

A New Pixel Circuit for Active Matrix Organic Light Emitting Diodes

Joon-Chul Goh, Hoon-Ju Chung, Jin Jang, *Member, IEEE*, and Chul-Hi Han

Abstract—We propose a new thin-film-transistor (TFT) pixel circuit for active-matrix organic light-emitting diode (AMOLED) composed of four TFTs and two capacitors. The simulation results, based on the device performances measured for an OLED and a poly-Si TFT, indicate that the proposed circuit has high immunity to the variation of poly-Si TFT characteristics.

Index Terms—AMOLED, device parameter variations, pixel circuit, poly-Si TFT.

I. INTRODUCTION

ACTIVE-MATRIX organic light-emitting diode (AMOLED) with polycrystalline silicon thin-film transistor (poly-Si TFT) has many attractive features over the passive-matrix OLED. However, in case of conventional two-TFT AMOLED [1], the variations in the performance of the poly-Si TFTs due to the material properties cause nonuniform, gray-scale over the display area. Several pixel circuits have been proposed to compensate the variation in the poly-Si TFT performance [2]–[5].

These can be classified into current-source [2]–[4] and voltage-source methods [2], [5]. The current-source method can compensate the performance variations of the poly-Si TFTs, however, voltage-source method is more attractive to integrate poly-Si TFT data drivers on the display panel. We have developed the voltage-source circuit scheme to improve the output current uniformity for the AMOLED with poly-Si TFTs [5].

The novel pixel circuit proposed in this work utilizes the subthreshold current of a poly-Si TFT and compensates threshold voltage variation. The OLED characteristics using the proposed pixel circuit are simulated and compared with those with conventional two-TFT circuit.

II. PROPOSED PIXEL CIRCUIT AND DRIVING METHOD

Fig. 1 shows an equivalent pixel circuit proposed in this work and its driving scheme. One driving (T1) and three switching n-channel TFTs are used together with two capacitors (C1 and C2). Control lines are two scan lines (Select1, Select2) and a

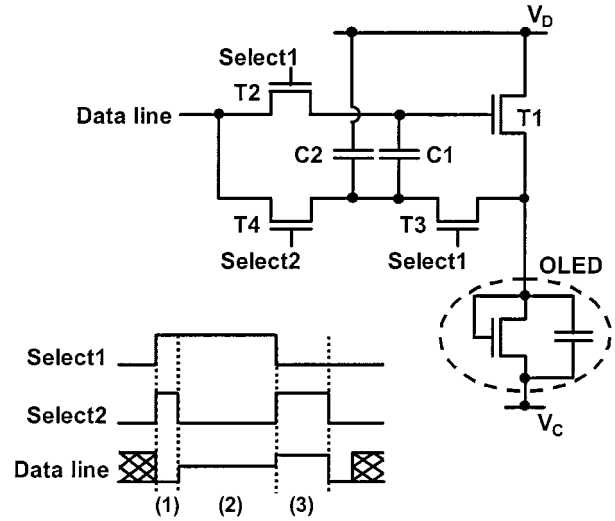


Fig. 1. Equivalent circuit and driving signals of a proposed pixel circuit for an AMOLED. (1) Initialization period, (2) compensation period, and (3) data-input period.

data line. An OLED is modeled by a TFT and a capacitor. The sizes of both driving TFT (T1) and OLED are chosen so that the output current range of an OLED is within the subthreshold current region of a driving TFT. The operation of the pixel circuit is as follows.

In an initialization period shown (1) in Fig. 1, T2, T3 and T4 are turned on and the data line is at ground. The gate of T1 and anode of OLED are initialized to ground. In a compensation period shown (2) in Fig. 1, only T4 is turned off and a compensation voltage V_{comp} is applied to the data line. The gate of T1 becomes V_{comp} and source of T1 settles to $V_{comp} - \Delta V$. Since ΔV is the V_{GS} of T1 and the drain current of T1 is in the subthreshold region, the ΔV corresponds to V_{th} (threshold voltage) of T1. This is stored in C1. In a data-input period shown in (3) in Fig. 1, only T4 is turned on and the data line is at an input voltage, V_{input} . Due to the bootstrapping effect, the gate of T1 becomes $V_{input} + V_{th}$. Because the driving current of T1 is within subthreshold region as described above, the source of T1 becomes $V_{input} - \Delta V_{input}$. The ΔV_{input} depends on the subthreshold slope of T1. If the drain currents of T1 in compensation period and data-input period are I_{comp} and I_{out} , respectively and drain-induced barrier lowering (DIBL) effect is negligible, the subthreshold slope, S_t (V/dec) of T1 can be written as

$$S_t = \frac{\Delta V_{GS}}{\Delta \text{Log}(I_{DS})} = \frac{(V_{th} + \Delta V_{input}) - V_{th}}{\text{Log}(I_{out}) - \text{Log}(I_{comp})} \quad (1)$$

Manuscript received May 30, 2002; revised July 10, 2002. The review of this letter was arranged by Editor J. Sin.

