Chapter 4

Experimental Results of the Conventional and Proposed Pixel Circuits for Driving Organic Light Emitting Diodes Using Low-Temperature Polycrystalline Silicon Thin Film Transistors

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4.1 Introduction

Active matrix organic light emitting diode display is considered as the competitive candidate for the next generation display due to the various superior features. In the display pixel circuits, the transistors are used to provide the different current levels for OLED and each OLED device can be driven by thin film transistors such as amorphous silicon thin film transistors (a-Si TFTs) [4.1]-[4.9], polycrystalline silicon thin film transistors (poly-Si TFTs) [4.10]-[4.14] and organic thin film transistors (OTFTs) [4.15].

Organic thin film transistors are not mature technologies nowadays but potential for low-cost disposable, large area, and flexible electronics [4.16]-[4.19]. Although a-Si TFTs are attractive for economical production and well established technology, the threshold voltage shifts easily under long-term operation, which will cause a sticking image [4.20]. Many challenges of a-Si TFTs are related to low field effect mobility and high defect density. On the contrary, poly-Si TFT provides superior driving capability due to the higher carrier mobility. The major shortcomings of LTPS TFTs are very large fluctuation of mobility and threshold voltage; this will result in display non-uniformity. Therefore, a compensation circuit is necessary for each type of TFTs.

As for amorphous silicon TFT, the commonly transistor type is n-type since the mobility of p-type is much lower which is not effective for driving OLED. Due to the reliability consideration of poly-Si TFT, the n-type TFTs are usually in lightly doped drain (LDD) structure, and the doping concentration condition is different from factory to factory. As a result, the mobility of n-type is not definitely higher than p-type, but both of them are effective enough for driving OLED.

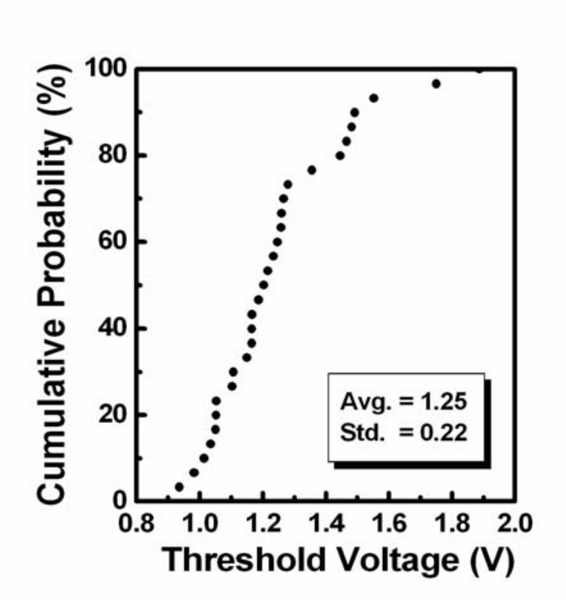
When OLED is under bias condition, the current flow is decided by the mobility, W/L ratio, and gate to source voltage (Vgs) of driving transistor. The gate to source voltage (Vgs) of driving transistor is decided by different ternimals in n-type or p-type TFTs. The gate to source voltage of p-type is determined by the data voltage and power supply voltage, and n-type is determined by the data voltage and OLED anode voltage. In p-type driving TFT case, the power line voltage drop varies the Vgs which becomes a serious problem in the large panel size. On the other hand, the threshold voltage increases with the operating time which affects the Vgs in driving TFT. In conclusion, each type transistor has its own considerations.

As mentioned before, voltage compensation pixel circuits are more attractive since poly-Si TFT data drivers, which are compatible with LCD data drivers, can be integrated on the display panel to decrease the module cost and increase the panel reliability. Many voltage programming were reported in chapter 3 with complex configurations and driving signals [4.21]. However, simpler pixel circuit is favored for high resolution and system on panel realization.

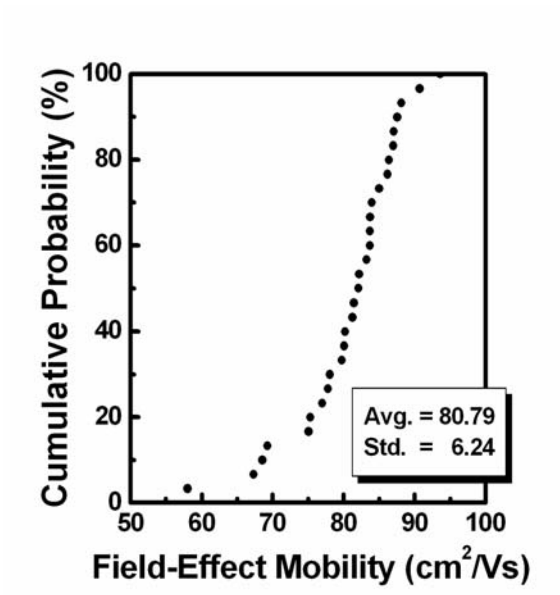
In this chapter, conventional pixel circuit with two transistors and one capacitor is fabricated and measured. To overcome the problems caused by spatially non-uniform characteristics between thin film transistors across the panel, two new pixel circuit designs for active matrix organic light emitting diodes based on the low-temperature polycrystalline silicon thin-film transistors were proposed and verified by fabrication results. After that, the proposed pixel circuit has been fabricated to compare with conventional pixel circuit.

