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A Novel Voltage Driving Method Using 3-TFT Pixel Circuit for AMOLED

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Active matrix organic light emitting (AMOLED) are considered potential future display technology, as they are thin, have a high degree of brightness, are self-emitting, have fast response time, a high contrast ratio and are flexible. The approaches for driving AMOLED pixel circuits can be divided into two kinds: the current programming method, and the voltage programming method.

Table 1 Comparison between voltage programming and current programming methods.

Method	V_{TH} Compensation	Charge time (low gray level)	Signal Source Manufacture
Voltage Programming	Provide	Fast	Easy
Current Programming	Provide	Slow	Difficult

(1) Current Programming Method

The current programming method can be divided into current copy and current mirror. Current copy technology adjusts the control-signal and pixel structure to store sufficient voltage in the capacitor to generate the same input data current (I_{DATA}). Then, TFT switching is controlled and the I_{DATA} is copied and functions as the OLED current. Conversely, the current mirror technology with a symmetrical structure produces the driving current, which is multiple I_{DATA}. The current method can overcome variations in electrical characteristics of the TFT process, such as mobility and threshold voltage. However, these current-programmed methods require prolonged settling time at a low data current and inconvenient constant current sources that control submicrometer ampere-level current in peripheral drivers. Thus, the current driving method is unsuitable for large-high-resolution displays.

(2) Voltage Programming Method

The compensation principle of the voltage driving method can be sorted as self-compensation and TFT-matching. The self-compensation method stores the threshold voltage (V_{TH}) information of driving TFT for compensation during the programming process. The TFT-matching method compensates for threshold voltage variations when driving TFTs by utilizing the neighboring TFT V_{TH}, which is assumed to have the same electrical characteristics as the driving TFT. Additionally, the voltage driving method is appropriate with fast programming time for application to large-high-resolution displays. Table 1 compares current and voltage program methods.

A conventional pixel circuit, composed of two TFTs and one capacitor, suffers from a non-negligible VTH variation results in display non-uniformity. Some studies used more than 4 TFTs to compensate for VTH variation. An excessive number of TFTs results in complex control lines that decrease the aperture ratio and luminance of displays. Therefore, how to best simplify the pixel circuit is an important issue.

This proposed circuit by low-temperature poly-silicon (LTPS) or amorphous silicon (a-Si) techniques, presents a novel simple driving scheme using three n-type TFTs for AMOLEDs. Compared with existing current programming and voltage programming circuits, the proposed pixel circuit does not require time of VTH generation; thus, the control signal is as simple as that of the conventional 2T1C pixel circuit. Furthermore, the proposed circuit reduces the number of components in a pixel, thereby improving the aperture ratio. The proposed circuit easily satisfies the refresh time requirement in large-high-resolution OLED.

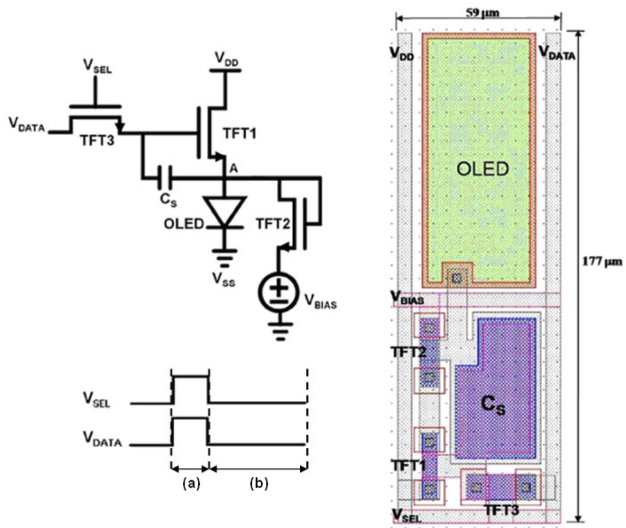

Fig. 1. Schematic circuit, control signal timing diagram, and layout of the proposed pixel circuit.

