Development of 40 inch Full Color AMOLED Display

K. Chung, J. M. Huh, U. C. Sung, C. C. Chai, J. H. Lee, H. Kim, S. P. Lee, J. C. Goh S. K. Park, C. S. Ko, B. S. Koh, K. J. Shin, J. H. Choi, J. H. Jung and N. D. Kim
LCD R&D Center, Samsung Electronics Co., Ltd., Kyunggi-do, Korea

Abstract
We have developed technology to fabricate large-size active matrix organic light-emitting diode (AMOLED) displays with good color purity. Using these innovations, we have developed a 40inch diagonal WXGA AMOLED full color display. Because the TFT circuitry occupies a large portion of the pixel structure, an efficient white emission OLED is essential to integrate the device onto the active matrix backplane. The development of these technologies enables OLED displays to fulfill the requirements for larger size applications such as HDTVs

1. Introduction
Full-color active-matrix organic light-emitting diode (AMOLED) displays based on a white emitter with an RGB color filter array have been previously reported as a potentially lower cost alternative to AMOLED displays with patterned RGB emitters [1]. However, RGB displays based on a white emitter are at a disadvantage in terms of power consumption because much of the white light is absorbed by the color filters. Recently, a white emitter-based AMOLED display with an RGBW pixel format was shown to require approximately one half the power of an analogous white emitter-based RGB display. This was made possible by the fact that a high efficiency, unfiltered White subpixel can be frequently used to replace the combined emission from the lower efficiency RGB subpixels [2].

The key to enabling the RGBW format is an efficient and stable white emitter [3]. In order to minimize power consumption for RGBW displays, it is also important that the white OLED emits close to the desired white point of the display. Although most development work can be accomplished on simple test devices, the emission of the white OLED must also be optimized to the display white point using an active-matrix substrate because there are usually additional dielectric layers, such as for planarization and passivation, that the emitted light must pass through before exiting the display. These layers affect the spectral characteristics of the emission as a result of thin-film interference effects. In addition to an optimized white point, the white OLED must also be designed to have little or no perceptible color shift when viewed at an angle, and of course, an acceptable lifetime.

OLED displays have been attracting more attention because of their various advantages including simple structure, fast response time and wide viewing angle. Recently, AMOLED displays using amorphous silicon thin film transistors (TFTs) demonstrated their potential for low cost and high uniformity [4-6]. However, the stability of a-Si TFT is still a fundamental problem. Solving this problem will enable large size applications such as desktop monitors and TVs, which require high image quality and long operating lifetimes. These issues must be resolved in order to ensure the future of AMOLED technology. We have developed and previously reported top emission a-Si TFT backplane technology to address these issues, which is also applicable for larger size displays [7]. Here we present a 40 inch full color WXGA display prototype, which has been publicly demonstrated.

2. Results and Discussions
2.1 TFT backplane
To compete with AMLCD in the flat panel TV market, AMOLED must adopt a cost effective mass production process. For inexpensive fabrication on large-size substrates, amorphous silicon TFT architecture is the desired choice, despite its intrinsic performance limitations like poor stability and low electron mobility. There is also an abundant existing capacity to produce large-size amorphous silicon TFT backplanes; TV panels of over 80” in diagonal have been fabricated using this equipment. We can use this same infrastructure to produce large screen AMOLED displays by simply integrating OLED processing equipment with the existing a-Si TFT process line.

In this work we have attempted to demonstrate technology to realize 40” AMOLED displays for large screen TV applications, using an established a-Si TFT process with an existing TFT line that is currently used to mass produce AMLCD panels. We have used a conventional 5 mask back channel etch(BCE) process to adopt an inverted staggered a-Si TFT architecture integrated with a color filter on array (COA). The COA process is identical to that used in our LCD panels, and requires an additional photo step, as does the wall layer, giving us 2 more steps when compared to the conventional 5 mask BCE process.

In order to use a-Si TFT backplane to drive a 40” AMOLED, we developed a panel architecture that can handle the very large current required to drive the OLED pixels as well as mitigate the potentially large voltage drop across the length of V_{dd}. This requires optimization of not only the metal line, but also the pixel layout and color filter architecture. Taking these considerations, we have chosen a 4 color, RGBW, checker board sub-pixel layout, and optimized the metal line; optimization of the thickness and material for V_{dd}. We have also developed optimum panel design to reduce the possibility of producing panel defects, which increases the yield of line defect free panels greatly. In our work, some of process technologies for AMLCD mass production have been examined for AMOLED application such as tests to determine the quality of the TFT backplane before continuing with the EL deposition process. Many of these methods are also proving to be effective for AMOLED display production.

