

# A New Voltage-Programmed Pixel Structure Compensating for Threshold Voltage Shift of Organic Thin Film Transistor

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**Abstract:** A new voltage-programmed pixel circuit using soluble-processed organic thin film transistors (OTFTs) for an active matrix organic light emitting diode (AMOLED) is proposed. The proposed circuit is composed of four switching TFTs, one driving TFT and one storage capacitor, which is simulated by HSPICE. The proposed circuit can compensate for the non-uniformity of OLED current caused by the threshold voltage degradation of the OTFT. The simulation results demonstrate that the variation of OLED current corresponding to a 3V threshold voltage shift is decreased by 30% compared to the conventional 2-TFT pixel circuit.

## 1. Introduction

Active-matrix organic light emitting diode (AMOLED) has considerable advantages for flat panel displays for a variety of reasons. As the OLED is a self-emitting device, AMOLED display can represent various colors without any color filters and it has a wide viewing angle, a fast response, light weight and low power consumption [1]-[5].

For AMOLED display, each pixel has switching and driving transistors for driving the OLED. Thin film transistors that are based on amorphous silicon (a-Si TFT) and polycrystalline silicon (poly-Si TFT) have been used typically [1]. Recently, organic thin film transistors (OTFTs) have been favored as the pixel driving transistor because the organic material can be used to create low cost, flexible displays using low temperature fabrication methods.

It has been reported that the mobility and on-off ratio of pentacene-based OTFTs are comparable to a-Si TFTs [6]. However, the performance of the OTFT is influenced by various external conditions, e.g. ultraviolet (UV) light, temperature, wafer dampness, and oxygen [7]. As with the a-Si TFT, the application of a DC bias to the gate of the OTFT results in a threshold voltage ( $V_{th}$ ) shift, which causes a reduction of the OLED current after long time.

As a result, the threshold voltage shift generates a non-uniform brightness since it is proportional to the OLED current [8]. To achieve good uniformity, we need to use a  $V_{th}$  compensation circuit, and various methods have been introduced to solve this problem.

In this paper, we will propose a new pixel circuit that is available to compensate for the degradation of the OLED current. Also, we will use the p-type soluble-processed OTFTs in the simulations. Although soluble-processed OTFTs show unstable electrical properties compared to OTFTs that use vacuum equipment to deposit pentacene, research is being conducted because of the potential for producing good OTFT displays at a much lower cost [9].

TABLE 1  
PARAMETERS OF SOLUBLE-PROCESSED ORGANIC TFT DEVICE

Parameter	Value
Mobility	0.2 cm <sup>2</sup> /Vs
Threshold Voltage	-5V
Sub-threshold Slope	2.28 V/dec
On-off ratio	1.03E05
Gate Dielectric thickness	100nm

First, we will perform p-type OTFT device modeling by using an HSPICE simulation. Also, we will verify the suitability of the modeled device by applying it to the conventional 2T1C circuit. Due to making the pixel circuit out of p-type OTFTs exclusively, we have problems with designing the pixel and the timing diagram. Also, since the characteristics of the soluble-processed OTFT are inferior to the characteristics of the pentacene deposited OTFT, the output current levels are lower than those of the pentacene OTFT, so the OLED current is controlled by the size of the device [3].

Despite the disadvantages of the p-type soluble-processed OTFT, we will propose a new voltage-driven pixel circuit that composed of five p-type soluble-processed OTFTs and one capacitor for compensating for the  $V_{th}$  degradation. Finally, the effectiveness of proposed circuit for dealing with the  $V_{th}$  sensitivity will be discussed.

## 2. Conventional Pixel Circuit for AMOLED

### 2.1 OTFT Device Modeling

First, I-V curve fitting of the OTFT was performed for the pixel design. To obtain the reference model, we measured the electrical characteristics of the soluble-processed OTFT by using HP4156B to extract the model parameters. The measured value of threshold voltage and mobility of the OTFT are -5V and 0.2cm<sup>2</sup>/Vs, respectively. The electrical characteristics are poor since the active region is composed of the soluble-processed organic material [3],[9]. The device parameters of the soluble-processed OTFT are listed in Table 1.

Fig. 1 shows the measured output curve of the OTFT along with the output that was simulated using HSPICE. SPICE level 61 RPI a-Si TFT model was used for curve fitting because the physics of a-Si are more similar to the physics of the organic material than polycrystalline silicon. Because of the difference of material characteristics between a-Si and the organic material, and because of the

technical limitations of modeling, a small error occurred in the high gate-source bias region. Since no large bias (like the -40V) is applied to the device, this modeling result is reasonable for this particular pixel circuit simulation.

