

40.4: Invited Paper: The Challenge of High Resolution to Active-Matrix OLED

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Abstract

In this article, the bottlenecks of achieving high display resolution on active-matrix OLED (AMOLED) based on currently available manufacturing processes are evaluated and compared. Shadow mask process has been proven to be a viable process for mass production, but the fabrication of high precision shadow mask becomes very difficult when the resolution exceeds 180ppi. This article presents the latest breakthrough to increase the display resolution. Without cost increase, AUO has successfully overcome the limitations of conventional shadow mask process using novel sub-pixel designs. A high display resolution reaching 270ppi has been successfully demonstrated on a 3" VGA format AMOLED, fabricated using shadow mask with a much lower resolution at 135ppi. This innovative pixel design opens up the possibilities of manufacturing high-resolution display using a relatively low-resolution shadow mask.

1. Introduction

According to the forecast by DisplaySearch, the market for OLED will reach US\$1227 million in 2006. The CAGRs (Compound Annual Growth Rate) of OLED is 57.1%, which is the highest among all flat panel displays. Most of these products are passive-matrix (PM) displays for applications such as MP3 players and sub-panels for mobile phones. However, active-matrix (AM) products are still absent from the growing market. Most AMOLED manufacturers have postponed or withdrawn their production plans due to various reasons.

From the analysis of these reasons, resolution is pointed out as one of the major differences between the requirements for AM & PM products. Most mature PM products are used for low-end applications; hence, monochrome or area color displays are sufficient. This means that high precision shadow mask process is not needed. However, for the active matrix display market, the competition of AMOLED against TFT-LCD has been anticipated.

Several superior intrinsic characteristics of AMOLED, such as high color saturation, fast response time, thin form factor, and high contrast ratio have made it an excellent candidate for the next generation display. However, the market share of AMOLED is still relatively low due to its difficulty in mass production. On the other hand, the attempt to use AMOLED on small size applications such as mobile phones and digital still cameras has been considered to be realistic when compared with large size applications. One of the key requirements for small size display is high resolution. None of any currently available production technologies can provide satisfactory solution for reliable full color patterning at high resolution.

In this article, several technologies for full color patterning are discussed. Shadow mask is one of the proven technologies for manufacturing AMOLED, however, bounded by the limitation to achieve high-resolution masks. By utilizing novel pixel designs innovated by AUO, the use of shadow mask to manufacture small size high resolution AMOLED becomes feasible.

2. Technical Review

Recently, several major technologies that can achieve full color AMOLED are shadow mask[1], white OLED with color filter[2], inkjet printing (IJP)[3], photolithography[4], laser-induced thermal imaging (LITI)[5] and radiation-induced sublimation transfer (RIST)[6]. This section provides a brief review, discussion, and a comparison among these technologies.

Shadow mask process is a currently available manufacturing process for volume production. The process ensures that the OLEDs can emit RGB light without further conversion nor filtering, resulting virtually no energy loss. Therefore, the advantages of low power consumption, high color saturation, long lifetime, and lower cost make it a popular technology to manufacture full color AMOLED. However, the high precision shadow mask required suffers from its physical limitation of not being able to achieve mask openings smaller than 50 μ m (Fig. 1). While high resolution is a general requirement for small size display, this hampers the use of shadow mask process in high resolution AMOLED manufacturing.

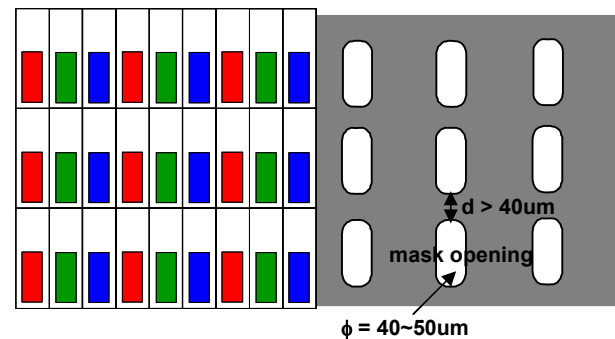


Fig 1. Conventional pixel design of full-color OLED and the corresponding shadow mask for individual color

