a-IGZO TFT Based Pixel Circuits for AM-OLED Displays

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Abstract

In this paper, we analyze application of amorphous Indium–Gallium–Zinc–Oxide thin film transistors (a-InGaZnO TFTs) to voltage-driven pixel electrode circuit that could be used for 4.3-in. wide video graphics array (WVGA) full color active-matrix organic light-emitting displays (AM-OLEDs). Simulation results, based on a-InGaZnO TFT and OLED experimental data, show that both device sizes and operational voltages can be reduced when compared to the same circuit using hydrogenated amorphous silicon (a-Si:H) TFTs. Moreover, the a-InGaZnO TFT pixel circuit can compensate for the threshold voltage variation (ΔV_{TH}) of driving TFT within acceptable operating error range.

1. Introduction

Although hydrogenated amorphous silicon (a-Si:H) thin film transistors (TFT) currently dominate the liquid crystal display (LCD) market due to their uniformity over large area, low cost of fabrication, and mature technology[1], the insufficient field-effect mobility and meta-stable shift in threshold voltage when subject to prolonged gate bias make their application to AM-OLEDs rather difficult. As a result, TFTs based on other semiconductor materials have been explored as an alternative approach [2, 3]. Among all, amorphous In-Ga-Zn-O (a-InGaZnO) TFTs possess certain advantages including visible transparency, low processing temperature, good uniformity, decent mobility, low off-current, sharp subthreshold swing, and potentially better electrical stability, which make them very favorable for AM-OLEDs [3]. So far, most of a-InGaZnO TFT driven AM-OLEDs are reported based on the two or three transistors and one capacitor voltage-programmed pixel circuit. The usage of such circuit requires the a-InGaZnO TFTs to be electrically very stable, which might not be the case [4, 5]. Therefore, whether these circuits are suitable for stable operation AM-OLEDs is still questionable. In this paper, we present a novel a-IGZO TFT based voltage programmed pixel circuits with an enhanced compensation function for device electrical instabilities in comparison to conventional 2-TFT pixel electrode circuits. The proposed circuit provides a wide dynamic OLED current range over lower data voltage levels, which is ideal for a high resolution AM-OLED. We also demonstrate the effect of ΔV_{TH} on the circuit performance based a-InGaZnO transistors.

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2. a-InGaZnO TFT Model Extraction

a-InGaZnO TFT SPICE model was developed based on the Rensselaer Polytechnic Institute (RPI) a-Si:H TFT model. Needed a-InGaZnO TFT SPICE parameters were extracted from

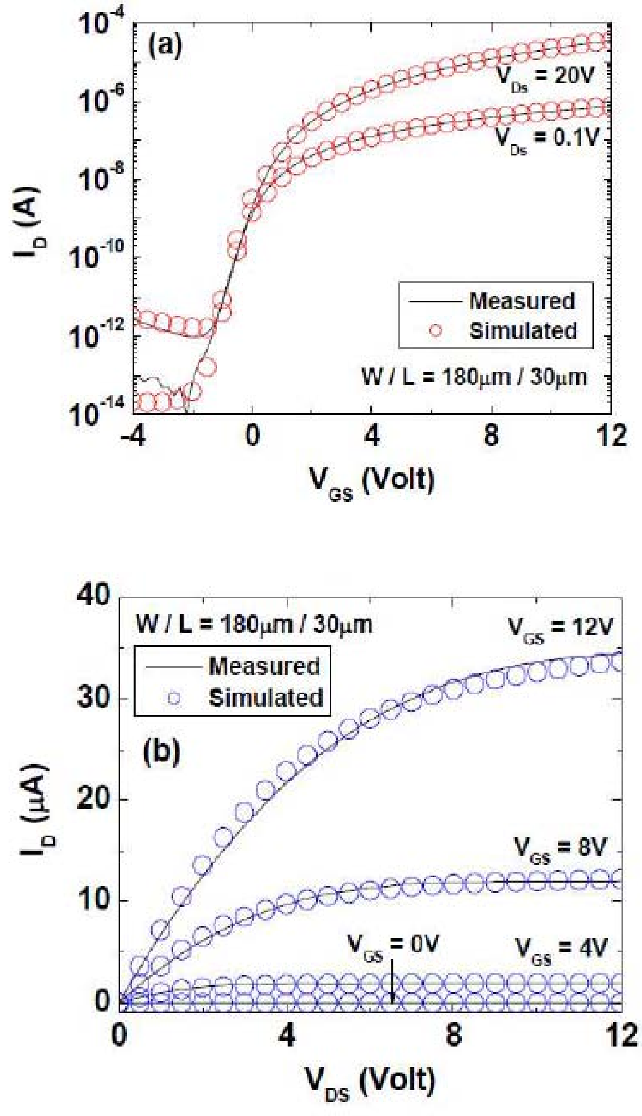

Figure 1 Measured and simulated (a) transfer and (b) output characteristics of a-InGaZnO TFT. Simulation is performed by HSPICE.

