# Chapter 3

# AMOLED Pixel Circuit

## 3.1 Introduction

Active matrix organic light emitting diode (AMOLED) display with polycrystalline silicon (poly-Si) thin-film transistors (TFTs) has been studied intensively because of its superior characteristics for display such as light, thin, self emissive characteristics, wide viewing angle and fast response time. However, it still has non-uniformity problems of display images because of the threshold voltage and the mobility variations of poly-Si TFTs among pixels. Therefore, various pixel circuits shown in Fig. 3.1 have been proposed to compensate for the variation in the poly-Si TFT performances [17-91].

The pixel circuits of AMOLED displays can be classified into voltage driving [17-60], current driving [61-82] and digital driving methods [83-91]. Fig. 3.2 shows the comparison of pixel circuit driving methods. Even though the current driving method can be applied to achieve an excellent image quality, its panel driving speed is too slow to implement high resolution displays. It requires inconvenient constant current sources which control sub-micrometer ampere level current in the peripheral drivers. It should be noted that low current increases the pixel charging time. This is the critical drawback for application to large-sized and high-resolution displays. In addition, it is difficult to build the current driving data driver circuit on the panel using poly-Si devices. Alternatively, the use of the current driving Si driver ICs leads to significantly high module cost. Digital driving method can reduce the threshold voltage sensitivity of display images, but it needs very fast addressing speed so that it may not be the good solution for high gray-scale displays. Besides, it needs the special analogue wave voltage for the panel load or the high speed addressing by using sub-frame data. The power consumptions of these driver circuits are higher than the other methods and one of them needs frame memory for making the sub-frame data. The voltage driving method can compensate for the variation of the threshold voltage and is more attractive to integrate poly-Si TFT data drivers on the display panel. It utilizes readily available data drivers from existing AMLCD technology, thus eliminating the cost associated with the development of a new data driver. In addition, a point scanning method has been employed in the voltage driving method, thus resulting in further cost reduction due to the reduced number of driver outputs required. Therefore, the voltage driving method would have been considered as the preferred driving method for AMOLED displays.

The purpose of our work is to propose a new voltage driving pixel circuit which is composed of five TFTs and two capacitors. The proposed pixel circuit successfully compensates for OLED current variations caused by threshold voltage variations of poly-Si TFTs.

## 3.2 Device Modeling & Review of Pixel Circuits

Fig. 3.3(a) and 3.3(b) show the typical $I_D$-$V_{GS}$ curves of the poly-Si TFTs represented by the RPI parameters and the I-V characteristics of an OLED modeled by a diode, respectively, which are used in this study. And the parameters used in the simulation are shown in Table I.

TABLE I. Parameters used in the pixel circuit simulation.

| | |
|---|---|
| $T_{DV}$ W/L | 7μm/5μm |
| Tsw W/L | 7μm/5μm |
| Cvt Cst | 0.5pF |
| Vdd | 10V |
| Vscan1 Vscan2 | 0-10V |
| $\Delta V_{TH}$ of $T_{DV}$ | +/-0.33V |

Although the poly-Si TFT is considered as the mainstream technology for AMOLED displays, pixel-driving scheme is still one of the most critical issues. The conventional 2T1C pixel circuit [16] shown is Fig. 3.4 suffers from the pixel to pixel luminance non-uniformity due to the variation of poly-Si devices. The problem would become serious, especially when the display size becomes large. To overcome this non-uniformity issue, several technologies have been proposed to compensate for the variation in the poly-Si TFT performances.

Fig. 3.5 shows the Dawson's pixel structure and timing diagram of that structure which can compensate for the threshold voltage variation [17]. But it needs 3 control lines and complex driving signals for data line and control lines. Moreover the data line must be alternated to supply voltage level with every row line time to store a threshold voltage.

Fig. 3.6 shows a modified structure and the timing diagram of Dawson's structure [18]. It reduces one control line by more complex controlling. But as the previous one, it wastes the row line time to store the threshold voltage of the driving TFT.

Fig. 3.7 shows another structure that simplify the driving method and pixel structure [20] compared with previously reported one [17]. However, the p-type driving TFT is sensitive to the degradation of panel supply voltage caused by finite resistivity of the metal line material because the actual programmed data of each pixel is set by Vdd and Vin, as the following equation.

$$I_{OLED} = K(Vdd - Vin)^2 \qquad (3.1)$$

Thus, the n-type driving TFT has good immunity against the degradation of panel supply voltage.

Fig. 3.8 shows a schematic of the Goh's pixel circuit and its operating principles [27]. The driving TFT of a pixel circuit is operated in the saturation regime to prevent the output current from the spatial variation of Vdd. The operating principles shown in Fig. 3.8 are as follows. In an initialization period (1), Tsw1, Tsw2 and Tsw3 are turned on and the data line is at ground.