4.2 Experimental Procedures and the Setup of Measurement System

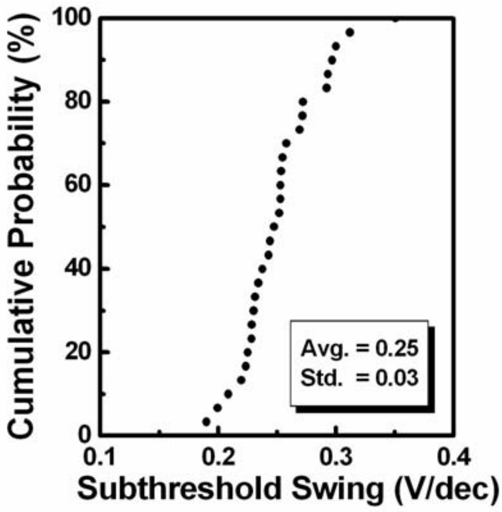
As previously mentioned, LTPS TFT suffers huge variations across the panel. Fig. 4-1 (a) shows the cumulative distributions of the threshold voltage variation in thirty poly-Si transistors with standard fabrication in factory while Fig. 4-1 (b) and Fig. 4-1 (c) show the cumulative distribution of field-effect mobility and sub-threshold swing variation, respectively. It is observed that the LTPS TFTs have 1 V maximum difference of the threshold voltage, 36 $cm^2/v \cdot s$ maximum difference of the field-effect mobility, and 0.15mV/dec maximum variation of the sub-threshold swing. The huge device-to-device variation will lead to the non-uniform picture across the display, thus pixel compensation circuit is essential for high quality AMOLED.


Cumulative Probability (%)
Threshold Voltage (V)
Avg. = 1.25
Std. = 0.22
0.8 1.0 1.2 1.4 1.6 1.8 2.0
0 20 40 60 80 100

(a)


Cumulative Probability (%)
Field-Effect Mobility (cm^2/Vs)
Avg. = 80.79
Std. = 6.24
50 60 70 80 90 100
0 20 40 60 80 100

(b)



(c)

Fig. 4-1. Cumulative distributions of the (a) threshold voltage, (b) field-effect mobility, (c) sub-threshold swing from thirty n-channel LTPS TFTs fabricated on the same glass substrate.

After finishing the proposed pixel design, testing pixel circuits were fabricated in factory and measured in laboratory. First of all, a buffer oxide and a 500Å-thick a-Si thin film were deposited on the glass substrate. Then, KrF excimer laser annealing at room temperature crystallized the amorphous Si thin film. After defining the active layer, the channel doping was carried out for adjusting the threshold voltage of n-type TFT. Then, high dose ion implantation was executed to source/drain regions of n-type TFT. Next, a 1000Å-thick gate oxide was deposited by plasma-enhanced chemical vapor deposition. A 3000Å-thick Cr film was then deposited for gate electrode. Then, the Cr thin film and gate oxide were etched to form gate electrodes. After that, a 4000Å-thick SiNx was deposited by PECVD as interlayer. TFT testing pixel circuits were formed after contact-hole formation and 4000Å-thick Cr metallization. Fig. 4-2 and Fig. 4-3 show the optical micrograph of the conventional pixel circuit and the proposed pixel circuit after fabrication.

