

A New AMOLED Pixel Circuit Employing a-Si:H TFTs for High Aperture Ratio

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Abstract

We propose a new pixel design for active matrix organic light emitting diode (AM-OLED) displays using hydrogenated amorphous silicon thin-film transistors (a-Si:H TFTs). The pixel circuit is composed of five TFTs and one capacitor, and employs only one additional control signal line. It is verified by SPICE simulation results that the proposed pixel compensates the threshold voltage shift of the a-Si:H TFTs and OLED.

Keywords : a Si:H TFT, AMOLED, pixel circuit, compensation pixel circuit, voltage programming pixel circuit

1. Introduction

Organic light emitting diodes (OLEDs) are potentially promising devices for flat panel display [1]. OLED pixel circuits employing low temperature polycrystalline silicon thin-film transistors (LTPS TFTs) have been reported due to their superior characteristics compared with hydrogenated amorphous silicon TFTs (a-Si:H TFTs), but the variation of the threshold voltage of poly-Si TFTs by fluctuation of excimer laser energy density would degrade the display quality [2,3].

The a-Si:H TFTs have good uniformity in the threshold voltage and mobility. This explains the considerable attention that has been given to AMOLED employing a-Si:H TFTs pixel [4]. However, the threshold voltage of driving a-Si:H TFT is shifted severely by the electrical bias that occur during the emission. Especially in the case of the common cathode type employing a-Si:H TFTs, the threshold voltage shift of OLED causes a decrease of gate-source voltage of driving TFT because the anode of OLED is connected to the source node of a driving TFT [5], and the overall aperture ratio is reduced by pixel circuit area [4]. These problems cause deterioration in the display quality. Therefore, the pixel circuit should compensate threshold voltage shift of TFTs and OLEDs, and the area occupied by the pixel circuit should be relatively small.

Several pixel designs of a-Si:H TFTs, which are employed through the voltage-programming method, have been reported [5-7]. The voltage modulation driving method is known to compensate or the threshold voltage shift of a-Si:H TFTs and OLEDs [5], but it requires two additional control signal lines and two capacitors.

We propose a simple voltage modulated a-Si:H TFT AM-OLED pixel design. The proposed pixel circuit, which is composed of 5-TFTs and 1-capacitor, can compensate for the threshold voltage shift of TFTs and OLEDs. An aperture ratio of pixel area would be increased by reducing the number of signal lines and capacitor.

2. Proposed Pixel Circuit

Fig. 1 shows the proposed pixel structure and the timing diagram. The proposed pixel design consists of four switching TFTs, one driving TFT (TR2) and one capacitor (C_{st}).

As shown in Fig. 1 (b), the proposed AMOLED pixel is driven by very simple driving scheme that requires an additional signal line entitled EMS (emission) line. Especially, the DATA signals have negative value of data voltage ($-V_{data}$) needed to operate a driving TFT. The timing diagram is composed of four stages during the 1

