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MIXED SIGNAL LETTER

Characterization of AMOLED pixel circuit without power line

**Seon Pyo Hong · Dong Sung Moon ·
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Abstract We fabricated and evaluated the simple active matrix organic light emitting diode (AMOLED) pixel circuits without power line and proved that it is useful for the AMOLED display. Without power line in the pixel circuit we got higher-aperture ratio of emission area than the pixel with power line and the pixel with high aperture ratio can give a long life time due to lower current density of organic light emitting diode. However, the lack of power line requires the verification of the driving scheme of the pixel circuit. After fabrication of two types of AMOLED with and without power line in the pixel, we evaluated the pixel currents under various conditions. The operation of the pixel circuit without power line gave similar characteristics to that of the pixel circuit with power line. By the comparison, we verified that the pixel without power line is acceptable for the application to the AMOLED display combined with feedback compensation scheme for the uniform brightness.

Keywords AMOLED · Pixel circuit · OLED · Thin film transistor

1 Introduction

The liquid crystal display (LCD) operates by modulating light from back-light and has small viewing angle due to liquid crystal orientation. On the other hand, emissive display does not require back-light and provides wide viewing angle. A promising emissive display is active matrix organic light emitting diode (AMOLED) which shows wide viewing angle, fast response time, and self emissive characteristics [1].

The brightness of the organic light emitting diode (OLED) is proportional to the amount of current passing through it. Therefore, a pixel of AMOLED is composed of a drive thin film transistor (TFT) as well as a switch TFT to flow a current through the OLED for one frame time. Variation of OLED current results in variation of the brightness of the OLED. Hence, the active matrix OLED pixel array needs to deliver uniform current to the OLED in order to create uniform brightness. Therefore, unlike the LCD, the uniformity of TFT's is quite important for the uniform brightness [2].

To acquire a uniform brightness, a variety of pixel circuits were suggested for AMOLED. There are two types of pixel circuit, one is simple two TFT's and one capacitor (2T1C) type and the other is threshold voltage shift compensation type [3]. The compensation type can reduce the OLED current variation when threshold voltage shifts. Many pixel circuits of compensation type have been reported for AMOLED [4–7].

There are two ways to make OLED pixel structure. One is top emission structure and the other is bottom emission structure [8]. Top emission structure attracts much interest due to its available design margin for increasing fill factor. Top emission needs transparent cathode electrode with low resistance. Bottom emission structure emits light through a glass substrate; therefore, the aperture for light emission is limited by the area of pixel circuit. The area of TFT's, capacitors and signal lines block the light. One way of increasing emitting area is to reduce the design rules. But, it is difficult to reduce the design rule with the existing process equipments. Moreover, smaller line width results in voltage drop across the line, which results in non-uniform brightness [9–11].

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Conventional 2T1C circuit is composed of a scan line, a data line, a power line (V_{DD} line), two TFT's and a capacitor, all of which reduce light emitting aperture in bottom emission structure. Aperture ratio can be increased by elimination of one of them and the pixel circuit without V_{DD} line was proposed [12]. In the pixel without V_{DD} line, the power for driving of the OLED is supplied by the scan line. Therefore, we can't use any level of voltages for the scan line because the voltages are the gate voltage of the switch TFT as well as the power voltage of the drive TFT. Therefore, in this paper we evaluated and verified scan voltages to get the appropriate operation for both the switch TFT and drive TFT in the 2T1C type pixel circuit without V_{DD} line. We fabricated two types of AMOLED pixels with and without power line. After encapsulation with glass to avoid degradation by oxygen or moisture, we evaluated them and proved that the pixel circuit without power line is acceptable for the application to the AMOLED.

2 Experiments

Figure 1(a) and (b) show the microphotographs of the fabricated AMOLED pixels taken from bottom side. Two pixel circuits with and without V_{DD} line were designed for the low temperature poly silicon TFT process. Figure 1(a) is the conventional 2T1C type and Fig. 1(b) is the 2T1C type circuit without V_{DD} line. In the 2T1C circuit without V_{DD} line, scan line was used for supplying V_{DD} to the drive TFT.

Pixels were fabricated on glass substrates via a low-temperature poly silicon process. Poly silicon was achieved by metal induced lateral crystallization of a 600 Å amorphous silicon thin film by low-pressure chemical vapor deposition (LPCVD). Crystallization was performed at 580°C for 2 h with nickel-catalyst metal. The gate insulator was a 700 Å thickness of SiO_2 layer deposited by plasma-enhanced chemical vapor deposition (PECVD) with SiH_4 and N_2O gas at 420°C. The source and drain regions were defined by boron doping.

