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4032ppi High-Resolution OLED Microdisplay

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Abstract

A 0.5 inch UXGA OLED microdisplay has been developed with 6.3µm pixel pitch. Not only 4032ppi high resolution, but high frame rate, low power consumption, wide viewing angle and high luminance have been achieved. This newly developed OLED microdisplay is suitable for Near-to-Eye display applications, especially electronic viewfinders.

Author Keywords

Microdisplay; OLED; High-Resolution; Near-to-Eye

1. Introduction

Microdisplay based organic light emitting diodes on a silicon backplane (M-OLED display) has expanded the market of Near-to-Eye display application since we launched our first M-OLED display in 2011 [1-2]. M-OLED display is widely used in consumer and professional cameras, camcorders, electronic binoculars, head mounted displays, and AR/VR glasses due to its superior image quality and form-factor [3-9].

On the other hand, a higher resolution has been strongly demanded in these applications [10-13]. To satisfy these requirements, we have developed high-resolution technologies in back plane (Si driving substrate) and front plane (OLED layer). As the result, the pixel pitch of 6.3µm has been achieved.

In this work, we report the newly developed 4032ppi 0.5inch UXGA M-OLED display.

2. Required Specification

M-OLED display offers significant advantage in terms of a high contrast ratio, a high color gamut and a high speed response as displays. In the viewfinder market, which is the main market of M-OLED display, it has also offered unique usability to the display besides this excellent image quality. However, in recent years, higher resolution, higher frame rate, lower power consumption, higher luminance and wider viewing angle demands are increasing because optical viewfinder (OVF) is a target for comparison in order to introduce it to high-end cameras. In addition, higher resolution of displays has been required with the expansion of the AR/VR market because of a use of expanding field of view (FOV) .Therefore we are developing devices mainly focusing on higher resolution.

There is no end to development of high resolution displays. However, we have a certain target resolution of display. That is the level at which human can't see the pixel dots. Figure 1 shows FOV vs Visual Angle per Dot by display resolution. Electric viewfinder (EVF) is generally used at about FOV 30 deg. and the minimum visual angle that human whose acuity is average can identify is about 1 arc minute represented by the reciprocal of visual acuity. Therefore UXGA resolution is our first target resolution of display for EVF.

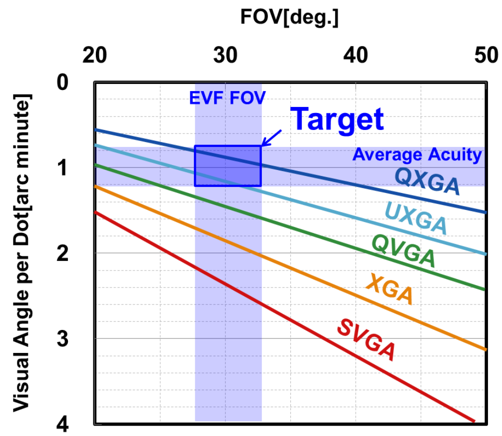

Figure 1. FOV vs Visual Angle per Dot by display resolution

3. High Resolution Technologies

In general, the display characteristics such as luminance variations, narrow viewing angle and pixel defects are caused by narrowing pixel pitch. It also makes it difficult to achieve higher luminance, higher frame rate and lower power consumption.

We have solved these problems and realized superior characteristics to conventional models in all specification.

3-1. Back Plane Technology

We had developed a 4T2C (four transistors and two capacitors) pixel driving circuit architecture to realize a high resolution 7.8µm OLED microdisplay [14]. Circuit design optimization has enabled to narrow pixel pitch from 7.8µm to 6.3µm.

Figure 2 shows schematic diagram of the pixel driving circuit. The pixel driving circuit consists of four p-channel MOSFETs (T1, T2, T3 and TD) and two capacitors (C1, C2).

Narrower pixel pitch causes an increase of the luminance variation for each pixel and pixel defects because reduction of the transistor size leads to both an increase of V_{TH} variation, leakage current and a decrease of breakdown voltage. In order to minimize these effects of phenomenon, we reduced the required input gate voltage from 10V to 5V by optimizing pixel driving circuit designs lowering signal voltage amplitude and V_{TH} of switching transistors (T1, T2). Moreover, we elucidated required minimum characteristics for each transistor to optimize their size. Both T1 and T2 require lower V_{TH} than conventional models to operate with lowered 5V gate input voltage. TD and T3 require a higher breakdown voltage than T1 and T2 because of connection to OLED to which a high voltage is applied for luminescence operation. TD which generate of the emission

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current flowing through OLED also requires less V_{TH} variation for good luminance uniformity.