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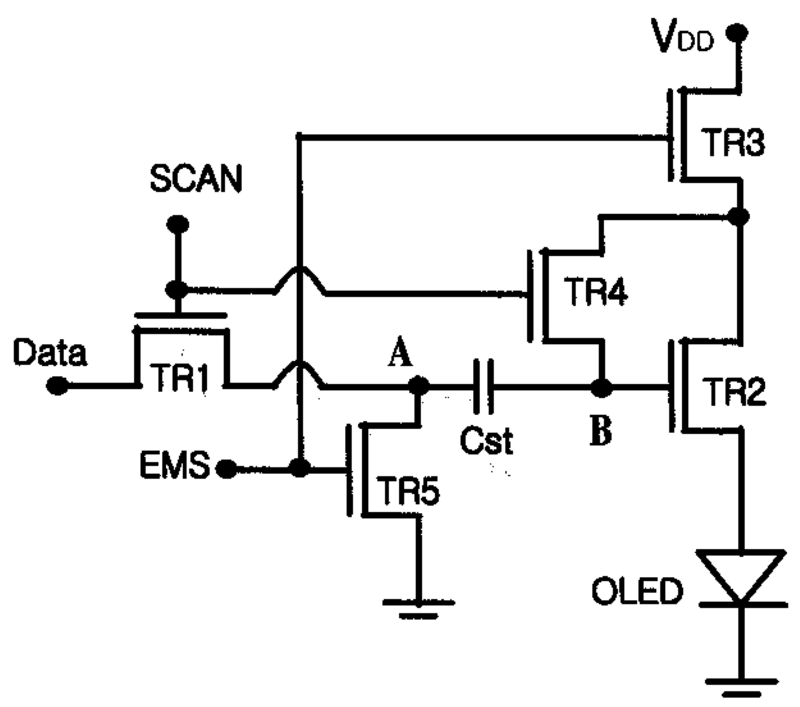
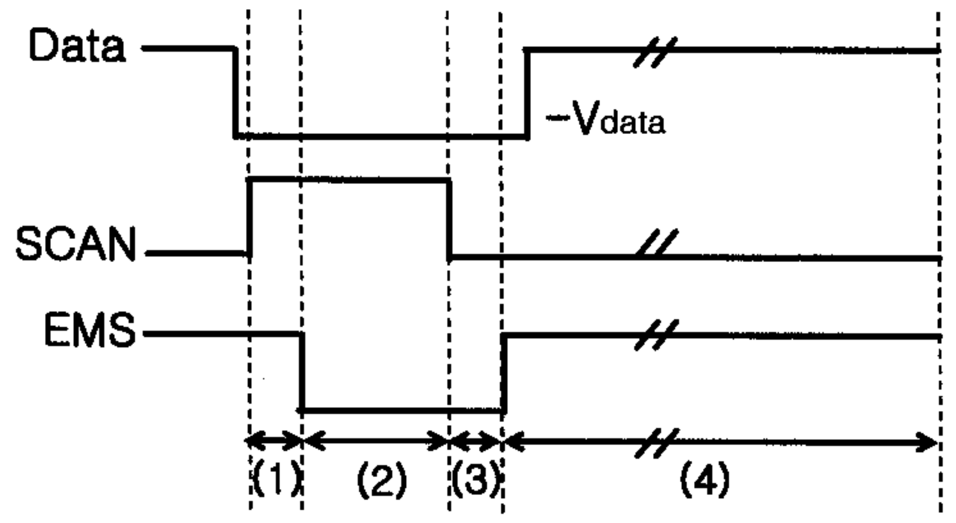


(a)



(b)

Fig. 1. (a) The proposed pixel design and (b) timing diagram.