The gate electrode was Mo metal deposited by sputtering. After deposition of a passivation layer, via hole was formed for contact of indium tin oxide (ITO). ITO was deposited and patterned for the pixel electrode. W/L of the fabricated TFT's of the pixel was 7 μm/7 μm. After the formation of bank with an organic insulator, OLED and cathode were deposited and encapsulation was formed with a glass.

The designed pixel size for both pixels was 65 μm × 195 μm. The widths of the scan line and data line were same as 7 μm. The size of the contact holes for the ITO electrode was 5 μm × 5 μm. The capacitance of the storage capacitor C_{st} was 0.3 pF. For the pixel with V_{DD} line, the storage capacitor formed between silicon layer and gate layer. Since the photo was taken from bottom side, silicon layer only can be seen. For the pixel without V_{DD} line, the storage capacitor formed between the ITO and cathode layer. Since the ITO layer is transparent, it is not easy to be seen. The ITO pattern for the storage capacitor was formed at the same step of the pixel ITO, and it is connected to the gate layer through the contact hole. By elimination of V_{DD} line, fill factor increased as can be seen in Fig. 1(a) and (b). The fill factor of Fig. 1(a) was 22.9% and the fill factor of Fig. 1(b) was 39.7%. The fill factor of the pixel without V_{DD} line was 16.8% larger than the conventional 2T1C pixel.

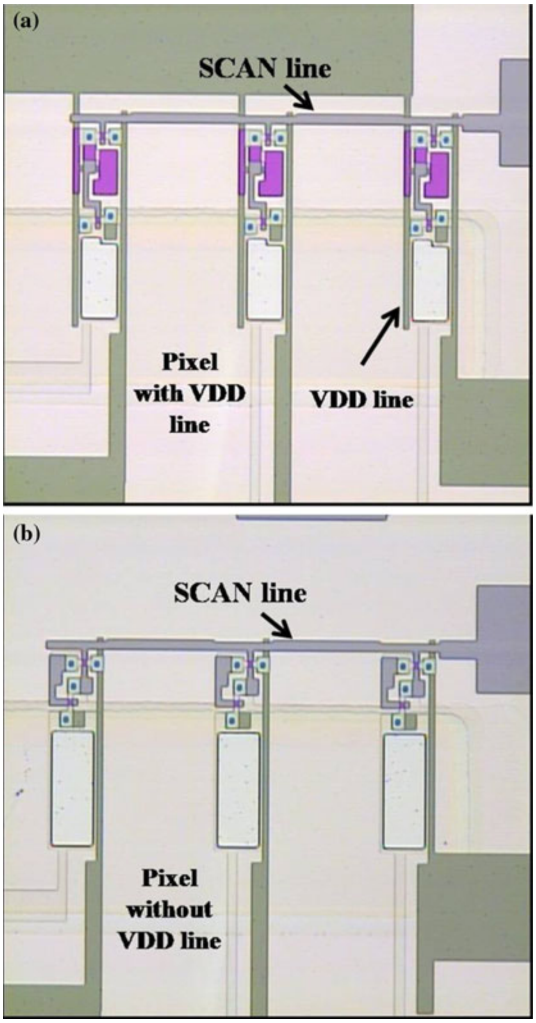

Fig. 1 The microphotographs of the fabricated pixel circuits with V_{DD} line (**a**); and without V_{DD} line (**b**)

Figure 2(a) and (b) show the measurement nodes and input voltage timing diagrams for each pixel circuit. At first, we measured OLED current as changing data voltages. When measuring OLED currents, TFT current meter was disconnected. Next, we measured TFT currents as changing data voltages. OLED was disconnected during the measurement of TFT currents.

The OLED currents depend on the stored voltages in C_{st} which is the gate voltage of the drive TFT. In the pixel without V_{DD} line, the C_{st} was not connected to the scan line to avoid voltage change of the C_{st} by capacitive coupling to the scan pulse. In the pixel without V_{DD} line, the scan voltages are applied to both the gate of the switch TFT and the drain of the drive TFT. Scan and data signals are shown in Fig. 1(a) and (b). Scan voltages have two periods, one is scan voltage period and the other is power voltage period. During scan voltage period, the switch TFT turns on and a data voltage is addressed to the gate node of the drive TFT. During the power voltage period, scan voltage becomes off-voltage of the switch TFT. Thus, in the case of the pixel without V_{DD} line, the off-voltage of the scan line plays a role of the power voltage by which OLED current flows through the drive TFT.

