Study of AMOLED short-term image sticking mechanism and improvement

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Abstract

We successfully developed an OLED pixel circuit which has shorter OLED image sticking time and better first frame brightness ratio. The root causes of short-term image sticking (STIS) was also studied. The effects of TFT and EL were tested separately. By matching with the phenomenon of STIS, it was confirmed that the reason of STIS is related to the characteristic of OLED driving thin film transistor (DTFT). DTFT has different stress conditions under black/white picture, resulting in difference of OLED current under the gray picture. We could minimize the differences by modifying circuit reset driving timing to improve the STIS.

Author Keywords

OLED; Short-term Image Sticking; Pixel Circuit

1. Background

Due to the merits of its picture quality and flexible bending, OLED gradually occupies superiority in the application of small and medium size display products. And as the gradual improvement of its yield and cost, its application prospect will be more and more extensive.

However, OLED has several unique picture quality problems, and the short-term image sticking (STIS) is one of them. About the image sticking, the burn-in issue was most studied [1]~.[2] It is generally accepted that the degradation of brightness due to the lifetime of EL materials caused by prolonged work is the main reason for the burn-in issue. However, with the improvement of EL lifetime and the algorithm modification of system software, the long-term image sticking is being greatly improved.

And the short-term image sticking (STIS) of OLED is currently more concerned by customers, especially mobile phone customers. The phenomenon is shown in Fig 1. Firstly, black and white plaid image was displayed on the OLED for a very short time (such as 10s). Then the phenomenon of residual image was observed in the gray pattern (such as 63 gray level). After a quantity of seconds, the residual image faded to invisible.

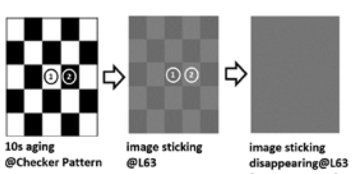

Figure 1. OLED short-term image sticking phenomenon

Following, the reason of OLED STIS was analyzed, and then the improvement pixel circuit scheme was proposed and verified by experiments. Finally, the mechanism of OLED short-term residual image was summarized.

2. Phenomenon and analysis

2.1 Brightness trend of STIS

Firstly, we measured the change process of the short-term image sticking. The luminance recording position was showed as Fig1.

Figure 2 shows the brightness change process measured in 5.5inch FHD OLED sample, and the test position was 1 and 2 as figure 1. The maximum gray scale of the display sample was 255 gray scale, in which the brightness of position 1 was initially white (255 gray scale), and the brightness was about 353nit, which switch to gray (63 gray scale); at the same time, the brightness of position 2 is initially black (0 gray scale), and the brightness is below 0.001nit, which switch to gray (63 gray scale).

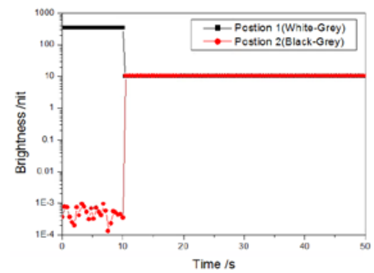

Figure 2. The brightness of position 1 and position 2

By amplifying the results of figure 2, from 11st seconds to 50th seconds, we can see the obvious change process of brightness in figure 3. When displaying the gray picture (48 gray level), the brightness of position 1 changes from high to low, while the brightness of position 2 changes from low to high, and the final brightness tends to be consistent. This process also accords with the actual observation of the human eye feeling.

In order to determine the time of image sticking, the following formula is proposed. L_1 represents the brightness of position 1 and L_2 represents the brightness of position 2. The x value is calculated by the following formula (1):

$$x = \frac{L_1 - L_2}{L_1 + L_2} \tag{1}$$

According to the principle of human visual sensitivity and actual human eyes observation, when the x value is less than 0.004, the human eyes cannot feel the obvious brightness difference [3]. So the corresponding image sticking time in figure 3 is 18.4s.

