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A 10.3" Full Color EWD Prototype

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ABSTRACT

A 10.3", 1152 x 1536 183 PPI reflective color display was manufactured by custom design of an oxide-TFT backplane with GOA gate structure. The display was subsequently formed by patterning a pixel structure for an electrowetting display and forming a 3 cell sandwich with cyan, magenta and yellow panels. The completed unit was driven by custom built drive electronics.

1 Introduction

Reflective color displays still lag in performance with emissive displays (backlit LCD or OLED). Creating an acceptable color performance can only be achieved by neglecting display brightness, so in a reflective color display until now the trade-off was always to maximize brightness at the expense of color saturation. Replacing traditional color solutions (RGB or RGBW color filter patterns for an additive color model) by layering three panels with a subtractive color model (cyan, magenta and yellow) has been described and prototyped on many occasions using electrophoretic, electrochromic or electrowetting technology [1]. Until now, however, this has not yet been extended to a large and relatively high resolution display.

In constructing a multilayer subtractive color display, several aspects have to be carefully taken care of:

- Maximum open area (panel aperture)
- Minimum reflective losses (ITO transmission / reflection)
- Maximum effect modulation (optical aperture)
- Optimal dye properties (high transmission in transmission band, high extinction in extinction band)
- Minimum vertical separation between primary colors

Optimizing all these factors is a continuing process, and subsequent generations of products show increasingly good results.

2 Construction

A three layer subtractive display is primarily made up of three components:

- The TFT backplane
- The technology implementation (pixel structure, layering of the panels etc.)
- Drive electronics

These will be described in the following sections

2.1 TFT backplane

The active matrix driving circuit is the backbone of any display. In the case of a reflective display, layering poses different requirements for different layers in the stack: The top cells need to have maximum transmission, meaning all technical structures like source and gate metal lines, storage capacitors and TFT switches, have to be made dependent on the aperture. The bottom plate needs to have an in-cell reflector offering the possibility to once again increase the effective aperture by burying some blocking elements behind the reflector.

The current design shows this in the design choices made:

- The backplane is using an Indium Gallium Zink Oxide (IGZO) active matrix. Because of the high mobility, a small transistor suffices to drive the panel. Also, technically, IGZO is transparent, although this doesn't add significantly to the aperture.
- Bus line widths were minimized avoiding blockage or reflection from the lines as much as possible
- Ground planes were fabricated using ITO,
- Pixel areas were clear of ITO as much as possible (figure 2)
- The in-cell reflector is made using silver to provide maximum reflectance.

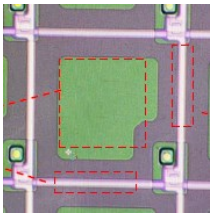

Figure 1: Pixel layout

Overall, the transparent backplanes provided over 90% effective aperture, while, measured individually, showed over 80% transmittance (including the reflections on front and rear substrate to air transitions). The reflective substrate showed over 80% reflection.

These substrates, if used without the electrowetting medium, and stacked using index matching materials, would provide 48% reflectance (0.86 x 0.90 x 0.80 x 0.90 x 0.86 = 0.479).

2.2 Electrowetting system

The electrowetting system is created as usual, with transparent dividing walls between pixels 15 um wide, which, for a 137 um pixel, means it's taking up 20% of the total pixel area. The pixel switch itself switches to approximately an aperture of 80% of the effective pixel. However, because the dyes are selected carefully, a switched pixel absorbs relatively little of the complementary colors, so we should mostly calculate the absorption of the switched color in each of the primary color cells. For example: The magenta cell is assumed to have 100% transmission for red and blue light, while only attenuating the green light. In such a way, we calculate the extra attenuation of the electrowetting system as a single cell absorbing all wavelengths, being passed twice. The well known excellent color reproduction of the three-layer electrowetting system (fig. 2) is, however, compromised (fig. 3)

