Organic Light-Emitting Diode-on-Silicon Pixel Circuit for Microdisplays with Wide Range of Data Voltage

Bong-Choon Kwak, Jae Sung An and Oh-Kyong Kwon

Department of Electronic Engineering, Hanyang University,
17 Haengdang-dong, Seongdong-gu, Seoul, 133-791, Korea
Phone: +82-2-2220-0359   Fax: +82-2-2297-2231   E-mail: okwon@hanyang.ac.kr

In this paper, we propose an organic light-emitting diode-on-silicon (OLEDoS) pixel circuit for 0.6 inch extended graphics array (XGA) resolution micodisplays with 8-bit gray scale. The proposed pixel circuit has wide range of data voltage to achieve 8-bit gray scale. For the wide range of data voltage, the proposed pixel circuit has bias circuit which consists of three p-channel metal oxide semiconductor field-effect transistors (MOSFETs). The proposed pixel circuit has 1.6 times wider range of data voltage than that of the OLEDoS pixel circuit with source follower and active load. The simulation results show that the error of emission current varies from -2.52 to +2.59%, when the threshold voltage variation of MOSFETs is from -5 to +5 mV.

1. Introduction

An organic light-emitting diode-on-silicon (OLEDoS) displays have many advantages of microdisplays such as pico projectors and head-mounted displays (HMDs). Because the OLEDoS displays are implemented on the single-crystalline silicon backplane, pixel circuits and display driving circuits can be integrated on a chip. Moreover, the OLEDoS displays use organic light-emitting diode (OLED) as luminous source. Therefore, OLEDoS displays can be thin and small. The OLEDoS displays also have high optical performance and low power consumption by using OLED.

Several OLEDoS pixel circuits have been reported. First, the OLEDoS pixel circuit uses source follower for analog voltage driving method. The OLEDoS pixel circuit is very simple. Moreover, the OLEDoS pixel circuit has wide range of data voltage. However, the OLEDoS pixel circuit has error of emission current due to electrical characteristic variations of OLED, because the programmed data voltage directly is applied to the OLED by using OLED.

Second, the OLEDoS pixel circuit uses source follower with active load for current driving method. The OLEDoS pixel circuit has immunity of the electrical characteristic variations of OLED. However, the OLEDoS pixel circuit has narrow range of data voltage because transconductance of driving metal oxide semiconductor field-effect transistor (MOSFET) in the pixel circuit is too high to supply such low current level for the OLEDoS. Therefore, the OLEDoS pixel circuit used source follower with active load for current driving method is not suitable to achieve high gray scale.

To solve the aforementioned problem, the bias circuit is added to the OLEDoS pixel circuit using source follower with active load. The wide range of data voltage can be achieved by using additional bias circuit. Therefore, the proposed pixel circuit has not only good immunity of the electrical characteristic variations of OLED but also wide range of data voltage.

2. Proposed pixel circuit

The proposed pixel circuit has bias circuit in order to expand the range of data voltage. Figure 1 shows the schematic diagram of the proposed pixel circuit. The proposed pixel circuit consists of seven p-channel MOSFETs (P1, P2, P3, P4, P5, P6 and P7) and one capacitor (C1). P1, P2 and P3 are used for bias circuit. P4 operates as switch between the output of bias circuit, node B, and the gate node of P6. C1 is storage capacitor to hold the gate voltage of P6 during a frame time. P6 operates as the source follower and the diode-connected P5 is used as the active load. P7 is clamping transistor to prevent the breakdown.

Figure 2 shows the timing diagram of the proposed pixel circuit. When the SCAN signal is low, the bias circuit operates. On the other hands, when the SCAN signal is high, the bias circuit does not operate. Therefore, the proposed pixel circuit can reduce the power consumption by operating the bias circuit only during the scan time. When SCAN signal is high, the voltage of node B become close to ELVDD. In this situation, if SCAN and SCANM signals become low at the same time, ELVDD is applied to the gate node of P6 in an instant. As this effect, the emission current becomes low in an instant. It can be caused the flicker. Therefore, SCAN and SCANM signals should not become low simultaneously. Thus, SCANM signal becomes low, after the SCAN signal becomes low. signals do not For the same reason,
Fig. 1. Schematic diagram of the proposed pixel circuit.

Fig. 2. Timing diagram of the proposed pixel circuit.

When the SCAN and SCANM signals become high at the same time, the voltage of node B becomes close to ELVDD. The gate voltage of P6 also become close to ELVDD and the emission current becomes low. Therefore, SCAN signal becomes high, after SCANM signal becomes high.