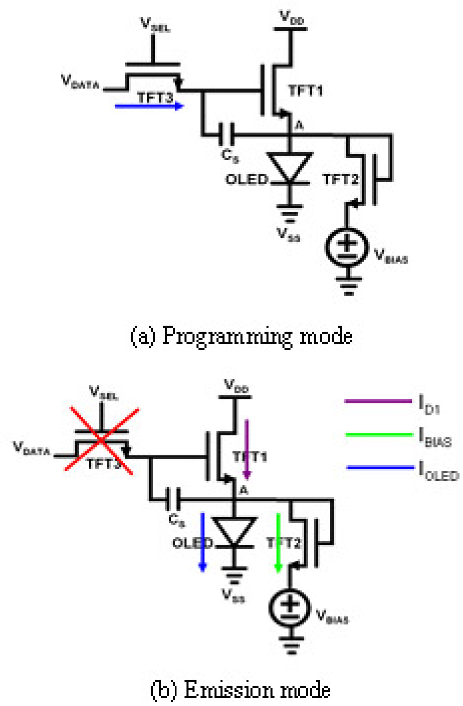

Fig. 2. Operation principle of the proposed pixel circuit

Figure 1 depicts the equivalent 3-TFT pixel circuit, its controlling signals, and the layout of the proposed circuit. For signal lines, the proposed circuit merely requires a data line and scan line, requirements similar to those of 2T1C conventional pixel circuits. The pixel circuit operates in programming mode and emission mode (Fig. 2). The operational principle is described as follows.

(1) Programming mode:

Figure 2(a) shows the programming mode, the select line (VSEL) goes to high voltage such that TFT3 is turned on and the data voltage VDATA is stored in the storage capacitor Cs through TFT3.

(2) Emission mode:

In the emission mode, showed in Fig. 2(b), VSEL goes to low voltage such that TFT3 is turned off. The driving current passing through the OLED is determined based on the difference between the drain current of TFT1 (I_{D1}) and the drain current of TFT2 (I_{BIAS}). In this circuit, V_{BIAS} must be selected properly to ensure that for the entire V_{DATA} range, TFT3 remains in saturation region, thereby satisfying the following condition:

$$V_{BIAS} \leq V_A - V_{TH\_T2}$$

where V_{TH_T2} denotes the threshold voltage of TFT2 and only when the gate-source voltage of TFT2 is larger than V_{TH_T2}; TFT2 remains in the saturation region because TFT2 is a diode connection. The OLED current is determined by I_{D1} and I_{BIAS} as follows:

$$\begin{aligned}
I_{OLED} &= I_{D1} - I_{BIAS} \\
I_{D1} &= \frac{1}{2} k_{T1} (V_{GS_T1} - V_{TH_T1})^2 \\
I_{BIAS} &= \frac{1}{2} k_{T2} (V_{GS_T2} - V_{TH_T2})^2 \qquad \text{(Saturation region)} \qquad (1) \\
\Delta V_{TH_DIFF} &= V_{TH_T1} - V_{TH_T2}
\end{aligned}$$

Where ΔV_{TH_DIFF} is the threshold voltage difference between TFT1 and TFT2, which results from long-term operation and process differences. The current deviation between different pixels due to the V_{TH} shift is estimated using the following equations:

$$\begin{aligned}
\frac{\partial I_{OLED}}{\partial V_{TH}} &= -k_{T1}(V_{GS_T1} - V_{TH_T1}) + k_{T2}(V_{GS_T2} - V_{TH_T2}) \\
&= -k_{T1} V_{eff1} + k_{T2} V_{eff2} = -gm_1 + gm_2 \qquad (2)
\end{aligned}$$

The condition to minimize the sensitivity of IOLED to VTH is shown as follows:

$$\begin{aligned}
&\frac{\partial I_{OLED}}{\partial V_{TH}} = 0 \Rightarrow gm_1 = gm_2 \Rightarrow \left(\frac{W}{L}\right)_1 V_{eff1} = \left(\frac{W}{L}\right)_2 V_{eff2} \qquad (3) \\
&V_{eff1} = V_{GS_T1} - V_{TH_T1} = V_{DATA} - V_A - V_{TH_T1} \\
&V_{eff2} = V_{GS_T2} - V_{TH_T2} = V_A - V_{BIAS} - V_{TH_T2}
\end{aligned}$$

According to Eq. (3), the driving current of different pixel circuits is related to the designed width and length. When V_{BIAS} and the width and length of TFT1 and TFT2 are selected properly such that $gm_1 = gm_2$, the OLED current does not vary with the nonuniformity of V_{TH}.

In the proposed circuit, the electrical characteristics of TFT1 and TFT2 are assumed identical ($\Delta V_{TH1} = \Delta V_{TH2}$, $gm_1 = gm_2$) as they are in the same horizontal line beam and use poly-Si TFTs fabricated by excimer laser annealing (ELA). Thus, when the V_{TH} of TFT1 and TFT2 varied from one pixel to another, the drain current of TFT1 is $I_{D1} + \Delta I_1$, and the drain current of TFT2 is $I_{BIAS} + \Delta I_{BIAS}$. ΔI_1 is approximately the same as ΔI_{BIAS}. Thus, the output OLED current has the same current–voltage (I–V) characteristics between different pixels.

