

## Novel a-Si:H TFT $V_{th}$ Compensation Pixel Circuit for AMOLED

Hee-Sun Shin\*, Jae-Hoon Lee, Joong-Hyun Park, Sung-Hwan Choi and Min-Koo Han

School of Electric Engineering and Computer Science #50

Seoul National University

Seoul, Korea, 151-742

\*vitriol@emlab.snu.ac.kr

**Abstract:** A pixel design for active matrix organic light emitting diode (AM-OLED) displays employing hydrogenated amorphous silicon (a-Si:H) thin film transistors (TFTs) is proposed. The proposed pixel circuit, which composed of five TFTs and one capacitor, could compensate the shift of threshold voltage of OLED as well as the threshold voltage of a-Si:H. We fabricated the pixel circuits on the glass substrate and verified that the proposed pixel circuit could successfully compensate the threshold voltages of a-Si:H TFT and OLED.

**Keywords:** degradation; a-Si:H TFT; AMOLED; pixel circuit; compensation pixel circuit; threshold voltage shift

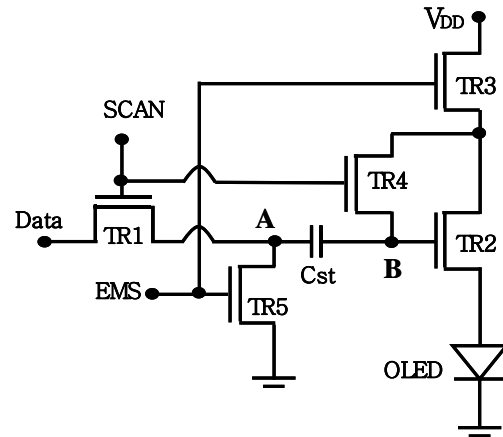
### Introduction

Organic light emitting diodes (OLEDs) may be attractive display for flat panel display due to high brightness, high efficiency and fast response time [1,2]. Recently, OLED pixel circuits employing hydrogenated amorphous silicon TFTs (a-Si:H TFTs) has been paid considerable attention because of good uniformity in the threshold voltage and mobility of the a-Si:H TFTs [3-6]. Moreover, the hydrogenated amorphous silicon (a-Si:H) technology has the mature infrastructure with low fabrication cost [3]. However, the threshold voltage of driving a-Si:H TFT is degraded severely by electrical bias during the emission. 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 [7]. These problems cause deterioration of display quality. The pixel circuit should compensate threshold voltage shift of TFTs and OLEDs. Several pixel circuits employing a-Si:H TFTs have been reported in order to compensate the instability of a-Si:H TFT.

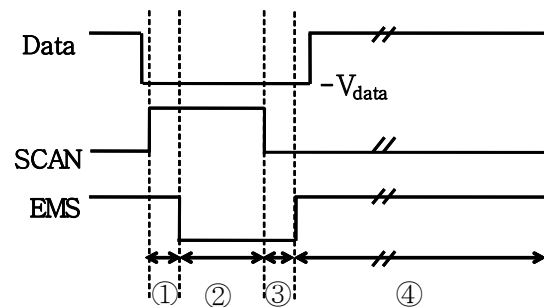
We have proposed and fabricated a simple voltage modulated a-Si:H TFT AM-OLED pixel design on the glass substrate. The proposed pixel circuit, which is composed of 5-TFTs and 1-capacitor, can compensate the threshold voltage shift of TFTs and OLEDs.

### Proposed Pixel Circuit

We propose an a-Si:H TFT backplane AMOLED pixel employing voltage modulation as shown Figure 1. The proposed pixel design consists of four switching TFTs, one driving TFT (TR2) and one capacitor (Cst), and needs one additional signal line (EMS).



(a)



(b)

**Figure 1.** (a) The proposed pixel design and (b) timing diagram. (One frame time is consist of pre-charging period, compensation period, holding period and emission period)

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 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 periods during 1 frame time.

During the pre-charging period (period ①), 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 VDD in order to reset a previous data stored in the storage capacitor.