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Publisher Item Identifier 10.1109/LED.2002.802684.

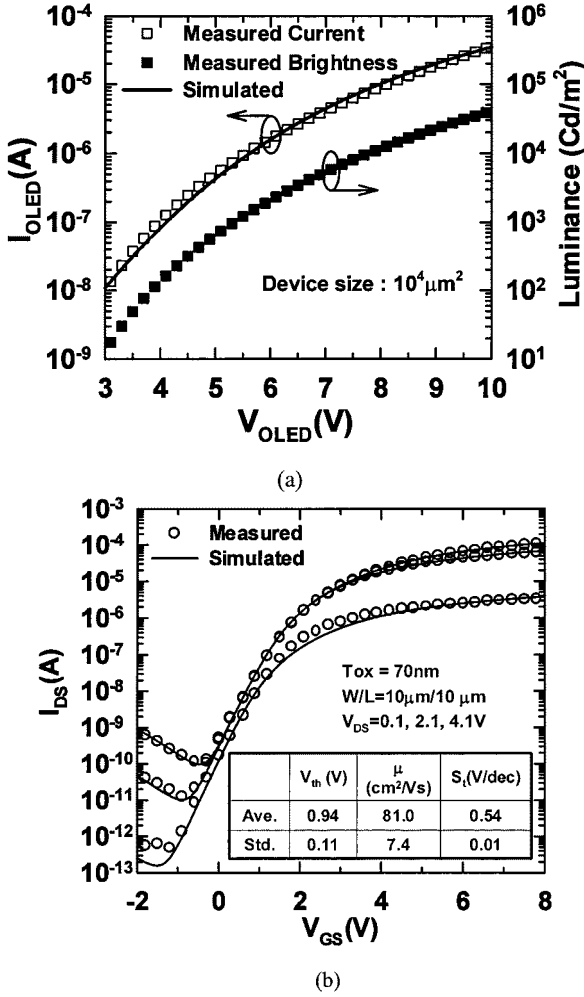


Fig. 2. Electrical characteristics of the devices fabricated in this work. (a) I - V -luminance characteristics of an OLED and (b) transfer characteristics of a poly-Si TFT and the inserted table shows average and standard deviation of device parameters extracted from 30 samples of the poly-Si TFTs.

and thus

$$\Delta V_{\text{input}} = [\text{Log}(I_{\text{out}}) - \text{Log}(I_{\text{comp}})] \times S_t. \quad (2)$$

The ΔV_{input} is approaching to zero as S_t decreases. Therefore, the pixel circuit controls the OLED current by changing V_{input} , regardless of the threshold voltage and mobility variations of the poly-Si TFTs. The compensation voltage, V_{comp} can be set to a constant voltage or to the input voltage, V_{input} ($V_{\text{comp}} = V_{\text{input}}$).

III. DEVICE PARAMETER EXTRACTION AND SIMULATION RESULTS

We have simulated the dependence of the output current on device parameter variation with an AIM-Spice model of a poly-Si TFT. In order to obtain realistic device parameters for the pixel circuit simulation, poly-Si TFTs and OLEDs were fabricated and their performances were measured.

Fig. 2(a) shows the current-voltage (I - V)-luminance characteristics of an OLED with a luminance efficiency of 12–13 Cd/A. The lines in Fig. 2(a) are the DC current simulated for an OLED modeled by a poly-Si TFT and a capacitor shown

TABLE I
PARAMETERS USED IN THE PIXEL CIRCUIT SIMULATION

Device sizes		Supply voltages		Period times	
W/L(T1-T4)	10 μm /10 μm	V_D	8V	$T_{(1)}$	1 μs
C1,2	0.4pF	V_C	-1V	$T_{(2)}$	14 μs
Area of OLED	10 μm^2	$V_{\text{select1,2}}$	0-10V	$T_{(3)}$	4 μs

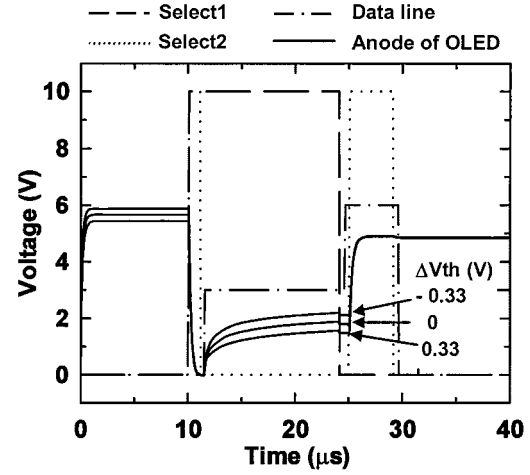


Fig. 3. An example of transient simulation result for the proposed pixel circuit at $V_{\text{comp}} = 3$ V and $V_{\text{input}} = 6$ V.

