Improvement of Brightness Uniformity by AC Driving Scheme for AMOLED Display

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Abstract—**We propose an ac voltage driving scheme which can improve the brightness uniformity of active-matrix organic light-emitting diode (AMOLED) displays. Through the use of a charge feed-through mechanism and an ac driving voltage, the voltage drop caused by the parasitic resistance can be compensated. A 2.2 in AMOLED panel with a resolution of 176 × RGB × 220 has been fabricated by low temperature polycrystalline silicon technology to evaluate the performance of the ac driving scheme. Experimental results show that a brightness uniformity of higher than 91.6%, achieved by the ac driving scheme, in contrast to that of 74% achieved by a dc driving scheme.**

Index Terms—**AC driving, active-matrix (AM), AMOLED, light-emitting diode (LED), thin-film transistor (TFT), uniformity.**

I. INTRODUCTION

ORGANIC LIGHT-EMITTING diodes (OLEDs) have attracted enormous attention because of potential flat panel display applications. Active-matrix (AM) addressing is required to achieve the continuous excitation during the entire frame period for economical power consumption and lifetime improvement in AMOLED display applications. In the past few years, several kinds of pixel circuits have been proposed for AMOLED based on voltage and current driving schemes [1]–[6]. Since device aging and fabrication processes cause variations in the characteristics of OLEDs and thin-film transistors (TFTs), the current driving scheme is capable of compensating the variations and produce the desired brightness uniformity [5], [6]. In recent years, owing to the progress of processing technology and development of OLED material, the characteristic variations can be eliminated. In this case, the voltage driving scheme becomes more attractive because of its simple structure, high aperture ratio, and compatability with AM liquid crystal display (AMLCD) driver technology. However, the intrinsic display loading effects induced by a voltage drops across the parasitic resistance of the AM addressing electrodes still result in the brightness nonuniformity in voltage driven AMOLED display panels. Increasing the width of the addressing electrodes can reduce the parasitic resistance, however, the aperture ratio will be decreased. It is expected that the voltage drop caused by the parasitic resistance will become the critical drawback in display applications of large size and high resolution.

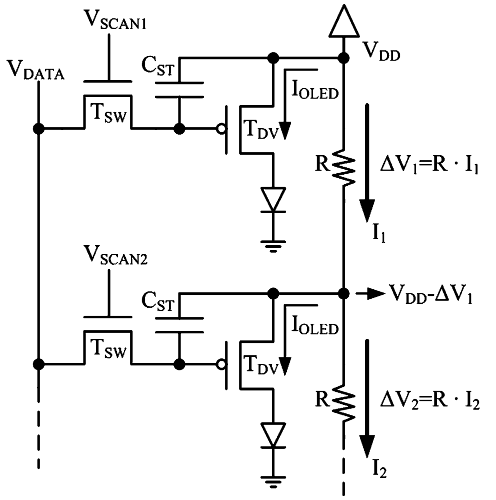

Fig. 1. Schematic diagram demonstrates the voltage drop caused by the intrinsic parasitic resistance (*R*) at $V_{\rm DD}$ electrode.

In this paper, we propose a simple ac voltage driving scheme with a conventional two-transistor (2-T) pixel circuit for AMOLED displays. By means of the charge feed-through mechanism, the proposed ac driving scheme can counteract the voltage drop caused by the parasitic resistance. The experimental results show that the ac driving scheme can effectively improve the brightness uniformity.

II. AC DRIVING SCHEME AND PANEL ARCHITECTURE

In the dc voltage driving pixel circuit, the OLED is connected to ground and the data voltage stored in a storage capacitor $(C_{\rm ST})$ keeps the OLED illuminated continuously, Fig. 1. The gate to source voltage $(V_{\rm gs})$, equivalent to $|V_{\rm DATA}–V_{\rm DD}|$, can generate the current signal to the OLED based on the transconductance of the driving TFT $(T_{\rm DV})$. However, the driving current passing through the $V_{\rm DD}$ electrode produces a voltage drop on account of the parasitic resistance (*R*) of the addressing electrode. Even if an identical data voltage is programmed into storage node and stored by $C_{\rm ST}$, the $V_{\rm gs}$ at each $T_{\rm DV}$ is different from pixel to pixel along the $V_{\rm DD}$ electrode, consequently, generating different driving currents. This intrinsic resistance of the addressing electrodes result in

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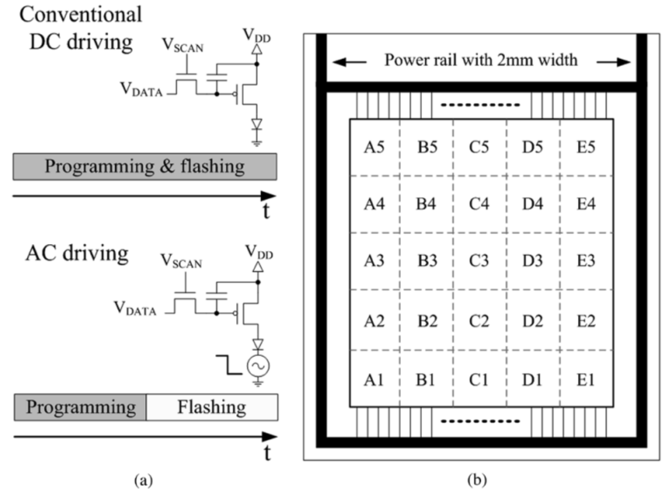


Fig. 2. (a) Pixel circuits for the dc and ac voltage driving schemes. (b) The active area of AMOLED display panel is divided into 5 × 5 regions for brightness measurement.

a brightness gradient from both sides to the central part of the panel.