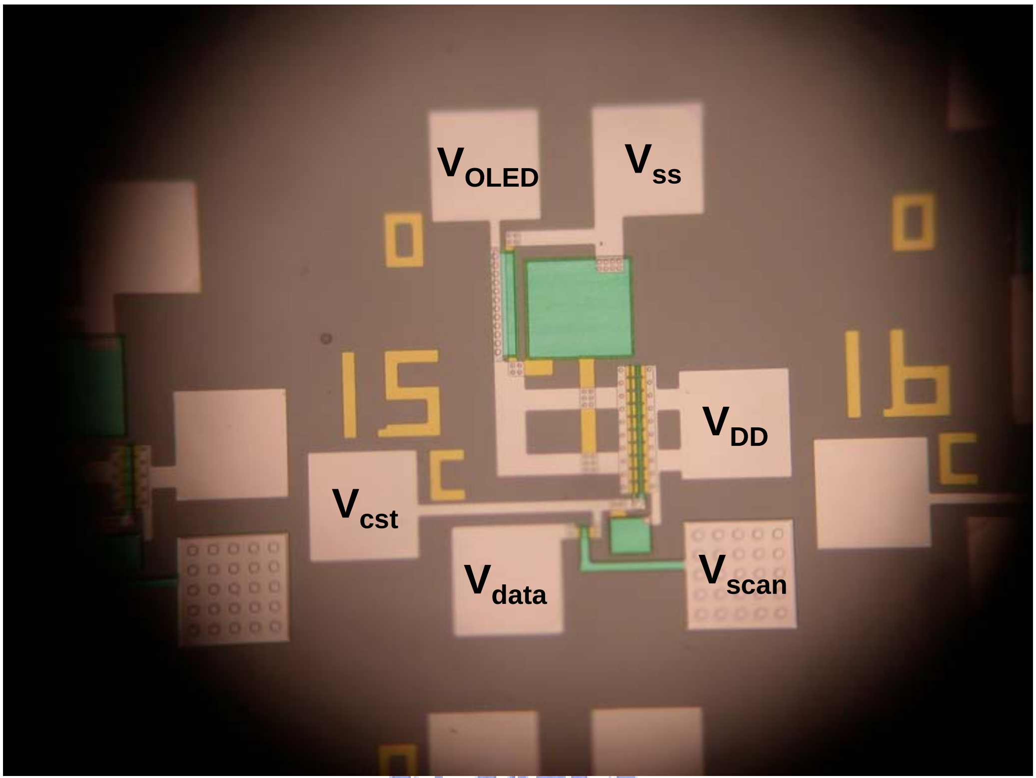


Fig. 4-2. Optical micrograph of conventional pixel circuit and its applied signals.

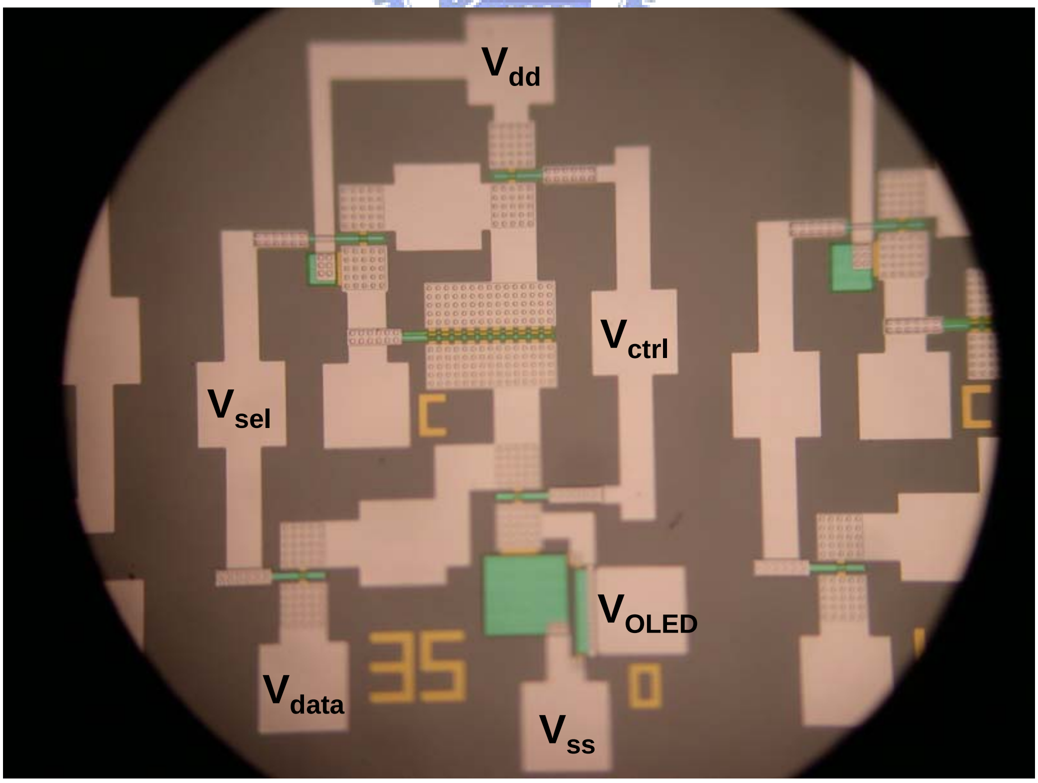


Fig. 4-3. Optical micrograph of the proposed pixel circuit.

Fig. 4-4 shows the measurement system for the fabricated testing pixel circuits, it consists of several units such as Agilent 4156C, HP 41501A pulse generator, Agilent 54622D mixed signal oscilloscope, and Keithley 617 programmable electrometer. The main system is HP 4156C including four probes typically. HP 41501A provides two voltage pulse signals and Keithley 617 programmable electrometer supplies one DC signal voltage through an additional probe. Another probe detected output signal and transmitted it through the coaxial cable and BNC connection, the output signal voltage can be appeared in Agilent 54622D mixed signal oscilloscope. One of the most important things is that the ground terminals of all instruments must be connected at fixed value together. Compared with the traditional pixel circuit, the proposed pixel needs one additional voltage signal provided by power supply or another pulse generator.

