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a-InGaZnO TFT Current-Scaling Pixel Electrode Circuit for AM-OLEDs

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In this paper, we analyze application of amorphous In-Ga-Zn-O thin film transistors (a-InGaZnO TFTs) to current-scaling pixel electrode circuit that could be used for 3 inch QVGA 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 compare to the same circuit using hydrogenated amorphous silicon (a-Si:H) TFTs.

1. Introduction

Active Matrix Organic light emitting displays (AM-OLEDs) possess certain advantages for high-quality, high–information-content display applications. These advantages include a high contrast ratio, broad color range, wide viewing angle, fast display response time, low power consumption and a thin and light display module.[1)] Pixel electrode circuits used in AM-OLEDs can be generally classified into two types: voltage-programmed and current–programmed, where a voltage or current signal is used to modulate the OLED current, respectively.[2)] Given the current-driven nature of the OLEDs and their steep current-voltage characteristics, current-programmed pixel circuits are more desirable to precisely generate distinct display grey levels. A variety of current-driven circuits have been proposed.[3, 4)] We have also demonstrated a current -scaling pixel circuit using a cascade structure of storage capacitors for AM-OLED.[5)] The pixel circuits are either based on low temperature polysilicon (LTPS) thin film transistors (TFTs) or hydrogenated amorphous silicon (a-Si:H) TFTs. Both backplane technologies have their own shortcomings, such as nonuniformity (LTPS) and low mobility (a-Si:H). On the other hand, amorphous In-Ga-Zn-O (a-InGaZnO) TFT appears to be ideal candidate for AM-OLEDs [6)]. So far, only a few a-InGaZnO TFT based voltage-driven pixel circuits have been reported [7, 8)]. In this paper, we analyzed application of a-InGaZnO TFTs to current-scaling pixel electrode circuit developed in our group. [5)] We also compared this circuit performance with the a-SiH TFT pixel circuit fabricated in our laboratory. [5)]

2. a-InGaZnO TFT SPICE Parameters Extraction

Measurements were done on inverted-staggered RF sputter a-InGaZnO TFTs[9)] and the results are shown in Fig. 1. The TFT electrical characteristics are summarized in Table I. Synopsys HSPICE simulation tool with the Rensselaer Polytechnic Institute (RPI) a-Si:H TFT model[10)] modified for a-InGaZnO TFT was used to evaluate the pixel circuit. Needed a-InGaZnO TFT SPICE parameters were extracted from experimental data. From the simulation results shown in Fig. 1, we concluded that the RPI a-Si:H TFT model with the appropriate SPICE parameters can reproduce very well measured a-InGaZnO TFT characteristics.

Table I . RF Sputter a-InGaZnO TFT Electrical Characteristics

Mobility (cm^2/V-s)	11±1
Threshold Voltage (V)	-0.1±0.7
Subthreshold Slope (mV/dec)	100±10
Current On-Off Ratio	~ 10^9
Off current (A)	10^{-15}~10^{-13}

