A commercial-ready, high resolution AMOLED mobile display with amorphous silicon backplane

Corbin Church, Reza Chaji, Stefan Alexander and Arokia Nathan
[1]IGNIS Innovation, Inc., Kitchener, Ontario, Canada
TEL:+1 514-396-3588, e-mail: cchurch@ignis.ca

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Abstract

An advanced backplane circuit technology for AMOLED using amorphous silicon TFTs with commercial level reliability, uniformity and lifetime was recently integrated into a prototype device. Differential aging of T98>100 hrs at 200 cd/m2 brightness and >10,000hrs lifetime is demonstrated. A 2.2" QVGA (240x320) prototype has been developed and shown having the above-mentioned high performance.

1. Introduction

While the technical merits of Active Matrix Organic Light Emitting Displays (AMOLED) have been successfully demonstrated and almost universally accepted, its promise as a low cost, or at least cost competitive, alternative technology has remained an elusive goal. The market for AMOLED is just beginning and is expanding rapidly, however its extent will be limited unless the display unit cost is dramatically reduced.

Until now, the industry has relied almost exclusively on polysilicon (poly-Si) as the backplane of choice. Poly-Si has numerous technical advantages ideal for the current-driven AMOLED which allows for greater design freedoms, but this flexibility comes at a price. Poly-Si manufacturing has proven to be difficult to scale-up or obtain high yields, which in turn drives unit costs higher. To address these concerns, new process techniques for large area [1] and compensating circuits [2-4] have been proposed. To date, none have yet been shown to completely overcome the issues.

On the other hand, amorphous silicon is not as technically suitable for AMOLED but offers key advantages such as high uniformity, size and capacity. Due to this, manufacturing unit costs can be dramatically lowered compared to polysilicon. However, for this to be possible certain serious problems must be addressed - namely the threshold voltage (Vt) shift and low mobility of the amorphous material.

We have succeeded in developing a high resolution AMOLED prototype that uses amorphous silicon for the backplane and which demonstrates commercial level performance and reliability for small displays. We believe the use of amorphous silicon will dramatically reduce the cost of the AMOLED to more competitive levels, while improving the success of industry to up-scale to larger form factors.

2. Panel description and design considerations

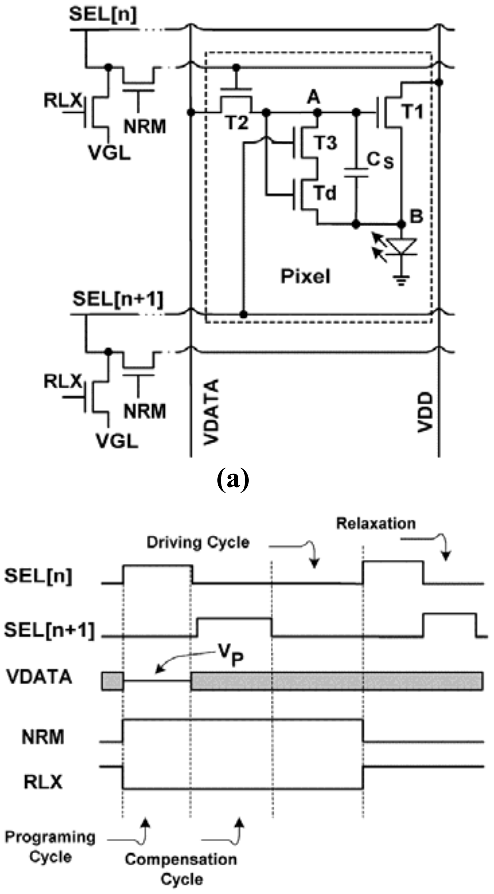
Our desire was to develop a prototype based on specifications which are mainstream in the market, and use conventional manufacturing methods. Table 1 shows the main specifications of the prototype built.

TABLE 1. Specs of 2.2" a-Si AMOLED prototype

Specification	a-Si AMOLED
Size (diagonal)	2.2"
Resolution (ppi)	240xRGBx320 (181ppi)
Front of Screen Luminance	200 cd/m^2
Polarizer transmittance	44%
Gamma	2.2
Color	262,144 (8-bit)
CIE1931 White point (x,y)	(0.31,0.33)
Emission type	Bottom, RGB stripe
Compensating circuit	4T1C
Aperture ratio (average)	27%
R,G, B efficiencies	R: 16-18 cd/A G: 25-28 cd/A B: 5-7 cd/A

In order to use amorphous silicon, a special compensating circuit was developed [5], called the Advanced Mobile, or AdMo^{TM}, circuit. AdMo^{TM}

uses four transistors and one storage capacitor, and has the ability to not only compensate the threshold voltage shift but also the difference in mobility, usually caused by temperature. In addition, the circuit is also immune to any pixel to pixel process variation that may be caused during manufacturing. This attribute expands the process window and improves fabrication yield. Moreover, the addition of a special relaxation function is used to slow the rate of threshold voltage shift and extend the life of the panel. The switches used to implement relaxation are designed on the edge of the panel and do not affect the subpixel aperture ratio. Figure 1 shows the pixel circuit and the corresponding timing diagram for the driving and relaxation cycles.



