31.2: Eight-Color High-Resolution Reflective Cholesteric LCDs

D. Davis, A. Kahn, X. Y. Huang, J. W. Doane
Kent Displays, Kent, OH
C. Jones
Liquid Crystal Institute, Kent State University, Kent, OH

Abstract

We report a unique eight color and black on white surface stabilized reflective cholesteric liquid crystal display. The display prototype is a triple stack, 100 dpi, 1/8 VGA, which shows eight vivid colors without parallax. The display is bistable so no power is used to show the image between user updates.

Introduction

Cholesteric liquid crystal displays[1-4] (Ch-LCDs) help fill a market need for low power, high resolution, reflective displays used in hand held and other portable devices. The bistablity of cholesteric optical textures allows for high resolution on a low cost passive matrix with reduced power consumption since power is not needed to continuously refresh the image. The reflected colors of the cholesteric liquid crystal materials provide for a bright display that is readily viewed in sunlight or low ambient light without dedicated illumination.

A double stack, four color display design[5] was extended by adding a third layer to produce a triple stack display[6] with cholesteric layers reflecting blue, green and red stacked on top of each other. The three reflected colors additively mix to provide a display with the capability of eight colors. We have found parallax not to be a problem even at 100 dpi resolution. The triple stack display also provides a way to achieve a black and white Ch-LCD with a highly reflective white state.

Other multiple color cholesteric displays have been made using polymer stabilization[7] of the optical textures or spatially tuning[8,9]; however, we use a polyimide alignment layer to stabilize the optical textures. This greatly increases the reflected luminance of the display.

Display Design

The number of substrates and the overall display thickness needed to build a stacked display can be decreased by using shared substrates. With this configuration, electrodes, insulating and alignment layers are on both sides of the shared substrates. A novel photolithography technique in which a single UV exposure step is used to expose photoresist coated on both sides of the substrate. This reduces the number of photolithography and etching steps while automatically registering the electrode patterns on each side of the shared substrates. Precise registration of the four substrates is still required. Special handling techniques are used to apply the insulating and alignment layers to both sides of the shared substrates.

ISSN0098-0966X/98/2901-$1.00 + .00 (c) 1998 SID

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1998**	2. REPORT TYPE	3. DATES COVERED **00-00-1998 to 00-00-1998**
4. TITLE AND SUBTITLE **Eight-Color High Resolution Reflective Cholesteric LCDs**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Liquid Crystal Institute,Kent State University,Kent ,OH,44242-0001**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**4**	

Since only four substrates are required, glass with 0.55 mm thickness is used to keep the overall display thickness the same as a 2.2 mm thick single display built using two 1.1 mm substrates. Figure 1 shows a cross-sectional view of the display.

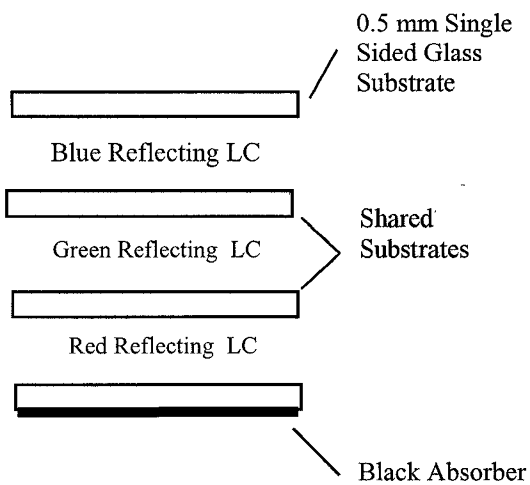

Figure 1. Cross sectional view of three layer stacked display. Shared substrates have electrodes and coatings on both sides.

Passive matrix displays with 240 columns and 160 rows at 100 dpi creating an active area of 41 mm by 61 mm have been fabricated. The pixel count is 1/8 that of a VGA display and the pixel aperture ratio is nominally 87%. The top layer is filled with a polymer free liquid crystal mixture that selectively reflects blue light, the center layer reflects green light while the bottom layer selectively reflects red light. The rear of the display is painted with flat black paint. The spacer size is 4.0 microns for the blue layer, 4.5 microns for the green layer and 6.0 microns for the red layer in order to achieve good color balance and keep the driving voltages similar for each layer.

Display Performance

Any pixel in the display is capable of displaying eight colors, namely blue, green, red, cyan, magenta, yellow, black or white. These colors are produced by color addition of the reflected light from the stacked RGB Ch-LCD layers. Figure 2 below shows the measured reflection spectra from a pixel of a triple stack display under diffuse illumination. The reflection spectra are not corrected for the spectral sensitivity of the human eye. Blue is measured with the top layer in the reflective state and the lower layers switched to the focal conic state. The focal conic texture is a weakly scattering state therefore, it is effectively transparent for all incident wavelengths. The green and red colors are measured with the respective layer in the reflective state and the other layers in the focal conic state. White is measured with all layers switched to the reflective state. Black is measured with all layers in the focal conic state.

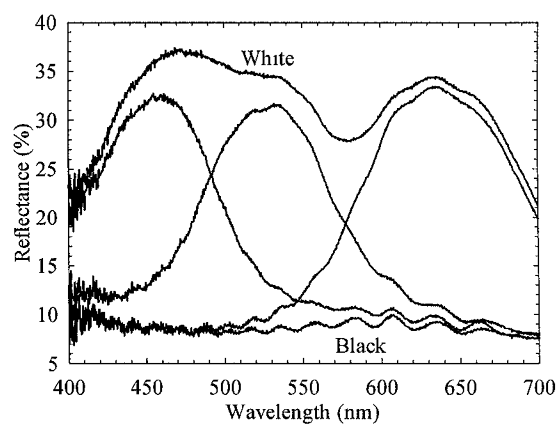

Figure 2. Reflection spectra of three layer stacked display under diffuse illumination

ISSN0098-0966X/98/2901-$1.00 + .00 (c) 1998 SID

Figure 3 shows a plot of the color coordinates of a 1/8 VGA, three layer stacked display on the CIE 1931 chromaticity diagram under standard D65 illuminant. The measurement angle is 8° off the display surface normal.