In the proposed ac voltage driving scheme, the OLED cathode is connected to an ac power supply instead of the ground, as shown in Fig. 2(a). The alternating voltage signal of the ac power supply divides the pixel operation into programming and flashing periods. In the programming period, the voltage at the OLED cathode is switched to V_{DD} to turn the OLED off. At this moment, neither a driving current nor a voltage drop is generated in the AMOLED display panel. Therefore, the initial V_{gs} is identical to the V_{DD} voltage and stored by C_{ST} in each pixel. In the following flashing period, the cathode voltage is switched to ground after programming all of the pixel circuits and the OLED begins to flash. Even though the driving current still produces the voltage drop ΔV_{DD} along the V_{DD} electrode, the V_{DATA} at the storage node is also decreased by the feed-through effect of C_{ST} and the parasitic capacitance (C_{gd}) of T_{SW} and T_{DV}. The data voltage drop ΔV_{DATA} at the storage node can be expressed as

$$\Delta V_{\mathrm{DATA}} = \frac{\Delta V_{\mathrm{DD}} \cdot (C_{\mathrm{ST}} + C_{\mathrm{gd(DV)}})}{(C_{\mathrm{ST}} + C_{\mathrm{gd(DV)}} + C_{\mathrm{gd(SW)}})}. \tag{1}$$

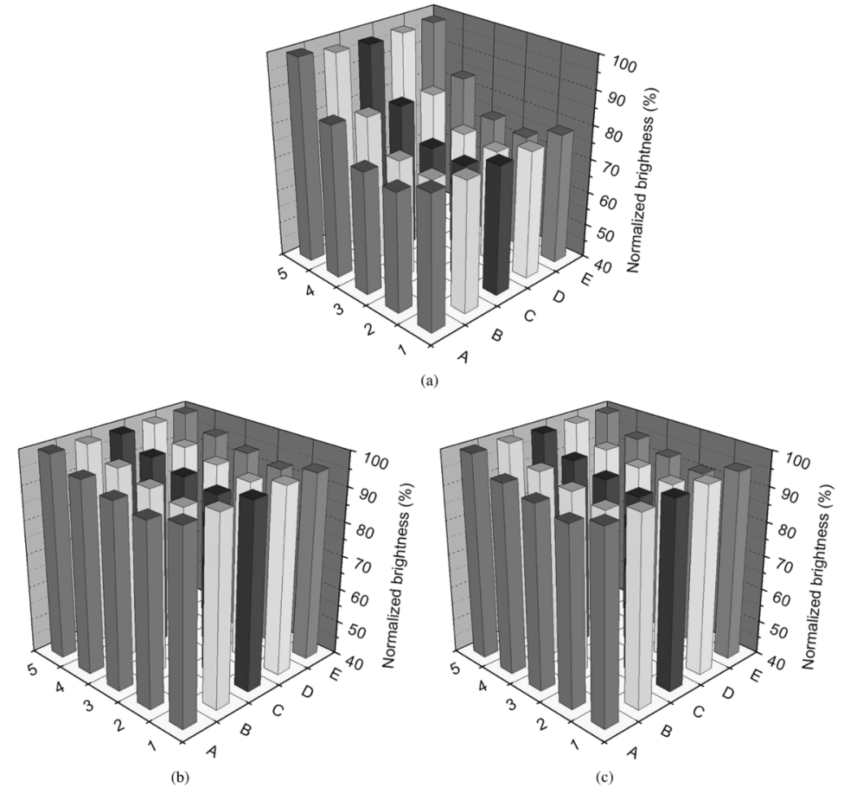
If C_{ST} is much larger than the parasitic capacitance of T_{SW} and $T_{\mathrm{DV}}, \Delta V_{\mathrm{DATA}}$ is almost equal to ΔV_{DD}. This means that the V_{gs} of T_{DV} is always kept at the initial value, and hence, the voltage drop does not affect the brightness of the panel.

III. EXPERIMENT AND DISCUSSION

In order to demonstrate an AMOLED display with the proposed ac driving scheme, we have fabricated a 2.2-in panel with a resolution of 176 × RGB × 220, by a top-gate low-temperature polycrystalline silicon (LTPS) process. A buffer and an a-Si layer were deposited by plasma-enhanced chemical vapor deposition (PECVD). Next, a XeCl excimer laser was used to crystallize the a-Si layer. After definition of the active island and deposition of the gate insulator, the gate metal was sputtered and patterned. After that, the n-channel TFT source/drain (S/D) and lightly doped drain (LDD) and the p-channel TFT S/D were doped. Finally, the TFTs were formed after dopant activation, interlayer dielectric deposition, hydrogenation, contact via formation and metallization. Once the TFT process is completed, a hole injection material PEDOT:PSS and a green light-emitting copolymer were spin-coated sequentially onto the ITO anode. Finally, a Ca/Al bi-layer cathode was thermally evaporated through a shadow mask to form the common cathode.

