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New pixel circuits for driving active matrix organic light emitting diodes

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Abstract

New pixel circuit designs for active matrix organic light emitting diodes (AMOLEDs), based on the low-temperature polycrystalline silicon thin-film transistors (LTPS-TFTs) were proposed and verified by SPICE simulation and fabrication results. Threshold voltage compensation pixel circuits consisting of five TFTs, one additional control signal, and one storage capacitor were used to enhance display image uniformity. The simulation and measured results show that this pixel circuit has high immunity to the variation of poly-Si TFT characteristics.

Keywords: Pixel design; AMOLED(active matrix organic light emitting diode); LTPS-TFTs(low-temperature polycrystalline silicon thin-film transistors)

1. Introduction

Organic light emitting diode (OLED) displays are widely researched and investigated nowadays due to various advantages such as fast response time, wide viewing angle, compact, simple structure and light weight [1–11]. Besides, active matrix driving methods are better than passive matrix driving for displays with high resolution and large panel size [1]. In this paper, low-temperature poly-Si thin-film transistors (LTPS-TFTs) are used to drive OLED device, since they have possession of higher driving capability due to the higher mobility than that of amorphous Si TFTs.

Although LTPS-TFTs have good characteristics, the inevitable non-uniformity problem is encountered because of process variation such as uncontrollable gate oxide trap density and grain size of poly-Si. In conventional pixel circuit design, the variation of TFTs will cause non-uniformity across the display. As a result, various compensation methods have been reported to overcome this problem. These circuits can be classified into voltage driving [1–6,10], current driving [5,8], and digital driving [11].

In this paper, two new voltage programming pixel circuits which consist of five poly-Si thin-film transistors, a storage capacitor and one additional control signal were developed. The simulation and experimental results show that pixel design is capable of reducing the non-uniformity of brightness problem and possessing larger output current.

2. Voltage compensation pixel circuit for AMOLEDs

In the beginning, our pixel design started from the measured and simulated OLED current versus bias voltage characteristics. Fig. 1 shows the transient response of conventional 2T1C pixel circuit. In this case the threshold voltage deviation of LTPS TFTs is assumed to be 0.33 V. It is observed that the anode voltage of OLED is dependent on

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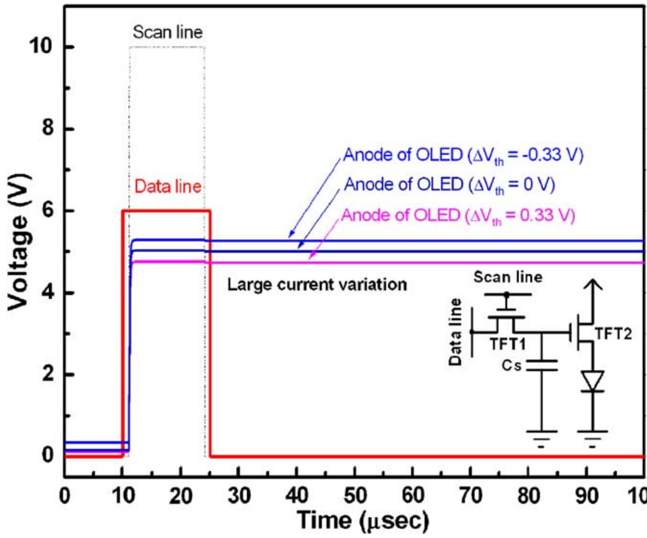

Fig. 1. Transient response of the conventional 2T1C pixel circuit.

the threshold voltage variation and the non-uniform image quality across the display is produced. Fig. 2 shows the proposed pixel structure [3] and the signal driving scheme, respectively. TFT1, TFT3, TFT4, and TFT5 are switching TFTs and TFT2 is a driving TFT. The operation scheme and compensation principle are described as follows.

2.1. Initialization period

During the first period, reset action is performed. V_{sel} and V_{ctrl} signals are high voltages, all TFTs in the pixel are on state. The previous stored voltage in the Cs would be charged up to a specific value.

2.2. Data input period

V_{ctrl} signal is low, turning off TFT4 and TFT5 for storing the threshold voltage of driving transistor (TFT2). At this time, the gate terminal of TFT2 is connected with the drain terminal by TFT3. Because TFT2 acts as a diode, V_{gs} is V_{th_T2} and stored voltage across the capacitor is $V_{data} + V_{th\_T2}$.