In accordance with these required transistor characteristics, we designed special transistors exclusively for pixel circuits. It is difficult to achieve both reduction of the transistors size and required its characteristics by common process for peripheral circuit. Thus, we made four transistors constituting the pixel circuit separately by using unique structure, size and process. Each of these transistors has its own channel size and ion implantation process, thereby realizing each required characteristic.

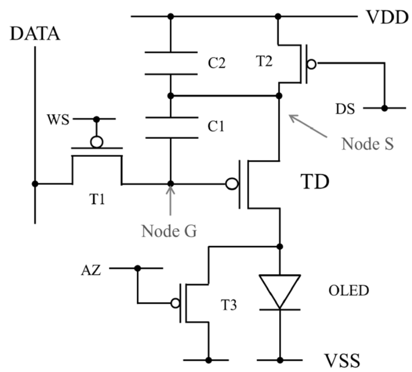


Figure 2. Schematic diagram of the pixel driving circuit

3-2. Front Plane Technology

The narrower pixel pitch causes the narrower viewing angle of chromaticity because the color filter of the adjacent pixel gets close to anode aperture. These become more monumental issues at using the color filter lamination process because it is necessary to design the aperture ratio in consideration of the alignment variation. Thus a novel pixel aperture array and On-Chip-Color-Filter (OCCF) structure are proposed.

Figure 3 shows Color filter array top and section view of pixels. If the pixel size is changed from 7.8µm to 6.3µm with the conventional structure, the viewing angle of chromaticity deteriorates. The OCCF structure provides an improvement in the viewing angle of chromaticity because the gap of OLED emission position and the color filter become closer. The pixels with OCCF improved its horizontal direction viewing angle of chromaticity to almost same level of conventional pixels, however, the result of vertical direction viewing angle of chromaticity was hardly changed.

To control the coloring of the viewing angle, it is key issue to align the viewing angle characteristics for each color RGB. In conventional pixel design of 7.8µm, we have aligned tristimulus values which have the wavelength dependency of viewing angle by the shading design of color size balance and Black pillar on Blue. However, this design is not appropriate to OCCF process. Figure 4 shows Vertical viewing angle vs Normalized tristimulus value of conventional pixel array with OCCF. It was found that Z tristimulus viewing angle was not aligned with X, Y tristimulus. This means that OCCF black don't have enough characteristics to shield Blue light. Coloring of viewing angle can't be controlled without Black which has equivalent shading performance to conventional Color Filter Black.

Therefore, we propose a new pixel array of which all color edges are adjacent to another color and shield from each other. Figure 5 shows Vertical viewing angle vs Normalized tristimulus value of newly designed pixel aperture array with OCCF. This result suggests that new pixel array enable to align tristimulus viewing angle with OCCF.

Figure 6 shows Vertical viewing angle vs Chromaticity Δu'v' by new pixel structures. By reducing the cell gap with OCCF and aligning the viewing angle by each color size adjustment, we realized a 6.3µm pixel which has wider viewing angle than 7.8 um pitch pixels.

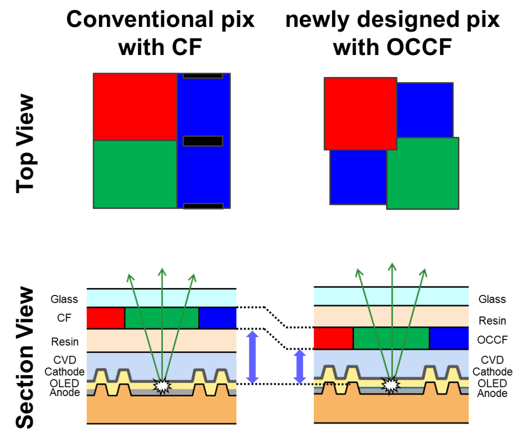


Figure 3. Top and section view of pixels

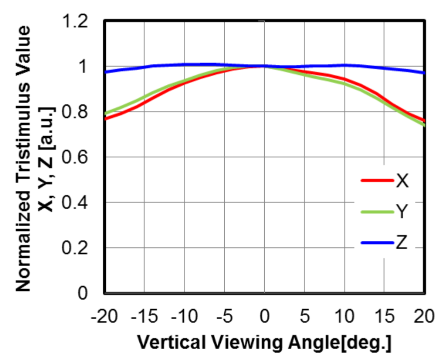


Figure 4. Vertical viewing angle vs Normalized tristimulus value of conventional pixel array with OCCF