The pixel size is 66×198 μm^2 with an aperture ratio of 25.3%. A 2-mm-wide power rail surrounds the active area, and each column of the VDD electrode connects to this power rail, as shown in Fig. 2(b). The active area was divided into 5 × 5 regions and the brightness of each region was measured using a GmbH Conoscope. The diameter of the measuring spot size, which covers about 80 pixels, was 2 mm. The brightness of the top left region (A5) was set to 730 cd/m^2 as a reference in the measurement.

The conventional dc driving scheme shows less brightness uniformity than the ac driving scheme, as shown in Fig. 3. The driving current I_{OLED} of each pixel was calculated by dividing the current measured at the cathode by the number of pixels. Although I_{OLED} is only 1.6 μA for the dc driving scheme, the voltage drop still causes a significant brightness decrease from the surrounding to the central regions. The lowest brightness was at region (C2), which was found to be only 74.54% of that at the reference region A5, as depicted in Fig. 3(a). In contrast, the ac driving scheme shows effective compensation for brightness uniformity variation. In Fig. 3(b), the normalized brightness of all measured regions were well above 91.6%, for a duty cycle of the flashing period of 80% and an I_{OLED} of 1.99 μA. The *RC* time constant of each data line, which is a critical issue for reducing the programming period, is 100 ns. Even though the programming period is reduced to 20% of the entire frame time, the data voltages still can be programmed accurately into the pixels. When the duty cycle of the flashing period decreases to 40%, so as to obtain more programming time, the driving current is increased to 3.9 μA to keep the reference brightness at 730 cd/m^2. Meanwhile, the ac driving scheme is still capable of maintaining the brightness uniformity higher than 92.4%, even though the higher driving current can lead to a significant voltage drop. Although a higher driving current is needed in the ac driving scheme, the treatment of reversed bias voltage can accelerate the recovery from degradation and lead to an improvement in the current–density voltage characteristics and device lifetime of the OLEDs [7], [8]. In other words, the higher driving current may degrade OLED performance rapidly, however, the ac driving scheme, with proper reversed bias voltage, can alleviate the degradation. Fig. 4 shows the normalized brightness at region C2 as a function of the duty cycle in which the duty cycle of 100% represents the dc driving scheme. The experimental results show that the normalized brightness is higher than 91.6% when the AMOLED panel operates in the ac driving scheme with various flashing duty cycles. In contrast, once the panel is driven by the dc driving scheme, the brightness drastically decreases to 74.5%. Nonetheless, the parasitic capacitance of T_{SW} between the storage node and the gate of T_{SW} causes the voltage drop at the storage node to be reduced so that ΔV_{DATA} is smaller than ΔV_{DD}. Besides, the thickness of spin-coated polymer film has a slight variation from the central to the outer



(a)

(b)

(c)

Fig. 3. Normalized brightness of AMOLED display panel for the dc and ac driving schemes. (a) dc driving scheme with 100% duty cycle, $I_{\mathrm{OLED}} = 1.6\mu\mathrm{A}$. (b) ac driving scheme with 80% duty cycle, $I_{\mathrm{OLED}} = 1.99\mu\mathrm{A}$. (c) ac driving scheme with 40% duty cycle, $I_{\mathrm{OLED}} = 3.9\mu\mathrm{A}$.

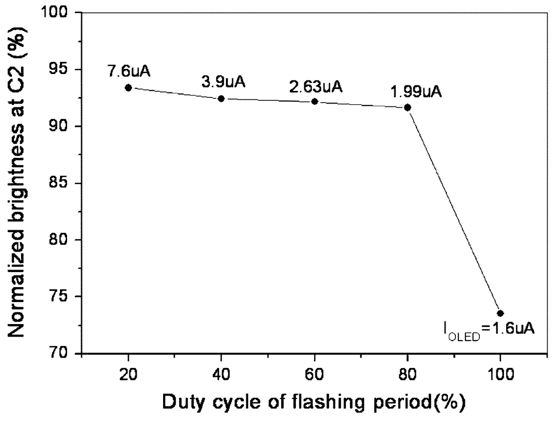


Fig. 4. Normalized brightness at region C2 versus flashing duty cycle.

areas. Consequently, the brightness uniformity cannot be compensated completely and a remaining nonuniformity of about 8% can be observed.

IV. CONCLUSION

An effective ac driving scheme and the corresponding pixel circuit were designed to improve the brightness uniformity of AMOLED. By means of an alternating polarity of the cathode voltage, and the charge feed-through mechanism, the voltage drop at the V_{DD} electrode caused by the intrinsic parasitic resistance of the addressing electrode can be compensated. The experimental results demonstrate that the proposed ac driving scheme can achieve the uniform brightness of higher than 91.6% with various flashing duty cycles.

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