Development of Large Sized AM-OLED

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Introduction

The organic LED (OLED) promises the thinnest, lightest, most energy-efficient, and most beautiful display with widest viewing angle, fast switching speed, rich color and highest contrast ratio. Passive-matrix OLEDs (PM-OLEDs) are already employed in mobile phones and MP3s. However, the size and the resolution of these displays are limited and there are several forecasts that these categories will suffer stagnant growth. The next growth should come from active-matrix OLEDs (AM-OLEDs), which can cover from small to large size displays. In this report, we discuss the requirements for making large-sized AM-OLEDs.

TFT Backplane

Cost effectiveness, wide process margin, simple process architecture, and highly stable backplane are the key requirements for the commercializing large-sized AM-OLEDs. One of the most challenging problems in AM-OLEDs is lack of a stable and cost-effective TFT backplane. The three main types of TFTs for AM-OLEDs are amorphous silicon (a-Si), poly-silicon and micro-crystalline silicon (mc-Si) based TFTs. [1, 2]. **Table 1** shows the comparison of the three technologies.

Table 1. Comparison of TFT backplane technologies for AM-OLED application

	a-Si	mc-Si	poly-Si	
			Laser	Non-laser
TFT performance **- Mobility (cm^2V/s)** **- Stability**	**< 1** **Low**	**1~20** **Medium**	**100~300** **High**	**20~100** **High**
TFT Uniformity (Compensation circuit)	**High** **(No need)**	**High** **(No need)**	**Low** **(Required)**	**Medium** **(Dependant)**
Large Panel Display	**OK**	**OK**	**Difficult**	**Available**
Process Cost	**Low**	**Low**	**High**	**Medium**
Investment	**Very Low**	**Low**	**High**	**Medium**

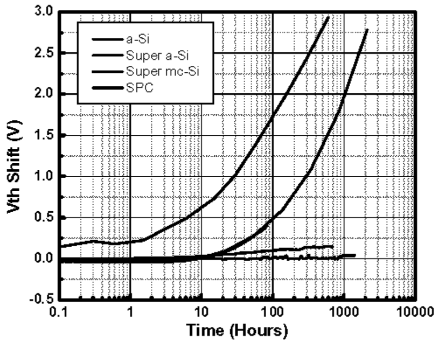


Figure 1. V_{th} shift variation of different kinds of TFT

None of the TFT backplane technologies in the above has met all of the requirements for large sized AM-OLEDs. Amorphous silicon has a good start of being able to exploit existing AM-LCD fabs up to generation 7. However, stability issues still remain unsolved. Laser based poly-silicon technologies [3] are currently limited to Gen 4 due to the size limitation of excimer laser and suffer from high cost of production. Non-laser based techniques are being developed with the goal of lowering production cost for poly-silicon. With poly-Si TFTs, however, it is still difficult to produce an uniform display.

The low process cost, large process window, simple backplane structure, and most importantly, uniform TFT performance make amorphous silicon quite attractive. However, the threshold voltage of a-Si TFT shifts over time due to electrical stress. **Figure 1** shows the V_{th} shift variation for different types of TFTs.

To overcome the instability of the a-Si:H TFT, we have explored a feedback system, optical and electrical to compensate any shift in the threshold voltage of a-Si TFT. The optical feedback system monitors any degradation in the OLED brightness and feedback the optical signal through the photo diode sensor. We have achieved significant compensation in the differential aging of the panel after compensation as seen in **Figure 2**. The electrical feedback system also works on the similar principle wherein the degradation of OLED brightness is being monitored by recording the current value over the time. Also we tried pulse driving to optimize the shift in the threshold voltage. Herein, we drive our TFT with negative bias stress and try to reverse any trapped charges across the gate insulator [4]. Significant progress has been achieved to compensate the threshold voltage to a minimal level so that there is no significant change in the brightness of OLED.

