ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/255576811

Current-Writing Active-Matrix Circuit for Organic Light-Emitting Diode Display Using aSi:H Thin-Film-Transistors

Article *in* IEICE Transactions on Electronics · May 2000

CITATIONS
24

READS
418

5 authors, including:

Reiji Hattori
Kyushu University
92 PUBLICATIONS **1,336** CITATIONS

SEE PROFILE

Jerzy Kanicki
University of Michigan
359 PUBLICATIONS **8,579** CITATIONS

SEE PROFILE

All content following this page was uploaded by Jerzy Kanicki on 12 May 2014.

The user has requested enhancement of the downloaded file.

SDC EX. 1015 - 1/5

LETTER

Current-Writing Active-Matrix Circuit for Organic Light-Emitting Diode Display Using a-Si:H Thin-Film-Transistors

Reiji HATTORI[†a)], ***Member***, **Tsutomu TSUKAMIZU**[†*], **Ryusuke TSUCHIYA**[†], **Kazunori MIYAKE**[†], **Yi HE**[††], ***and*** **Jerzy KANICKI**[††], ***Nonmembers***

SUMMARY In this letter, we describe a four thin-film-transistor (TFT) pixel circuit based on hydrogenated amorphous silicon (a-Si:H) technology for the active-matrix organic light-emitting diode (AMOLED) display applications. The circuit uses current-writing mechanism and can automatically adjust the threshold-voltage shifts of both the organic light-emitting diodes (OLEDs) and the TFTs induced by the circuit aging or process variations. Experimental results indicate virtually no variation of the output driving current after long-term bias-temperature-stress (BTS).

key words: *hydrogenated amorphous silicon, thin-film-transistor, active-matrix, organic light-emitting diode, bias-temperature-stress*

1. Introduction

Recent progresses in improving the device luminous efficiency [1], brightness [2], lifetime [3] have made possible the application of organic light-emitting diodes (OLED) for high-resolution large area flat panel displays, where the low cost fabrication and emissive characteristics of OLED are advantageous. Recently, a passive-matrix driving organic based color panel prototype is presented by Pioneer Electronic Corporation [4]. However, for the application of high information content flat panel displays (FPD), active-matrix driving technique has to be applied. In the last two years, several efforts have been made for the development of the active-matrix driving organic light-emitting displays [5]–[7]. These efforts, using either a two-TFT or a four-TFT pixel circuit, are all based on polycrystalline silicon TFT technology.

Hydrogenated amorphous silicon (a-Si:H) TFT is industrially preferred because of the low-cost fabrication steps and the uniformity for large area. However, a-Si:H TFT has much smaller field mobility ($< 1\,\mathrm{cm^2/Vsec}$) than poly-Si TFT ($\sim 50\,\mathrm{cm^2/Vsec}$). Therefore, the OLED driving current provided by an a-Si:H TFT circuit will be much smaller than a poly-Si TFT circuit. Because the luminance of the OLED is usually proportional to the applied current, it is argued [5] that the a-Si:H TFT circuit cannot provide enough current to light up the OLED display panel to the necessary brightness ($\sim 100\,\mathrm{cd/m^2}$) for the display application. However, recent progress [1]–[3] in the OLED research significantly improved the device efficiency, which makes it possible to achieve a high brightness with much smaller current. According to our calculation, a-Si:H TFT is still sufficient for the general display applications. For a typical OLED emission efficiency of 4.0 cd/A and a pixel area of $2.0\times10^4\ \mu\mathrm{m}^2$, a current of 5.0×10^{-7} A is needed to achieve a pixel brightness of $\sim$100 cd/m^2. Table 1 compares the saturation currents of a-Si:H TFT and poly-Si TFT. The results indicate that a-Si:H TFT based active-matrix array is capable of supplying sufficient current for the organic light-emitting display.

2. Pixel Circuit for OLED

In an OLED display, in order to continuously supply the current to the OLED pixel while the other rows are addressed, at least two TFTs are needed for one pixel. Figure 1 shows the equivalent pixel circuit for this approach based on the n-channel TFTs. Figures 1(a) and (b) are the source follower configuration and the constant current configuration, respectively. For the p-channel TFTs, the equivalent pixel circuit is opposite: the configuration as illustrated in Fig. 1(a) is the constant current configuration and Fig. 1(b) shows the source follower configuration. For the AMOLED operation, constant current configuration is preferred be-

Table 1 Comparison of the saturation currents of a-Si:H and poly-Si TFTs.

	a-Si:H TFT	poly-Si TFT
Typical Mobility (cm^2/Vsec)	0.6	50
TFT W/L Ratio	10:1	10:1
Saturation Current (A)	2.5×10^{-6}	2.1×10^{-4}
Maximum Luminance (cd/m^2)	500	$> 4\times10^4$

Manuscript received October 12, 1999.
Manuscript revised February 14, 2000.

