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A Novel LTPS-TFT Pixel Circuit Compensating for TFT Threshold-Voltage Shift and OLED Degradation for AMOLED

Chih-Lung Lin

Department of Electrical Engineering, National Cheng Kung University

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Active-matrix organic light-emitting diodes (AMOLED) have been extensively studied owing to their promising features such as thin thickness, self-emission, lower driving voltage, a wide viewing angle, fast response time, high efficiency, high brightness, and flexible characteristics. Two programming methods exist- the passive matrix (PM) and active matrix (AM) driving methods (Fig. 1). The PM driving method has some benefits, such as a simple structure and low cost. However, the PM method cannot emit light continuously and power consumption is markedly higher than that of the AM method when applied to large displays.

The difference between PMOLEDs and AMOLEDs is that the pixel in an AMOLED includes a capacitor for storing data and emitting light continuously. Therefore,AMOLED is applicable to large-high-resolution displays and highly promising for future flexible displays. However, the structure of AMOLEDs is more complex than that of PMOLEDs. Additionally, the following factors affect the brightness uniformity in AMOLED.

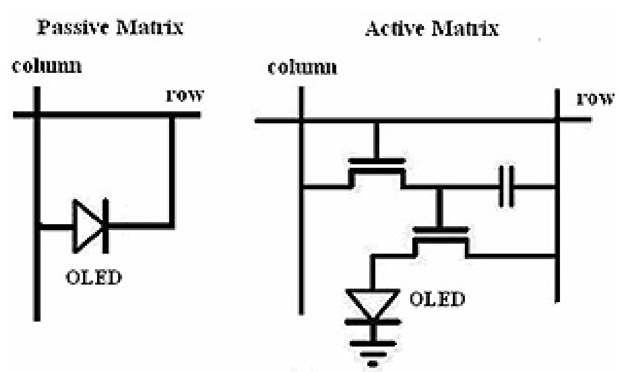


Fig 1. Schematic of PMOLED(PM) and AMOLED (AM)

(1) Threshold voltage variations:

The OLED current is determined by the driving thin-film transistor (TFT), operated in the saturated region. Therefore, VTH variations are due to process differences and long-term operational result for OLED brightness non-uniformity. The OLED current formula is

$$I_{OLED} = \frac{1}{2}k(V_{GS} - V_{TH})^2 \qquad (1)$$

where VTH represents the threshold voltage of a driving TFT.

(2)OLED degradation and brightness efficiency:

The anode potential of OLEDs must be considered as OLED threshold voltage degrades at 0.2 mV/h during operation. In most OLED pixel circuits, the source node of an n-type drive TFT connects to the OLED anode. Therefore, an n-type pixel circuit must accommodate the threshold-voltage degradation of OLEDs as OLED current is determined by VGS of the driving TFT.

(3) Influence of I-R Drop:

Voltage drop problems due to parasitic resistance of a supply power line causes image degradation and crosstalk in AMOLED panels (Fig. 2). This is a priority concern for a large display.

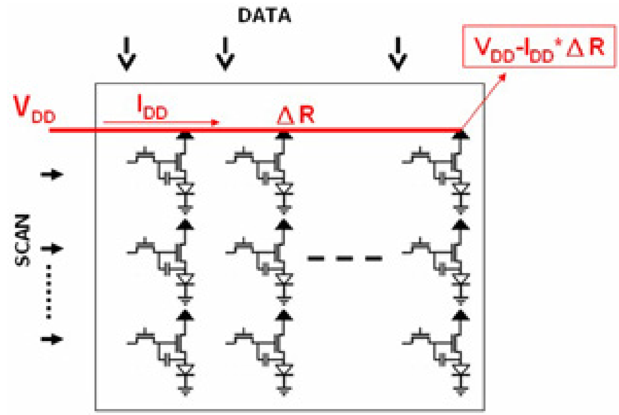


Fig 2. This schematic diagram demonstrates the voltage drop caused by the intrinsic parasitic resistance (R) at the V_{DD} supply power line.

(4) Process consideration:

The AMOLED pixel driver can be fabricated as a low-temperature poly-silicon (LTPS) and amorphous silicon (a-Si). An N-type TFT can be fabricated by LTPS and a-Si processes. However, p-type TFT can only be fabricated using the LTPS process. Furthermore, although including several advantages, low cost, mature manufacturability, and high stability, an a-Si process technology has a serious threshold voltage shift over long-term operation. Table 1 compares LTPS and a-Si processes.