The gate of $T_{DV}$ and anode of OLED are initialization to ground. In a compensation period (2), only Tsw1, Tsw2 are turned on and Cvt stores a voltage drop ($\Delta$V) corresponding to the $|V_{GS}|$ of the driving TFT. In a data-input period (3), only Tsw3 is turned on and the data line is at an input voltage. Due to the bootstrapping effect, the gate voltage of $T_{DV}$ becomes Vin+$\Delta$V. From that time $I_{OLED}$ can be evaluated from the following equations：

$$a = \sqrt{\frac{K_{T_{DV}}}{K_{T_{OLED}}}} \qquad (3.2)$$

$$Cvt\_stored\_\Delta V = \frac{a}{1+a}\times V_{TH\_T_{DV}} - \frac{1}{1+a}\times V_{TH\_OLED} + \frac{1}{1+a}\times V_{in} \qquad (3.3)$$

$$I_{OLED} = K(V_{GS} - V_{TH\_T_{DV}})^2 = K(V_{in} + \Delta V - V_{out} - V_{TH\_T_{DV}})^2 \qquad (3.4)$$

Thus, the output current can not been completely compensated by the voltage stored in Cvt, as shown in equation (3.4) unless the parameter $a$ is very large. Besides, the pixel circuit produces an unnecessary OLED current during the compensation period.

Fig. 3.9(a) and 3.9(b) are the simulation results for the conventional 2T1C pixel circuit and the Goh's pixel circuit, correspondingly. In each graph, the cases of $\Delta V_{TH}$=0 and +/-0.33V for $T_{DV}$ are plotted. Fig. 3.9(a) reveals a large variation and confirms the necessity of the compensation for light uniformity of OLED pixels and gray level expression. The results shown in Fig. 3.9(b) indicate the output variation is reduced, but remains. So, the Goh's pixel circuit can not completely reduce the variation problem.

## 3.3 Proposed Pixel Circuit

Fig. 3.10(a) shows an equivalent pixel circuit proposed in this work and its driving scheme. One driving TFT ($T_{DV}$) and four switching TFTs (Tsw1-Tsw4) are used together with two capacitors (Cvt and Cst). Control lines include two scan lines and one data line. The TFT, Tsw4, prevents the current from flowing through the OLED during initialization and compensation period and effectively improves the dark gray level, increases the contrast ratio and decreases power consumption of the panel. Tsw4 also increases the output resistance of $T_{DV}$ in a cascode configuration, so that the drain current of $T_{DV}$ is not severely affected by the OLED threshold voltage variation. The capacitor, Cst, is needed to sustain the gate voltage of $T_{DV}$ against the leakage currents of switching TFTs during a frame time and Cvt is the capacitor for storing the $V_{TH}$ of $T_{DV}$.

The operation of the pixel circuit can be described as three periods shown in Fig. 3.10(a). In an initialization period (1), Tsw1, Tsw2 and Tsw3 are turned on and the data line is at ground. The gate and the source of $T_{DV}$ are initialized to ground. In a compensation period (2), only Tsw1, Tsw2 are turned on. Thereby, a voltage drop corresponding to the threshold voltage of $T_{DV}$ is stored in Cvt. In a data-input period (3), only Tsw3, Tsw4 are turned on. Due to the bootstrapping effect, the gate voltage of $T_{DV}$ becomes Vin+$V_{TH\_TDV}$. Then, $I_{OLED}$ can be evaluated from the following equations：

$$
\begin{aligned}
I_{OLED} &= K(V_{GS} - V_{TH\_T_{DV}})^2 \\
&= K(V_{in} + V_{TH\_T_{DV}} - V_{out} - V_{TH\_T_{DV}})^2 = K(V_{in} - V_{out})^2 \qquad (3.5)
\end{aligned}
$$

Thus, the output current is compensated by the voltage stored in Cvt. Fig. 3.10(b) shows a transient response result simulated for different threshold voltage ($\Delta V_{TH}$=0 and +/-0.33V) of $T_{DV}$. In this way, the wide variation of poly-Si TFTs can be easily compensated and the pixel circuit controls the accurate OLED current by changing Vin.

The non-uniformity of an OLED can be defined as the difference between maximum and minimum output current, divided by the average output current at an input voltage. The simulated non-uniformity of the conventional 2T1C pixel structure, the Goh’s pixel structure and the proposed one are shown in Fig. 3.11. It depicts a significant improvement and the OLED current of the proposed pixel structure become almost independent of the threshold voltage variation of poly-Si TFT.

## 3.4 Conclusions

We have developed a new pixel circuit composed of five TFTs and two capacitors for AMOLED using a voltage-source method. The simulation results indicate that the proposed circuit has high immunity to the variation of poly-Si TFT characteristics.

