A Novel a-InGaZnO TFT Based Voltage Programmed Pixel Circuit to Compensate Threshold Voltage and Mobility Variations

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In this paper, we proposed a novel voltage-programmed pixel circuit based on amorphous indium gallium zinc oxide thin-film transistor (a-InGaZnO TFT) for active-matrix organic light-emitting display (AMOLED) with an enhanced electrical stability and uniformity. Through an extensive simulation work based on a-InGaZnO TFT and OLED experimental data, we confirm that the proposed pixel circuit can compensate for both mobility variation and threshold voltage shift of the driving TFT.

1. Introduction

Recently active-matrix organic light emitting display (AMOLED) have been a focus among display industries due to its superior properties such as fast response time, low power consumption, and wide-viewing angle over liquid crystal displays (LCDs) [1, 2]. So far as a backplane technology for AMOLEDs, different types of thin film transistors (TFTs) are developed to be applied in the pixel circuit; hydrogenated amorphous silicon (a-Si:H) TFTs and low-temperature polycrystalline silicon (LTPS) TFTs. However, it is found that the conventional pixel circuit with two-TFT and one capacitor (2T1C) is not suitable for AMOLEDs since the OLED current degrades over time due to the threshold voltage shift of a-Si:H TFT by the operation bias [3], or since the OLED current is not uniform due to the localized crystallization on the panel during the LTPS TFT fabrication [4]. As a result, TFTs based on other semiconductor materials have been explored as alternative approaches [5, 6]. Among all, amorphous indium gallium zinc oxide (a-InGaZnO) TFT possess certain advantages including visible transparency, low processing temperature, good uniformity, decent mobility, low off-current, sharp sub-threshold swing, and potentially better electrical stability, which make it very favorable for AMOLEDs [6]. Although a-InGaZnO TFT offers prominent device performance, its threshold voltage instability under gate voltage bias-stress and mobility non-uniformity during the TFT fabrication over large area still remains as problems to be used for AMOLEDs.

To resolve these problems, several voltage-programmed pixel circuits based on a-InGaZnO TFT have been reported [7, 8]. Mo et al. proposed a five-TFT and two-capacitor pixel circuit to compensate the positive and negative threshold voltage and OLED degradation [7]. Jung et al. also developed a five-TFT and one-capacitor voltage-programmed pixel circuit which can compensate for threshold voltage degradation of a-InGaZnO TFT [9]. However, none of AMOLED pixel circuits developed so far has been reported to compensate the inherent mobility variations of TFT over large size panel, which results in the non-uniformity on the image of AMOLEDs.

This paper presents a novel a-InGaZnO TFT based voltage-programmed pixel circuit for AMOLEDs, which can compensate the mobility variation as well as both positive and negative threshold voltage variations of driving TFT. The function of mobility variation compensate for this pixel circuit is experimentally verified.

2. TFT fabrication and characterization

a-In-GaZnO TFTs were fabricated on glass substrates. The gate electrode Ti (5nm)/Au (40nm)/Ti (5nm) was deposited by electron-beam and patterned by lift off. The gate insulator SiO2 (200nm) and a-InGaZnO thin film were both deposited by RF sputtering and patterned by wet etch. The source/drain electrodes Ti (5nm)/Au (100nm)/Ti (5nm) were deposited by electron-beam and patterned by lift off [10]. The measured TFT transfer characteristics and the cross-sectional schematic of fabricated TFT are shown in Fig. 1. Then a-InGaZnO TFT SPICE model was developed based on the Rensselaer Polytechnic Institute (RPI) a-Si:H TFT model. SPICE parameters needed for circuit simulations are extracted from the measurement data, and used to simulate the TFT transfer characteristics (illustrated as the open circles in Fig. 1). To verify

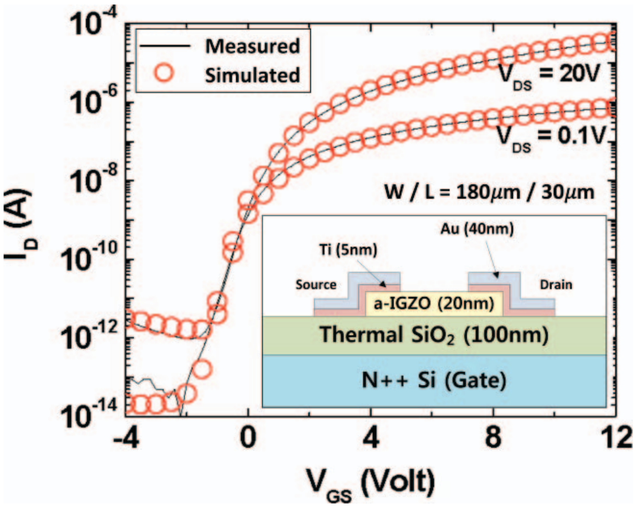

Fig. 1. Measured and simulated (by HSPICE) a-InGaZnO TFT transfer characteristics.

the proposed pixel circuit, simulations were performed using H-SPICE software supported by IC design education center (IDEC). The OLED model used in the simulation consists of two junction diodes and two series resistors connected in parallel with a capacitor [11].