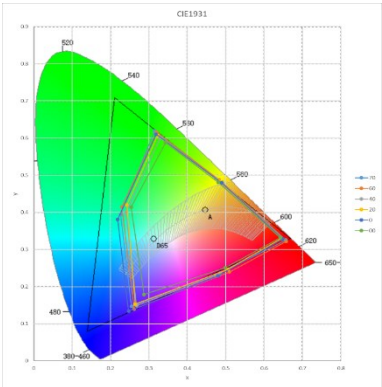

Figure 2: color reproduction of passive samples

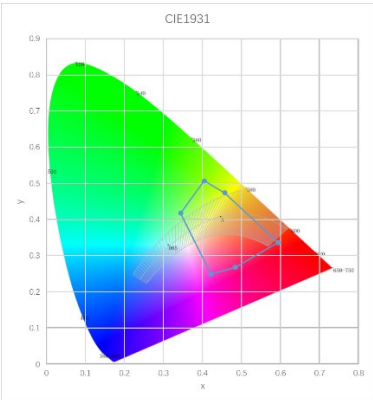

Figure 3: Color reproduction of this display

Calculation example: If the effective aperture of the active pixel area is 80%, then the aperture of the pixel including pixel wall is 84%, and if passed twice, this number should be squared, yielding approximately 70%.

Combining this with the effective reflectance of the TFT plates, the total reflectance should be close to 0.479 x 0.7 = 33.8%. Although this is not as much as would be desirable (target value is 50%) it is much better than existing, color filter based e-paper systems (20% with low color saturation).

2.3 Electronics system

The electrowetting system behaves differently from an LCD. To begin with, it has a kinetically defined opening voltage, and so the T-V curves show hysteresis. In order to prevent the lower greylevels to become inaddressable, the drive system needs to provide a method to open the pixel before addressing the greylevel voltage. Also, a sophisticated lookup-table needs to be used to provide the correct representation of voltage versus perceived luminance (in LCDs usually taken care of by gamma-corrections.

Finally, the driving system also needs to take care of the gate driving sequences of this GoA TFT panel design.

A block diagram can be seen in figure 4.

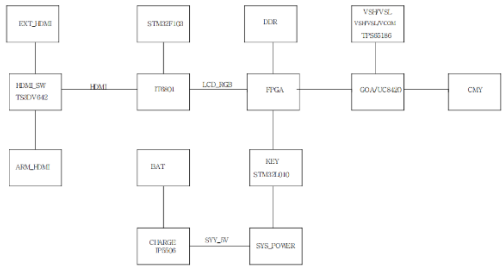

Figure 4: Block diagram of driving system

3 Results

The assembled panel looks very satisfying in terms of color saturation and general appearance. The reflectance, measured at 19%, is a bit disappointing. Possible causes for this are the ITO layers of the counter-electrodes (6 additional ITO to glass transitions, providing 12 additional passes at ~ 1% loss each) as well as a non-optimal aperture of the pixel that is closer to 70% than 80%. (this is due to the relatively small effective size of the pixel). The resulting image can be seen in figure 3, the color reproduction in figure 5.

Figure 5: Resulting image of full color device

4 Discussion

. The overall result of the final demonstration device is satisfying the set requirements. Total reflectance of the display is still not fully satisfactory, but given the pixel resolution, the result is certainly not disappointing.

Additional steps have to be made in order to achieve still better reflectance (additional care for interface scattering and reflections, [2])

5 Conclusions

. We have succeeded in creating a 10.3”, 1152 x 1536, 183 PPI three-layered reflective color display. It was demonstrated such a display can achieve acceptable reflectance while maintaining excellent color saturation and good contrast. Since this is only a step in the continuous improvement process of subtractive color displays, it is more than likely the targets of high reflectance will also be met in the future. It is clear that a reflective display with excellent reproduction of colors, bright, paper-like appearance and very low power consumption will significantly disrupt the display product mix as it is today.

6 Acknowledgements

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7 References

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