(a)

(b)

Fig.1: (a) AdMo^{TM} pixel circuit and (b) corresponding timing diagram.

As an in-pixel correction circuit, no specialized external driving electronics or feedback signal is required. This is essential for system simplicity and low cost.

The OLED material used was a conventional set of high efficiency small molecule R, G, B emitters fabricated in a side-by-side format.

Since standard processing was a project criterion, this meant bottom emission was required. A major design challenge was to keep the aperture ratio high in an effort to minimize current density and thus prolong OLED lifetime. Using a multi-transistor circuit with amorphous silicon TFTs further added to the complexity. To achieve a good aperture ratio we chose to focus on reducing interconnect area rather than transistor size or count, and was mainly accomplished by sharing the Vdd line between two subpixels. In addition, a special set of switches was added to the periphery of the panel that enabled us to share the two address lines of the circuit between subsequent rows. Finally, we purposely borrowed aperture from the red and green subpixels and lent this to the blue subpixel since it's the most susceptible to higher current densities. The result of these efforts was an average aperture ratio of ~27%, which is similar to a comparable polysilicon backplane design. It is worth mentioning a higher aperture ratio would have been possible had it not been limited by the OLED design rules of this particular process. Figure 2 shows the pixel cell layout used.

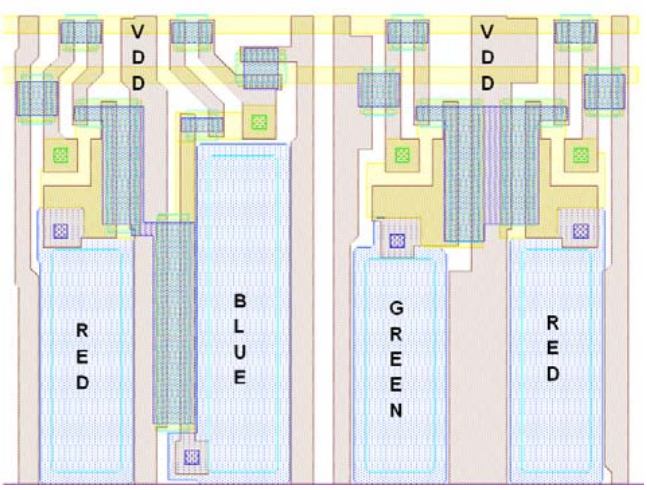


Fig.2: Subpixel layout with shared VDD lines.

A further consideration dealt with power distribution, which if not properly designed can result in perceptible long-range mura across the display, even in a small display. Rather than tune the TFT process parameters in order to achieve lower metal resistivity for wiring, which can affect any one of throughput, yield or aperture ratio, it was decided that the best approach was tuning the layout and connection scheme of the Vdd contacts. We simulated various scenarios in which the number and size of Vdd connections and their locations were varied. It turns out small changes can have large affects in power distribution uniformity, as illustrated by Fig. 3.

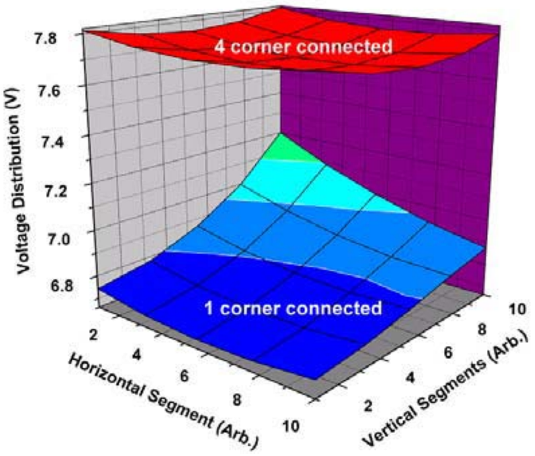


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Fig.3: Effect of VDD connection on IR drop across a 2.2” diagonal panel.

Lastly, our criterion of using standard manufacturing and processes mandated the OLED be located in the source of the drive TFT. This means the Vgs is dependent on Voled, which itself rises as the material degrades, affecting current output and luminance. Fortunately, the use of the 4T1C AdMo^{TM} circuit delivers drive current to the OLED that is independent of the Voled rise, meaning manufacturability of the display remains straightforward and high yielding.

3. Panel Driving

For mobile panels, manufacturing cost is the primary concern. The average selling price of mobile phones continues to fall, placing further demands on AMOLED to be competitive. Our panel uses only an in-pixel correction system and leaves the driving system intact. In other words, the same LCD drivers are used, meaning transparency from a systems and assembly perspective compared to LCD manufacturing.

A major compatibility issue with LCD drivers is the inversion driving (0-1/2Vdd, 1/2Vdd-Vdd) which is not suitable for AMOLED since the full dynamic range (0-Vdd) is required. In addition, all-in-one mobile LCD or polysilicon AMOLED drivers have a lower dynamic range, which is inappropriate for amorphous silicon AMOLED needs.

The current prototype described herein uses twice the number of LCD source drivers to overcome the inversion and low dynamic range issues for the time being.

