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Driving Circuit for AMOLED with Fault Tolerance*

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Abstract: The defects of an OLED-based display, mainly electrical shorts, cause pixels to stay dark, decrease the brightness of a panel, severely influence the display uniformity, and also consume a considerable amount of power. In this paper, for AM-OLEDs, a novel circuit employing p-type low-temperature poly-Si thin-film transistors is introduced to offer fault-tolerant capabilities for such defects. The results show that this circuit can save significant power and maintain the luminance of the pixel without changing the driving current.

Key words: organic light-emitting diode; active matrix OLED; fault tolerance
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1 Introduction

Organic light-emitting diodes (OLED) have been widely used for a variety of electronic products such as flat panel displays, large-area signs, and panels of general lighting applications[1,2]. A key obstacle to the development of large-area OLEDs is the presence of local defects that cause electrical shorts[3]. Causes of shorting defects include particle contamination during fabrication, asperities from electrode roughness, and non-uniformities in organic layer thickness. Some shorts “burn-out” quickly, resulting in only a small non-emissive and non-conducting area[1,4]. Others develop over time and cause the current to flow through the defective areas rather than the working areas[5]. Thus, the brightness of the surrounding pixels decreases, and a considerable amount of power is wasted around the defective parts[3,4]. This problem is significant for panels on the scale of square meters since the defect rate increases with the size of the display.

In order to tackle this problem, for passive matrix OLED displays, a series of OLEDs is used for one pixel, providing a scalable defect tolerance capability[1]. For active matrix OLED (AM-OLED) displays, redundant rows/columns can be used to avoid the defects. However, defects that develop during operation are difficult to monitor, and redundant rows/columns cannot be reprogrammed in time. Therefore, it is crucial to develop a defect-tolerant circuit that can detect such defects and switch to a spare OLED automatically. This paper introduces a novel circuit for AM-OLEDs that achieves such fault-tolerant capabilities and significantly reduces power consumption.

2 Proposed circuit

Figure 1(a) shows a schematic diagram of the proposed defect-tolerant circuit. For comparison, the diagram of a standard OLED driving circuit is shown in Fig. 1(b). All the transistors are p-type thin film transistors (TFTs). The selection transistor M1 and the current source transistor M2 are the same for the two circuits. Whenever the OLED circuit is operating, both M1 and M2 are ON. The main feature of the proposed circuit (Fig. 1(a)) is to use M3, M4, M5, and an inverter to detect defective shorts and switch OLED1 to OLED2 when there is one.

Case Ⅰ: When the OLED circuit is operating and both OLED1 and OLED2 are functional, the drain current of M2 flows through both M3 and M4. In the branch of M4, the capacitor C_D is in parallel with OLED2, reducing the charge to OLED2. Hence, the current going through M3 is

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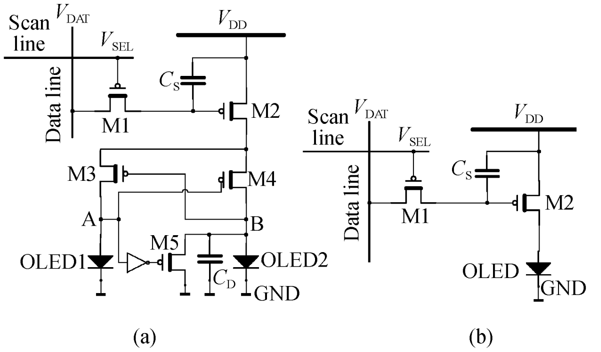

Fig. 1 (a) Proposed fault tolerance circuit; (b) Standard OLED driving circuit

more than that of M4. M3 is then biased in the linear region and M4 will be cut off. Thus, V_A will remain high, and V_B is "floating" and uncertain. In order to force V_B to be '0' V, an inverter and M5 are introduced. Since V_A is high, the output of the inverter will be low and turn on M5. M5 will in turn reduce the uncertain voltage of V_B to the threshold voltage and let V_B approach '0' V through the "subthreshold conduction" effect. Therefore, in Case I, M3 and OLED1 are in operation; M4 and OLED2 are OFF to save power consumption.

Case II: In the case that OLED1 has electrical shorts, the anode of OLED1 will be "stuck-at-0", V_A is '0' V, and M4 is ON all the time. Then OLED2 starts working and the current from M2 flows through OLED2 and charges the capacitor C_D. Thus V_B rises, letting M3 operate in saturation with a reduced current. Since the total current from M2 is a constant, the reduction of the M3 current will in turn increase the M4 current and V_B. The high V_B will then turn off the M3 and OLED1 branch completely. At the same time, the M4 and OLED2 branch operates normally, since the low V_A will turn off M5 through the inverter without disturbing the operation of this branch. Therefore, in Case II, M3 and OLED1 will be OFF to save power; while M4 and OLED2 will operate to maintain the luminance of the pixel.