[†]The authors are with the Department of Electronic, Graduate School of Information Science and Electrical Engineering, Kyushu University, Fukuoka-shi, 812-8581 Japan.
[††]The authors are with Electronic Manufacturing Laboratory, Center for Integrated Microsystems, Department of Electrical Engineering & Computer Science, University of Michigan, Ann Arbor, MI, 48109, USA.
[*]Presently, the author is with Fujitsu Co. Ltd.
a) E-mail: hattori@ed.kyushu-u.ac.jp

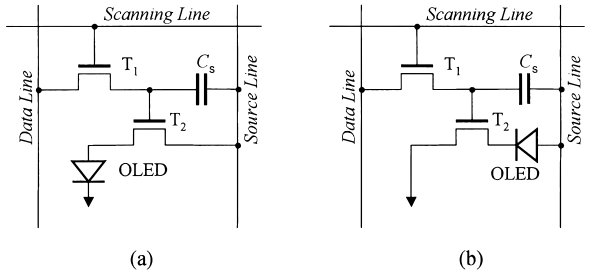

Fig. 1 Two TFT active-matrix addressing scheme for OLED. (a) Source follower configuration. (b) Constant current configuration.

cause the circuit can automatically cancel slight threshold voltage ($V_{\rm th}$) shift of OLED and maintain the same output current level. Therefore, the OLED brightness can remain unchanged even if a slight OLED $V_{\rm th}$ shift is present. Since the OLEDs are extremely sensitive to moistures, wet processing steps like photolithography are usually avoided after the deposition of the organic layers. Therefore, the pixel circuits for the AMOLED needs to be fully defined before the deposition of the organic layers. This limitation makes it very difficult to achieve the configuration as shown in Fig. 1(b), where the interconnect between the cathode of the OLED and the drain electrode of T_2 needs to be established. This implies that the constant current configuration for the n-channel TFT is difficult to realize for the two-TFT circuit. Unfortunately, p-channel a-Si:H TFT has an extremely low mobility at the present time. Therefore, the circuit-compensation approach has to be developed for a-Si:H TFT to achieve the self-adjustability of OLED $V_{\rm th}$ variation.

A basic function of the pixel electronics is to consistently provide a constant current for the OLED during the frame period. The current level has to be adjustable in order to achieve the gray levels. As discussed previously, to maintain the constant current flow during the frame period, one pixel requires at least two TFTs. However, the two-TFT circuitry usually cannot be commercially used because of the threshold voltage variations of the driving TFT due to the manufacturing variations and the circuit aging. Figure 2 shows the effect of $V_{\rm th}$ shift after the bias temperature stress (BTS) for the two-TFT (a-Si:H) circuit shown in the inset. The OLED was emulated by the TFT (T_3) to omit the fabrication process of OLED. The T_3 whose gate is connected to its drain shows a rectifying characteristics. Therefore the circuit is thought to be compatible with the pixel circuit as shown in Fig. 1(a). This circuit was fabricated on the glass substrate (Corning #7059) using a conventional back-channel-etching process. The channel length of each TFTs is 6 μm. The channel widths of T_1, T_2 and T_3 are 10, 300 and 200 μm, respectively. A constant voltage of 20 V was applied as $V_{\rm s}$. A series of the BTS experiments were conducted under DC bias-stress conditions at room-temperature. The

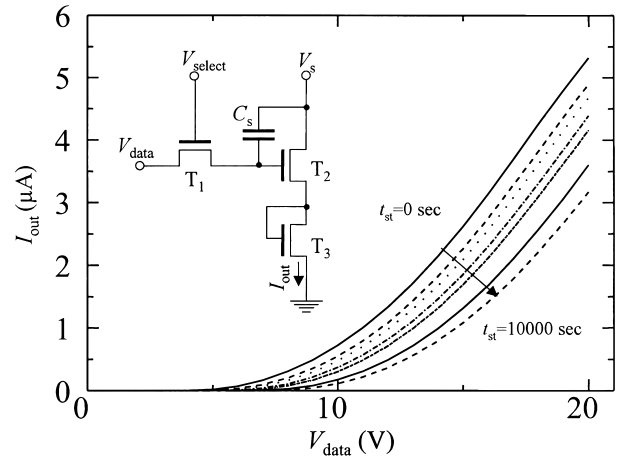

Fig. 2 The output current variation due to the T_2 $V_{\rm th}$ shift after the bias temperature stress for the two-TFT circuit.

