

0.5-inch XGA Micro-OLED Display on a Silicon Backplane with High-Definition Technologies

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Abstract

We have developed a high-definition (0.5-inch XGA) Micro-OLED display that employs high-definition technologies, including a new pixel driving circuit and a high-efficiency top-emitting white OLED device with a color filter. These technologies were incorporated in the world's first XGA OLED electronic viewfinder for digital single-lens cameras and HD-personal 3D viewer with two 720p Micro-OLED displays.

Author Keywords

Active-Matrix Devices; OLEDs; Micro Displays; Near-to-Eye Displays

1. Introduction

AM-OLED displays on silicon backplane are very promising for microdisplays since they have a high contrast ratio, a high color gamut, and a high speed response [1-3]. However, it is difficult to realize high-definition Micro-OLED displays due to various problems including spatial restrictions when designing the pixel-driving circuit, realizing precision patterning of the OLED layer using a shadow mask and optical color mixture. In this study, we fabricated high-definition Micro-OLED displays with a new compact pixel circuit that consists of two transistors on a Si wafer and a white OLED device with a high-gamut color filter (CF). Last year, we announced two new overwhelming products: a digital single-lens camera with an XGA Micro-OLED electronic viewfinder (EVF) and a HD-personal 3D viewer with two high-definition 720p Micro-OLED displays. This paper describes the latest high-definition technologies, focusing on the new pixel driving circuit.

2. A New High-Definition Technologies

2-1. Pixel Circuit on a Si Backplane

(a) Pixel circuit design

The pixel driving current of Micro-OLED displays is several nanoamperes because the emission current of OLED devices is proportional to the pixel size. Consequently, the pixel-to-pixel luminescence has non-uniformity due to slight variations in the driving current. A pixel circuit is required to precisely control these variations in the driving current. In recent years, many display manufacturers have developed pixel compensation circuits on low-temperature poly-Si (LTPS) or Si crystalline backplane [4-7]. A pixel circuit conventionally requires many transistors to compensate the variations in the driving current. However, it is difficult to produce so many transistors on sub-pixel areas much smaller than 10 μ m. To overcome this problem, we have developed a new pixel circuit on a Si backplane that consists of only two

MOSFETs and is capable of compensating variations in both the threshold voltage (V_{th}) and the mobility (μ) of the driving transistor. Consequently, we achieved a smallest pixel size of 3.3 μ m x 9.9 μ m and a good pixel-to-pixel luminance uniformity.

Fig. 1 shows a schematic diagram of the pixel circuit. The pixel circuit employs voltage-programmed current driving method. The pixel circuit consists of two n-channel MOSFETs (T1, T2), two capacitors (C1, C2), two gate lines (WS, DS), and a data line (DATA). T1 is the OLED driving transistor that controls the emission current of the OLED device. T2 is a switching transistor for voltage-programming operation. C1 is a storage capacitor to hold the voltage of T1 during the frame time. C2 is a load capacitor of the OLED device during writing of signal voltage.

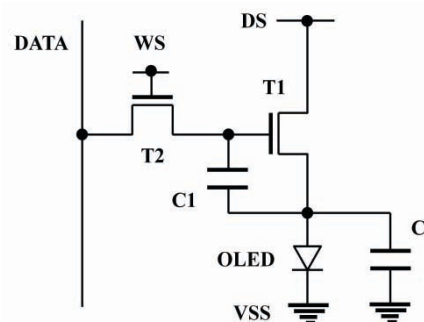


Figure 1. Schematic diagram of new pixel circuit

(b) Pixel driving method

Fig. 2 shows the timing diagram. DS controls the light emitting period. WS is the gate pulse of T2 for controlling the write and cancel operations. Additionally, in the new driving method, two data voltages (V_{ofs} / V_{sig}) are alternately applied to the data line during the horizontal period. V_{ofs} is a constant reference voltage for compensating variations in V_{th} of T1. V_{sig} is the signal voltage that is correlated with the luminescence of each pixel. The new pixel driving operation consists of the following four operations: 1) Reset operation; 2) V_{th} cancel operation; 3) write and mobility cancelling operation; and 4) light emitting operation. The new pixel driving method automatically compensates the electrical characteristics of the driving transistor through two operations (namely, V_{th} cancelling operation and mobility cancelling operation). The operations are described below.

1) The reset operation is shown in Fig. 3-1. The DS line converts a positive supply voltage (V_{dd}) to the initial voltage (V_{ini}). V_{ini} can be set to a low voltage in order to completely turn off the OLED device. We realized a high contrast ratio.

