7.3: Reliability Enhancement of AM-OLED with a-Si:H TFT and Top-Anode OLED Employing a New Pixel Circuit

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Abstract: *This paper reports a new pixel circuit suitable for enhancing the reliability of AM-OLED with the a-Si:H TFT backplane and top-anode OLED structure. The propose pixel circuit is composed of 5 a-Si:H TFTs for switching and driving device, and it does not require any complicated drive ICs. The compensation of OLED current against threshold voltage shift of the drive TFT has been verified by SPICE simulations.*

Keywords: AM-OLED; a-Si:H TFT; Pixel Circuit

1. Introduction

Amorphous silicon technology has drawn much attention recently as a competitive candidate for active-matrix organic light emitting display (AM-OLED) due to the benefit of using existing active matrix liquid crystal display (AM-LCD) infrastructures thus maintaining low investment and manufacturing cost [1]. However, amorphous silicon thin film transistor (a-Si:H TFT) has long term stability problems, such as threshold voltage shift due to gate bias stress. Such effect amplifies differential ageing of the drive TFT of each pixel, resulting in non uniform picture quality, as well as the life time degradation of the display [2]. There are several pixel circuits with OLED current compensation scheme to overcome this issue, some of which employs current-programming [3], time ratio gray scaling [4] or threshold voltage compensating [5] methods. Former two methods require development of complicated source drive ICs which are not used in the conventional AM-LCD. Therefore, in order for the display industry to move rapidly from AM-LCD to AM-OLED, utilizing their current a-Si:H TFT facilities, it is favorable to develop a pixel drive scheme based on drivers used in AM-LCD. In this paper, we introduce a pixel circuit capable of controlling the effect of threshold voltage shift to enhance the reliability of AM-OLED without requiring any development of complicated drive ICs.

2. Experiment and Results

2.1. Device Modeling

In order to perform accurate and realistic circuit simulations, we extracted SPICE parameters for a-Si:H TFT and OLED devices. The device fitting results using RPI Amorphous Silicon TFT and Spectre Diode Level-1 models are shown in Figure 1. For reference of TFT modeling, we used measured I-V characteristics of a W/L = 60um/5um a-Si:H TFT, shown in Figure 1.A, and for OLED modeling, we used small molecule RGB samples converted to pixel aperture size (area = 66um×198um), as shown in Figure 1.B. The maximum relative fitting error is less than 10% within operation range.

2.1. AM-OLED Pixel Circuit Operation

We propose a new pixel circuit for AM-OLED using a-Si:H TFT as the driving device and top-anode OLED structure as a top light emission device. We focused on maintaining constant OLED current during threshold voltage shift of the drive TFT by compensating its gate node voltage. The timing diagram and the schematic diagram of the proposed pixel circuit are shown in Figure 2 and Figure 3, respectively. Each pixel is composed of a power line, 2 control lines, 2 capacitors and 5 TFTs; 2 switch TFTs (SW1, SW2), a precharge TFT (PC), a drive TFT (DR) and a mirror TFT (MR). The pixel circuit operates in 4 states; precharge, compensate, restore and drive, as illustrated in Figure 2 and 3. The transient analysis of SPICE simulation during these 4 states is plotted in Figure 4.

During precharge state (Figure 3.A), previous gate2 (Gate2[n-1]) is high (*VGH*), which turns on the precharge TFT (PC). The precharge TFT has its drain and gate node connected, which act as a diode with turn-on voltage same as the TFT's threshold voltage (*Vto*=*Vth*). Since this diode is forward biased, the gate node of drive TFT (DR) is *precharged* to the gate high voltage minus the TFT's threshold voltage (*VGH-Vth*) and stored in the first storage capacitor (Cst1), as noted in Figure 4(a).

During compensate state (Figure 3.B), previous gate2 is turned off, whereas gate1 (Gate1[n]) and gate2 (Gate2[n]) are turned on, and the data signal (D[n]) voltage *Vd* is applied to the source node of the mirror TFT (MR). The first switch TFT (SW1) connects the gate and drain of mirror TFT to form a diode with turn-on voltage equal to the TFT's threshold voltage (*Vto*=*Vth*). Since *VGH-Vth* was precharged in Cst1 during precharge state, and this voltage is higher than *Vd*, MR diode is forward biased. The gate node voltage of DR (or the anode voltage of MR) is decreased as Cst1 is discharged by MR diode, which will converge to the data voltage plus the turn-on voltage of MR diode (*Vd*+*Vth*), as noted in Figure 4(b). Assuming that the threshold voltage of MR and DR is identical, the voltage value now stored in Cst1 will *compensate* the OLED current by cancelling out the threshold voltage of DR, as explained in the following equations.