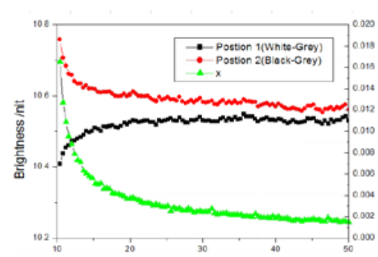

Figure 3. The brightness of position 1 and position 2

(Time: 11st ~50th s)

2.2 Effect of EL

In order to decompose the cause, we tested EL and TFT separately to determine whether they are related to STIS. Firstly, the green LTC was tested. The LTC electrodes are connected to a constant current supply. We set two current change mode: 1) 50nA lasts for 10s and then jumps to 12nA (White to Gray), 2) 0A lasts for 10s and then jumps to 12nA (Black to Gray). The brightness change process is shown in Figure 4. Inserted figure of figure 4 was the amplifying EL brightness change under the 12nA current. It can be found that the brightness was almost unchanged. Therefore, it can be judged that the brightness EL brightness was directly related to the current intensity, and there was no residual process during the constant current power source was switching.

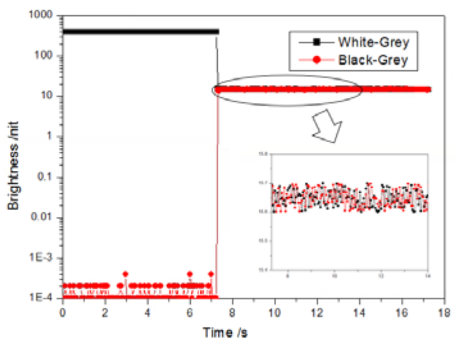

Figure 4. Brightness of EL by change of current

2.3 Effect of TFT

Then, the similar analysis was performed on the TFT. And the change process of the output current Ids was observed by giving different instantaneously varying Vgs voltages, as shown in figure 5. We set two Vgs voltage change mode: 1) -1.8v lasts for 10s and then jumps to -1.5v (White to Gray), 2) 0v lasts for 10s and then jumps to -1.5v (Black to Gray). It can be found that the current varies when the Vgs is -1.5v as shown in the enlarged diagram on the right side of Figure 5.

So if the current went through TFT for 10 seconds of high current stress (8E-7A), the current would increase gradually from the lowest current, as shown in the black line of figure 5. Conversely, if the current went through TFT for 10 seconds of low current stress (1E-12A), the current would decreased gradually from the highest current.

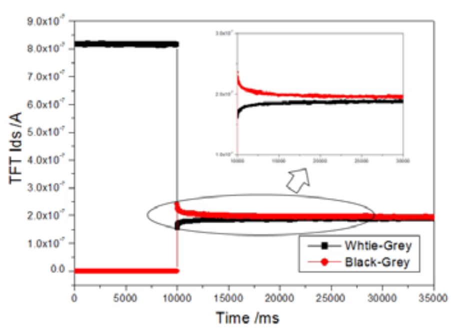

Figure 5. Output current (Ids) of TFT by change of Vgs

It can be inferred from figure 5 that this current variation trend was exactly consistent with phenomenon of STIS in figure 3. When a black and white checkered pattern was switched to a gray one, the brightness of the black checker changed from bright to dark after it was switched to gray; at the same time, the brightness of the white checker changed from dark to bright after it was switched to gray. And eventually the brightness of the black and white checker tends to be the same.

Therefore, it was considered that the short-term image sticking problem was related to the TFT Ids current (current between drain and source) discrepancy caused by the characteristic shift of TFT subjected to different current stresses.

3. Improvement method and result

3.1 Analysis of TFT hysteresis effect

In general, for the conventional P-type TFT, it existed obvious hysteresis phenomenon. TFT exhibited different drain current at the same gate voltage depending on the gate sweep direction. The mechanisms was attributed to the electron trapping/detrapping processes associated with the deep-level traps in the grain boundaries of the poly-Si channel and the hole trapping/detrapping into/from the gate oxide defects[5].

So TFT hysteresis phenomenon was directly related with thin film deposition process and interface treatment process technology. It was generally believed that the higher density of defect state in gate insulating layer and semiconductor layer, the greater difference of TFT output current at the same Vgs.

