AM backplane for AMOLED

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Abstract: *Active matrix organic light emitting diode (AMOLED) displays are considerably attractive for high brightness, high efficiency and fast response time. Active matrix employing thin Film Transistors (TFTs) allows OLED displays to be larger in size, higher in resolution and lower in power consumption than passive matrix. Especially, low temperature polycrystalline silicon (LTPS) TFT employing excimer laser annealing (ELA) is widely used due to high mobility and high stability. A number of TFT active matrix pixel circuits have been developed in order to compensate for TFT parameter variations due to the fluctuation of excimer laser energy. We discuss various compensation schemes of LTPS TFT pixel circuits.*

Keywords: AMOLED; poly-Si TFT; pixel circuit; threshold voltage compensation circuit; mobility compensation

Introduction

Active matrix organic light emitting diode (AMOLED) has attracted considerable interest for flat panel display due to a brightness, response time and compactness [1]. Polycrystalline silicon thin film transistors (poly-Si TFTs) can be used to allow a constant current in each pixel for active matrix addressing due to its high electron mobility and its driving capability [2]. Although the high current driving capability of poly-Si TFTs can integrate the peripheral driver circuits and pixel switching devices simultaneously on a glass substrate, the non-uniformity of electrical properties of poly-Si TFT, such as the threshold voltage and field effect mobility, causes the non-uniformity of luminance in one pixel to another one [3]. Poly-Si TFT pixel circuit should compensate the non-uniform characteristics of the current, which originate from the inherent process variation of the crystal growth in polycrystalline film [4].

Conventional AMOLED pixel and the previous reported pixels which use compensation scheme are reviewed [2,5-11]. Although the voltage modulation driving method can compensate the threshold voltage variation, it is not able to eliminate the current variation induced by non-uniformity of mobility [2,5,6]. The current programming pixel circuits can compensate mobility variation as well as threshold voltage variation [2,7,8]. The pixel charging time to write a current data is long due to the large capacitive load of data line. Recently, the feedback-type pixel circuits are reported in order to solve both the problem of the voltage programming pixel circuits and that of the current programming pixel circuits [9-11].

The purpose of this paper is to discuss the widely considered compensation scheme, such as the voltage programming and the current programming methods. The representative poly-Si TFT pixel circuits, which can compensate the non-uniformity of the current, will be analyzed and described.

Discuss

1. LTPS-TFT pixel design for AMOLED

In the AMOLED pixel design, OLEDs (Organic light emitting diodes) are presently fabricated with the anode (hole injection electrode) and the cathode (electron injection electrode). The current driving transistor is conventionally connected from the supply voltage to the anode of OLED. Therefore, p-type devices are desired to prevent variations in the OLED material turn on voltage from leading to current variations in the OLED material.

The simplest AMOLED pixel which has pixel memory uses two transistors and one capacitor. One TFT drives the current for the OLED and another TFT acts as a switch to sample and hold a voltage onto the storage capacitor C1 as shown Fig. 1 (a). It is noted that variations in the threshold voltage, carrier mobility, or series resistance will directly impact the uniformity of the saturation current of OLED driving TFT and consequently the brightness of the display. The major factor of non-uniformity current is the threshold voltage variation of the OLED drive transistors. The current flow through the LTPS TFT suffers from large pixel to pixel variations due to the nature of the LTPS grain growth. The effects of TFT non-uniformity on the conventional 2 transistor pixel design of Fig. 1 (a) were reported as shown in Fig. 1 (b). The local brightness non-uniformity was almost 17%. The OLED current driven by the TFT is expressed by the equation (1).

$$I_{OLED} = 1/2 \cdot k \cdot (V_{GS} - V_{TH})^2$$
$$= 1/2 \cdot k \cdot (V_{DATA} - V_{DD} - V_{TH})^2 \quad \ldots\ldots\ldots\ldots (1)$$
(where, k is $\mu_{eff} \cdot C_{OX} \cdot W/L$ and $V_{TH} < 0$)

2. Voltage programmed LTPS-TFT pixel

In order to compensate the OLED current variation in LTPS-TFT AMOLED display, several voltage programming and current programming methods have been already reported [2,5-8]. The voltage programming method addresses the data voltages to the pixel circuit, while the current programming method addresses the current data to the pixel.

However, it is noted that both the methods use voltages as data which are modulated and stored finally at the gate node of the OLED driving TFT.

