Data Compensation Scheme for AMOLED Pixel Circuit Based on Double-Gate Structural IGZO TFTs

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Abstract

We proposed a data compensation scheme for the bottom gate-to-source voltage difference of double-gate IGZO TFTs in AMOLED pixel circuit. We found the compensation factor in the current equation within the pixel circuit and verified through the simulation that the variation was effectively reduced.

Author Keywords

Organic light-emitting diode; pixel circuit; double-gate; indium-gallium-zinc oxide thin-film transistor; data compensation scheme

1. Introduction

Active-matrix organic light-emitting diode (AMOLED) displays have been widely used because of their advantages such as low power consumption, high contrast ratio, and excellent image quality [1]. In recent years, AMOLED displays have been extensively developed based on indium-gallium-zinc oxide (IGZO) thin-film transistors (TFTs), which have relatively high carrier mobility, and extremely low off-current characteristics.

In the pixel circuits, the threshold voltage (V_{TH}) variation of IGZO TFTs, degrades display image quality. Moreover, because IGZO TFTs can operate in depletion mode, TFTs are turned on when the gate-to-source voltage (V_{GS}) is 0 V [2]. Therefore, the previously reported IGZO TFTs-based pixel circuits have used a source-follower structure [3], [4].

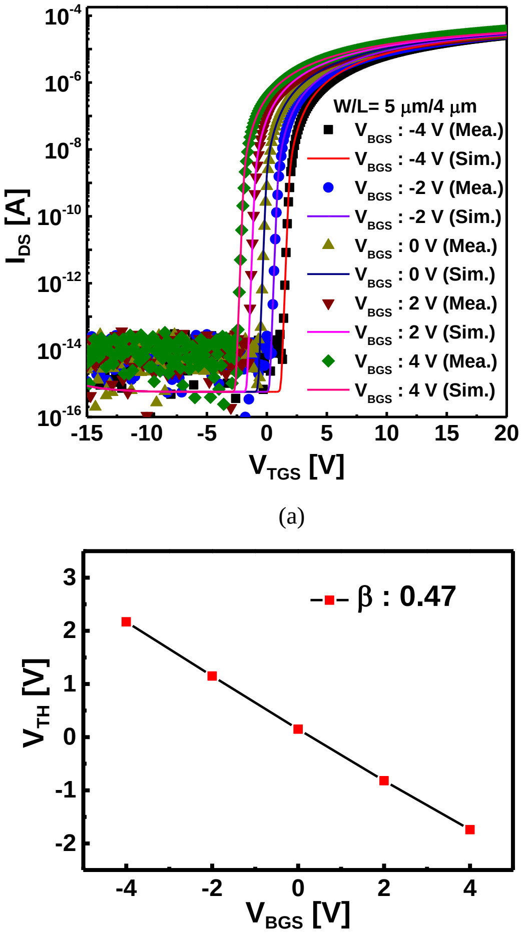
In OLED pixel circuits, the source-follower structure requires a minimum of two capacitors to compensate for the V_{TH} variation of driving TFT and reduce the effect of the OLED capacitor [3], [4]. However, the positive V_{TH} shift of TFT can be achieved using the double-gate structure [5]. Accordingly, the diode-connection structure with one capacitor can be applied in the pixel circuits when TFT with a double-gate structure is employed.

However, the source node voltage (V_S) of the driving TFT with a double-gate structure differs in data writing and emission periods. It results in the V_{TH} variation of the driving TFT due to the bottom gate-to-source voltage (V_{BGS}) difference between the data writing and emission periods [6]. Consequently, this phenomenon causes luminance distortion in OLED displays.

In this study, we propose a data compensation scheme for the V_S variation of the driving TFT with a double-gate structure in the pixel circuit based on IGZO TFTs. The proposed method compensates for the V_S differences in data writing and emission periods by applying the additional voltage to the data voltage (V_{data}). We investigate the error rates of OLED current and demonstrate that the proposed scheme successfully compensates for the V_S variation between the data writing and the emission periods.

2. V_{TH} modulation of double-gate TFT

Figure 1(a) illustrates the simulated and measured transfer characteristics of IGZO TFT with double-gate structure by V_{BGS} variation from -4 to 4 V. The extracted V_{TH}, subthreshold slope, and the field-effect mobility are 0.32 V, 0.104 V/dec, and 10.5 cm^2/V·s, respectively, when V_{BGS} is 0 V. The V_{TH} of TFT was shifted by modulating the V_{BGS} value from -4 V to 4 V with a 2 V interval, as shown in Figure 1(a) and (b). The V_{TH} changed by 0.47 V when the V_{BGS} shifted by 1 V. This ratio of the V_{TH} and V_{BGS} is represented as beta (β), and its value is 0.47.



(a)

(b)

Figure 1. (a) Simulated and measured transfer characteristics of the double-gate IGZO TFT under V_{BGS} of -4 to 4 V and (b) Measured V_{TH} by V_{BGS} of -4 to 4 V.