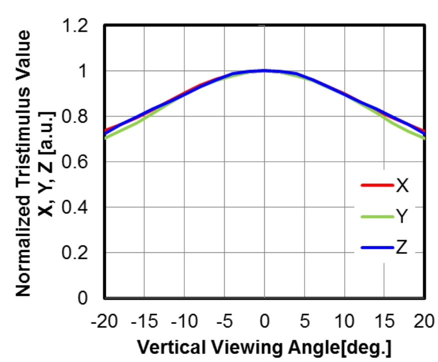


Figure 5. Vertical viewing angle vs Normalized tristimulus value of newly designed pixel array with OCCF

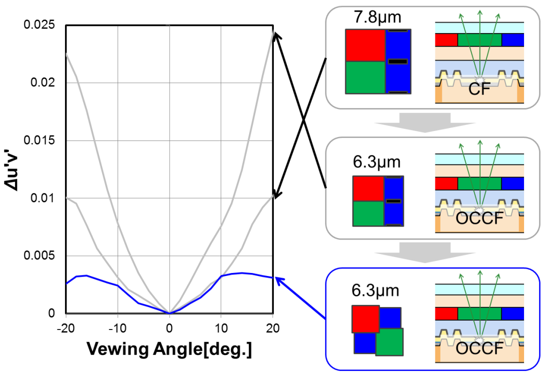


Figure 6. Vertical viewing angle vs Chromaticity Δu'v' by pixel structures

4. Circuit and System Design

In general, there is a trade-off relationship between high resolution and both high frame rate and low power consumption. However, we achieved improvements in all these specifications required for Near-to-Eye display particularly by circuit and system design approaches.

Figure 7 shows the block diagram of driving circuits and system configuration. In this work we redesigned these driving circuits.

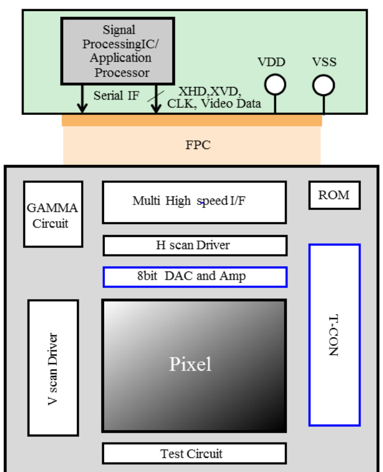


Figure 7. Block diagram of driving circuit and system configuration

4-1. Low Power Consumption

It is effective to lower the driving voltage of the circuit in order to lower the power consumption. In our conventional models, both peripheral analog and pixel driving circuit work by 10V power supply. In this work, we designed peripheral analog circuit working by 5V and pixel driving circuit working by 5V/-5V respectively to reduce power consumption. By using 5V power supply as the basis of the driving voltage of the peripheral analog circuit and using 5V/-5V power supply only for the limited circuit, our display achieves low power consumption, high speed driving and suppression of chip size expansion. Figure 8 shows Power consumption of our conventional 0.5 inch QVGA and newly designed 0.5 inch UXGA. Owing to this design, the new display can be driven with almost the same power consumption despite the fact that the number of pixels increased by 1.5 times.

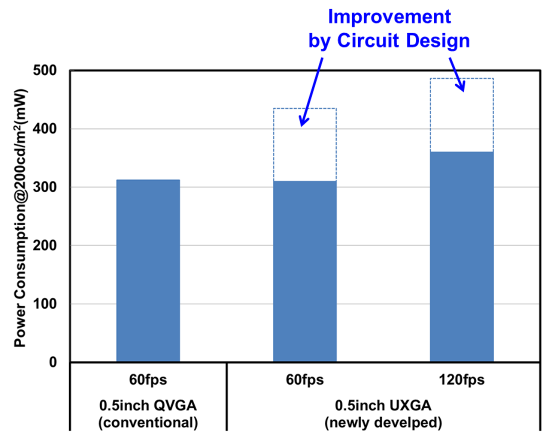


Figure 8. Power consumption of 0.5inch M-OLED display

4-2. High Frame Rate

Our display supports 120fps and also unique high speed driving by T-CON function. It has the function of realizing twice frame rate 240fps by simultaneous scan of 2 vertical lines and shifting bundled lines every frame in its driving. This function is shown in Figure 9.