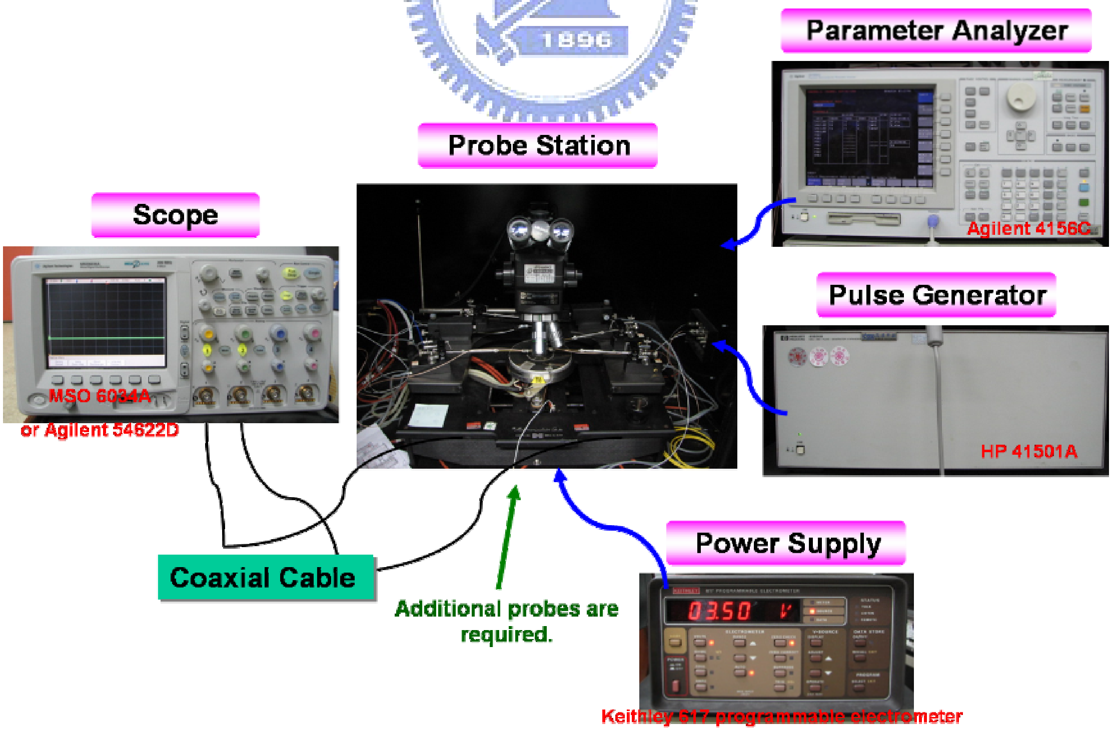


Fig. 4-4. Measurement system for testing pixels.

4.3 Experimental Results of Dimensional Effects on Transistors and Storage Capacitor in Conventional Pixel Circuit

In the applied signal connection part, HP 41501A can provide two voltage sources which are the scan line (V_{scan}) and data line (V_{data}) signals. One additional probe is needed to detect the anode voltage of OLED. Through BNC connection, the output signal voltage (V_{OLED}) can be recognized in Agilent 54622D mixed signal oscilloscope. After the measurement system is ready, the output signal voltages were measured and analyzed.

4.3.1 The Effect of Switching TFT

Three different dimensions of switching TFT including W/L = 10μm/10μm, 20μm/10μm, and 10μm/20μm are compared after fabrication where the driving TFT is fixed at 100μm/10μm size and the capacitance of the storage capacitor is 0.5pF in the conventional pixel circuit. In this case, the power supply (V_{DD}) is assumed 10V, and the scan line (V_{scan}) is a voltage pulse signal with peak value 10V and base value 0V which is the same as simulation. Fig. 4-5 shows the simulation and experimental results with the varied switching TFT dimensions. Even though the largest W/L ratio reaches four times than smallest one in switching TFT dimension, there is no obvious difference between the anode voltages of OLED either in the simulation or experimental results. The only difference between these two cases is that the anode voltage of OLED in experimental results is lower than that in the simulation results.

The possible reason for this phenomenon is the large impedance or loading in the real circuits or instruments which is not totally considered in the simulation case.