Table 1 Comparison of the LTPS and a-Si processes.

Attribute	a-Si	Poly-Si
Mobility	Low	High
Manufacturability and accessibility	Mature and accessible	New and not yet accessible
V_{TH} uniformity across array	Good	Poor
V_{TH} shift	Poor	Good
Driver integration	Poor	Good

Due to these problems associated with AMOLEDs, numerous mechanisms were developed to maintain display brightness uniformity. However, these studies focused on TFT threshold voltage variation; the effect of OLED degradation on brightness is seldom discussed. To overcome the brightness degradation, some compensating methods have been developed, such as the optical feedback and ac driving methods. However, the disadvantages of optical feedback are a strong wavelength dependence on photo efficiency and sensitivity to ambient light. Additionally, the ac driving method does not account for V_{TH} variations completely. Therefore, this work presents a novel five TFT pixel circuit with a feedback structure that detects OLED aging phenomena and produces additional current to compensate for OLED degradation, thereby preventing luminance drops. Besides, the proposed pixel circuit has a high degree of immunity to the varying threshold voltage of LTPS-TFTs and compensates for variation of the turn-on voltage of the OLED degradation leading to non-uniformity and degradation of pixel luminance over time.

To reduce the non-uniform brightness problem mentioned above, this work proposes a novel circuit comprising of 3 n-type TFTs, 2 p-type TFTs, a storage capacitor, and an additional control signal. Figure 3 schematically depicts the proposed pixel circuit and its control-signal-timing diagram. First, TFT1 determines the OLED current by analyzing the storage capacitor voltage of C1, utilized to store the driving voltage during one frame, and the other TFTs are used for a switching function. The operational scheme and compensation principle of the proposed circuit are described as follows.

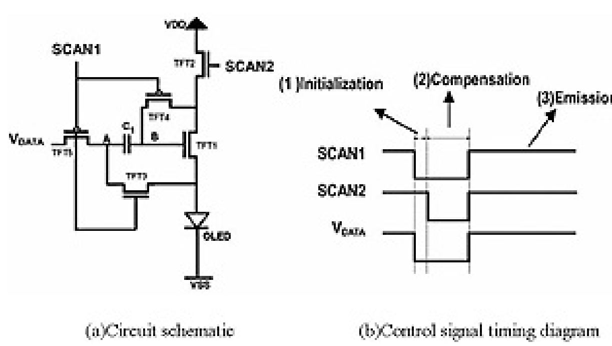


Fig 3. Circuit schematic and control signal timing diagram for the proposed driving method.

(1) Initialization Period: During the first period, SCAN1 goes to low voltage and SCAN2 is high voltage; TFT2, TFT4, and TFT5 are turned on and TFT3 is turned off. The data voltage (V_{DATA}) is applied to node A (VA) through TFT5, and the gate voltage of TFT1 (VB) is charged approaching to V_{DD} through TFT2 and TFT4. The previously stored voltage in C1 is reset to the voltage difference between V_{DATA} and VB, that is, the initialization period.

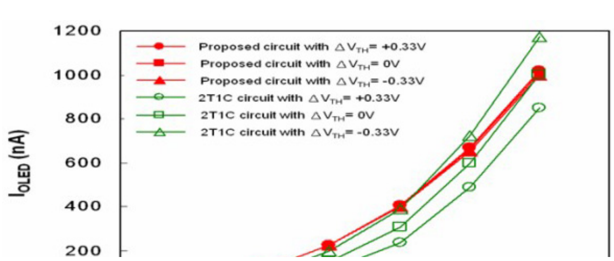
(2) Compensation Period: SCAN2 signal goes to low voltage, turning off TFT2, and TFT3 remains turned off. The VB is discharged through TFT4 and TFT1 until TFT1 is turned off. This node voltage settles to $V_{OLED\_0} + V_{TH\_T1}$, where V_{TH_T1} is the threshold voltage of TFT1, and V_{OLED_0} is the threshold voltage of OLED when no current is flowing through OLED. The storage capacitor (C1) is discharged to $V_{OLED\_0} + V_{TH\_T1} – V_{DATA}$.

