Chapter 4

Simulation Results

4.1 Overview

The proposed pixel circuit for emi-flective display is simulated by the software Hspice. The pixel circuit consisting of six thin film transistors and one capacitor is depicted in Fig. 2.11. The simulation results of Vth variation, OLED degradation and operation in LCD mode are presented and discussed in the following sections. The simulation parameters, such as geometric size of TFT, threshold voltage, mobility, storage capacitance, and driving voltage, are listed in Table 4.1.

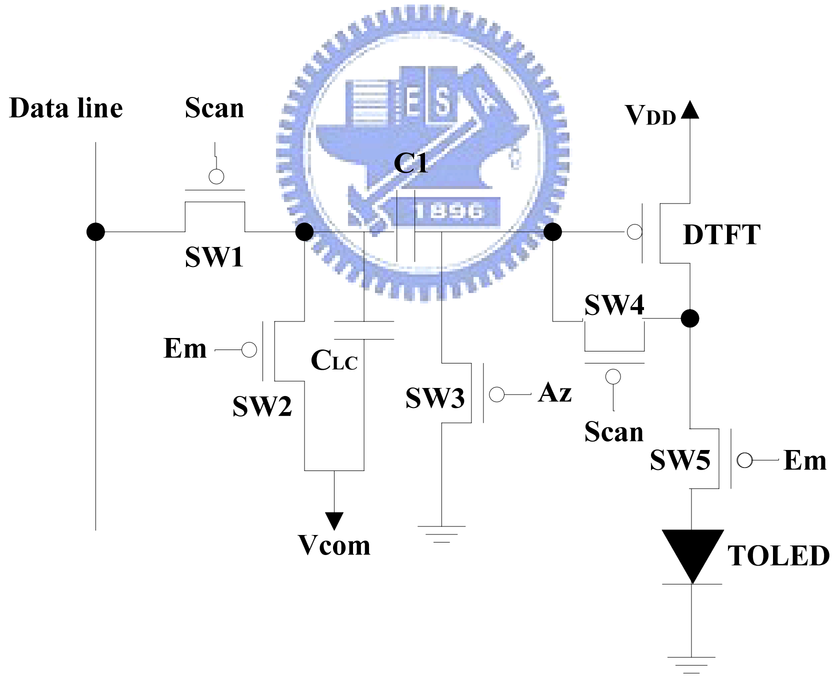


Table 4.1 Simulation parameters

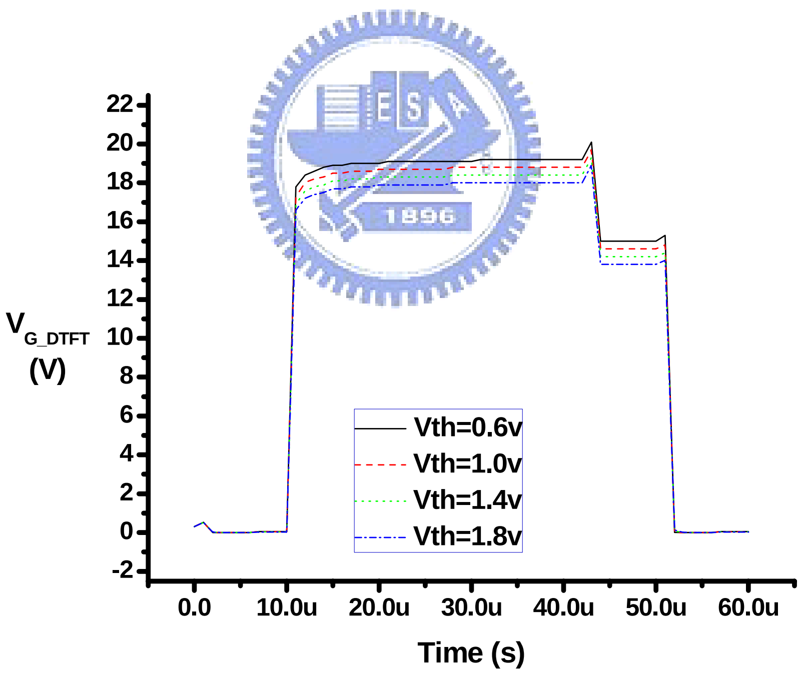
Type of TFT	P channel
W/L of SW1,3,4,5(μm)	4 / 10
W/L of SW2(μm)	4 / 20
W/L of DTFT(μm)	4 / 30
C1(fF)	500
High field mobility(cm2/Vs)	85
Threshold voltage(V)	-1
V_{Scan}(V)	-3~20
V_{Em}(V)	-3~20
V_{AZ}(V)	-3~20
V_{com}(V)	6
V_{DD}(V)	20

