

A Novel Top Emission Pixel Circuit Compensating for TFT Threshold Voltage Variation and Luminance Degradation of OLED

Chih-Lung Lin*, Kuo-Chao Liao

Abstract—This work demonstrates a novel pixel circuit composed of top emission architecture with a voltage programming method. Besides compensating for the threshold voltage variation of TFTs, the proposed circuit can improve the luminance degradation of active-matrix organic light-emitting diode (AMOLED) by using OLED voltage as a feedback of OLED luminance degradation. In addition, the reversed-bias voltage applied to OLED can suppress the degradation of OLED. The simulation results show that the proposed circuit can effectively compensate for TFT threshold voltage variation and improve luminance degradation of OLED.

Index Terms—Active-matrix organic light-emitting diode (AMOLED), reversed-bias voltage, top mission, degradation

I. INTRODUCTION

Organic light-emitting diode (OLED) displays have attractive attributes, such as wide view angle, high contrast ratio, and fast response time [1]. However, process variation in electrical characteristics of low-temperature polycrystalline-silicon (LTPS) or hydrogenated amorphous silicon (a-Si:H), such as threshold voltage (V_{TH}), causes differences in the OLED current among pixels and the display is non-uniformity. Thus, various compensation circuits have been published and generally classified by the current [1] and voltage programming methods [1]-[5]. Although the current method can compensate for the threshold voltage variation (ΔV_{TH}), the constant current source is difficult to design for controlling the small current level and the charging time is prolonged for low data current [2]. The voltage programming method can effectively compensate for TFT threshold voltage variation. Besides, the aperture ratio is a critical issue for AMOLED applications. Fewer TFTs can improve aperture ratio in a pixel circuit with

bottom emission [3]. However, the aperture ratio of the pixel circuit with top emission architecture can be significantly increased [6].

During recent years, the degradation and lifetime of OLED are the main concerns. With long term operation, luminance and efficiency of OLED often decay gradually. Thus, numerous compensation schemes are proposed to postpone the degradation of OLED [4], [5], [7], [8]; these approaches can be categorized as optical-feedback compensation [7], and circuit compensation [4], [5], [8]. Although optical-feedback scheme can compensate for OLED luminance degradation, the compensation efficiency is sensitive to ambient light [4]. Shieh *et al.* proposed an ac driving method to prolong the lifetime of OLEDs by using the reversed-bias voltage [8]. However, ΔV_{TH} is not compensated and the display doesn't perform well against non-uniformity. Lee *et al.* proposed a novel pixel circuit with the stable current independent of ΔV_{TH} of TFTs and OLED, but luminance still drops due to OLED degradation [5]. For the purpose of holding the same luminance, our previous research proposed the OLED current can be compensated by a feedback of OLED voltage [4]. OLED degradation can be effectively improved, but overmuch TFTs affect the aperture ratio and luminance efficiency.

The proposed pixel circuit with top emission architecture can significantly improve the aperture ratio. Meanwhile, the reversed bias voltage can suppress the degradation of OLED and the luminance can be improved by the feedback compensation of OLED voltage [8]. Therefore, the display has better uniform luminance and a high degree of immunity to ΔV_{TH} for AMOLED display. The simulation results show that the proposed circuit can compensate for ΔV_{TH} and improve the luminance by OLED voltage compensation.

II. PROPOSED PIXEL CIRCUIT OPERATION

Fig. 1 shows the equivalent circuit of the proposed circuit and driving signals. The proposed pixel is composed of a driving TFT (T1), four switching TFTs (T2-T5), two storage capacitors (C1-C2) and an OLED, three scan lines (V_{SCAN1} - V_{SCAN3}), a data line (V_{DATA}) and PVDD is a power supply line. V_{REF} is a constant voltage source line and set to 3V. The scan lines (V_{SCAN1} - V_{SCAN3}) range is between -20—20V. PVDD, V_P and VSS are set to -2—3V, -6V and -9V, respectively. ΔV_{DATA} range is about between -6.5—-4V. C1 and C2 are 0.3pf. V_{OLED}

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is the applied voltage when the current passes through OLED. The OLED current can be analyzed by the gate-source voltage of T1. T2 is used for the diode connection of T1. V_{SCAN1} - V_{SCAN3} are used to control TFTs (T2-T5) individually. V_{REF} is a reversed-bias voltage used to extend the lifetime of OLED. The frame of a pixel is as showed in Fig. 1(b), and the operation scheme and compensation principle of the proposed pixel circuit are described as follows.