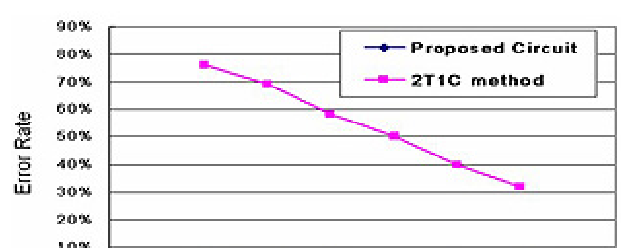
(3) Emission Period: Both TFT2 and TFT3 are turned on; V_{DD} is connected to the drain node of TFT1 through TFT2. Node A is connected to a source node of TFT1, such that VA becomes V_{OLED_1}. The C1 continues to sustain the voltage ($V_{OLED\_0} + V_{TH\_T1} – V_{DATA}$) until the next initialization period; consequently, VB becomes $V_{OLED\_0} + V_{TH\_T1} + V_{OLED\_1} – V_{DATA}$, where V_{OLED_1} is the voltage of OLED when the OLED is emitting light. The corresponding OLED current is determined based on the VGS of TFT1. At this time, the drain–current of TFT1 (I_{OLED}) is given as

$$
\begin{aligned}
I_{OLED} &= \frac{1}{2} \cdot k \cdot (V_{GS} - V_{TH\_TFT1})^2 \\
&= \frac{1}{2} \cdot k \cdot (V_{OLED\_0} + V_{TH\_TFT1} + V_{OLED\_1} \\
&\quad - V_{DATA} - V_{OLED\_1} - V_{TH\_TFT1})^2 \\
&= \frac{1}{2} \cdot k \cdot (V_{OLED\_0} - V_{DATA})^2 \text{..............(1)}
\end{aligned}
$$

Therefore, the drain–current of TFT1 is independent of threshold voltage from (2) and only affected by $V_{OLED\_0} – V_{DATA}$; consequently, the pixel-to-pixel threshold-voltage variation does not change OLED currents. Notably, when the increase in OLED threshold voltage (V_{OLED_0}) was caused by the degradation, the drain–current of TFT1 (I_{OLED}) increased to compensate for the drop in luminance. The proposed pixel circuit is not affected by OLED threshold-voltage degradation.

To confirm the effectiveness of the proposed pixel circuit, the simulation using AIM-SPICE was performed. The simulations represent that the proposed pixel circuit can effectively improve the non-uniformity of OLED displays and compensate for OLED luminance degradation with long time operation. Additionally, the simulation parameters were set to enable the proposed circuit to compensate for the threshold variation of OLED during the predefined anticipation lifetime. A conventional 2T1C pixel circuit was fabricated, and the luminance drop was measured; threshold voltage of the OLED degraded as operating time increased. In this 2T1C pixel circuit, the OLED display area is 2 in with 176 × 220 resolution.





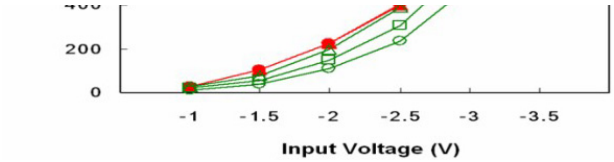


Fig 4. Transfer characteristics of the conventional 2T1C circuit and the proposed pixel circuit with different data voltages and threshold voltage variations ($\Delta V_{TH}=\pm 0.3V$)

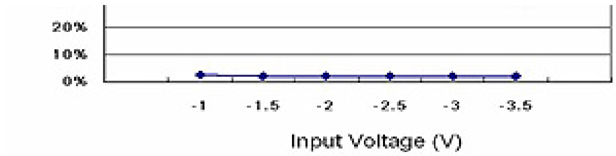
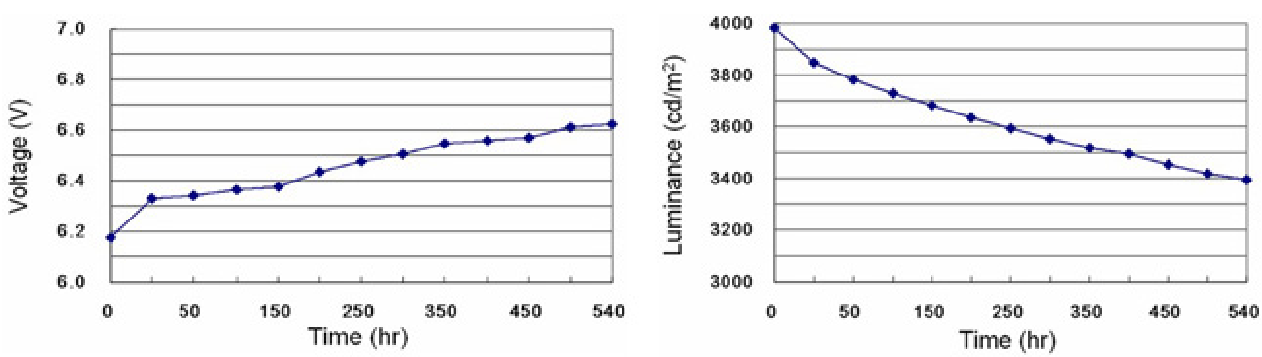


Fig 5. Simulation results show that the non-uniformity of the proposed pixel circuit is significantly lower than that of the conventional pixel circuit.

