

P-72: A Novel Pixel Circuit for Active-Matrix Organic Light-Emitting Diodes

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Abstract

In this paper, a novel pixel circuit for active-matrix organic light-emitting diodes (AMOLED's), is proposed. This circuit is composed of 4 TFT's and one capacitor. It has high immunity to threshold voltage and mobility variations of poly-Si TFT's.

1. Introduction

Active-matrix organic light-emitting diodes (AMOLED's) have more attractive advantages for flat panel display than AM liquid-crystal displays (LCD's). OLED's promise to achieve thin, compact, lightweight, and inexpensive displays. Moreover, the display can have low power consumption, wide viewing angle, and fast response.

There are many candidates for active-matrix devices, i.e., single-crystal silicon MOSFET, hydrogenated amorphous silicon thin film transistors (a-Si:H TFT), high-temperature polycrystalline Silicon TFT (poly-Si TFT), low-temperature poly-Si TFT, etc. Among them, the low-temperature poly-Si (LTPS) TFT's are suitable as switching and driving devices for active-matrix light-emitting diodes (AMOLED's) on glass substrate. The mobility of poly-Si TFT's is high enough for pixel devices and driver circuits of AMOLED's. However, there are variations in the performance of the poly-Si TFT's over the display area. These variations are due to the nature of the polysilicon material. Thus, it is difficult to produce uniform current sources over large-area.

In order to realize AMOLED's with poly-Si TFT's, each pixel should be composed of circuits with compensation scheme. Recently, several pixel circuits have been proposed to compensate the performance variations of poly-Si TFT's. These can be classified into current-source method [1-3] and voltage-source method [1, 4, 5]. The current-source method can compensate the performance variations of the poly-Si TFT's, but voltage-source method is more attractive to integrate poly-Si TFT data drivers on the display panel. However, each of the schemes with voltage-source methods has its own demerit, very sensitive to mobility variation [1, 5], or mismatching problem between TFT pairs [5], too large-area occupancy for two capacitors [1, 4]. In this paper, we propose a novel pixel circuit with a voltage-source method. The pixel circuit has high immunity to threshold voltage and mobility variations of poly-Si TFT's without the above demerits.

2. A Proposed Pixel Circuit Scheme

2.1 Circuit Operation

Figure 1 shows the equivalent pixel circuit and timing diagram for the proposed pixel circuit. The pixel circuit consists of three switching N-channel TFT's (Sw1-Sw3), one driving N-channel TFT (DTFT), one storage capacitor (C_{ST}) and one OLED. Control signal lines are three row lines (TNO, SLT and CTD) and two

column lines (DT and V_{DD}). Among the row lines, TNO and SLT lines are formed with gate metal but CTD is formed with patterned cathode metal of OLED, which can be made by using metal mask as in passive-matrix OLED [6]. DT is a voltage data signal line and V_{DD} is a common constant voltage source line. The operation of the pixel circuit is as follows.

The first stage is precharging. During the previous frame time, SLT and CTD are low, and TNO is high. Then, SLT goes high, turning on Sw1 and Sw2, and CTD goes high, preventing currents from flowing to OLED, while TNO stays high, sustaining Sw3 in 'on' state. When an input data, V_{data} is applied to DT, the source of DTFT becomes V_{data} and the gate of DTFT is charged up to a potential, high enough not to interfere with compensation operation at the next stage

