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A New AC Driving Method for a Current-Programmed AM-OLED Pixel Circuit*

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Abstract: A new, improved pixel-driving circuit is presented based on a current-programmed pixel circuit in order to achieve an AC-driving mode. This driving method realizes an AC-driving mode, removes the threshold voltage variation of the driving TFT due to the process variation or long-term operation, which can bring about brightness non-uniformity, and eliminates high peak pulse currents at the beginning and end of recovery time. Simulation is done with AIM-SPICE, and simulation results demonstrate that the OLED is in the reverse-biased state during recovery time.

Key words: active matrix OLED; AC pixel-driving circuit; TFT; AIM-SPICE simulation; current-programmed pixel-driving circuit
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1 Introduction

With the development of OLED display technology, improving OLED lifetime is becoming more important. Many factors that affect it, such as the OLED structure and material and the electrode material, have been considered, and it has been determined that the driving mode, especially the AC-driving mode, which is actually a pulse-driving mode with a reverse-biased voltage on the OLED, is one of the most important factors[1]. Earlier, we[2~4] proposed AC-driving methods based on a two-TFT voltage-programmed pixel circuit. The circuit configuration is very simple, but it suffers from non-negligible threshold voltage variation of the driving TFT due to either the fabrication process or long-term operation, which brings about brightness non-uniformity. Therefore, a four-TFT current-programmed AM-OLED pixel circuit was presented to solve this problem[5].

The OLED has a multilayer structure, doped emitting layers, novel transport and luminescent materials including polymers, and efficient injection contacts. The emitting layer is Alq, and the hole transport layer is NPB. An additional layer of CuPc was inserted between the NPB layer and the ITO electrode. Through testing the OLED, it was found that the luminance decay rate is directly proportional to the injection current density. This means that the luminance degradation is coulombic, and that the degradation event resulting from charge injection is cumulative and irreversible. The improvement in operational stability in the OLED may be attributed to an AC drive wave form that provides a reverse bias component.

The basic form of the four-TFT current-programmed pixel driving circuit is shown in Fig. 1[6]. This circuit consists of six components: two address thin-film transistors (T1, T2), two current source transistors (T3, T4), a storage capacitance (C_S), and the OLED. This circuit is based on a current mirror, which provides a constant current through the OLED irrespective of V_{th} shifts in the

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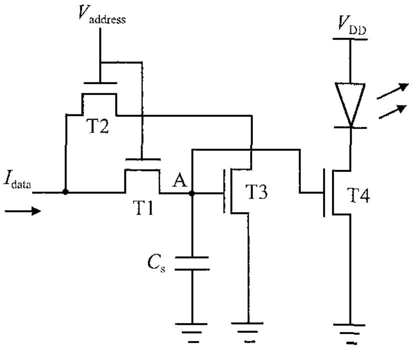

Fig. 1　Four-TFT current-programmed pixel driving circuit

drive TFT, T4. When $V_{address}$ becomes high, the pixel is selected by the gate drivers, and the transistors T1 and T2 conduct. Initially I_{data} flows through T1, charging up the storage capacitor C_S. After some time, the entire I_{data} flows through T2 and T3. Since the gates of transistors T3 and T4 are tied together, the stored data on C_S programs the data signal on T4, and thus the desired current flows through the OLED. This way, the T4 output current can be calculated using the following equation:

$$I_{OLED} = \frac{1}{2} \times \mu_f C_{ox} \frac{W}{L} (V_{GS4} - V_{th4})^2 \quad (1)$$

V_{GS4} is stored across C_S, and it can be expressed as

$$V_{C_S} = V_{GS4} = \left(\frac{2 I_{OLED}}{\mu_{FET} C_{OX} (W/L)_{T4}} \right)^{\frac{1}{2}} + V_{th4} \quad (2)$$

As discussed above, the output current is expected to remain constant and directly controlled by the data current. Therefore, the OLED brightness is proportional to the data current, and a different data current is used to generate a different OLED brightness in order to control the display gray levels.