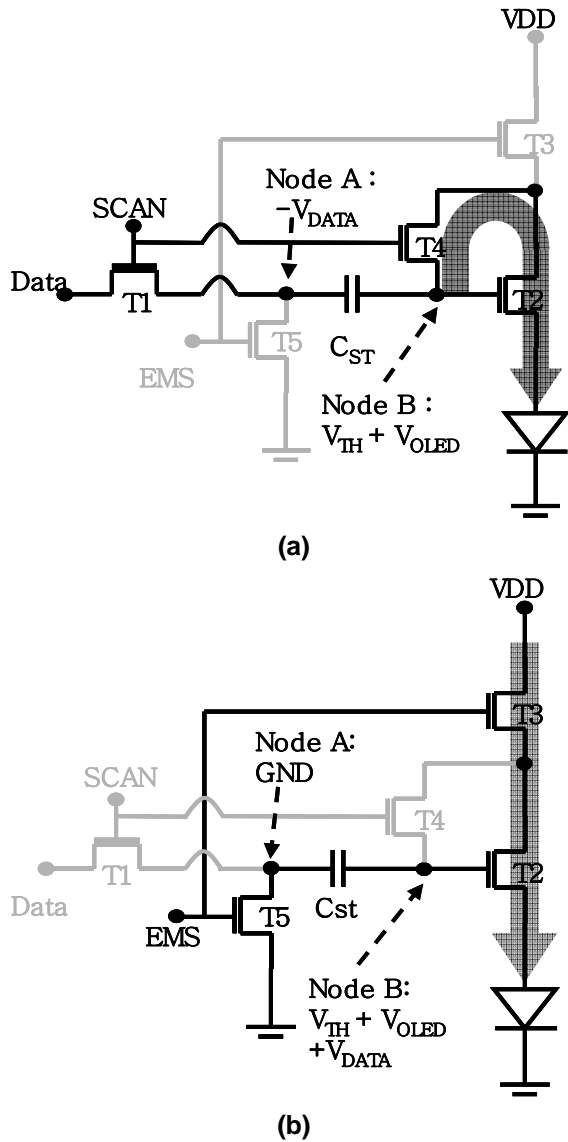


Fig. 2 Operation scheme of (a) compensation period and (b) emission period.

During the compensation period (period ②), the threshold voltage of driving TFT ( $V_{th}$ ) and the threshold voltage of OLED ( $V_{TO}$ ) are detected by compensating operation. As shown in Fig.2(a), the EMS signal is low and the SCAN signal is high so that TR3 and TR5 are turned off. The voltage of node A holds on  $-V_{data}$ , and the voltage of node B is closed to the sum of the  $V_{th}$  and  $V_{TO}$ . The  $C_{st}$  stores  $-V_{data}$ , the threshold voltage of TR2 ( $V_{th}$ ) and OLED ( $V_{TO}$ ) as following equation (1).

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

In the holding period (period ③), all control signals become low. TR5 and TR4 should not turn on at the same time in order to hold the stored voltage in the

capacitor. Finally, EMS signal becomes high and TR5 and TR3 turns on during the emission period (period ④), as shown in Figure 2(b). Node A connects to ground by T5 and TR2 operates on saturation regime. Because of the 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  $I_{OLED}$  are given by following equations (2) and (3).

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

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

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 compensation period and that of the emission period is dependant on data voltage ( $V_{data}$ ). However, the variation of  $V_{gs}$  of TR2 by  $\Delta V_{OLED}$  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.

**Simulation and Fabrication**

To verify the pixel circuit performance, we carried out device simulation using SMART SPICE. For more realistic investigation, device parameters of an a-Si:H TFT were extracted from the a-Si:H TFTs fabricated. The width and length of the driving TFT is  $200\mu\text{m}$  and  $7\mu\text{m}$ . The threshold voltage of OLED was 2.5 V and the storage capacitance was 0.3 pF.

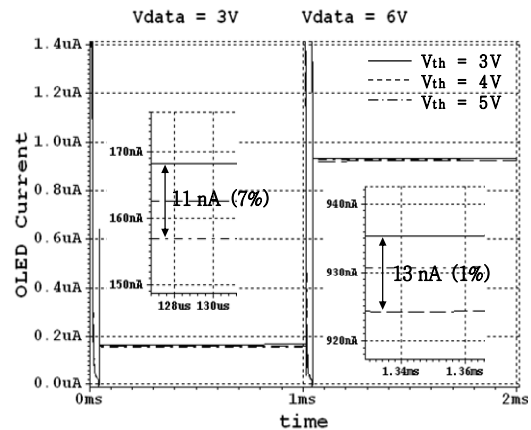
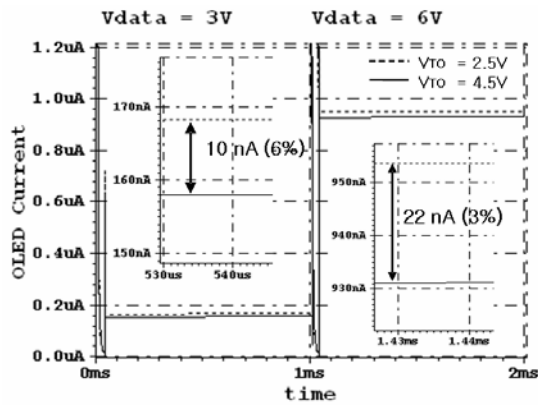


Figure 3. Simulation results : The OLED current variation of the proposed AMOLED pixel according to the threshold voltage shift of driving TFT, in case of  $V_{data} = 3V$  and  $V_{data} = 6V$ .

