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

***Hee-Sun Shin**, Jae-Hoon Lee, Sang-Hoon Jung, Chang-Yeon Kim and Min-Koo Han*
School of electrical engineering, Seoul National University, Seoul, Korea
Phone: +82-2-880-7992, Fax: +82-2-871-7992, E-mail: vitriol@emlab.snu.ac.kr

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.

1. Introduction

Organic light emitting diodes (OLEDs) may be promising devices for flat panel display [1]. OLED pixel circuits employing low temperature polycrystalline silicon thin-film transistors (LTPS TFTs) have mostly reported due to 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. AMOLED employing a-Si:H TFTs pixel has been paid considerable attention [4]. However, the threshold voltage of driving a-Si:H TFT is shifted severely by electrical bias during the emission. Especially in the case of the bottom emission type employing a-Si:H TFTs, because the anode of OLED is connected to the source node of a driving TFT, the threshold voltage shift of OLED makes a decrease of gate-source voltage of driving TFT [5], and the overall aperture ratio is reduced by pixel circuit area [4]. These problems cause deterioration of display quality. 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 voltage-programming method, have been reported [5-7]. And The voltage modulation driving method reported compensate 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 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

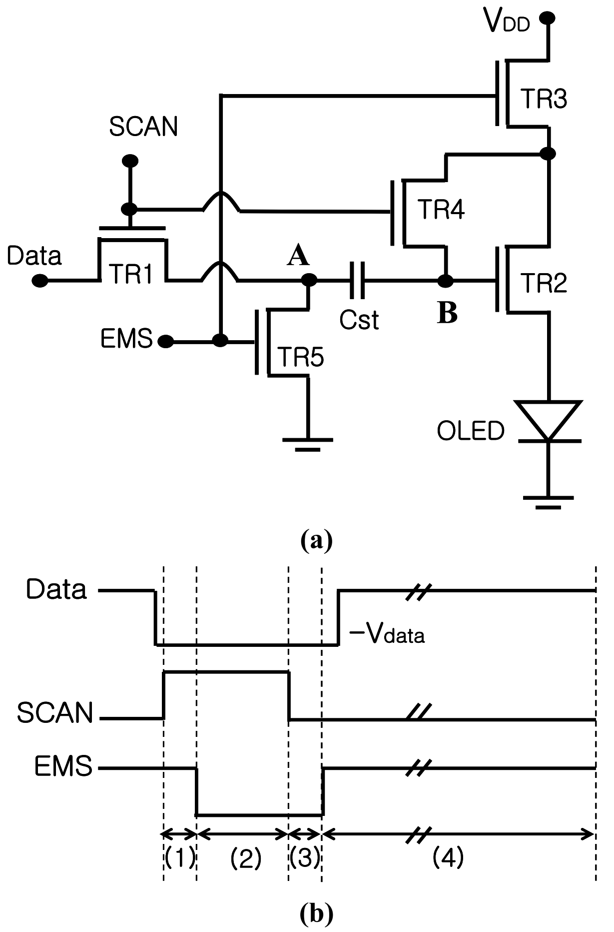

Figure 1 . (a) The proposed pixel design and (b) timing diagram.

Figure 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 figure 1 (b), the proposed AMOLED pixel is driven by very simple driving scheme which required an additional signal line entitled EMS (emission) line. Especially, the DATA signals have negative value of data voltage ($-V_{data}$) which is needed in operating driving TFT. The timing diagram is composed of four stages during the 1 frame. In the period (1), pre-charging block, all TFTs turn on and the voltage of node B, which is the gate node of 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 the 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 hold 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 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 following equation (1).

$$
\begin{aligned}
V(C_{st}) &= V(node\ \ B) - V(node\ \ A) \\
&= V_{th} + V_{TO} - (-V_{data}) \\
&= V_{th} + V_{TO} + V_{data} \qquad \text{...............(1)}
\end{aligned}
$$

In the period (3), all control signals become low. TR5 and TR4 should not turn on at the same time in order to maintain voltage of previous period (Period (2)) in C_{st}. Finally, period (4) is emission period. As EMS signal becomes high, TR5 and TR3 turns on. Node A connects to ground and TR2 operates on saturation regime. Because of stored voltage in C_{st}, the voltage of node B becomes to $V_{th}+V_{TO}+V_{data}$. And the anode voltage of OLED is $V_{TO} + \Delta V_{OLED}$. Therefore, V_{gs} and I_{OLED} is given by following equations (2) and (3).

