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38.2: 302-ppi High-Resolution AMOLED using Laser-Induced Thermal Imaging

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Abstract

Samsung SDI has developed 2.6-inch full color VGA Active Matrix Organic Light-Emitting Diode (AMOLED) display with the world's highest resolution of 302ppi using Laser Induced Thermal Imaging (LITI) method with the top emission structure. A voltage compensating pixel circuit with $2\mu\text{m}$ design-rule in low-temperature poly-Si (LTPS) thin film transistors (TFTs) was introduced to compensate the variation of the threshold voltage (V_{th}) in order to improve the image quality. Moreover, an aperture ratio of $\sim 40\%$ was obtained for each pixel even though the sub-pixel pitch was $28\mu\text{m}$. The luminance for the white color was 200cd/m^2 and color gamut was 74% compared to national television standard committee (NTSC) standards. These results show the possibility of high-resolution AMOLED display incorporating the LTPS technology and LITI method for digital mobile era applications in the near future.

1. Introduction

In recent year, AMOLED display has attracted great attention due to many advantages such as wide viewing angle, fast response time, high brightness, vivid images, low power consumption and thin structure. The commercialization of small AMOLEDs has already been proceeding in spite of several issues still to be resolved. One of the important issues is the pixel resolution limitation of AMOLED display caused by the conventional evaporation method, which uses a fine metal mask (FMM). Even though FMM is the most common method for patterning primary colors for full color AMOLED, it is almost impossible to realize a resolution higher than 230ppi in a mass production environment. The other issue is the use of voltage compensation circuit that AMOLED needs to compensate for the V_{th} variation originating from laser crystallization process. Although many groups are developing compensation circuits, it is more difficult to integrate such circuits in the case of higher pixel density display due to restricted pixel area. However, there is a demand for improved image quality requiring higher resolution. The products for multimedia applications such as DSC (Digital Still Cameras), cellular phones and DMB (Digital Multi-media Broadcasting) etc. will be merged in the mobile space in the near future. The digital convergence of mobile devices will lead to rapidly increasing demand for higher resolution display products^[1-4].

We have developed the AMOLED display with resolution higher than 230ppi by optimizing the panel design, improving the TFT fabrication process and utilizing the LITI^[5-6] method. To realize higher resolution display, each red, green and blue sub-pixel requires $28\mu\text{m}$ pitch which is lower than conventional FMM limit of $35\mu\text{m}$. Furthermore the photolithography design rule in this panel must be $2\mu\text{m}$ for a pixel circuit with V_{th} compensation circuit consisting of 6TFTs and 1 capacitor. In order to form three

different OLED colors in the $28\mu\text{m}$ sub-pixel pitch, we have utilized LITI method on the top emission structure and achieved adequate patterning accuracy.

By incorporating these technologies, we developed the first-ever 2.6 inch full color VGA AMOLED display with a resolution of 302ppi.

2. LTPS Substrate Design

In order to achieve high resolution AMOLED display, we need to realize compensation circuit with $2\mu\text{m}$ design rule, lower resistance metallization to minimize signal delay and top emission structure with flatness for LITI process. The LTPS TFT substrate of the newly developed 2.6-inch (302ppi) VGA AMOLED panel consists of $480 \times \text{RGB} \times 640$ voltage programming pixel array and peripheral circuits as shown in Figure 1. The scan driver is integrated by LTPS TFTs on the glass substrate and data driver is directly connected to external driver ICs. We have applied our own 6 TFTs and 1 capacitor structure to compensate the V_{th} variation of the driving TFT in the pixels. This pixel circuit is suitable to realize a high image quality and high resolution for AMOLED panel. The transistor and capacitor size of each sub-pixel is optimized by simulation. We have also used $2\mu\text{m}$ design rule and $28\mu\text{m}$ sub-pixel pitch to fabricate active matrix substrate with very high resolution. Due to limited sub-pixel area, we adopted switching transistors with short channels and dual-gate structure in order to reduce the leakage current. We obtained stable TFT characteristics by properly engineering Lightly Doped Drain (LDD) structure, which reduced short channel effect caused by hot carrier. It was controlled by LDD length and dose concentration and we also improved the reliability by optimizing the activation condition. Figure 2 shows a schematic diagram of each RGB sub-pixels with $28\mu\text{m}$ pitch and cross sectional view of the top emission device^[7-8] used to realize high resolution. This structure has excellent flatness as shown in Figure 2(b) after