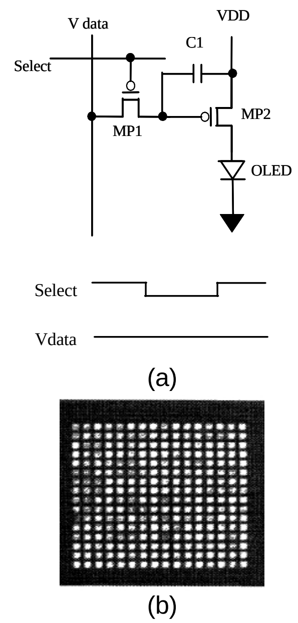

Figure 1 (a) Conventional AMOLED pixel circuit employing two transistors and one capacitor. (b) the brightness non-uniformity (17%) of the conventional 2-TFT pixel [2].

In the reported voltage modulation driving method, R.M.A Dawson's group reported an effective method to compensate for the threshold voltage variation of LTPS TFTs [2]. The AMOLED pixel is shown in Fig. 2 where two additional transistors are used to auto zero the threshold voltage of the current drive transistor. The timing diagram is shown in Fig. 2.

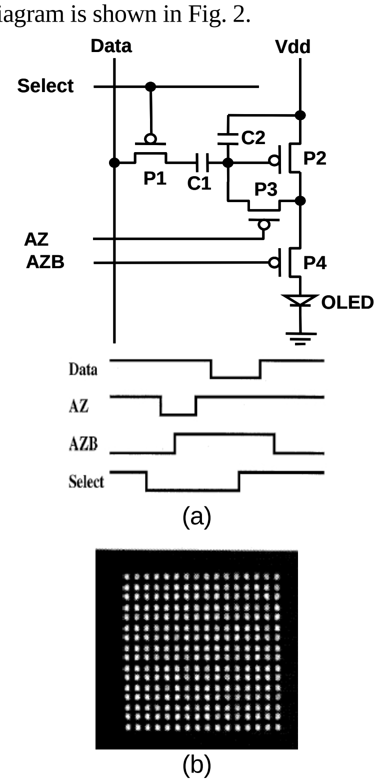

Figure 2. V_{th} compensated pixel (4 TFTs, 2 caps and 2 additional signals).The improvement of the pixel to pixel brightness uniformity [2].

The improvement of the pixel to pixel brightness uniformity obtained using this technique is demonstrated in Fig. 2. This pixel does not rely on the settling time of the OLED to calibrate out the TFT threshold voltage variations. It is programmed by applying a voltage to the gate of driving TFT which supplies a constant current throughout the frame time, so it does not rely on the charging time of the OLED for programming.

The demerits are the additional signal lines (AZ/AZB) to control the V_{TH} cancelling operation. The signal lines cover all the row arrays for the scanning the pixels as the scan signal so that the layout area consumption is increased and the pixel aperture ratio is considerably reduced.

Fig. 3 shows a simple voltage programming V_{th} compensated pixel, which reduces an additional signal lines [5]. It can compensate V_{th} variation of LTPS-TFT and kink effect inevitable of LTPS-TFT because it has a cascode configuration.

Although the voltage programmed (or modulated) pixel circuits have provided an evident performance of non-uniformity compensation, they still suffer from the I_{OLED} non-uniformity due to the other variation factors. One is the mobility variation and it cannot be memorized itself. It is rather difficult to compensate the mobility variation of LTPS TFTs in the voltage modulation method. On the other hand, it is almost possible to compensate the non-uniform mobility of TFT as well as the threshold voltage of TFT in the current programming method.

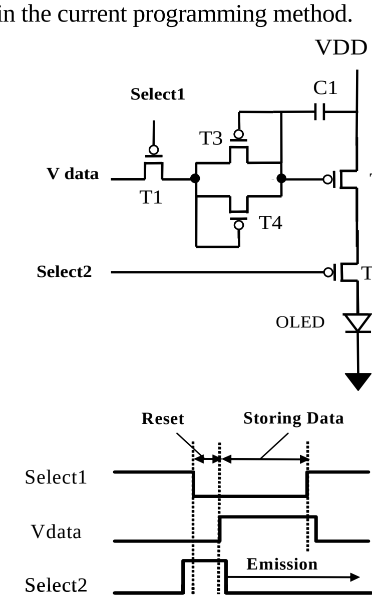

Figure 3. The reported AMOLED pixel circuit employing a voltage modulation which compensates the threshold voltage variation of poly-Si TFT, and its timing diagram [5].