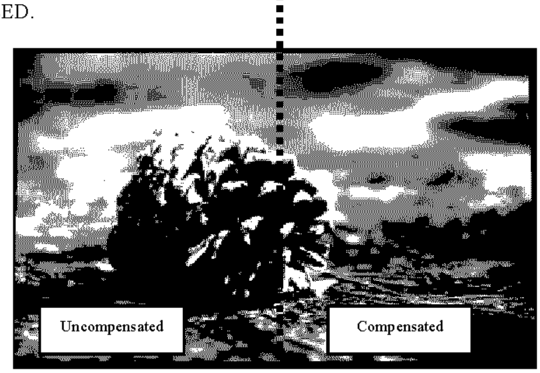
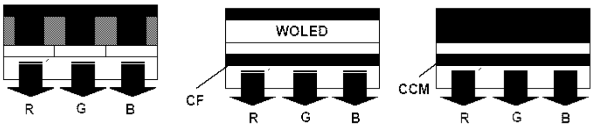


Figure 2. Effects of the optical feedback system on the degradation of AM-OLED. Left half: degraded area without compensation. Right half: with compensation.

We have also developed TFT process and architecture resulting in the improvement of the stability of a-Si:H TFT as shown super a-Si in the figure 1, but it does not meet the stability requirements for AM-OLED mass production yet. We have significant progress in the area of micro crystalline silicon in terms of stability and mobility using the standard bottom etch back structure used in LCD [5]. But it still needs to improve off-current, uniformity, and process time.

EL Process

RGB Patterning Processes. A full-color OLED display can be realized by methods like RGB separate emission, white emission with RGB color filters, and blue emission with CCM (color conversion medium).



RGB separate emission **White emission with C/F** **Blue emission with CCM**

Figure 3. Methods for fabricating of full-color AM-OLEDs.

In RGB separate emission, the efficiency and color can be easily modulated because RGB are fabricated individually. These can be fabricated by three methods: evaporation with fine metal mask (FMM), ink-jet printing, and laser-induced thermal imaging (LITI). The use of white emitter greatly simplifies the fabrication of OLED displays by eliminating the need to separately deposit three adjacent light-emitting materials. For blue emission with CCM, it also has a potential for large area application. But the efficiency of color conversion is low and the cost of CCM is expensive.

Shadow Mask vs White OLED vs Inkjet Printing. The current mass production of OLED (passive-matrix) is being done exclusively by evaporation through FMM. But ink-jet printing and white OLED with color filter (CF) are more attractive paths for large size active-matrix (AM) OLED because FMM is not expansible for substrates larger than Gen 4.

For the OLED performance side, FMM and white OLED with CF are much superior to ink-jet printing. Polymer LED (PLED) is

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more than 3 years behind in performance compared to small molecules. Because it is very difficult to apply the multi-layer stacking structure with polymers, the catching up will take immense time and efforts. Currently, ink-jetting is most economical. However, with more enhancements in the material usage ratio of evaporation in sight, the advantage will disappear soon. More comparison data between these three patterning routes are detailed in **Table 2**.

Table 2. Comparison between various color patterning techniques

	Fine metal mask	**Ink-Jet Printing**	**White/CF**
Material	Small Molecule	Polymer	Small Molecule
Performance (efficiency and lifetime)	High	Low	High
Color gamut	High	Low	High
Patterning accuracy	± 20 μm	± 15 μm	± 2.5 μm
Resolution	~130ppi	~150ppi	>200ppi
Expansibility	< Gen 4	> Gen 5	> Gen 5
OLED material usage	Medium	High	Medium
OLED material cost	Expensive	Medium	Inexpensive
Panel cost	Expensive	Inexpensive	Inexpensive
Yield	High	Low	Excellent

RGB vs RGBW CF

RGB CF vs RGBW CF. Having established that the white OLED + color filter combination is the only practical solution for patterning large sized full color AM-OLED, we now return to the review of the color system.

It was shown that an RGBW color system can increase the transmission of LCDs by 50% [6, 7]. For OLEDs, the focus is on the power consumption, or the efficiency rather than the overall luminance. The advantage of RGBW color system is obvious: a white subpixel can replace three equally-lit RGB subpixels. Therefore, for achromatic grays, the power saving is 66.7%.

We calculated the efficiency of the RGB and RGBW color system for a "full color" system (FC). In FC, it is assumed that the histogram of the whole colors is flat. That is, every digital combination of RGB color has an equal probability of appearing in the FC system.