Table 2 Deviation of the drain current due to the $V_{\rm th}$ variation.

$\Delta V_{\rm th}(V)$	0.5	1	2	5
$\Delta I/I_0$	4.9%	9.8%	19.0%	43.8%

bias stress voltage (+20 V) was applied to the T_2 gate. After a BTS of 10,000 second, the $V_{\rm th}$ shifted by 3.5 V. The output current $I_{\rm out}$ was measured during the OFF period. Table 2 lists the amount of deviation of the current from the original desired value $\Delta I/I_0$ due to the threshold voltage variation $\Delta V_{\rm th}$. This table suggests that even 0.5 V threshold voltage shift is not acceptable for the AMOLED display. Although polysilicon TFT has a similar degree of manufacturing variation and a smaller amplitude of threshold voltage variation after a long-term operation in comparison to the a-Si:H TFT, the grain size variation of the poly-Si over the whole panel is still difficult to control. This grain size variation can induce large performance fluctuation of the poly-Si TFT. Therefore, a simple replacement of a-Si:H TFT by poly-Si TFT cannot fully recover the induced pixel brightness non-uniformity. A circuitry compensation approach is needed.

3. Operation of Current-Writing Four-TFT Circuit

To improve the pixel brightness non-uniformity induced by the TFT $V_{\rm th}$ variation, Dawson et al. developed a four-TFT circuit based on the p-channel poly-Si TFT technology [6]. This approach uses a voltage-setting method and an autozero cycle to compensate the $V_{\rm th}$ shift of the driving TFT. Using this circuit, the amplitude of the brightness variation over the panel has been significantly reduced from 10.1% to 2.6%. Although the circuit seems cleverly designed and nearly perfect, there are still rooms for further improvement. For example, the circuit has six terminals including four

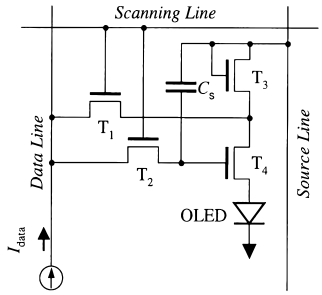

Fig. 3 The equivalent circuit of the current-set, self-compensate four-TFT pixel circuit design.

control lines for each pixel. The driving scheme for this circuit is, therefore, very complicated. In addition, one of the controlling TFT, which is connected in series with the driving TFT and OLED, could also affect the OLED brightness uniformity because of its own threshold voltage shift. Therefore, this four-TFT approach only partially compensates the V_{th} shift of the pixel circuit. As long as the driving current is set by the voltage, the threshold voltage shift of the TFTs cannot be completely adjusted. To fully adjust the threshold voltage variation of the TFTs, a current-compensation method is needed.

Figure 3 shows the equivalent circuit of the current-writing four-TFT pixel circuit we designed based on the a-Si:H TFT technology. T_1 and T_2 serve as the switches to adjust the data current (gray level) of the OLED. A common source line is used to consistently supply the current even when the pixel is de-selected. Transistor T_1 and T_2 also set the drain voltage and gate voltage of T_4 when the pixel is selected. T_4 works as the driving TFT and is hopefully operated in the saturation region, in which the drain current only changes with the gate potential. The OLED gray level, which is proportional to the drain current, can be controlled by adjusting the gate voltage of T_4. T_3 works as a one-direction diode that only allows the current flow in the direction from the source line to the OLED. Because of the unavoidable leakage of T_2 and the voltage reduction effect due to the parasitic capacitance, a storage capacitor C_s is needed as a charge reservoir to maintain the gate voltage of T_4 during the pixel OFF-period. The source line is the common voltage source connected to every pixel on the panel. Its function is to provide the power to all the OLEDs on the panel regardless if the pixel is selected or not.