4.2 Operation in the Emission Mode

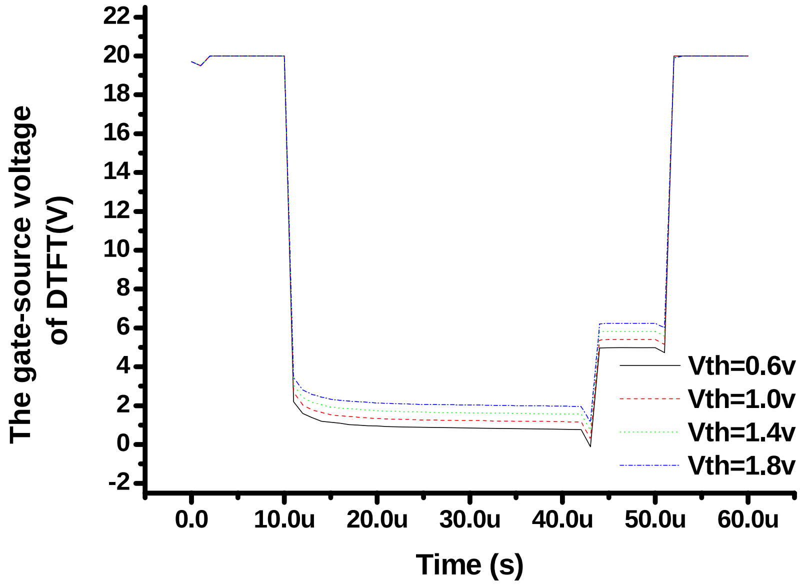
According to ambient light, the emi-flective display is operated in either the emission or reflective mode. In the emission mode, the device encounters several issues of non-uniformity of displayed images mentioned in Chapter 2.

4.2.1 Transient Response

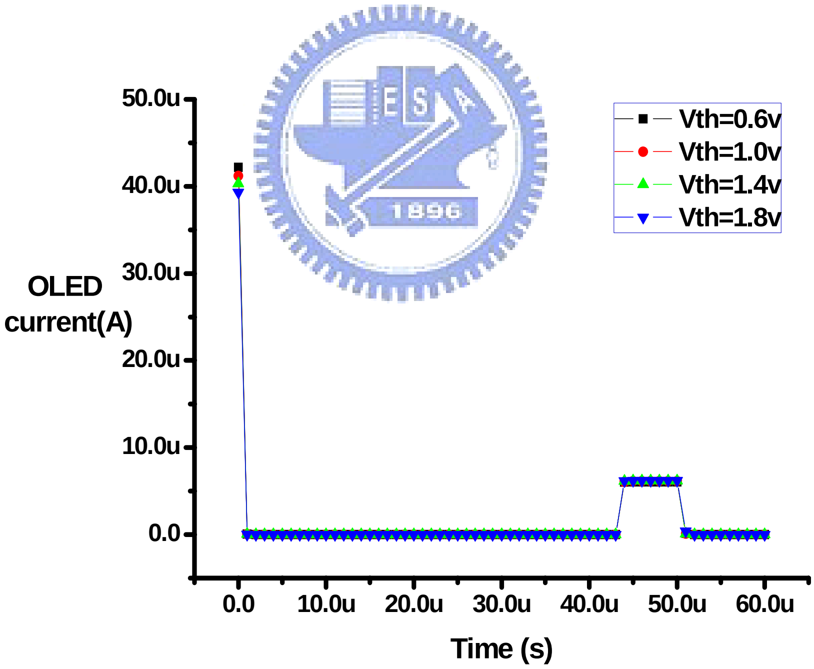
The operation stage in the emission mode illustrated in Fig. 2.12 can be divided into initialization, addressing and illumination. In order to compensate Vth variation, the diode connection is employed to store Vth of each driving poly-Si TFT. The simulation results with varied Vth of TFTs are shown in Fig. 4.1. As shown in Fig. 4.1(a), the gate voltage of DTFT reduces as Vth of DTFT increases. In addition, the gate-to-source voltage of DTFT, shown in Fig. 4.1(b), responses to TFTs with various Vth. As reviewed in chapter 2, Eqs. (2-15) explains why different TFTs can sustain constant current. As shown in Fig. 4.1(c), the compensation for Vth variation is verified.