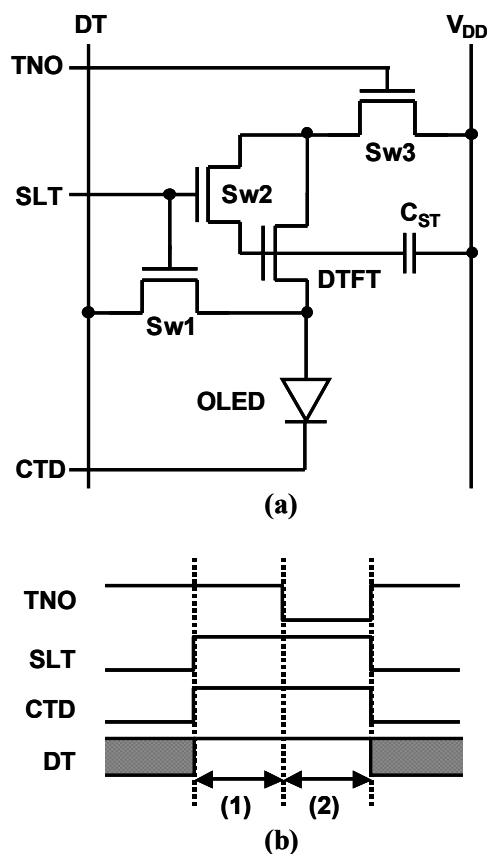


Figure 1. (a) Circuit schematic and (b) control signal timing diagram of the proposed pixel circuit. (1) Precharging stage and (2) data-input stage.

The second stage is data-input stage. TNO goes low, turning off Sw3, while SLT and CTD remain high. The gate voltage of DTFT is discharged through Sw1 and Sw2 until DTFT is turned off. This node voltage settles to $V_{data} + V_{th}$, where V_{th} is the threshold voltage of DTFT. Therefore, the threshold voltage can be compensated in this stage.

After data-input stage, SLT and CTD return low and TNO returns high. Then, DTFT starts to drive OLED. The C_{ST} sustains the gate voltage of DTFT during a frame time. On the other hand, the sizes of both DTFT and OLED are chosen so that the output current through OLED is the subthreshold current of DTFT. Generally, the variation of subthreshold slope is less than that of mobility. Therefore, subthreshold current, instead of linear or saturation current, is suitable to driving current. Consequently, OLED current in the proposed pixel circuit has high immunity to the variation of threshold voltage and mobility of TFT.

In short, as driving TFT's are modulated by data voltages added to threshold voltages and their driving currents are set within subthreshold regime, the pixel circuit is very effective to provide a uniform output current against threshold voltage and mobility variations in the poly-Si TFT's. This is verified by simulation results at next section.

2.2 Circuit Simulation

The pixel circuit simulations have been carried out with an AIM-SPICE simulator. In order to obtain realistic device parameters for the pixel circuit simulation, poly-Si TFT's and OLED's were fabricated and their performances were measured.

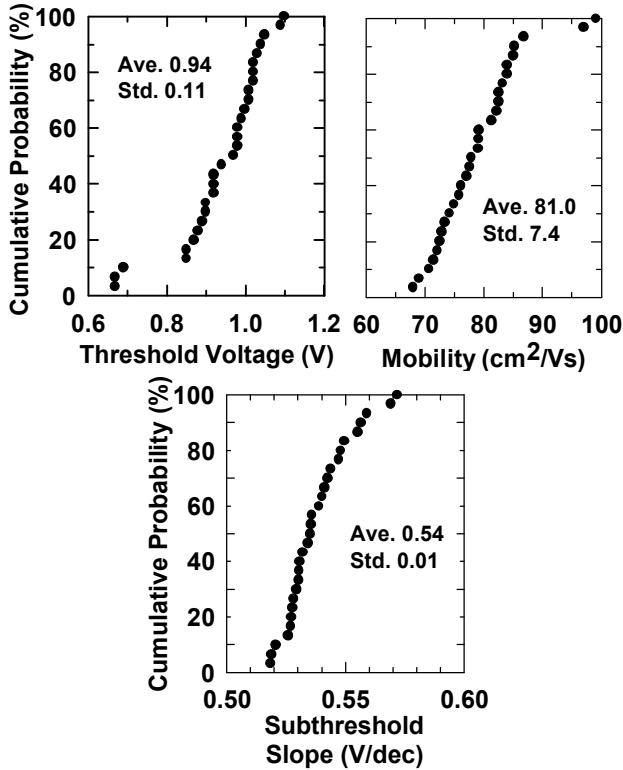


Figure 2. Cumulative distributions of device parameters from 30 samples of the fabricated poly-Si TFT's

Table 1. Circuit simulation parameters

W/L	10/10 nm
C_{ST}	0.3 pF
Area of OLED	10^4 nm^2
V_{DD}	8 V
TNO, SLT	0 – 10 V
CTD	-1 – 3 V
$T_{precharging}$	5 msec
$T_{data-input}$	8 msec