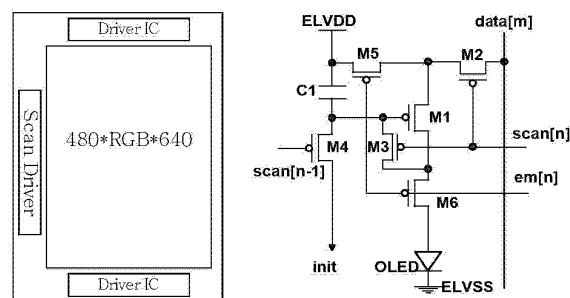


Figure 1. Block diagram of the LTPS substrate and pixel circuits for the 2.6-inch AMOLED display

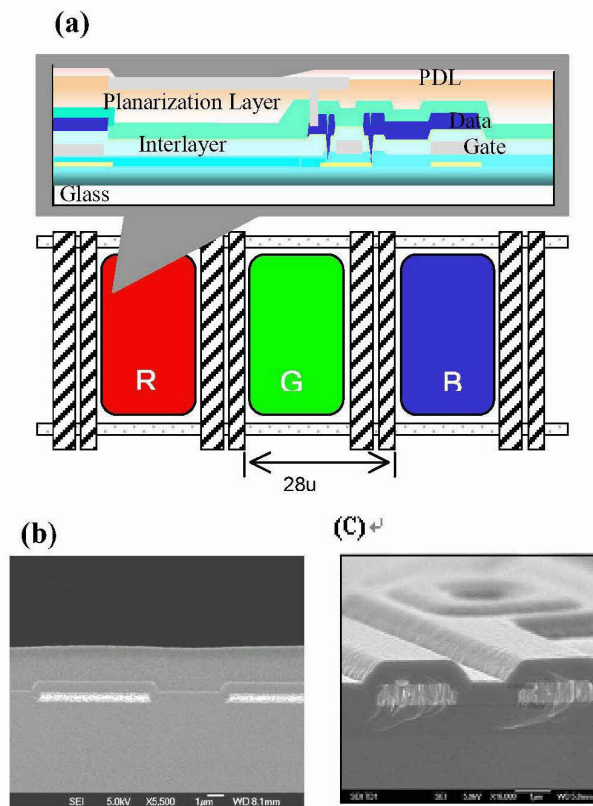


Figure 2. (a) A schematic diagram of R, G, B sub-pixel with 28μm pitch and the cross sectional SEM image of the top emission device adopted (b) Planarization layer to eliminate the roughness of the pixel and (c) 2μm design rule to achieve high resolution

planarization. To achieve 2μm design rule shown in Figure 2(c), line pattern was defined by I-line photolithography and etched by an inductively coupled plasma (ICP) dry etcher. In addition, we used lower resistance aluminum metal as a data line to minimize signal delay and IR drop. The metal-line etch using high density plasma (HDP) was tuned to control critical dimension (CD) bias for 2μm design rule. The top emission structure is mainly composed of reflective anode layer, organic emitting layer and semi-transparent cathode on the planarization layer. In order to improve efficiency of LITI devices, we optimized the structure of anode layer which consists of an electrode of indium-tin-oxide (ITO) on a highly reflective metal layer. Finally we achieved the optimal structure and reproducible TFT characteristics for high resolution AMOLED display.

