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New AMOLED Compensation Pixel Circuit with Simultaneous Emission Method for Non-uniform Electrical Characteristics Based on P-type LTPS TFTs

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Abstract

This work proposes a compact pixel circuit using low-temperature polycrystalline silicon thin-film transistors (LTPS TFTs) for high-definition resolution AMOLED displays. The new design is composed of the adjacent pixels with seven TFTs and four capacitors, so the structure of each pixel is only 3.5 TFTs and two capacitors, increasing the aperture ratio of displays. The proposed circuit uses the simultaneous emission method and adjusts the voltage level of ELVSS to compensate for threshold voltage variations of TFTs and eliminate the flicker phenomenon. Simulated results shows the relative current error rates are below 4.4% as the threshold voltage varies ±0.5 V.

1. Introduction

Active-matrix organic light-emitting diode (AMOLED) displays are a developed mainstream because of their merits including fast response time, high contrast ratio, wide viewing angle, and low power consumption [1]-[5]. Low-temperature polycrystalline silicon (LTPS) backplane is widely used in AMOLED displays due to its high mobility and exceptional driving capability. Despite these attractive features, the threshold voltage (V_{TH}) and mobility variations result in the non-uniform OLED currents among pixels, decreasing the image quality of displays. Hence, various compensating pixel circuits have been proposed to improve the variation of V_{TH} in the LTPS backplane. Lin *et al.* developed a voltage modulation pixel circuit that uses the AC driving and progressive emission (PE) method to compensate for the V_{TH} variation [4]. In the PE method, the compensation period and data input period are performed in a scan time of a row. For AMOLED displays with a high-definition resolution, the each scan time is shortened, leading to the insufficient compensating time for sensing the V_{TH} variation, so the pixel circuits with PE method may be unsuitable for use in high-definition resolution AMOLED displays. To produce a longer compensation time, the simultaneous emission (SE) method, which separates the compensation period from the data input period, was presented. Lin *et al.* [5] proposed a pixel circuit that utilizes the SE method and diode-connection structure to compensate for V_{TH} variation of LTPS thin-film transistors (TFTs) for the uniform images. However, the complicated circuit structure that was composed of five TFTs, two capacitors, and four control signal line, reducing the aperture ratio of displays. Also, there is a large current flowing through OLED during

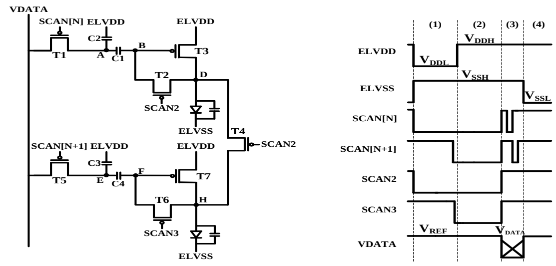

Fig. 1. Proposed AMOLED pixel circuit. (a) Schematic. (b) Timing diagram.

the compensation period, leading to flicker phenomenon and lowering the contrast ratio of displays.

This work proposes a simplified pixel circuit that only consists of 3.5 TFTs and two capacitors per pixel structure. The new design adopts the SE method and adjusts the voltage range of ELVSS signal to compensate for the V_{TH} variation of LTPS-TFTs and eliminate the flicker phenomenon. The simulated results show that the relative OLED emission current error rates are less than 4.4 % when the V_{TH} of driving TFT varies by ± 0.5 V. Consequently, the proposed pixel circuit is highly promising for use in high-definition resolution AMOLED displays.

2. Circuit Schematic and Operation

Fig. 1(a) shows the proposed pixel circuit structure that is composed of two driving TFT (T3 and T7), three switching TFTs (T1, T2, T4, T5, and T6), and four capacitors (C1 ~ C4) for the adjacent pixels, and its corresponding timing diagram is shown in Fig. 1(b). The operation of the proposed circuit can be divided into the following four periods.

(1) Reset period: SCAN[N] is low to turn on T1 to reset the node A to V_{REF} through VDATA. SCAN2 is low to turn on T2 and T4 to reset the nodes B, D and H to V_{DDL}. ELVDD is at a lower voltage V_{DDL} to dramatically pull down the node E and node F through capacitive coupling effect, enabling T7 to be operated in the triode region. ELVSS is modified to a high voltage level V_{SSH} to turn off OLED for preventing flicker phenomenon. In this period, all pixels of the display are reset at the same time because of adopting SE method.

(2) Compensation period: SCAN[N+1] goes low to turn on T5, so the node E is reset to V_{REF} through VDATA. SCAN3 goes low to turn on T6 for making the initial voltage of V_{TH} compensation is identical in both pixels. Then, ELVDD goes to a high voltage V_{DDH}, enabling T3 and T7 to be operated in the saturation region. Therefore, the node B and F are charged to V_{DDH}-|V_{TH}|, where V_{TH} is assumed to be equal to the threshold voltage of T3 and T7.

