Large-Sized AMOLED for TV Application

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Keywords : AMOLED, TV, Large-size, WOLED, Ink-jet

Abstract
Since the scalability of OLED process is crucial factor for large-sized TV manufacturing, various technologies are reviewed based on the published information. Despite of recent technology advancement enabling high color purity, large-sized AMOLED, a lot of problems to solve still exist to enter the large-sized display market. Here, Samsung will discuss what has to be concerned for large panel and how far the OLED technologies need to go more for the large-sized AMOLED TV marketplace.

1. Introduction

AMOLED have gained a considerable interest for next-generation flat panel displays due to their demonstrated capacities in high brightness, wide viewing angle, fast response time, lower manufacturing cost, and low power consumption compared to AMLCD. Due to impressive performance, it attracts the manufacturer's and consumer's interest as a lucrative market segment of the display industry. However, in order to compete with AMLCD and PDP, the AMOLED should overcome a lot of hurdles in commercialization.

First of all, since OLED is a current driven device, the active matrix needs a driver circuit with at least two thin-film transistors (TFTs) to control the driving current. Although a-Si:H TFT is well-developed in LCD business, the stability of a-Si:H is poor at a current driven device, the shift of threshold voltage happens due to electrical stress over time**.** Another issue for large-sized AMOLED TV is a patterning of OLED to describe RGB pixels. In this paper, we will discuss the technologies developed for large-size panel, and discuss the requirements for AMOLED TV application.

2. Candidate technology for AMOLED TV fabrication

Patterning with conventional photolithography and etching processes is commonly used in microelectronics fabrication. However, the photoresist developer and the etching solutions would cause damage to the underlying organic semiconductor in AMOLED panel. The simplest method to form OLED patterns is by fine metal shadow mask in vacuum evaporation [1]. This approach is hard to achieve fine patterns with pixel spacing of 100 μm or less due to the precision limitations in manufacturing the fine metal shadow masks and the strength of the mask materials. In addition, alignment of the separate fine metal mask with substrate in a vacuum system is always difficult, and the distance between the mask and the substrate could result in blur pattern edges that could be a cause for low contrast and cross talk among adjacent pixels [2]. The usual method to keep the gap is stretching the sheet of patterned metal on metal frame, but it can cause the off-centered pixel across the active area in the AMOLED panel. It is generally known that this off-centered patterning in large-area patterning limits the scalability of shadow mask. Also the weight of shadow mask and the periodic cleaning are the critical issues in production. The weight of fine mask in 300×400 mm^2 mask is ~35 kg, and it is estimated to be more than 80 kg in Generation-5.

(1) Dry Patterning

Laser Induced Thermal Imaging (LITI) technology has been proposed as an alternative method in the fabrication of full color PLEDs and OLEDs [3]. It is done by the donor film and a laser patterning system. S. T. Lee et. al. have described the LITI process as follows. The donor films are prepared, which are composed of 3 thin film layers – laser-to-heat conversion (LTHC) layer and the interlayer, and the OLED material layer. The donor film is laminated to a TFT substrate, and the donor and a TFT surface must be in intimate contact. The donor side is then exposed in a certain pattern with the precisely positioned laser beam. The release of the OLED layer from the donor surface is accomplished due to the thermal expansion of LTHC and the enhanced adhesion of the OLED layer to the TFT surface, and then the used donor is peeled away and discarded. In the exposed regions the patterned OLED films are transferred to the TFT substrate. These processes are repeated two- or three-times in one panel using different colored donor films – red, green, and blue - to create a full color display [3, 4].

The major parameters that determine the patterning quality in LITI are adhesion between the donor film and the OLED layer, cohesion of the OLED layer, and the adhesion between the OLED film and the surface of TFT substrate. The cohesion of OLED layer must be stronger in polymer film rather than that in small evaporating molecule film, which will help to result in clearly defined OLED pattern [3]. The reported LITI patterning accuracy is ca. ± 2.5 microns, and the resolution is over 200ppi [3].