3. LITI Patterning

In order to realize high resolution, it's essential to use LITI process instead of FMM as it was mentioned before. LITI process involves the use of a donor film, a highly accurate laser exposure system and an active substrate. The donor film consists of a transparent base film with several coated layers. The thermal transfer layer is typically a 30 nm thick small-molecule material. We have employed conventional small-molecule materials, which are vacuum-deposited onto the LITI donor film at normal

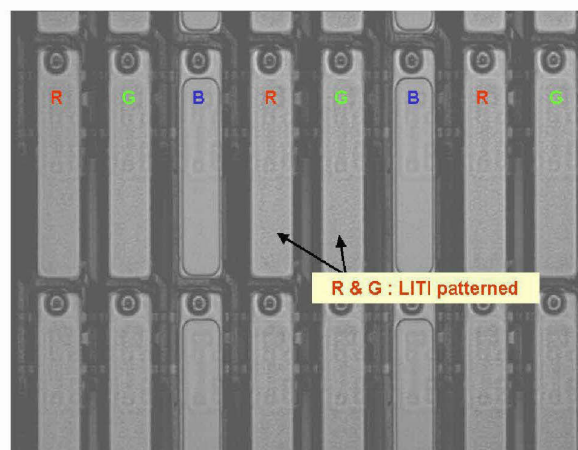


Figure 3. Microphotograph of LITI patterned stripe using conventional small-molecule emitter

evaporating condition (<10⁻⁷ Torr). Upon the anode pixel of active matrix poly-Si TFT substrate which is covered with hole injecting and transport materials, donor film is placed in intimate contact and exposed with the laser system. Exposed regions are laminated as flat, smooth, uniform stripes with significantly high resolution. Figure 3 shows active matrix substrate after two colors LITI patterning. It is not easy to optimize the laser power condition to obtain fine pattern in 28μm pixel pitch. And we also have to consider the accuracy of LITI machine. Typical pattern width of transferred small-molecule weight emitting material is about 30μm. Three donor films (red, green and blue) are used sequentially to make a full color display. The position accuracy of LITI laser imaging system is ±3.5 μm and the pattern width variation of LITI transferred pattern is ±2.0 μm. Using this LITI patterning accuracy, we calculated possible aperture ratio with 302 ppi resolution as shown in Figure 4. The critical is horizontal gap between sub-pixels which consist of each primary color, R, G and B. With 10.0 μm horizontal gap, we can realize 302 ppi AMOLED with very high aperture ratio around 40 ~ 50 % with this LITI machine. And it means we can possible to realize up to ~ 50% open ratio by high accuracy LITI machine in spite of high resolution display.

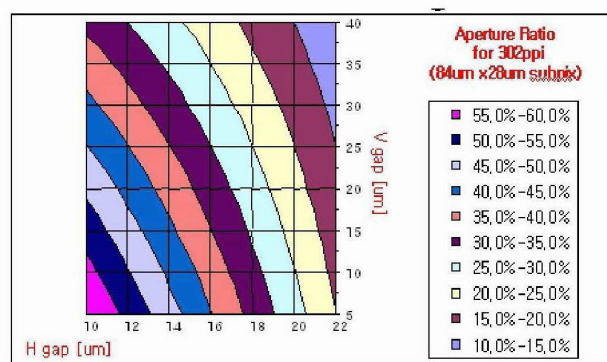


Figure 4. Aperture Ratio dependence on horizontal and vertical gap at 302ppi display

Color	CIE1931(x, y)	Efficiency (cd/A)	Required Brightness (cd/m ²)
Red	(0.67, 0.32)	5.0	840
Green	(0.30, 0.65)	20.0	1707
Blue	(0.15, 0.15)	4.0	862