2.3. Emission period

After pixel scanning time and sampling the signal voltage stage, V_{sel} is low and V_{ctrl} is high. During this period, driving TFT (TFT2) starts to drive OLED. Because stored voltage in Cs would maintain until the next reset period, the drain current of TFT2 in the saturation region for OLED becomes as follows:

$$I_{OLED} = \frac{1}{2}k_2(V_{gs\_T2} - V_{th\_T2})^2 = \frac{1}{2}k_2(V_{data} + V_{th\_T2} - V_{th\_T2})^2 = \frac{1}{2}k_2V_{data}^2 \quad (1)$$

Therefore, the drain current of TFT2 is independent of the threshold voltage of TFT2, and only affected by V_{data}, the pixel-to-pixel threshold voltage variations can be compensated effectively and uniform brightness image performance can be achieved.

Compared with conventional 2T1C pixel circuit, the transient response of the proposed pixel circuit shows much consistence of driving current against the threshold voltage variation as shown in Fig. 3. It is demonstrated that the anodes of OLED devices are insensitive to different threshold voltages. The difference of the stored voltage in the capacitor almost equals the difference of threshold voltage in driving transistor.

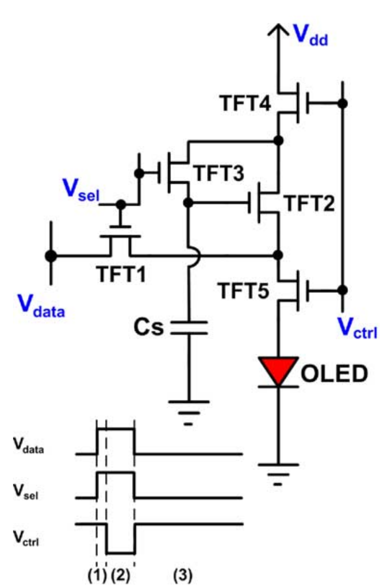

Fig. 2. Proposed circuit schematic and driving signals of voltage compensation circuit for AMOLED.

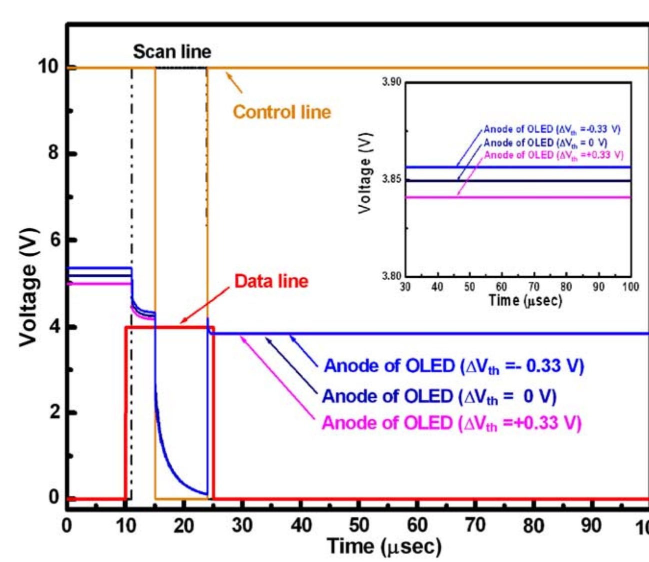

Fig. 3. Transient response of the proposed pixel circuit.

3. Fabrication and measured results

After pixel design finished, testing pixel circuits were fabricated and measured. First, a buffer oxide and 500 Å-thick a-Si thin-film was deposited on glass substrate. Then, the amorphous Si thin-film was crystallized by KrF excimer laser annealing at room temperature. After defining the active layer, a 1000 Å-thick gate oxide was deposited by plasma-enhanced chemical vapor deposition. A 3000 Å-thick Cr film was then deposited for gate electrode. Then, the Cr thin-film and gate oxide were etched to form gate electrodes. Next, a 4000 Å-thick SiNx was deposited by PECVD as interlayer. TFT testing pixel circuits were formed after contact-hole formation and 4000 Å-thick Cr metallization. Fig. 4 shows the optical micrograph of proposed pixel circuit.

After system ready for measuring, proposed pixel and conventional pixel circuits were measured. Ten testing pixel circuits have been measured and the results compared to conventional pixel circuits with different data voltages are shown in Fig. 5(a). It is obvious that proposed pixel circuit posses higher output voltage and better uniformity after calibration threshold voltage variation. Fig. 5(b) shows the measured and simulation results of non-uniformity compared with conventional 2T1C pixel circuit. The voltage non-uniformity is defined as the difference between the maximum output voltage (OLED anode voltage) and the minimum output voltage divided by the average output voltage. By experimental results, the non-uniformity can be suppressed in the proposed circuit. It is verified that the proposed pixel design has high immunity to the variation of poly-Si TFT characteristics.