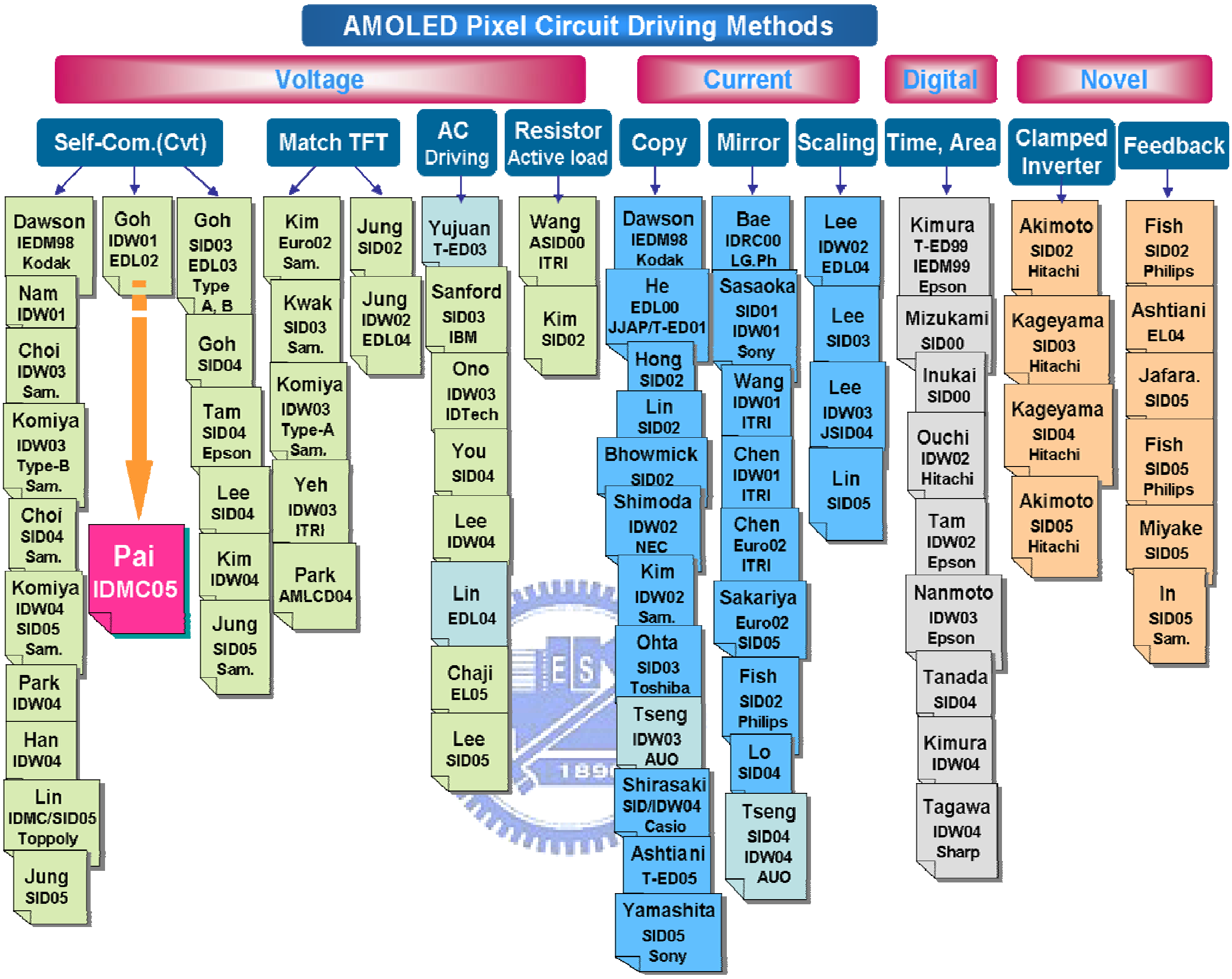
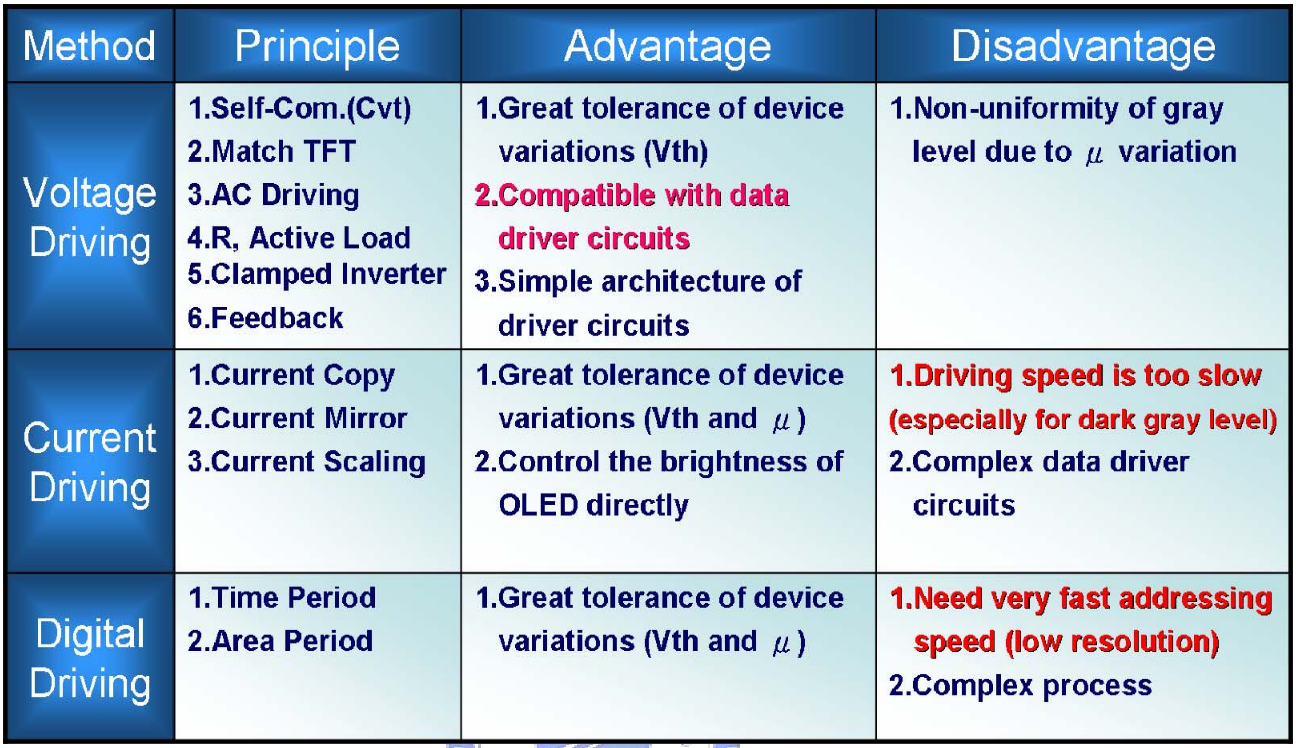