Future all-in-one AMOLED mobile drivers for amorphous silicon backplanes will exhibit higher dynamic range, no inversion and a small die footprint that will further enable long-term manufacturability and cost competitiveness in the mobile market.

4. Testing

For amorphous silicon based AMOLED, the most important qualities - and most difficult to achieve - are good lifetime and image sticking free. The use of the AdMo^{TM} circuit shown in Fig. 1 is designed to both deliver high lifetimes and be free of image-sticking or burn-in when operated under normal use conditions.

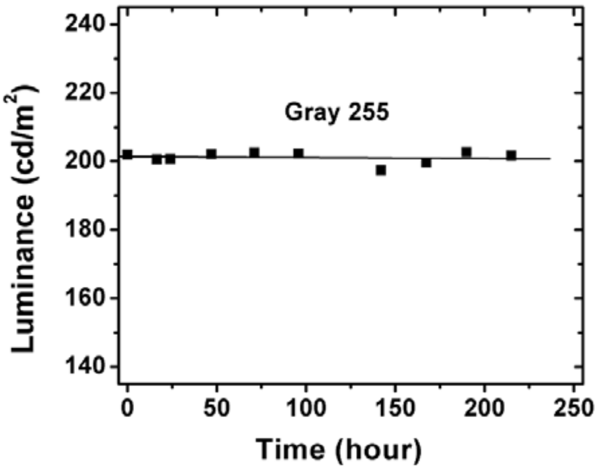
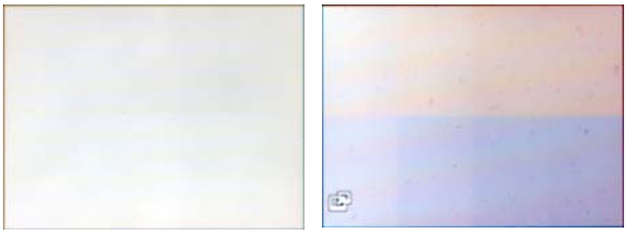


Fig.4: Lifetime measurement for constant stress at 200 cd/m^2 luminance.

In Fig 4, the luminace output of the panel under full white condition remains constant for over 200hr, which matches the lifetime specification of mobile phone panels and is similar to a polysilicon backplane performance.

This equates into greater than 10,000hrs of device lifetime under normal usage.

Similarly, Fig. 5 clearly illustrates the results of the image sticking burn-in tests when a full white flat field is displayed after a period of displaying a constant differential grayscale pattern. The darker areas mean they have been stressed at higher luminances. It is notable that in the case of the amorphous silicon panel, no visual differences along the grayscale boundaries can be seen, including the boundary in the extreme case of full white and full black. This means that after 100hrs the luminance difference between grayscales is less than 2%, again within the target specified for mobile phones and other handheld applications.



(a) (b)

Fig.5: Image sticking results under flat field illumination after 100hrs constant differential aging stress pattern for (a) AdMo^{TM} a-Si and (b) polysilicon displays.

The data for the amorphous silicon case actually show better performance than the polysilicon control sample in our in-house testing. Whereas there is no burn-in for the amorphous silicon even after 100hrs, it is clearly visible on the polysilicon panel, beginning at just 1hr. The burn-in on the polysilicon control sample is caused by the OLED degradation (manifested as increasing OLED voltage, Voled) which results in luminance loss. This is expected if the drive current from the backplane remains constant, as it does for polysilicon.

On the other hand, we designed the AdMo^{TM} circuit to increase current over time in order to counterbalance the OLED degradation. In so doing, we compensate for both the Vt shift and Voled shift thus prolonging the image sticking immunity dramatically.

(a) (b)

Fig.6: Comparison of display quality between (a) AdMo^{TM} and (b) conventional displays.

Figure 6 highlights the image sticking compensation after applying a checker board burn-in pattern after 100hrs for both AdMo^{TM} and a conventional uncompensated 2-TFT pixel circuit.

5 Summary

We have demonstrated a prototype AMOLED panel using amorphous silicon backplane with reliability, image quality and power consumption on par or better than a typical polysilicon backplane.

Testing results clearly show that with a novel 4T1C compensating circuit called AdMo^{TM}, commercial level performance is achieved. The use of OLED drivers – essentially the same as those used by LCD – ensures low cost and a small footprint which lends itself to excellent overall manufacturability and cost competitiveness for the long term. Most importantly, we have achieved similar or better panel performance using an amorphous silicon backplane compared to polysilicon. This will significantly reduce the manufacturing cost of AMOLED and make it competitive to LCD.

TABLE 2. Comparison of mass produced (MP) poly-Si vs a-Si 2.2" AMOLED

Spec	Target	MP poly-Si	AdMo^{TM} a-Si
Luminance (cd/m^2)	200	200	200
Gamma	2.2	2.2	2.2
Contrast Ratio (black level)	2,000:1	2,500:1 (0.08 cd/m^2)	10,000:1 (0.02 cd/m^2)
Lifetime (T98)	200h	1h	200h

5. References

(1 line spacing)

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