3 Results and discussion

Figure 3(a) and (b) show the comparison between OLED currents and TFT currents. The currents were measured for various data voltages from 0 to 5 V. Black squares are OLED currents and white circles are TFT currents. V_{DD} was 15 V and the scan voltages swing from 0 to 15 V. OLED current became zero level around 5 V which was relatively small value because the absolute value of threshold voltage and sub-threshold slope were rather high for the fabricated TFT's. However, the comparison between the pixel with and without V_{DD} line is possible and it shows that there is not much difference of currents between two pixels with and without V_{DD} line.

Though OLED currents results in decrease of source-drain voltages of the drive TFT due to the voltage drop across the OLED, the measured OLED currents were almost the same with the TFT currents which is measured without OLED. The same TFT and OLED currents verify that the drive TFT operates in a saturation mode. The pixel without V_{DD} line also shows the same TFT and OLED currents, which verify that the drive TFT operates in a saturation mode in the pixel without V_{DD} line.

For the lower data voltages below around 1.5 V, the operation regime changed to the linear region because the absolute value of the voltage between the gate and the

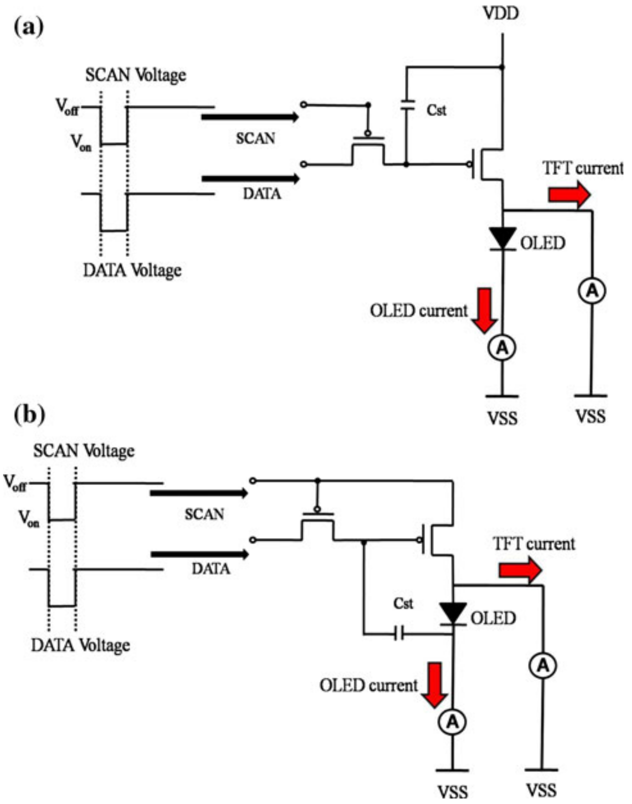

Fig. 2 The measurement nodes and input voltages for the 2T1C pixel with V_{DD} (**a**); for the 2T1C pixel without V_{DD} (**b**)