Fig. 3.1 AMOLED pixel circuit driving methods



| Method | Principle | Advantage | Disadvantage |
|---|---|---|---|
| Voltage Driving | 1.Self-Com.(Cvt)<br>2.Match TFT<br>3.AC Driving<br>4.R, Active Load<br>5.Clamped Inverter<br>6.Feedback | 1.Great tolerance of device variations (Vth)<br>2.Compatible with data driver circuits<br>3.Simple architecture of driver circuits | 1.Non-uniformity of gray level due to $\mu$ variation |
| Current Driving | 1.Current Copy<br>2.Current Mirror<br>3.Current Scaling | 1.Great tolerance of device variations (Vth and $\mu$)<br>2.Control the brightness of OLED directly | 1.Driving speed is too slow (especially for dark gray level)<br>2.Complex data driver circuits |
| Digital Driving | 1.Time Period<br>2.Area Period | 1.Great tolerance of device variations (Vth and $\mu$) | 1.Need very fast addressing speed (low resolution)<br>2.Complex process |

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Fig. 3.2 The comparison of pixel circuit driving methods

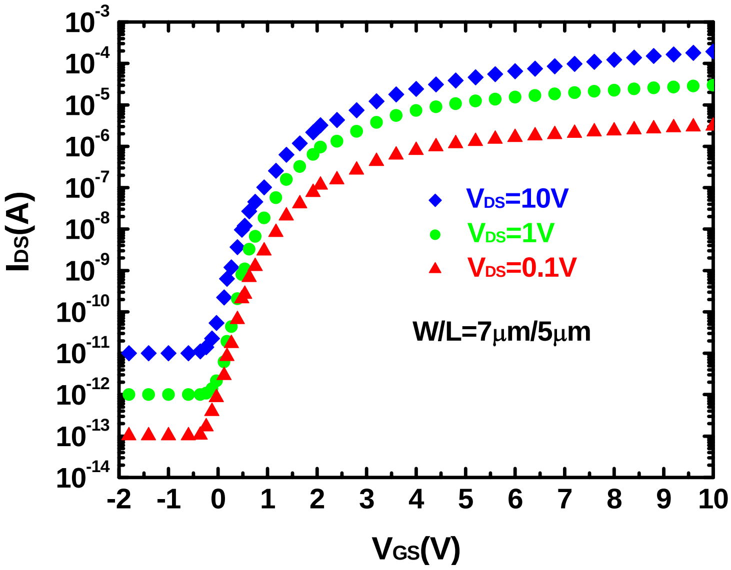

Fig. 3.3(a) The $I_D$-$V_{GS}$ of poly-Si TFT curves

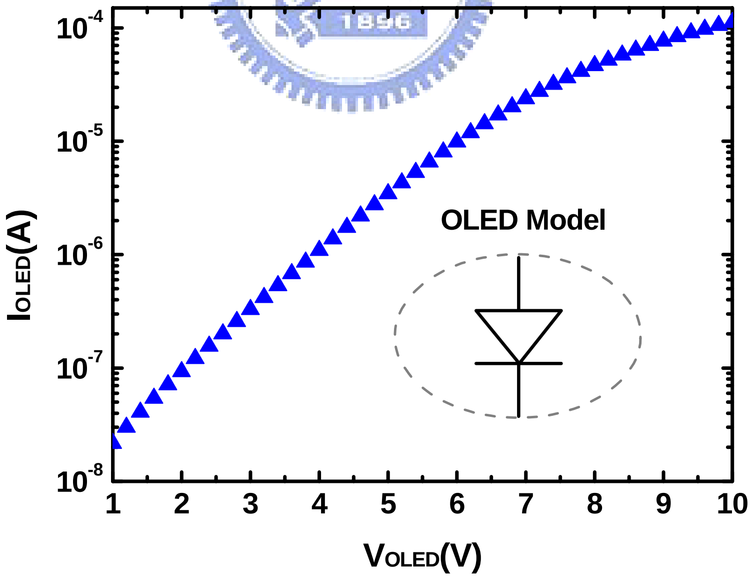

Fig. 3.3(b) I-V characteristics of an OLED

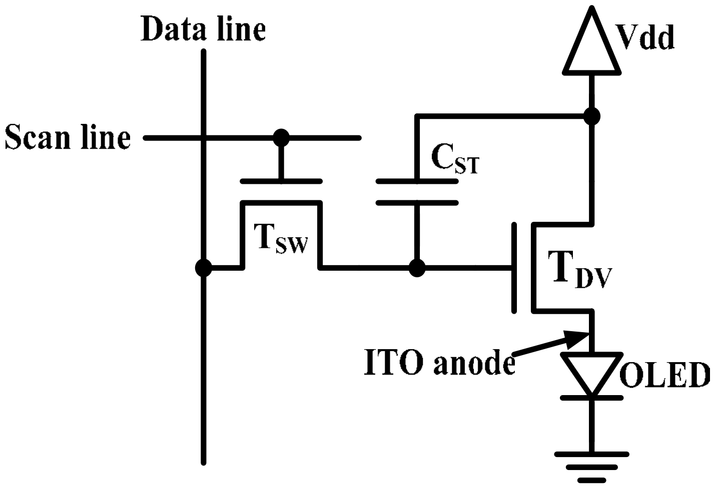

Fig. 3.4 Conventional 2T1C pixel circuit [16]

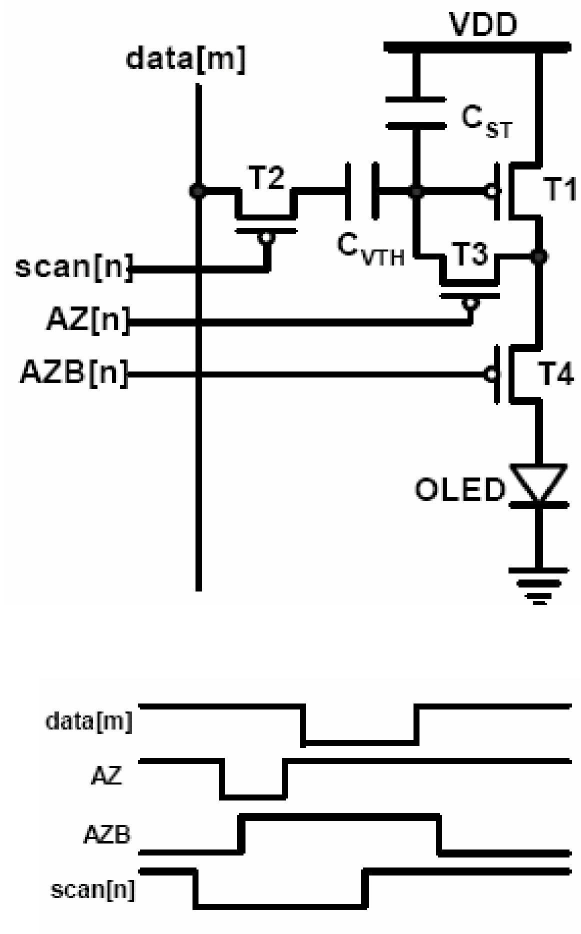

Fig. 3.5 Dawson’s pixel structure and its timing diagram [17]