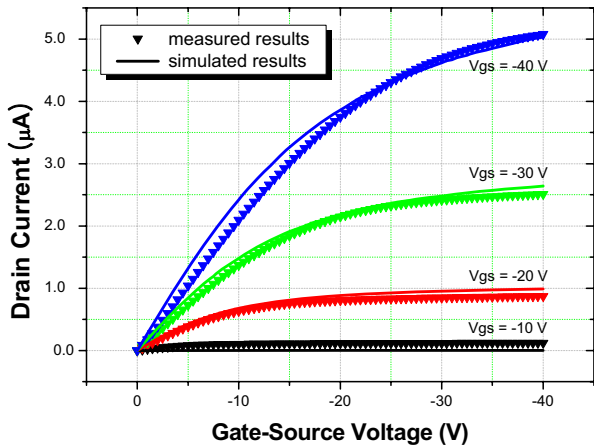


Fig. 1. Measured and Simulated output characteristics of soluble-processed organic thin film transistor for gate-source voltage.

## 2. 2 Simulation of Conventional Pixel Structure

Fig. 2 shows the conventional structure of an AMOLED pixel circuit (i.e., the 2T1C pixel circuit) driven by OTFTs. The pixel circuit is composed of a switching TFT (M1), a driving TFT (M2), and a storage capacitor (Cst) [1],[5].

The OTFTs that were simulated previously were used in this pixel structure. Table2 shows the specific circuit parameters. The simulation was performed for a QVGA (320x240) resolution with a frame rate of 60Hz. The scan time is about 70µs because 240 row lines are processed during a period of about 16.7ms [2].

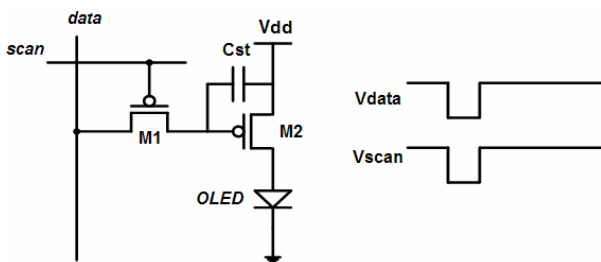


Fig. 2. Conventional pixel structure and timing diagram.

TABLE 2  
PARAMETERS OF CONVENTIONAL PIXEL CIRCUIT

Parameter	Value	Description
M1 (W/L)	60u / 6u	SW Tr.
M2 (W/L)	180u / 6u	DR Tr.
Cst	500fF	Storage cap.
Vdd	20 V	VDD
scan	-20 ~ 5 V	Scan
data	5 ~ 15 V	Data input

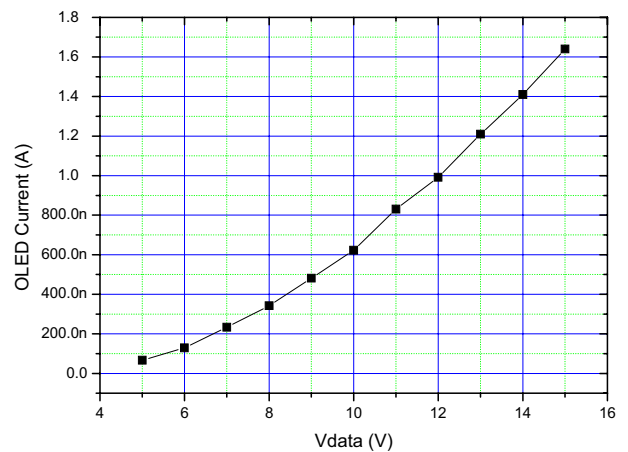


Fig. 3. OLED current versus data voltage of 2T1C pixel structure.

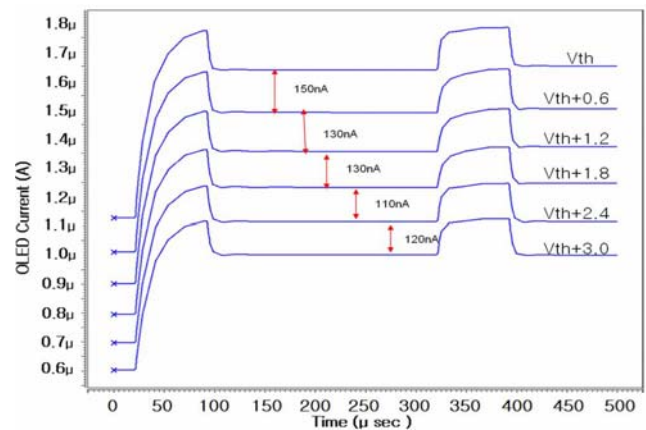


Fig. 4. Variation of OLED current by Vth shift at 2T1C pixel structure.