Conventional RGB sub-pixel arrangements of full-color OLEDs are similar to that of TFT-LCD, and common arrangements are stripe, delta and mosaic. When adopting shadow mask process to manufacture full-color OLED, each opening of the mask corresponds to the emitting area of each sub-pixel. Thus, the panel resolution depends on the size of the mask opening and the density of these openings. In order to maintain the strength of the very thin and high precision metal mask, a distance between the edges of adjacent openings is normally in the range of a few tens μ m and, practically, a minimum of 40 μ m is required. Furthermore, the size of the mask openings has to be at least 40 μ m to ensure a good yield for mask fabrication. Therefore, the highest resolution of the shadow mask process is about 180ppi due to physical limitations of manufacturing precision shadow masks.

Recently, there has been considerable interest in the industry to develop white OLEDs in combination with color filter to create RGB pixels. This alternative approach provides a means to overcome the difficulty of using shadow mask for making high-resolution display. However, the major portion of emitted light is lost when color filter transmits the appropriate bandwidth of light emission while absorbing the rest. Approximately, two thirds of white emission is absorbed by color filter. Since small size displays are usually applied to mobile applications, the increase of power consumption caused by the use of such approach can prevent the entry of AMOLED in the segment.

Inkjet printing is another process to accomplish full color patterning. However, the drop size and alignment accuracy also limit the resolution of display; so far a 130 ppi PLED display has been demonstrated using inkjet-printing process [3]. The display was printed pixel-wise using solutions of differently colored electroluminescent polymers or dendrimers. When using the ink jet printing process to print organic solution, the control of the shape of the well and surface conditions are critical to its thickness uniformity and this in turns reflects the quality of the display. Moreover, the lack of high efficiency and long lifetime of blue polymer also prevents the commercialization of AM polymer LED.

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 30nm thick small molecule material. The small molecule material is evaporated onto the donor film before the LITI process. In the literature, 302ppi and 40% aperture ratio can be achieved. However, when considering the manufacturing mechanism, optimization of the laser power conditions and precision control of the accuracy present manufacturing difficulties, especially for mass production. Besides, the turn around cycle time may cause problems when irradiating each sub-pixel in the panel.

In summary, the performance comparisons of the above patterning technologies are shown in Table 1.

3. Development of New Pixel Design

3.1 Technical Concept

To overcome the resolution constrain, developments of innovative pixel arrangements of the RGB sub-pixels are required.

	White + CF	IJP	Photo-lithography	LITI	RIST	Shadow mask
Resolution	⊙	△	⊙	⊙	⊙	○
Power	△	○	○	○	○	⊙
Color saturation	△	⊙	⊙	⊙	⊙	⊙
Cost	△	⊙	△	○	○	△

⊙: better ○: good △: acceptable

Table 1. Comparisons of different patterning technologies

Otherwise, the previously mentioned bridge limitation raises the small aperture ratio problem. Here, a novel pixel design is proposed. With the new pixel arrangement, two sub-pixels of the same color can be deposited through the same opening of the shadow mask. Thus, the size of the opening of the shadow mask can be doubled in both length and width. The area of each opening can be up to four times of the conventional design. In other words, a 300 ppi resolution display can be achieved by using a shadow mask resolution of only 150 ppi.

3.2 Results

To further compare with conventional sub-pixel arrangement, we calculate the ideal aperture ratio by considering only the limitation when using the mask. The bridge between mask openings is 40 μm , the tolerance for mask alignment is 10 μm , and the border between two same-color sub-pixels is 10 μm . Fig 2(a) shows the ideal aperture ratio, the actual aperture ratio should be smaller than the ideal one due to the constraint of TFT design rule. Examples illustrated in Fig. 3 and Fig. 4 has the same aperture ratios at lower resolution (< 200 ppi). However, the aperture ratio of the shadow mask design illustrated in Fig. 3 will dramatically decrease at higher resolution because of the widening of bridges between mask openings.