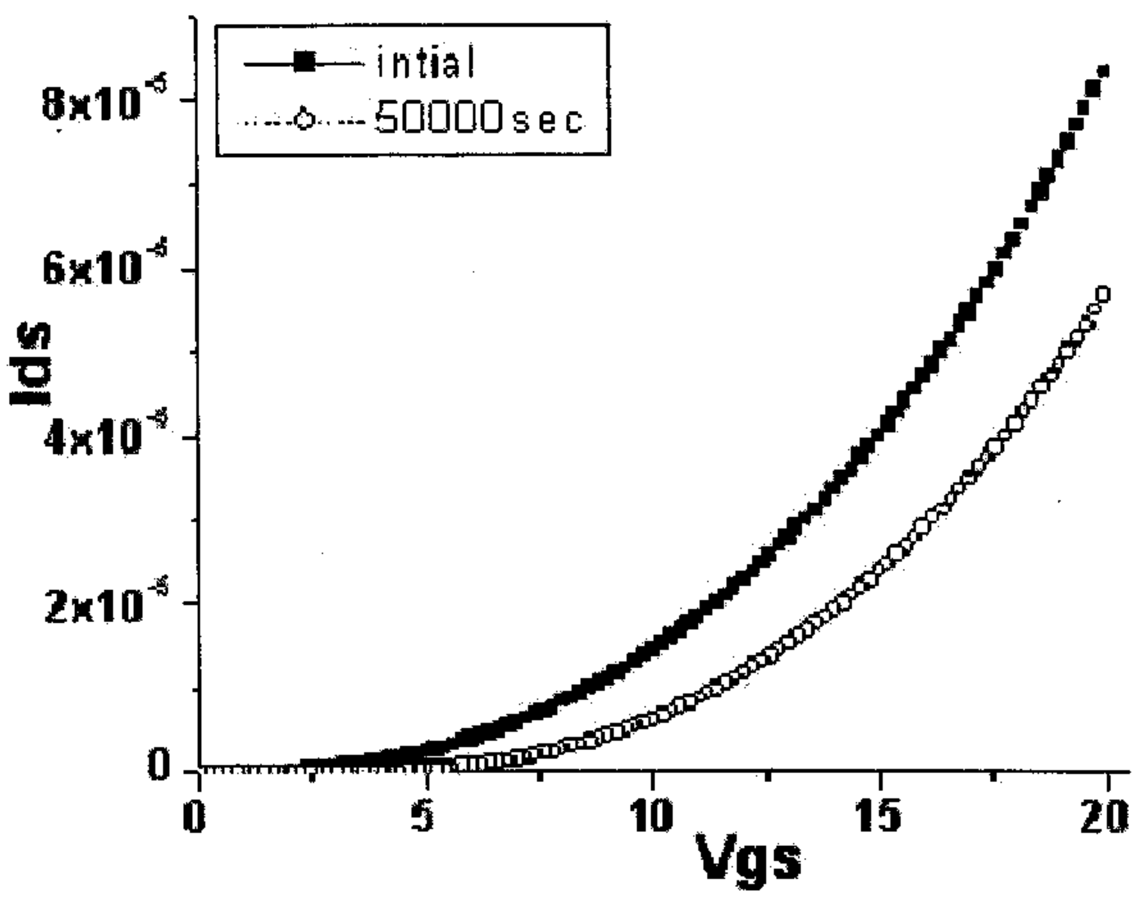


Fig. 2. Experiment results : the degradation of a-Si:H TFT after 50000 sec stress (V_{gs} =25V, V_{ds} = 0V).

frame. In period (1), pre-charging block, all TFTs turn on and the voltage of node B, which is the gate node of the driving TFT (TR2), would be charged up close to V_{DD} in order to form the diode connection of TR2. The voltage of node A is fixed to $-V_{data}$ at this time. During period (2), the EMS signal is low and the SCAN signal is high, then TR3 and TR5 are turned off. The voltage of node A still holds on $-V_{data}$ and the voltage of node B is closed to $V_{th}+V_{TO}$ by the diode connection of TR2, where V_{th} is the threshold voltage of the driving TFT and V_{TO} is the threshold voltage of the OLED. The C_{st} stores $-V_{data}$, the threshold voltage of TR2 (V_{th}) and OLED (V_{TO}) as follows.

$$V(C_{st}) = V(node\ B) - V(node\ A)$$

$$= V_{th} + V_{TO} - (-V_{data})$$

$$= V_{th} + V_{TO} + V_{data} \qquad ....(1)$$

In period (3), all control signals become low. TR5 and TR4 should not turn on at the same time so that the voltage of previous period (Period (2)) in C_{st} is maintained.

Finally, period (4) is the emission period. As EMS signal increases to high, TR5 and TR3 turns on. Node A connects to the ground and TR2 operates on the saturation regime. As there is stored voltage in C_{st}, the voltage of node B becomes $V_{th}+V_{TO}+V_{data}$. Meanwhile, the anode voltage of OLED is $V_{TO} + \Delta V_{OLED}$. Therefore, V_{gs} and I_{OLED} can be represented by following equations (2) and (3).