Fig. 3 shows the simulation results for the data voltage versus the OLED current. The OLED current increases proportionally to the data voltage, so we can conclude that the simulated OTFT is accurately representing the pixel circuit, but the conventional pixel structure is sensitive to the Vth shift. Fig. 4 shows the OLED current when the Vth shift is implemented at a data voltage of 5V. When Vth increases by 0.6V, the OLED current decreases by an average of about 130nA which causes a degradation of the brightness.

Attempts have been made to create Vth compensation circuits using 2TFTs and 1Capacitor [4], but the 2T1C Vth pixel compensation circuit has complicated driving schemes and that are difficult to realize. For this reason, many compensation circuits that added some switching TFTs to 2T1C structure have been proposed and we will propose a new pixel circuit.

## 3. Proposed Pixel Circuit for compensating Threshold Voltage Shift

### 3. 1 Operation of Proposed Pixel Circuit

Fig. 5 shows the new voltage-programmed pixel compensation circuit using five OTFTs and one capacitor and driving scheme. The circuit is comprised of four switching OTFTs (M1~M4), one driving OTFT (M0), and one storage capacitor (Cst). The operation of the proposed circuit is divided into the four stages that are shown in Fig. 6 and the compensation principle is described as follows.

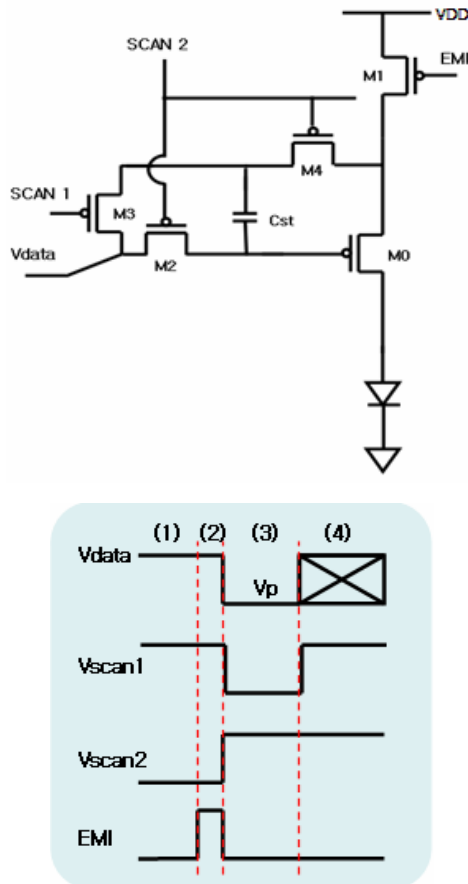


Fig. 5. Proposed 5TFTs and 1Capacitor pixel structure and timing diagram.

#### 1) Initialization

In the first period, SCAN2 and EMI go to a low voltage and SCAN1 goes to a high voltage. The equivalent circuit is described as stage (1) in Fig. 6. The gate voltage of the driving TFT is initialized to Vdata.

#### 2) Vth generation

In the second period, SCAN1 and EMI are set at a high level to yield current to the OLED until the gate-source voltage of the driving TFT comes up to Vth. With this, the charge corresponding to the threshold voltage of the driving OTFT is stored in a storage capacitor and Vth is generated.

#### 3) Voltage programming

In the third period, SCAN2 is sets at a high level and

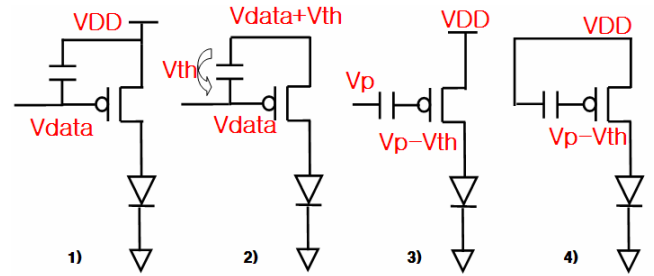


Fig. 6. Operation of proposed 5T1C circuit for compensating Vth shift.

SCAN1 is set at a low level, the programming voltage Vp is added to the stored Vth by capacitive coupling, resulting in a gate voltage of the driving TFT that is Vp-Vth.

#### 4) Emission

In the final period, SCAN1 and SCAN2 are set at a high level, M2 and M3 are off. Nevertheless, the driving TFT generates an OLED current due to the difference of potential between the gate and the source of the driving TFT, so the current is sustained uniformly.

If we assume that the OTFT is an ideal switch that does not have any voltage drop, in the emission period, the OLED current is evaluated as follows.

$$I_{OLED} = K(V_{GS} - V_{th})^2 = K(V_{DD} - V_p + V_{th} - V_{th})^2 = K(V_{DD} - V_p)^2$$

$$\text{where, } K = \frac{1}{2} \mu_p C_{OX} \frac{W}{L}$$

From the calculation, we know that the OLED current becomes insensitive to the threshold voltage shift.