Device parameters	2-TFT	Proposed Circuit	
		a-IGZO	a-Si:H
W/L(SW1,SW2,PC) [µm]	4/4	5/5	5/60
W/L(MR,DR) [µm]	4/24	5/5	5/60
C_{ST1} [pF]	1	0.22	0.22
C_{ST2} [pF]	N/A	0.04	0.04
C_{GS}, C_{GD} [fF/m]	10	10	10
Supplied signals			
V_{DD} [V]	10	10	20
V_{DATA} [V]	3 → 9	0 → 4.4	5 → 11
V_{GATE2}[n-1] [V]	N/A	-5 → 15	-10 → 30
V_{GATE2}[n] [V]	N/A	-5 → 15	-10 → 30
V_{GATE1}[n] [V]	-1 → 10	-5 → 15	-10 → 30
Time frames			
t_{ox} [ms]	0.04	0.04	0.04
t_{off} [ms]	16.7	16.7	16.7

Table 1 Device and Circuit Parameters based on a-InGaZnO TFT and a-Si:H TFT for SPICE Simulation

experimental data. HSPICE simulation tool was then used to simulate the TFT characteristics (illustrated as the open circles in Fig. 1). We can see that the RPI a-Si:H TFT model with appropriate a-InGaZnO TFT SPICE parameters can reproduce very well our measured device characteristics. SPICE parameters were extracted based on experimental data reported in [6, 7], and summarized in Table 1. The OLED area was assumed to be 4563µm^2 which is about the subpixel area of an RGB 4.3" WVGA display (39µm x 117µm). The OLED capacitor was calculated by assuming the capacitance per unit area is 25nF/cm^2. The electrical behavior of the OLED was modeled with two junction diodes and two series resistors connected in parallel with a capacitor for the simulation.

3. Results and Discussions

3.1 Pixel Circuit Configurations

In this paper, all reported AM-OLEDs driven by a-InGaZnO TFTs are based on the 2-TFT voltage-programmed pixel circuit. The 2-TFT voltage-programmed pixel circuit is very simple in design and enables a high aperture ratio. However, since this simple circuit does not compensate for the TFT threshold voltage variation (ΔV_{TH}), the usage of this circuit requires the TFTs to be electrically very stable (ΔV_{TH} ~ 0). Authors have previously explored the possible application of a-InGaZnO TFTs to a current scaling pixel circuit that provides a wide dynamic OLED current (I_{OLED}) range and compensation abilities [8]. Here, we apply a-InGaZnO TFTs to a voltage-programmed pixel electrode circuit that has shown some enhancement with a-Si:H TFT[9]. Synopsys HSPICE simulation tool with the a-InGaZnO TFT and OLED

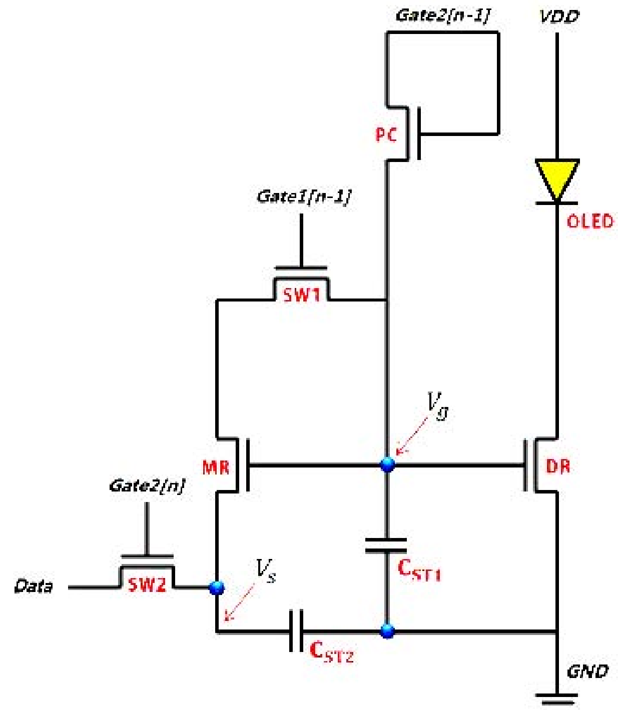

Figure 2 Schematic diagram of the proposed voltage-programmed pixel circuit.

