

Design of an Amorphous In-Ga-Zn-O TFT Current-Scaling Pixel Driving Circuit for AMOLED with Threshold-voltage Shift Compensating

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Abstract—An Amorphous In-Ga-Zn-O TFT (a-IGZO TFTs) Current-Scaling Pixel Circuit for Active Matrix Organic Light-emitting Displays (AMOLEDs) is presented, it composes of four amorphous a-IGZO TFTs and one capacitor (4T-1C), which effectively compensates the threshold-voltage-shift ($\Delta V_{th} \approx 1V$) of the drive TFT as well as degradation of the OLED. In a monochromatic 2-inches QVGA AMOLED display, simulating results show that programming current between several pA and hundreds of nA can realize OLED luminance from 1cd/m^2 to 200cd/m^2 , and the aperture ratio of AMOLED with this pixel driving circuit is high as 80%.

Keywords—AMOLED; a-IGZO-TFT; threshold-voltage-shift; pixel circuit;

I. INTRODUCTION

Organic Light-emitting Displays (OLEDs) are promised to be next generation of flat panel displays (FPDs) due to its perfect characteristics such as low power consumption, fast response, high contrast ratio, broad color range, wide viewing angle and thin display module etc. [1-4]. Active Matrix OLEDs (AMOLEDs), which consists of a thin film transistor (TFT) array as a series of switches to control the current flowing to each individual pixel, provide higher refresh rates than the passive-matrix OLED counterparts, improving response time often to under a millisecond, and AMOLEDs consume significantly less power. This advantage makes AMOLEDs well suited for portable electronics, where power consumption is critical to battery life. In addition, it has been proved to be feasible to convert an existing AMLCD line to an AMOLED production line, and the cost is only 40% of that for ramping up a new one [5]. Hydrogenated amorphous silicon TFTs (a-Si:H TFTs) and low temperature polycrystalline silicon TFTs (LTPS TFTs) currently are all used as the driving circuits for FPDs. Compared with LTPS TFTs, a-Si:H TFTs is more uniform for large area AMOLEDs, and its technology is mature and low cost, but its mobility is low (about $1\text{cm}^2/\text{Vs}$), on the other side LTPS TFTs have the advantage of high field-effect mobility ($>50\text{cm}^2/\text{Vs}$). The low field-effect mobility of a-Si:H TFTs and non-uniformity of LTPS TFTs limit their applications for FPDs in future [6,7]. Recently, amorphous In-Ga-Zn-O thin-film transistor (a-IGZO TFT) have gained special attentions as an alternative to a-Si:H TFTs and LTPS TFTs due to its good uniformity, higher mobility ($>10\text{cm}^2/\text{Vs}$), low leakage current, low processing temperature, visible transparency, sharp sub-threshold

swing and potentially better electrical stability[8-11], which make it very attractive for the AMOLEDs driving circuits.

Here a current-scaling pixel circuit composed of four a-IGZO TFTs and one capacitor is presented, which usually is called 4T-1C a-IGZO TFTs pixel circuit, and it could be applied to monochromatic 2-inches QVGA (Quarter Video Graphics Array) AMOLEDs. The proposed pixel circuit is programmed with a current input signal and effectively compensates threshold-voltage-shift of the drive TFT and the degradation of OLED, compared with the conventional 2T-1C a-IGZO TFTs pixel circuit in which the driving current on OLED will be reduced because the threshold voltage of the driving TFT and the turn-on voltage of OLED all increase with the operating time. This 4T-1C a-IGZO TFTs pixel circuit has a high aperture ratio of circuit as 80%, and 16 gray-scales of AMOLED with the luminance between 1cd/m^2 and 200cd/m^2 is achieved too.