(a)



(b)



(c)

Fig. 4.1 The transient response of (a) gate voltage of DTFT (b) gate-to-source voltage of DTFT and (c) OLED current

4.2.2 Threshold Voltage Variation

The conventional process of poly-Si TFTs is that develop a-Si layer on the substrate, then apply excimer laser (ELA) to re-crystalize the a-Si layer. However, the ELA process leads to Vth variation of poly-Si spatially which results in non-uniformity of displayed images. It is economical and feasible to develop the compensation function on each pixel circuit. The proposed pixel circuit is simulated with different threshold voltages of poly-Si TFTs, and the simulation results are shown in Fig. 4.2. Conventional 2T1C pixel circuit is sensitive to Vth variation, and each poly-Si TFT provides different OLED currents to form non-uniform images. The proposed pixel circuit effectively compensates Vth variation due to diode connection in the first stage.

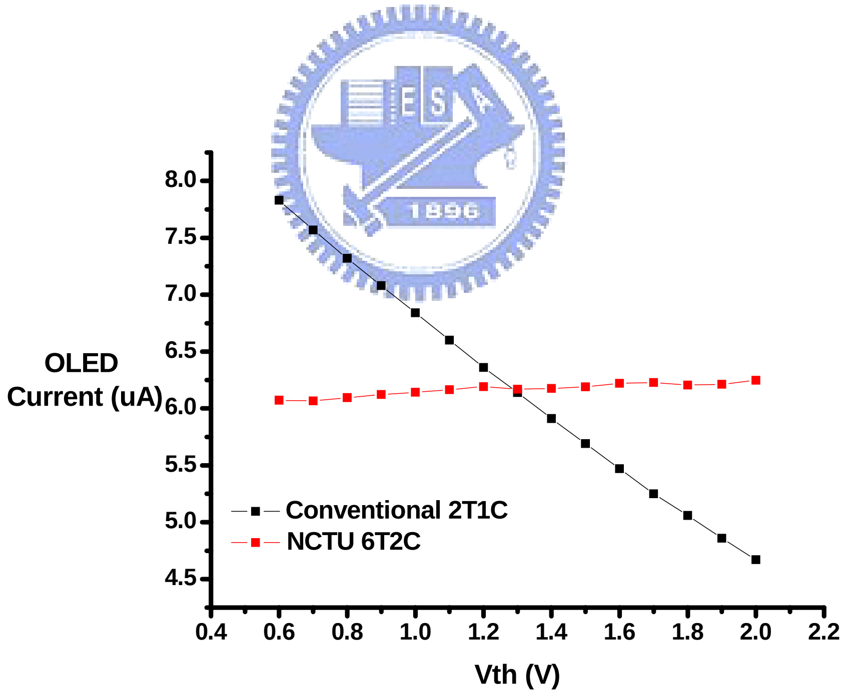


Fig. 4.2 The simulation results of the OLED current

with different threshold voltage of poly-Si TFTs

4.2.3 Turn-on Voltage Shift of OLED

Although OLED displays have benefits of high light efficiency, low process temperature, long-time operation, large operation current and oxidation lead to the degradation. During the alignment process of emi-flective display, the baking of alignment layer affects electrical characteristics of OLED illustrated in Chapter 4. The alignment process results in the OLED resistance also boost the operation voltage. For conventional 2T1C n-channel pixel circuit, OLED current determined by the gate-to-source voltage of the driving TFT is affected by the effect of turn-on voltage shift and decreased. The electrical characteristics of OLEDs with different sheet resistance are shown in Fig 4.3. The simulation results with distinct OLEDs are shown in Fig. 4.4.