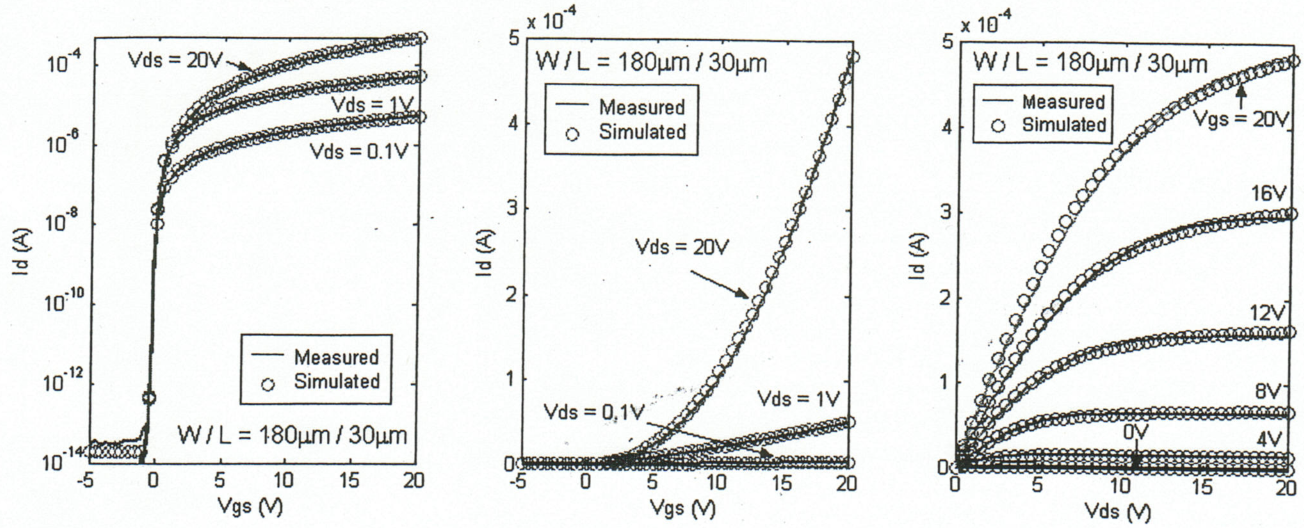

Fig. 1. Measured and simulated RF sputter a-InGaZnO TFT transfer (in log and linear scale) and output characteristics, from left to right.

3. Current-Scaling Pixel Electrode Circuit

The current-scaling pixel electrode circuit consists of three switching TFTs (T1, T2 and T4), one driving TFT (T3) and two storage capacitors (C_{ST1} and C_{ST2}), as shown in Fig. 2. The OLED is modeled by an a-Si:H TFT with gate and drain connected together.[5] The operation detail of this circuit is described elsewhere.[11] An example of operation waveforms simulated by HSPICE is shown in Fig. 3. Since the field-effect mobility of a-InGaZnO TFTs is around 10 times larger than that of a-Si:H TFTs, smaller device dimensions and lower supply voltages can be used to achieve an adequate OLED driving current level, compared to our previous design based on a-Si:H TFTs.[5] Parameters used in a-InGaZnO TFT current-scaling pixel electrode circuit simulation are summarized in Table Ⅱ.

The circuit was simulated for I_{DATA} ranging from 0.2 to 10 μA and the results are shown in Fig. 4. During the ON state, I_{OLED_ON} is identical to I_{DATA}. When the pixel operates in the OFF state, I_{OLED_OFF} is scaled down from I_{OLED_ON} by an amount determined by V_{B_OFF},

$$V_{B\text{-}OFF} = V_{B\_ON} - \Delta V_{SCAN} \cdot \frac{C_{ST2} // C_{GS2}}{C_{ST1} // C_{P3} + C_{ST2} // C_{GS2}} \quad (1)$$

where C_{GS2} is the parasitic capacitor associated with the gate-to-source overlap of T2 and C_{P3} is the total parasitic capacitance looking into the gate of T3.

Since the OLED current value is different in the ON- and OFF-states, we define the average OLED current (I_{AVE}) during one frame time as

$$I_{AVE} = \frac{I_{OLED\_ON} \cdot t_{ON} + I_{OLED\_OFF} \cdot t_{OFF}}{t_{ON} + t_{OFF}} \quad (2)$$

where t_{ON} and t_{OFF} is the ON- and OFF- periods during the frame time, respectively. Due to the much longer OFF-state period than the ON-state, I_{AVE} is pretty much dominated by I_{OFF}, even when I_{ON} is large. For example, the pixel circuit can provide I_{AVE} ranging from 2 nA to 3μA, while I_{DATA} is swept from 0.2 μA to 10 μA. Therefore, we can obtain a very wide dynamic range of OLED current levels by supplying high data current values.