### 3. 2 Simulation Results

The simulation of the proposed pixel circuit was implemented by using the OTFTs that were modeled previously. The specific values of parameters used for simulation are listed in Table 3. Because we selected the value of the threshold voltage shift induced bias stress to be an average of 3V [8], the simulation was implemented by increasing the increment of Vth from 0 to 3V.

Fig. 7 shows the simulation results for a threshold voltage shift from Vth to Vth+3V at a data voltage of -5V. The variation of voltage at the anode of the OLED is small compared with the 2T1C pixel circuit and the maximum OLED current variation corresponding to the Vth shift is about 30nA. We can see the improved uniformity of the OLED current as a function of the threshold voltage variation in Fig. 8. The error represented in the graph in Fig. 8 is defined as the ratio of the change in current caused by the Vth shift to the total current as follows.

$$\frac{\Delta I_{OLED}}{I_{OLED}} = \frac{I_{OLED} - I_{OLED\_Shift}}{I_{OLED}}$$

The proposed pixel circuit improves the uniformity by about 30% compared to the conventional 2T1C structure when the  $V_{th}$  shift is 3V.

TABLE 3  
PARAMETERS OF PROPOSED 5T1C PIXEL CIRCUIT

Parameter	value	Description
M0 (W/L)	360u / 6u	DR Tr.
M1 (W/L)	60u / 6u	SW Tr.
M2 (W/L)	60u / 6u	SW Tr.
M3 (W/L)	60u / 6u	SW Tr.
M4 (W/L)	60u / 6u	$V_{th}$ programming Tr.
Cst	500 fF	Storage cap.
Vdd	20 V	VDD
SCAN1	-20 ~ 5 V	Scan 1
SCAN2	-20 ~ 5 V	Scan 2
EMI	-20 ~ 5 V	Emission
Vdata	15 ~ -5 V	Data input

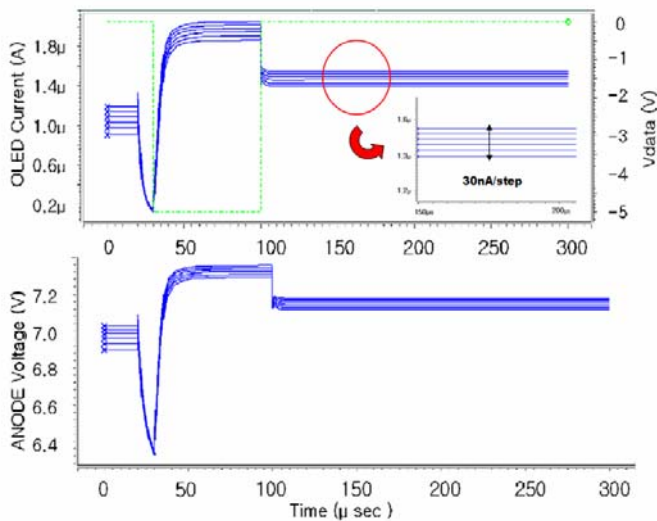


Fig. 7. Variation of current and voltage at anode of OLED with  $V_{th}$  shift

#### 4. Conclusions

A new voltage-programmed pixel circuit using OTFTs for AMOLED has been proposed to compensate for the threshold voltage shift. The pixel circuit is composed of five soluble-processed p-type OTFTs and one storage capacitor. By applying a coupling capacitor through the two switching TFTs, the proposed circuit compensates for non-uniformity caused by the bias stress induced  $V_{th}$  shift. This circuit demonstrated an improved uniformity of brightness of about 30% when the  $V_{th}$  shift is 3V.

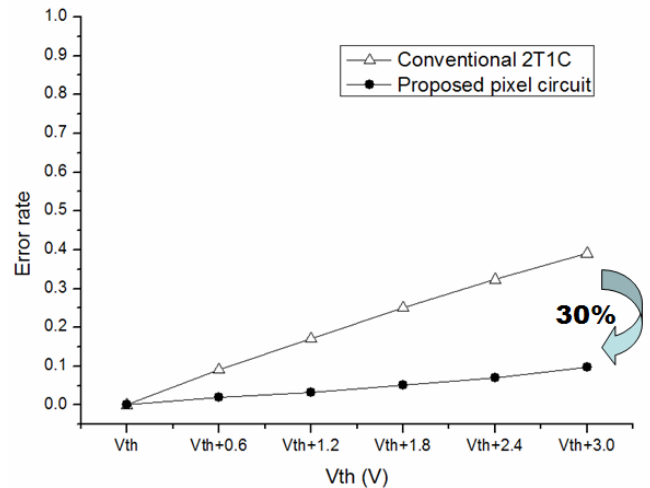


Fig. 8. Comparison of error rate between proposed circuit and conventional 2T1C circuit

#### Acknowledgment

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