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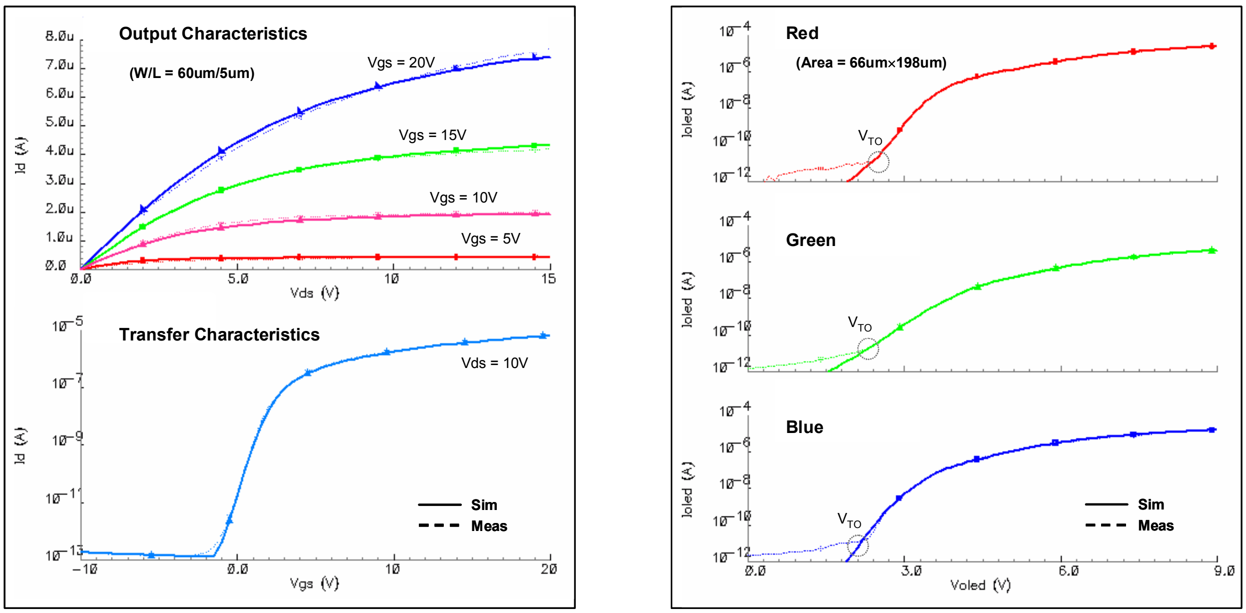
$$Vth_{DR} = Vth_{MR}$$

$$Ioled = \frac{k}{2}(Vgs - Vth_{DR})^2, Vgs = Vd + Vth_{MR}$$

$$Ioled = \frac{k}{2}(Vd + Vth_{MR} - Vth_{DR})^2 = \frac{k}{2}Vd^2$$

During restore state (Figure 3.C), gate1 signal is turned off, whereas gate2 is still on, and the data signal voltage is 0V (*Gnd*). While the gate voltage of DR and MR is held at *Vd+Vth*, the source voltage of MR is decreased from *Vd* to *Gnd*, and restored in the second storage capacitor (Cst2), as noted in Figure 4(c). Our recent studies convey that when the gate-to-source voltage of both DR and MR is identical, the amount of threshold voltage shift due to gate bias stress should also be identical [6]. This corresponds to the previous assumption that the threshold voltage of DR and MR is the same.

During drive state (Figure 3.D), gate2 signal is finally turned off, and DR *drives* the compensated OLED current. SPICE simulation result verifies that the proposed pixel circuit compensates OLED current against TFT's threshold voltage shift up to 5V, resulting in maximum current shift ($= \Delta I_{OLED}/I_{AVE}$) of less than 15%, as shown in Figure 5.