The supply voltage drop phenomena is also the serious problem in the voltage programmed pixel circuits [6]. The OLED current flows in each pixel are supplied by the voltage source (typically V_{DD}). Although the voltage

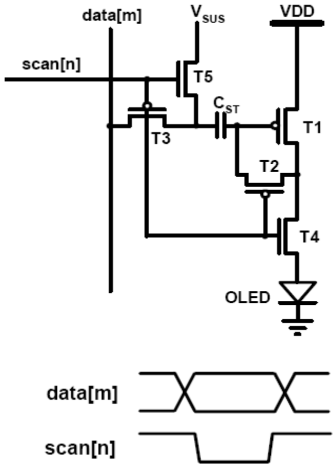

Figure 4. The reported AMOLED pixel circuit employing a reference voltage source V_{SUS} which compensates the V_{DD} supply voltage drop as well as the threshold voltage variation of poly-Si TFT [6].

supply line has a low resistance across the panel, it undergoes the voltage drop by the large amount of current flows (~ mA) required in a column array. Fig. 4 has been reported by Choi et al. to compensate the supply voltage drop problem in the voltage programmed pixel circuit [6]. It employs additional supply voltage (V_{SUS}) for a reference voltage and n-type TFT for switching. When the n-type TFT is replaced by p-type, an additional signal line will be added, apart from the select line.

3. Current-programmed LTPS-TFT pixel

The current programming method employs the current source unit from the data driver and addresses the current data to the pixel circuit in which the data current is memorized during the emission frame. It should be noted that the scheme can compensate both threshold voltage and mobility variations of poly-Si TFTs. They are free from cross talk caused by the voltage drop in power supply line, while most of voltage modulation schemes suffer from it especially when we go to larger panels or higher brightness [2]. In the pixel circuit, the data current (I_{DATA}) determines a drive voltage (V_{GATE}) of the driving TFT to flow the OLED current with respect to I_{DATA}.

The current programming pixel was also reported by Dawson et al., and is shown in Fig. 5 with timing diagram. Programming of this pixel is accomplished by turning off MN4 with VGP. And MN1 and MN3 are turned on by SELECT, which drives the data current (I_{DATA}). This adjusts and sets the gate to source voltage ofMN2 which is stored on C1. Once the programmed voltage (V_{GATE}) is stored, the pixel can be connected to the power supply for illumination. However, the large load capacitance of column array should be charged to V_{GATE} by I_{DATA}. Therefore, very small current of I_{DATA} at low brightness may lead to long programming time. The settling time of the OLED is an issue for this pixel, and it is applicable to low resolution displays which have longer row times.

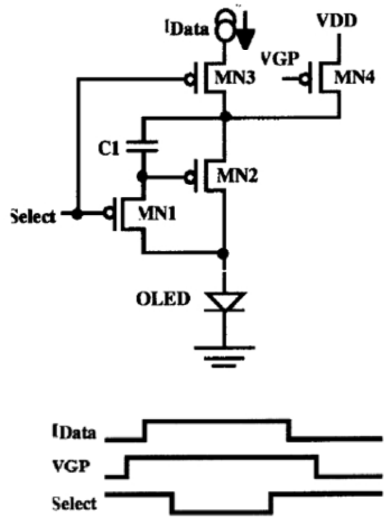

Figure 5. The reported current programming AMOLED pixel in which I_{DATA} is memorized and V_{GATE} of MN2 is determined to allow I_{DATA} [2].

The data current scaling scheme which employs a current-mirror structure has been reported. The widely used assumption that the neighboring TFTs in each pixel have the identical electrical characteristics, such as threshold voltage and mobility is employed in the current scaling pixel.

The other type of current programming method was reported by Sasaoka et. al [7]. Fig. 6 is the developed pixel circuit and the photograph, which shows an improvement of the luminance uniformity.

When the data current is applied to the Data line, the current I_{OLED} through T2 will be scaled down by a current mirror T1. For the current mirror configuration, it should be assumed that the neighboring TFTs have identical electrical characteristics, which is also often used in voltage programming method. By defining the channel width of T1 larger than that of T2, the data current becomes larger than OLED current, which made write operation fast enough even at low brightness compared with the previous current programming method.