In programming time, T4 should be maintained in the saturation state, and $V_{DS4} \geq V_{GS4} - V_{th4}$ must be satisfied. Because $V_{DS4} = V_{DD} - V_{OLED}$, T4 must be driven into the saturation state if $V_{DD} - V_{OLED} \geq V_{GS4} - V_{th4}$. Thus we can get:

$$\left(\frac{W}{L} \right)_{T4} \geq \frac{2 I_{data(max)}}{\mu_{FET} C_{OX} (V_{DD} - V_{OLED})^2} \quad (3)$$

The fabricated poly-Si TFT with a 100nm-thick oxide has an $89 cm^2/(V \cdot s)$ electron field effect mobility, and $C_{OX} = 4.87 \times 10^{-8} F/cm^2$. The source voltage is $V_{DD} = 18V$. According to the data from the photoelectron laboratory, the maximum luminance is $1000 cd/m^2$, and thus the maximum current $I_{data(max)}$ is 10μA. Thus from Eq. (3), we can get $W_4/L_4 \geq 0.15$. Because of the short channel effect, the kink effect, and the pixel dimensions, we choose $W_4/L_4 = 10μm/25μm$. Because T3 and T4 form a current mirror circuit, the size of T3 should be the same as that of T4.

In programming time, the charging time of C_S must be much less than the addressed time t_{on}, and C_S must be large enough to eliminate the effect of the T1 leakage current. Thus C_S must satisfy:

$$\frac{1}{C_S} I_{data} t_{on} > V_{GS4}, \quad C_S \geq \frac{I_{off} T_f}{\Delta V_{GS4}} \quad (4)$$

ΔV_{GS4} is the change of V_{GS4} when the pixel brightness is changed by one gray-scale change. I_{off} is the leakage current of the poly-Si TFT. If $I_{off} \approx 10^{-11} A$, $T_f = 1/60 \approx 16.7ms$, $V_{GS4} = 7.5V$, and $\Delta V_{GS4} = 0.25V$, then we can get $277pF > C_S > 0.67pF$. For many reasons, such as pixel dimension size, $C_S = 1pF$ is preferred.

Since transistors T1 and T2 operate in a linear state, the power dissipation P is mainly emphasized when we choose their width/length ratio; the leakage current must also be considered. From Eq. (5), we see that W/L is proportional to P. Because the leakage current is proportional to the TFT width, we choose $W/L = 5μm/5μm$.

$$P = V_{DS} I_{DS} = \mu_{FET} C_{OX} \frac{W}{L} \left(V_{GT} V_{DS}^2 - \frac{V_{DS}^3}{2} \right) \quad (5)$$

To summarize, all parameters used in the four-TFT current-programmed pixel driving circuit are listed in Table 1.

Table 1　Parameters of four-TFT current-programmed pixel-driving circuit

$W_{T1,2}$, $L_{T1,2}$ /μm	$W_{T3,4}$, $L_{T3,4}$ /μm	C_s /pF	V_{DD} /V	V_{sel} /V
5,5	10,25	1	18	10 → 0

2　AC-driving mode pixel circuit

In order to lengthen the lifetime of the OLED, an AC-driving mode must be realized in the pixel-driving circuit. In the AC-driving mode, the frame time should be divided into two parts: programming time and recovery time. Generally, in order to realize the AC-driving mode during the recovery time, reverse power is needed; the OLED is reverse-biased during the recovery time, and its output current decreases to zero. Furthermore, in this period V_{DD} is idle and does not supply a driving current to the OLED. Therefore, V_{DD} can be designed as a pulse source, which is positive during the programming time, but it will have a negative value as reverse power during the recovery time. Thus additional reverse power in a peripheral circuit is not needed. The four-TFT current-programmed AC-driving pixel circuit is shown in Fig. 2.

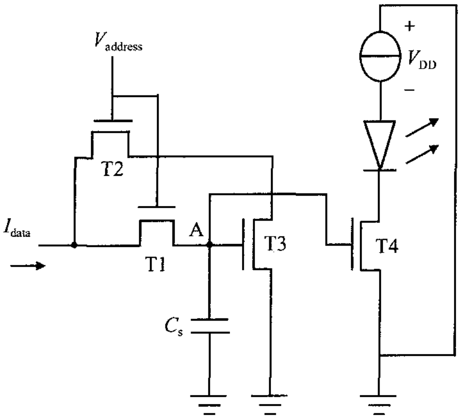

Fig. 2 AC-driving circuit

In Fig. 2, power source V_{DD} is designed as a pulse source in contrast to the pixel circuit in Fig. 1. During the programming time, V_{DD} is positve, and thus the pixel circuit is the same as the pixel circuit in Fig. 1, but during the recovery time, V_{DD} is negative, and the charge accumulated in the OLED discharges quickly through T4. Consequently, the OLED voltage is $-V$, which is just the opposite of its value during the programming time. In this period, the OLED is in the reverse-biased state. During the recovery time, the source voltage is $+V$, which results in exchange with the drain. As a result, T4 is driven into a linear state, and the OLED cathode voltage is almost equal to $+V$. Therefore, in this period the OLED voltage is $-V$ and is in the reverse-biased state. The voltage of C_S remains constant because there is no loop to discharge, and the OLED output current can be restored during the programming time. This is important for display operation.