4. Modified voltage compensation pixel circuit for AMOLEDs

In order to reduce the current flow through OLED during the reset period, a p-channel TFT5 used to block the emission current through OLED is modified as shown in Fig. 6. Since the modified circuit can block current flow through TFT5 and OLED shown in Fig. 7, the power reduction can further be obtained through simulation results.

Fig. 4. Optical micrograph of proposed pixel circuit.

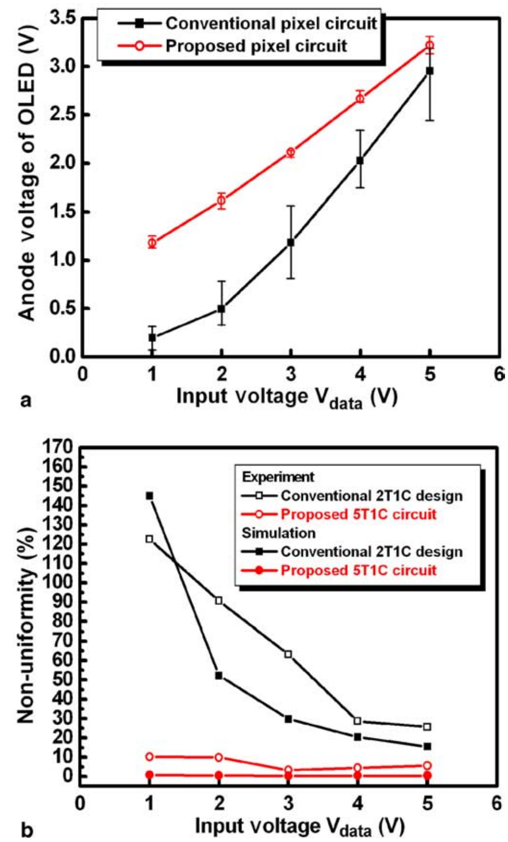

Fig. 5. (a) The measured results compared to conventional pixel circuit of different data voltage; (b) the measured and simulation results of non-uniformity compared with conventional 2T1C pixel circuit.

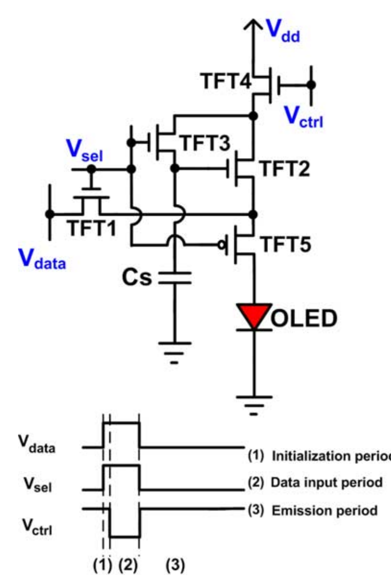

Fig. 6. Modified pixel circuit schematic and the timing diagram of control signals.

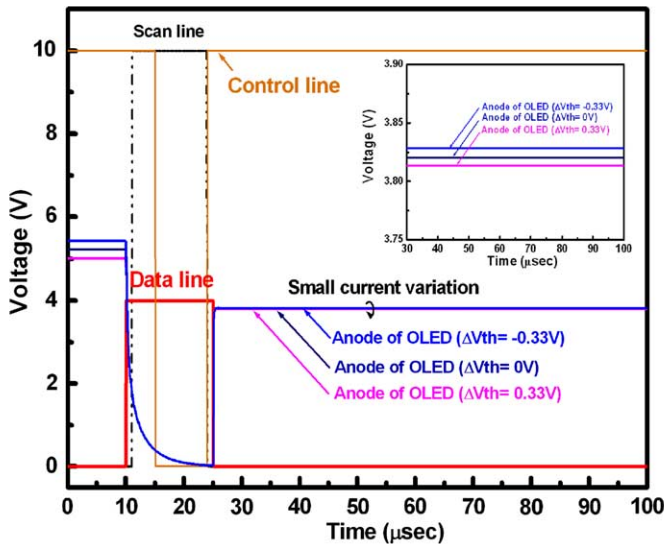

Fig. 7. Transient response of the modified pixel circuit.

5. Conclusions

New voltage modulated low-temperature polycrystalline silicon thin-film transistors (LTPS-TFTs) pixel circuits for active matrix organic light emitting diodes (AMOLEDs) are proposed and verified. The circuits show high immunity to the threshold voltage variation of poly-Si TFT characteristics which will lead to uniform display image for AMOLED. Through experimental results, it is verified that the proposed circuit is capable of reducing the threshold voltage variation problem of conventional pixel circuit and possessing larger output current.

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