3 Experiment and simulation

We now demonstrate the fault tolerance and power saving capabilities of the proposed circuit through the following experiments and simulations. A 5mm × 5mm OLED was fabricated and characterized by a Keithley 4200-SCS semiconductor characterization system to abstract the OLED parameters. Figure 2 shows photos of this OLED for the cases of non-operation and operation. For 8V operation, a current of 9.12mA is obtained with a brightness of 800cd/m^2. A current of around 10.95μA is then required for a pixel the size of 300μm × 100μm. The OLED can be modeled as a capacitor and a diode-connected TFT. Using these values for current and pixel size, the capacitor is obtained as $C_{CA} = 6.5$pF and the size of the OLED TFT is $W/L = 43\mu m/10\mu m$.

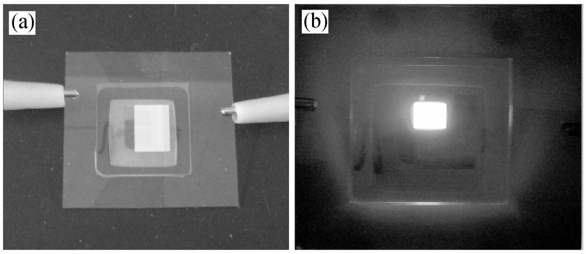

Fig. 2 (a) Fabricated OLED; (b) Fabricated OLED in operation (generating green light)

The current source TFT, M2, will operate in saturation. Its drain current is determined only by the gate-source voltage,

$$I_{DS} = \mu C_{OX}\left(\frac{W_2}{L_2}\right)\frac{(V_{GS2} - V_{TH})^2}{2} \tag{1}$$

where μ is the mobility of charge carriers, C_{OX} is the gate oxide capacitance per unit area, and V_{TH} is the threshold voltage. In Case I, if OLED1 is turned on and OLED2 off, $V_{GS2} - V_{TH} \leqslant V_{DS2}$ must be satisfied in the saturation region of M2, where $V_{DS2} = V_{DD} - V_{DS3} - V_{OLED1}$. Thus, the smallest possible width-to-length (W/L) ratio of M2 is given by

$$\frac{W_2}{L_2} \geqslant \frac{2I_{DS}}{\mu C_{OX}(V_{DD} - V_{DS3} - V_{OLED1})^2} \tag{2}$$

Here, the source voltage V_{DD} is 15V. Therefore, assuming $V_{DS3} = 1$V and a certain margin, we choose $W_2/L_2 = 92\mu m/5\mu m$. Similarly, we obtain $C_S = 10$pF and $W_1/L_1 = 10\mu m/10\mu m$ for M1[6]. In Case I, when both OLED1 and OLED2 are functional, the source-drain voltage of M3 is expected to be smaller than V_{TH} in order to turn off M4 and offer a desirable drain current. Therefore, the aspect ratio $W_3/L_3 = 160\mu m/10\mu m$ is chosen for M3 to satisfy this criterion. Since the configuration of the circuit is symmetric, the aspect ratio of M4 is the same as M3. Furthermore, M5 and the inverter are used as a switching branch without any specif-

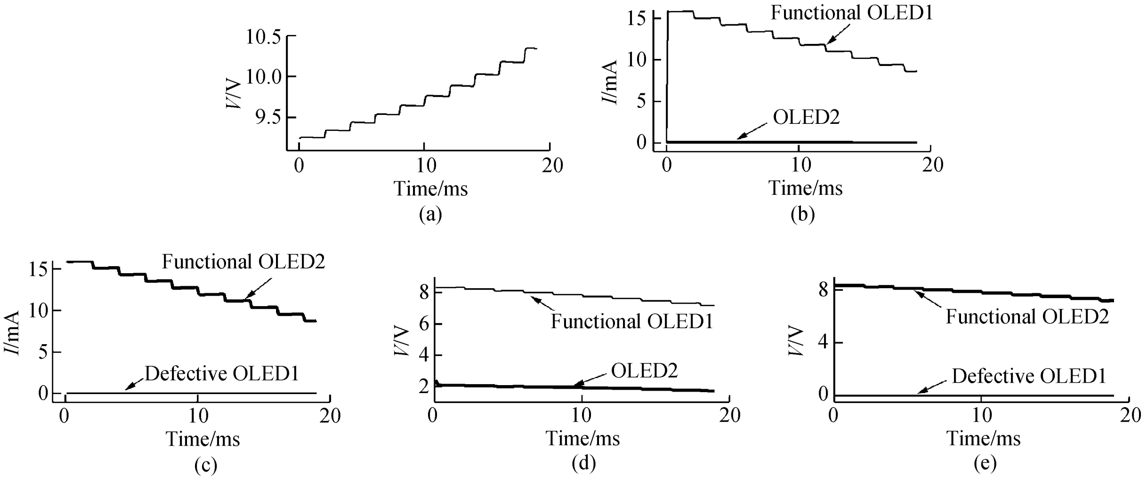

Fig. 3　Simulation results of the proposed circuit　(a) Different gate voltages of M2; (b) Currents of OLED1 and OLED2 for Case I; (c) Currents of OLED1 and OLED2 for Case II; (d) Anode voltages of OLED1 and OLED2 for Case I; (e) Anode voltages of OLED1 and OLED2 for Case II

ic current requirement, and thus the aspect ratio $W_5/L_5 = 10\mu m/10\mu m$ is used for M5.