3. Proposed Circuit Configuration and Its Operation

As shown in Fig. 2(a), the proposed AMOLED pixel circuit is composed of one driving TFT (T5), one set-up TFT (T6), four switching TFTs (T1, T2, T3, and T4), one capacitor. Fig. 2(b) show the driving schematics of this proposed pixel circuit. V_{SCAN}, V_{GATE1}, and V_{GATE2} are for control signal lines while V_{DATA}, V_{DD}, and V_{SS} refer to a data voltage signal, a constant voltage source line, and a ground line, respectively. The operation of the proposed circuit is divided in four periods; reset, setup, write, and drive. The detailed operation scheme and compensation principle of the proposed voltage-programmed pixel circuit are described as follows.

Reset Period: During the reset period, the control signal V_{GATE1} and V_{SCAN} are set to high level, turning on the T1, T2, and T3, while V_{GATE2} and V_{DATA} are set to low level. By turning on T1, T5 operates as the diode with its gate and drain node connected, of which turn-on voltage equals to the threshold voltage of T1. Because the drain voltage of T5 is set as V_{DD}, the gate node of the driving TFT (T5) is reset to a voltage equal to the V_{DD} minus the T1's threshold voltage. In this period, since T5 is maintained to be turned on, the current flows from V_{DD} to OLED and emit the light.

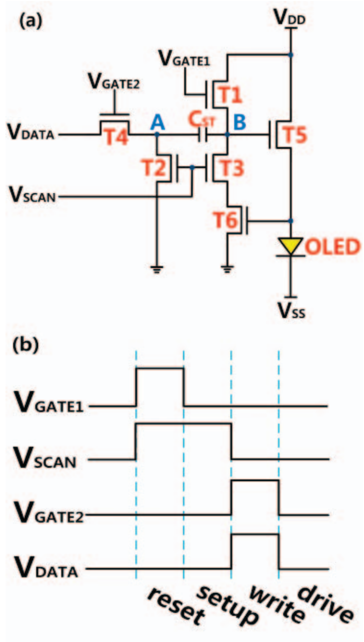

Fig. 2. (a) Schematic circuit diagram and (b) operational waveforms of the proposed voltage-programmed pixel circuit.

Setup Period: During the set-up period, the previous scan line (V_{GATE1}) is set to low level, whereas the other signal line (V_{SCAN}) maintains its previous voltage level (high). Since the V_{SCAN} keeps turning on T2 and T3, the gate node of driving TFT (T5) is starts to be discharged until it reaches to the compensation voltage for the threshold voltage of T5 as well as that of T6. Moreover, in this period, the compensation for the mobility variation of driving TFT (T5) also occurs at the same time. If the mobility of T5 gets lower, the resistance of T5 becomes increased, resulting in the source node voltage of T5 decreases by ΔV_{μ_T5} since the OLED has a fixed resistance. As a result, the gate node voltage of T5 increases by ΔV_{μ_T5}, which approximately depends on the mobility of T5. Thus, the mobility variations of T5 can be controlled by controlling ΔV_{μ_T5} in this period. Therefore, the final gate node voltage of T5 during this period equals to $V_{comp} = V_{TH\_T5} + V_{TH\_T6} + \Delta V_{\mu\_T5}$.

Write Period: During this period, V_{GATE1} is maintained as low level and V_{SCAN} turns to low level while V_{GATE2} is set to high level in order to write data signal. A data voltage goes through T4, and at the same time this data voltage is bootstrapped to the gate node (B) of the driving TFT (T5) by the C_{ST}. Therefore, the gate node voltage of the driving TFT (T5) is changed to the bootstrapped data voltage plus the compensation voltage stored in the previous period ($V_{DATA} + V_{comp}$).