Therefore, the TFT hysteresis effect had striking effect on the STIS of OLED. Its mechanism, as shown in figure 6, could be explained by the TFT hysteresis curve. When from the black picture switch to the gray picture (Lv0 to Lv63), that was from Ⅰ to Ⅱ; When from white picture switch to gray picture (Lv255 to Lv63), that was from Ⅲ to Ⅳ. At this point, the Ⅱ and Ⅳ correspond to different current, namely Lv63 gray-scale. Subsequent Ⅱ and Ⅳ would gradually change to Ⅴ, and residual image was gradually disappear. This process was accompanied by trapping/detrapping process of electron/hole in the layer interface between semiconductor and gate dielectric layer.

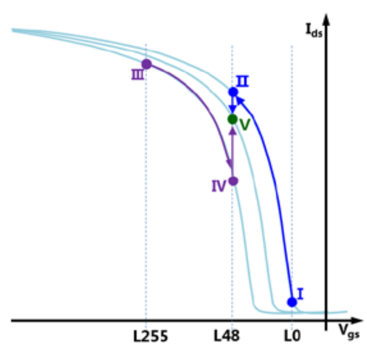

Figure 6. Diagram of TFT hysteresis

3.2 Improvement concept

Considering the principle of STIS was caused by hysteresis of TFT characteristic. Therefore, the conventional way to solve the problem was to reduce the hysteresis of TFT characteristic. In this paper, another idea was proposed. By changing the driving circuit and the driving signal timing, the following figure 8 indicated the voltage changing processes. The Vgs voltage of the black/white picture changed to the same voltage, as III to VI and I to VI. Then, according to the changing path of VI to IV, the problem of residual image leaded by the inconsistent brightness of the original black-and-white checker position when changing to Lv48 gray scale would be improved.

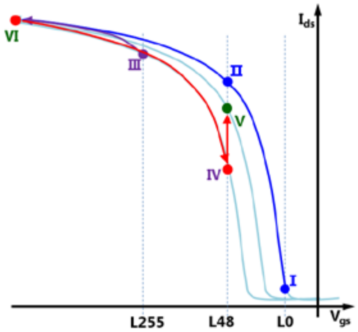

Figure 7. Diagram of TFT hysteresis（Improvement Concept）

3.3 Improved circuit and simulation

Furthermore, according to the improvement concept, we proposed the new circuits which were different from the normal 7T1C circuit, such as figure 8. As the normal case, T1 timing was reset period, T2 timing was Vth compensation period, and T3 timing was emitting period. We believed that T1 reset period was the key influencing factor to STIS. All TFT of circuit were P-type TFT.

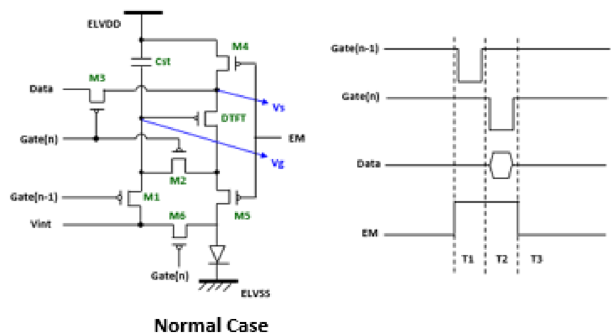

Figure 8. Normal case of AMOLED pixel circuit diagram

So, in this paper, we put forward two pixel circuit structure and signal timing, as shown in figure 9 and 10. Comparing to the existing pixel circuit structure, there were no added TFT numbers, no additional driver signal sources, and no increased the border of panel. The main differences from the existing circuits were that M4 and M5 TFTs were separately controlled by EM(n) and EM(n+1) signal, and M6 TFT was controlled by Gate(n-1) signal in figure 10.