Even though OLEDs have different electrical response curves, the proposed pixel maintains more stable OLED current than conventional one.

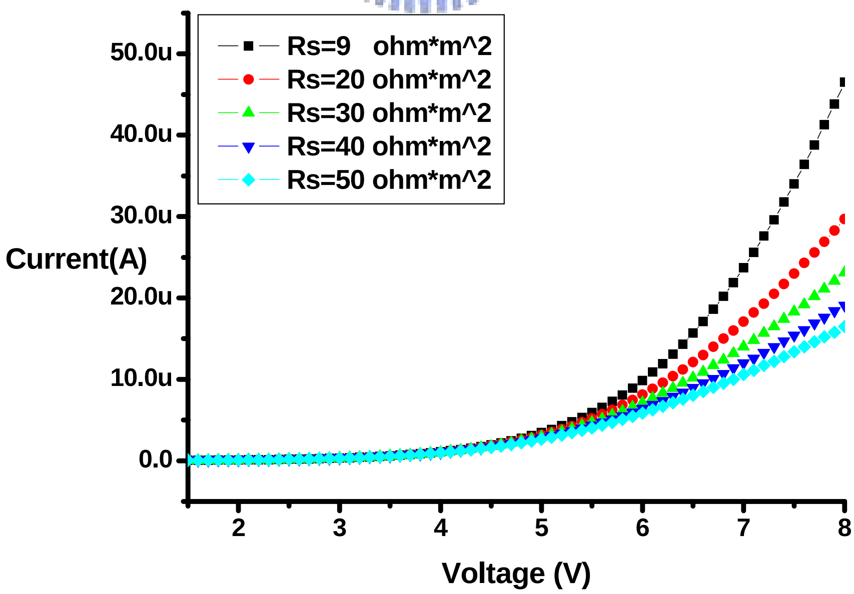


Fig. 4.3 The electrical characteristics of OLEDs

with different sheet resistance

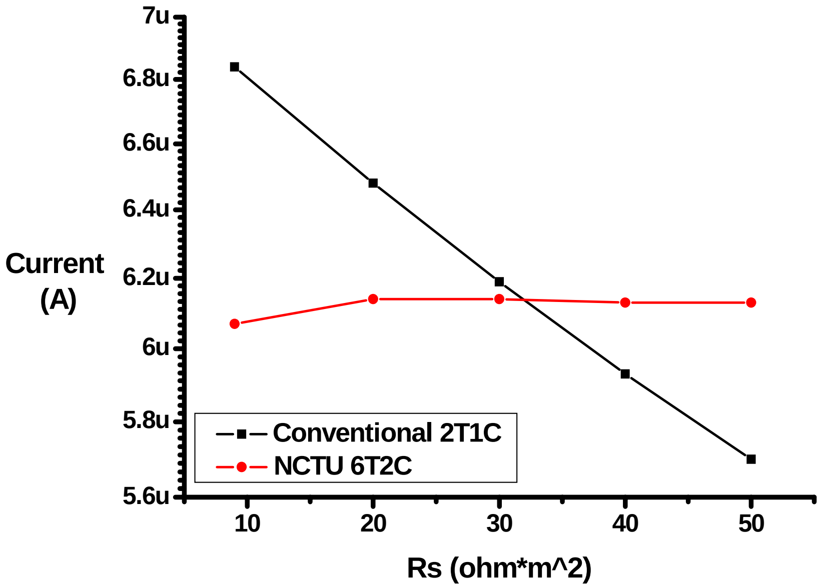


Fig. 4.4 The simulation results of the OLED

with different sheet resistance

In order to quantify the simulation results, the definition of the uniformity is shown in Eqs. 4.1:

$$\text{Uniformity (\%)} = 100 \times [\ 1 - 2 \times (\text{standard deviation/average})\ ] \qquad (4\text{-}1)$$

The quantified simulation results for threshold voltage variation of poly-Si TFTs and turn-on voltage shift of top emission OLED are listed in Table 4.2.