Drive Period: At last, during the drive period, all signal lines are set to low level and the driving TFT operates in the saturation regime to drive the programmed OLED current. The voltage

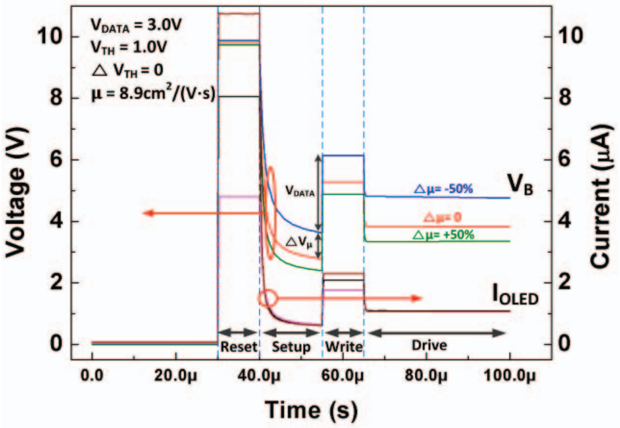

Fig. 3. Simulation results of the node voltage and OLED current for the proposed pixel circuit in time domain.

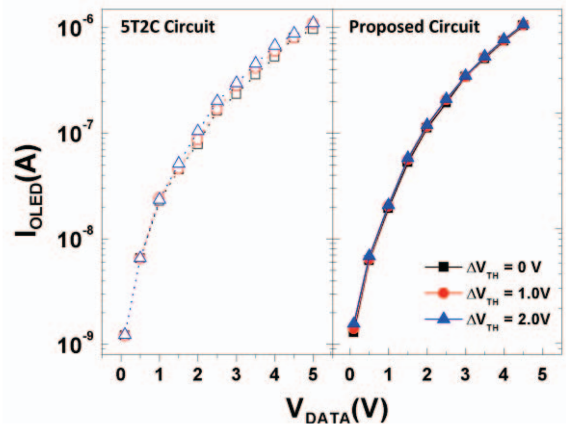

Fig. 4. I_{OLED} as a function of V_{DATA} of the proposed (closed symbols), and 5T2C (open symbols) pixel circuit.

stored in the storage capacitor (C_{ST}) during the write period will compensate the OLED current both for threshold voltage and mobility variations of driving TFT (T5). Note that the OLED current is equal to the corresponding drain current of T5, as in equation given below,

$$I_{OLED} = \frac{k}{2}(V_{GS} - V_{TH})^2,$$
$$V_{GS} = V_{DATA} + V_{comp},$$
$$I_{OLED} = \frac{k}{2}(V_{DATA} + V_{TH\_T5} + V_{TH\_T6} - V_{TH\_T5})^2, \quad (1)$$
$$\therefore I_{OLED} \propto \frac{k}{2}(V_{DATA} + \Delta V_{\mu\_T5})^2$$

where $k=\mu W/L$. As shown from Eq. (1), the OLED current during the drive period is independent of the mobility and threshold voltage variations of T5 because the mobility variation of T5 is cancelled by the stored voltage ΔV_{μ_T5}. Here we assume that the threshold voltages of T2, T3, and T6 are kept constant during the operation since they act as only switching transistors. Therefore, the threshold voltage and mobility variations of driving TFT (T5) can be compensated effectively, and uniform OLED brightness can be achieved.

Fig. 3 shows the transient simulation results of OLED current and gate node voltage of driving TFT (T5) with a 3.0 V input data for the proposed pixel circuit. It is obviously shown that the mobility variation of the driving TFT (ΔV_{μ}) is detected in the setup period, and added to the gate node of driving TFT (T5), resulting that the OLED current remain unperturbed from the programmed value. It should be noted that if the mobility of T5 gets higher than other transistors, the negative value of ΔV_{μ} is detected and then subtracted from the programmed data voltage. Therefore the OLED current variation of the proposed pixel circuit can be minimized regardless of any mobility variation.

4. Simulation Results and Discussion

In order to confirm the performance of proposed pixel circuit, it is compared with previously reported 5T2C pixel circuit [9]. Fig. 4 shows the OLED currents (I_{OLED}) delivered by the previously reported voltage-programmed pixel circuit (5T2C) and by our proposed pixel circuit as a function of V_{DATA}, respectively. Obviously, a wide dynamic I_{OLED} range (~10^3) was achieved by both pixel circuits when the threshold voltage shift is zero (ΔV_{TH} = 0V). However, as shown in Fig. 4, when the drive TFT exhibits 1.0 or 2.0V of ΔV_{TH}, we can see that OLED current of 5T2C pixel circuit shows small perturbation compared to the proposed circuit. Fig. 5 plots ΔI_{OLED} as a function of I_{OLED} when the threshold voltage shift varies positively from 0.5 to 2.0V for the previous 5T2C and the proposed pixel circuit. Here the percentage change in I_{OLED} (ΔI_{OLED}) is defined as the ratio of the OLED current difference between OLED currents with varying ΔV_{TH} values to the unperturbed OLED current (ΔV_{TH} = 0V) for the input data. It is shown that the OLED current variations are significantly reduced as less than 9% even for ΔV_{TH} equals to 2.0V while the 5T2C pixel circuit shows more than 18% variation. As shown in Fig. 6, when the V_{TH} of driving TFT is shifted negatively, the proposed voltage-programmed pixel circuit can compensate for negative ΔV_{TH} below 10%, while the 5T2C voltage-programmed pixel circuit still shows over 15% OLED current variation.