II. 4T-1C a-IGZO TFTS PIXEL CIRCUIT

It is well known that the luminance of OLED is proportional to its driving current, Fig. 1 shows the luminance versus current characteristic ($L \sim I$) of the bottom-emitting OLED (BEOLED), and pixel area (S_{pixel}) for a 2-inches QVGA display is about $120\mu\text{m} \times 120\mu\text{m}$. Both voltage-scaling and current-scaling pixel driving circuit can be used for AMOLEDs, Fig. 2 (a) shows a current-scaling pixel circuit which is programmed with a current input signal, it composed of four a-IGZO TFTs T1~T4 and a storage capacitor, in which T4 is used as the driving transistor, T1 and T2 as switches and T3 as the threshold voltage compensating transistor, the diode represents the luminescent unit OLED in each pixel.

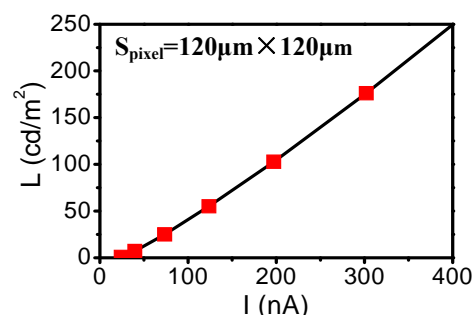


Figure 1. Luminance versus current curve of BEOLED.

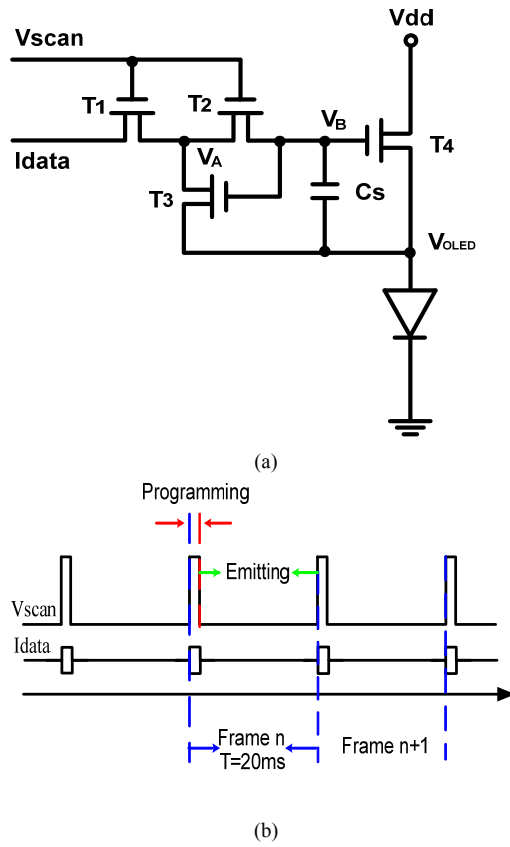


Figure 2. (a) Schematic of the 4T-1C a-IGZO TFTs pixel circuit, (b) Control-signal timing diagram of the proposed pixel circuit.

The proposed pixel circuit operates in two periods in each frame, as shown in Fig. 2(b). The first stage is data programming period, during this stage V_{scan} is high so switching TFTs T1 and T2 are turned on, input current I_{data} charge up C_s and V_B at the T3 and T4 gate increases. When the voltage of C_s (V_{Cs}) become higher than the threshold-voltage of T3 and T4 (V_{th3} and V_{th4}), they are turned on and the current of both T3 and T4 (I_{T3} and I_{T4}) grow. Current from T4 drive OLED in the pixel and current of T3 reduce the charging current of C_s , finally the charging to C_s finish until I_{T3} is equal to I_{data} , which is the end of this data programming period, see (1) and (2). At this moment, V_B is a constant related to I_{data} . During the second period, voltage V_{scan} becomes low and T1~T2 are turned off to maintain the V_{Cs} of C_s , therefore I_{T4} and the current of OLED (I_{OLED}) would be a constant until the next data is written in.

$$I_{data} = I_{T3} = \frac{1}{2} \times k \times \left(\frac{W}{L} \right)_3 \times (V_B - V_{OLED} - V_{th3})^2 \quad (1)$$

$$I_{OLED} = I_{T4} = \frac{1}{2} \times k \times \left(\frac{W}{L} \right)_4 \times (V_B - V_{OLED} - V_{th4})^2 \quad (2)$$