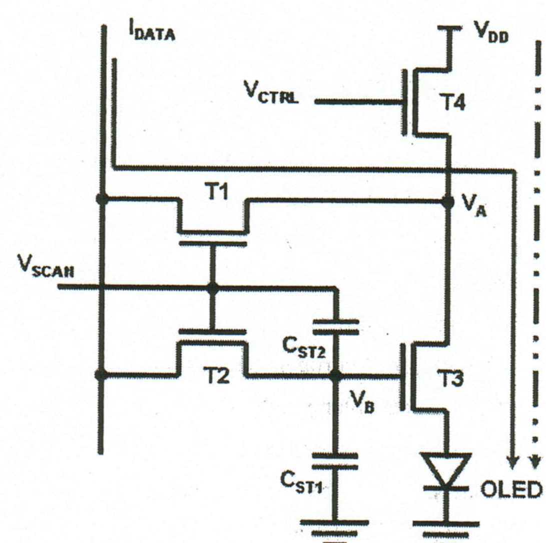

Fig. 2. Schematic diagram of the current-scaling pixel circuit used in this work.

Table Ⅱ. Example of Parameters Used in Pixel Circuit Simulation

Device Parameters	a-InGaZnO	a-Si:H [5]
W/L (T1, T3, T4) (μm/μm)	20/4	50/4
W/L (T2) (μm/μm)	4/4	30/4
C_{ST1} (pF)	0.15	2.5
C_{ST2} (fF)	150	625
C_{GS}, C_{GD} (nF/m)	5	5
Supplied Signals	**a-InGaZnO**	**a-Si:H [5]**
V_{SCAN} (V)	0→15	0→30
V_{CTRL} (V)	0→15	0→30
V_{DD} (V)	15	30
I_{DATA} (μA)	0.2 ~ 10	0.2 ~ 10
Time Frames	**a-InGaZnO**	**a-Si:H [5]**
t_{ON} (ms)	0.33	0.33
t_{OFF} (ms)	33	33

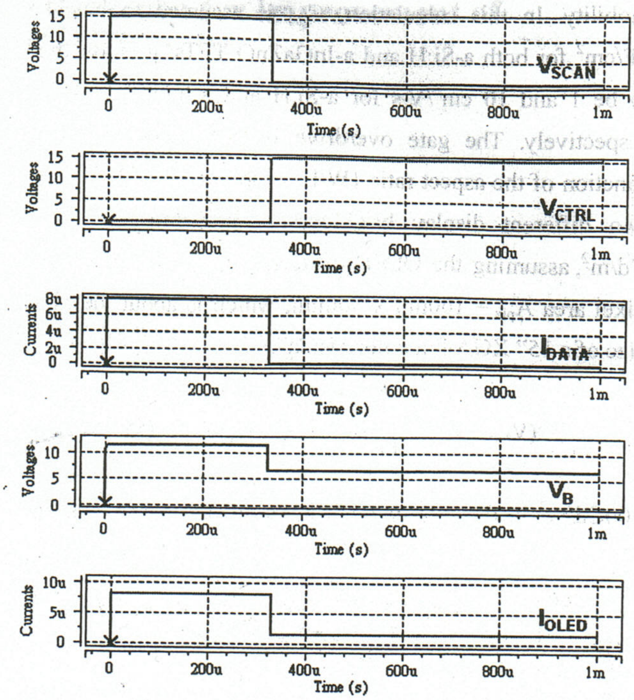

Fig. 3. Example of pixel operation waveforms used in HSPICE.

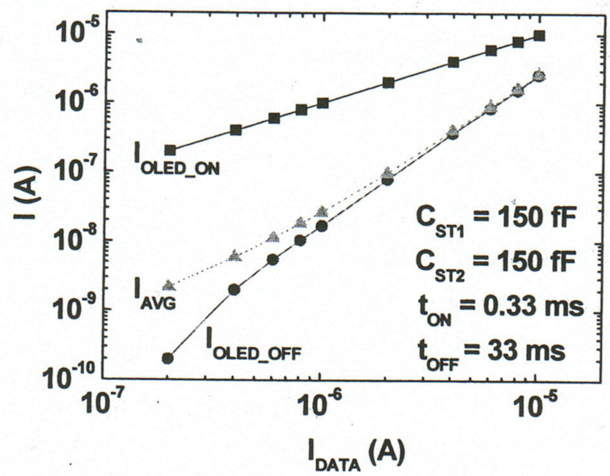

Fig. 4. Variation of I_{OLED_ON}, I_{OLED_OFF} and I_{AVG} as a function of I_{DATA} (=I_{OLED_ON}).