Considering the current etching limitation for mask opening at approximately 50 μm , the highest resolutions achievable for conventional and the shadow mask design shown in Fig. 3 are about 170 ppi and 350 ppi, respectively, as shown in Fig 2(b). Example illustrated in Fig 4 can reach higher resolution at up to 400 ppi with an acceptable aperture ratio (28%).

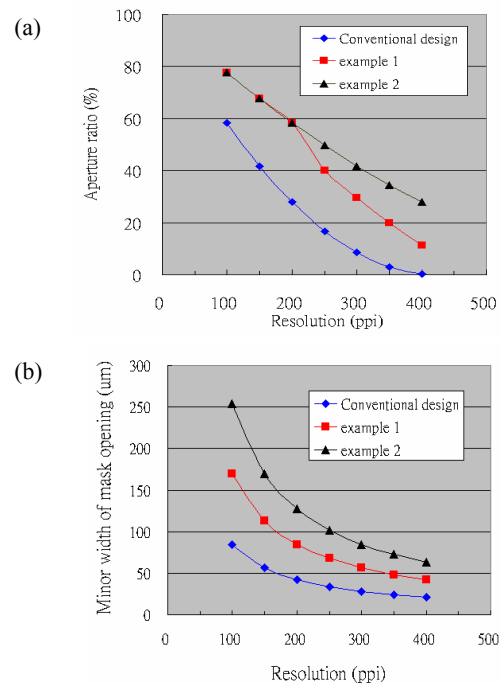
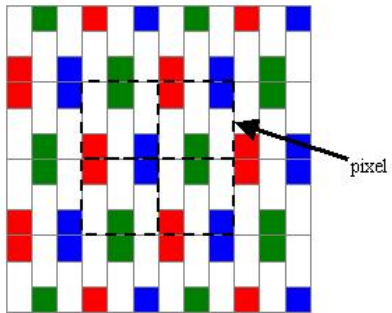


Fig 2. The aperture ratio (a) and minor width (b) of mask opening calculated for different resolutions

(a) Pixels on panel



(b) Shadow mask for blue pixels

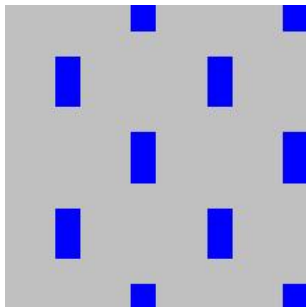
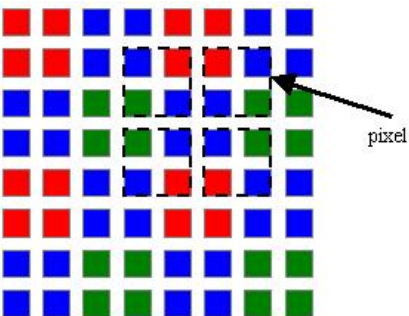


Fig. 3. Example 1 of shadow mask design

(a) Pixels on panel



(b) Shadow mask for blue, red and green pixels

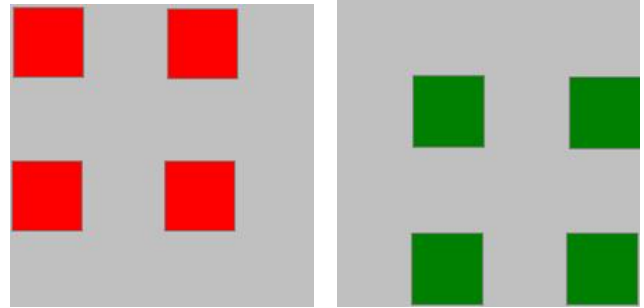
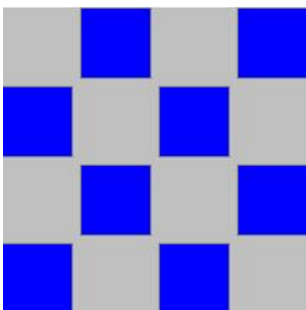


Fig. 4. Example 2 of shadow mask design

A display resolution of 270 ppi was successfully demonstrated on a 3" AMOLED with VGA format. The resulting image and the specifications of this display are shown in Fig.5 and