TFTs in the same driving circuit are fabricated simultaneously during the same fabrication process

simultaneously, and the voltage V_B at the gate of T3 and T4 is always same, then V_{th3} and V_{th4} are considered equal approximately and both will be increased with the operating time [12]. The turn-on voltage of OLED (V_{OLED}) also increases over the operating time. From (1)&(2) and the mechanism of the 4T-1C a-IGZO TFTs pixel driving circuit, we know that I_{OLED} is only decided by the size ratio between T3 and T4 and the programming current I_{data} , as shown in (3), hence the threshold-voltage-shift of driving TFT and degradation of OLED would be compensated.

$$\frac{I_{OLED}}{I_{data}} = \frac{(W/L)_4}{(W/L)_3} \quad (3)$$

III. EQUIVALENT MODEL OF OLED

In the 4T-1C a-IGZO TFTs pixel driving circuit the diode represents the luminescent unit OLED in each pixel, in fact a dual diode paralleled model is adopted as the equivalent circuit of BEOLED used during simulation, shown in Fig. 3. The maximum error (<10%) between experiment data and the fitted data is tolerable. The fitted parameters of equivalent model are shown in Table I. Where I_s is the reverse saturation current of diode, n is the Non-ideological factor and r_s is the series resistance.

IV. HSPICE SIMULATION RESULT

To detect the effect of the proposed pixel circuit, simulation using HSPICE was performed. The a-IGZO TFT HSPICE model was developed from the LEVEL 61 Rensselaer Polytechnic Institute (RPI) a-Si:H TFT model [13].

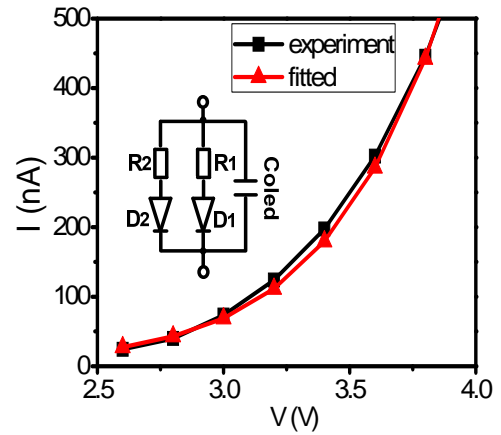


Figure 3. OLED equivalent model and experimental vs fitted curve.

TABLE I. BEOLED HSPICE PARAMETERS

Parameter	Value
Area	120 μ m \times 120 μ m
Coled	2.704pF
R1	3.2 \times 10 ⁴ Ω
R2	2.4 \times 10 ⁵ Ω
D1	Is=8.0 \times 10 ⁻³ A, n=50, r_s =0, level=1
D2	Is=1.0 \times 10 ⁻⁴ A, n=14, r_s =0, level=1

The scan time (programming time) of each row is about $83\mu\text{s}$ when frame frequency is 50 Hz, the data programming time must be short than $83\mu\text{s}$, thus the value of C_s shouldn't be too large. But a small storage capacitor C_s also impacts the stability of V_{cs} after programming due to the leakage current of switching TFTs T1&T2. Here $C_s=0.5\text{pF}$ was selected and it exists

$$C_s = \epsilon_0 \cdot \epsilon_r \times \frac{S}{d_0} \quad (4)$$

Where d_0 is the thickness of oxide layer of C_s , if $d_0=100\text{nm}$, the area of C_s would be about $1450\mu\text{m}^2$. Table II shows parameters used in HSPICE simulation, the aperture ratio of the proposed circuit with parameters shown in Table II is higher to 80%. Fig. 4 shows the HSPICE simulation results of I_{oled} and I_{data} while the threshold-voltage-shift of driving TFT is 0V, 0.5V and 1V.