To support the above analysis, a pixel electrode circuit simulation has been performed to examine the operation course using AIM-SPICE with the p-Si TFT model. The simulation results are shown in Fig. 3. In the simulation, we chose a frame time of 100μs and a recovery time of 10μs, from 60 to 70μs in the frame time, in order to verify whether the OLED output current can be restored to that during the programming time. The circuit parameters are the same as those in Table 1.

Figure 3(a) shows the OLED output current character. The OLED output current decreases to zero during the recovery time and is restored to the value of the programmed current following the recovery time. This indicates that the OLED current remains constant except during the recovery time. During the transition process, a large negative peak pulse can be observed for the discharging effect of charge accumulated on the OLED during the programming time. This peak pulse does not affect the display quality, and there is a positive peak pulse that is very low, which is beneficial to this AC-driving mode and OLED display.

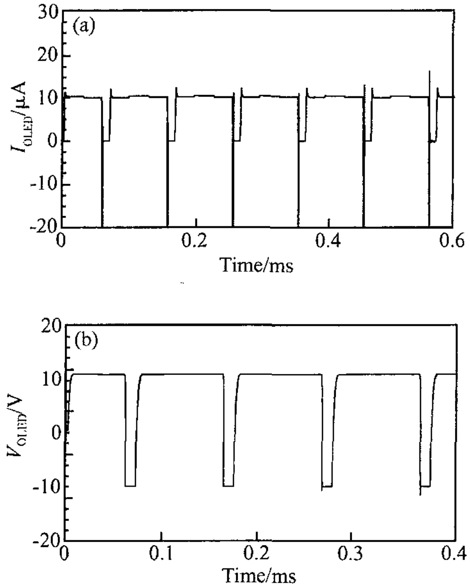

Fig. 3 Simulation of current-programmed AC-driving pixel circuit (a) OLED output current; (b) OLED voltage character

Figure 3(b) shows the OLED voltage character. It can be seen that during the recovery time, the OLED voltage is − 10V, just the opposite of the value of V_{DD}, which illustrates that the OLED works in the AC mode with reverse-biased voltage. During the programming time, the OLED voltage is in forward bias and the current flowing through the OLED is constant. During the recovery time, the OLED voltage is reverse-biased and the OLED current decreases to zero.

From the above simulation results, we can conclude that an AC-driving mode can be achieved in a four-TFT current-programmed pixel circuit using this method. Simulation results support our analysis. It is also clear that the parameters that we chose in the pixel circuit are reasonable.

3 Conclusion

It is well known that an AC-driving mode can extend the lifetime of an OLED and that a four-TFT current-programmed pixel circuit can overcome the defect of threshold voltage variation in a two-TFT voltage-programmed pixel circuit. Therefore it is important to realize an AC-driving mode in a current-programmed pixel circuit. We use a pulse source V_{DD} to achieve an AC-driving mode successfully in a circuit. Simulation has been done on all of the circuits we designed, and the results support our analysis. It can be concluded that this AC-driving mode is effective in four-TFT current-programmed pixel and matrix circuits.

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一种新的有源 OLED 交流驱动电路*

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摘要: 在电流编程像素电路的基础上提出了一种新的交流驱动电路结构. 该电路结构不仅能实现 OLED 的交流驱动, 而且能避免由于制作过程的变化和长时间的工作引起的驱动管阈值电压漂移的现象, 这种现象将导致 OLED 显示屏的亮度不一致. 另外这种驱动方式还能消除在反偏脉冲起始和结束时刻的尖峰电流. 最后, 用 AIM-SPICE 软件对电路进行了仿真, 仿真结果表明 OLED 器件在恢复时间内处于反偏状态.

关键词: 有源 OLED; 交流驱动像素电路; 薄膜晶体管; AIM-SPICE 仿真; 电流编程像素驱动电路

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