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Novel Pixel Circuit with External Compensation Scheme to Compensate for V_{TH} Variations in LTPS TFTs for High-Resolution AMOLED Displays

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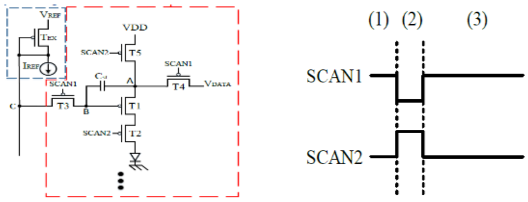
Abstract

This work proposes a novel pixel circuit using external compensation structure to compensate for threshold voltage (V_{TH}) variations and V_{DD} I-R drop. The proposed internal circuit is simplified and the accurate compensation is achieved by the proposed external compensation circuit. The simulation results show that the relative current error rates are suppressed below 4.3% when the V_{TH} of driving TFTs and V_{DD} I-R drops varies by ±0.5 V and 0.5 V, respectively. Therefore, the proposed circuit is highly promising for use in high-resolution AMOLED displays.

1. Introduction

As the demand for higher image quality and better visual experience increases, high-resolution active-matrix organic light-emitting diode (AMOLED) displays have become the developed mainstream. To implement the high-resolution AMOLED displays, the pixel circuits with high-speed operation are required. Low-temperature polycrystalline silicon thin-film transistors (LTPS TFTs) are highly recommended since they have high mobility and outstanding driving capability. However, their electrical characteristic variations, such as threshold voltage (V_{TH}) and mobility caused by the fluctuation of excimer laser annealing (ELA) in process, lead to the non-uniform OLED currents. Many groups proposed pixel circuits with current-programmed or voltage-programmed methods to compensate for the non-uniformity [1]-[3]. The current-programmed method can compensate for the threshold voltage (V_{TH}) precisely. Nevertheless, the driving current is small at a low gray level, so it needs longer programming time to sense $V_{TH.}$ In contrast, the voltage-programmed method provides a faster compensation than the current-programmed method especially at a low gray level. However, the structures of the pixel circuits with the voltage-programmed method are more complicated, causing that they are difficult for use in high-resolution AMOLED displays. To simplify the pixel circuit for a high aperture ratio, external compensation structure is needed[4],[5]. Moreover, using the external compensation structure can perform the compensating operation in the off line so the compensation time is not restricted by the scan time of each row. Although the V_{TH} variations of LTPS TFTs have been improved, the current-resistance voltage drop (I-R drop) in the power line is a critical issue for the uniform OLED currents.

This work presents a novel 5T1C pixel circuit with an external compensation scheme to compensate for V_{TH} variations in LTPS TFTs and V_{DD} I-R drop. By the external compensation structure, the proposed internal pixel circuit is simple for high aperture ratio and the compensation time is not limited by the scan time for the accurate compensation performance. Simulation results show that the relative current error rates are all below 4.3 % as the V_{TH} of driving TFTs varies by ±0.5 V and V_{DD} I-R drops by 0.5 V.



(a) (b)

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

2. Circuit Schematic and Operation

Fig. 1 shows the schematic of the proposed pixel circuit based on LTPS TFTs and its corresponding timing diagram. The proposed circuit can be divided into two parts - external compensating circuit and internal pixel circuit. The circuit operation can be divided into three stages - compensation, data input, and emission, as follows.