The most important thing in this circuit design is that the current following across the OLED is set by the current through the data line I_{data}. Therefore, a current source is needed to provide the data signal for each pixel. During the operation, the drain voltage and the gate voltage of T_4 are determined by the current source from the data line. When the pixel is selected, T_1 and T_2 are ON and both the drain voltage and the gate voltage of T_4 are set to the data line

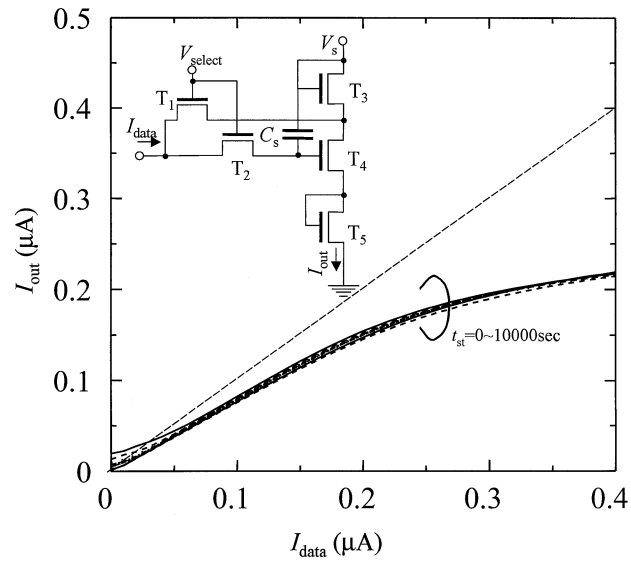

Fig. 4 Experimental results of BTS on the current-writing four-TFT circuit, which show no variation for the output current after the BTS.

voltage. This voltage is variable and can be different from pixel to pixel and from time to time, according to the desired current flow and the magnitude of the V_{th} shifts of both OLED and T_4 of the addressed pixel. This variation of the drain/gate voltages of T_4 is to ensure the desired current flowing through T_4 and the OLED. If an OLED and/or T_4 threshold voltage variation appears, the drain voltage and gate voltage of T_4 will always be set to ensure the desired current flowing through the OLED. This local voltage variation is automatically adjusted by the current source on the data line. In this manner, we can always maintain the current to the set-value, no matter how high the V_{th} shift is for the driving TFT and/or the OLED. When the pixel is de-selected, T_1 and T_2 are OFF. The gate voltage of T_4 remains almost the same due to the existence of the storage capacitor C_s. The source line serves as the constant supplier for the OLED. Because that the gate voltage of T_4 remains unchanged and that T_4 is in the saturation region, the current flowing through T_4 will be kept constant until the pixel is selected again. This constant current ensures a minimum variation of pixel gray level. The threshold voltage shifts of other TFTs in this circuit will not have a major impact on the output current. This approach allows a complete correction of the manufacturing variations or circuitry aging.

Figure 4 shows our initial experimental results on the current-writing four-TFT circuit described in the inset. The OLED was emulated by T_5 because of the same reason as mentioned before. The W/L of T_1, T_2, T_3, T_4 and T_5 are 50/6, 100/6, 250/6, 250/6 and 200/6 (μm/μm), respectively. The voltage of V_s was 9 V. In this figure, the horizontal axis represents the current

value (I_{data}) applied throught the data line. The BTS voltage of +20 V was applied to the gate of T_4 in the same manner as is in the case of two-TFT circuit. The results indicate that the output current I_{out} remains essentially unchanged before and after the BTS, showing no sign of the V_{th} variation effects.

The I_{out} should be equal to the I_{data} in principle as explained above and the curves should be on the straight line described by the dashed line in Fig. 4. However, the measured value of I_{out} is less than the ideal value and the deviation increases as I_{data} increases. The curve looks almost saturated around $0.4\,\mu$A of I_{data}, resulting in a smaller I_{out} in comparison with the two-TFT circuit in Fig. 2, although the circuit is capable of providing higher current.

