High Resolution Phase-only 4K2K LCoS Spatial Light Modulator for Holographic Display Technology

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Keywords: Liquid Crystal on Silicon (LCoS), Spatial Light Modulator (SLM), Holographic Display, 4K2K

ABSTRACT

High resolution, full phase modulation, small pixel pitch, high aperture ratio, and fast response time are the requirements to enhance the quality of holographic display by using the LCoS-SLM. In this paper, we develop a 3D floating holographic display and to increase the angle of view as 36.67 degree with high resolution phase-only 4K2K LCoS-SLM.

1 INTRODUCTION

A reflective type Liquid Crystal on Silicon – Spatial Light Modulator (LCoS-SLM) has the properties of small pixels, higher aperture ratio, and thinner cell gap, these properties can made LCoS-SLM have higher diffraction angle, light efficiency, and faster response time [1]. LCoS-SLM is a useful and powerful optical instrument to modulate the optical wavefront and has been widely used on various application [2] and various integration of display and holography research, for example, holographic display, holographic near eye displays [3], focal surface displays [4], high dynamic rang (HDR) displays [5], and automotive head-up display (HUD) [6-7], etc. Moreover, augmented reality (AR) and virtual reality (VR) are emerging technologies that have been popular in recent years. Researchers invest a lot of research on enhancing the quality or AR and VR. The stringent requirements are high resolution, wide field of view, and high frame rate. In addition, more and more researchers would like to improve the image clarity and depth of focus on the image, they use the spatial light modulator technology into AR and VR application. The function of phase-only LCoS-SLMs are like dynamic diffractive optical element (DOE) and expect to be used for adaptive focus depth and holographic 3D display. The requirements of idea LCoS-SLM include full phase modulation, high resolution, small pixel pitch, high aperture ratio, and fast response time. Because these above requirements are useful for the depth-focus display, high pixel density, high diffraction angle, large field of view (FoV), and image blur reduction, respectively. Regarding the high-resolution pixels of LCoS-SLM product, Jasper Display Corp. (JDC) introduced two types of 4K2K LCoS panels to the market. (1) active area diagonal 0.7", resolution 4096 × 2400, pixel pitch 3.74 μm, and fill factor > 90 %. (2) active area diagonal 1.2", resolution 4096 × 2400, pixel pitch 6.4 μm, and fill factor > 93 %. Table 1 shows the comparison of 0.7 inch and 1.2 inch 4K2K LCoS-SLM. Fig. 1 shows the scheme of high resolution phase-only 4K2K LCoS-SLM panel.

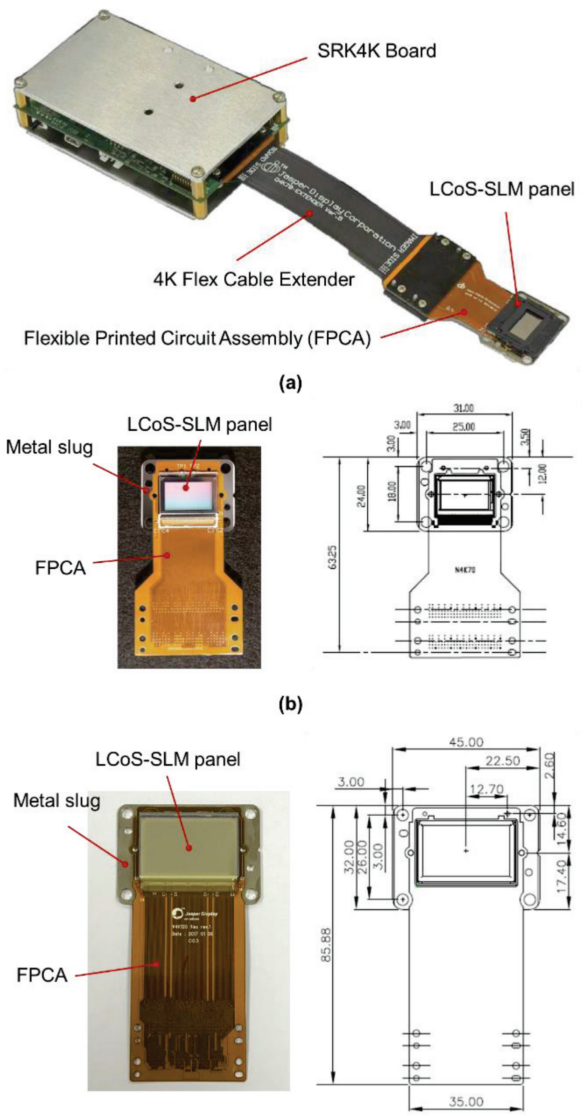

Fig. 1 Scheme of high resolution phase-only 4K2K LCoS-SLM, (a) SLM controller and microdisplay, (b) 0.7 inch, 3.74 μm LCoS-SLM panel, and (c) 1.2 inch, 6.4 μm LCoS-SLM panel.

