PS-10-13

Extended Abstracts of the 2019 International Conference on Solid State Devices and Materials, Nagoya, 2019, pp989-990

Suppressing Electrical Characteristic Variations in LTPS TFTs with External Compensation Method to Generate Uniform Driving Currents for High Resolution AMOLED Displays

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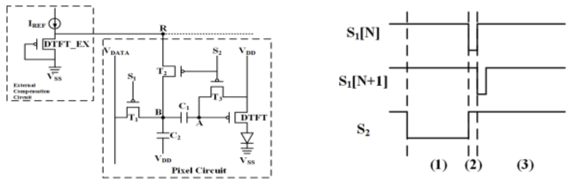
Abstract

This work presents a pixel circuit based on p-type low-temperature polycrystalline silicon thin-film transistors (LTPS TFTs) with an external compensation method. The threshold voltage (V_{TH}) variations of LTPS TFTs are compensated by an external compensation circuit with a current-bias method for generating highly uniform OLED driving currents. The proposed pixel circuit also compensates for supply voltage (V_{DD}) drops. Notably, the compensation time of the proposed circuit is not limited by the scan time of each row, which makes the proposed pixel circuit is suitable for high resolution AMOLED displays. Simulation results demonstrate that the relative current error rates of OLED driving currents are below 4% and 4.8% when the V_{TH} varies by ±0.5 V and V_{DD} drops by 0.5 V, respectively.

1. Introduction

Low-temperature polycrystalline silicon thin-film transistors (LTPS TFTs) are commonly utilized to compose the pixel circuits for active-matrix organic light-emitting diode (AMOLED) displays because of their high mobility and excellent driving capability [1]-[5]. However, the variations of manufacturing process cause the non-uniform electrical characteristics of LTPS TFTs, such as the variations of mobility and threshold voltage (V_{TH}). Although the fabrication process becomes mature in recent years to increase the uniformity of the V_{TH} of LTPS TFT in the same row, there still are V_{TH} variations between different rows, leading to the non-uniformity of OLED driving currents. To compensate for V_{TH} variations, the current-programming (CP) and voltage-programming (VP) methods are proposed [1]-[3]. The CP method compensates for V_{TH} variations accurately, but it needs a longer compensation time especially at low gray level due to a low data current. In contract, the VP method provides a more accurate compensation at low gray level. However, the pixel circuit with a VP method has complicated structure and control signals. Therefore, Wang *et al.* proposed a simple pixel circuit with current-biased voltage-programming (CBVP) to achieve fast and accurate compensation [3]. However, Wang's pixel circuit needs to finish the compensation operation for V_{TH} variation within scan time (T_{SCAN}), so its compensation time is limited by T_{SCAN}. As the resolution of AMOLED displays becomes higher, the T_{SCAN} of each row becomes shorter, causing that the pixel circuit may not complete the accurate compensation for V_{TH} variations within the shrunk T_{SCAN}.



(a) (b)

Fig. 1. (a)Schematic proposed pixel circuit and external compensation circuit (b) timing diagram of proposed pixel circuit.

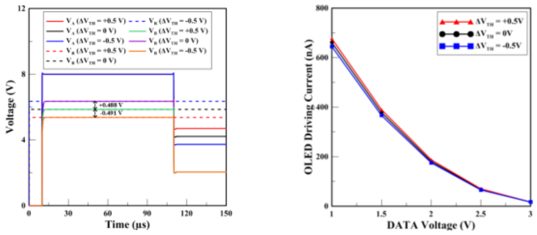
This work proposes a 4T2C pixel circuit with an external compensation method to compensate for V_{TH} variations and supply voltage (V_{DD}) drops to generate uniform OLED driving currents. The proposed external compensation circuit utilizes a current-bias method for detecting the V_{TH} of driving TFT accurately. Moreover, the compensation of V_{TH} variation is performed by an external compensation circuit, which makes the compensation time is not limited by T_{SCAN}. Therefore, the proposed pixel circuit is suitable for high resolution AMOLED displays. Simulation results illustrate that the relative current error rates of OLED driving currents are below 4% as the V_{TH} variations are ±0.5 V and below 4.8% as V_{DD} drops by 0.5 V.

2. Circuit Schematic and Operation

Fig. 1(a) shows the schematic of the proposed pixel circuit and the external compensation circuit, and Fig. 1(b) shows the corresponding timing diagram. The proposed pixel circuit is composed of one driving TFT (T_{DTFT}), three switching TFTs (T_1, T_2 and T_3), and two capacitors (C_1 and C_2), and the external compensation circuit only uses a driving TFT (T_{DTFT_EX}) connected in series with a reference current (I_{REF}). In this work, because of the developed mature fabrication process technology of LTPS TFTs, the electrical characteristics of T_{DTFT} can be assumed the same as that of T_{DTFT_EX} in the same row.

The operation of the proposed pixel circuit can be divided into three periods – compensation period, data input period, and emission period. At first, the external compensation circuit applies a reference current flowing through T_{DTFT_EX}, and the voltage of node R (V_R) can be expressed as,

$$I_{REF} = \frac{k}{2}(V_R - V_{SS} - |V_{TH\_DTFT\_EX}|)^2$$
$$\Rightarrow V_R = \sqrt{\frac{2I_{REF}}{k}} + V_{SS} + |V_{TH\_DTFT\_EX}| \quad (1)$$



(a) (b)

Fig. 2. (a) Transient waveforms of V_A, V_B and V_R with V_{TH} variation of ±0.5 V. (b) OLED driving currents versus data voltages with V_{TH} variation of ±0.5 V.

where k is $\mu \cdot C_{OX} \cdot W/L$, and $V_{TH\_DTFT\_EX}$ is the V_{TH} of T_{DTFT_EX}.

