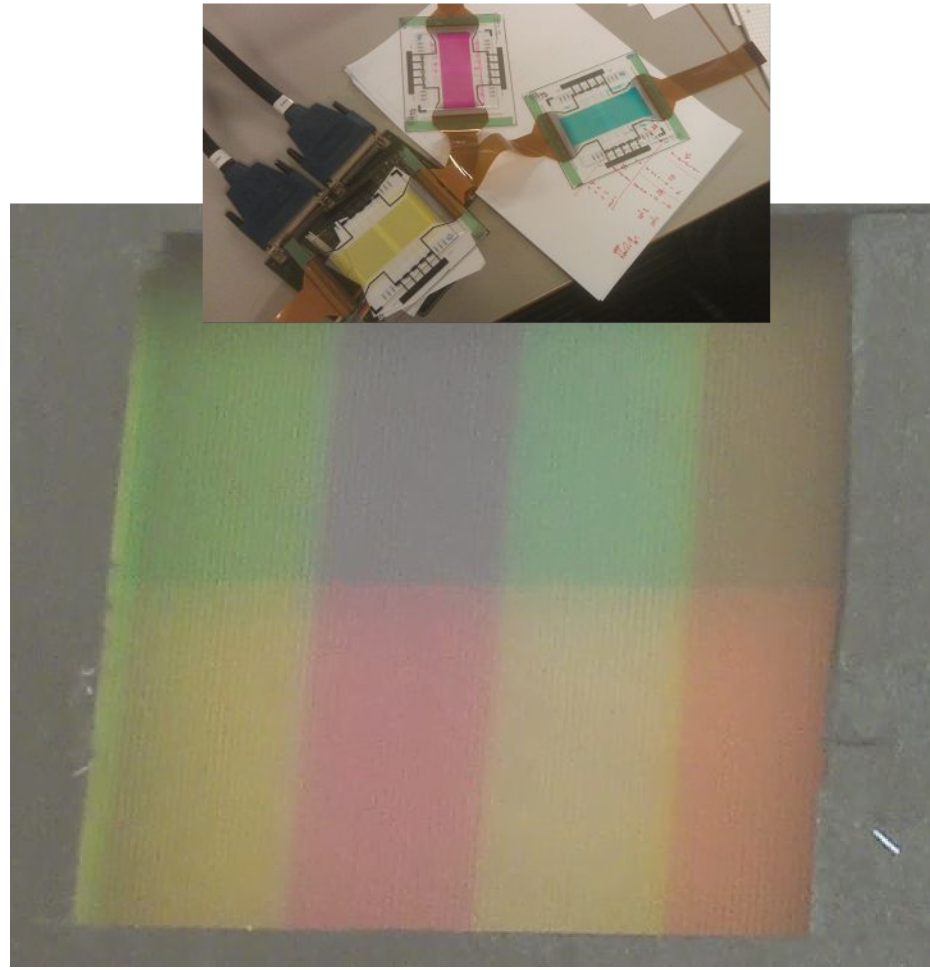
Passive matrix result

- 3 layer, 8 primaries
- 25-30% reflectivity
  for every color
- Aperture 90%
- Pixel size 300 x 300 μm²
- Switching time
  (on + off) 3s
- Contrast: 3:1
  (single layer + stack)



PM-E-Osmosis demonstrator

Active matrix result

- In preparation
- Triple layer CMY panel and single panel B/W
- 800 x 600 pixels
- Aperture 87%, transmission 75% (single layer)
- Pixel size 168 x 168 μm²

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Conclusions

- The electro-osmotic color system offers a substantially better color performance
- Commercialization is only months away
- Electro-osmotic displays will enable a variety of color applications soon
- Electro-osmosis will be able to fulfill more general color quality requirements: Development continues
- Electro-osmosis will be video-capable in several years
- Come see us at the author interview

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