Table 1 Comparison of 0.7 inch and 1.2 inch 4K2K LCoS-SLM panel

	Q4K70	V4K120
Wafer Name	JD2704	JD2124
Resolution	4096 x 2400	4096 x 2400
Active Area Diagonal	0.7 inch	1.2 inch
Die Size (mm^2)	19.15 x 13.57	30.63 x 19.97
Active Area (mm^2)	14.36 x 8.08	26.60 x 15.77
Pixel Pitch	3.74 μm	6.4 μm
Pixel-to-Pixel Gap	0.2 μm	0.2 μm
Fill Factor (Aperture Ratio)	≥ 90 %	≥ 93 %
Reflectivity (Aluminum only)	94 %	90 %

2 DIGITAL MODULATION

There are mainly two types of driving method for LCoS-SLM, such as analog driving and digital driving. The analog modulation typically has lower power consumption due to lower clock frequency, and no significant digital flicker noise. The digital driving has several advantages due to only ON and OFF state. For instance, digital modulation has better repeatability, gray scale accuracy, and smaller pixel size. The small pixel size makes a higher diffraction angle and more suitable to be used on phase modulation. However, the drawbacks of digital modulation include dynamic false contouring and phase stability problem. The stability problem could be improved by high frequency digital pulse. In this section, we will introduce the pulse width modulation (PWM) and terminated write pointer (TWP) for digital modulation.

The PWM divides a frame into several binary weighted sub-frame, and those sub-frames are the bit planes that represent the length of time. Fig. 2 shows the relationship between PWM and Least Significant Bit (LSB). Four sub-frames are composed as one frame and it can be arranged for 4 bit amplitude/ phase levels. This shortest sub-frame is called LSB and it depends on the speed of progressive scan. The horizontal axis in this figure is time and vertical axis is row on LCoS panel. At the begging, we start at certain time in bit plane 0, all the signals are blue in the entire panel. When the time pass the bit plane 1 comes, the signal become red from 1st row so your will see the panel partial red at the transition state. And then it will scan to the latest row, let the signal becomes all red. Before scanning to the latest row, we cannot update bit plane 2 to the first row. Therefore, we need to wait the addressing time, and it's also the shortest time we can defined for bit plane, such as bit plane 3.

TWP has the same concept of partial unit, but with more flexibility. In addition, TWP is a powerful tool for digital modulation and it can alter a bit plane's state before next bit plane. TWP can be applied to any bit plane in the digital driving system, it especially works when it applied to the LSB as shown in Fig. 3. It gives the targeted bit plane an additional state. This state is previously defined, and it can be set to "ON" or "OFF", but it cannot be changed after you defined it. So, the bit plane with terminated write pointer can have four possibilities but only two in one defined modulation.

At the top is LSB without TWP, it only has two state "ON" and "OFF". When we use TWP to give LSB an additional state "OFF". Then it will be off at the end of LSB. At the beginning of LSB, it still follows the signal input and have two state, partial on and full off. If we use TWP to give an additional ON state, the result will be FULL on and partial off. In addition, we can predefine the additional state. Hence, besides 0.5 unit, we can also make 0.25 and 0.125 unit in our digital modulation. This is an important feature for digital modulation, because it makes those LSB be unique in digital modulation. So, we can use a lot of shortest element to create high frequency modulation.

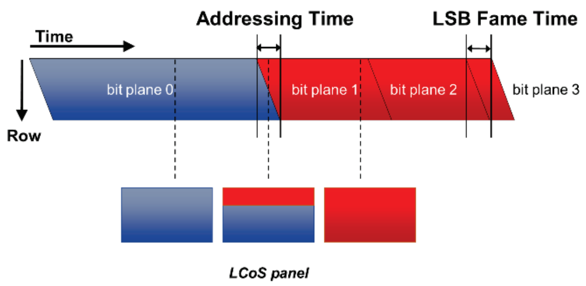

Fig. 2 Relationship between PWM and LSB.