1) Reset Period: During this period, T2, T3, T4 and T5 are all on and T1 is in diode connection. The voltages of node N1, N2, and N4 are all V_{REF} , the voltage of node N3 is V_P and PVDD is low. At this time, V_{N1} is larger than PVDD and the reversed-bias voltage can accelerate the recovery of OLED degradation. The voltages of nodes, V_{N1} , V_{N2} , V_{N3} and V_{N4} at this period are

$$\begin{aligned} V_{N1} &= V_{N2} = V_{N4} = V_{REF} \\ V_{N3} &= V_P \end{aligned} \quad (1)$$

2) Programming Threshold Voltage Period: During the second period, T4 and OLED are off. Because of T1 in diode connection, C1 starts to discharge through T1 until the gate voltage of T1 (V_{N4}) is $V_{SS} + V_{TH_TFT1}$ (the threshold voltage of T1). The voltages of nodes, V_{N1} , V_{N2} , V_{N3} and V_{N4} at this period are

$$\begin{aligned} V_{N1} &= V_{N2} = V_{N4} = V_{SS} + V_{TH_TFT1} \\ V_{N3} &= V_P \end{aligned} \quad (2)$$

3) Data Input Period: T2 is off. At the beginning, because V_{N3} is changed from V_P to $V_P + \Delta V_{DATA}$, V_{N4} is changed from $V_{SS} + V_{TH_TFT1}$ to $V_{SS} + V_{TH_TFT1} + \Delta V_{DATA}$. Meanwhile, PVDD is turned high and the current begins to pass through OLED and T1. Therefore, V_{N1} and V_{N2} are both $PVDD - V_{OLED}$. The voltage of each node at this period is

$$\begin{aligned} V_{N1} &= V_{N2} = PVDD - V_{OLED} \\ V_{N3} &= V_P + \Delta V_{DATA} \\ V_{N4} &= V_{SS} + V_{TH_TFT1} + \Delta V_{DATA} \end{aligned} \quad (3)$$

4) Holding V_{OLED} Period: The voltages of C1 and C2 are $N4$ - $N3$ and $N3$ - $N2$, respectively.

$$\begin{aligned} V_{C1} &= V_{N4} - V_{N3} = V_{SS} + V_{TH_TFT1} - V_P \\ V_{C2} &= V_{N3} - V_{N2} = V_P + \Delta V_{DATA} - PVDD + V_{OLED} \end{aligned} \quad (4)$$

where V_{C1} and V_{C2} are the different voltages stored in C1 and C2, individually.

5) Emission Period: During emission period, T4 is turned on and V_{N2} is changed from $PVDD - V_{OLED}$ to V_{REF} . Therefore, V_{N4} is boosted from $V_{SS} + V_{TH_TFT1} + \Delta V_{DATA}$ to $V_{SS} + V_{TH_TFT1} + \Delta V_{DATA} + V_{REF} - PVDD + V_{OLED}$ due to the charge conservation of C1 and C2.

