Pixel Circuit with High Immunity to the Degradation of TFTs and OLED for AMOLED Displays

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Abstract

A simple voltage compensation pixel circuit for AMOLED is produced using low temperature poly-crystalline silicon (LTPS) technology. Its operation is verified by AIM-SPICE. Simulation results show that the pixel circuit has high immunity to variation of LTPS-TFT and reduces the drop in luminance due to the degradation of the OLED.

1. Introduction

Low temperature polycrystalline silicon thin-film transistors (LTPS-TFTs) have attracted much attention for their use in active-matrix organic light-emitting diode (AMOLED) displays because of their high current driving capability [1]-[5]. However, the threshold voltage (V_{TH}) variation of LTPS-TFT is a critical issue due to the variation of electrical characteristics in the fabricated process, which result in non-uniformity of the brightness of the display panel [1]-[6]. The OLED current is determined by V_{GS} of the n-type driving TFT and the OLED is arranged at the source end of the driving TFT. The OLED degradation, which involves gradual decay of luminance and efficiency, may reduce the image quality of the display panel during the aging process [1], [2], [6]-[8]. Therefore, Lu *et al.* presented a new pixel circuit with five TFTs and one capacitor to diminish the current variations via the aging process, as shown in Fig. 1 [1]. The presented circuit can compensate for the variation of the TFTs and ameliorate the effect of OLED degradation. Nevertheless, it uses an excess of components in the pixel, reducing the aperture ratio of the display panel [2], [5]. Thus, this work successfully reduces the components of the pixel circuit and simultaneously maintains the OLED current stability regardless of the variations of TFTs and OLED devices.

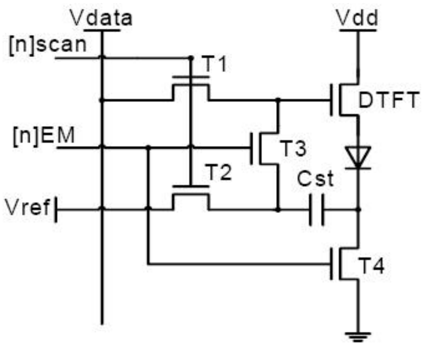

Fig. 1. Pixel circuit described by Lu *et al.* in SID07.

In this study, a simple voltage driving scheme is presented and the aperture ratio is increased. Additionally, this work can effectively compensate for the V_{TH} variations of TFT and ameliorate the luminance drop due to the OLED degradation as long time operation. Simulation result shows the proposed pixel circuit can effectively maintain brightness uniformity among pixels.

2. Pixel structure and timing diagram

To maintain the OLED current stability, this study provides a simple compensating pixel circuit shown in Fig. 2(a) and the timing diagram is shown in Fig. 2(b). The proposed pixel circuit consists of one driving TFT (T1), two switch transistors (T2 and T3), two capacitors (C1 and C2), and an additional control signal. T1 is employed to determine the OLED current. Each C1 and C2 is a storage capacitor and area consumption is approximate the capacitor of the conventional 2-TFT pixel circuit. The operation of the proposed circuit is as follows.

1) Compensation Period: During the first period, V_{SCAN1} is set at the high voltage and V_{SCAN2} goes to low voltage. T2 is turned on and T3 is

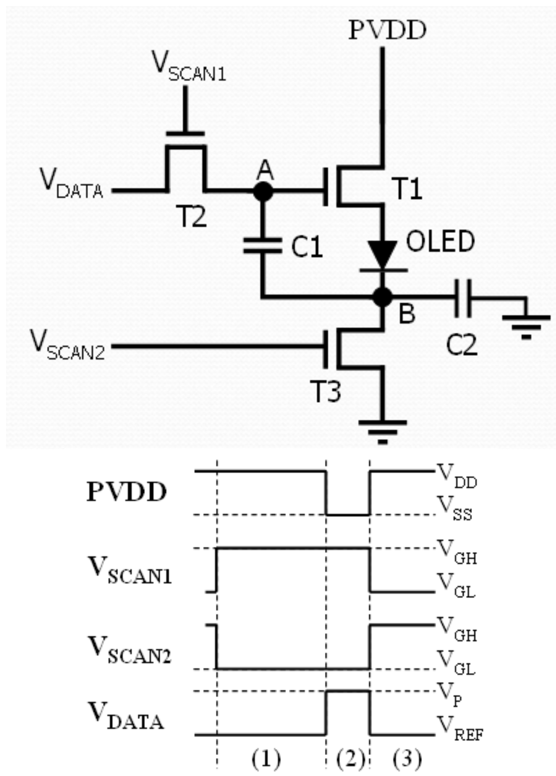

Fig. 2 The proposed pixel circuit design and the timing scheme of the signal line. (1) Compensation period (2) Programming period (3) Emission period.