$$V_{gs} = (V_{th} + V_{TO} + V_{data}) - (V_{TO} + \Delta V_{OLED}(V_{data}))$$

$$= V_{th} + V_{data} - \Delta V_{OLED}(V_{data}) \qquad .....(2)$$

$$I_{OLED} = \frac{1}{2}k(V_{gs} - V_{th})^2$$

$$= \frac{1}{2}k(V_{data} + V_{th} - \Delta V_{OLED}(V_{data}) - V_{th})^2$$

$$= \frac{1}{2}k(V_{data} - \Delta V_{OLED}(V_{data}))^2 \qquad ....(3)$$

where k is $\mu \cdot C_{ox} \cdot W/L$

$\Delta V_{OLED}(V_{data})$, which is the difference between the anode voltage of period (2) and that of period (4), is dependant on the data voltage (V_{data}). However, the variation of V_{gs} of TR2 by ΔV_{OLED} is smaller that of the V_{gs} due to the threshold voltage shift of TFT. This causes the variation of the OLED current by the threshold voltage shift to become reduced.

Table 1. The device parameter of pixel circuit used in the simulation

Parameters	values
(W/L) of TR2, TR3	200/3.5 μm
(W/L) of TR1 TR4, TR5	50/3.5 μm
Storage Capacitor (C_{st})	0.4 pF
SCAN Voltage	-8 ~ 25 V
EMS Voltage	-8 ~ 25 V
V_{DD}	16 V
V_{SS}	0 V
Line select time	20 μsec
Data voltage ($-V_{data}$)	-2.5 ~ -7.5 V

To verify the pixel circuit performance, we carried out circuit simulation using SMART SPICE. For more realistic investigation, the device parameters of a a-Si:H TFT were extracted from the fabricated a-Si:H TFTs. Fig. 2 shows the transfer characteristics of a-Si:H TFT before and after 50,000 sec stress at V_{gs}=25V and V_{ds}=0V. The simulation parameters are summarized in Table 1.

3. Simulation Result

Fig. 3 shows the modulated voltages of node A and node B in the proposed AM-OLED pixel. It shows that the negative value of data voltage is written to node A during compensation stage (period (2)), and that voltage of node B becomes the sum of the threshold voltage of driving TFT and OLED. The capacitor (C_{st}) is charged to the compensated data voltage (V_{th}+V_{TO}+V_{data}), and maintains the stored voltage until pre-charging period of the next frame. In period (4), it is verified that the voltage of node B is the compensated data voltage, which is the same as the stored voltage in C_{st}. This is because the value of data voltage successfully transfers to node B through C_{st}.

Fig. 4 shows the simulation results of the proposed AMOLED pixel, when the threshold voltage of driving TFT varies from 3V to 5 V. The OLED current variation is 7% of current at 3 data voltage and 1% at 6V data voltage.

Fig. 5 shows the OLED output current after 10,000 hours operation. Throughout this operation, the rate of the threshold voltage shift of OLED is 0.2mV/h and total voltage shift is 2V after 10,000 hours [5]. Fig. 6 shows the

