XGA OLED Microdisplay for Personal Display Application

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ABSTRACT

A 0.6-inch XGA OLED Microdisplay was developed. Integrated driving circuit was fabricated on Si wafer backplane and white OLED aligned with color filter at each sub pixels was fabricated to show color images. A current efficiency of 19.5 cd/A for simple stack top emitting white OLED was achieved. Horizontal stripe type sub pixel array was adopted. 8-bit gray scale of each RGB data was realized on the panel. The XGA OLED Microdisplay panel is suitable for personal display applications showing HD grade images.

1. INTRODUCTION

Organic light-emitting diodes (OLEDs) are considered as proper Microdisplay that are capable of meeting the most demands of personal display applications, especially Near Eye Display applications. [1-2] For the personal display application, Microdisplay is required to have high resolution color patterning and high efficiency. Also thin and light form factor and low power consumption are required. Compared with LCoS and LCD panel that have additional backlight system, top emitting white OLED with color filter array is good solution for this applications. [3]

In this work, a 0.6-inch XGA OLED Microdisplay has been developed. The display panel was named OLEDoS as OLED-on-Silicon. [4] Si wafer was used for backplane of the OLEDoS. Pixel circuits and display driving circuits of OLEDoS can be integrated on a chip because OLEDoS display is implemented on the single-crystalline silicon backplane. Simple stack top emitting all fluorescent white OLED was used for light emitting device. RGB sub pixel color filter array on encapsulation glass was aligned with white OLED sub pixel respectively to produce color image and to encapsulate the panel. Chip On Board (COB) packaging is applied to OLEDoS module and flexible cable is applied to connect the OLEDoS module to driving circuit board. The OLEDoS panel which is as small as thumbnail was demonstrated showing XGA resolution images.

2. Circuit Design

2.1 Pixel circuit design

A pixel of OLEDoS is very small to the range of 12 µm, so the numbers of transistors, capacitors and signal lines in each pixel are severely restricted. Therefore, the pixel circuit for OLEDoS should be simple. Also OLEDoS requires very low level current less than several nA to drive pixel. Therefore, the pixel circuit should control a very low current accurately. [5]

We designed OLEDoS pixel circuit using source follower with active load and additional bias circuit. The pixel circuit structure is robust to each OLED device characteristics and the emission current of OLEDoS pixel is constant even if OLED device degradation. We obtained wide band data range with the bias circuit. Therefore, the pixel circuit has not only good immunity of the electrical characteristic variations of OLED but also wide range of data voltage.

The schematic diagram of the pixel circuit is shown in Fig. 1. The pixel circuit is consists of seven p-channel MOSFETs and one capacitor. Three transistors are used for bias circuit. P4 operates as switch between the output of bias circuit 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 transistor is used as the active load. Protection circuit is clamping transistor to prevent the breakdown.

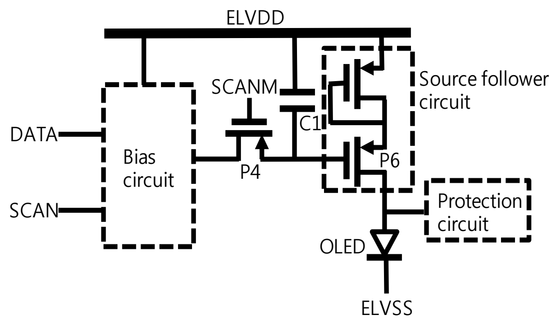


Fig. 1 Schematic diagram of the pixel circuit

The timing diagram of the pixel circuit is shown in Fig. 2. 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 pixel circuit can reduce the power consumption by operating the bias circuit only during the scan time. The SCAN signal and the SCANM signal are not changed at the same time to prevent flicker caused by instant emission current lowering.