2.2.1 Parameter extraction

The electrical characteristics of an OLED used in this simulation were replaced by those of a diode-connected TFT of which device parameters have been extracted from the experimental data on an OLED having a luminance efficiency of 12-13 Cd/A [4]. Figure 2 shows the cumulative distribution of device parameters of the fabricated poly-Si TFT's. Threshold voltage and subthreshold slope were extracted from V_{GS} at $I_D = 10 \text{ nA}$ (W/L) and $V_D = 0.1 \text{ V}$. The field-effect mobility was calculated from the maximum transconductance in the linear regime ($V_D = 0.1 \text{ V}$). 30 TFT's were measured. Note that the subthreshold slope is more uniform 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. By applying the variation results, non-uniformities of output current were investigated in the circuit simulations.

2.2.2 Simulation Results

The circuit simulation parameters are summarized in Table 1. Row select time of one frame is 12 μsec ($T_{precharging} + T_{data-input}$), corresponding to SXGA (1280 × 1024).

Figure 3 shows transient response results with combined V_{th} , μ , and S_t variations of poly-Si TFT at $V_{data} = 5.85 \text{ V}$. The variations are ± 3 times standard deviations. In precharging stage (1), the gate voltages of DTFT rise up closely to V_{DD} (8V). The anode voltages of OLED become V_{data} (5.85V), however OLED currents are negligible because the cathode of OLED, CTD, is 3V. In data-input stage (2), anode voltages of OLED are still V_{data} (5.85V) and the gate voltages of DTFT decrease and nearly become $V_{data} + V_{th}$'s. After the data-input stage, anode voltages are almost identical.

Figure 4 shows transient response results to see the non-uniformity of OLED current with the same TFT variations as in Fig. 3. When average parameter values (CASE 2) are used, the output OLED current is 1 μA (10 mA/cm²), and the luminance is 1300 cd/m². By TFT performance variations, the OLED current varied to 1.031 μA (CASE 1), and 0.985 μA (CASE 3). The non-uniformity of the OLED current is less than 5 % at 1 μA (+3.1 % and -1.5 %).

These simulation results verify that the proposed pixel circuit can effectively provide uniform OLED current regardless of the variations in poly-Si TFT performance.

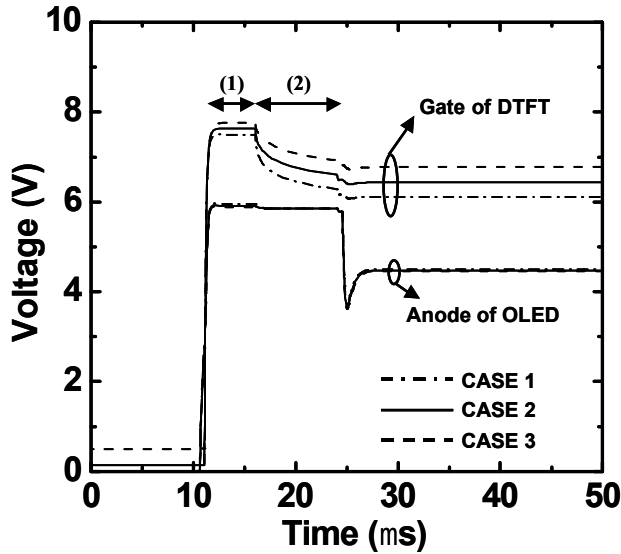


Figure 3. Transient response simulation with TFT variations at $V_{data} = 5.85$ V. (1) Precharging stage, (2) data-input stage.

