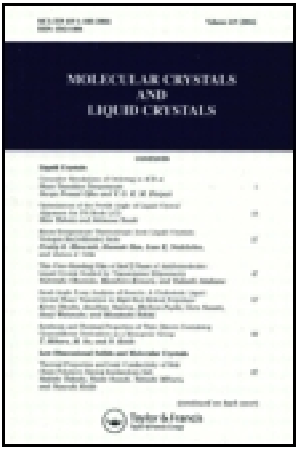

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A Novel Poly-Si TFT Pixel Circuit for AMOLED to Compensate TFT Threshold Voltage Variation

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A new pixel circuit for Active Matrix Organic Light Emitting Diodes (AMOLEDs), based on the polycrystalline silicon thin film transistors (Poly-Si TFTs), was proposed and verified by SMART SPICE simulation. One driving and four switching TFTs and one storage capacitor was used to improve display image uniformity without any additional control signal line. The proposed pixel circuit compensates an inevitable threshold voltage variation of Poly-Si TFTs and compensates for degradation of the OLED.

Keywords: active matrix organic light emitting diodes (AMOLEDs); polycrystalline silicon thin film transistors (Poly-Si TFTs); threshold-voltage variation, and compensation

INTRODUCTION

Organic Light Emitting Diode (OLED) displays are widely researched and investigated nowadays due to various advantages such as fast response time, wide viewing angle, compact, simple structure and light weight [1]. Active Matrix OLED (AMOLED), which employs thin film transistor (TFT) pixels, has been attracted for a low power consumption and high resolution display [2]. AMOLED displays with Polycrystalline TFTs (Poly-Si TFTs) and amorphous silicon TFTs (a-Si TFTs) have been widely researched and developed because of their superior characteristics in flat panel displays [1–3].

Low-temperature polycrystalline silicon TFTs (LTPS TFTs) are widely used for the pixel devices of AMOLEDs because of their high mobility and superior current stability. Although LTPS TFTs have good characteristics, the inevitable non-uniformity of threshold

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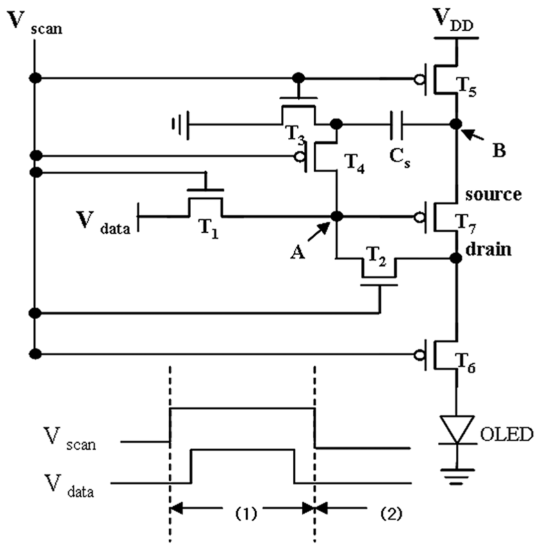
voltages is encountered because of process variations such as uncontrollable gate oxide trap density and grain size variation of Poly-Si. Therefore, various compensation methods have been reported to overcome these problems [1–5].

We have recently reported a pixel circuit for AMOLED based on Poly-Si TFTs as shown in Figure 1(a) [6], where the proposed circuit



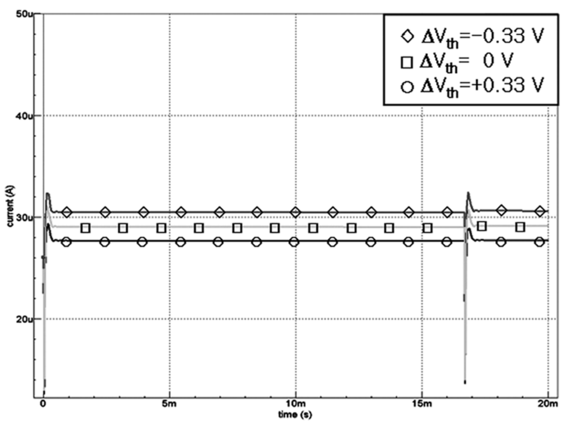


FIGURE 1 The reported pixel circuit for AMOLEDs [6]. (a) Schematic circuit and timing diagram and (b) simulation result of reported circuit with varied threshold voltage of driving TFT ($\Delta Vth = +0.33\,V$, $0\,V$ and $-0.33\,V$).