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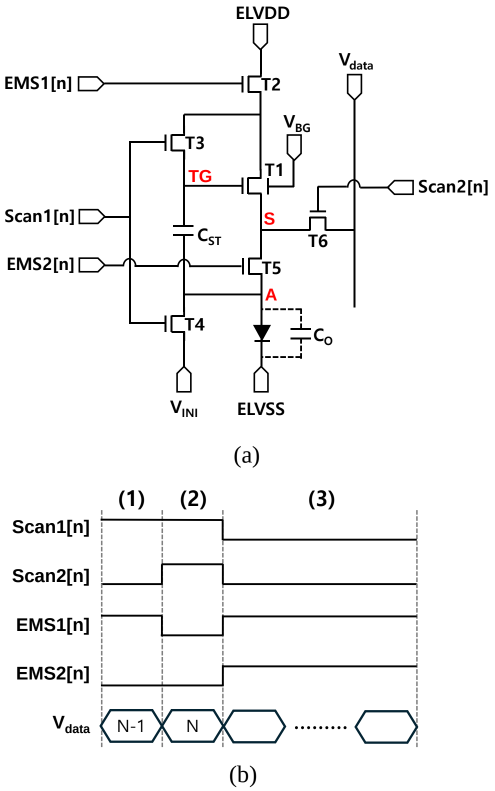

(a)

(b)

Figure 2. Modified AMOLED pixel circuit structure: (a) circuit schematic and (b) timing diagram.

3. Modified Pixel Circuit

Figure 2 shows the schematic and timing diagram of the modified pixel circuit. To verify the proposed compensation method, we modified the reference circuit, composed of low-temperature polycrystalline and oxide TFTs, to consist only of IGZO TFTs. Additionally, double-gate structure IGZO TFT was employed to the driving TFT to apply the proposed compensation scheme [7]. The modified pixel circuit consists of a driving TFT with a double-gate structure, five switching TFTs, and one capacitor. As shown in Figure 2(a), the driving TFT, T1 is compensated for V_{TH} using a diode-connection structure. From Figure 2(b), the operation of the modified pixel circuit has three periods: (1) Reset period, (2) Data writing period, and (3) Emission period.

In period (1), node A, which is an anode of OLED is reset to initial voltage (V_{INI}) through T4, and node TG is reset to ELVDD through T2 by Scan1[n] and EMS1[n], respectively. So, the voltage of node A (V_A) becomes V_{INI}, and the voltage of node TG (V_{TG}) becomes ELVDD.

In period (2), T6 is turned on by Scan2[n]. The V_S becomes V_{data} and because of V_{TH} at the data writing period (V_{TH_1}), V_{TG} becomes V_{data} + V_{TH_1} with the diode-connection structure. Therefore, $V_{data} + V_{TH\_1} - V_{INI}$ is stored at the storage capacitor. When V_{BGS} is 0 V, V_{TH} is described as V_{TH_0}, and V_{TH_1} is expressed as $V_{TH\_0} - \beta V_{BGS}$. Then, V_{TG} follows equation (1).

$$V_{TG} = V_{data} + V_{TH\_0} - \beta(V_{BG} - V_{data}) \qquad (1)$$

In period (3), T2 and T5 are turned on by EMS1[n] and EMS2[n] respectively. The current flows from ELVDD line to ELVSS line, and the light is emitted from OLED. In this period, the V_{TH} at emission period (V_{TH_2}) is expressed as equation (2).

Table 1. Dimensions of devices in the modified pixel circuit

Parameter	Value	Parameter	Value
W of all TFTs	3 μm	C1	50 fF
L of T1	20 μm	ELVDD	4.6 V
L of T2, T3, T4, T5, T6	5 μm	ELVSS, V_{INI}	-3 V
		Scan1[n], Scan 2[n], EMS1[n], EMS2[n]	-7 V ~ 7 V
L = TFT channel length, W = TFT channel width			

$$V_{TH\_2} = V_{TH\_0} - \beta V_{BGS} = V_{TH\_0} - \beta(V_{BG} - V_A) \qquad (2)$$

Then, the difference between top gate-to-source voltage (V_{TGS}) and V_{TH_2} is expressed as equation (3).

$$V_{TGS} - V_{TH\_2} = V_{TG} - V_{INI} - V_{TH\_2} \qquad (3)$$

From equation (1) and (2), equation (3) becomes as follows

$$\begin{aligned} V_{TGS} - V_{TH\_2} = V_{data} + V_{TH\_0} - \beta(V_{BG} - V_{data}) - V_{INI} \\ - V_{TH\_0} + \beta(V_{BG} - V_A) \qquad (4) \end{aligned}$$

Finally, according to equation (4), the OLED current equation can be substituted to equation (5).