Table. 4.2 The comparison of different pixel circuits for uniformity

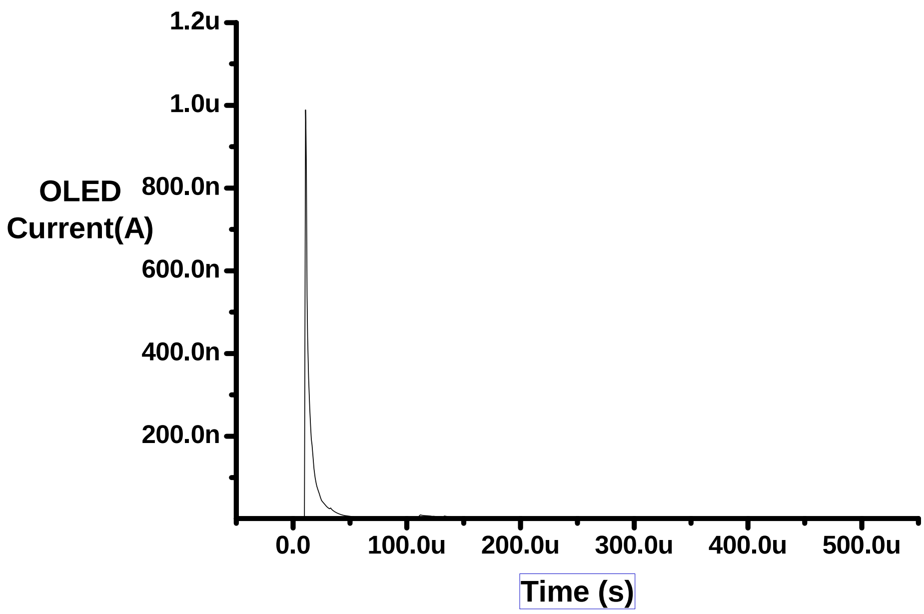
Uniformity		
	Threshold Voltage Variation	Turn-on Voltage Shift
NCTU 6T2C	98.2%	99.1%
Conventional 2T1C	67.2%	85.6%

4.3 Operation in the Reflective Mode

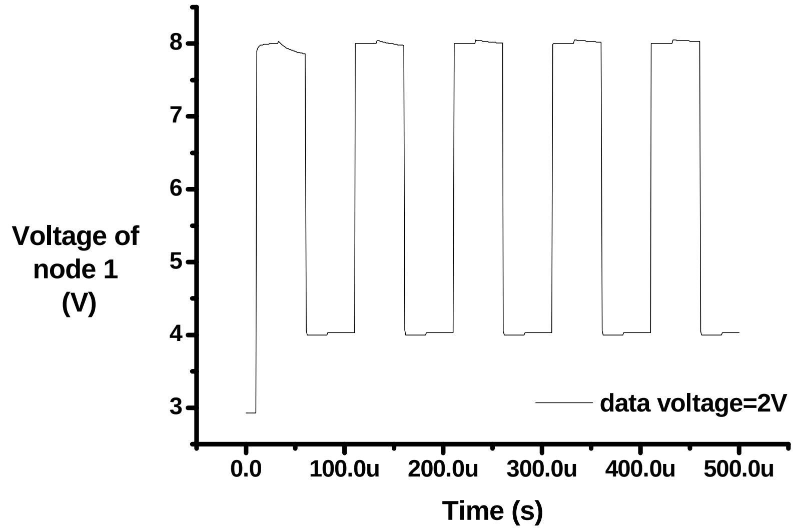
In the bright ambience, the emi-flective display is operated in the reflective mode. In the reflective mode, the gray level of the R-LCD is confirmed by the voltage across the R-LCD.