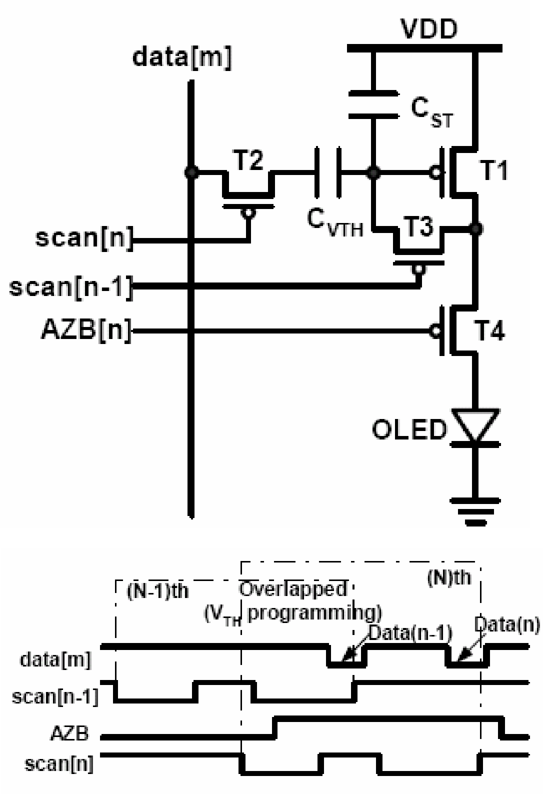

Fig. 3.6 A modified structure and the timing diagram of Dawson's structure [18]

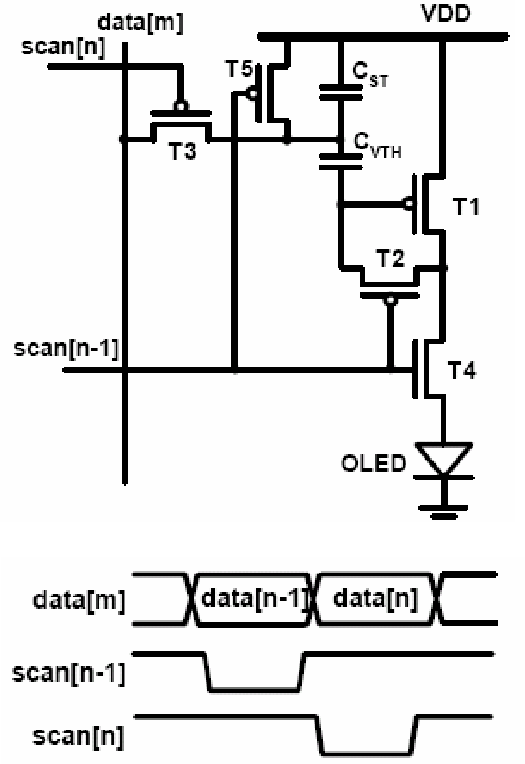

Fig. 3.7 Komiya's pixel circuit and its timing diagram [20]