To elucidate how the V_{TH} shift of TFT1 and TFT2 affects the OLED driving current in the proposed circuit, Automatic Integrated Circuit Modeling Spice simulation (AIM-SPICE) is performed. Notably, V_{DD} is supply power line, and V_{SS} is common ground. Simulation model parameters were based on the measurement of the fabricated OLED and poly-Si TFTs.

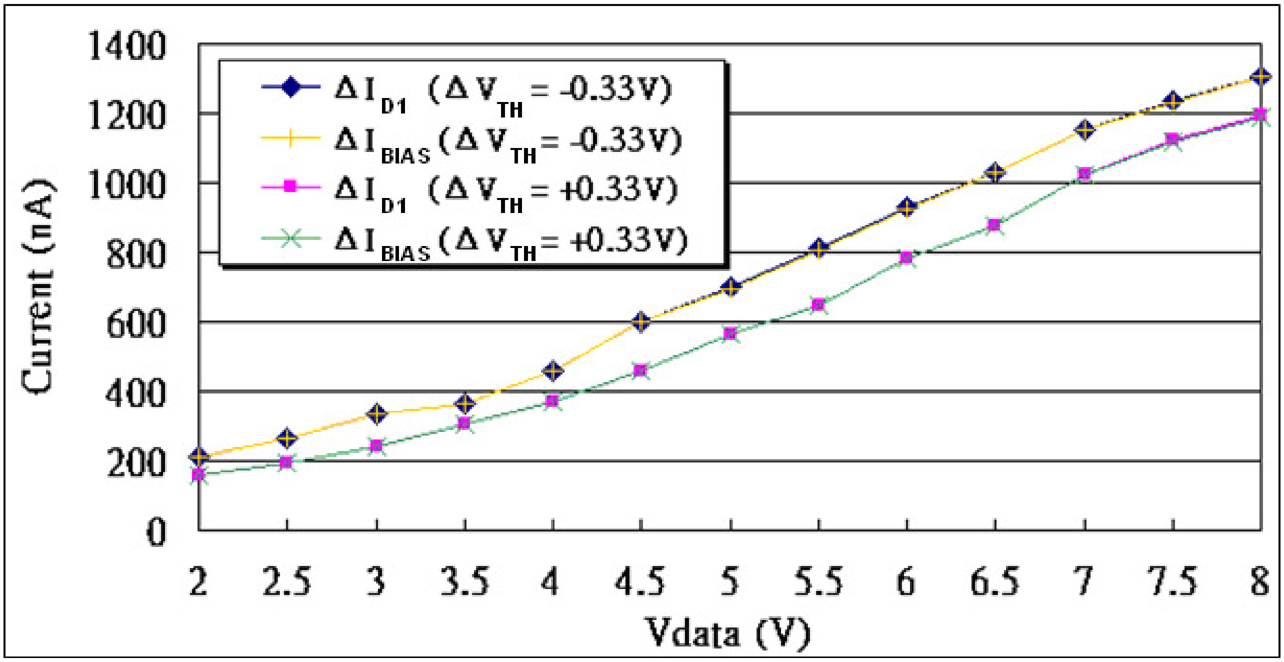

Fig. 3. Differences between ΔI_{D1} and ΔI_{BIAS} with threshold variation (ΔV_{TH} = –0.33 and + 0.33 V).

The OLED current is based on the difference between I_{D1} +ΔI_{D1} and I_{BIAS} +ΔI_{BIAS}, where ΔI_{D1} and ΔI_{BIAS} are current variations due to the threshold voltage variations (ΔV_{TH} = –0.33 and + 0.33 V) of TFT1 and TFT2, respectively. Figure 3 presents that ΔI_1 is approximately equal to ΔI_{BIAS} at different input V_{DATA} and V_{TH} shifts, and consequently, the output OLED device has similar I–V characteristics despite the variation in poly- Si TFT characteristics.