$$\begin{aligned} I_{OLED} &= \frac{1}{2}\mu_n C_{OX}\frac{W}{L}\left(V_{TGS} - V_{TH\_2}\right)^2 \\ &= \frac{1}{2}\mu_n C_{OX}\frac{W}{L}\{V_{data} - V_{INI} + \beta(V_{data} - V_A)\}^2 \qquad (5) \end{aligned}$$

Therefore, the V_{data} should be compensated by the compensation factor $\beta(V_{data}\text{-}V_A)$. The compensation of V_{data} (V_{data_C}) is expressed as

$$V_{data\_C} = V_{data} - \beta(V_{data} - V_A) \qquad (6)$$

Consequently, by inputting V_{data_C}, equation (5) becomes

$$\begin{aligned} I_{OLED} &= \frac{1}{2}\mu_n C_{OX}\frac{W}{L}\{V_{data\_C} - V_{INI} + \beta(V_{data} - V_A)\}^2 \\ &= \frac{1}{2}\mu_n C_{OX}\frac{W}{L}(V_{data} - V_{INI})^2 \qquad (7) \end{aligned}$$

Eventually, we can terminate the V_S variation of driving TFT in the IGZO TFT-based pixel circuit with a diode-connection structure.

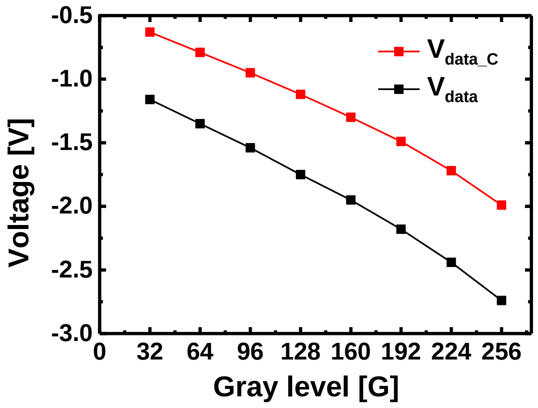

Figure 3. V_{data} and V_{data_C} according to gray level.

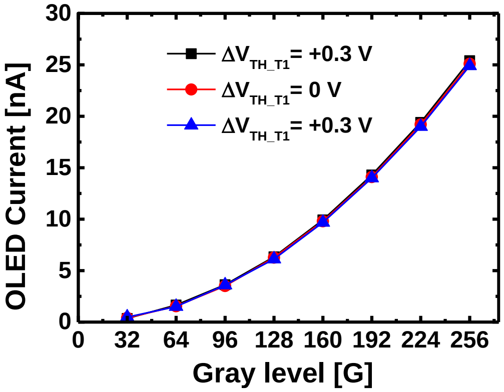

Figure 4. Simulated OLED current with V_{TH} shift ±0.3 V of driving TFT, T1.

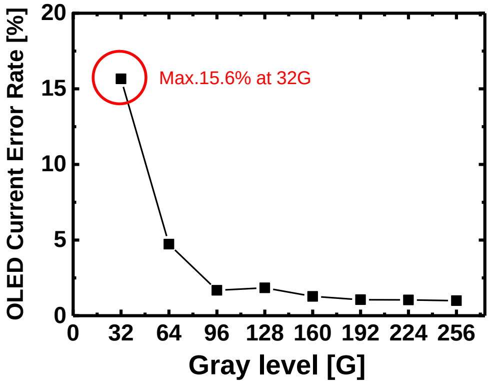

Figure 5. Simulated OLED current error rate with V_{TH} shift ±0.3 V of driving TFT, T1.

4. Results and Discussion

The operation of the proposed compensation scheme of the modified pixel circuit was investigated using circuit simulation software (SmartSpice, Silvaco). We used the RPI model (Level=36) for the single gate TFTs, and the 4-terminal model (Level=363) for the double-gate TFT. The design parameter values for the pixel circuit are shown in Table 1. Figure 3 shows V_{data} and V_{data_C} according to gray level. The V_{data} was compensated by calculating the compensation factor, thus, the data voltage range of V_{data_C} is from -0.6 V to -2 V.

Figure 4 and Figure 5 show the OLED current and OLED current error rate, respectively. The V_{TH} variation of driving TFT, T1 was ±0.3 V. The maximum current flowing through the OLED was about 25 nA and the minimum current was about 0.4 nA. The maximum current error rate was 15.6% at 32G. The result shows that the proposed pixel circuit operates stably under the V_{TH} variation conditions.

5. Conclusion

This paper proposes a new compensation scheme for the pixel circuit with the double-gate structure IGZO TFT. The modified pixel circuit used the diode-connection structure to compensate for the V_{TH} variation. The proposed scheme can compensate for the V_S variation during data writing and emission period through the method. We found the compensation factor from the current equation and adjusted the V_{data}. In addition, we verified the proposed scheme enables us to compensate the V_S variation through the simulation. Therefore, the diode-connection structure is applicable to the pixel circuit with the IGZO TFTs with the proposed scheme.

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