CASE 1 : $V_{th} = 0.61$ V, $m = 103$ cm^2/Vsec , $S_t = 0.51$ V/dec

CASE 2 : $V_{th} = 0.94$ V, $m = 81$ cm^2/Vsec , $S_t = 0.54$ V/dec

CASE 3 : $V_{th} = 1.27$ V, $m = 59$ cm^2/Vsec , $S_t = 0.57$ V/dec

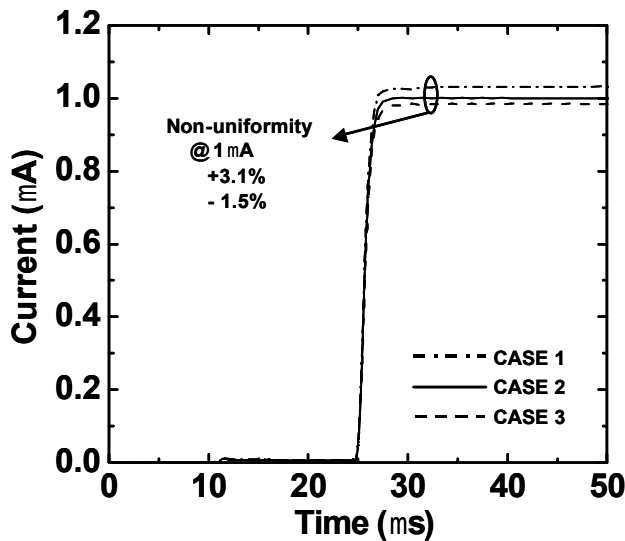


Figure 4. Simulation results of the pixel circuit for the OLED output current at $V_{data} = 5.85$ V.

CASE 1 : $V_{th} = 0.61$ V, $m = 103$ cm^2/Vsec , $S_t = 0.51$ V/dec

CASE 2 : $V_{th} = 0.94$ V, $m = 81$ cm^2/Vsec , $S_t = 0.54$ V/dec

CASE 3 : $V_{th} = 1.27$ V, $m = 59$ cm^2/Vsec , $S_t = 0.57$ V/dec

3. A Modification of the Proposed Pixel Circuit

CTD, a row line the pixel circuit shown in Fig. 2, should be formed with patterned cathode metal. It is required some additional fabrication processes to have patterned cathode, which may be complicated. Figure 5 shows a modified pixel circuit, eliminating the issue by inserting a TFT (Sw4) between DTFT and OLED. The number of TFT's increase to five while that of row lines decrease to two, the cathode of OLED changed to common node. Sw4, newly inserted, is controlled by TNO^{n-1} , which is from TNO of the previous row. Its operation is similar to the previous pixel circuit. Sw4, turned off by TNO^{n-1} , hinders current from flowing to OLED during precharging and data-input stages. TNO goes low at data-input stage and must remain low until the data-input stage in the next row is complete.

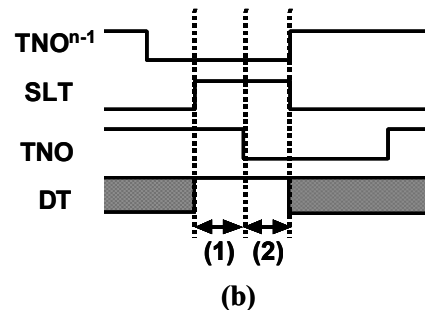
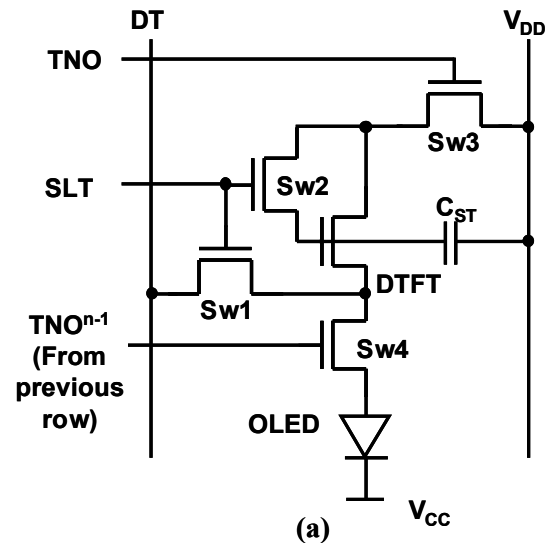


Figure 5. A modified pixel circuit. (a) Circuit schematic, and (b) timing diagram. (1) Precharging stage, (2) data-input stage. TNO^{n-1} is from TNO of the previous row. And TNO must be low until the data-input stage in the next row is complete.

4. Conclusion

We have proposed a novel pixel circuit for AMOLED's, which is composed of four TFT's and a capacitor. The pixel circuit, designed with the voltage-source method, is very attractive to integrate data driver on display panel. Simulation results based on

experimental data, verify that the pixel circuit has high immunity to TFT performance variations for providing uniform OLED current. In addition, a modified pixel circuit is proposed, composed of five TFT's and a capacitor, to make fabrication steps easy.

5. References

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