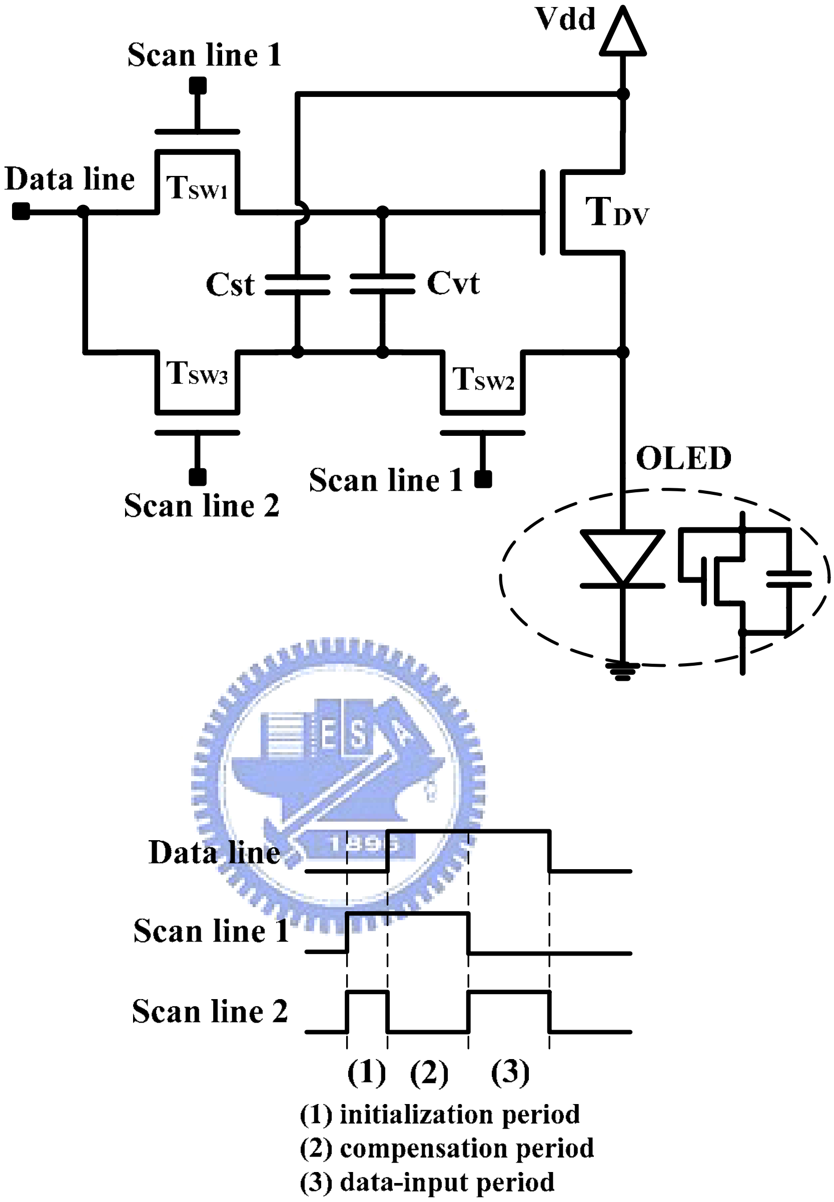

Fig. 3.8 Goh's pixel circuit and its timing diagram [27]

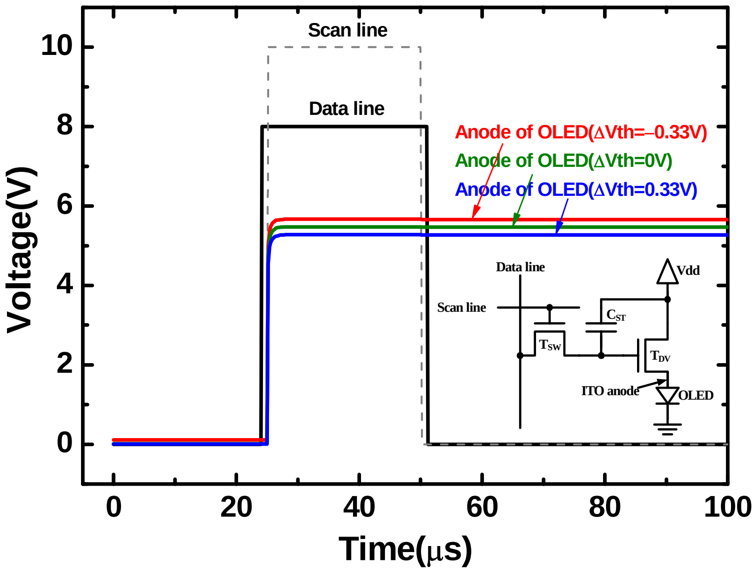

Fig. 3.9(a) The transient simulation results for the conventional 2T1C pixel structure