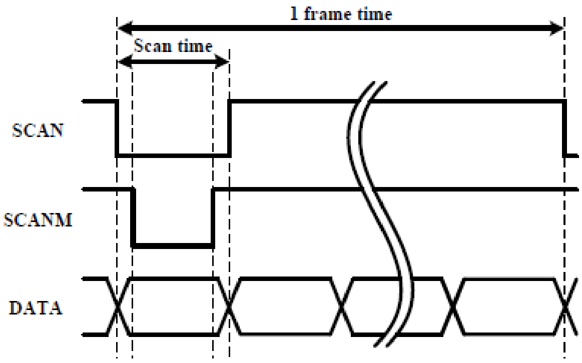
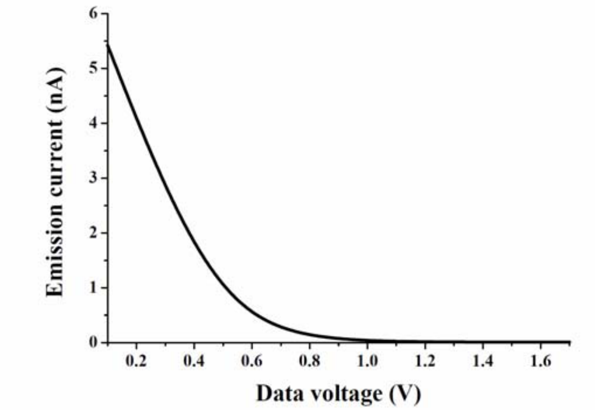
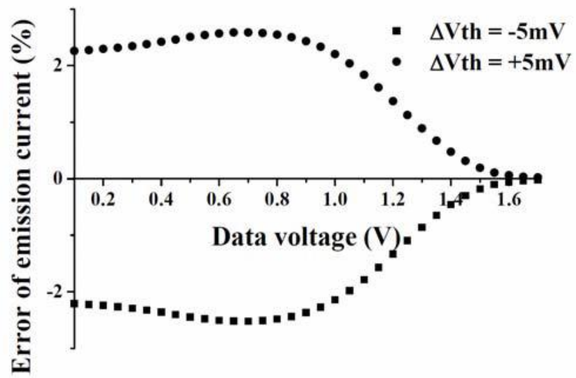


Fig. 2 Timing diagram of the pixel circuit

We measured the characteristics of pixel circuit to verify the pixel circuit operation as designed. Fig. 3 shows the measured results of I-V characteristics. When the data voltage varies from 0.1 to 1.7 V, the emission current varies from 6.37 pA to 5.42 nA. The error range of emission current is from -2.52 to + 2.59% under ±5 mV threshold voltage variation conditions.



(a)



(b)

Fig. 3 Measured result of OLEDoS pixel curcuit
(a) Emission current according to data voltage
(b) Error of emission current under threshold voltage variation condition

2.2 Driving circuit design

We designed OLEDoS driving circuit and panel layout. The block diagram of driving circuit is shown in Fig. 5. Around the active display area with pixel array, the data driver and scan driver is located. 8-bit gray scale of each RGB data was realized on the panel. The panel layout of OLEDoS is shown in Fig. 6. The pixel array has 1064 x 808 pixels including 20 dummy pixels at each side. Horizontal stripe type sub pixel array was adopted to reduce loads of data driver.

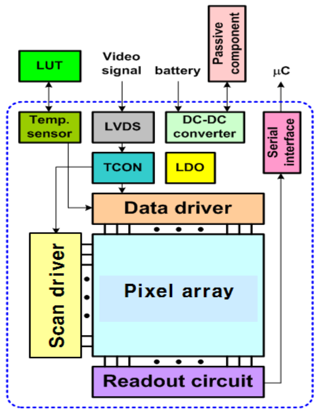


Fig. 5 Block diagram of driving circuit

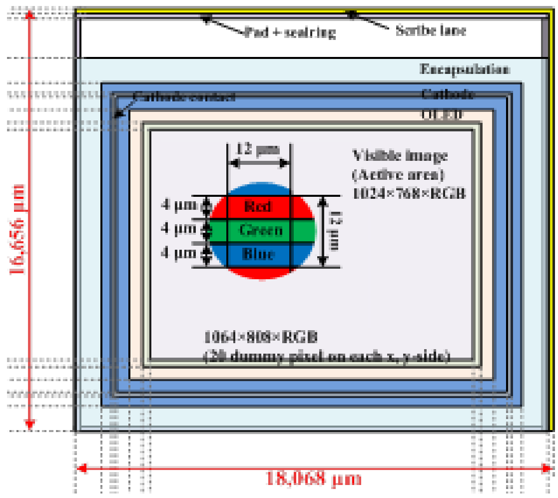


Fig. 6 Panel layout of OLEDoS

3. OLED device

3.1 Top emitting white OLED

A simple stack top emitting white OLED was developed. The materials used in white OLED were all fluorescent materials. A simple stack white OLED has simple device structure and is easy to fabricate though the efficiency is rather lower than that of tandem white OLED.