The conventional dual line progressive realize twice frame rate without lowering the luminance. However, it causes degradation of the resolution since the vertical resolution is halved. On the other hand, the novel dual line progressive supported by our display is possible to suppress degradation of resolution feeling, since it interpolates the resolution of the vertical direction in time division by displaying the image of which vertical scan line shifts between frames. This result is shown in Figure 10. It can be seen that the twice high frame rate is realized in a state with less degradation of resolution feeling and luminance maintained. In addition, this 240fps scanning technique can drive with almost the same power consumption as 120fps because it requires only a change in vertical scan driver operation and there is no increase in the amount of data transfer.

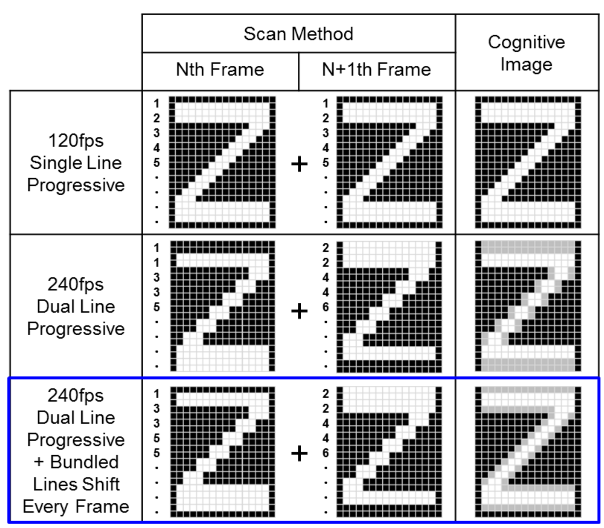
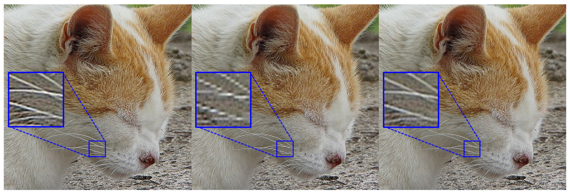


Figure 9. Supported high frame rate drive



(a)120fps Single Line Progressive (b)240fps Dual Line Progressive (c)240fps Dual Line Progressive + Bundled Line Shift

Figure 10. Display image for each driving method

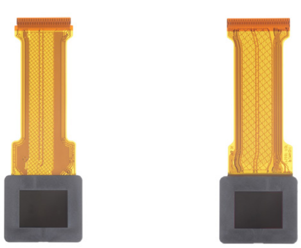
5. Newly developed M-OLED Displays

We have developed the new 0.5inch UXGA M-OLED display. Table 1 shows the specification of the conventional 0.5inch QVGA and the new 0.5inch UXGA M-OLED display using newly developed technologies as above. Figure 11 shows the photograph of 0.5inch M-OLED displays comparison. In spite of improved specifications, it can seem that the two displays have almost same form-factor.

As a result, the new 0.5 inch UXGA display realizes all the specifications that exceed the conventional 0.5 inch QVGA display, including the characteristics (maximum frame rate, power consumption and viewing angle) which are trade-off relationship with high resolution. It is suitable for Near-to-Eye display applications, especially high-end viewfinders.

Table 1. 0.5inch M-OLED display specifications

Specifications	Conventional	Newly developed
Screen diagonal	0.5 inch	
Resolution (Number of Dots)	QVGA (1280H x RGB x 960V)	UXGA (1600H x RGB x 1200V)
Pixel Pitch	7.8µm	6.3µm
Maximum Luminance	1,000cd/m^2	2,000cd/m^2
Contrast Ratio	100,000:1 or more	
Color Gamut(u'v')	sRGB : 110%	
Signal I/F	LVDS sub-LVDS mini-LVDS	LVDS sub-LVDS
Driver	Integrated	
Power Supply	1.8V(logic) 10V(analog)	1.8V(logic) 5V(analog) -5V(OLED)
Maximum Frame Rate	90fps progressive	120fps progressive/ 240fps progressive (dual line)
Power Consumption 60fps 200cd/m^2	310mW	
Response	0.01msec or less	



(a)Conventional QVGA (b)Newly developed UXGA

Figure 11. Photograph of 0.5inch M-OLED comparison

6. Conclusion

We have successfully developed the 0.5inch UXGA M-OLED display with high resolution 6.3µm pixel pitch. The Sony's M-OLED displays have excellent characteristics of high visibility, small size, lightweight, and high reliability. The newly developed M-OLED displays also achieved 120fps higher frame rate, lower power consumption, 2000cd/m^2 higher luminance and wider viewing angle. We are going to start mass production of the new display in 2018.

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