P-172: A Same 0.38" Liquid-Crystal-on-Silicon Backplane for Color-Sequential and Color-Filter Projector Applications

Chiu-Ho Wong and Ho-Chi Huang
Department of Electronic and Computer Engineering, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong

Yung-Yuan Ho
Himax Display, 2F, No. 26, Zih Lian Road, Sinshih Township, Tainan County 744-45, Taiwan

Abstract

We present a 0.38" liquid-crystal-on-silicon (LCOS) backplane for color-sequential and color-filter microdisplays. This LCOS has a monochrome VGA resolution for color-sequential operation, and could become a QVGA display when RGBW color filters are coated. With a space dithering algorithm, we also demonstrated a virtual VGA resolution on the color-filter mode.

1. Introduction

As the mobile devices become smaller in size and the display contents are increased due to a larger data bandwidth, the conventional direct-view liquid crystal displays (LCDs) cannot meet this small-size and high-resolution request. Therefore, there is an increasing demand for pico projectors, which are small in size, but can project a large image of higher resolution. Today, there are quite a few of pico projector technologies available that can deliver large projection with a small size [1-5]. Among them, we believe the liquid-crystal-on-silicon (LCOS) microdisplays and the associated projectors are the best candidates because they could leverage on the best display technology in LCD, the best semiconductor technology in silicon, and the best light source technology in light-emitting diode (LED). We also see the application of the LCOS projectors in various mobile devices has been increased significantly in recent months because of its potential advantages [6].

There are two kinds of single-panel LCOS projectors; that is, single-LED color-filter LCOS (CF-LCOS) projector and multiple-LED color-sequential LCOS (CS-LCOS) projector as illustrated in Figure 1. It can be seen from the figure that both types of the projectors share the same polarizing beam splitter (PBS) and projection lenses if the LCOS microdisplays are of the same size. The difference would be on the LED illumination in which the CF-LCOS projector uses a white LED, while the CS-LCOS projector requires red (R), green (G) and blue (B) LEDs. Figure 1 shows an X-cube RGB LED illumination unit for examples, but it could be any other RGB LED illumination approach.

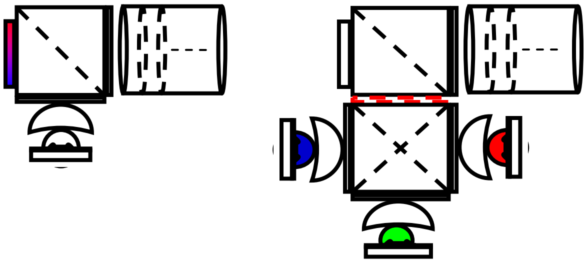


Figure 1 Schematics of single-LED CF-LCOS and multiple-LED CS-LCOS projectors.

In this paper, we further explore the possibility of using a same LCOS backplane for both the single-panel color-filter and color-sequential projectors. By this arrangement, both the single-panel LCOS projectors could share the same components in projection lenses, PBS and the LCOS backplane. The preparation of the projector components could be leveraged with each other and the time to market for the development of the projector could be shorten.

2. The LCOS Microdisplay and Projector

2.1. The 0.38" LCOS microdisplay

In our earlier work, we have developed a 0.59" CS-LCOS microdisplay of 15μm pixel and of SVGA resolution or 800x600 pixels [7]. A frame buffer was integrated onto the silicon backplane to accelerate the data upload time, and a thin mixed twisted nematic (MTN) LC mode was used for fast LC response [8]. This 0.59" LCOS microdisplay was a true color-sequential display and showed excellent optical performance [9], but its associated projector was too large to be regarded as a pico projector.

In this work, we kept the same design architecture, but used a more advanced silicon semiconductor process to squeeze the pixel pitch from 15 to 12μm, and led to a 0.38" color-sequential VGA display of 640x480 pixels. In addition to the color-sequential mode, we also tried to apply R, G, B and white (W) color filters onto the silicon backplane and turned it into a color-filter QVGA display of 320x240xRGBW sub-pixels. The RGBW color filters are arranged in mosaic pattern as shown in Figure 2, as captured from an optical microscope.

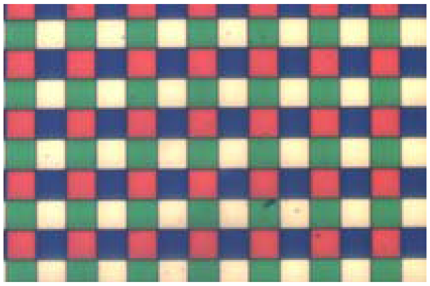


Figure 2 The microscope picture of the mosaic RGBW sub-pixels from the CF-LCOS microdisplay

2.2. The Projector Designs

With these two LCOS microdisplays of the same size, but in different LC configurations, we proceeded to design a color-sequential VGA projector and a color-filter QVGA projector as

ISSN/009-0966X/09/3903-1766-$1.00 © 2009 SID

illustrated in Figure 3. In these two projector designs, the same PBS and projection lenses were used, together with a same LCOS backplane. The CF-LCOS projector module measured a smaller size of 8 cm^3 because of a simpler white LED illumination, while the color-sequential projector module measured a larger size of 15 cm^3 because of a more complicated R, G and B LED illumination. The 15 cm^3 CS-LCOS projector module could provide a better resolution and color saturation. While the 8 cm^3 CF-LCOS projector module was more compact and had a higher assembly yield because of simpler projector architecture.