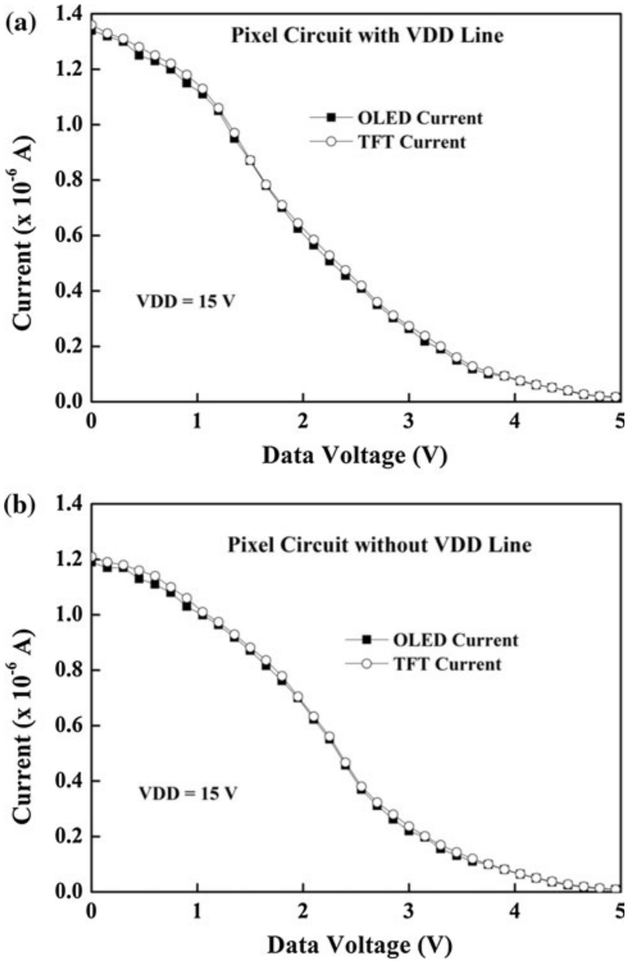

Fig. 3 Comparison between OLED currents and TFT currents for the pixel circuits with V_{DD} (**a**); and without V_{DD} (**b**)

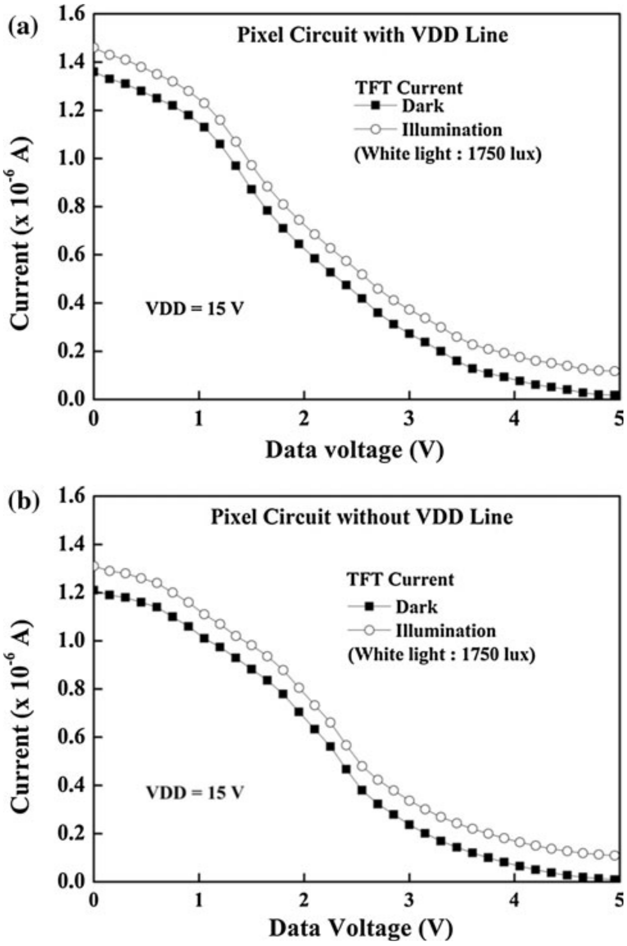

Fig. 4 Photo and dark TFT currents of both the pixel circuits with V_{DD} line (**a**); and without V_{DD} line (**b**). Illuminance of the white light was 1750 l×

source/drain increase to the negative sign. As a result, currents do not show quadratic relationship with respect to the data voltages and also the TFT currents and OLED currents become different a little.

We measured the effect of illumination on the pixels. Figure 4(a) and (b) show both the dark and illuminated TFT currents. Figure 4(a) shows TFT currents of the pixel circuit with V_{DD} line and Fig. 4(b) shows TFT currents of the pixel circuit without V_{DD} line. Illuminance of white light was 1750 lx. TFT photo currents increase when TFT is illuminated; therefore, the illuminated TFT currents were larger than the dark TFT currents. Since the brightness of OLED is proportional to the amount of current passing through it, display brightness can change by illumination onto the TFT. For uniform brightness it is necessary to prevent illumination onto TFT's. In this measurement, it was verified that the photo-currents for the pixel without V_{DD} line were similar to those of the pixel with V_{DD} line.

Figure 5(a) and (b) show TFT currents versus data voltages for various V_{DD}'s and scan-off voltages.