The current scaling scheme has been also reported and the scaling down capability is increased [8]. It employs the p-type poly-Si TFTs only without additional signal line as shown in Fig. 7. The data current is memorized by T3 in the programming period and the V_{GATE} of T3 is stored in C_{STG}. In the emission period, the T4 is turned on and the memorized current would be decreased and scaled down by the size effect of T3 and T4. The photograph of luminance at 50 nit. The non-uniformity of luminance is less than 10%.

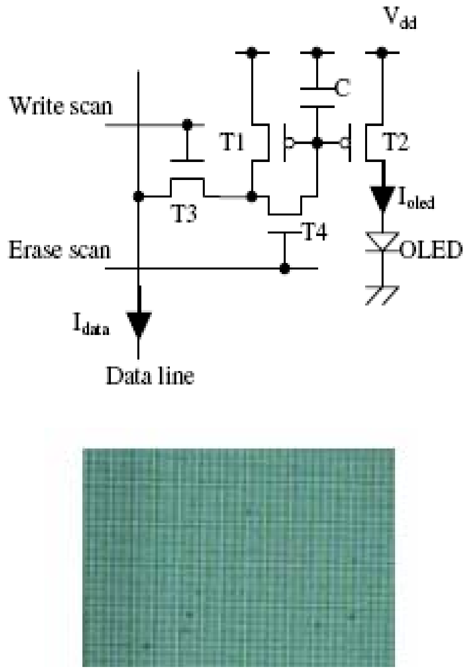

Figure 6. The reported current programming AMOLED pixel employing a parallel current-mirror structure and a luminance uniformity [7].

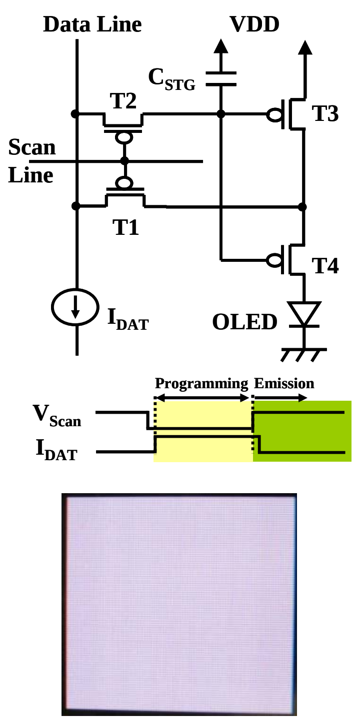

Figure 7. The reported current programming AMOLED pixel using a serial current-mirror structure [8]

Although the current programmed pixel can supply a better compensation capability compared with a voltage programmed pixel, the accurate IC and the current data driver, which can reduce a pixel charging time, should be developed for a mass production.

4. Feedback-type LTPS-TFT pixel

We have discussed various AMOLED pixels, based on the voltage programmed method and current programmed [2,5-8]. Mostly, voltage programming methods have the OLED current variation problem from the mobility variation of poly-Si TFTs, and current programming methods still have the problem of charging the large capacitive load of a data line with a low level current. Recently, the feedback type pixel circuits which are sensing the OLED current or OLED brightness and using this data in the feedback sequence are reported [9-11]. The feedback type pixel circuits could solve the problem of charging the load of a data line as current programming method because the data of the feedback type pixel circuits are supplied by the voltage source. Moreover, the OLED current variation by the mobility variation of poly-Si TFTs as well as by the threshold voltage variation is compensated by the feedback type pixel circuits due to sensing directly the OLED current or OLED brightness. However, the feedback type pixel circuits have complex composition to be fabricated. The feedback type pixel circuits are consisted of the many TFTs and additional signal line. Besides the a-Si:H NIP diodes or the feedback controllers are necessary to compensate the electrical characteristic variation of the poly-Si TFT.

The optical feedback pixel circuit was reported and developed by Philips Research Laboratories [9,10]. Fig. 8 shows the developed optical feedback pixel circuit using LTPS technology with integrated a-Si:H NIP diode [10].