4. Comparison with the a-Si:H TFT Circuit

In first approximation, the circuit size is estimated by simply adding up the areas of the 4 TFTs and 2 storage capacitors, without considering the interdot and interconnect (data, scan, control and supply lines) areas. The area of a TFT with width W and length L is given by $(W + W_{overhead}) \cdot (L + L_{overhead})$, where $W_{overhead}$ and $L_{overhead}$ (source/drain and gate contact areas) are assumed to be 10μm and 20μm, respectively. The area of the storage capacitors (C_{area}) is calculated by

$$C_{area} = (C_{ST1} + C_{ST2}) / \frac{\frac{\varepsilon_s}{t_s} \cdot \frac{\varepsilon_{ins}}{t_{ins}}}{\frac{\varepsilon_s}{t_s} + \frac{\varepsilon_{ins}}{t_{ins}}} \quad (3)$$

where ε_s (ε_{ins}) and t_s (t_{ins}) are the permittivity and thickness of the semiconductor (insulator) layer. The circuit size estimated by this method is 24450μm² and 3405μm² for the current-scaling pixel circuit based on a-Si:H TFTs and a-InGaZnO TFTs, respectively. The aperture ratio is then calculated for several display sizes and resolutions (xRGB), as shown in Fig. 5. Overall much higher pixel aperture ratio can be achieved with the a-IGZO TFT technology. For example, a subpixel of a 3 inch QVGA full color display has an area of 63.5μm x 190.5μm = 12096.75μm², which is impossible for this circuit based on a-Si:H TFTs. However, an aperture ratio of (1- 3405/12096.75) × 100% = 71.85% can be achieved by this circuit based on a-InGaZnO TFTs.

We also calculated the gate overdrive voltage ($V_{GS} - V_T$) of the drive TFT (T3), which is critical to power consumption and device lifetime. The gate overdrive is determined by the pixel current I_{pix}, which depends on the OLED brightness (υ) and efficiency (η), and pixel area A_{pix}.

$$I_{pix} = \frac{\upsilon \cdot A_{pix}}{\eta} = \frac{1}{2} \cdot C_{ins} \cdot \mu \cdot \frac{W}{L} \cdot (V_{GS} - V_T)^2 \quad (4)$$

where C_{ins} is the gate capacitance, μ is the field-effect mobility. In this calculation, C_{ins} is assumed to be 34.5 nF/cm^2 for both a-Si:H and a-InGaZnO TFTs; μ is assumed to be 1 and 10 cm^2/V-s for a-Si:H and a-InGaZnO TFTs, respectively. The gate overdrive is then calculated as a function of the aspect ratio (W/L) of the drive TFT (T3) for two different display brightnesses, 300Cd/m^2 and 1000 Cd/m^2, assuming the OLED efficiency η = 5 Cd/A and the pixel area A_{pix} = 100μm x 300μm, which is about the pixel size of a 15" XGA full color display.

$$(V_{GS} - V_T) = \sqrt{\frac{2 \cdot \upsilon \cdot A_{pix}}{\eta \cdot \mu \cdot C_{ins}} \cdot \left(\frac{W}{L}\right)^{-1}} \qquad (5)$$

300Cd/m^2 is the minumum brightness luminance required

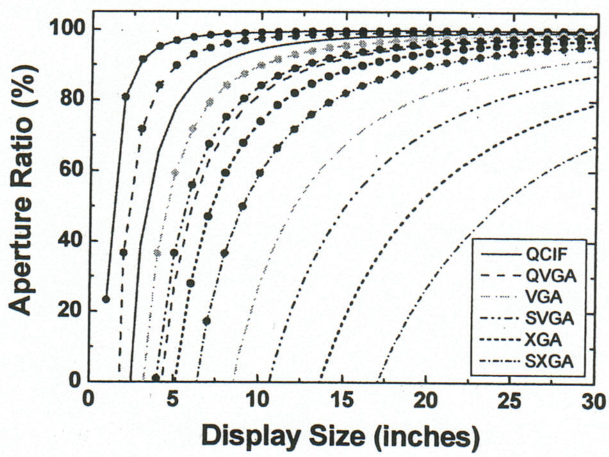

Fig. 5. Aperture ratio as a function of display diagonal for different resolutions. (Dots: a-InGaZnO TFTs; lines: a-Si:H TFTs).