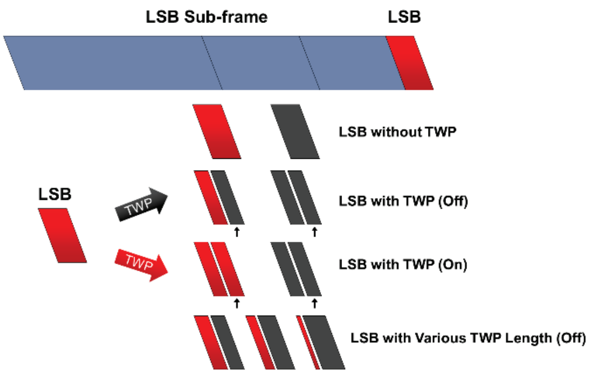

Fig. 3 Four state of LSB with TWP.

3 3D HOLOGRAPHIC DISPLAY

Holographic near eye displays include holographic projector and various see-through combiner optics. The holographic projector could be LCoS-SLM and could be projected image at variable focal length. Through the functionality of LCoS-SLM, the researcher can extend these capabilities by incorporating true per-pixel focal depth, complex full-color shaded imagery, faster real-time calculation, more powerful aberration correction, vision correction, significantly wider fields of view, and more compact form factors.

In this paper, we develop a 3D floating holographic display and to increase the field of view by using three pcs phase-only 4K2K LCoS-SLM. The experiment setup and optical system for 3D floating holographic display as shown in Fig. 4. Fig. 5 shows the schematic diagram of increasing the field of view by using three 4K2K LCoS-SLM. In this experiment, we need to make sure that the coherent light source runs parallel to the surface of the table by calibrating its light path firstly. Then, install other optical components, such as green light-emitting diode (LED), polarizer, lens, beam splitter, LCoS-SLM, image lens, and mirror. The CGH pattern is transmitted into LCoS-SLM panel, and then the diffraction pattern would be changed immediately. Based on this method, the 3D floating holographic display with large field of view could be achieved.

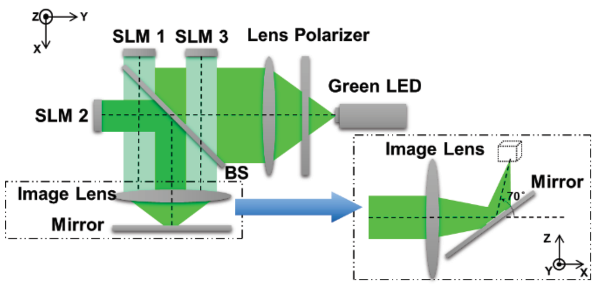

Fig. 4 Experiment setup and optical system for 3D floating holographic display.

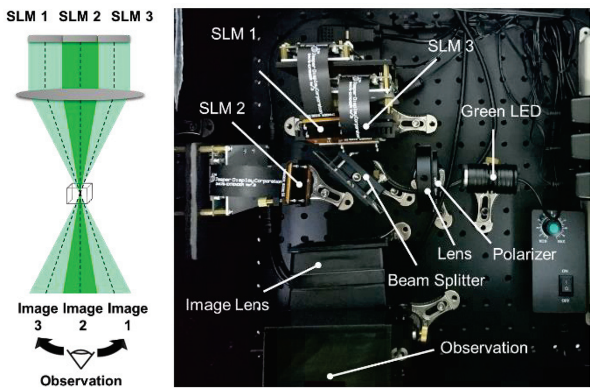

Fig. 5 Schematic diagram of increasing the field of view by using the three 4K2K LCoS-SLM.

Fig. 6 shows the limitation of LCoS-SLM in 3D floating holographic display. Three high resolution phase-only LCoS-SLM are placed at the left side as a hologram plane. The function of convex lens is for image process as Fourier transform and project the image at the focal plane. In geometric point of view, the illumination light is steered by LCoS-SLM with limited angle. Hence, the steered light rays can be converged to the triangle region at the right side and it's also the region where LCoS-SLM can produce the 3D image.