$$
\begin{aligned}
V_{gs} &= (V_{th} + V_{TO} + V_{data}) - (V_{TO} + \Delta V_{OLED}(V_{data})) \\
&= V_{th} + V_{data} - \Delta V_{OLED}(V_{data}) \qquad \text{..... (2)}
\end{aligned}
$$

$$
\begin{aligned}
I_{OLED} &= \frac{1}{2} k (V_{gs} - V_{th})^2 \\
&= \frac{1}{2} k (V_{data} + V_{th} - \Delta V_{OLED}(V_{data}) - V_{th})^2 \\
&= \frac{1}{2} k (V_{data} - \Delta V_{OLED}(V_{data}))^2 \qquad \text{....... (3)}
\end{aligned}
$$

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

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

To verify the pixel circuit performance, we carried out device simulation using SMART SPICE. For more realistic investigation, device parameters of a a-Si:H TFT were extracted from the a-Si:H TFTs fabricated. Figure 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. And the simulation parameters are summarized in Table 1.

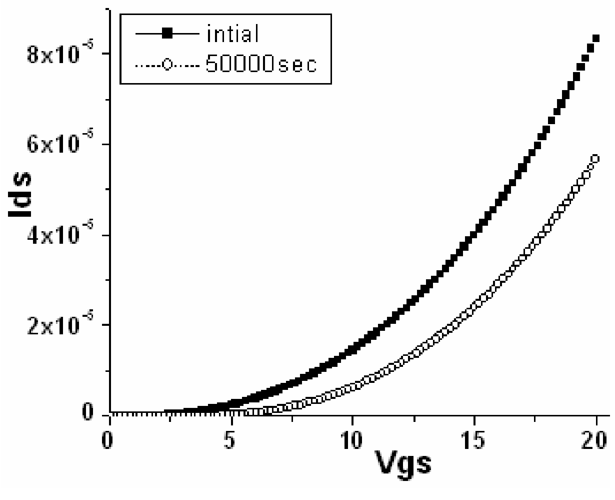

Figure 2. Experiment results : the degradation of a-Si:H TFT after 50000 sec stress

(V_{gs} =25V V_{ds} = 0V).

Table 1. Device parameter of pixel circuit used in 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

3. Simulation result

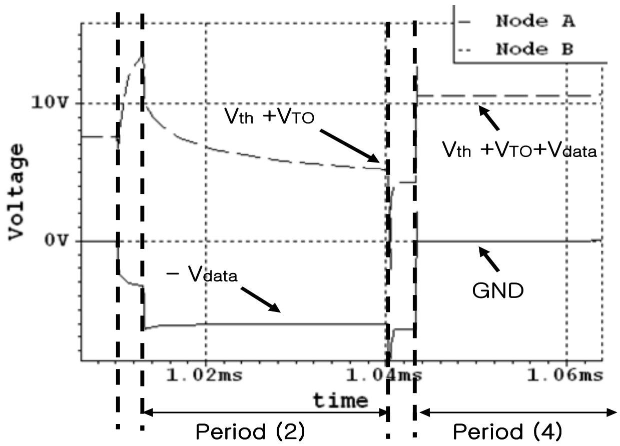

Figure 3. The voltages of node A and node B with operation stages. (Period (2) : compensation stage, (4) : emission stage.)

Figure 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 next frame. In the period (4), it is verified that the voltage of node B is the compensated data voltage as same as stored voltage in C_{st}, because the value of data voltage successfully transfer to node B through C_{st}.

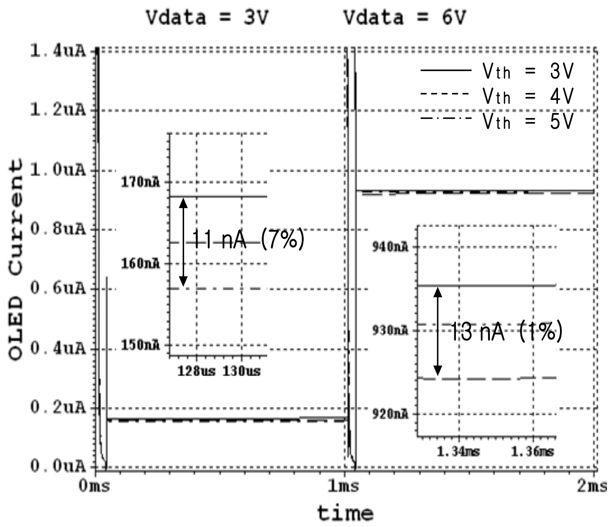

Figure 4. Simulation results : The OLED current variation of the proposed AMOLED pixel according to threshold voltage shift of driving TFT, in case of V_{data} = 3V and V_{data} = 6V.