(1) Compensation stage: SCAN1 is high to turn off T3 and T4. SCAN2 is low to turn on T2 and T5. By a reference current (I_{REF})flowing through the diode-connection of T_{EX}, the voltage of node C can be derived as:

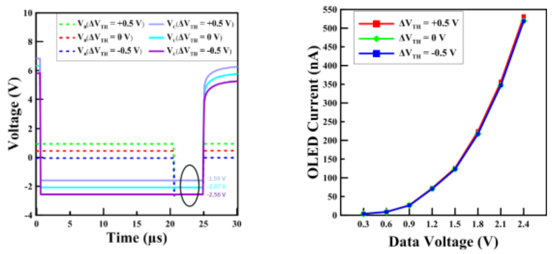
$$I_{REF} = \frac{1}{2}k_{T_{EX}}(V_{SG}-|V_{TH\_T_{EX}}|)^2 = \frac{1}{2}k_{T_{EX}}\left(V_{REF}-V_C-|V_{TH\_T_{EX}}|\right)^2 \quad (1)$$

$$V_C = -\sqrt{\frac{2I_{REF}}{k_{T_{EX}}}}+V_{REF}-|V_{TH\_T_{EX}}|$$

where $k_{T_{EX}}$ is $\mu_{T_{EX}} \cdot C_{OX\_T_{EX}} \cdot \left(\frac{W}{L}\right)_{T_{EX}}$.

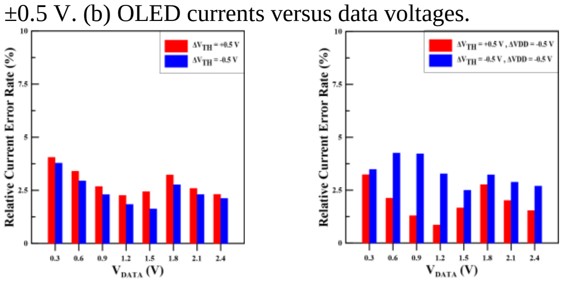
(2) Data input stage: SCAN1 becomes low to turn on T3 and T4, and SCAN2 goes high to turn off T2 and T5. Therefore, V_C is applied to node B and the data voltage is applied to node A. Moreover, since T2 is in the off state, there is no large current flowing through OLED, preventing flicker phenomenon to increase the contrast ratio of AMOLED displays.

(3) Emission stage: SCAN1 goes high to turn off T3 and T4, enabling the node B to be a floating point. SCAN2 changes low to turn on T2 and T5. Hence, the node A is charged to V_{DD}, and the node B is coupled to V_B, as follows:



(a) (b)

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



(a) (b)

Fig. 3.(a) Relative current error rates as V_{TH} varies ±0.5 V(b) relative current error rates as V_{TH} varies ±0.5 V and ΔV_{DD}=-0.5 V

$$V_B = -\sqrt{\frac{2I_{REF}}{k_{TEX}}}+V_{REF}-|V_{TH\_TEX}|+V_{DD}-V_{DATA} \quad (2)$$

Hence, the OLED emission current (I_{OLED}) flowing through T1 can be derived as:

$$\begin{aligned} I_{OLED} &= \frac{1}{2}k_{T1}\left(V_{SG_{T1}}-|V_{TH\_T1}|\right)^2 \\ &= \frac{1}{2}k_{T1}(V_{DD}+\sqrt{\frac{2I_{REF}}{k_{TEX}}}-V_{REF}+|V_{TH\_TEX}| \\ &\quad - V_{DD}+V_{DATA}-|V_{TH\_T1}|)^2 \\ &= \frac{1}{2}k_{T1}(V_{DATA}+\sqrt{\frac{2I_{REF}}{k_{TEX}}}-V_{REF})^2 \end{aligned} \quad (3)$$

where k_{T1} is $\mu_{T1}\cdot C_{OX\_T1}\cdot\left(\frac{W}{L}\right)_{T1}$.

Notably, because of the aforementioned feature of ELA process, the electrical characteristics of T_{EX} and T1 are supposed to be the same. Consequently, the $|V_{TH\_TEX}|$ and $|V_{TH\_T1}|$ can be cancelled in Eq. (3). According to Eq. (3), I_{OLED} is independent of V_{TH} and V_{DD}. Therefore, the proposed circuit can compensate the variations of V_{TH} and V_{DD} drop.