The width of diffraction image is at Fourier plane of the LCoS-SLM and the diffraction image is inversely proportional to the pixel size. That means small pixel size can enables a large diffraction angle or a large diffraction image. In addition, the angle of view of 3D object is proportional to the panel size. That means the large panel size can enables large angle of view. Therefore, a good pure holographic display needs small pixel pitch and large panel size. It also needs massive pixels to present 3D information. We choose the small pixel pitch 3.74 μm of LCoS-SLM to increase diffraction angle. Besides, we combine three 4K2K phase-only LCoS-SLM in parallel to increase the angle of view of 3D cube image. The total size of LCoS-SLM panels could be extended to 12K x 2K. The diffraction angle, angle of view, and cube size can be approximated by these equations

$$\theta_1 = \sin^{-1}\left(\frac{\lambda}{2 \times pixel\ pitch}\right) \tag{1}$$

$$cube\ size = \frac{1}{2} \times 2f \times \tan(\theta_1) \tag{2}$$

$$\theta_2 = 2 \times \tan^{-1}\left(\frac{SLM\ total\ size/2}{f}\right) \tag{3}$$

where θ_1 is the diffraction angle, θ_2 is the angle of view, λ is the LED wavelength, and f is the focal length of lens. In this experiment, the parameters are chosen as $\lambda = 532$ *nm*, f = 6.5 cm, pixel pitch = 3.74 μm, the width of single SLM (4K2K) = 14.36 mm, and the SLM total size (12K2K) = 43.08 mm. Then we can get diffraction angle (θ_1) = 4.08 degree, angle of view (θ_2) = 36.67 degree, and the cube size = 0.46 cm.

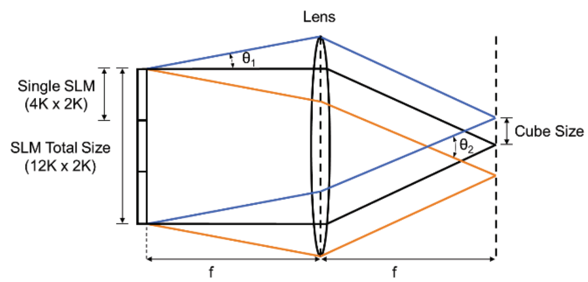

Fig. 6 Limitation of LCoS-SLM in 3D floating holographic display.

However, if we want to get a strong holographic display, we need to use high resolution LCoS-SLM. Even 4K2K LCoS-SLM does not have enough pixel number to generate large image size and large angle of view. From the above equations, there is a trade-off between image size and the angle of view. The key parameter is the focal length of lens. Long focal length can generate large image size, but small angle of view. On the contrary, short focal length can generate large angle of view, but small image size. Hence, different purpose is based on different parameter of focal length of lens. In near eye display, such as AR and VR system, we may want to get large image size but small angle of view because the light was sent to our pupil directly. For this demonstration of glass free 3D holographic display, we want to show large angle of view but small object size.

By this concept, we build a Holographic display for two eyes. So, the angle of view must be large, and we fix the object size around 0.46 cm. One 4K2K LCoS-SLM device is hard to have a large angle of view for two eyes in short distance. That is why we use three 4K2K LCoS-SLM to increase the angle of view as 36.67 degree. However, the SLM total panel size is combined by beam splitter to form a 12K x 2K SLM. Fig. 7 shows the demonstration of 3D floating holographic display by 12K x 2K SLM.

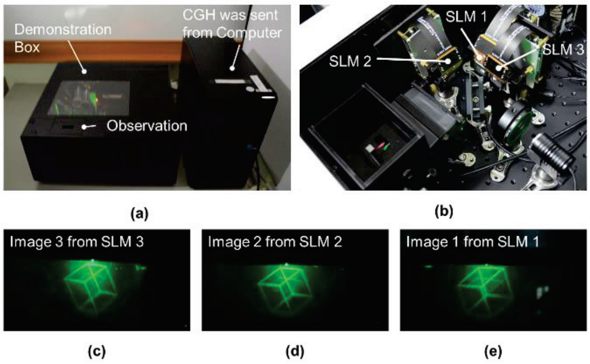

Fig. 7 Demonstration of 3D floating holographic display by 12K x 2K LCoS-SLM

4 CONCLUSIONS

High resolution, full phase modulation, small pixel pitch, high aperture ratio, and fast response time are the requirements to enhance the quality of holographic display by using the LCoS-SLM. Through the image stitching process by using three high resolution phase-only 4K2K LCoS-SLM, we can increase the angle of view of 3D floating holographic display. The angle of view is around 36.67 degree. It is a successful case for phase-only LCoS-SLM to be used into holographic display and near eye application, such as AR and VR.

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