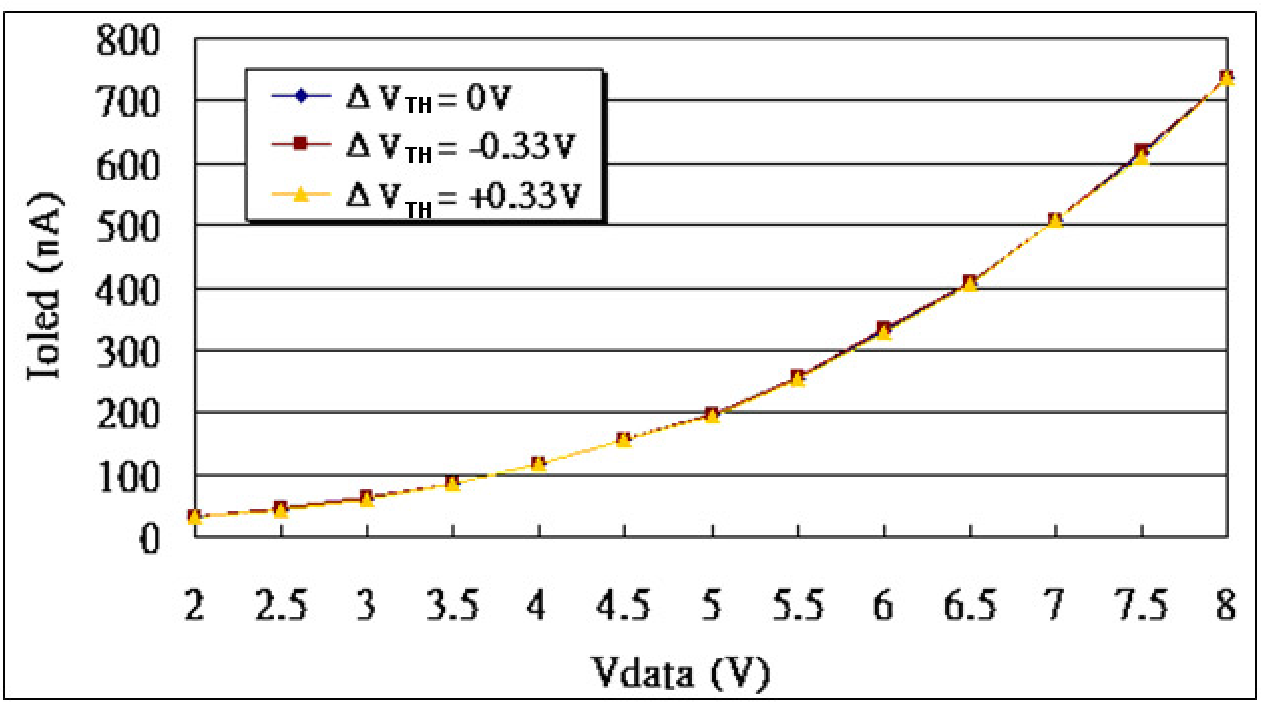

Fig. 4. Simulation results showing the range of the current flow through the OLED at different VDATA and threshold voltage variations (ΔV_{TH} = 0, –0.33, and + 0.33 V).

Fig. 4 presents the I–V characteristics of the proposed OLED device with different threshold voltage deviations ΔV_{TH} as a result of different VDATA (ΔV_{TH} = –0.33, ΔV_{TH}= 0 V, and + 0.33 V). The plot shows a successful compensation for OLED current and also indicates that the OLED output current is independent of V_{TH} variation with different input data signals. To be more specific, when the input data voltage ranges 2–8 V, the error rates in the proposed pixel circuit are all < 1.5%. Therefore, the OLED current in novel pixel circuit exhibits better immunity against the V_{TH} variation of poly-Si TFTs.