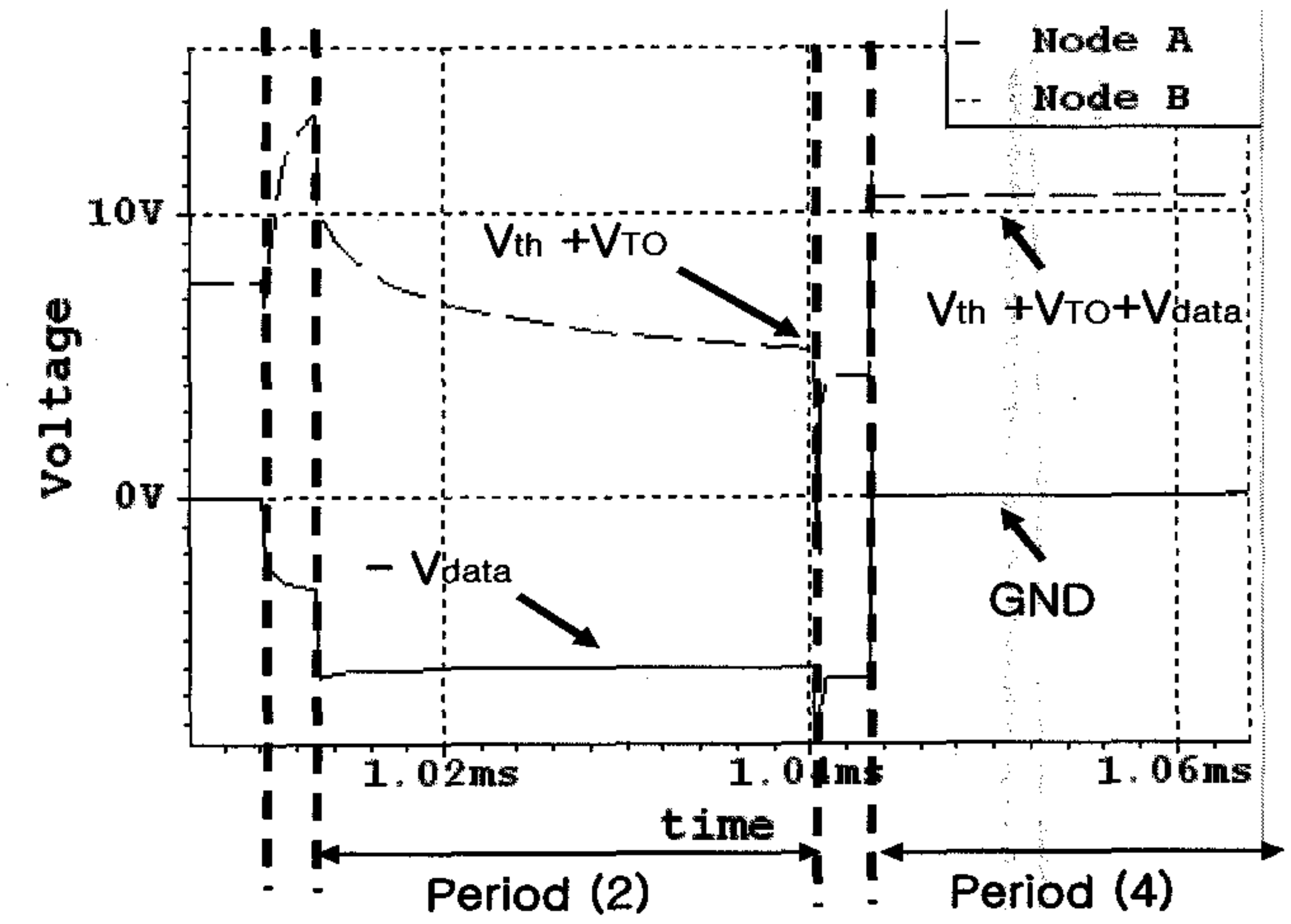


Fig. 3. The voltages of node A and node B with operation stages. (Period (2) : compensation stage, (4) : emission stage)