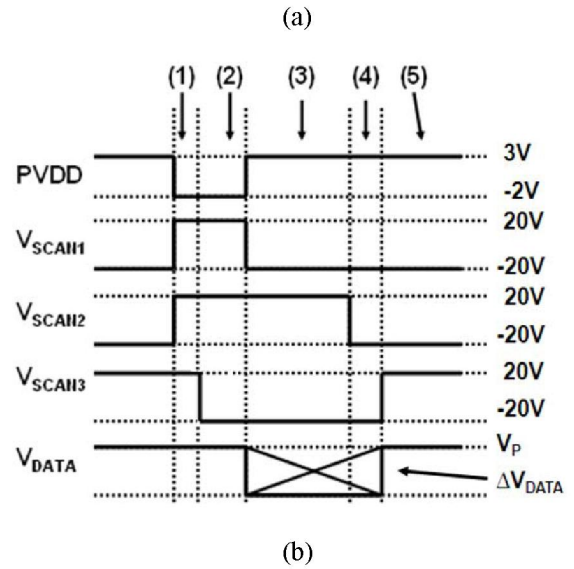
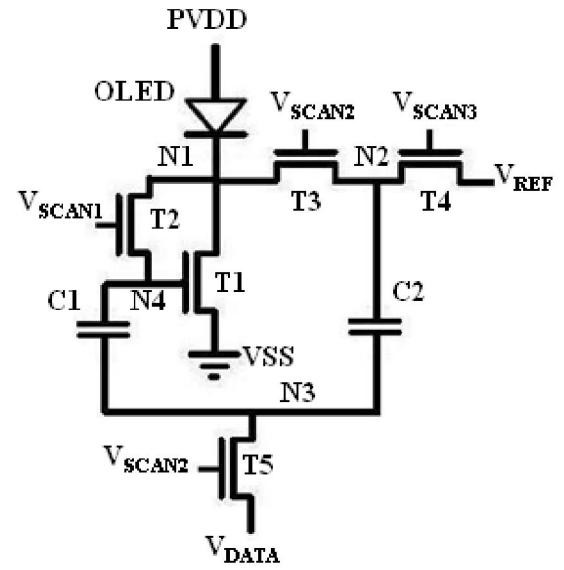


Fig. 1. (a) Equivalent circuit of the proposed pixel circuit. (b) Driving signals. (1) Reset Period, (2) Programming Threshold Voltage Period, (3) Data Input Period (4) Holding V_{OLED} Period, and (5) Emission Period.

Therefore, the OLED current (I_{OLED}) can be determined by the gate-source voltage of T1. I_{OLED} is

$$\begin{aligned} I_{OLED} &= \frac{1}{2} k_1 (V_{GS} - V_{TH_TFT1})^2 \\ &= \frac{1}{2} k_1 (V_{N4} - V_{SS} - V_{TH_TFT1})^2 \\ &= \frac{1}{2} k_1 (V_{SS} + V_{TH_TFT1} + \Delta V_{DATA} \\ &\quad - PVDD + V_{OLED} + V_{REF} - V_{SS} - V_{TH_TFT1})^2 \\ &= \frac{1}{2} k_1 (\Delta V_{DATA} - PVDD + V_{OLED} + V_{REF})^2 \end{aligned} \quad (5)$$

where k_1 is $\mu \cdot C_{OX} \cdot W_1/L_1$.

Besides, PVDD and V_{REF} are both 3V. Therefore, the equation (5) can be simplified as follows.

$$I_{OLED} = \frac{1}{2} k_1 (V_{OLED} + \Delta V_{DATA})^2 \quad (6)$$

From equation (6), I_{OLED} is independent of ΔV_{TH} and only affected by $V_{OLED} + \Delta V_{DATA}$. Consequently, ΔV_{TH} doesn't affect the OLED current. Moreover, V_{OLED} can provide another part of the OLED current and improve the display luminance due to OLED degradation. In the first period of one frame, Reset Period, the reversed-bias voltage can accelerate the recovery of OLED degradation and extend the OLED lifetime.

III. SIMULATION RESULTS

To confirm the functionality of the proposed pixel circuit, the simulation results are achieved by AIM-SPICE. Simulation model parameters were extracted from the measurements of fabricated OLED panels. The V_{TH} of n-type TFT is 1.88V and the width and length of T1 are 12 μ m and 25 μ m, respectively. The width and length of T2, T3, T4 and T5 are all 5 μ m. The threshold voltage variation of TFT is set to ± 0.3 V.

Fig. 2 shows the gate voltage of T1 with ΔV_{TH} during one frame operation. The simulation result represents that the voltage stored in C1 includes ΔV_{TH} information and the uniformity of OLED current can be achieved.