To enhance current efficiency, a white EML structure, consist of RGB emitting layers, was developed and each layer thickness and emitting layer doping ratio were optimized. The current efficiency of white OLED device is 19.5 cd/A, and conversion white efficiency is 4.2 cd/A. The performance of white OLED is summarized as the below table.

Table. 1 White OLED device performance

CIE		Efficiency (cd/A)	EQE[1] (%)	Conversion white efficiency (cd/A,(0.31,0.33))[2]
0.30	0.39	19.5@4V	7.8	4.2

@1000nit, 1) Lambertian approximation, 2) with color filter

3.2 Encapsulation and color filter array process

Glass encapsulation process with transparent sealant covering surface of OLED device was fabricated. In the previous research, Thin Film Encapsulation and low temperature curing color filter was applied to OLEDoS panel. [6] The color filter array on Thin Film Encapsulation was unstable because curing temperature is lower than conventional color filter process temperature. Therefore we applied color filter array on encapsulation glass for reliable OLEDoS panel. RGB sub pixel color filter array was patterned on encapsulation glass. The color filter array was aligned with white OLED sub pixel to produce color image. The characteristics of color filter are shown in Fig. 7.

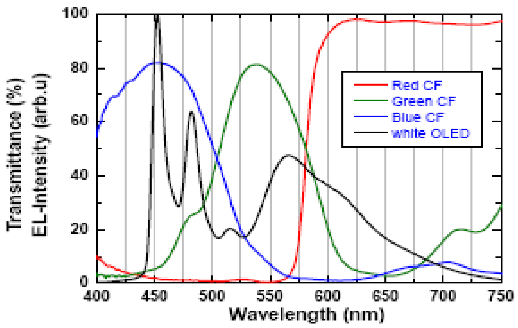


Fig. 7 Spectrum of white OLED and color filter

4. Panel and module fabrication

The Si wafer backplane of OLEDoS was fabricated at a semiconductor foundry using 0.18 µm process according to the circuit design. An 8 inch Si wafer was used for CMOS process and 50 OLEDoS chip were obtained in an 8 inch Si wafer.

OLED device deposition process was performed at 200 x 200 mm thermal evaporation chamber equipment. Color filter array glass wafer corresponding to sub pixels of OLED device was aligned and bonded to OLED device wafer substrate. Then, scribing and packaging process were performed to get OLEDoS panel.

We applied COB bonding process for module packaging. The pads on OLEDoS panel were connected to panel mounting PCB by wire bonding. A 70 channel flexible cable was used to connect OLEDoS panel and driving circuit board.

We verified functions of OLEDoS panel driving circuit and demonstrated OLEDoS panel with XGA resolution moving images. HD grade moving images were displayed on OLEDoS panel with 60 Hz frame rate and 8-bit gray scale. Luminance of 235 cd/m^2 was achieved at the OLEDoS panel, which is bright enough to personal display applications such as eye glasses type display, Head Mounted Display (HMD).

The brief specification of OLEDoS is summarized as the below table.

Table. 2 Specification of OLED Micro Display

Active size	0.6-inch (diagonal)
Resolution	XGA (1024x768)
Pixel pitch	12.0 µm
Sub pixel arrangement	RGB horizontal stripe
Gray scale	8-bit RGB
Panel size	18.0 x 16.5 mm
Luminance	235 cd/m^2

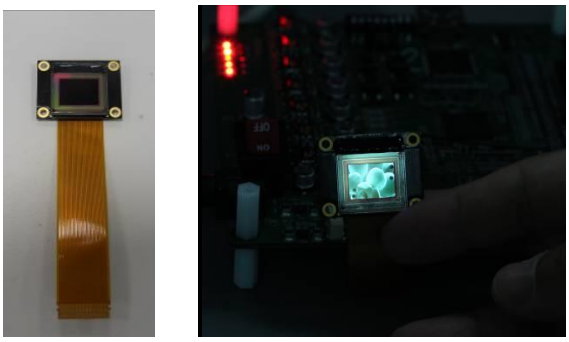


Fig. 8 OLEDoS panel with flexible cable and OLEDoS panel driving with XGA image

5. Conclusion

A 0.6-inch XGA OLEDoS panel which is composed of Si wafer backplane and white OLED with color filter pixel on encapsulation glass was designed and fabricated. We designed OLEDoS pixel circuit using source follower with active load and additional bias circuit. The pixel circuit has good immunity of the electrical characteristic variations of OLED and wide range of data voltage as well. We examined that the XGA OLEDoS panel is very suitable display device for personal display applications such as eye glasses display and HMD for HD grade images.

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