Table 3 compares the performance of the RGB CF and the RGBW CF system. The RGBW CF system is superior in almost all categories. The few disadvantages are peak stress and driving margin. However, we believe these two are non-factors in actual application.

The power consumption of a RGB OLED system (no CF) is at 100 for full white. That is, the average power consumption is 30, assuming a flat histogram and a gamma value of 2.33. Therefore, a RGB CF + White OLED system consumes 3 times more power than a RGB OLED. A RGBW CF system consumes 2.5 times more power for full color. However, the efficiency is equal for achromatic grays. Colors in most real video materials have a very strong correlation with one another [8], meaning the white subpixel will be employed more often than the RGB subpixels. The power consumption should be somewhere between these two values: x1 and x2.5.

Table 3. RGB CF vs RGBW CF

		RGB	**RGBW**	**Remark**
Power Consump-tion.	Peak (FC)	300	200	33% ↓
	Average (FC)	90	75	16.7% ↓
	Peak (Gray)	300	100	66.7% ↓
	Average (Gray)	90	30	66.7% ↓
Stress	Average	1500	1155	23% ↓
	Peak	5000	6000	20% ↑
Others	Max White Luminance	500	1000	2 x
	# of Colors (bits)	24	32	256 x
	Pixel Geometry	3x1	2x2 or 4x1	Lower driving margin

After analyzing various kinds of video sources, we have reached a conclusion that for the average "real" video sequences, the power consumption in a RGBW CF system is roughly a half of that for the FC video. Therefore, the power consumption now drops to just 37.5, which is only 25% higher than that of an equivalent RGB OLED. For most DVDs, the value is even lower.

An advantage of a RGBW CF + W OLED system over a RGB OLED is its daylight contrast ratio (D-CR). The back electrode of an OLED is usually aluminum or silver. Thus, OLEDs are almost like mirrors, reflecting ambient light very strongly. The reflectance can be curtailed by covering the OLED with black matrix, leaving only pixel area open. Since CF absorbs ambient light as well as the emitted light from OLED, a RGBW CF + W OLED has twice higher D-CR than a RGB OLED.

In conclusion, the RGBW CF + W OLED consumes 25% more power, but its D-CR is 100% higher. We believe the W OLED will be quite competitive against the RGB OLED even in the performance point of view.

Issues of White OLED

Compared to monochrome OLEDs, there have been less R&D activities for white OLED. It still lags in the device performance such as efficiency and lifetime. Large-sized AM-OLEDs will compete against LCDs and PDPs. OLEDs should meet very high standards. The properties of recent emitting materials of R, G, and B are shown in the **Table 4**. Although they have been improved dramatically in the past three years, efficiencies, lifetime and color coordinates are not sufficient to warrant the initial high price premium. The efficiency in white, which is the stack of R, G, and B emitters, shows ~10 cd/A [9, 10]. The device efficiency of at least 30 cd/A with the lifetime of ~ 50,000 h at 1,000 nits is required for a competent OLED TV..

Table 4. OLED Performance

	Small Molecule			Polymer		
	Color Index	Max Efficiency [cd/A]	Life time (hrs)	Color Index	Max Efficiency [cd/A]	Life time (hrs)
Blue [12]	0.14, 0.16	7.2	12,000 @ 1,000nit	0.15, 0.24	3.9	1300 @ 500nit
Green [12]	0.29, 0.64	20.5	100,000 @1,000nit	0.42, 0.56	6.2	3,500 @ 1,000nit
Red [12]	0.67, 0.33	11.4	100,000 @ 1,000nit	0.64, 0.36	1.5	15,000 @ 500nit
White [13]	0.32, 0.35	10.7	50,000 @ 1,000nit			

Conclusions

Large-sized AM-OLEDs are facing tougher circumstances than AM-LCDs had. The performance of AM-OLED beats that of AM-LCD, but it is not enough to cover the initial high cost. Efficiency and color coordinates of blue EL has yet to improve. However, with the on-going research activities, it is very likely that the goal will be achieved soon. The key for large-size AMOLED lies with a cost-competitive TFT backplane.

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