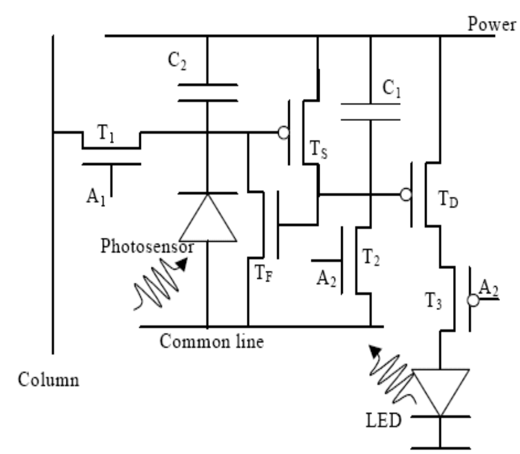

Figure 8. The reported optical feedback type AMOLED pixel using the a-Si:H NIP diode [10]

When A1 and A2 are high, the analog data voltage is applied on the column and charged the capacitor C2. T_S is off by the data voltage stored on C2 and capacitance C1 is charged from the common line due to T2 turned on. When A1 and A2 are low, OLED could emit light and the photo-sensor (light controlled current source) detects this light. The photo sensor using a-Si:H NIP diode creates a photocurrent that starts to charge up the capacitance C2. Eventually the gate node of T_S will become low enough to turn on T_S and discharge C1. At this time, the gate of T_F starts to rise and to turn T_F on so that the gate of T_S is pulled down further. Therefore, the gate of T_S gets rapidly charged to the common line and the gate of T_F is rapidly charged to the power line. The OLED is also turned off very rapidly. The circuit creates gray-scales by controlling the on time of the OLED over a frame period. The on time of OLED would depend on the data voltage and the threshold voltage of T_S.

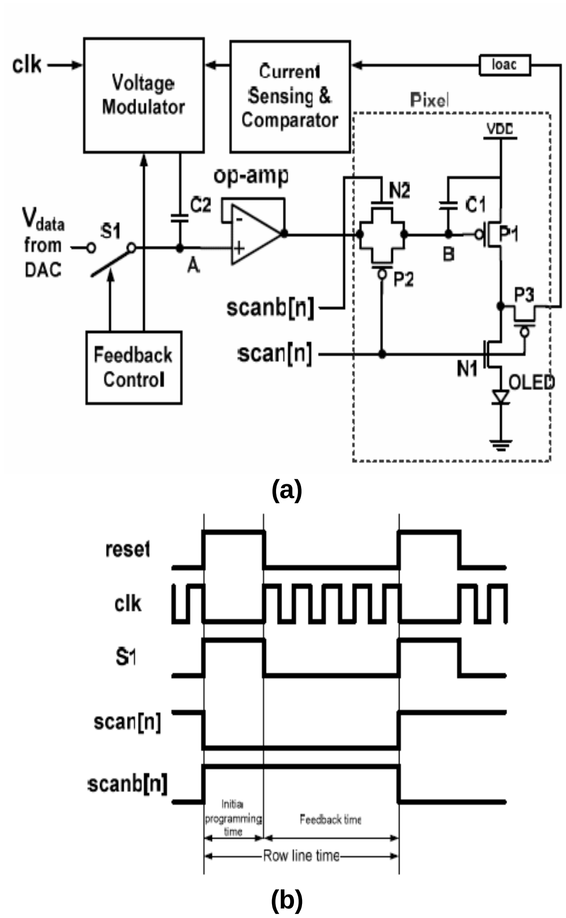

Figure 9 (a) The reported feedback-type driving circuits, which is sensing the OLED current, and pixel block diagram, and (b) the timing diagram [11]

The other feedback type pixel circuit, which is sensing the OLED current, is also reported [11]. In order to employ this feedback sequence, voltage and current DACs and a high-speed Op-Amp, current sensing and comparator circuits, voltage modulator circuits, and feedback controller are necessary as shown in Fig. 9.

During the data programming period, scan[n] and scanb[n] signals turn on P2 and N2, and S1 switch is closed by the signal from feedback control block. Data voltage is applied to node B, which is the gate of the driving TFT of a pixel. N1 is turned off for protecting unexpected current flowing into the OLEDs and the current generated by driving TFT (P1) flows to the current sensing and comparator block. During the feedback time, the current comparator compares the feedback current with the reference data current. And the modulator block change the voltage of node A into the suitable voltage. And the current of driving TFT is adjusted and the feedback cycle is repeated rapidly so that the voltage of node B is close to the target voltage which supplies the expected current.

Conclusion

We discuss a highly stable TFT pixel employing LTPS for AMOLED. ELA (excimer laser annealing) LTPS-TFT pixel should compensate OLED current variation caused by the non-uniformity of LTPS-TFT due to the fluctuation of excimer laser. In order to drive high quality AMOLED, the various compensation schemes of LTPS TFT are discussed.

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