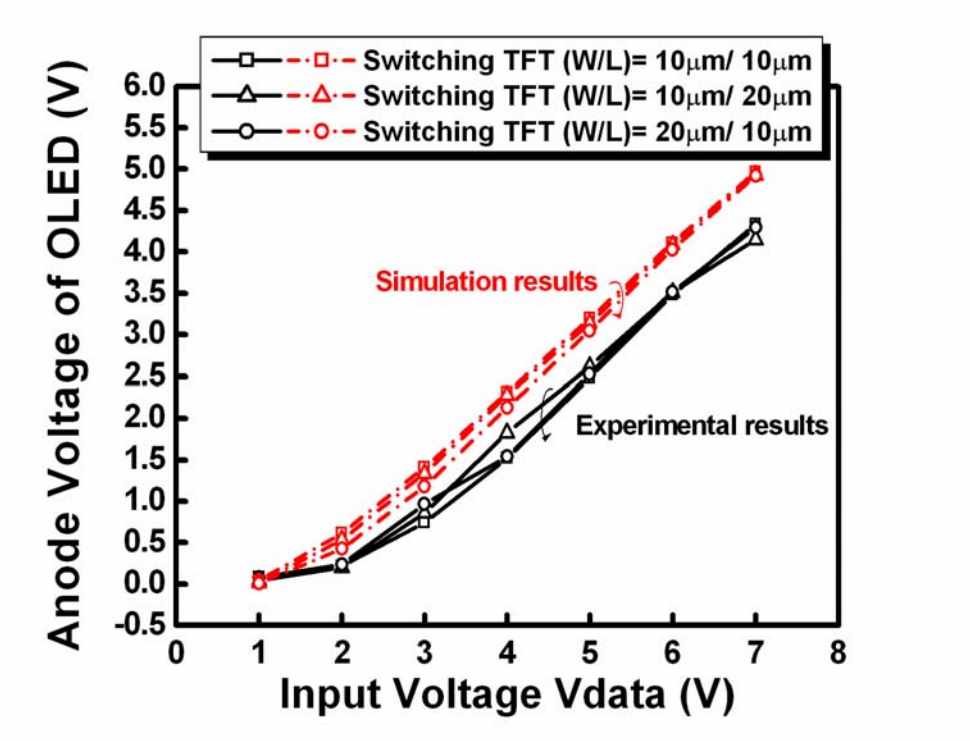


Fig. 4-5. The simulation and experimental results are compared with the varied switching TFT dimensions.

4.3.2 The Effect of Driving TFT

Three different dimensions of driving TFT including W/L = 10μm/10μm, 50μm/10μm, and 100μm/10μm are compared after fabrication where the switching TFT is fixed at 10μm/10μm and the capacitance of the storage capacitor is 0.5pF in the conventional pixel circuit. In this case, the power supply (V_{DD}) is assumed 10V, and the scan line (V_{scan}) is a voltage pulse signal with peak value 10V and base value 0V mentioned before. Fig. 4-6 shows the comparison of simulation and experimental results with the varied driving TFT dimensions. From the simulation results, the anode voltage of OLED is a function of input voltages; it is also increased slightly with the size of driving TFT, which is more obvious in the experimental results. The anode voltages of OLED in experimental results are lower than those in the simulation results, which coincide with the varied switching TFT situation. Nevertheless, it doesn't mean that the larger dimension the better it is, it must be depended on the panel specification to design the proper size.

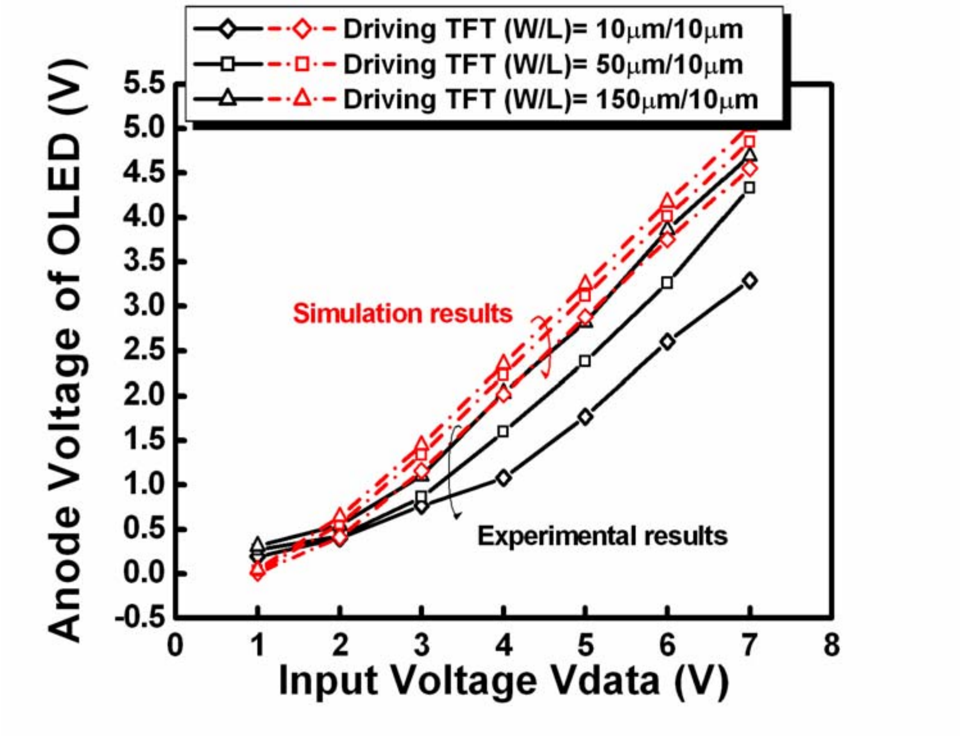


Fig. 4-6. The simulation and experimental results are compared with the varied driving TFT dimensions.

4.3.3 The Effect of Storage Capacitor

To study the effect of storage capacitor, two different storage capacitors including 0.1pF, and 2pF are compared after fabrication where the switching TFT is fixed at 10μm/10μm and the driving TFT is fixed at 100μm/10μm in the conventional pixel circuit. In this case, the power supply (V_{DD}) is assumed 10V, and the scan line (V_{scan}) is a voltage pulse signal with peak value 10V and base value 0V. The Fig. 4-7 shows the measured voltages stored in the capacitors with varied capacitances when the input data voltage= 5V. It shows the same trend with the simulation results. There are absolute voltage discrepancies between the simulation and measured results due to the parasitic capacitance exist in testing circuit and instruments. The proper storage capacitor is also decided by the panel specifications such as resolution, gray scale, and so on.