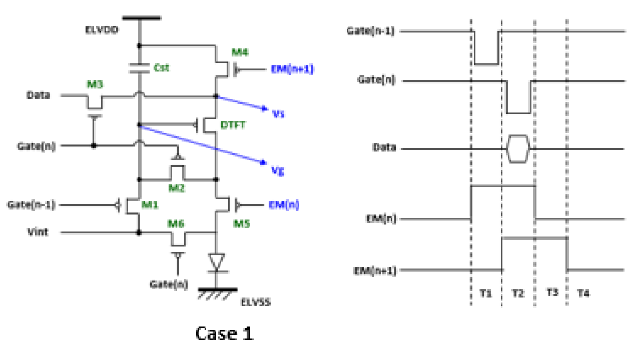

Figure 9. Case 1 of AMOLED pixel circuit diagram

Such as in figure 10, the circuit diagram and signals timing was showed. Working course of case 1 was that the EM (n+1) signal turned on M4 firstly, making the source voltage of DTFT become Vdd voltage; and the Gate (n-1) signal turned on M1, making the gate voltage of DTFT became Vint voltage. Thus in T1 period the case 1 circuit realized the multi-point simultaneous reset of DTFT. At the same time, Gate (n-1) turned on M6 to achieve OLED anode reset. T2 was the DTFT Vth compensation period. T3 was transitional state, which did not affect the Vgs voltage of DTFT. Period T4 was the light emission state. The key point of case 1 was reset period T1, in which the Vgs voltage of DTFT was a negative voltage (Vint-Vdd). So the DTFT was in the state of On-Bias-Reset during period T1.

Similarly, the case 2 circuit was proposed in figure 10. When the EM (n+1) signal turned on M5 and Gate (n-1) turned on M6, the drain voltage of DTFT became Vint voltage. And Gate (n-1) turned on M1, which made the gate voltage of DTFT became Vint voltage. Thus, the multi-point simultaneous reset of DTFT was realized. The Vgd voltage of DTFT is Vint-Vint=0v, and the DTFT is in the state of Off-Bias-Reset.

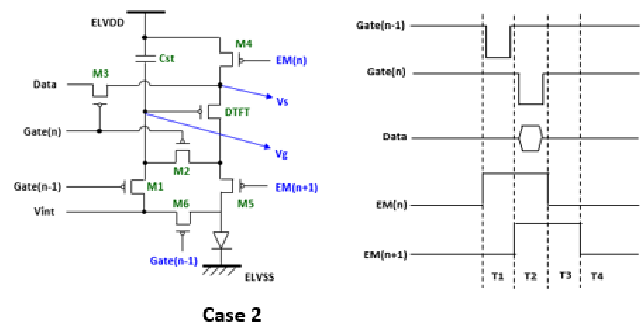

Figure 10. Case 2 of AMOLED pixel circuit diagram

Figure 11~13 were Vgs voltage simulation of normal case, case 1 and case 2. Each scheme simulates two picture changing situations, from white to gray and from black to gray. In figure 11~13, the vertical axis was the voltage, and the horizontal axis was the time. The Vg and Vs changing process were represented by two curves. In the reset period, the Vgs voltages were different between L255➔L63 and L0➔L63, which was mainly because source point of DTFT was floating. As in figure 12 and 13, the Vgs voltages were same between L255➔L63 and L0➔L63.