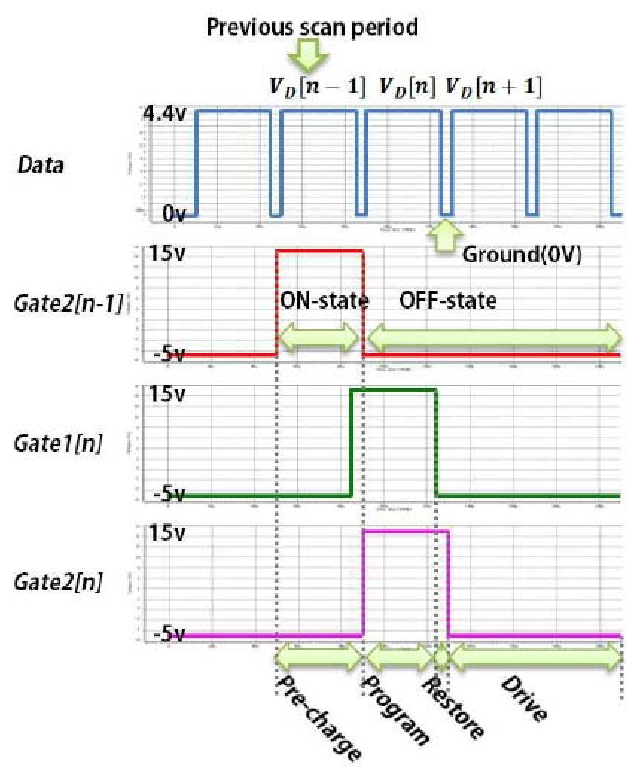

Figure 3 Operation waveforms of the proposed pixel circuit simulated by HSPICE

SPICE models developed previously were used to evaluate the pixel circuit performance. As shown in Figure 2, each pixel is composed of one power line (V_{DD}), two control lines (Gate1, Gate2), two capacitors (C_{st1}, C_{st2}), and five TFTs; two switch TFTs (SW1, SW2), a pre-charge TFT (PC), a drive TFT (DR), and a mirror TFT (MR). The operation detail of this circuit can be found elsewhere [9]. Since the field-effect mobility of a-InGaZnO TFTs is about 10 times larger than that of a-Si:H TFTs, smaller device sizes (W/L = 5μm/5μm) and lower supply voltages (V_{DD} = 10V) can be used for this circuit based on a-InGaZnO TFTs. The pixel circuit operates in four stages; pre-charge, program, restore, and drive. An example of operation waveforms simulated by HSPICE is shown in Fig. 3.

3.2 Simulation Results

The OLED currents (I_{OLED}) delivered by the 2-TFT voltage-programmed pixel circuit and by the proposed 5-TFT voltage-programmed pixel circuit with compensation capability as a function of V_{DATA} are shown respectively in Fig. 4 (a). When the frame rate is set to be 60Hz, t_{ON} (40μs) and t_{OFF} (16.7ms) are the ON- and OFF-state periods, respectively. As we can see from Fig. 4, wide dynamic I_{OLED} range (~10^3) was achieved by both pixel circuits. We also simulated the two pixel circuits assuming that the drive TFTs exhibit 1 and 2V of threshold voltage shifts (ΔV_{TH}), as shown in Fig. 4 (a). The percentage change in I_{OLED} (ΔI_{OLED}) is defined as following,

$$\Delta I_{OLED} = \frac{I_{OLED}(\Delta V_{TH} = 0) - I_{OLED}(\Delta V_{TH})}{I_{OLED}(\Delta V_{TH} = 0)} \quad (1)$$