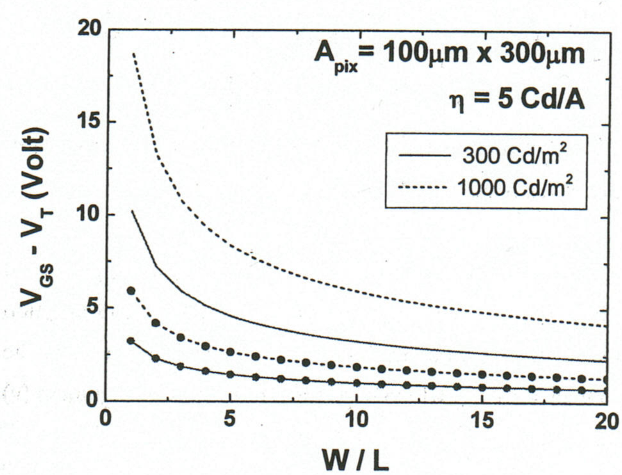

Fig. 6. Gate overdrive versus W/L of the drive TFT for different display brightness. (Dots: a-InGaZnO TFTs; lines: a-Si:H TFTs).

for televisoin displays, and 1000Cd/m^2 is a typical luminance for sunlight readable high brightness displays. As seen from the calculation results shown in Fig. 6, the aspect ratio and gate overdrive of the drive a-InGaZnO TFT can remain low even for a brightness of 1000Cd/m^2, which is critical for stable operation of the AM-OLEDs.

5. Conclusion

A current-scaling pixel electrode circuit is evaluated based on a-InGaZnO TFTs. This pixel circuit provides a wide dynamic OLED current range and a nonlinear current scaling ratio. The circuit also requires lower supply voltages and smaller device sizes compared to the same circuit using a-Si:H TFTs. Consequently, this circuit has great potential for a more stable operation, lower power consumption, and higher resolution AM-OLED.

References

1) C. W. Tang: J. SID., vol. 5, no. 1, 1997, p. 11.

2) J. L. Sanford and F. R. Libsch: Dig. Tech. Papers of SID., vol. 34, no. 1, 2003, p. 10.

3) A. Yumoto, M. Asano, H. Hasegawa and M. Sekiya: Proc. Int. Display Workshop, 2001, p. 1395.

4) K. Sakariya, P. Servati and A. Nathan, IEEE Trans. Electron Devices, vol. 51, no. 12, 2004, p. 2019.

5) H. Lee, Y. C. Lin, H. P. Shieh and J. Kanicki, IEEE Trans. Electron Devices, vol. 54, no. 9, 2007, p. 2403.

6) K. Nomura, H. Ohta, A. Takagi, T. Kamiya, M. Hirano and H. Hosono, Nature, vol. 432, 2004, p488.

7) J. Y. Kwon, K. S. Son, J. S. Jung, T. S. Kim, M. K. Ryu, K. B. Park, J. W. Kim, Y. G. Lee, C. J. Kim, S. I. Kim, Y. S. Park, S. Y. Lee and J. M. Kim, IDW, AMD9-3, 2007, p1783.

8) R. Hayashi, M. Ofuji, N. Kaji, K. Takahashi, K. Abe, H. Yabuta, M. Sano, H. Kumomi, K. Nomura, T. Kamiya, M. Hirano and H. Hosono, J. SID., vol. 15, no. 11, 2007, p. 915.

9) H. Yabuta, M. Sano, K. Abe, T. Aiba, T. Den, H. Kumomi, K. Nomura, T. Kamiya and H. Hosono, Appl. Phys. Lett., vol. 89, 2006, p. 112123.

10) M. S. Shur, H. C. Slade, M. D. Jacunski, A. A. Owasu and T. Ytterdal, J. Electronchem. Soc., vol. 144, no. 8, 1997, p. 2833.

11) Y. C. Lin, H. P. Shieh and J. Kanicki, IEEE Trans. Electron Devices, vol. 52, no. 6, 2005, p. 1123.