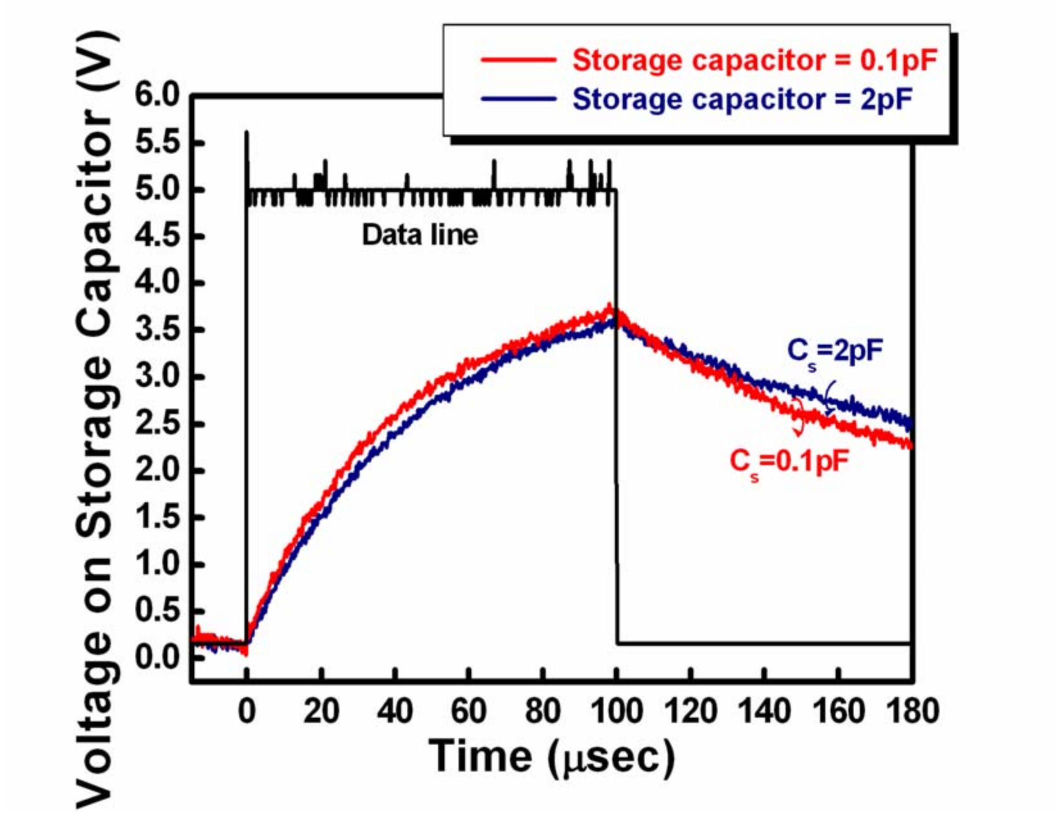


Fig. 4-7. The measured voltages stored in the capacitors with varied capacitances when the input data voltage= 5V.

4.3.4 The Effect of Transistor Slicing Layout

Due to the previous investigation in chapter 2, multi-channel structure is used to improve uniformity of transistors which can enhance high display quality. In this section, the slicing layout referred to multi-channel structure is applied to the driving

TFT.

Fig. 4-8 shows the comparison of the slicing method effect in simulation and measured results of OLED anode voltages versus input data voltage ranges 1V to 6V. It shows the OLED anode voltage enhanced which represents higher current driving capability of driving TFT with transistor slicing layout is. As for simulation results, Monte Carlo simulation with an assumption of normal distribution was also executed. The RPI model typical parameters and the deviation value of the threshold voltage and mobility belonged to driving TFT are 1.55V, ± 1V, 52.02 cm^2/V-s, and ± 20 cm^2/V-s, respectively. In this experiment, ten smaller LTPS TFTs with each one 10μm/10μm stripe are used to replace a larger 100μm/10μm driving TFT.

On the other hand, the measured results were calculated from ten individual testing pixel circuits. Definition of the non-uniformity here is the difference between the minimum output voltage and the maximum output voltage values divided by the average output voltage. It can be seen that the non-uniformity can be reduced effectively from the conventional layout to slicing layout in Fig. 4-9. Since slicing layout can promote the output current and improve the uniformity for the LTPS TFTs, non-uniformity problem in the circuit can be slightly solved in traditional pixel circuit.