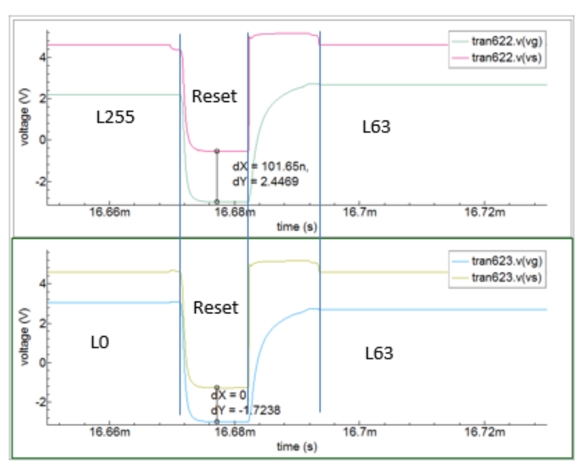

Figure 11. Diagram of normal case voltage simulation

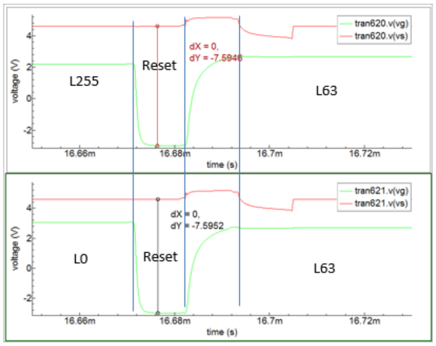

Figure 12. Diagram of case 1 voltage simulation

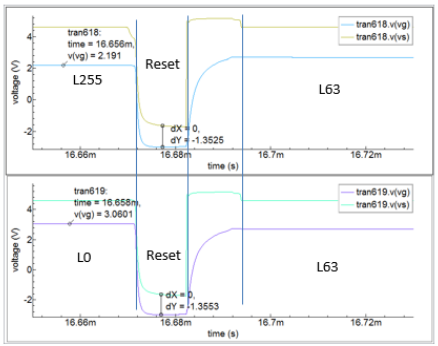

Figure 13. Diagram of case 2 voltage simulation

3.4 Actual Measurement and Verification

Then we made some samples according to these three pixel circuit designs. And we tested the STIS of these OLED panels by CCD. In the figure 14, the results showed that the proposed circuit of case 1 and 2 can significantly improve the short-term residual image time compared with the normal case circuit. The STIS time was within 12s, and the average time was decreased about 37% (11.3s➔7.1s/7.4s).While state of all DTFT which in the black or white checker was reset to the same condition, so the influence of the previous frame was eliminated.

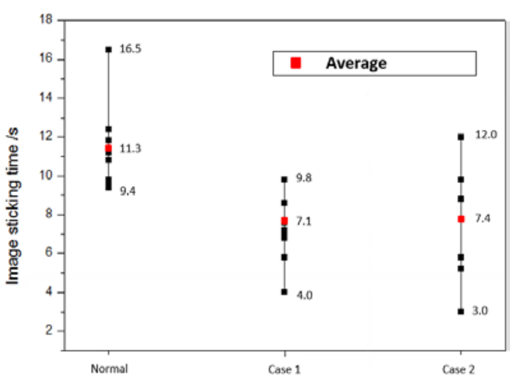

Figure 14. STIS time of different circuit case

At the same time, the first frame brightness ratio was also improved 11% (82.2%➔92.9%) in figure 16. Because the first frame brightness ratio was related to the reset period too, when from black (L0) to white (L255).

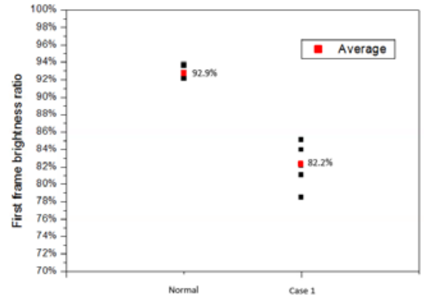

Figure 15. First frame brightness ratio of different circuit case

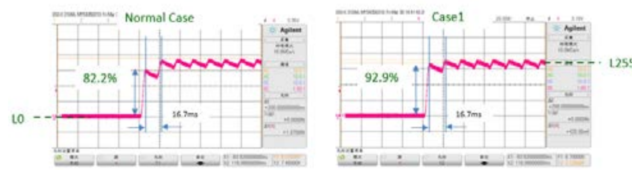

Figure 16. Comparison of first frame brightness ratio between normal case and case 1

4. Conclusion

This paper presented a quantitative description method for the short-term image sticking (STIS) by CCD. The phenomenon and reason of SITS was analyzed. It was confirmed that STIS was caused by DTFT different output current, which due to different stress conditions under black/white picture. Further, two new circuits was proposed to improve the STIS by modifying reset timing of DTFT, and the improvement effect was verified. Under the same process technology, nearly 37% (11.3s➔7.1s/7.4s) of the STIS time was shortened. And this scheme also had an 11% (82.2%➔92.9%) improvement in brightness of the first frame. So, STIS could be improved in two way, pixel circuit reset timing and TFT characteristics stability.

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