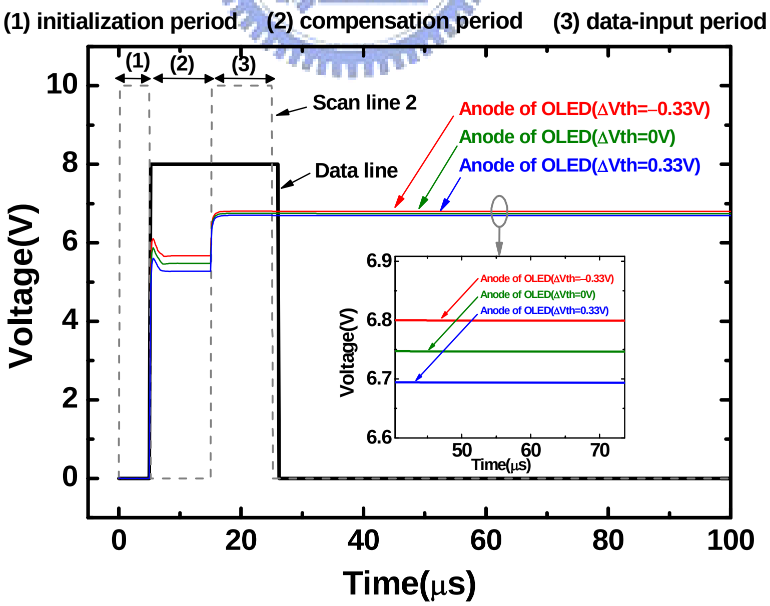

Fig. 3.9(b) The transient simulation results for the Goh's pixel structure

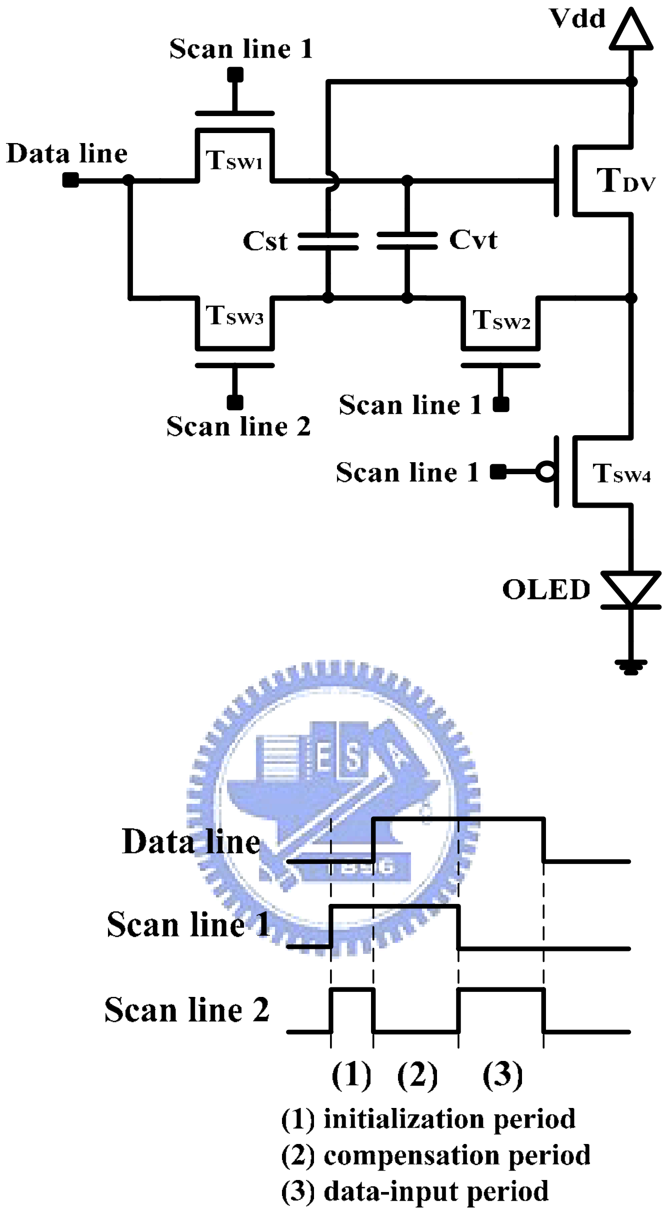

Fig. 3.10(a) The proposed pixel circuit and its timing diagram