2) V_{th} cancel operation is shown in Fig. 3-2. When T2 is turned on, V_{ofs} is applied to the gate node of T1 from the DATA line. Then, the DS line changes to V_{dd} from V_{ini} , and T1 is turned on in the saturation region. Since the driving current flows to the OLED device, the source node of T1 gradually increases and the driving current decreases. Finally, the source node reaches $V_{ofs} - V_{th}$, and T1 is then turned off (see Fig. 2). Consequently, the V_{th} of T1 is stored in C1 after WS is turned off.

3) Fig. 3-3 shows the signal data writing and the mobility cancelling operation. The DATA line changes to V_{sig} from V_{ofs} . When T2 is turned on again, V_{sig} is applied to the gate voltage of T1 from the DATA line and T1 is turned on again. The source voltage increases when WS is high. As a result, the source node increases by $\Delta V_s(\mu)$ (see Fig. 2). Since V_{th} compensation has previously been accomplished, $\Delta V_s(\mu)$ approximately depends on the mobility of T1. Therefore, the $\Delta V_s(\mu)$ is much greater for higher mobility pixels. Thus, the mobility variations of T1 can be controlled by controlling $\Delta V_s(\mu)$ in this period.

4) Fig. 3-4 shows the light emitting operation. When T2 is turned off, the gate-source voltage (V_{gs}) of T1 is stored in C1. The value of V_{gs} is given by $V_{sig} - V_{ofs} + V_{th} - \Delta V_s(\mu)$. The emitting current (I_{OLED}) flows to the OLED device. The gate and source voltages of T1 both increase with maintaining the V_{gs} of T1. Finally, the source voltage reaches the emission voltage (V_{OLED}). Accordingly, I_{OLED} is given by

$$I_{oled} = \frac{1}{2} k \mu (V_{gs} - V_{th})^2 = \frac{1}{2} k \mu (V_{sig} - V_{ofs} + V_{th} - \Delta V_s(\mu) - V_{th})^2$$

$$= \frac{1}{2} k \mu (V_{sig} - V_{ofs} - \Delta V_s(\mu))^2 \quad \left(k = \frac{W}{L} C_{ox} \right) \quad (1)$$

This equation implies that the variations of both V_{th} and the mobility of T1 are canceled out. Consequently, the new pixel circuit enables a highly uniform pixel-to-pixel luminance to be realized despite its tiny size.