turned off. The V_{DATA} supplies a reference voltage (V_{REF}) to node A (V_A) through T2 and node B (V_B) should be charged to V_{REF}-V_{TH_T1}-V_{OLED} until T1 is turned off.

2) Programming Period: V_{SCAN1} and V_{SCAN2} still retain the same voltage at this period. The supply voltage (PVDD) is changed form V_{DD} to V_{SS}. It is employed to ensure that T1 is turned off and avoid the voltage stored in C2 leaking through T1. Simultaneously, the data voltage is applied to node A. For the charge conservation, the voltage of node A and B is

$$\begin{aligned} V_A &= V_P = V_{REF} + V_{DATA} \\ V_B &= V_{REF} - V_{TH\_T1} - V_{OLED} \quad (1) \\ &+ \frac{C1}{C1+C2}(V_P - V_{REF}) \end{aligned}$$

3) Emission Period: V_{SCAN1} goes to low voltage and turns off T1. V_{SCAN2} is changed to high voltage and T3 is turned on. V_B is changed to ground and V_A should be boosted to (2), described as follows.

$$\begin{aligned} V_A &= V_P - V_{REF} + V_{TH\_T1} \\ &+ V_{OLED} - \frac{C1}{C1+C2}(V_P - V_{REF}) \quad (2) \\ &= V_{TH\_T1} + V_{OLED} + \frac{C2}{C1+C2}V_{DATA} \end{aligned}$$

Therefore, the OLED current, determined by the gate-source voltage of T1, becomes as follows.

$$\begin{aligned} I_{OLED} &= \frac{1}{2}k(V_{GS\_T1} - V_{TH\_T1})^2 \\ &= \frac{1}{2}k(V_{TH\_T1} + V_{OLED} + \frac{C2}{C1+C2}V_{DATA} \\ &\quad - V_{OLED} - V_{TH\_T1})^2 \quad (3) \\ &= \frac{1}{2}k(\frac{C2}{C1+C2}V_{DATA})^2 \\ &\quad where\ k\ is\ \mu \cdot C_{OX} \cdot W_{T1} / L_{T1} \end{aligned}$$

According to (3), the OLED current is independent of V_{TH_T1} and V_{OLED} and is only depended on V_{DATA} and the factor (C2/C1+C2). Consequently, the proposed pixel circuit successfully ameliorates the aperture ratio and maintains the brightness uniformity among pixels. The capacitors (C1, C2) are employed to extend the input data range and improve the brightness resolution of display panel [3].

3. Simulation results

To demonstrate the effectiveness of the proposed pixel circuit, this work is verified by using Automatic Integrated Circuit Modeling Spice. The aspect ratio and threshold voltage of driving TFT are 3μm /12μm and 1.888V. C1 and C2 are 0.3pf and 0.2pf. The voltage of V_{DD}, V_{REF}, and V_{SS} is set as 15V, 6V, and 0V, respectively. The control signals range between 20V and -20V. To validate the functionality of the proposed pixel circuit in the worst case, the threshold voltage of TFT is set as ±0.33V.

Fig. 3 compares the I_{OLED} of the conventional 2T1C pixel circuit with that of the proposed pixel circuit. When the normalized input voltage range is from 8V to 15V and the V_{TH} variations of driving TFT set as ΔV_{TH} = -0.33V, 0V, +0.33V, the OLED current of the proposed pixel circuit is more uniform than that of the conventional 2T1C pixel circuit. Therefore, the I_{OLED} is nearly independent of the V_{TH} variations of TFTs.