To investigate the mobility compensation ability of the proposed pixel circuit, we assume that the mobility of driving TFT is swept from -50% to +50% of the initial mobility value, and plot ΔI_{OLED} as a function of Δmobility when V_{DATA} = 0.5

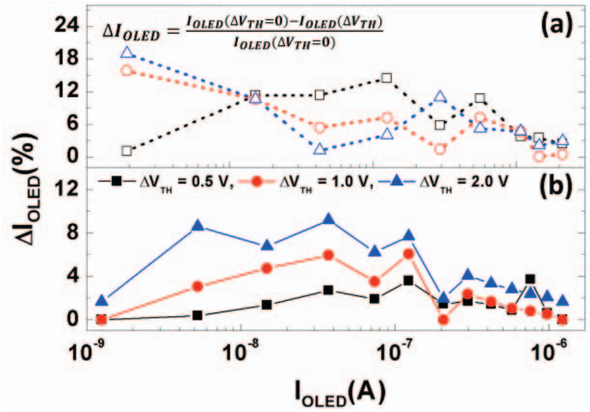

Fig. 5. ΔI_{OLED} as a function of I_{OLED} for different levels of negative ΔV_{TH} shift in (a) 5T2C and (b) proposed pixel circuits.

OLED current is less than 10% even for ±50% mobility variations while conventional 5T2C pixel circuit has easily over 32% OLED current error for same levels of mobility variation. Therefore, the simulation results indicate that the proposed voltage-programmed pixel circuit has higher immunity to mobility variation of a-InGaZnO TFT from one pixel to another, compared with the conventional 5T2C pixel circuit.

4. Conclusions

We proposed a novel voltage-programmed pixel circuit based on a-InGaZnO TFT for AMOLEDs. The proposed pixel circuit minimizes the non-uniformity on the display image caused by variations of V_{TH} and mobility. As shown from our simulation results, the non-uniformity of OLED current for the threshold voltage and mobility variation is significantly reduced compared to that of the conventional 5T2C pixel circuit. Thus, the proposed a-InGaZnO pixel circuit with dual-compensating function can supply highly stable current to OLED device and can be applied to a large size, high resolution AMOLEDs.

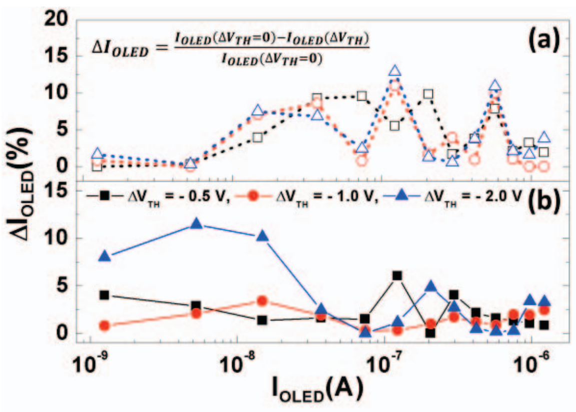

Fig. 6. ΔI_{OLED} as a function of I_{OLED} for different levels of negative ΔV_{TH} shift in (a) 5T2C and (b) proposed pixel circuits.

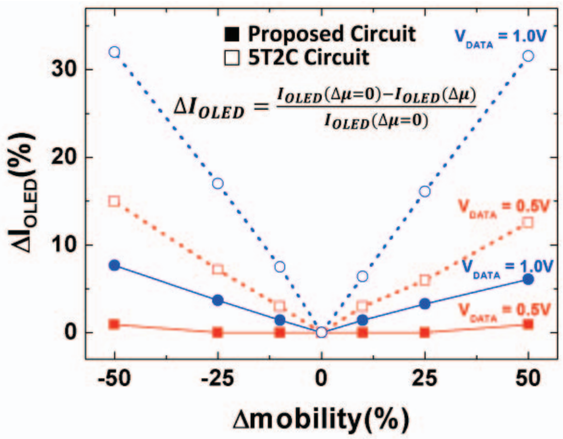

Fig. 7. OLED current error ratio as a function of Δmobility for the proposed and conventional 5T2C pixel circuits.

Acknowledgments

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