Table 1. LITI device performances of 302ppi AMOLED

4. Device Fabrication and Performance

Table 1 shows the 302ppi LITI OLED device performance. Preliminary results indicate that the efficiency and stability of LITI small-molecule devices are comparable to conventional evaporated OLED devices. With top-emitting AMOLED, many groups introduce micro-cavity effect to improve color purity. For this micro-cavity effect, we utilize LITI patterning technology. The additional hole injection layer (HIL) material is directly transferred onto the anode of the Red pixel using LITI. As a results, red pixels have the thicker HIL than green and blue pixels and give better color purity due to the micro-cavity effect. After this additional HIL formation by LITI, the normal deposition step for hole transport layer (HTL) is followed in the conventional evaporation chamber. Through LITI process, the light emitting materials are patterned with the high accuracy laser system to fabricate full color AMOLED. The OLED device structure is shown in Figure 5. The specifications of the high resolution AMOLED panel are indicated in Table 2. The developed display has 2.6-inch diagonal size with VGA (480 X RGB X 640) resolution. Its sub-pixel pitch is 28 μ m (302ppi) with 40% aperture ratio, making it the world's highest density AMOLED display reported to date. The white CIE coordinate is $x = 0.31$, $y = 0.31$ and the luminance is 200cd/m². The color gamut is obtained up to 74.1%. The display image of 302ppi high resolution AMOLED developed by Samsung SDI is shown in Figure 6.

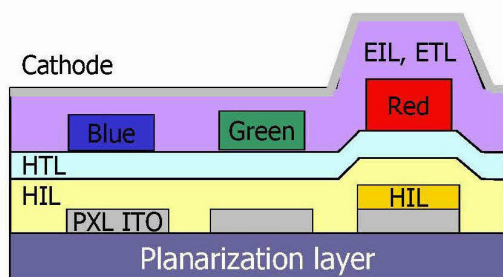


Figure 5. OLED Device structure with Top Emission

5. Summary

We have developed 2.6-inch full color VGA AMOLED display with the highest resolution to date of 302ppi. We used Vth compensating pixel circuit to improve image quality and 2 μ m design rule in LTPS TFT fabrication process to realize the 28 μ m

Parameter	Specification
Display size	2.6-inch diagonal
Number of pixels	480 x RGB x 640
Pixel pitch	28 μ m x 84 μ m
Pixel per inch	302 ppi
Aperture ratio	40 %
Pixel circuit	Voltage programming type
Pixel structure	6TFT + 1Capacitor
Emission type	Top emission
Brightness	200cd/ m ²
Color Coordinate	White (0.31, 0.31)
	Red (0.67, 0.32)
	Green (0.3, 0.65)
	Blue (0.15, 0.15)

Table 2. Specifications of the developed AMOLED

sub-pixel pitch with 40% aperture ratio. In spite of employing short channel TFTs, we obtained stable TFT characteristics by proper LDD engineering such as length and dose concentration. Pattern quality and EL performance with LITI were satisfied in 302ppi pixel density and LITI method was also used to introduce the micro cavity effect for better red color purity with top emitting AMOLED structure. The efficiency and stability of the LITI devices of 2.6-inch VGA panel are comparable to conventionally evaporated OLED devices. These results show a clear possibility that AMOLED is able to achieve high resolution needed for digital convergence era of the near future.

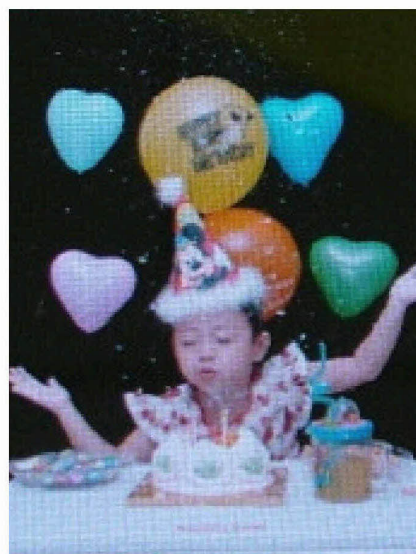


Figure 6. Display image of 2.6-inch VGA (302ppi) AMOLED.

6. Acknowledgements

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7. References

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