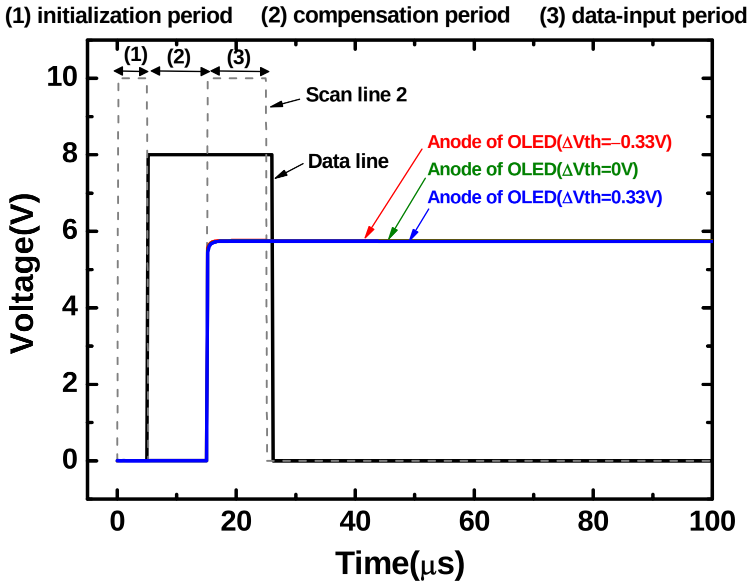

Fig. 3.10(b) The transient simulation results

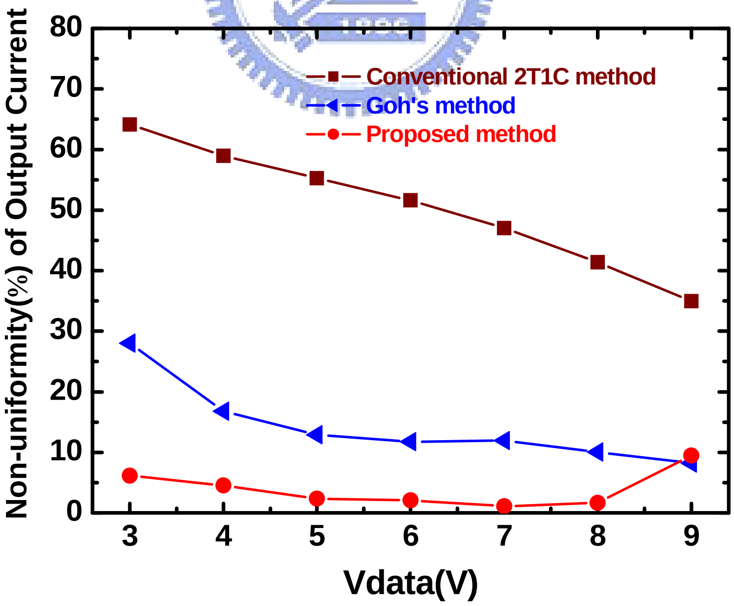

Fig. 3.11 Non-uniformity of the output current due to the variation in the device performances