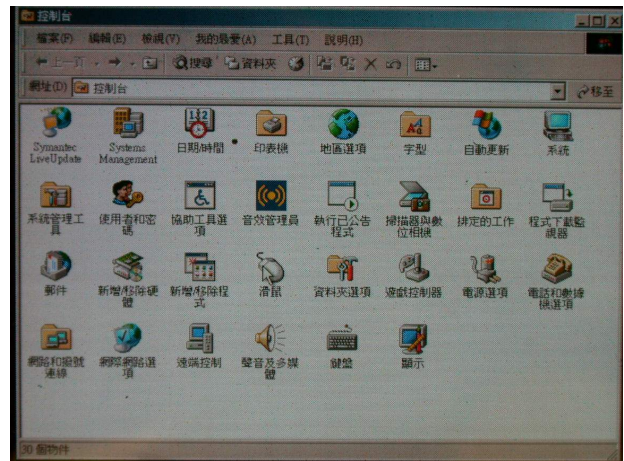


Fig. 5. AUO 3"VGA AMOLED at 2005 FPD.

Items	Spec.
Display size (inch)	3
Display Resolution WxH	640 (RGB) x 480
Color	18 bits
Outline Dimensions WxH (MM)	66.2 x 56.5
Active Area (mm)	60.2 x 45.1
Module Thickness (mm)	2.05
Pixel Size (mm x mm)	0.094 x 0.094
Peak Brightness (cd/m ²)	150
Interface	Digital RGB
Contrast Ratio	Dark: 10,000:1
Color Saturation	> 60%
Viewing Angle (degree)	> 170
Response Time (ms)	< 1

Table 2: The specification of the 3" VGA AMOLED

Table 2, respectively. The resolution count of the shadow mask used for fabricating the display is only 135 ppi. Two types of novel pixel designs to realize high resolution for AMOLED display are illustrated below. The first type is configured in the way that each opening covers two sub-pixels of the same color as shown in Fig. 3, and this effectively brings up the resolution of the display by a factor of two. The other type has each opening covering four sub-pixels of the same color as shown in Fig. 4. By using the novel sub-pixel design, we can immediately utilize current OLED process and mask technique to achieve an aperture ratio larger than that of the conventional design. The only one minor disadvantage is the difference of straight line shown by sub-pixels between conventional design and this novel design. However, it is not distinguishable in a panel with such a high resolution.

4. Conclusion

High resolution is one of the important specifications for small size display. Although this article focuses on the shadow mask method, several alternative approaches to achieve high resolution AMOLED are discussed.

The latest breakthrough to increase the display resolution without increasing the resolution of the shadow mask is presented. A display resolution as high as 270 ppi fabricated using shadow mask with a lower resolution of 135ppi has been successfully demonstrated on a 3" VGA format AMOLED by AUO. This

innovative pixel design opens up the possibility of manufacturing high-resolution display with a low-resolution shadow mask. Higher production yield can also be expected due to the elimination of very high-resolution shadow mask process.

5. References

- [1] G. Rajeswaran, M. Itoh, S. Barry, T. K. Hatwar, K. B. Kahen, K. Yoneda, R. Yokoyama, T. Yamada, N. Komiya, H. Kanno, H. Takahashi, SID 00 DIGEST, p974.
- [2] K. Mameno, S. Matsumoto, R. Nishikawa, T. Sasatani, K. Suzuki, T. Yamaguchi, K. Yoneda, IDW03, p267.
- [3] T. Funamoto, Y. Matsueda, O. Yokoyama, A. Tsuda, H. Takeshita, S. Miyashita, SID 02 DIGEST, p899.
- [4] T. Tachikawa, N. Itoh, S. Handa, D. Aoki and T. Miyake, SID 05 DIGEST, p1280.
- [5] K.-J. Yoo, S.-H. Lee, A.-S. Lee, C.-Y. Im, T.-M. Kang, W.-J. Lee, S.-T. Lee, H.-D. Kim, H.-K. Chung, SID 05 DIGEST, p1344.
- [6] M. Boroson, L. Tutt, K. Nguyen, D. Preuss, M. Culver and G. Phelan, SID 05 DIGEST, p972.