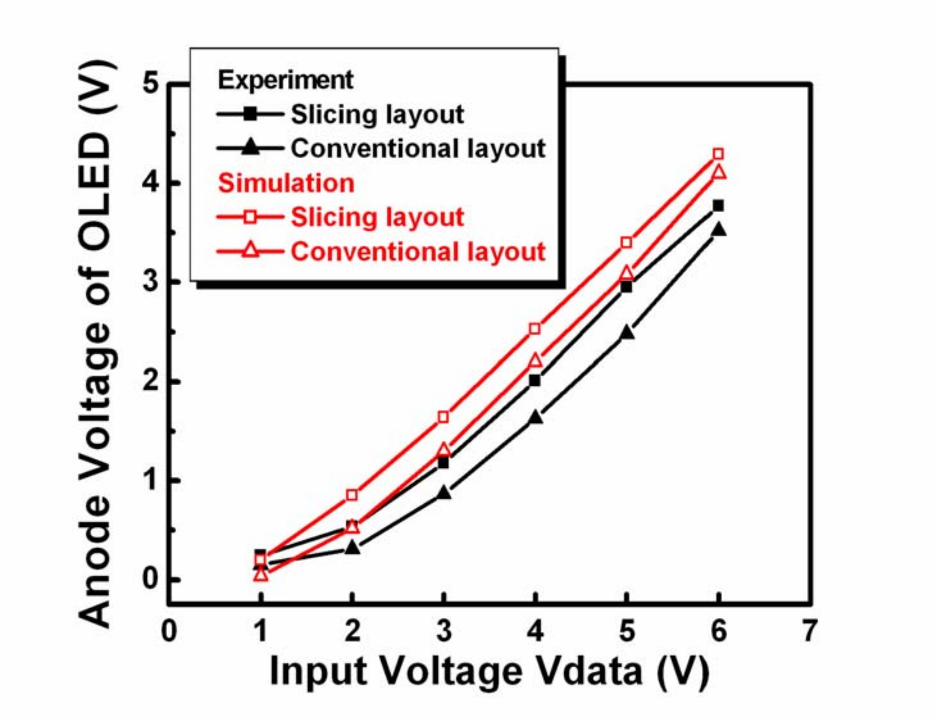


Fig. 4-8. Comparison of the slicing method effect in simulation and measured results of OLED anode voltages versus input data voltage ranges 1V to 6V.

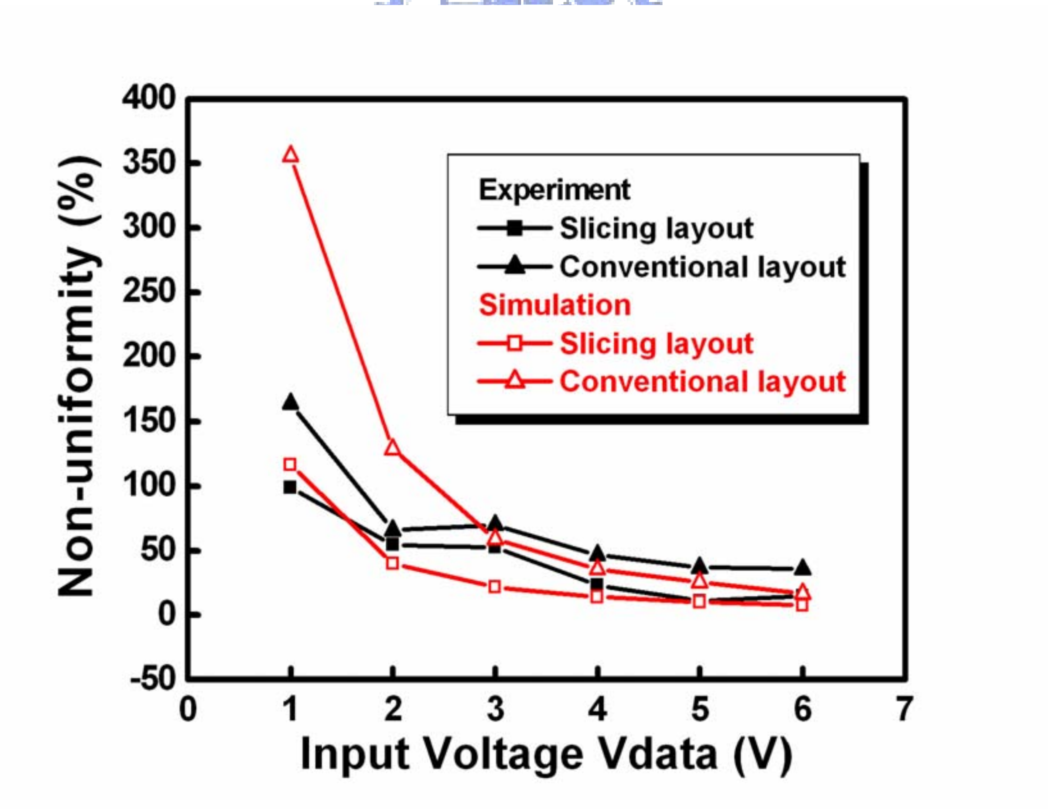


Fig. 4-9. Comparison of the slicing method effect in simulation and measured results of non-uniformity versus input data voltage ranges 1V to 6V.