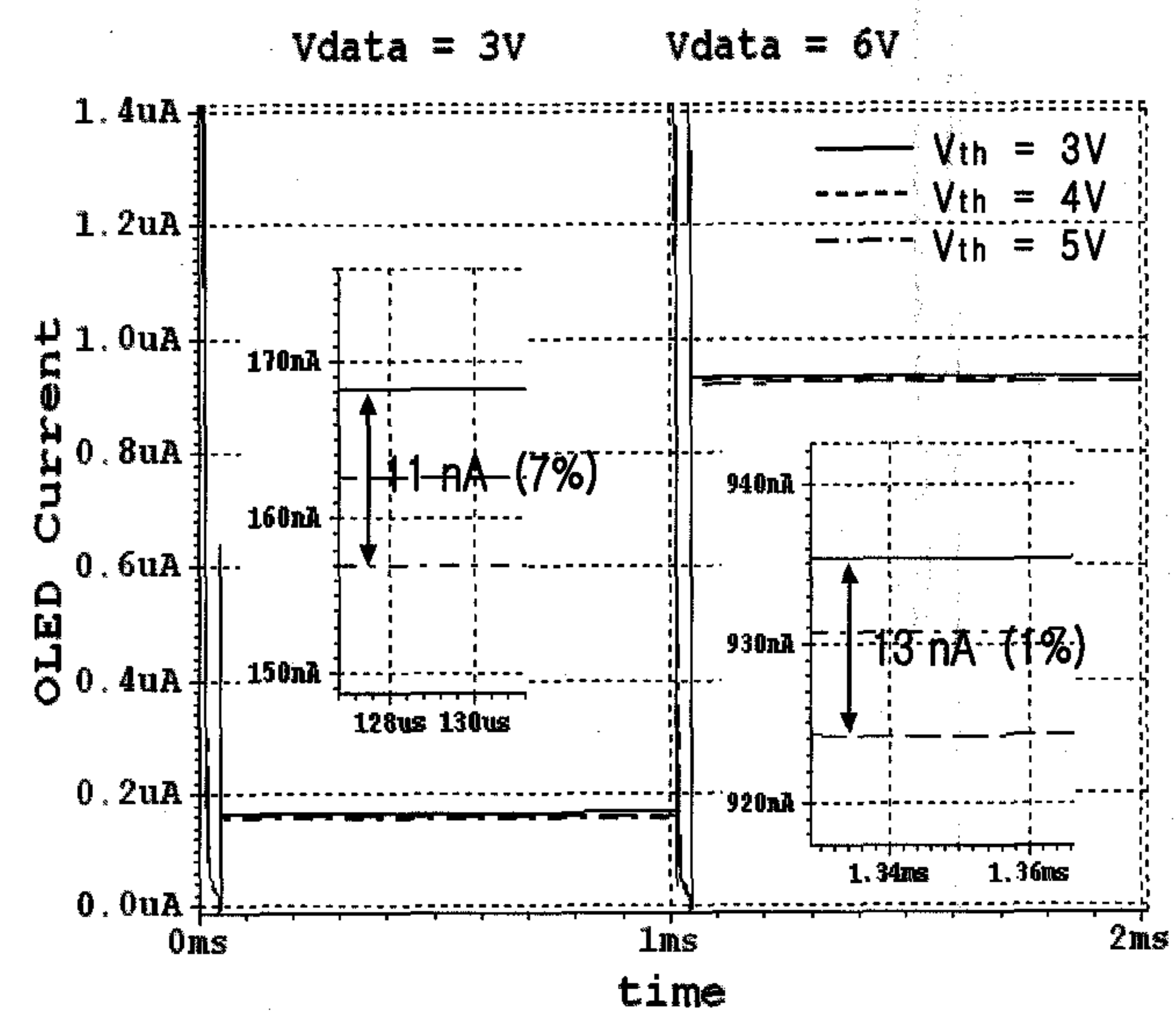


Fig. 4. Simulation results : The OLED current variation of the proposed AMOLED pixel according to threshold voltage shift of driving TFT, in case of V_{data}= 3V and V_{data}= 6V.

variation of OLED current when the threshold voltage of OLED varies from 2.5V to 4.5V. The current variation is 6% at 3V of data voltage and is 3%, 6V of data voltage. This simulation results indicate that the threshold voltage shift of OLED does not have much effect on OLED current in proposed pixel circuit.

As the proposed pixel circuit is simulated with both the V_{th} and V_{TO} shift (ΔV_{th} =2V, ΔV_{TO}=2V), OLED current reduction is about 7%. When the compensation circuit reported by Goh [5] was simulated by using the same