3. Results and Discussion

This work conducted the simulation with HSPICE software to confirm the feasibility of the proposed pixel circuit. The simulation parameters of the proposed circuit are shown in Table I. Notably, due to the mature LTPS process, the electrical characteristic of the driving TFTs in the external circuit (T_{EX}) can be assumed the same as that in pixel circuits (T1). Fig. 2(a) shows the transient waveforms of V_B and Vc as V_{TH} varies by ±0.5 V. The transient waveforms of Vc illustrate that the proposed circuit senses the variations of 0.48 V and 0.49 V, which are close to the real V_{TH} variations when V_{TH} variations are +0.5 V and -0.5 V, respectively. Fig.2 (b) depicts the OLED currents versus each gray level with different data voltages. Although the threshold voltages of LTPS TFTs vary, the uniform OLED currents can be still generated, verifying that the proposed pixel circuit successfully compensates

Table I
PARAMETER OF PROPOSED AMOLED PIXEL CIRCUIT

Parameter	Value	Parameter	Value
V_{DD}(V)	5	$(W/L)_{Tex,T1}$ (um)	3/15
V_{SS}(V)	-4	$(W/L)_{T2,T3,T4,T5}$(um)	3/3
V_{REF}(V)	7.5	$(W/L)_{TOLED}$(um)	5/18
SCAN(V)	-7~7	C_{st},C_{OLED}(pF)	0.3/0.2
ΔV_{TH}(V)	0.5	I_{REF}(mA)	0.01

for the V_{TH} variations of LTPS TFTs. Fig. 3 (a) shows the relative current error rates of OLED emission among the entire data range with the V_{TH} variations of the driving TFT. Based on the simulated results, the error rates are all below 4.1% when the variations of V_{TH} are +0.5 V and -0.5 V, proving that the OLED currents of the proposed pixel circuit have high immunity to V_{TH} variations. To further confirm the feasibility of the pixel circuit, Fig. 3 (b) plots the relative current error rates when the V_{DD} I-R drop is 0.5 V and the V_{TH} variations are ±0.5 V. The simulated results show that the error rates are all below 4.3%, indicating that the proposed circuit has the capability to compensate for the V_{DD} I-R drop and V_{TH} variations of LTPS TFTs for uniform OLED currents. According to the aforementioned simulation results, the proposed circuit can precisely compensate for V_{TH} variations and V_{DD} I-R drop. Therefore, the proposed pixel circuit is suitable for use in high-resolution AMOLED displays.

4. Conclusions

This work proposed a new pixel circuit composed of five TFTs and one capacitor with the external compensation method for high-resolution AMOLED displays. Through the external compensation method, the compensation time is not limited by the scan time of each row. Moreover, the proposed circuit compensates for the threshold voltage variations of LTPS TFTs and VDD I-R drop. The simulation results demonstrate that the relative current error rates are all below 4.3% when the variations of V_{TH} are ±0.5 V and the V_{DD} I-R drop is 0.5 V. Therefore, the proposed pixel circuit is favorable for use in high-resolution AMOLED displays.

Acknowledgements

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References

[1] N. Komiya, et al., "Comparison of Vth compensation ability among voltage programming circuits for AMOLED panels." IDW'03 Tech. Dig (2003): 257-278.

[2] J. P. Lee, et al., "Threshold Voltage and IR Drop Compensation of an AMOLED Pixel Circuit Without a V_{DD} Line." IEEE Electron Device Letters 35.1 (2014): 72-74.

[3] J. H. Lee, et al., "A new poly-Si TFT current-mirror pixel for active matrix organic light emitting diode." IEEE Electron Device Letters 27.10 (2006): 830-833.

[4] H. J. In, et al., "External compensation of nonuniform electrical characteristics of thin-film transistors and degradation of OLED devices in AMOLED displays." IEEE Electron Device Letters 30.4 (2009): 377-379.

[5] H. J. In, et al., "An advanced external compensation system for active matrix organic light-emitting diode displays with poly-Si thin-film transistor backplane." IEEE Transactions on Electron Devices 57.11 (2010): 3012-3019.