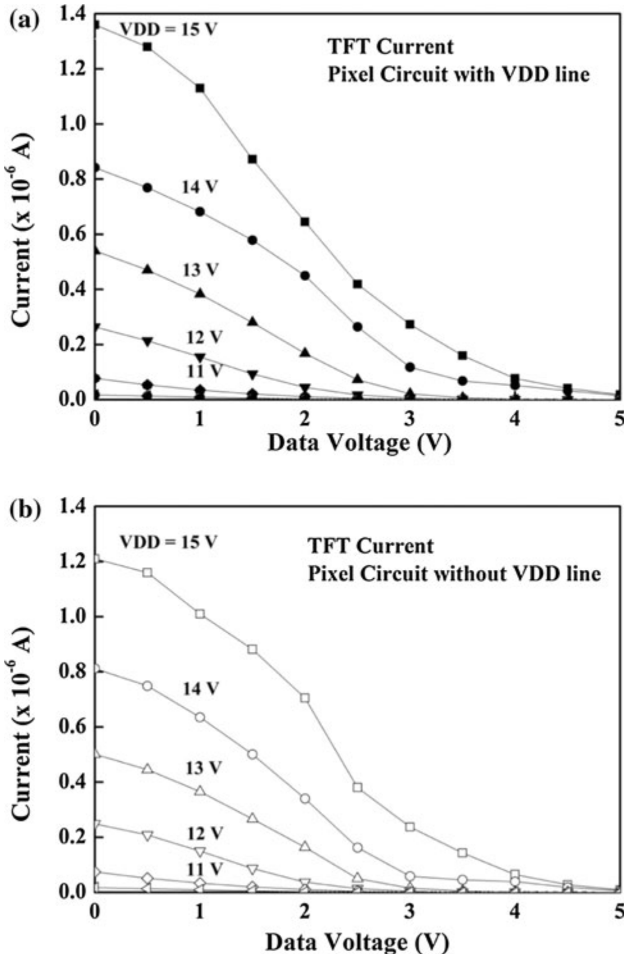

Fig. 5 TFT currents dependence on V_{DD} for both the pixel circuits with V_{DD} line (**a**); and without V_{DD} line (**b**)

Figure 5(a) shows dependence of the TFT currents on V_{DD}'s for the pixel circuit with V_{DD} line. Figure 5(b) shows dependence of the TFT currents on scan-off voltages connected to the drain of the drive. In the case of the pixel circuit without V_{DD} line, scan-off voltage is supplied to the drive TFT while the switch TFT is off-state.

As the V_{DD}'s or scan-off voltages decreased, TFT currents also decreased due to the change of the gate-source voltages. In the case of the circuit without V_{DD} line, scan-off voltages are applied to the switch TFT as well as the drive TFT. Since the off currents of the switch TFT depend on scan-off voltages, we should be careful to set the scan-off voltage. If the leakage currents of the switch TFT of the pixel without V_{DD} line are large, the C_{st} node voltage decrease rapidly. Thus, the TFT current should decrease rapidly due to voltage decrease at the C_{st} node. While varying the scan-off voltages from 15 to 11 V the currents shown in Fig. 5(b) are similar to those of the pixel with V_{DD} line, which verifies that pixel without V_{DD} line can be used for the OLED pixel array and allows enough voltage windows of the scan-off voltage. Scan-off voltages resulted in enough low off-currents of the switch TFT and appropriate drive currents of the drive TFT simultaneously.

We verified that the pixel without V_{DD} line can be used for the OLED display. However, there are preliminary terms to be concerned with. The first one is the scan driver IC which provides scan voltages and the power voltage in the case of the pixel without V_{DD} line. Therefore it is necessary to develop the scan driver which has enough current driving capability for the drive TFT's. The second one is the compensation scheme for the unstable TFT characteristics. The 2T1C type can't compensate threshold voltage variation; however, the compensation by video data correction by the sensing the pixel were reported [13] and can be combined with the 2T1C type pixel circuit for the good uniformity of OLED display.

4 Conclusion

We fabricated and analyzed the 2T1C type pixel circuits with and without V_{DD} line. They were encapsulated with glass after evaporation of OLED. In the pixel without V_{DD} line, the aperture for the emission area was larger than that of the pixel with V_{DD} line. For the two types of AMOLED pixels with and without power line, we measured the OLED and TFT currents under the dark and illumination, and TFT currents for various V_{DD}'s. TFT currents and OLED currents measured under various conditions were similar for both pixels. In the pixel without V_{DD} line, TFT currents for various data voltages were measured for various scan-off voltages changed from 15 to 11 V. The measured currents were similar to those of the pixel with V_{DD} line measured with various V_{DD} voltages changed from 15 to 11 V. The dark and illuminated currents were compared between two pixels and showed similar results, also. In this paper, the operation of the pixel circuits without V_{DD} line was verified to be used for OLED pixel array with a scan drive IC which can provide high current capability for the drive TFT's. With the compensation by video data correction, the 2T1C type pixel is able to provide uniform brightness against the variation of the TFT characteristics as well as high aperture of light emission area.

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