A. RPI a-Si:H TFT model

B. Spectre Diode Level-1 model

Figure 1. SPICE parameter extraction for device modeling of a-Si:H TFT and OLEDs.

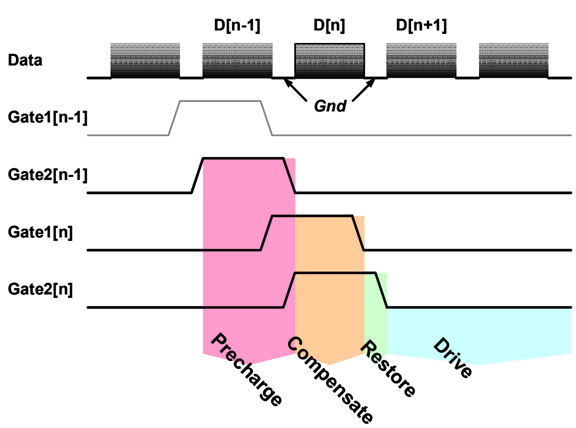


Figure 2. Timing diagram of control signals

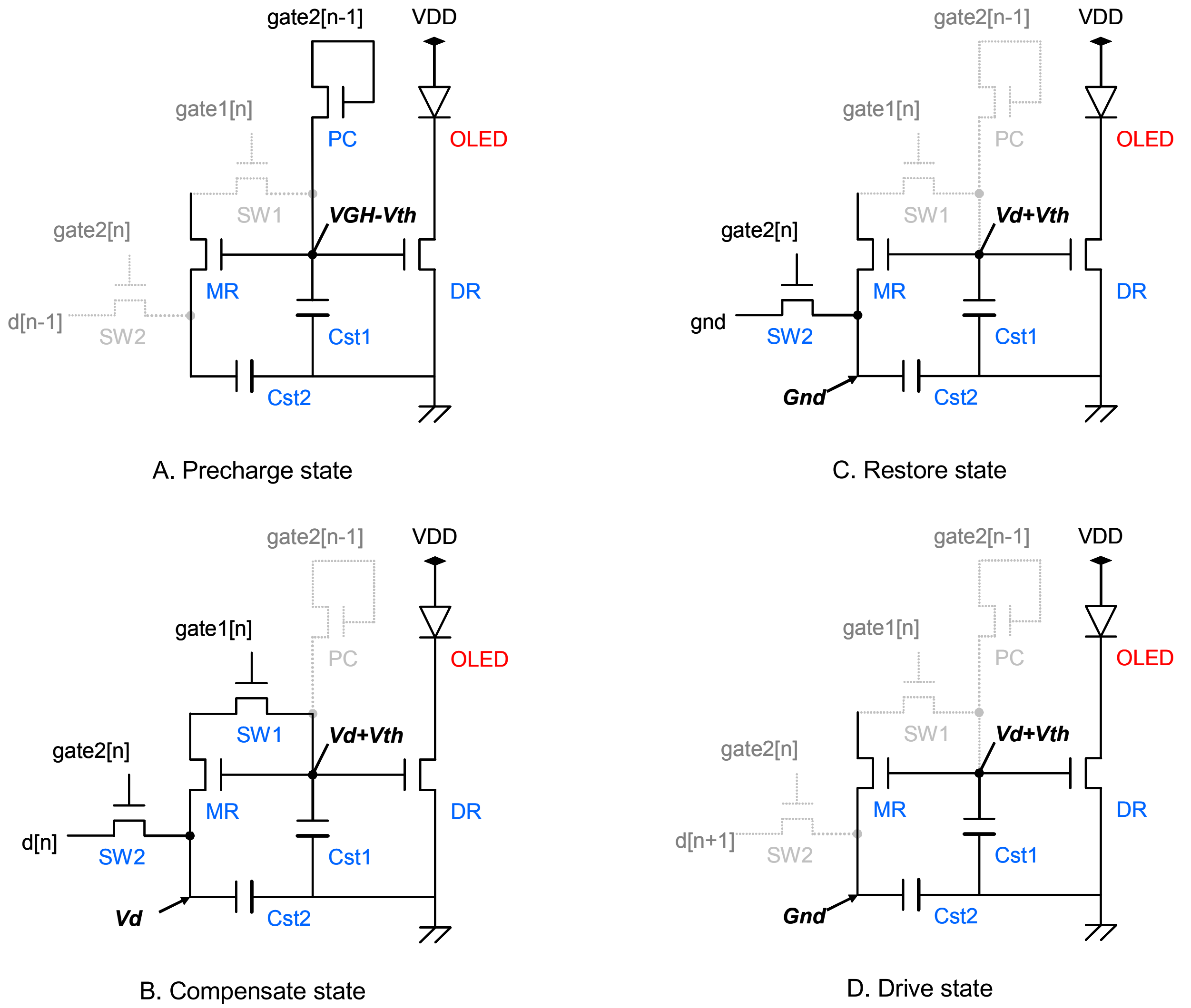


Figure 3. Schematic diagram and operation of proposed pixel circuit.

3. Conclusion

We have reported a new pixel circuit suitable for enhancing the reliability of AMOLED display. The propose pixel circuit is composed of a-Si:H TFTs and top-anode OLED structure, and it does not require any complicated drive ICs. We have verified