has showed high immunity to the threshold voltage variation of Poly-Si TFT. In this paper, we suggest more improved pixel circuit using less TFTs than the previously reported pixel circuit. The number of TFT is also an important parameter in OLED pixel circuit due to aperture ratio; it would degrade an efficiency of OLED. We propose a novel pixel circuit that consists of one driving and four switching TFTs and a storage capacitor without any additional signal line. For demonstration of the ability of this circuit, we used SMART SPICE. The simulation results show that the pixel circuit successfully compensates the threshold voltage variation of driving TFT and this pixel circuit has better compensation ability than our recently reported pixel circuit [6].

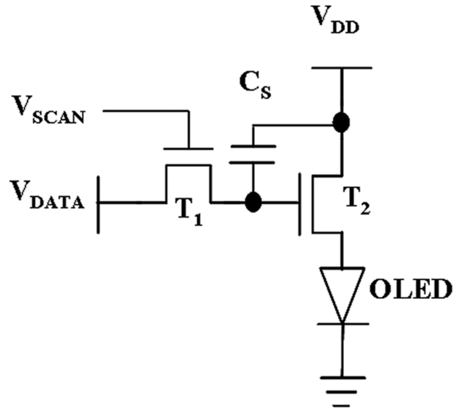
PROPOSED PIXEL CIRCUIT OPERATION

Figure 2(a) shows the conventional pixel circuit schematic. It is composed of two TFTs and one storage capacitor (2Tr1C). Figure 2(b) shows the driving current variation depending on the threshold voltage variation. In this case, the threshold voltage deviation of driving TFT, LTPS TFTs, is assumed to be ± 0.33 V. It is observed that the output current of OLED is highly dependent on the threshold voltage variation and it was more than 35% current variation.

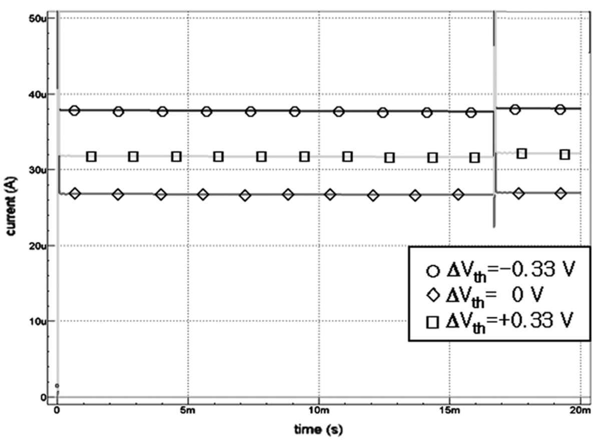
Figure 1(a) shows the reported pixel circuit [6] and the timing diagram. T_1, T_2, T_3, T_4, T_5 and T_6 are switching TFTs and T_7 is a driving TFT. T_2 is a TFT used for diode connection of T_7. T_6 prevents the current flowing to the OLED during period (1). T_7 determines the OLED current, and C_s is a capacitor for storage of data voltage. Other TFTs are used for a switching function. The operation scheme and compensation principle are described as follows. In Period (1), the scan signal is high, T_4, T_5 and T_6 turn off and T_1, T_2 and T_3 turn on, therefore the voltage at node A become V_{data}. Because the gate terminal of T_7 is connected with the drain terminal by T_2, and thus T_2 acts as a diode, V_{sg-T7} is $|V_{th-T7}|$, so the voltage of node B becomes $V_{data} + |V_{th-T7}|$ and stored voltage across the capacitor is $V_{data} + |V_{th-T7}|$. In Period (2), the OLED emits light. T_1, T_2 and T_3 turn off and T_4, T_5 and T_6 turn on. The source voltage of T_7 is charged to V_{DD} and the voltage at node A will jump to VDD-$(V_{data} + |V_{th-T7}|)$. Thus, the current of OLED can be derived as follows:

$$
\begin{aligned}
I_{OLED} &= \frac{1}{2}k(V_{sg-T7} - |V_{th-T7}|)^2 \\
&= \frac{1}{2}k\{V_{DD} - [V_{DD} - (V_{data} + |V_{th-T7}|)] - |V_{th-T7}|\}^2 = \frac{1}{2}k(V_{data})^2
\end{aligned}
$$

Where k is $\mu \cdot C_{ox} \cdot \frac{W}{L}$.