The discrepancy between the set value and the measured experimental value is due to the fact that T_4 operation point slides from the saturation region into the linear region. During the OFF period, if the V_{s} is not high enough, T_4 will work in the linear region instead of the desired saturation region. So the current cannot keep the same level at the writing-time. In order to avoid this effect, we have to applied higher V_{s}. However, if the V_{s} is too high, the current through the T_4 flows from the source line even though the I_{data} is set to zero because the voltage of data line is equal to the voltage of T_4 drain and the voltage could be higher than V_{th} of T_4. This effect can be seen slightly near the origin of Fig. 4. Therefore, in this circuit we need to choose a reasonable V_{s} value and the dynamic range of I_{out} is restricted. However, in a circuit with real OLED the maximum value of I_{out} will actually be much higher. The emulated circuit of T_5 shows the diode-like characteristics but the increase of the current after the threshold voltage is not as steep as is in the real OLED. The current of emulated circuit shows the parabolic increase while the current of OLED increases exponentially. This means that we can set the V_{s} higher without the effect of current flowing from the source line. Therefore, we will be able to obtain I_{out} as high as $0.5\,\mu$A if we use the real OLED.

Similar pixel circuit has been presented by Dawson et al. [8] as a current programmed circuit. The idea is essentially the same as ours although the circuit is a little different because they used a p-type poly-silicon TFT and an extra line to control the current from the source line. They mentioned in their paper that the setting time of OLED is an issue for this circuit because it takes a longer time for the current source to charge up the huge capacitor of OLED. However, there is no need to charge it up within the selecting time. The driving TFT can be set immediately by the constant current from data line, then the OLED will be charge up within a frame time. Therefore, the slow charging times of OLED may not cause this circuit to fail for the display as large as VGA.

4. Conclusion

We have developed a current-writing four-TFT based pixel circuit based on a-Si:H technology for the AMOLED displays. This circuit can automatically adjust the TFT threshold voltage shift due to the local heating or circuit aging. The experimental results indicate that there is virtually no variation of the output driving current after long-term bias-temperature-stress (BTS).

Acknowledgement

This work is partially supported by the Center for Display Technology and Manufacturing at the University of Michigan and by the Grant-in-Aid for Science Research (No. 11694167) from the Ministry of Education, Science, Sports and Culture of Japan.

References

[1] L.S. Hung, C.W. Tang, and M.G. Mason, "Enhanced electron injection in organic electroluminescence devices using Al/LiF electrode," Appl. Phys. Lett., vol.70, pp.152–154, Jan. 1997.

[2] F.G. Celii and S.J. Jacobs, "High-efficiency organic LEDs," IDRC'97, p.314, 1997.

[3] C.W. Tang, "Organic luminescent materials and devices," Proc. Information Display, vol.12-10, pp.16–19, Oct. 1996.

[4] Japan Electronics Show'98 in Makuhari Messe, Chiba, Japan, 1998.

[5] T. Shimoda, H. Ohshima, S. Miyashita, M. Kimura, T. Ozawa, I. Yudasaka, S. Kanbe, H. Kobayashi, R.H. Friend, J.H. Burroughes, and C.R. Towns, "High resolution light emitting polymer display driven by low temperature polysilicon thin film transistor with integrated driver," Proc. Asia Display'98, pp.217–220, 1998.

[6] R.M.A. Dawson, Z. Shen, D.A. Furst, S. Connor, J. Hsu, M.G. Kane, R.G. Stewart, A. Ipri, C.N. King, P.J. Green, R.T. Flegal, S. Pearson, W.A. Barrow, E. Dickley, K. Ping, C.W. Tang, S. Van Slyke, F. Chen, J. Shi, J. Sturm, and M.H. Lu, "Design of an improved pixel for a polysilicon active-matrix organic LED display," Symposium Digest for 1998 SID sym., pp.11–14, 1998.

[7] M. Stewart, R.S. Howell, L. Pires, M. Hatalis, W. Howard, and O. Prache, "Polysilicon VGA active matrix OLED displays—Technology and performance," Proc. IEDM'98, pp.871–874, 1998.

[8] R.M.A. Dawson, Z. Shen, D.A. Furst, S. Connor, J. Hsu, M.G. Kane, R.G. Stewart, A. Ipri, C.N. King, P.J. Green, R.T. Flegal, S. Pearson, W.A. Barrow, E. Dickley, K. Ping, S. Robinson, C.W. Tang, S. Van Slyke, F. Chen, J. Shi, M.H. Lu, and J. Sturm, "The impact of the transient response of organic light emitting diodes on the design of active matrix OLED displays," Proc. IEDM'98, pp.875–878, 1998.

View publication stats