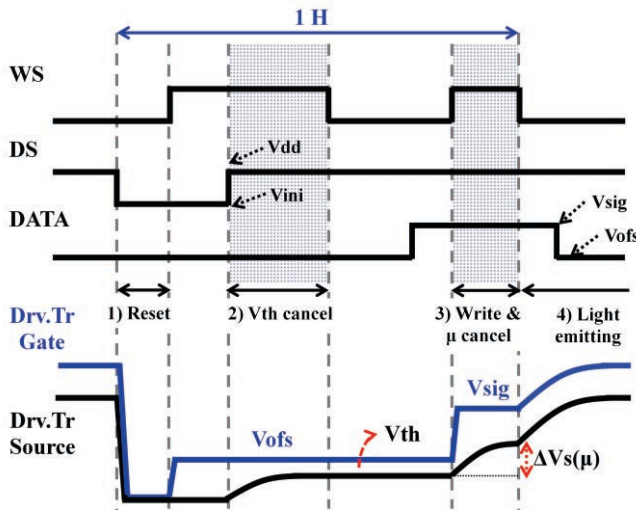


Figure 2. Timing diagram of new pixel circuit

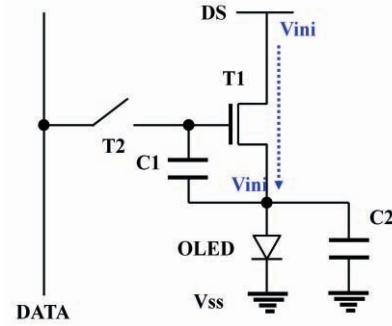


Figure 3-1. Reset operation diagram

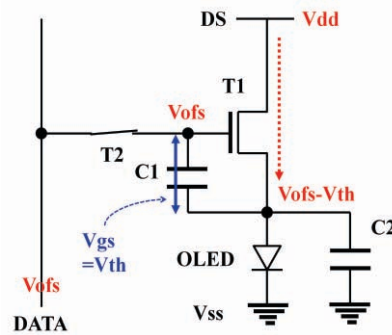


Figure 3-2. V_{th} compensation operation diagram

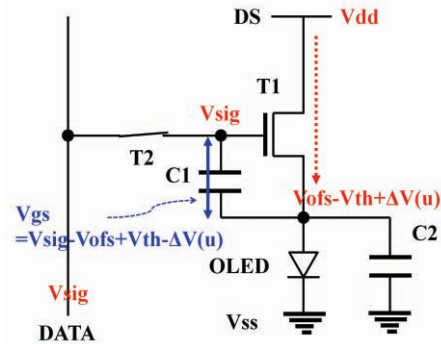


Figure 3-3. Write and mobility compensation operation diagram

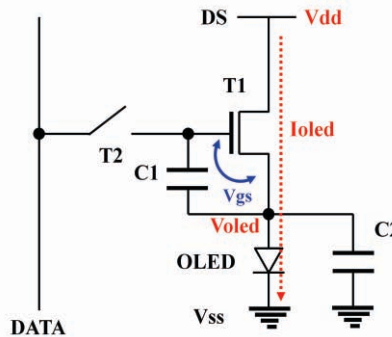


Figure 3-4. Light emitting operation diagram

We performed circuit simulations in order to verify the ability of the new pixel circuit to compensate variations in V_{th} and mobility. Fig. 4 shows simulation results for the dependence of the I - V characteristics on various electrical parameters of the driving transistor. V_{th} and mobility of the driving transistor are assumed to both have variations of $\pm 10\%$. The result indicates that the new pixel driving method successfully compensates variations in V_{th} and mobility

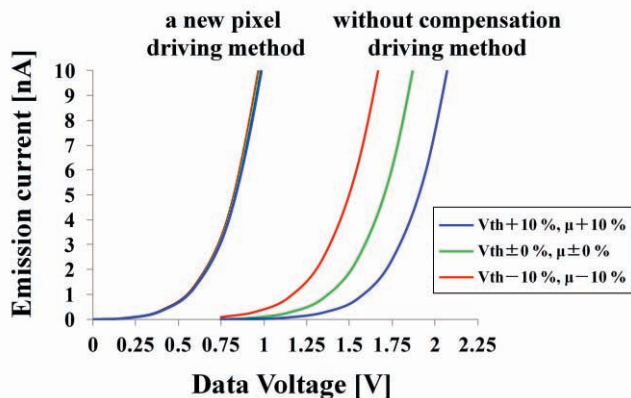


Figure 4. Simulation results of the ability to compensate variations in V_{th} and mobility

2-2. Frontplane Technologies

With decreasing sub-pixel size, it becomes difficult to pattern RGB OLED layers using shadow-mask. To solve this problem, we have developed a top-emitting white OLED device with a CF. High-definition white OLED devices can be fabricated without using a fine metal mask. We developed a simple stack top-emitting white OLED device for a Micro-OLED display. All the materials used in this white OLED device were fluorescent. We realized a higher efficiency and a longer life by controlling the carrier balance [8]. A high-definition display was fabricated by forming a CF on this white OLED layer. Fig. 5 shows its cross-sectional composition. We achieved a high NTSC color gamut of 90%.

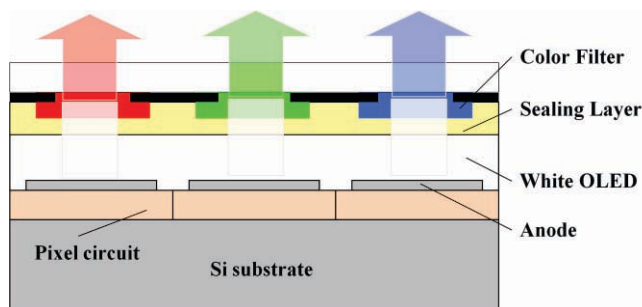


Figure 5. Cross-sectional composition

2-3. Driving Circuit and System Design

Fig. 6 shows a block diagram of the driving circuit and the system configuration. Various driving circuits required for the Micro-OLED display have been built into the Si backplane. The vertical and horizontal scan drivers are both fabricated on the Si backplane. Additionally, 8-bit digital-to-analog (DAC) converters, a gamma voltage generation circuit, and timing controllers (TCON) were realized on the panel. The Micro-OLED display is an all-in-one package, which makes it easy to handle and ensure that it does not occupy much space on an electrical board.