From Fig. 4, we know that the deviation is little even when $\Delta V_{th}=1\text{V}$, therefore the proposed pixel circuit has the capability to compensate for threshold-voltage-shift of drive TFT which is helpful to improve the luminescent stability and uniformity of OLED. Furthermore, a smaller current (several nA) could be realized even though the writing data I_{data} is larger (hundreds nA), which can shorten the charging time at low gray-scale significantly. When the luminance of OLED is between 1cd/m^2 and 200cd/m^2 , the simulation result of I_{oled} and V_{cs} (V_B-V_{oled}) are shown in Fig. 5.

TABLE II. PARAMETERS USED IN HSPICE SIMULATION

parameters	value
T1 T2 T4	$30\mu\text{m}/30\mu\text{m}$
T3	$300\mu\text{m}/30\mu\text{m}$
C_s	0.5 pF
Vdd	15 V
Vscan	$0 \rightarrow 15\text{ V}$
Idata	290 nA \rightarrow 4105 nA

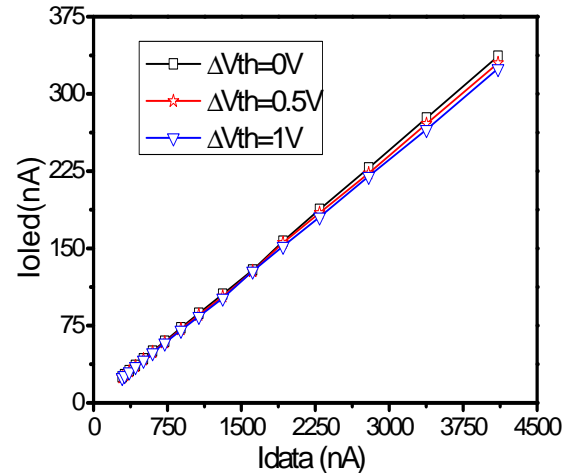


Figure 4. Simulated I_{oled} and I_{data} with different V_{th} shifts.

V. CONCLUSION

A current-scaling pixel circuit using four a-IGZO TFTs and one storage capacitor is proposed in the paper, its mechanism and the simulation results show that it can compensate the threshold-voltage-shift of drive TFT and the degradation of OLED effectively, and the aperture ratio of AMOLED applied this circuit is high to 80%. At the same time, 16 gray-scales of AMOLED have been realized accurately corresponding to the luminance of OLED between 1cd/m^2 and 200cd/m^2 .

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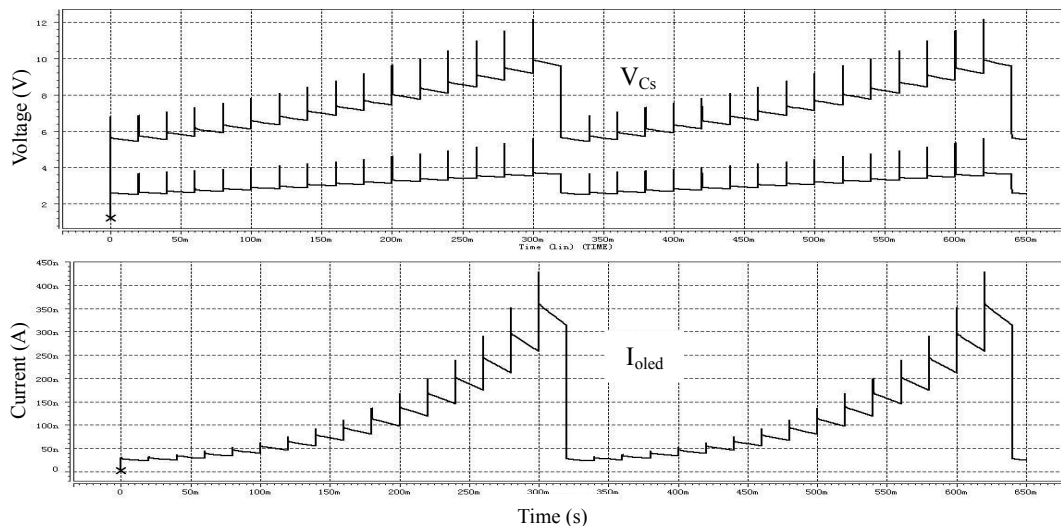


Figure 5. The simulation result of I_{oled} and V_{cs} with 16 gray-scales.