(a)

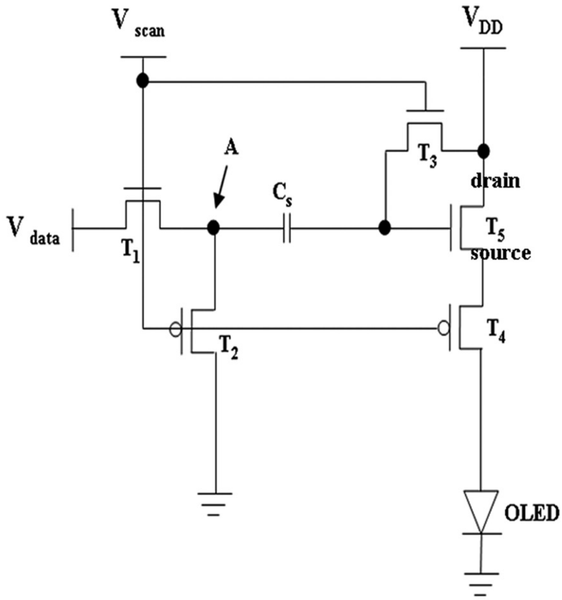


(b)

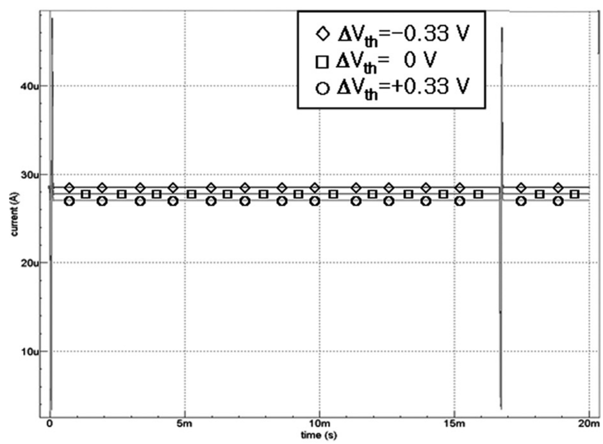
FIGURE 2 The conventional 2Tr1C pixel circuit. (a) Schematic circuit and (b) simulation result of conventional 2Tr1C pixel circuit with varied threshold voltage of driving TFT ($\Delta Vth = +0.33\,V$, $0\,V$ and $-0.33\,V$).

We can find the output current of OLED is not associated with the threshold voltage of driving TFT (T_7).

Figure 3 show the newly proposed pixel circuit. T_1, T_2, T_3 and T_4 are switching TFTs and T_5 is driving TFT. T_3 is a TFT used for diode connection of T_5. T_4 prevents the current flowing to the OLED during period (1). C_s is a capacitor for storing the data voltage. T_5 determines the OLED current. Other TFTs are used for a switching function. Additional signal lines are not required in this pixel circuit. The operation scheme and compensation principle are described as follows.



(a)



(b)

FIGURE 3 The proposed pixel circuit. (a) Schematic circuit and (b) simulation result of the proposed pixel circuit with varied threshold voltage of driving TFT ($\Delta Vth = +0.33\,V$, $0\,V$ and $-0.33\,V$).

Period (1): When scan signal is high, scanning time, T_1 and T_3 turn on and T_2 and T_4 turn off, therefore the voltage at node A become V_{data}. Because gate and drain of T_5 is connected through the diode connection transistor T_3, V_{gs-T5} is V_{th-T5} and the source voltage of T_5 become $V_{DD} - V_{th-T5}$. The stored voltage across the capacitor is $V_{DD} - V_{data}$.

Period (2): In this period, the OLED emits light. After scanning time, T_1 and T_3 turn off and T_2 and T_4 turn on. The voltage at node A becomes zero, so the gate voltage of T_5 becomes $V_{DD} - V_{data}$. The source voltage of T5 remains $V_{DD} - V_{th-T5}$, and thus the current of OLED can be derived as follows:

$$\begin{aligned} I_{OLED} &= \frac{1}{2}k(V_{gs-T5} - V_{th-T5})^2 \\ &= \frac{1}{2}k[V_{DD} - V_{data} - (V_{DD} - V_{th-T5}) - V_{th-T5}]^2 \\ &= \frac{1}{2}k(V_{data})^2 \end{aligned}$$

Where k is $\mu \cdot C_{ox} \cdot \frac{W}{L}$.