The commonality between AMLCD and AMOLED process architecture also allows us to take advantage of existing fabrication facilities to make TFT backplanes on large-size mother glass. Using our Generation 7 line (1870 x 2200 mm^2), we can produce 8 backplanes for 40" displays on one sheet of glass. This gives us a tremendous cost advantage over fabrication in LTPS facilities, which are currently limited to Generation 4 size, giving only one 40" backplane per substrate. This work was done on our Generation 6 line, which enables 2 backplanes per mother glass.

The field-effect mobility of the a-Si:H TFT is around $0.75cm^2/Vsec$ with a threshold voltage between 2.5V to 3V. There are some on-current variations of the switching TFT over the panel less than 10%. With this variation, it is difficult to see some variation of brightness, because the a-Si:H TFTs have good short-range uniformity.

2.2 White OLED

White OLEDs consisting of two separate emission layers have been studied extensively. Each emission layer typically contains at least one host and one dopant, where the dopants are selected such that the combined emission from the two layers results in an overall white color. Various combinations of emitters have been explored, and the resulting EL spectra can be seen in Figure 1, along with a typical set of LCD color filter curves. For each combination, the relative peak heights of the two emitters can be adjusted to provide any given color lying between the colors of the two individual emitters when plotted in an additive color space.

Figure 2 shows the well matched 3-peak white spectra with color filter. In order to verify the modeling results, RGB and RGBW displays were fabricated using the combination of B+G+R. The white emitter was optimized on a simple test device (ITO anode on glass), as well as on an active-matrix (AM) substrate. To account for the color shift, the spectrum of the white emitter can be tuned to a slightly reddish-white color by adjusting the organic stack thickness and the dopant concentrations, so that the final white color emitted by the AMOLED device meets the target white point of the display. The relative peak heights can be adjusted by optimizing the dopant concentrations and thickness of each emission layer, as previously reported [3]. For the RGBW system, it is important that the emitter white point matches the target display white point to optimize both power consumption and lifetime.

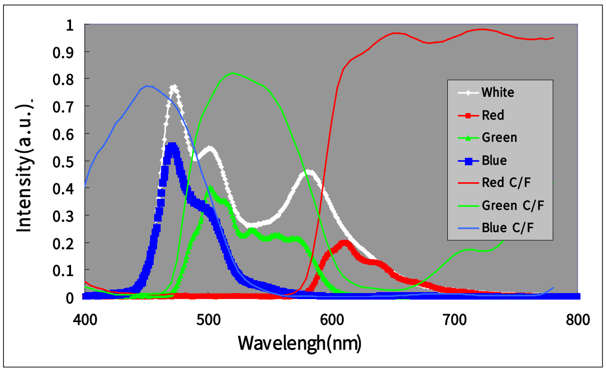

Fig. 1. EL spectra of 2-peak white emitter and color filter

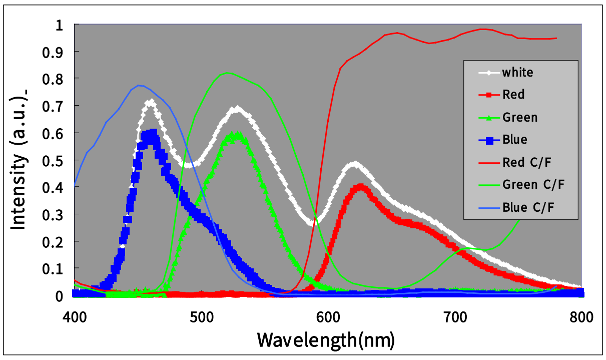

Fig. 2. EL spectra of 3-peak white emitter and color filter

For the white emitter and RGB color filter display format, the power consumption is also determined by the color and efficiency of the white emitter and RGB primaries, but the color of the white emitter is not as important as it is in the RGBW display. Therefore, it is important to determine a method of tuning a white emitter to a target white point. Slight changes in color may be made by adjusting the layer thicknesses to take advantage of cavity effects; these adjustments can only be used to fine tune the emission color and cannot be used to correct for major color differences from the target display white point. This technique has been experimentally verified, as shown by the many data points (each representing a particular device configuration) plotted on the chromaticity diagram. Figure 3 shows the EL spectra of 3-peak white emitter with buffer layer in OLED device. By incorporating the buffer layer in the emission stack, herein referred to as the controlled device, we can easily obtain the optimal EL spectra.