Virtually no parallax is observed in the triple stack display even though the spacing between the layers (0.5 mm) is larger than the nominal pixel size (0.24 mm).

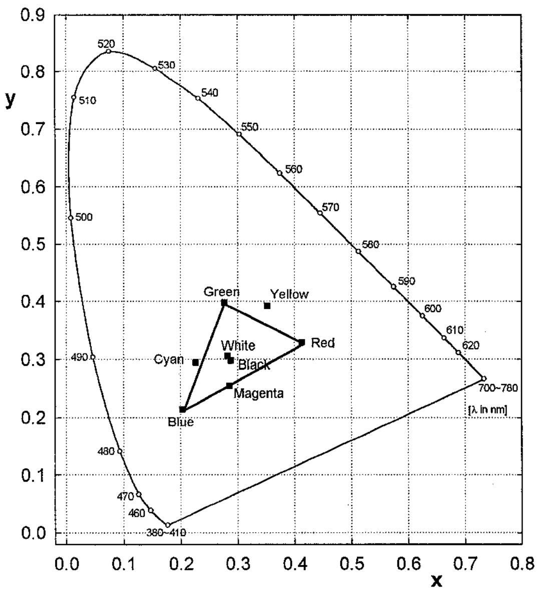

Figure 3. Color coordinates of 1/8 VGA three layer display plotted on the CIE 1931 2° chromaticity diagram.

The frame time, or the time it takes to update the entire display, is less than 1.2 seconds. The energy required to update the display is 270 mJ. The display was addressed using 40V STN driver chips in a unipolar drive scheme.

Impact

This display technology is particularly suited for handheld display applications due its low power consumption and wide viewing angle. Figure 4 shows a photograph of a 1/8 VGA, 100 dpi, triple stack display addressed with an eight color image.

The display is bistable so that once a pixel is addressed it stays in that state without an applied voltage until being updated by the user. Continuous addressing of the display is not required. This produces a low power display for applications like GPS receivers or electronic maps where the user takes considerable time while reading text before the display needs updating. Also, since cholesteric liquid crystal displays operate by reflecting incident light, no backlight is required.

Figure 4. Photographs of 1/8 VGA, 100dpi triple stack display addressed with two images from typical applications.

This figure is reproduced in color on page 1267.

ISSN0098-0966X/98/2901-$1.00 + .00 (c) 1998 SID

Conclusion

The first high resolution multiple color and black on white surface stabilized reflective cholesteric liquid crystal display is demonstrated by stacking three Ch-LCD layers. A triple stack, 1/8 VGA, 100dpi display prototype is capable of displaying graphics or text images in eight vivid colors without parallax.

Our future work includes adding grayscale and transferring this technology to plastic substrates. Monochrome VGA Ch-LCDs with 16 levels of gray have been demonstrated[10]. Adding this grayscale drive to each layer of the triple stack display would produce a Ch-LCD with 4096 colors. Currently, the apparent color depth can be extended past eight colors through the use of spatial dithering. We expect to build upon our recent results on plastic Ch-LCDs[11] to produce full color plastic Ch-LCDs.

Acknowledgements

The authors wish to thank Christine Martincic for display assembly, Ross Armbruster for display filling and characterization, Kathy Stump for electronics assembly and bonding, and Doug Bryant at the Liquid Crystal Institute at Kent State University for the use of the scriber. Finally, we wish to thank Kellie Hoke for her initial insights into the design of this display.

This work is supported by DARPA under contract N61331-96C-0042.

References

1. D.-K. Yang, L.-C. Chien, and J.W. Doane, *Proc. 11th Intl Display Research Conf.*, 49-52 (1991)
2. W.D. St. John, Z.J. Lu, and J.W. Doane, *J. Appl. Phys.* 78, 5253 (1995)
3. X.Y. Huang, D.-K. Yang P.J. Bos and J.W. Doane, *SID Intl. Symp. Digest Tech Papers XXVI*, 347-350 (1995)
4. M. Pfeiffer, D.-K. Yang, J. W. Doane, et. al., *SID Intl. Symp. Digest Tech Papers XXVI*, 706-709 (1995)
5. D. Davis, K. Hoke, A. Khan, C. Jones, X.Y. Huang and J.W. Doane, *Conference Record 17th Intl Display Research Conf.*, 242-245 (1997)
6. Patent application pending
7. M. Okada, T. Hatano, and K. Hashimoto, *SID Intl. Symp. Digest Tech Papers XXVIII*, 1019-1022 (1997)
8. L.C. Chein, U. Müller, M.-F. Nabor and J.W. Doane, *SID Intl. Symp. Digest Tech Papers XXVI*, 169-171 (1995)
9. Y. Cai, X. Shao, Y.Tian and X. Huang, *Proceedings from the International Display Workshops*, 289-292, 1997
10. X-Y Huang, D.-K. Yang, N. Miller, D. Davis and J.W. Doane, *SID 98, Late News Paper,* to be published
11. G. Podogil, D. Davis, X.-Y. Huang, N. Miller, J.W. Doane, *SID 98*, paper 6.3, to be published