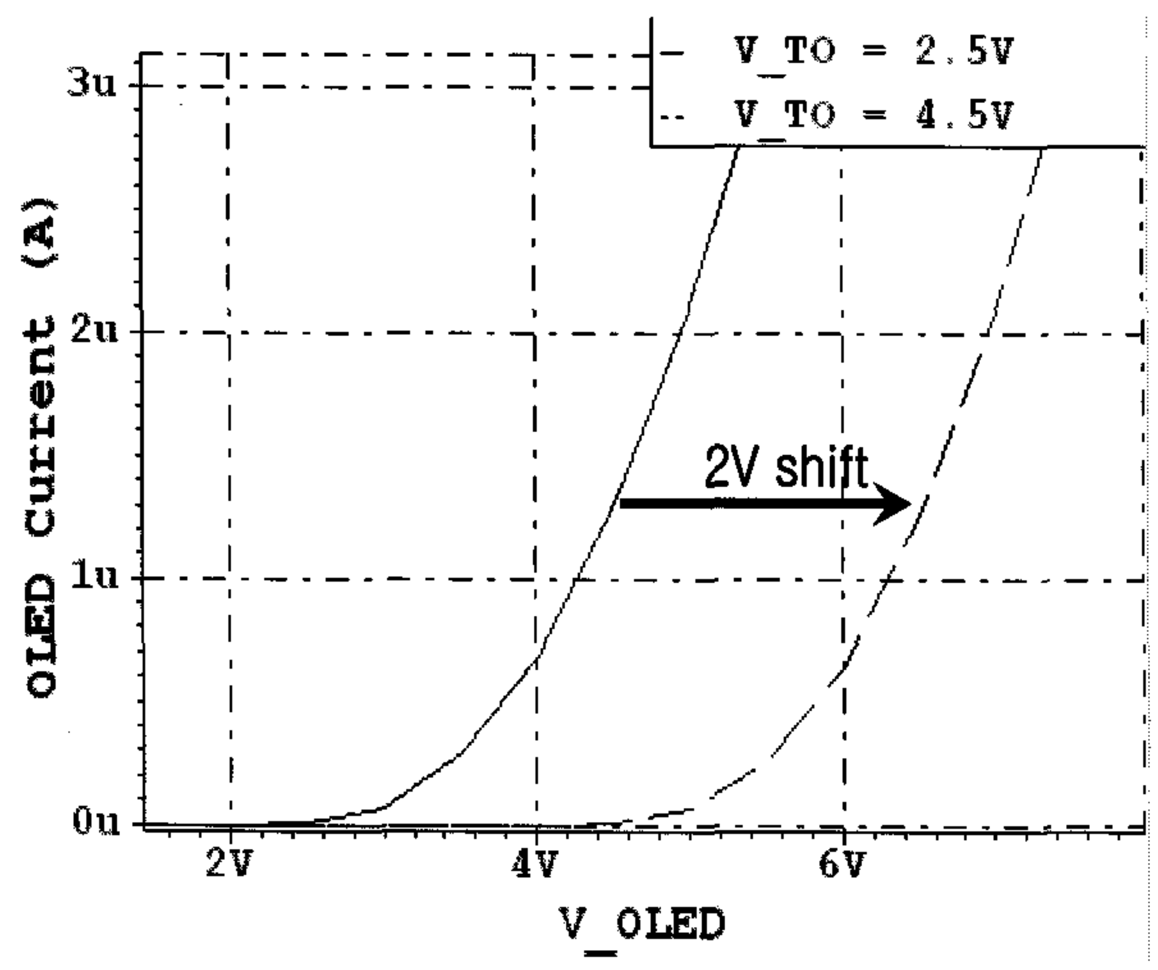


Fig. 5. Simulation results : the turn-on voltage shift of OLED after 10,000 hours operation. (1) Initial condition : V_{TO}=2.5 V, (2) After stress condition : V_{TO}=4.5 V.