TABLE I

DESIGNED PARAMETERS OF PROPOSED PIXEL CIRCUIT

Parameter	Value	Parameter	Value
ELVDD (V)	9 / 0	$(W/L)_{T3, T7}$ (μm/μm)	3 / 22
ELVSS (V)	-2 / 6	$(W/L)_{T1,T2,T4,T5,T6}$ (μm/μm)	3 / 3
VDATA (V)	-0.8~0	$(W/L)_{TOLED}$ (μm/μm)	7 / 25
V_{REF} (V)	0	C1, C4 / C2, C3 (pF)	0.1 / 0.2
SCAN (V)	-10 /10	V_{OLED_0} (V)	4
ΔV_{TH_T4} (V)	±0.5	C_{OLED} (pF)	0.125

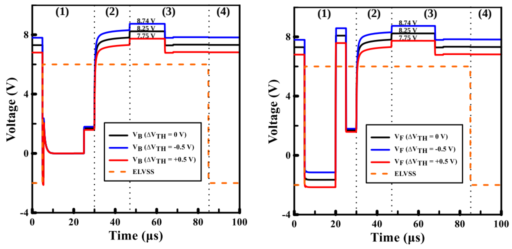

Fig. 2. Simulated transient waveforms of (a) node B and (b) node F as threshold voltage varies ±0.5 V.

(3) Data Input period: SCAN2 and SCAN3 are high to turn off T2, T4 and T6 of all pixel circuits. SCAN[N] goes low to turn on T1 to deliver data voltage to node A. The node B is changed to V_{DDH}-$|V_{TH}|$+V_{DATA_N}-V_{REF} owing to the capacitive coupling effect of C1. The lower pixel's circuit operation in data input period is same as upper one.

(4) Emission period: All SCANs are high to turn off all switching TFTs. ELVSS is modified to a lower level V_{SSL} to turn on OLEDs, so T3 and T7 are operated in the saturation region. The OLED emission current of pixel is calculated as

$$I_{OLED\_N} = \frac{1}{2}\,\mu C_{OX}\left(\frac{W}{L}\right)(V_{SG} - |V_{TH}|)^2$$
$$= \frac{1}{2}\,\mu C_{OX}\left(\frac{W}{L}\right)(V_{DDH} - V_{DDH} + |V_{TH}| - V_{DATA\_N} + V_{REF} - |V_{TH}|)^2$$
$$= \frac{1}{2}\,\mu C_{OX}\left(\frac{W}{L}\right)(V_{REF} - V_{DATA\_N})^2$$

Based on the aforementioned equation for the OLED current, the OLED current is independent on the threshold voltage variation of TFTs.

3. Results and Discussion

To confirm the feasibility of the proposed pixel circuit, a HSPICE simulator with the LTPS TFT model (RPI=62) is used. Table I shows the designed parameters in this work. For use in FHD AMOLED displays with 240 Hz, the data input time is set to 3.5 μs. The OLED model is simulated by a p-type diode-connection TFT with a parallel capacitor. Fig. 2(a) and Fig. 2(b) show the transient waveforms of the node B and node F with the V_{TH} variation of the driving TFTs of ± 0.5 V, demonstrating that the detected voltage difference in the compensation period is almost the same as the V_{TH} variation of ± 0.5 V. Fig. 3 plots the simulated I_{OLED} and V_D when the V_{TH} varies ± 0.5 V when the data voltage is set -0.8 V to simulate the high gray level. The highest voltage difference of the node D and ELVSS in the programming period is only 3 V, which is less than V_{OLED_0} (4 V), so all of OLEDs are shut down to avoid any current flowing through OLEDs, verifying that the proposed pixel circuit can eliminate the flicker phenomenon. Fig. 4(a) presents the OLED current during the emission period over the entire data voltage range of -0.8 V to 0 V, illustrating that the uniform currents of OLEDs are generated. Fig. 4(b) shows the relative current error rates under different data voltages with

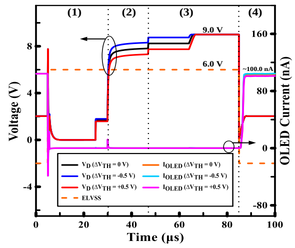

Fig. 3. Transient waveforms of I_{OLED} and V_D with ±0.5 V V_{TH} variation.

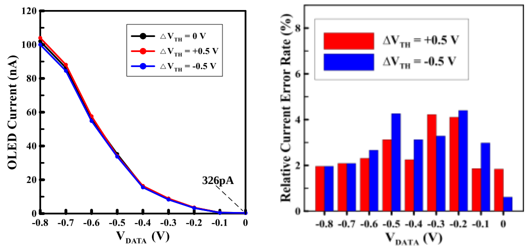

Fig. 4. (a) OLED currents versus data voltages and its (b) relative current error rates as V_{TH} varies ±0.5 V

± 0.5 V V_{TH} variation. According to the simulated results, all of the error rates are below 4.4%, proving that the OLED current is independent on the V_{TH} of the driving TFTs. Consequently, the proposed pixel circuit is highly effective for use in high-definition resolution AMOLED displays.

4. Conclusions

This work proposes a simple pixel circuit that is composed of seven LTPS TFTs and four capacitors especially for high-definition resolution AMOLED displays. By the changeable power line and simultaneous emission method, the new design compensates for the V_{TH} variation of TFTs and eliminates the flicker phenomenon. Simulation results verify that the proposed circuit can generate the uniform current flowing through OLEDs.

Acknowledgements

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