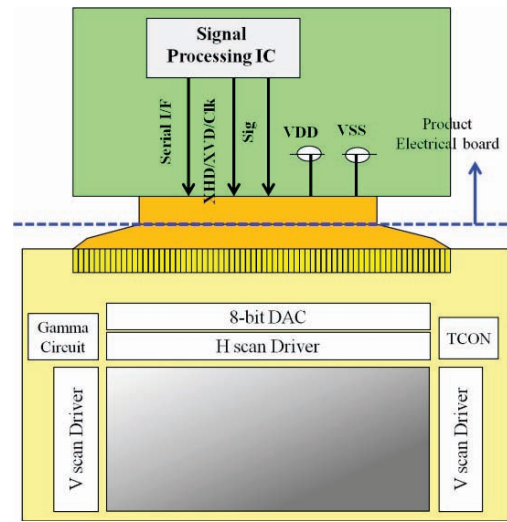


Figure 6. Block diagram of driving circuit

3. 0.5-inch XGA Micro-OLED Display

3-1. Panel SPEC

We developed a high-definition pixel circuit and a high-efficiency top-emitting white OLED device with a high gamut CF. Using these high-definition technologies, we mass produced 0.5-inch XGA and 0.7-inch 720p Micro-OLED displays. Fig. 7 shows images of the panels of these devices. Table 1 lists the main specifications of these displays and their basic characteristics. Both displays generate high NTSC color gamut of 90% with a maximum contrast ratio of 10,000:1, a maximum brightness of 200 cd/m², and a fast response of 0.01 ms or less. High-definition moving 8-bit images can be displayed on these Micro-OLED displays with a frame rate of 60 Hz.

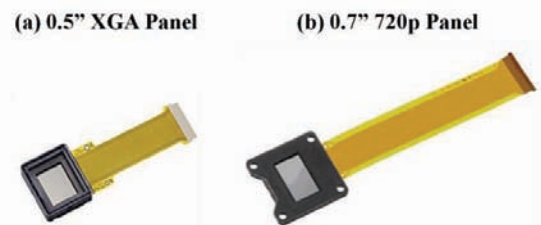
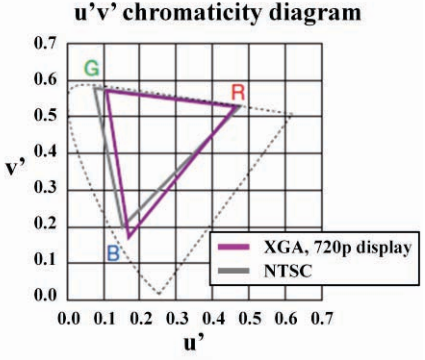


Figure 7. Newly developed high-definition Micro-OLED displays: (a) 0.5-inch XGA, (b) 0.7-inch 720p

Table 1. 0.5-inch XGA and 0.7-inch 720p Panel Specifications

Micro-OLED	XGA	720p
Panel size	Diagonal 12.7 mm 0.5-inch	Diagonal 18.0 mm 0.7-inch
Resolution	XGA 2.4M dots (1024xRGBx768)	720p 2.8M dots (1280xRGBx720)
Pixel Size	3.3 μm x 9.9 μm	4.0 μm x 12.0 μm
Frame Rate	60 Hz/50 Hz supported	
Input data	Digital 8 bits x RGB parallel input	
Color Gamut	 u'v' chromaticity diagram The diagram shows the color gamut of the XGA 720p display (purple triangle) compared to the NTSC standard (black triangle). The XGA gamut is larger, indicating better color reproduction. The vertices are labeled G (green), R (red), and B (blue). The axes are labeled u' and v'.	
Contrast	Maximum 10000:1	
Brightness	Maximum 200 cd/m^2	
Response	0.01 ms or less	

3-2. Impact through EVF/3D viewer

These two Micro-OLED displays resulted in the commercialization of attractive devices. Last year, we announced the mass production of the world's first digital single-lens camera with an XGA Micro-OLED EVF and HD-personal 3D viewer with high-definition 720p Micro-OLED displays.

The XGA Micro-OLED EVF produced excellent definition and high-contrast images. It enables realistic images to be formed in digital single-lens cameras. The HD-personal 3D viewer has a natural, bright, and crosstalk-free 3D picture quality since it employs a dual-panel 3D configuration, which utilizes separate high-definition Micro-OLED displays for the left and right eyes. Viewers can watch videos on a big theater-like screen (virtual width: 750-inches; virtual viewing distance: approximately 20 m). These applications demonstrate that the Micro-OLED display can provide a greatly enhanced visual experience.

5. Acknowledgment

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6. Reference

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