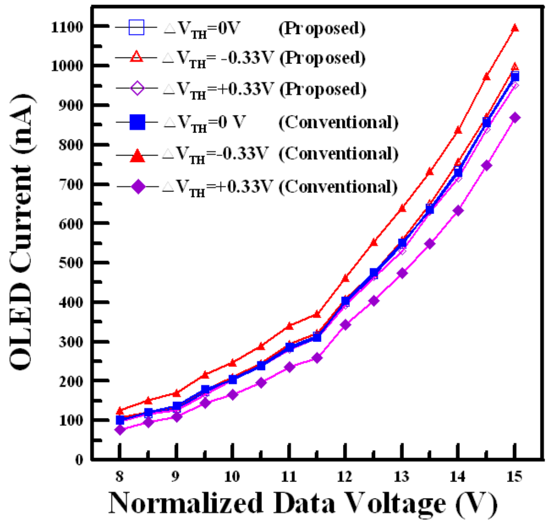

Fig. 3. Comparison of the proposed and the conventional pixel circuit for OLED current with ±0.33V threshold voltage shift.

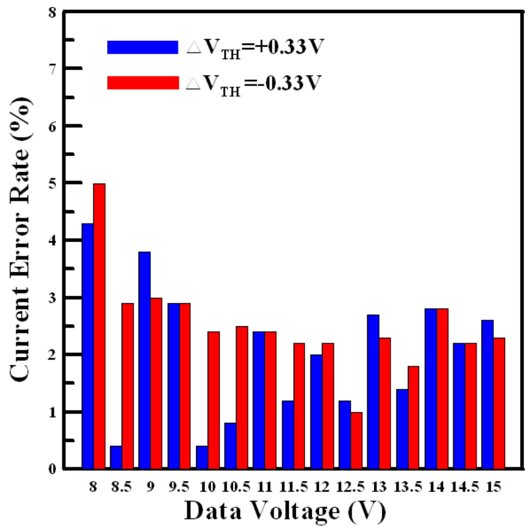

Fig. 4. The current error rate of the proposed pixel circuit with ±0.33V V_{TH} variations.

Based on the simulation results shown in Fig. 3, the current error rate, defined as the different current between the varied output current and the initial OLED current divided by the initial OLED current, is demonstrated in Fig. 4. It is apparently that the current error rate is less than 5% throughout the input data range. Therefore, the proposed pixel circuit can effectively maintain brightness uniformity and keep the OLED current stable in the same gray level.

Fig. 5 shows the OLED current error rate as the threshold voltage shift of the OLED (ΔV_{OLED}) is varied from 0.1V to 0.5V. When ΔV_{OLED} equals to 0.5V, the error rate in the conventional pixel circuit is more than 10% and that in the proposed circuit is less

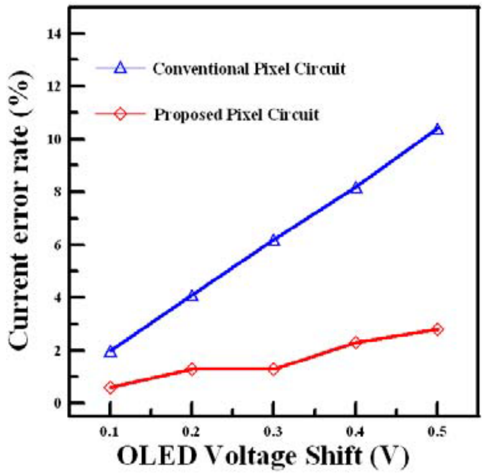

Fig. 5. Current error rate as the V_{OLED} shift

than 3%. Thus, this work retains the output current and suppresses the effect of OLED degradation. Furthermore, this novel circuit improves the luminance drop with long-term operation.

4. Conclusion

A simple compensating pixel circuit for AMOLED is developed. The proposed pixel circuit with fewer components in the pixel for LTPS technology successfully improves the aperture ratio and maintains the OLED current stability. This work can effectively compensate for the threshold voltage variation of TFT and reduce luminance drop of display panel as long term operation. Additionally, the factor of the equivalent capacitors can increase the input data range and the resolution of the display can be extended. Simulation results demonstrate that the proposed pixel circuit has high immunity to the V_{TH} variations of TFT and the OLED degradation.

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