Fig. 3 shows the simulation of OLED current with ΔV_{TH} between input data range. Compared with that of the conventional 2T1C pixel circuit, OLED current of the proposed pixel circuit are obviously independent of ΔV_{TH} . Therefore, the result illustrates that the proposed pixel circuit successfully compensate for ΔV_{TH} and has superior immunity against non-uniformity.

Fig. 4 shows the result of OLED current with V_{OLED} shift. As V_{OLED} increases, OLED current can be compensated to improve the degradation of OLED.

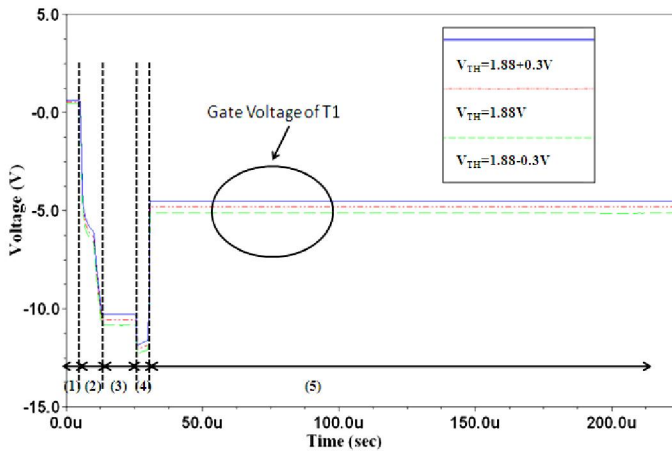


Fig. 2. The simulation of the gate voltage of the driving TFT (T1) with threshold voltage variation. (1) Reset Period, (2) Programming Threshold Voltage Period, (3) Data Input Period (4) Holding V_{OLED} Period, and (5) Emission Period.

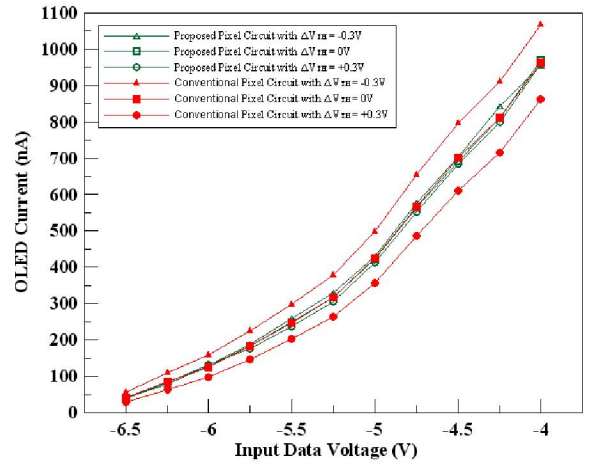


Fig. 3. Simulation of OLED current with threshold voltage variation between input data range.

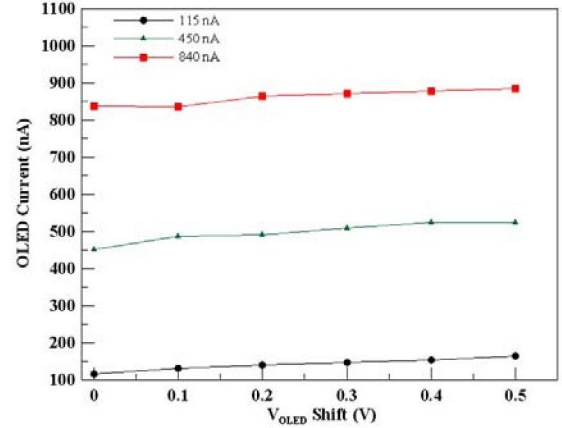


Fig. 4. OLED current as a function of shift in OLED voltage.

IV. CONCLUSION

In this study, a novel top emission architecture pixel circuit with five TFTs and two capacitors is presented. In addition to compensating for the threshold voltage variation, the proposed pixel circuit can increase the aperture ratio and suppress the degradation of OLED by reversed-bias voltage applications. OLED luminance can be partially compensated by a feedback voltage of V_{OLED} in OLED current. Therefore, this proposed pixel circuit can improve uniformity and the lifetime of OLED displays.

V. ACKNOWLEDGMENT

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