We can see that the proposed 5-TFT voltage-programmed pixel circuit can compensate for ΔV_{TH} within operating error range from 1 to 19%, depending on the I_{OLED} level, while the 2-TFT voltage-programmed pixel circuit does not compensate for ΔV_{TH} at all (ΔI_{OLED}: 40~90%). Keeping in mind that 1V of ΔV_{TH} is quite large comparing to the small gate overdrive (0~5V) designed to be used in the pixel circuit simulations, this result indicates that we need electrically very stable a-InGaZnO TFTs to be used in the 2-TFT pixel electrode circuit for AMOLEDs. To further investigate the compensation ability of the 5-TFT voltage-programmed pixel circuit, we plotted ΔI_{OLED} as a function of I_{OLED} for positive ΔV_{TH} = 0.5V, 1.5V, and 2.0V, as shown in Fig. 4 (b). We can observe that ΔI_{OLED} is severe at lower I_{OLED} levels due to the smaller gate overdrive of the drive TFT. The percentage error can be maintained below 20% for all levels of I_{OLED} as long as positive ΔV_{TH} is kept below 2.0V, which is acceptable operation range for commercial products.

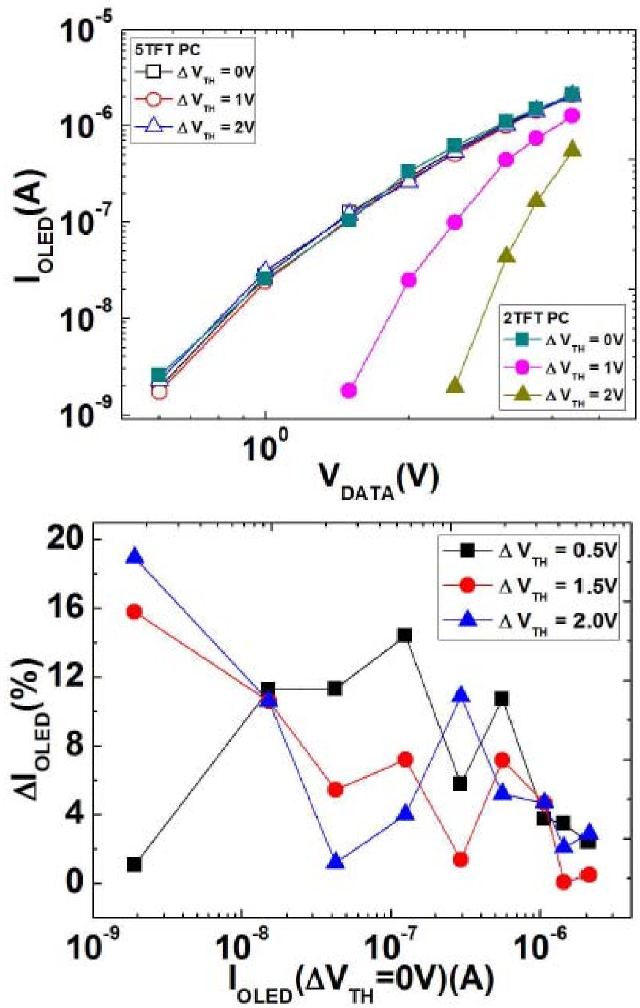

Figure 4 (a) I_{OLED} as a function of V_{DATA} of the 2-TFT pixel circuit (solid symbols), and our proposed 5-TFT pixel circuit (open symbols). (b) ΔI_{OLED} as a function of I_{OLED} of the proposed voltage-programmed pixel circuit for various levels of ΔV_{TH}.

4. Conclusion

We fabricated and characterized inverted-staggered a-InGaZnO TFTs on glass substrates, and SPICE model was developed based on experimental data. Both simple voltage-programmed pixel circuits and 5-TFT voltage-programmed pixel circuits with ΔV_{TH} compensation ability were simulated. Smaller device sizes and lower supply voltages could be used in a-InGaZnO TFT pixel circuits due to their superior electrical properties compared to those of a-Si:H TFTs. The simple voltage-programmed pixel circuits could be used provided that the a-InGaZnO TFTs are electrically very stable (ΔV_{TH} ~ 0V). Otherwise, 5-TFT voltage-programmed pixel circuit is needed to compensate for ΔV_{TH}. It is shown that our 5-TFT voltage-programmed pixel circuit can compensate ΔV_{TH} under bias stress conditions below 20%. In conclusion, a-InGaZnO TFTs, if fully optimized, have great potential for higher resolution, lower power consumption, and more stable operation AM-OLEDs.

5. Acknowledgements

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6. References

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