We can find the output current of OLED is not associated with the threshold voltage of driving TFT (T_5), and is only impacted by the data voltage. The pixel-to-pixel threshold voltage variations can be compensated effectively and uniform brightness image performance can be achieved.

PROPOSED CIRCUIT SIMULATION RESULTS

To verify the effectiveness of OLED driving current compensation ability of proposed pixel circuits, SMART SPICE simulation is performed with RPI poly-Si model (level = 36). Figure 2(b) presents the OLED output current of conventional 2Tr1C pixel circuit with threshold voltage shift (ΔVth = +0.33 V, 0 V and −0.33 V) and the transfer characteristics of the conventional 2Tr1C pixel circuit with threshold voltage variation for different input data voltage is shown in Figure 4. Although the same data voltage comes into the pixel circuit, the output current is different due to threshold voltage variation of driving TFT. In the conventional pixel circuit, OLED output current varies about 35% in ± 0.33 V threshold voltage variation. Clearly, the driving current is dependent on the threshold voltage variation.

Figure 1(b) presents the OLED output current of reported pixel circuit [6] with threshold variations (ΔVth = +0.33 V, 0 V and −0.33 V) at same simulation condition with the 2Tr1C pixel circuit. In this pixel circuit, the OLED current varies about 9% when threshold voltage varies ±0.33 V. Figure 5 shows that the comparison of non-uniformity of OLED output current in the reported pixel circuit [6] and the conventional 2Tr1C pixel circuit. The simulation results show a successful compensation of OLED output current.

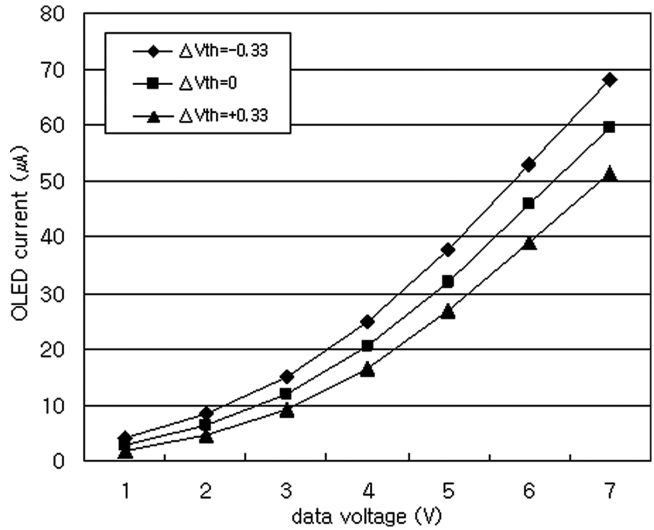


FIGURE 4 The simulation result of 2Tr1C shows the range of OLED output current at different V_{data} and threshold voltage variation ($\Delta Vth = +0.33\,V$, $0\,V$ and $-0.33\,V$).

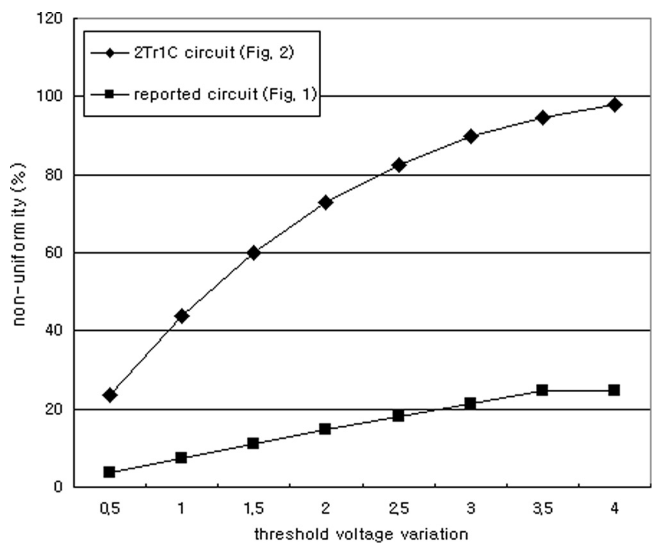


FIGURE 5 Non-uniformity of the output current due to threshold voltage variation in the reported pixel circuit (Fig. 1) compared with conventional 2Tr1C pixel circuit.