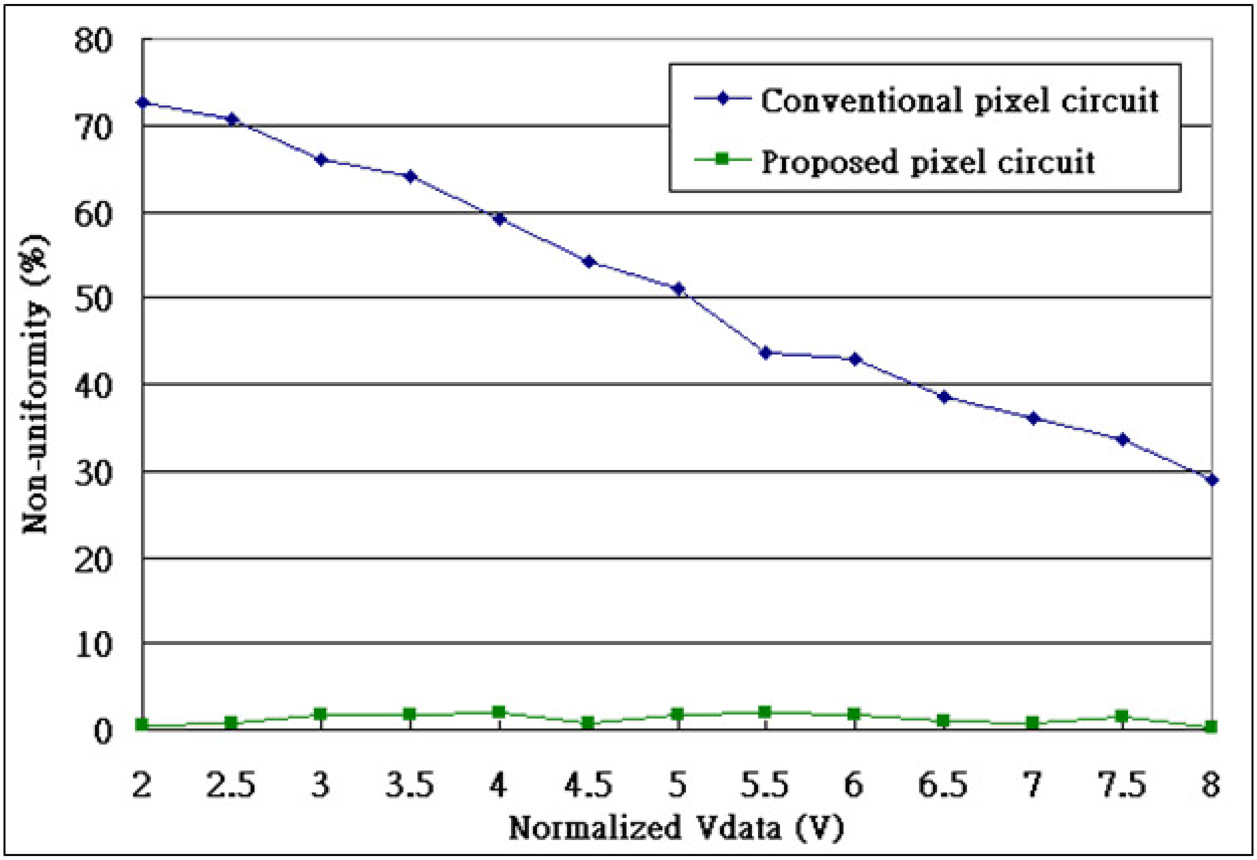

Fig. 5. Nonuniformity of the output current due to threshold voltage variation at different normalized VDATA in the proposed circuit compared with that in the conventional 2T1C pixel circuit.

Fig. 5 presents the nonuniform output current of an OLED simulated with combined V_{TH} variation of poly-Si TFT during programming. The traditional 2T1C input data voltage is normalized to compare the nonuniformity of OLED current with that of the proposed circuit using the same OLED current. Compared with the nonuniformity of a conventional 2T1C pixel circuit (>25%), the nonuniformity of the proposed pixel circuit is significantly reduced (< 2%).

The assumption in the proposed pixel circuit is that the electrical characteristics of TFT1 and TFT2 are ideally the same. If the threshold voltage of neighboring TFTs (ΔV_{TH_DIFF}) varies by 0.08 V, the proposed pixel circuit tolerates 0.08-V threshold voltage variations between TFT1 and TFT2 with an output current error rate of < 5%. Substituting $\Delta V_{TH\_DIFF} = V_{TH\_T1} - V_{TH\_T2}$ into (2), the following equation is obtained:

$$\frac{\partial I_{OLED}}{\partial V_{TH}} = -k_{T1}(V_{GS\_T1} - V_{TH\_T1}) + k_{T2}\left[(V_A - V_{BIAS}) - (V_{TH\_T1} - \Delta V_{TH\_DIFF})\right] \quad (4)$$

Just after the panel is fabricated, although $|\Delta V_{TH\_DIFF}|$ exceeds 0.08 V, V_{BIAS} can still be adjusted to make $g_{m1} = g_{m2}$. The worst case of ΔV_{TH_DIFF} is set to 0.3 V ; thus, ΔV_{TH_DIFF} varies from –0.3 to 0.3 V as $\triangle V_{BIAS}$ is adjusted from -2.7 to -3.3 V. Therefore, the proposed pixel circuit provides stable OLED current. However, when the V_{BIAS} line is already set in the panel and after extended operation with V_{TH} varied, the V_{BIAS} line is difficult to adjust.

Whether using the current or voltage driving method, existing compensating pixel circuits have complex pixel structures. Furthermore, fast scan time and high aperture ratio are essential for large-high-resolution displays. The proposed approach, composed of three n-type TFTs and one capacitor, does not need time for V_{TH} generation such that the control signal waveform is as simple as that of a conventional 2T1C pixel circuit and is significantly easier to manufacture. Furthermore, the proposed pixel circuit has been issued a Taiwanese patent.

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