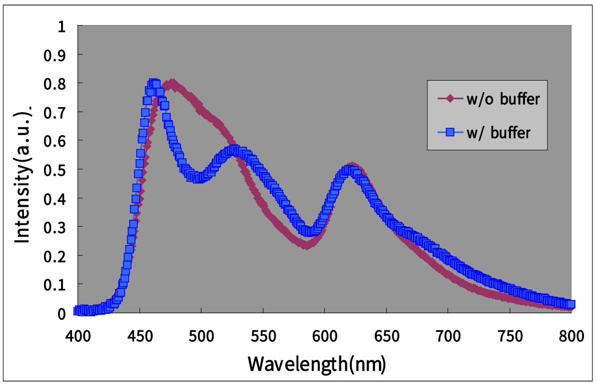

Fig. 3. EL spectra of 3-peak white with and without buffer layer

Figure 4 shows a lifetime measurement of normal and controlled 3-peak white OLED. The projected lifetimes at an initial brightness of 1,000cd/m^2 are 30,000 hours in case of controlled 3-peak white OLED and 5,000 hours in normal white emitter, respectively. Measurements were taken from an encapsulated device under constant current driving at room temperature. Lifetime is remarkably increased by adopting the controlled layer into the OLED device.

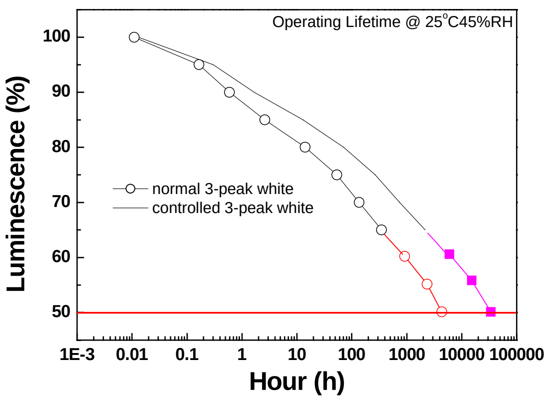

Fig. 4. Expected life time to 50% initial luminance for both a controlled 3-peak white OLED and a normal white.

Figure 5 shows the increase in operating voltage over time for a constant current driven device. We are able to greatly reduce the voltage shift by introducing the controlled layer.

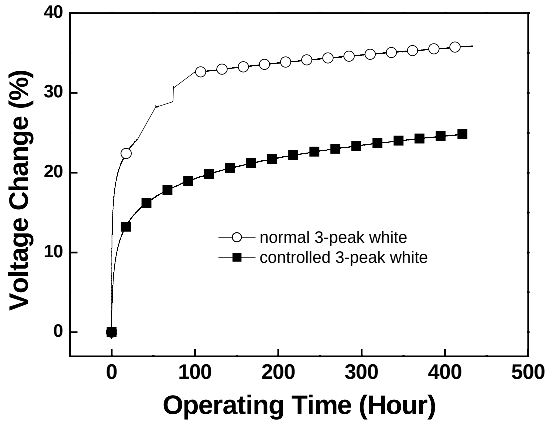

Fig. 5. Voltage rise versus operating time for normal and controlled white OLED device

3. Display performance of 40 inch AMOLED

The 40 inch display has 1280 x 800 pixels, each of which has individual R, G, B and W subpixels. We applied a conventional evaporation method to fabricate the pixel arrangement in the 40 inch display. The pixel alignment is well controlled with a pixel-pitch of 0.675mm. The developed display produces the large color gamut by optimizing the color filter structure. The R, G, B and W luminescence yield CIE coordinates of (0.67, 0.33), (0.25, 0.67), (0.14, 0.12) and (0.31, 0.38), respectively. Color gamut is about 84.8% (NTSC). Another feature of our display is high luminance. The white peak luminance is more than 600cd/m^2. This is very favorable for the reliability of the panel. Power consumption during motion picture operation is typically 80~100W at a brightness of 300 nits. This compares very favorably to 40" AMLCD TVs, which consume about 200W at the same operating condition

Figure 6 shows a typical image of the AMOLED display. Pixel to pixel luminance variation is almost invisible. To our knowledge, this is the first demonstration of 40inch white OLED Display with color and quality characteristics in the range required for general display.

4. Summary

We have developed a-Si TFT AMOLED technology, which is effective for designing large OLED display panels with high image quality. As a result, a 40 inch WXGA AMOLED display has been realized. The developed display demonstrates attractive progress such as long lifetime, large color gamut and all solid-state panel structure.

Fig. 6. Image of 40 inch WXGA AMOLED Display.

5. References

[1] K. Mameno et al, Proc. 8th Int. Conf. Electron. Mater. P.275, (2002).
[2] A. Arnold et al, Proc. ASIA Display (2004).
[3] Hatwar et al, Proc. EL Toronto (2004).
[4] J. J. Lie et al, SID'03 Digest, p.14 (2003).
[5] T. Tsumimura et al, SID'03 Digest, p.6 (2003).
[6] T. Shirasaki et al., SID'04 Digest, p.1516 (2004).
[7] J. Jung et al, SID'05 Digest, p. 1538 (2005).