REFERENCES

- [1] C. W. Tang, "An overview of organic electro-luminescent materials and devices," *J. Soc. Inf. Disp.* Vol. 5, no.1, pp. 11–14, Mar 1997.
- [2] Urabe Tetsuo, "The outstanding potential of OLED displays for TV applications," *Inf. Disp.* Vol. 24, no. 9, pp. 14–17, Sept 2008.
- [3] AM-OLED-Tv Samsung versus LG-Display technical background <http://www.oled-display.net/am-oled-tv-samsung-versus-lg-display-technical-background/>, Mar 2012.
- [4] AUO is ready to mass produce high resolution AM OLEDs OLED-TV samples end 2012 <http://www.oled-display.net/auo-is-ready-to-mass-produce-high-resolution-amoleds-oled-tv-samples-end-2012/>, Feb 2012.
- [5] LG Display mass production of 55 inch OLED-TV can start end 2013 <http://www.oled-display.net/lg-display-mass-production-of-55-inch-oled-tv-can-start-end-2013/>, Jan 2012.
- [6] Juhn Suk Yoo, Hojin Lee, Jerzy Kanicki, Chang-Dong Kim, In-Jae Chung, "Novel a-Si:H TFT pixel circuit for electrically stable top-anode light-emitting AMOLEDs," *J. Soc. Inf. Disp.* Vol. 15, no. 8, pp. 545–551, Aug 2007.
- [7] Kenji Nomura, Hiromichi Ohta, Akihiro Takagi, Toshio Kamiya, Masahiro Hirano and Hideo Hosono, "Room-temperature fabrication of transparent flexible thin-film transistors using amorphous oxide semiconductors," *Nature* 432, pp. 488–492, Nov 2004.
- [8] Toshio Kamiya, Kenji Nomura and Hideo Hosono, "Present status of amorphous In-Ga-Zn-O thin-film transistors," *Sci. Technol. Adv. Mater.* Vol.11, no.4, 044305 (23pp), Aug 2010.
- [9] Tze-Ching Fung Katsumi Abe, Hideya Kumomi and Jerzy Kanicki, "DC/AC Electrical Instability of R.F. Sputter Amorphous In-Ga-Zn-O TFTs", *SID Symp. Dig. Tech.*, vol. 40, no.1, pp. 1117–1120, Jun 2009.
- [10] Charlene Chen, Katsumi Abe and Hideya Kumomi and Jerzy Kanicki, "a-InGaZnO thin-film transistors for AMOLEDs: Electrical stability and pixel-circuit simulation." *J. Soc. Inf. Disp.* Vol. 17, no.6, pp. 525–534, Jun 2009.
- [11] Charlene Chen, Katsumi Abe, Tze-Ching Fung, Hideya Kumomi and Jerzy Kanicki, "Amorphous In-Ga-Zn-O Thin Film Transistor Current-Scaling Pixel Electrode Circuit for Active-Matrix Organic Light-Emitting Displays," *Jpn. J. Appl. Phys.* Vol. 48, 03B025 (7pp) Mar 2009.
- [12] Y. Toyota, M. Matsumura, M. Hatano, T. Shiba, M. Ohkura, "A new study on the degradation mechanism in low-temperature p-channel polycrystalline silicon TFTs under dynamic stress," *IEEE Trans. Electron Devices*, vol. 53, no. 9, pp. 2280–2286, Sept 2006.
- [13] Michael S. Shur, Holly C. Slade, Mark D. Jacunski, Albert A. Owusu and Trond Ytterdal, "SPICE Models for Amorphous Silicon and Polysilicon Thin Film Transistors," *J. Electrochem. Soc.*, vol.144, no. 8, pp. 2833–2839, Aug 1997.