A Method to Improve IR Drop issue of Large-Size Top-Emission AMOLED

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Abstract. Top-emitting active-matrix organic light-emitting diode (AMOLED) displays usually use a thin cathode layer to obtain high transmittance. However, the thin surface cathode inevitably raises an IR drop issue or even a Mura effect that is visible to the naked eyes, especially in large-size displays. Therefore, to reduce the IR-drop effect and improve the display quality, a plurality of cathode separators are provided to separate the cathode of AMOLEDs to electrically connect the cathode to the auxiliary electrodes under the cathode separators. In this work, we report how to control the process of organic photoresist to obtain a good anti-taper (cathode separator). The organic photoresist is formed through the steps of coating, pre-bake, exposure, post exposure bake (PEB) and then developing, but the exposure and PEB processes are the key factors, which can improve the anti-taper below 53° (The EL evaporation angle is 53°).

Keywords. AMOLED, IR Drop, Cathode separator, anti-taper

1. Introduction
Active-matrix organic light-emitting diode (AMOLED) displays are rising as the next generation display device, surpassing liquid crystalline (LCD) displays in areas such as viewing angle, color gamut, flexibility, and contrast ratio [1]. AMOLED may be used for curved display and their development tends to large-size applications [2-3]. However, large-size top emission applications will raise an IR drop issue [4-6], or even a mura effect that is visible as Figure 1 because the cathode is very thin. Therefore, technically, cathode separators (Pillar) are provided to separate cathodes of AMOLEDs in order to electrically connect the cathode and auxiliary electrodes under cathode separators.

The cathode separator on the auxiliary electrode is showed in Figure 2. The way of manufacturing a plurality of cathode separators is made up of a series of steps, including coating an organic photoresist (Negative), pre-bake, exposing, PEB, and then developing. An inverted-trapezoid shape of the cathode separator, having two anti-taper $\alpha$ and $\beta$, is formed by controlling process parameters. We controlled both anti-taper under 53° because the EL evaporation angle is 53°. The cathode separators provide a certain length between EL and itself after the EL process (as shown by the dashed circle in Figure 2), which for connecting the cathode and auxiliary electrodes (ITO layer). The anti-taper of cathode separators can be decreased by tuning some parameters of the pre-bake, exposure, and PEB Process. In
this study, we have proposed some methods to optimize it. Finally, it was demonstrated that the IR drop is reduced and the display quality is improved in an AMOLED panel like with cathode separators.

2. **Experiments**

ITO (750nm) film was deposited by DC magnetron sputtering on a G4.5 glass. 4200-nm-thick cathode separators were made with different conditions on the above substrate. The process flow is slit coating, then pre-bake, exposing, PEB and then developing. Finally, the panel like with cathode separators was fabricated by using the optimal conditions.

![Figure 1. Simulation model of IR Drop](image1)

**Figure 1.** Simulation model of IR Drop

![Figure 2. Structure of panel like](image2)

**Figure 2.** Structure of panel like

Exposure light source Illuminance is 12000 mW·mm/cm² (g, h, I Line). After exposure, the glasses were baked on a hot plate, which is in the PEB process. After PEB process, they were developed in 2.38% TMAH at room temperature. Then, they were baked in an oven with clear dry air (CDA). Finally, the anti-tapers were measured by a scanning electron microscope (SEM).

3. **Results and Discussion**

3.1. *The relationship between anti-tapers and different exposure energy*

The anti-tapers of different exposure energy after slit coating and pre-bake were showed in Figure 3. We found that the exposure energy of E2 mJ/cm² has the lower anti-tapers (α) and (β) compared to E1 mJ/cm². As a consequence, we showed the result in Figure 4(a) and Figure 4(b). The dependence between the anti-taper (α) and different exposure energy, which were measured at different sites on a G4.5 glass, showed that when the exposure energy was higher, the anti-tapers (α) and (β) were higher in Figure 5.

Exposure energy has an impact on anti-taper, because when the exposure energy decreased, the corresponding organic solidification is reduced, and anti-taper (α) and (β) become lower. To form cathode separators, the exposure energy would be more helpful to become lower. However, low exposure energy usually leads to new issues, such as a peeling issue.
Figure 3. Anti-tapers of difference exposure energy by SEM analyse (E1>E2)

Figure 4. Effect of different exposure energy on the (a) anti-taper(α) and (b) anti-taper(β) (E1>E2>E3)

Figure 5. The dependence between the anti-taper (α) and different exposure energy (E1>E2).