During the compensation period, S1 is high to turn off T_1, and S2 is low to turn on T_2 and T_3. The node A (V_A) is charged to V_{DD} by T3 to turn off T_{DTFT}, preventing a current flowing through OLED. The node B (V_B) is reset to V_R through T2.

During the data input period, the S1 goes low to turn on T_1, and S2 goes high to turn off T_2 and T_3. Then, the data voltage is applied to V_B, and V_A is coupled to a low voltage,

$$V_A = V_{DD} + \left(V_{DATA} - \sqrt{\frac{2I_{REF}}{k}} - V_{SS} - \left| V_{TH\_DTFT\_EX} \right| \right) \quad (2)$$

Finally, during the emission period, S_1 and S_2 are high to turn off T_1, T_2 and T_3. The OLED driving current (I_{OLED}) generated by driving TFT can be written as,

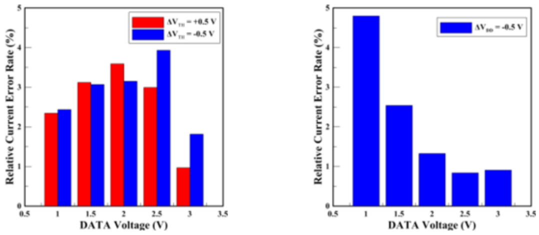
$$I_{OLED} = \frac{k}{2}(V_{SG} - |V_{TH\_DTFT}|)^2$$
$$= \frac{k}{2}(V_{DD} - V_A - |V_{TH\_DTFT}|)^2$$
$$= \frac{k}{2}\{V_{DD} - \left[V_{DD} + V_{DATA} - \sqrt{\frac{2I_{REF}}{k}} - V_{SS} - |V_{TH\_DTFT\_EX}| \right] - |V_{TH\_DTFT}|\}^2$$
$$= \frac{k}{2}\left(\sqrt{\frac{2I_{REF}}{k}} + V_{SS} - V_{DATA} \right)^2 \quad (3)$$

where $V_{TH\_DTFT\_EX}$ is assumed to be the same as V_{TH_DTFT}.

According to Eq. (3), the V_{TH_DTFT} and V_{DD} are eliminated, verifying the proposed circuit can compensate for the V_{TH} variation and the V_{DD} drop for uniform OLED currents.

3. Results and Discussion

This work adopts HSPICE to conduct the simulations of the proposed pixel circuit for confirming its feasibility. The aspect ratios of T_{DTFT} and T_{DTFT_EX} both are 3 µm/15 µm, and that of T_1, T_2, and T_3 are 3 µm/3 µm. The capacitances of C_1 and C_2 both are 0.3 pF. The voltage swings of S_1 and S2 are from -10 V to 10 V, and data voltage is from 1 V to 3 V. V_{DD}, V_{SS}, and I_{REF} are set to 8 V, -1 V, and 3.5 µA, respectively. For the use in high resolution AMOLED displays, the data input time is set to 1.5 µs. Fig. 2(a) plots the transient waveforms of V_A, V_B, and V_R with the V_{TH} variation of ±0.5 V as the data voltage is 2 V. According to the transient waveforms of V_R, the external compensation circuit successfully detects the V_{TH} variations, and the detected V_{TH} variations are +0.488 V and -0.491 V, which are close to the V_{TH} variations of ±0.5 V, verifying the compensation ability of the proposed pixel circuit. Fig. 2(b) demonstrates the I_{OLED} versus entire data voltage as the V_{TH} varies by ± 0.5 V.



(a) (b)

Fig. 3. Relative current error rates of proposed pixel circuit with (a) V_{TH} variations of ±0.5 V (b) V_{DD} drop of 0.5V

As shown in Fig. 2(b), the I_{OLED} at every gray level is nearly the same, revealing that the proposed pixel circuit generates high uniform I_{OLED}. Fig. 3(a) shows the relative current error rates as V_{TH} varies by ± 0.5 V for verifying the uniformity of generated I_{OLED}, and the relative current error rates are suppressed lower than 4%. Moreover, Fig. 3(b) also shows the relative current error rates of I_{OLED} are below 4.8% when V_{DD} drops by 0.5 V, verifying the V_{DD} compensation ability of the proposed pixel circuit. According to simulation results, the compensation ability and the high uniformity of the I_{OLED} of the proposed pixel circuit are verified.

4. Conclusions

This work proposes a 4T2C pixel circuit with an external compensation method based on p-type LTPS TFTs to compensate for the V_{TH} variations in LTPS TFTs and V_{DD} drop. The proposed pixel circuit uses the external compensation structure with a current-bias method to detect V_{TH} precisely and prevent the compensation time from the limitation of T_{SCAN}. Simulation results reveal that the relative current error rates are lower than 4% and 4.8% as V_{TH} varies by ±0.5 V and V_{DD} drops by 0.5 V. Therefore, the proposed pixel circuit can generate uniform OLED driving currents for high resolution AMOLED displays.

Acknowledgements

The work was supported by the projects from the Ministry of Science and Technology (MOST 107-2221-E-006-188-MY3) of Taiwan, as well as AU Optronics Corporation is appreciated for its technical and funding support.

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