The device performances of monochrome are disclosed that the relative efficiencies of are 1.20 (red), 1.23 (green), and 0.9 (blue) compared with evaporated ones, and the lifetimes under fixed currents are insisted to be comparable [3]. In later report, 2.0-inch QVGA device under white brightness of 150 cd/m^2 shows the panel lifetime of longer than 20,000 hrs, which is much shorted than that of commercialized AMOLED Panel manufactured in the same company. However, they did not provide any reasons why they showed different performances from evaporation method [4]. By the way, the authors have demonstrated 17-inch UXGA fabricated with LITI in 2004, and have prepared Gen-4 machine with the glass size of 730 × 920 mm^2.

Radiation-Induced Sublimation Transfer (RIST) and Laser-Induced Pattern-wise Sublimation (LIPS) have been proposed in 2005 and 2007, respectively [5, 6]. The x-y positioning radiation source in RIST is a diode laser with a nominal operating wavelength of 800 ~ 810 nm. The donor includes a polyimide support, a silicon anti-reflection layer, a chromium absorption layer, and an OLED. The total reflectivity of the donor at the laser wavelength is <7% (including the air/organic interface), resulting in highly efficient conversion of the laser energy to heat, in order to sublime the OLED layer. The OLED is typically vacuum evaporated onto the TFT substrate, which is the major difference from LITI process; therefore, the donor and active portion of the TFT substrate are spaced apart within the vacuum system to maintain a transfer gap of 1–10 µm. As most of the layers in a full-color OLED can be common and do not require patterning, only the emissive layer need to be patterned; therefore, three donors, each containing one of the three emissive layers, are necessary [5]. The relative efficiencies compared to the evaporated ones are 0.73 (red), 0.93 (green), and 0.93 (blue), respectively, and the relative lifetimes are 0.45 (red), 0.23 (green), and 0.99 (blue), respectively. And the authors have demonstrated 2.4-inch (222 × 284 × RGB) AMOLED fabricated with RIST in 2005 [5].

In LIPS, the rigid donor glass is applied to keep the transfer gap between the glass donor and the TFT substrate, and other parameters such as the height of the PDL and atmospheric pressure are precisely controlled. The position accuracy is better than 4 µm, and the pattern width variation is within ±2.0 µm in a 550 × 650 mm substrate. All the rest processes look similar to RIST. The relative efficiencies in LIPS are 0.77 (red) and 0.94 (green), respectively, and the expected lifetime is ~20,000 hrs, which is expected to be shorter than that formed by evaporation. Also the authors demonstrated the 27.3-inch full HD (1920 x 1080) panel in 2007 [6].

(2) Solution Process

For the solution processable materials there are many printing techniques that have been developed, which include screen printing, flexography printing and ink-jet printing. Among these methods, ink-jet printing has attracted more attention because it is expected to be well compatible with fabrication process using large mother glasses. The other advantages of ink-jet printing include high resolution pattering, high throughput by applying multiple heads, and high efficiency of material usage [7]. The best resolution reported up to now is 202 ppi that has demonstrated in 3.6-inch panel on 2006 with the drop accurate of ±5.4µm and the size of droplet of 23.7 µm [8]. And the expected material usage is approximately 80% under the assumption that the prime, which is the high flowrate jetting to make a nozzle surface clean and keep the jetting stability, is conducted in every 15 glasses [9].

Fig. 1. Photography of SEC's 14.1 inch WXGA AMOLED Panel fabricated by ink-jet printing. It was demonstrated on 2004.

Surface treatment in ink-jet process to have a hydrophilic ITO and hydrophobic bank surface is very crucial to realize accurate patterning. The treatment is usually done by the plasma or UV, which affect all the surface area without regional selectivity. Therefore, the suitable bank material should be selected carefully [7]. Also ink formulation should be optimized due to the ink-jet process stability and quality of resultant polymer films. Ink-jet process strongly depends on surface tension, viscosity and boiling point of solvents in light-emitting ink. However, the ink formulation can degrade the material performance such as lifetime and efficiency. Recently the efficiencies of LEPs are comparable with those of small molecules, but still the device lifetimes are not enough to compete with [10].