Using these parameters and a LEVEL 62 RPI Poli-Si TFT model[7], the proposed circuit is simulated in HSPICE. The simulation results are based on 10 different gate voltages of M2 or 10 sample/hold input voltages by C_S (from 9.25 to 10.4V in 10 steps as shown in Fig. 3(a)). Figure 3(b) demonstrates that in Case I, OLED2 is turned off when OLED1 is functional, and the current of OLED1 is modulated by the voltage of the data line. As shown in Fig. 3 (c), in Case II when OLED1 is defective, the OLED1 branch is turned off to save power while the OLED2 branch is operating normally. It can be seen that the current of OLED1 in Case I is the same as that of OLED2 in Case II. Also, Figures 3(d) and (e) show that the corresponding anode voltages of these two working OLEDs are the same. Therefore, this circuit will smoothly switch from OLED1 and OLED2 without any current or voltage penalty. Since both current and voltage remain the same, the brightness of the pixel will not change after switching. It should be noted that the anode voltage of OLED2 in Case I (non-operational) is slightly higher than '0', which is smaller than the threshold voltage of the OLED. Therefore, this spare functional OLED2 is completely dark and will not disturb the brightness of the pixel.

As shown in Fig. 4, for Case II when OLED1 becomes defective, the average power consumption of the proposed circuit is 0.2mW, where the power consumption of OLED1 is zero and OLED2 is 0.12mW. That of a standard OLED driving circuit (Fig. 1(b)) is 0.37mW, where the power consumption of the OLED is zero for the shortage, and the driver circuit consumes most of the power, which should be avoided. Thus, power savings of around 90% can be achieved when the proposed circuit is used to cut off the defective branch. For Case I, the average power consumption of the proposed circuit is slightly higher than that of a standard OLED driving circuit due to the extra control circuit. However, since the control circuit functions as a logic control, the power consumption of this part of the circuit is acceptable. Actually, the average power consumptions of the proposed circuit and the standard circuit are 0.195 and 0.19mW, respectively. This result demonstrates the power efficiency of the proposed circuit.

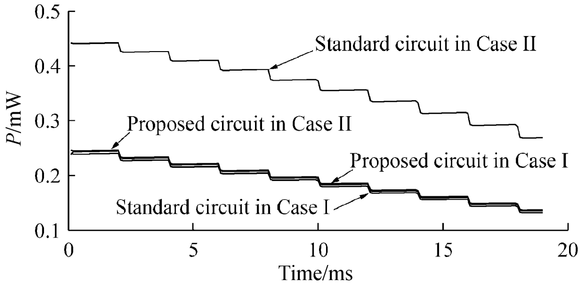

Fig. 4　Power consumption of the proposed and standard OLED driving circuits

4 Conclusion

Local defects in an OLED display such as electrical shorts during operation cause serious problems by decreasing the brightness of pixels and consuming a considerable amount of power. In this paper, a simple OLED driving circuit is introduced to automatically detect short defects and switch to a spare OLED to maintain the luminance of the pixel without changing the driving current. Thus, fault tolerance capability is obtained and a significant amount (around 90%) of power is saved by cutting off the defective branch. Furthermore, although there is a spare OLED in the proposed circuit, it is still based on the mature TFT driving OLED technology. We expect that this proposed circuit can be used for many OLED designs due to its simplicity and effectiveness and have a huge impact on the industry.

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具有容错功能的OLED有源驱动电路*

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摘要： 以有机电致发光器件(OLED)为基础的显示或照明器件，通常会受到短路故障的影响，从而使得像素失效，降低面板的亮度，进而严重地影响亮度的均匀性，并且会产生大量的功耗.本文介绍了一种新的有源OLED驱动电路，以自动检测在OLED中发生的短路故障并切换至备用OLED.该电路采用p型低温多晶硅薄膜晶体管制造.当发生短路故障时，本电路可以在不改变驱动电流的情况下，保持OLED像素的亮度维持不变.实验结果表明，本电路不仅具有容错功能，而且与标准电路相比可以显著地降低功耗.

关键词： 有机发光二极管；有源矩阵OLED；容错

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