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

Figure 5 shows the OLED output current after 10,000 hours operation, assuming the rate of the threshold voltage shift of OLED is 0.2mV/h and total voltage shift is 2V after 10,000 hours [5]. Figure 6 shows the variation of OLED current when 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 of 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] is simulated by using the same conditions and device parameters, the current reduction is 6%. That is similar to the proposed pixel, though the proposed pixel has smaller pixel circuit area due to reduce control signal line and capacitor.

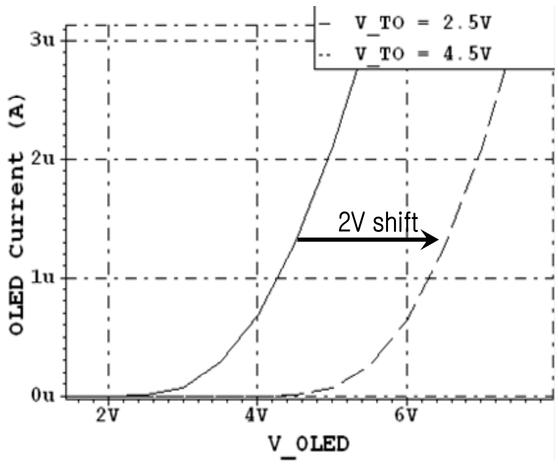

Figure 5. Simulation results : the turn-on voltage shift of OLED after 10,000 hours operation.

(1) Initial condition : V_{TO}=2.5V, (2) After stress condition : V_{TO}=4.5V.

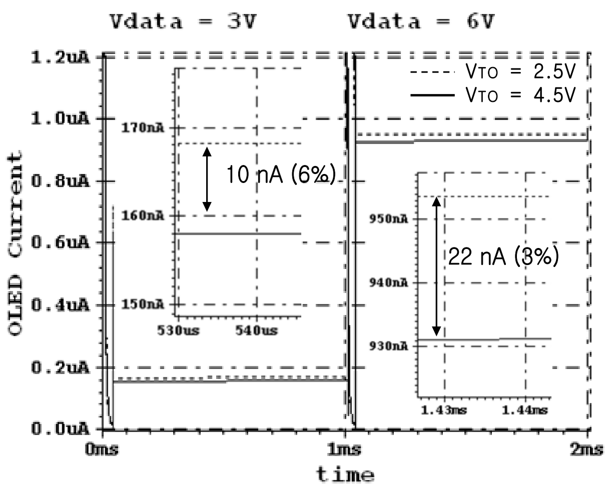

Figure 6. Simulation results : The OLED current variation of the proposed AMOLED pixel according to turn-on voltage shift of OLED, in case of V_{data} = 3V and V_{data} = 6V.

4. Conclusion

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, may have high aperture ratio. SPICE simulation results, of which device parameters are extracted from experiment data, shows that the pixel successfully compensates for the shift of threshold voltage of TFTs and OLED

5. References

[1] J. A. Nichols, T. N. Jackson, M. H. Lu, and M. Hack, “a-Si:H TFT Active-Matrix Phosphorescent OLED Pixel”, SID Dig. 33, pp1368-1371, 2002.

[2] M. J. Powell, C. van Berkel, I. D. French, D. H. Nicholls, “Bias dependence of instability mechanisms in amorphous silicon thin-film transistors”, Applied Physics Letters, Vol 41, p1242, 1987

[3] Y.He, R.Hattori, J.Kanicki, “Improved a-Si:H TFT pixel electrode circuits for active-matrix organic light emitting displays”, IEEE Trans. Electron Devices, Vol 48, pp1322-1325, 2001

[4] A.Nathan, K.S.Karim, “Amorphous Silicon Back-Plane Electronics for OLED Displays”, IEEE Journal of Selected Topics in Quantum Electronics, pp58 - 69, 2004

[5] J.C.Goh, C.K.Kim, J.Jang, “A New a-Si Pixel Design for Amorphous-Silicon Backplane of Active-Matrix Organic Light-Emitting Diode Displays”, SID Dig. 35, P276, 2004

[6] J.L.Sanford and F.R.Libsch, “TFT AMOLED Pixel Circuits and Driving Methods”, SID Dig. 34, pp10-13, 2003

[7] J.C.Goh, J.Jang; K.S.Cho; C.-K. Kim “A New a-Si:H Thin-Film Transistor Pixel Circuit for Active-Matrix Organic Light-Emitting Diodes”, IEEE Electron device letter Vol 24, pp583- 585, 2003