For an alternative method, a stripe patterning technology has been developed as follows [11]. The first two layers, HIL and primer, are continuously coated with the standard coating processes in the TFT backplane. The primer, which is covered on the HIL, is patterned into wetting and non-wetting lanes that contain the emitting inks as they are printed. A common cathode is vapor deposited over the entire active area. However, the author did not have comments on the scalability and the throughput [11]. The OLED materials used in the process are the solution materials of small molecule with the comparable performances in efficiency and lifetime with those of small molecules for evaporation developed in the same company [11].

(3) White OLED & Color filter

The white OLED with CF (Color filter) panel is fabricated as follows: the CF is prepared by conventional lithography as developed in the LCD process and then the stack of organic layer of OLED is evaporated on it without any fine patterning mask. Since the anode is aligned with CF sub-pixel, the panel can display full color while the OLED stacks are deposited on the whole display area. One drawback, however, is relatively lower light efficiency than that of the shadow masked RGB system since only about 1/3 of white light can pass through the CF. As RGBW 4 primary color system was developed to compensate the problem, the RGBW & CF system improves the light efficiency as much as 50% over strict RGB & CF one [12].

Even though a lot of hurdles to overcome in white EL (electroluminescence), it has a strong merit of the relatively simple scalability. It makes the pattern of pixel with conventional lithography of color filter, which AMLCD industry already has. The white EL behaves as a merged role of a backlight and liquid crystal that turn on and off an individual pixel. One of the major difficulties in this approach is the performance of white EL – efficiency and lifetime, which strongly depends on the OLED material properties.

Emitting materials with long lifetime, better efficiency with pure color (especially in blue emitter), transport materials with low operating voltage of higher mobility are required to improve the AMOLED. Fluorescent emitters have become better in lifetime especially in past three years. Phosphorescent emitters that have relatively high efficiencies still show not enough lifetimes [13, 14]. Engineers are in agony to choose fluorescent or phosphorescent, since both qualities are not acceptable yet. The bright point of the OLED materials for white EL is that there are aggressive developments for the lightening as well. Recently, the white EL performance reported was 64 lm/W, and 10,000 hours of lifetime at initial luminance of 1,000 cd/m^2 with light out-coupling technique, which is quite promising results for lightening and display [13]. Using the fluorescent materials, 19.6 cd/A, 16.8 lm/W, EQE 9.05% at (0.375, 0.404) has been reported [14].

Fig. 2. Photography of SEC's 40-inch AMOLED Panel fabricated with white & color filter approach. It was demonstrated on 2005.

3. Discussions for the current technology for AMOLED TV fabrication

In addition to the process-ability, device performances are a crucial factor to choose a technology for large-size mother glass. Fine metal mask approach can show the best performances in efficiencies, lifetime, and color purity due to their separate optimization of individual emitters and easy to achieve microcavity technique. The one major drawback is not to verify the fine metal mask process in more than Generation-4 (730 x 920 mm^2) glass size in the viewpoint of massive production. Alternative approaches to achieve the same architecture (patterned RGB pixel) are LITI, RIST, and

LIPS as discussed above, but their device performances are quite poor compared to those of the fine metal mask process. It is not simple that those laser patterning technologies will show better performances than OLED solution process and white approaches. If the materials for solution process are comparable with the materials for evaporation in efficiencies and lifetimes, the solution process can be a strong candidate for the AMOLED TV technology. Also the white approach can be the alternative ways to achieve the best performance if the laser patterning methods are not developed successfully, and the technology developments accelerate in white device owing to the lightening application.

4. Conclusion

Several candidates for the large-sized AMOLED panel have been introduced and discussed their merits and demerits. All those technologies are not fully developed, but they have to compete to achieve a competitive AMOLED TV. However, it has no enough time to develop, since it has to compete with AMLCD that is developing so fast. If the performance of AMLCD is far away from that of AMOLED, AMOLED can be disappear. Also the strategy of AMOLED to beat AMLCD is quite important, and the manufacturer will make better quality and lower price go ahead. Based on the current AMLCD's trend, the cheap manufacturing price of panel can be a strong merit of AMOLED TV, therefore the cheapest technology among what we have discussed above can be the final answer assuming they can achieve the acceptable quality as a display.

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