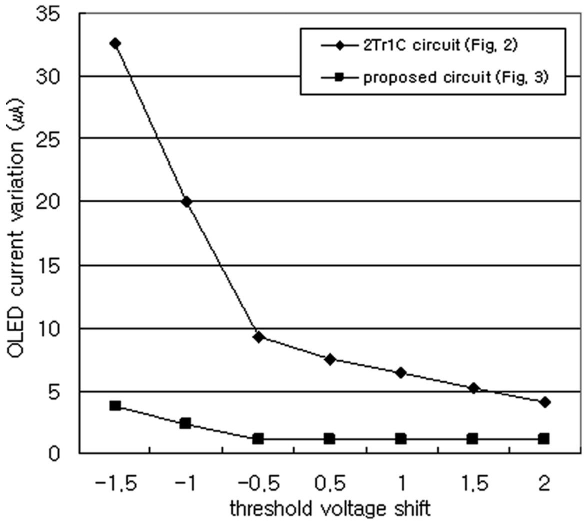


FIGURE 6 OLED output current variation due to threshold voltage variation in the proposed pixel circuit (Fig. 3) compared with conventional 2Tr1C pixel circuit.

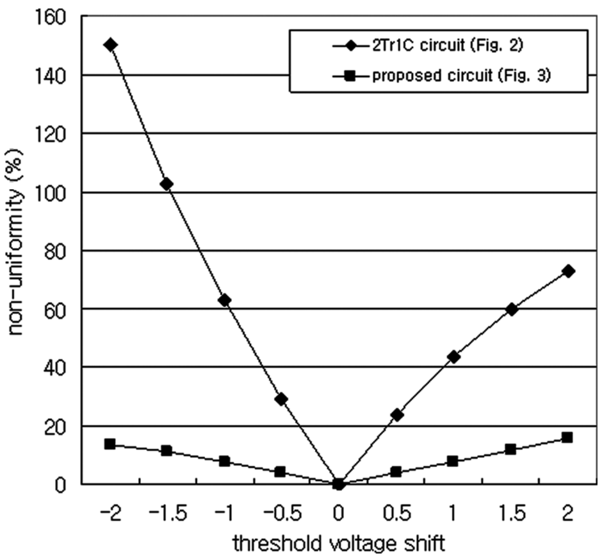


FIGURE 7 Non-uniformity of the output current due to threshold voltage variation in the proposed pixel circuit (Fig. 3) compared with conventional 2Tr1C pixel circuit.

Figure 3(b) presents the simulation result of the proposed pixel circuit with threshold voltage variations ($\Delta Vth = +0.33\,V$, $0\,V$ and $-0.33\,V$) at same simulation condition with others. The OLED current varies about 5%, where threshold voltage varies $\pm 0.33\,V$. The result shows that the proposed pixel circuit successfully compensates the threshold voltage variation and more powerful than our previously reported circuits [6]. Figure 6 show that the comparison of OLED output current variation with conventional 2Tr1C pixel circuit. Figure 7 presents the non-uniformity of output current of OLED simulated with threshold voltage variation. Compared with the non-uniformity of the conventional 2Tr1C pixel circuit, the non-uniformity of the proposed pixel circuit is significantly reduced. In the proposed pixel circuit, the OLED output current variation was reduced more than 87% of the original current variation of 2Tr1C pixel circuit.

SUMMARY

This study proposes a novel pixel circuit for AMOLEDs composed of five TFTs and one capacitor. The proposed pixel circuit was verified by SMART SPICE. Through simulation results, it is verified that the proposed circuit is capable of reducing the threshold voltage variation problem of conventional 2Tr1C pixel circuit and produce stable OLED output current. In conventional 2Tr1C pixel circuit, the output current varies about 35% (Fig. 2), the OLED output current of the reported pixel circuit varies about 9% (Fig. 1) and the output current of proposed pixel circuit varies about 5% (Fig. 3) when threshold voltage shift $\pm 0.33\,V$. Therefore, the proposed pixel circuit can reduce the effect of OLED degradation and increase the life time of an AMOLED display.

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