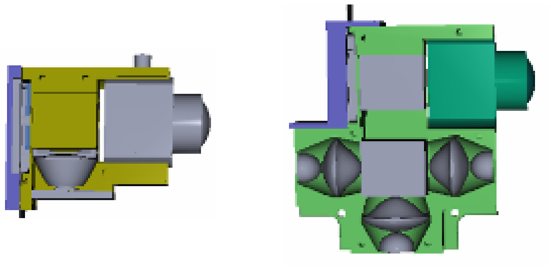


Figure 3 Schematics of a 0.38" color-filter QVGA and color-sequential VGA projectors

2.3. The Projector Performances

Figure 4 showed the optical response times and NTSC color of the 0.38" CS-LCOS projector characterized in a wide range of ambient temperature. The color-sequential projector was driven at RGB sequence of 360Hz. The color gamut was poor at low temperature because of a high viscosity of the liquid crystal mixture and slow optical response at a low temperature. The color gamut could be improved to 100% NTSC when the ambient temperature exceeded 35ºC as illustrated in Figure 4. At this temperature, the LC response time was small and in the range of 1ms.

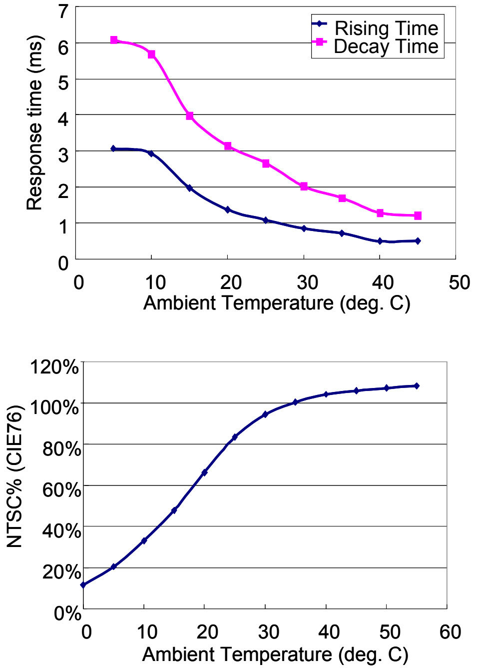


Figure 4 Optical response and NTSC color of the 0.38" CS-LCOS projector

In comparison, the CF-LCOS projector could only achieve typically 40% NTSC color in the same range of ambient temperature. The CF-LCOS projector was driven at a frame rate of 120Hz to eliminate the flickering. The poor color was mainly due to the fringing effect and the low color temperature of a white LED [10]. However, it was noted that the CF-LCOS projector also exhibited the same color saturation even the ambient temperature was reduced to 0ºC or lower. It was because the CF-LCOS projector runs at a lower frame rate, so the LC could still respond in time for a good color performance. But apparently, the CF-LCOS projector was inferior to the CS-LCOS projector of the same LCOS backplane, in terms of color and resolution, in a dimmed light environment.

In the room light environment, the color difference between the CF-LCOS and CS-LCOS projectors were not significant. Both the color representations of both the projectors were diluted by the ambient light to some extent, so both the projectors exhibited comparable color.

Figure 5 shows a color representation of the CS-LCOS projector in dimmed light environment for a good 100% NTSC color. Also shown in the figure was the same image at a room light, and the color representation was dropped down to less than 30% NTSC, which is comparable to that by the CF-LCOS projector. The real advantage was on the resolution that the CS-LCOS microdisplay could have four times of resolution than that of the CF-LCOS microdisplay of the same LCOS backplane.