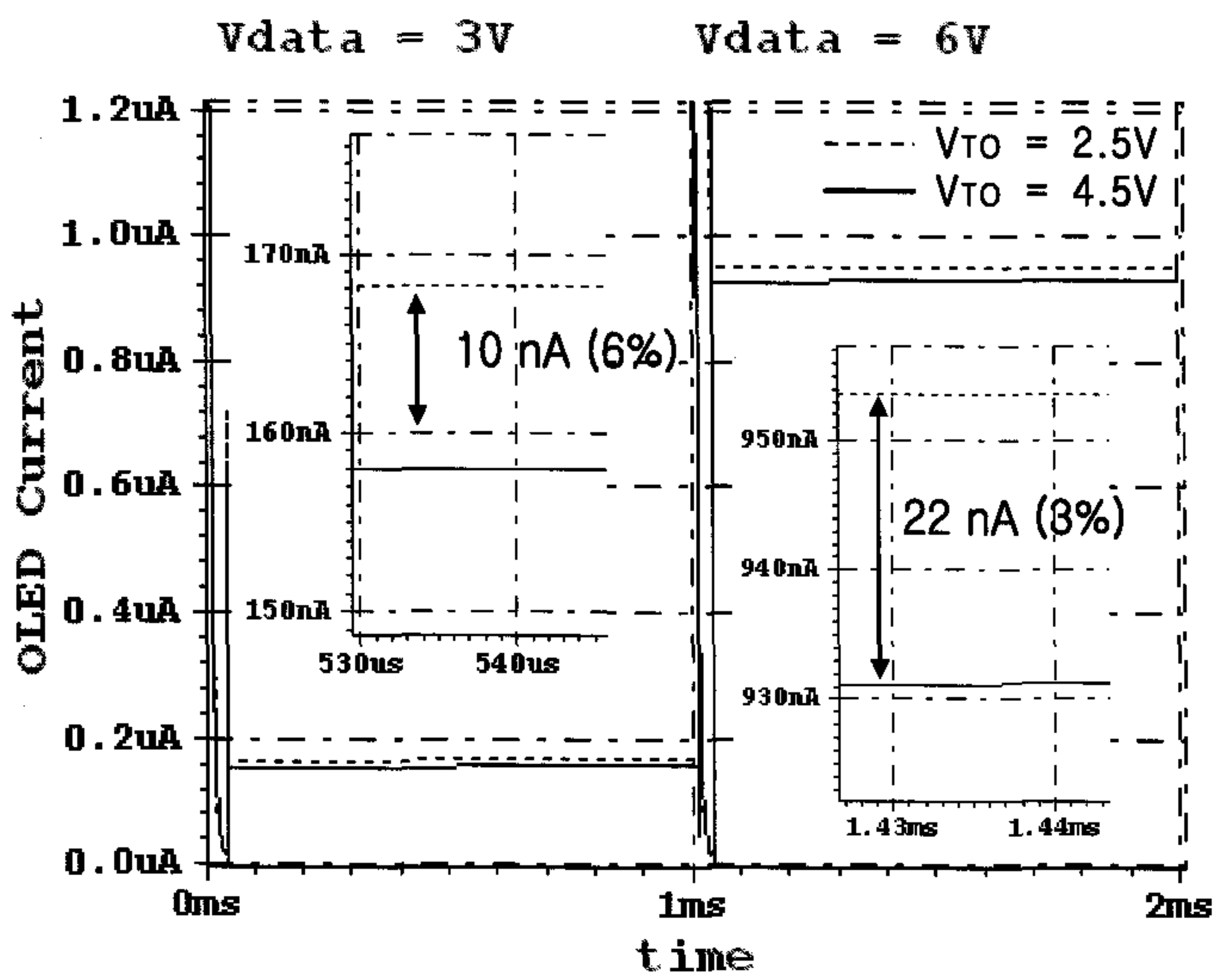


Fig. 6. Simulation results : The OLED current variation of the proposed AMOLED pixel according to turn-on voltage shift of OLED, in case of V_{data} = 3V and V_{data} = 6V.

conditions and device parameters, the current reduction was 6%. That is similar to the proposed pixel, even though the proposed pixel had smaller pixel circuit area due to reduce control signal line and capacitor.

4. Conclusions

We have proposed a new voltage modulated AMOLED pixel design based on the a-Si:H TFTs. The proposed pixel, which consists of five TFTs, one capacitor and two control signal, can have high aperture ratio. SPICE simulation results, of which device parameters are extracted from experimental data, show that the pixel successfully compensates for the shift of the threshold voltage of TFTs and OLED.

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