4.3.1 Transient Response

The time diagram in the reflective operation is shown in Fig. 2.13. The pixel circuit providing two kinds of signals for R-LCD and OLED has the issue of ion charge effect [8]. The insertion of SW2 is an effective access to avoiding the issue. During operation in the reflective mode, there is only stable leakage current, about 10 pA, flowing through OLED. As shown in Fig. 4.5(a), OLED is in the dark state during the reflective mode. The transient response of voltage of node 1 is depicted in Fig. 4.5(b). In order not to affect the switching of SW1, the voltage of Vcom is set to 6 volt. The voltage across R-LCD is plotted in Fig. 4.5(c).



(a)



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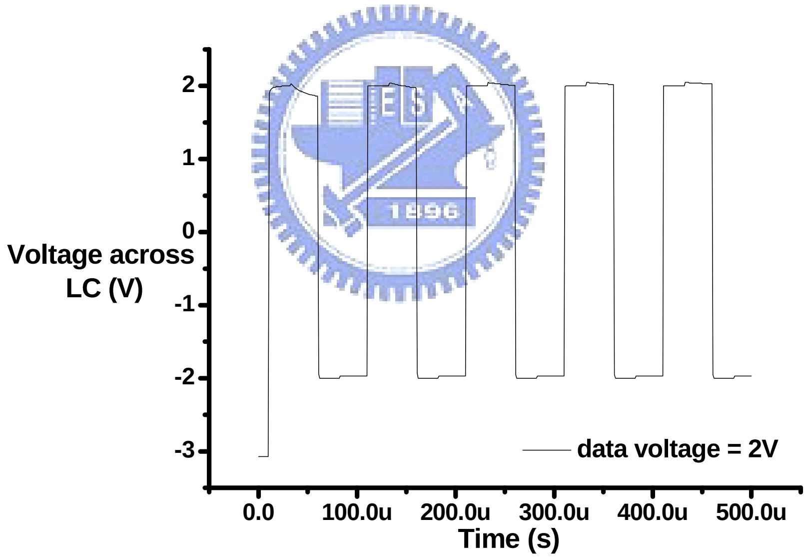

(c)

Fig. 4.5 The transient response of (a) OLED current (b) voltage of node1 and (c) LC voltage

4.4 Summary

The simulations, based on the issues of Vth variation and turn-on voltage shift of OLED, are conducted by the software Hspice. Compared to conventional pixel circuit, proposed pixel circuit has immunity to Vth variation and turn-on voltage shift and the uniformity of 98.2% and 99.1% respectively. The transient response curves in both the emission mode and the reflective mode are presented and explained. In the design rule of the pixel circuit for the bottom emission OLED display, the number of TFTs and capacitors directly reduces the aperture ratio and light efficiency. Although the circuit is composed of six TFTs and one capacitor, the emi-flective display consists of top emission OLED and R-LCD. As shown in Fig. 4.7, top emission OLED is free of aperture ratio limitation as illuminating light does not pass through pixel circuitry.

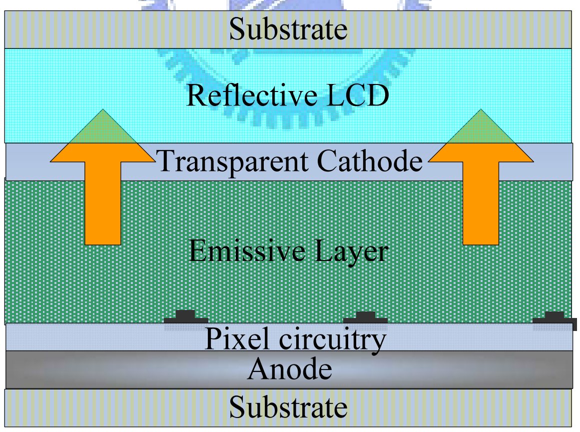

Fig. 4.6 Schematic diagram of emi-flective display