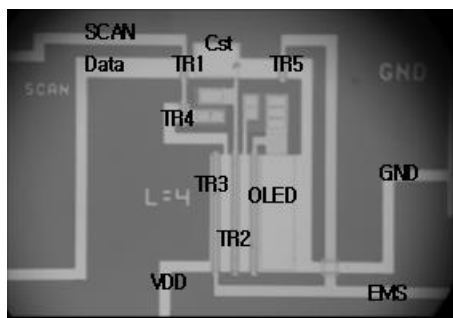


**Figure 4.** Simulation results : The OLED current variation of the proposed AMOLED pixel according to turn-on voltage shift of OLED, in case of  $V_{data} = 3V$  and  $V_{data} = 6V$ .

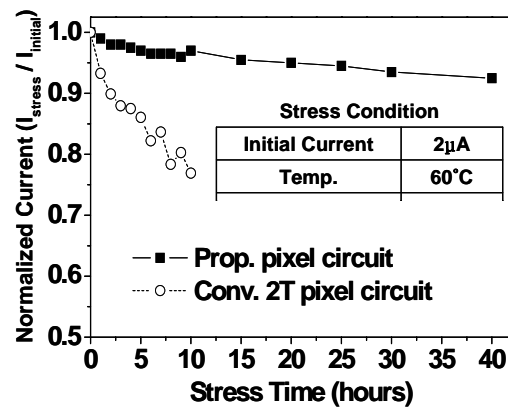
Figure 3 shows the OLED current variation of the proposed pixel according to the TFT threshold voltage shift. For three different threshold voltage of driving TFT such as 3V, 4V and 5V, the OLED current of the proposed pixel varies under 7% of OLED current at 3V data voltage and 1% at 6V data voltage.

Figure 4 shows the variation of OLED current according to the threshold voltage shift of OLED. When the threshold voltage of OLED varies from 2.5V to 4.5V, the OLED current is decreased about 6% at 3V of data voltage and about 3% at 6V of data voltage. This simulation results indicate that the threshold voltage shift of OLED does not have much effect on OLED current in the proposed pixel circuit. As the proposed pixel circuit is simulated with both of  $V_{th}$  and  $V_{TO}$  shift ( $\Delta V_{th}=2V$ ,  $\Delta V_{TO}=2V$ ), OLED current reduction is about 7%.

We fabricated the conventional 2-TFT pixel circuit and the proposed pixel circuit in order to verify the simulation results as shown in Figure 5(a). We carried out the long-term operation of 40hours for the proposed pixel circuit and of 10hours for the conventional pixel circuit. In order to accelerate the degradation of TFT, the data voltages during the operation time were determined to supply 2 $\mu$ A of the initial OLED current on the 60°C. The OLED is modeled by the parallel connection of an a-Si:H TFT and a capacitor. The compensation of the threshold voltage shift of OLED could be supposed without real OLED, because the a-Si:H TFT modeled as OLED may be also degraded during the operation time.



(a)



(b)

**Figure 5.** (a) photograph of the fabricated pixel circuit and (b) the experimental results : the decrease rate of the OLED current during 40 hours operation.

Figure 5(b) shows the experimental results of conventional 2 TFT pixels and the proposed 5 TFT pixels, which were fabricated. In case of the conventional 2-TFT pixel circuit, although the conventional pixel circuit was operated during 10 hours, the decrease rate of the OLED current was 25%. On the other hands, the OLED current of the proposed circuit is decreased about 8% of initial OLED current after 40hours operation due to the compensation of the threshold voltage shifts of driving TFT and OLED.

### 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 signals, may have a high aperture ratio. SPICE simulation results and experimental results show that the pixel successfully compensates for the shift of threshold voltage of TFTs and OLED

### 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 and D. H. Nicholls, "Bias dependence of instability mechanisms in amorphous silicon thin-film transistors", *Applied Physics Letters*, Vol 41, p1242, 1987
3. G.R. Chaji, P. Servati and A. Nathan," Driving scheme for stable operation of 2-TFT a-Si AMOLED pixel", *Electronics Letters*, Vol. 41, pp499-500, 2005
4. Y.He, R.Hattori and 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
5. A.Nathan and K.S.Karim, "Amorphous Silicon Back-Plane Electronics for OLED Displays", *IEEE*

*H. S. Shin*

*Journal of Selected Topics in Quantum Electronics*,  
pp58 - 69, 2004

6. J.-H. Lee, J.-H. Kim and M.-K. Han, "A new a-Si:H TFT pixel circuit compensating the threshold voltage shift of a-Si:H TFT and OLED for active matrix

OLED", *IEEE Electron Device Letters.*, Vol. 26,  
No. 12, pp897 – 899, 2005

7. J.C.Goh, C.K.Kim and 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