Fig. 4 shows the transfer characteristics of the proposed pixel circuit and the conventional pixel circuit with threshold-voltage variations for different input data. Obviously, the proposed pixel circuit is nearly independent of the TFT threshold voltage variation (ΔV_{TH} = –0.33, 0, and +0.33 V) for different input data voltage. In other words, the proposed pixel circuit demonstrates the good uniformity of OLED displays against the variant threshold voltage of the driving TFT. Figure 5 shows a comparison of non-uniformity between the proposed pixel circuit and the conventional 2T1C pixel circuit. Non-uniformity is defined as the difference between maximum current and minimum current, divided by average output current. The non-uniformity of the conventional pixel circuit is approximately 32-76% for differently normalized input data voltage, whereas that of the proposed pixel circuit is < 5%. Simulation results show that the proposed pixel circuit can almost completely compensate for threshold voltage variation, and has the same current level and luminance at the same input data voltage.

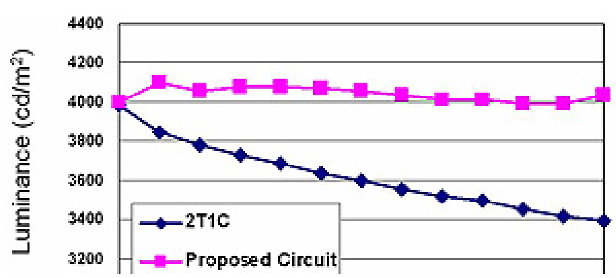


(a) Relationship of the potential across OLED and time. (b) Relationship of OLED brightness and time.

Fig 6. Measurement results for degradation for the conventional 2T1C pixel circuit.

In conventional 2T1C experiments, the driving current was elevated to set the luminance at 4000 cd/m^2, and the current was kept stable for over 540h to investigate the OLED-degradation characteristics. Fig. 6(a) presents the decrease in luminance when the OLED displays for over 540 h with constant driving I_{OLED} in the conventional 2T1C pixel circuit and also shows the increase in OLED threshold voltage based on the experimental measurement at the same time in Fig. 6(b). According to experimental results, the OLED threshold voltage increases from 6.18V to 6.63V, and the luminance of the OLED decreases from 4000 cd/m^2 to 3400 cd/m^2. Thus, the proposed circuit generates sufficient current using a feedback structure to compensate for variation in the turn-on voltage of the OLED degradation. The OLED luminance can be the same as the input data for the proposed pixel circuit.

Compared with experimental results for the conventional 2T1C pixel circuit, simulation results for the proposed pixel circuit help to compensate for the decrease in luminance, as shown in Fig. 7. Initially, the proposed circuit and the 2T1C circuit are both 4000 cd/m^2, and after 540 h, the luminance of the



2T1C circuit is < 3500 cd/m^2, whereas current compensation keeps that of the proposed circuit about the same as the initial value. Therefore, luminance of the proposed pixel circuit can overcome OLED degradation using the proposed feedback method.

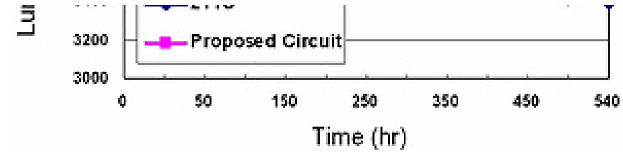


Fig 7. Comparison of simulation results for luminance in the proposed circuit and measurement results for the conventional 2T1C circuit.

The advantages of OLEDs, such as being lightweight and thin with a low power consumption and high response time, are superior to the current mature technology, TFT-LCDs. However, the OLED material deficiencies and process yield increase manufacturing costs. The proposed pixel circuit effectively compensates for the TFT threshold voltage variations, and improves OLED luminance drops using the novel voltage feedback method. The OLED panels of the proposed pixel circuit are fabricated and measured by AU Optronics corporation. Measurement results reveal that this novel method can improve OLED luminance drops over long-term operation. Additionally, this proposed pixel circuit has completed the process for American and Taiwanese patents.