(a) **(b)**

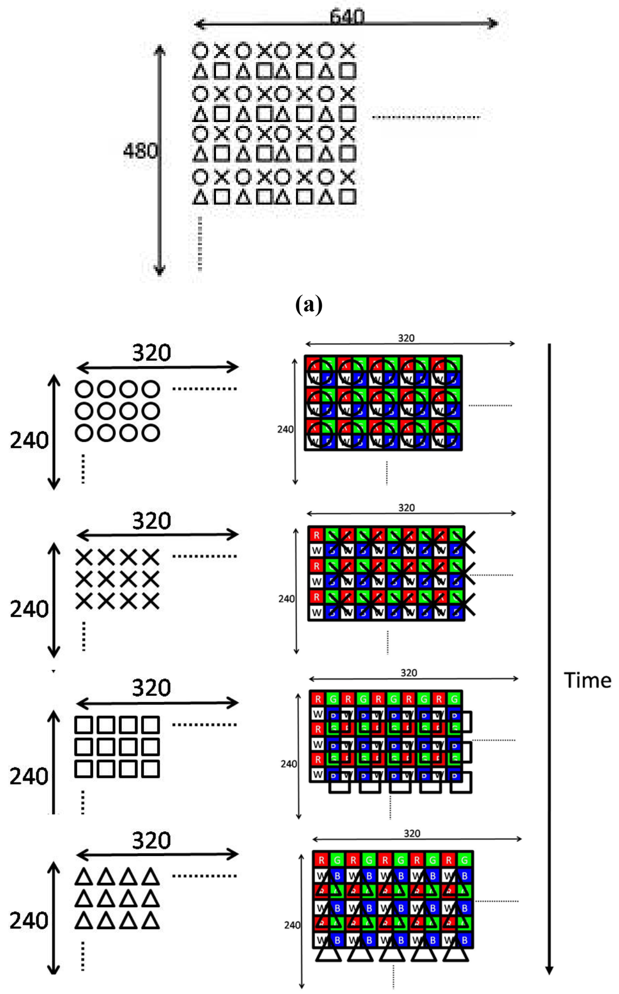
Figure 5 The projection picture from a 0.38" CS-LCOS projector at (a) dimmed light and (b) room light environments

3. Resolution Improvements

3.1. The Space Dithering Algorithm

We might not have a quick cure for the CF-LCOS projector to improve its color at a dimmed light environment, but we were able to improve its resolution by a space dithering algorithm [11]. The CF-LCOS projector has to be refreshed at 120Hz for a flicker-free projection. For a color-filter QVGA display, the common video input of VGA resolution and 30Hz frame rate can be down-scaled to QVGA resolution and written in four times to the color-filter QVGA display for a flicker-free 120Hz projection in true QVGA resolution.

In addition to this conventional QVGA projection, we could actually add white pixels to the original VGA frame of the video input of 30Hz frame rate. The new VGA frame would be of 640x480xRGBW sub-pixels as shown in Figure 6 (a). This VGA frame of RGBW sub-pixels can then be partitioned into four QVGA sub-frames of 320x240xRGBW sub-pixels as illustrated in Figure 6 (b), and then written into the color-filter QVGA display in different locations in sequence.



(a)

(b)

Figure 6 The illustration of the space dithering algorithm : (a) the original VGA frmae of RGBW pixels, and (b) 4 QVGA sub-frames to be written in sequence

Figure 6 illustrates the space dithering algorithm, in which the original VGA frame in Figure 6 (a) was partitioned in to four QVGA sub-frames as shown in Figure 6 (b), and then written to the color-filter QVGA display in different locations in sequence for a 120Hz flicker-free projection. It was noted that each QVGA sub-frame was not written into the same location of the color-filter QVGA display, but was shifted by one sub-pixel or half pixel in horizontal and/or vertical directions as illustrated in Figure 6 (b). As a result, the output resolution was restored virtually back to the original VGA resolution. In short, the color-filter QVGA display could show a virtual VGA resolution by the space dithering algorithm.

3.2. Characterizations

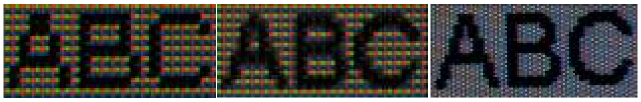
We characterized the resolution improvements of the CF-LCOS projector by text and graph, respectively. Figure 7 shows the close-up microscopic pictures of the 0.38" CF-LCOS projector in a true QVGA mode and in a virtual VGA mode. Also shown in the figure is a same graphic picture from a 0.44" CF-LCOS projector of a true VGA resolution for comparison.

(a) (b) (c)

Figure 7 The graphic representations of (a) a true QVGA, (b) a virtual VGA and (3) a true VGA CF-LCOS projectors

These pictures were taken under an optical microscope to reveal the graph details. The illumination was made by the halogen lamp of the microscope, so only the CF-LCOS microdisplays could be compared. It was seen clearly from the figure that the 0.38" CF-LCOS display in the virtual VGA mode did represent the original graph better than that on the same 0.38" panel in the QVGA mode. The virtual VGA picture was actually quite comparable with the true VGA picture for the graphs.

Figure 8 shows another comparison of these three CF-LCOS projector configurations in a more detailed pixel level. It was observed that the true QVGA and VGA images were sharper on the edges, while the virtual VGA showed rounded images. It could also be seen from the figure that the 0.38" panel employed mosaic RGBW color filters as shown in Figure 8 (a) and (b), while the 0.44" panel employed the triad RGB ones as shown in Figure 8 (c).