When SCAN signal is low, the data voltage, $V_{DATA}$, is applied to the gate node of P2. In this time, the current of bias circuit flows through P1, P2 and P3. When P1, P2 and P3 operate on the saturation region, we can use small signal analysis and express the equations as

$$-g_{m1}V_A + \frac{V_B}{r_{o1}} = g_{m2}(V_B - V_{DATA}) + \frac{(V_B - V_A)}{r_{o2}}$$  \hspace{1cm} (1)

and

$$g_{m2}(V_B - V_{DATA}) + \frac{V_B - V_A}{r_{o2}} = g_{m3}V_A + \frac{V_A}{r_{o3}}$$  \hspace{1cm} (2)

where $g_{m1}$, $g_{m2}$, $g_{m3}$, $r_{o1}$, $r_{o2}$, $r_{o3}$, $V_A$ and $V_B$ are transconductance of P1, P2 and P3, output resistance of P1, P2 and P3 and voltage of node A and B, respectively. The transconductance, $g_m$, is expressed as

$$g_m = \sqrt{2\mu C_{ox} \frac{W}{L} I_D},$$  \hspace{1cm} (3)

where $\mu$, $C_{ox}$, $W$, $L$ and $I_D$ are mobility of p-channel MOSFET, gate capacitance per unit area, channel width of MOSFET, channel length of MOSFET and drain current of MOSFET, respectively.

By using eqs. (1) and (2), the voltage of node B can be express as

$$V_B = \frac{X}{X + g_{m1}r_{o1}r_{o3} + g_{m2}r_{o2}r_{o3} + r_{o1} + r_{o2} + r_{o3}} V_{DATA}.$$  \hspace{1cm} (4)

As shown in eq. (4), the gain of bias circuit is less than one. Therefore, the voltage range of data is expanded by adding bias circuit.

3. Simulation results

The proposed pixel circuit is designed by 0.18 $\mu$m complementary metal oxide semiconductor (CMOS) process. HSPICE simulation is performed to verify the extension of data voltage range and the error range of emission current due to the threshold voltage variation of MOSFET. The simulation conditions are summarized in Table I.

Figure 3 shows the simulation result of voltage of node B according to data voltage. As shown in Fig. 3, when the data voltage varies from 0.1 to 1.7 V, the voltage of node B varies from 1.96 to 2.94 V. Thus, the proposed pixel circuit has 1.6 times wider range of data voltage than that of the OLEDoS pixel circuit without bias circuit.

Figure 4 shows the simulation result of the emission current according to data voltage. When the data voltage varies from 0.1 to

<table>
<thead>
<tr>
<th>Table I. Simulation conditions.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel size (inch)</td>
</tr>
<tr>
<td>Resolution</td>
</tr>
<tr>
<td>ELVDD (V)</td>
</tr>
<tr>
<td>ELVSS (V)</td>
</tr>
<tr>
<td>Color depth (bit)</td>
</tr>
<tr>
<td>Luminance (cd/m²)</td>
</tr>
<tr>
<td>CMOS process (µm)</td>
</tr>
<tr>
<td>Threshold voltage variation (mV)</td>
</tr>
</tbody>
</table>
1.7 V, the emission current varies from 6.37 pA to 5.42 nA. Figure 5(a) shows the simulated waveforms with the SCAN, SCANM and DATA signal and Fig. 5(b) shows the emission current of the proposed pixel circuit. The emission current does not become low because SCAN and SCANM signals do not become low and high at the same time.

Figure 6 show the error range of emission current is from -2.52 to +2.59% under ±5 mV threshold voltage variation conditions. The maximum error of emission current occurs when the data voltage is 0.8 V.

4. Conclusions
In order to achieve high gray scale, we propose the OLEDoS pixel circuit with wide range of data voltage for microdisplays. For the wide range of data voltage, the proposed pixel circuit adds bias circuit on the OLEDoS pixel circuit using source follower with active load. The proposed pixel circuit reduces the power consumption by operating the bias circuit only during the scan time. From the simulation results, the proposed pixel circuit has 1.6 times wider range of data voltage than that of the OLEDoS pixel circuit without bias circuit. The error range of the emission current is from -2.52 to +2.59% under ±5 mV threshold voltage variation conditions.
variation conditions. The proposed pixel circuit is suitable for microdisplays with high gray scale.

Acknowledgments

This research was supported by the grant (F004060-2010-33) from information Display R&D Center, one of the Knowledge Economy Frontier R&D Program funded by the Ministry of Knowledge Economy of Korean government.

References