in Fig. 1. The device size was $10^4 \mu\text{m}^2$. In this simulation, the OLED capacitance is set to $25 \text{ nF}/\text{cm}^2$ from the reference [2]. The transfer characteristics of the poly-Si TFT are shown in Fig. 2(b) and the extracted device parameters from the poly-Si TFT are in the inserted table. Note that the subthreshold slope is more attractive than mobility. Therefore, subthreshold current is more attractive to drive the OLED than linear or saturation current if the variation in the threshold voltage is compensated.

Table I shows the parameters used in the simulation. Fig. 3 shows a transient response result simulated for different threshold voltages ($\Delta V_{th} = 0$ and ± 0.33 V) of a driving TFT (T1) shown in Fig. 1. In compensation period (11–24 μs), the difference between data line voltage and anode voltage of an OLED is stored in C1 and this corresponds to a threshold voltage. Therefore, the anode potential of an OLED is independent of the threshold voltage of a driving TFT.

Fig. 4 shows the simulation results for three driving methods: conventional two-TFT method and our methods with $V_{\text{comp}} = 3$ V and $V_{\text{comp}} = V_{\text{input}}$. Fig. 4(a) shows the output OLED current, I_{out} as a function of input voltage, V_{input} , where the device parameters shown in the inset of Fig. 2(b) were used. Due to the threshold voltage compensation in our method, output current of an OLED is higher than that of conventional two-TFT method. When $V_{\text{comp}} = V_{\text{input}}$, the I_{comp} increases exponentially with V_{input} and the threshold voltage stored in C1 increases linearly with V_{input} in the compensation period. Consequently, the output current when $V_{\text{input}} > 4$ V is higher than that at $V_{\text{comp}} = 3$ V. Fig. 4(b) shows the nonuniformity in the output current of an OLED simulated with combined

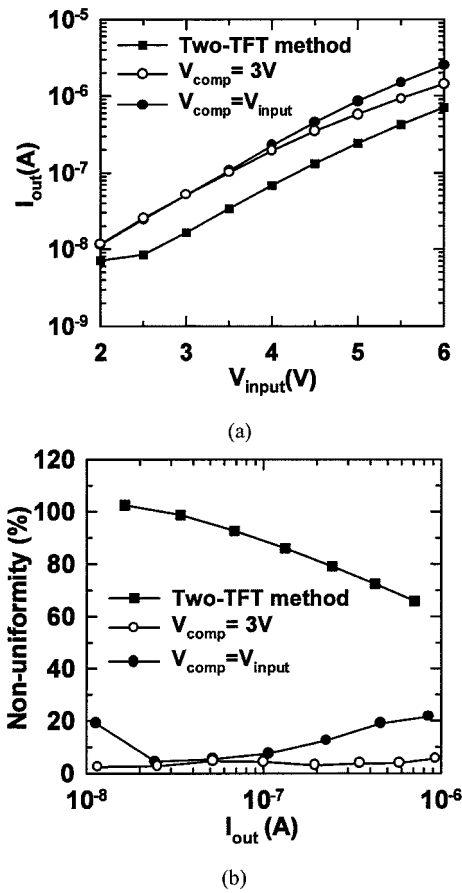


Fig. 4. Simulation results for three driving methods: conventional two-TFT method and our methods with $V_{comp} = 3V$ and $V_{comp} = V_{input}$. (a) Output current I_{out} versus input voltage V_{input} characteristics and (b) nonuniformity of the output current due to the variation in the device performances.

V_{th} , μ , and S_t variations of the poly-Si TFT. The variations are ± 3 times standard deviations, $\Delta V_{th} = \pm 0.33V$, $\Delta \mu =$

$\pm 22 \text{ cm}^2/\text{V s}$, and $\Delta S_t = \pm 0.03 \text{ V/dec}$, respectively. The nonuniformity is defined as the difference between maximum and minimum output current, divided by average output current [I_{out} shown in Fig. 4(a)] at an input voltage. Compared to simulation results of conventional two-TFT circuit (nonuniformity: 66–103%), significant improvement ($< 6\%$) has been obtained when $V_{comp} = 3V$.

IV. CONCLUSION

We have developed a new pixel circuit composed of four TFTs and two capacitors for an AMOLED using a voltage-source scheme. Simulation results based on the performances of the fabricated poly-Si TFTs indicate that the pixel circuit is effective to provide a uniform output current against the variation in the poly-Si TFT performances.

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