(a) (b) (c)

Figure 8 The text representations of (a) a true QVGA, (b) a virtual VGA and (3) a true VGA CF-LCOS projectors

It should be noted that the space dithering algorithm was a simple algorithm that could be easily implemented onto the silicon backplane without extra cost. It should be also noted that the RGBW sub-pixels could provide much better reflectivity for the LCOS microdisplay than the conventional RGB triad sub-pixels. Both the resolution and the reflectivity are important figures of merits for the LCOS microdisplay, and the associated pico projector. We believe a small CF-LCOS projector with RGBW pixels for better optical efficiency and the space dithering algorithm for better virtual resolution, and an inherited simple projector architecture for low cost, could find applications in entry-level mobile projectors.

4. Projection Characterizations

4.1 The Electronic System

The space dithering algorithm was implemented by a field programming gate array (FPGA), where a Spartan-III Xilinx XC3S200 was used. Figure 9 shows the block diagram of this space dithering system board. The 640x480 analog VGA signal was firstly digitized by an analog-to-digital converter (ADC) to a digital form. Then, the digital R, G and B date were sent to the FPGA, in which W and the new values of R, G and B were calculated by the conversion algorithm [11]. Thereafter, the FPGA partitioned and stored these four QVGA sub-frames in the

SDRAM frame buffer, and wrote to the color-filter QVGA projector in the corresponding locations in sequence. The gate count of this implementation was 536k, and there was no problem in implementing this algorithm to the LCOS backplane.

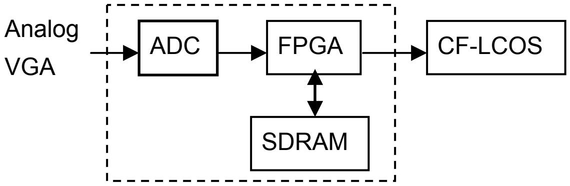


Figure 9 The block diagram of the space dithering system board

4.2 The Optical Observation

With this space dithering system board and the 8 cm^3 CF-LCOS projector engine, a small CF-LCOS projector was made. Figure 10 (a) shows a virtual VGA projection by this system with a 0.38" color-filter QVGA microdisplay. Figure 10 (b) also shows a similar projection in true VGA resolution using a 0.44" color-filter VGA microdisplay. Figure 10 (b) has a poor uniformity since the projection system was designed for the 0.38" LCOS panel. The 0.44" CF-LCOS panel was too big for this projection system. Nevertheless, we did observe a comparable resolution on these two pictures, whereas one showed virtual VGA resolution, and the other showed true VGA resolution.

(a) (b)

Figure 10 The projection pictures of (a) the virtual VGA and (b) the true VGA CF-LCOS projector

5. Conclusion

In summary, we have applied a same silicon backplane to assemble two different kinds of LCOS microdisplays, and then two different kinds of LCOS projectors. One was a 0.38" color-sequential VGA microdisplay and a 15cc CS-LCOS VGA projector. The other was a 0.38" color-filter QVGA microdisplay and an 8cc CF-LCOS QVGA projector. The CS-LCOS projector showed better color and a higher resolution, while the CF-LCOS projector had a more compact size and a higher assembly yield. In an attempt to improve the resolution of the color-filter QVGA projector, we employed a space dithering algorithm to achieve virtual VGA resolution on the color-filter QVGA display. Both the color-filter and color-sequential LCOS projectors were compact, and could find applications in the emerging mobile projector market.

6. Acknowledgements

This work is supported partly by the Research Grant Council of the Government of the Hong Kong Special Administrative Region.

7. References

[1] Refer to www.dlp.com for DLP projectors

[2] Refer to www.microvision.com for Microvision laser projectors

[3] Refer to www.3mmpro.com for 3M MPro LCOS projectors

[4] Refer to www.iljindisplay.com for Iljin LCD projectors

[5] Refer to www.displaytech.com for Displaytech FLCOS projectors

[6] Private communications with Himax Display; www.himaxdisplay.com

[7] H C Huang, "Single-panel spatial-color and sequential-color LCOS projectors using LED lamps", SID'07, p.903 (2007).

[8] S T Wu, "Mixed-Mode Twisted Nematic Liquid Crystal Cells for Reflective Displays", Applied Physics Letters, Vol. 68, p.1455, (1996).

[9] K H Fan Chiang, "LCOS Panel Using Novel Color-Sequential Technology", SID'07, p.150 (2007)

[10] B L Zhang, "Three-dimensional optical modeling and optimizations of color filter liquid-crystal-on-silicon microdisplays", J. Appl. Phys. vol. 98, 123103 (2005)

[11] H C Huang, "Color-filter LCOS microdisplay with space dithering for virtual resolution improvement", IDW'08, p.199 (2008)