4.4 Experimental Results of Proposed Pixel Circuit Design

Ten testing pixel circuits have been measured and the results compared to conventional pixel circuits with different data voltages are shown in Fig. 4-10. It is obvious that the proposed pixel circuit posses higher output voltage and better uniformity after the calibration of threshold voltage variation. Fig. 4-11 shows the measured and simulation results of OLED anode voltage 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.

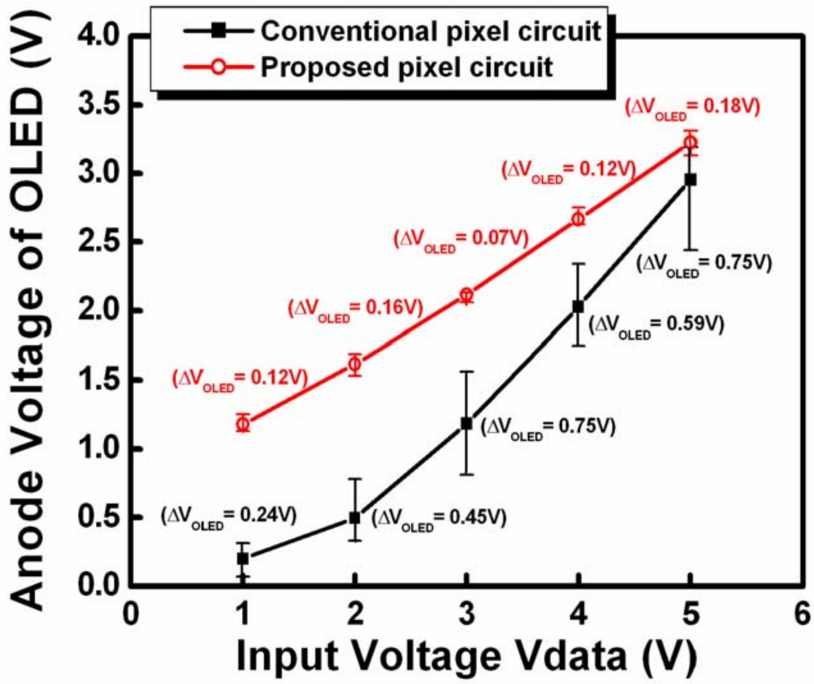


Fig. 4-10. The measured results the proposed pixel circuit compared to conventional pixel circuit with different data voltages.

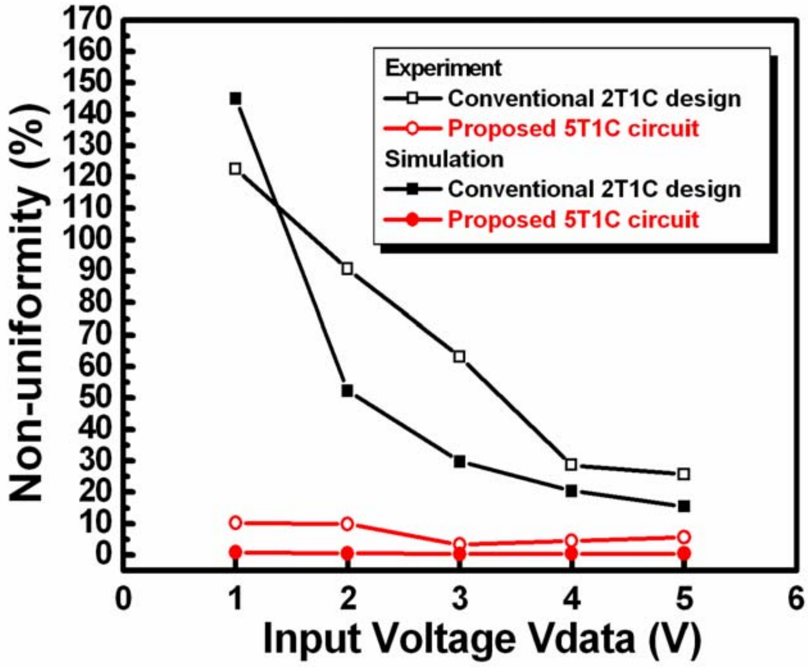


Fig. 4-11. The measured and simulation results of non-uniformity compared with conventional 2T1C pixel circuit.

4.5 Summary

In this chapter, dimensional effects of transistors and storage capacitor in conventional pixel circuit are fabricated and measured proving individual functions. In order to measure the impacts of each component on individual pixel circuit, a measurement system was set up to evaluate the anode voltage of OLED successfully.

Slicing layout can promote the output current and improve the uniformity for the LTPS TFTs, non-uniformity problem in the circuit can be slightly solved in traditional pixel circuit. Furthermore, two new voltage modulated low-temperature polycrystalline silicon thin-film transistors pixel circuits for active matrix organic light emitting diodes are fabricated and measured. Compared with the traditional pixel circuit, the proposed pixel needs one additional voltage signal provided by power supply.

Through experimental results, it is also verified that the proposed circuit is capable of reducing the threshold voltage variation problem of conventional pixel circuit and possessing larger output current. The non-uniformity can be suppressed to less than 10% measured in the proposed circuit.