3.2. The relationship between anti-tapers and different exposing focal lengths
SEM results revealed the effect of the exposing focal length on the anti-taper is obvious in Figure 6. Compared with the focus condition of 0 um, anti-taper (α) decreased nearly 10° when the focus condition is adjusted to a um. Subsequently, when the focus condition was set to b um, the value of anti-taper (α) is reduced about 10° again, which meant that the anti-taper (α) was reduced about 20° when the focus condition was b um, compared with that of the focus condition of 0 um. Modifying the focal length is very obvious to affect the anti-taper (α), but does not affect the anti-taper (β), as shown in Figure 7.

The main reason that increasing the focal length would reduce the anti-taper is to enhance the light diffraction. Because the negative photoresist is still retained during irradiation, the diffraction of surface light will enhance the anti-taper taper (α), but will not affect the anti-taper (β) at the bottom.
Figure 6. Anti-taper of difference exposure focus by SEM analyse (a<b)

Figure 7. Effect of different exposure focus on the anti-tapers (α) and (β) (a<b)

3.3. The relationship between anti-tapers and different PEB temperature

Compared with T1°C, the anti-taper (α) at PEB temperature T3°C increases by 5 degrees, as shown in Figure 8. As the PEB temperature increases, the anti-tapers (α) and (β) increase in Figure 9-10. At the same time, the anti-taper (α) becomes sleek.

PEB is a step between exposure and development, mainly cross-linking. When the temperature of PEB increases, the cross-linking function is diffused and enhanced, so the anti-taper (α) and (β) become larger.

Figure 8. The anti-taper at difference PEB temperature by SEM analyse (T1<T2<T3)
Figure 9. Effect at different PEB temperature on the (a) anti-taper (α) and (b) anti-taper (β) (T1<T2<T3)

Figure 10. The dependence between the anti-taper (α) and different PEB temperature (T1<T2<T3).

Based on the above research, we confirm that the first most important factor is exposing focal length, then PEB temperature, and final exposure energy, as shown in Table 1.

| Element          | Improving method | Impact | Reason-analysis                      |
|------------------|------------------|--------|--------------------------------------|
| Exposure energy  | ↓                | ↑↑     | Organic solidification is reduced when reduce exposure energy |
| PEB temperature  | ↓                | ↑↑     | Crosslinked weaken by reduce PEB temoerature |
| Exposing focal length | ↑              | ↑↑↑↑   | Focus enhance optical diffraction |

We optimized the best conditions so that the anti-tapers (α) and (β) are less than the evaporation angle. At this time, the contact length between the cathode and the auxiliary electrodes is about 1um in Figure 11. Finally, a 31inch panel like with cathode separators was fabricated. When using cathode separators, the cathode connects the auxiliary electrodes to reduce the IR drop, and the display quality is improved obviously in Figure 12.
**Figure 11.** The contact length between the cathode and the auxiliary electrodes is about 1μm after EL process.

**Figure 12.** 31inch Panel like with and without cathode separators.

4. **Conclusion**
We successfully improve IR Drop by producing cathode separators. The main factors in the production process are exposing focal length, PEB temperature, and final exposure energy. All these factors can improve anti-tapers, but at the same time, they may create new issues, such as peeling. Finally, we get an optimized condition to produce cathode separators and make sure the contact length between the cathode and the auxiliary electrodes is about 1μm. For the 31inch panel like, the IR drop is reduced and the display quality is improved.

5. **References**
[1] So F, Kido J, Burrows P 2008 MRS Bulletin.Cambridge Univ Press 33 663.
[2] Kunimasa H, Hiroto I, Yasushi O, Hiroshi K 2014 SID Symposium Digest 45 679.
[3] Chang-Wook H, Jung-Soo P, Young-Hoon S, Moo-Jong L, Bong-Chul K, Yoon-Heung T, Byung-Chul 2014 SID Symposium Digest 45 770.
[4] Jongwoong P, Mitsuru F, Jiye M, Insu W, Donghwan L, Wonju S, Wonjun C 2019 SID Symposium Digest 50 81.
[5] Zhibin W, Yilu C, Qi W, Yingjie Z, Jacky Q, Michael H, Yi-Hsiang H, Wei-Lung T, Kuan-Ting C, Jia-Chong H 2019 SID Symposium Digest 50 853.
[6] Daiki Nakamura, Shingo E, Nozomu S, Tomoya A, Sho K, Takeru S, Taisuke K, Kazunori W, Masayoshi D, Chieko M, Masataka N, Shunpei Y 2018 SID Symposium Digest 49 910.

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