the compensation of OLED current against threshold voltage shift of the drive TFT by SPICE simulations. The results show that the OLED current varies less than 15% when Vth shift is 5V.

4. Acknowledgement

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5. References

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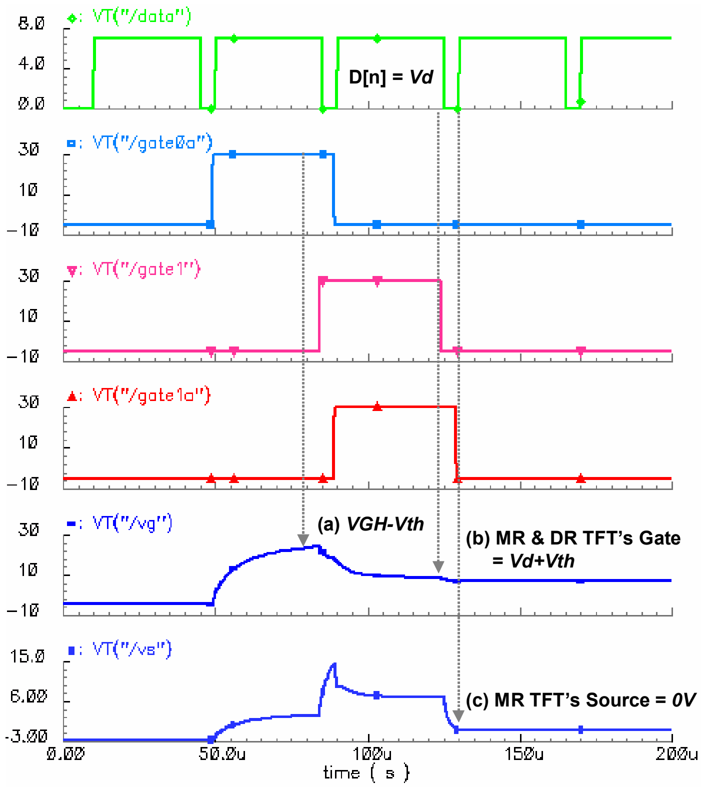

Figure 4. SPICE simulation results – Transient analysis of (a) precharge, (b) compensate and (c) restore states.

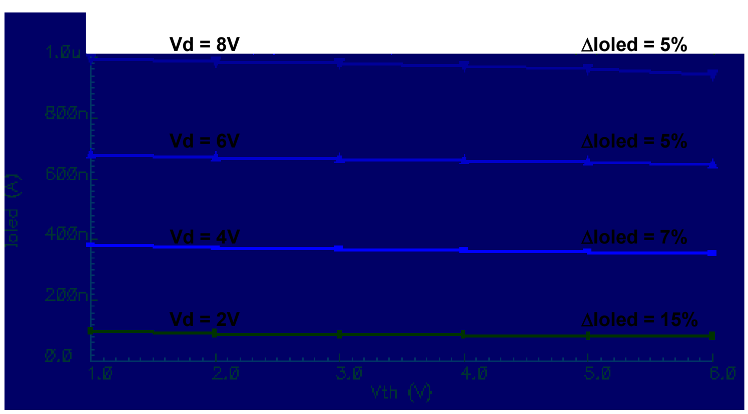

Figure 5. SPICE simulation results – I_{OLED} shift as TFT's Vth shift.