Color Sequential Display based on Stacked Bistable Ferro-electric LCD

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ABSTRACT

A new color sequential display based on stacked bistable ferroelectric liquid crystal (FLC) has been proposed. The optimized parameters for the new structure including the orientation of the polarizers and ferroelectric liquid crystal cells, the cell gap of the cells have been found. The optical performance and color coordinates of the output of the system have been examined in simulation. The results show that bistable FLC has a good potential in color sequential display applications.

INTRODUCTION

Liquid Crystal Displays (LCD) are getting more and more popular in the display market due to their small bulk and low power consumption. Recently, color sequential LCDs have become a hot topic of research since they require no color filter to show color information but display primary colors in temporal sequence in a pixel. This merit provides a potential to realize high definition display based on current semiconductor technology level, which is difficult to achieve using traditional color filter LCD technology since its single pixel consists of three sub-pixels R, G, B. Furthermore, the brightness of color sequential LCD could be much higher than a conventional LCD with color filters, because the absorption of the color filters vanishes. Less complexity in the fabrication and the driving circuit can also be expected.

Since colors are reproduced by displaying primary colors in temporal sequence, fast response is thus required in color sequential LCDs to avoid flicker phenomenon. Therefore, traditional Twist Nematic (TN) mode and Super Twist Nematic mode are not suitable in such situation. Much interest has been focused on Optically Compensated Bend (OCB) mode [1]-[3] and Ferroelectric LCDs [4]-[8]. In this paper, we have chosen Ferroelectric Liquid Crystal as our cell structure since it has very fast response time of tens microseconds, high contrast ratio, wide viewing angle, and remarkable intrinsic bistability [9], [10]. Lately our group has successfully fabricated a passive driving bistable FLC display with memorized grey scales and 160x160 resolution on 48 x 44 mm glass substrate [11].

Unlike using LED back light to realize color field sequence in other systems, we used three stacked FLC cells as the analogous component to provide arbitrary color sequences. Each stage switches between a subtractive primary color (Cyan, Magenta, and Yellow) and white. Internal neutral polarizers are inserted to decouple each stage. The schematic display structure is shown in figure 1. The optimal parameters of the configuration for the structure have been found. The optical performance and the output color coordinates of the system based on the optimized parameters are presented in the results.

THEORY AND RESULTS

Color coordinates of a display in RGB space can be presented as

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \int \begin{bmatrix} r(\lambda) \\ g(\lambda) \\ b(\lambda) \end{bmatrix} S(\lambda)d\lambda \quad , \qquad (1)$$

where $r(\lambda)$, $g(\lambda)$, $b(\lambda)$ are spectral tristimulus coefficients, $S(\lambda)$ is spectral power distribution of light passed through the display. $S(\lambda)$ for transmissive FLC display can be written as

$$S(\lambda) = L^t(\lambda) \cdot T(\alpha, \beta, \Delta nd, \varphi, \Gamma, \gamma, \theta, \phi, \lambda) \qquad (2)$$

where $L^t(\lambda)$ are illuminant spectral intensity of backlighting source, $T(\alpha, \beta, \Delta nd, \varphi, \Gamma, \gamma, \theta, \phi, \lambda)$ is the transmittance of the LC layer and retardation film sandwiched between a pair of polarizers, $\alpha, \beta, \varphi, \gamma$ are angles described orientations of the polarizers, optical axes of the liquid crystal and the retardation film, respectively, θ, ϕ are angles described direction of incident light, Δnd, Γ are optical retardations of liquid crystal and retardation film, respectively.

The optimal values for the configuration parameters can be found from the minimization of Eq.(1) under the following conditions [12][13].

a) Cyan & White: $\begin{bmatrix} R \\ G \\ B \end{bmatrix} \rightarrow \begin{bmatrix} 0 \\ 1 \\ 1 \end{bmatrix} \& \begin{bmatrix} R \\ G \\ B \end{bmatrix} \rightarrow \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$, (3)

b) Magenta & White: $\begin{bmatrix} R \\ G \\ B \end{bmatrix} \rightarrow \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix} \& \begin{bmatrix} R \\ G \\ B \end{bmatrix} \rightarrow \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$, (4)

c) Yellow & White: $\begin{bmatrix} R \\ G \\ B \end{bmatrix} \rightarrow \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix} \& \begin{bmatrix} R \\ G \\ B \end{bmatrix} \rightarrow \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$, (5)

Figure 1 shows the schematic structure of our stacked color sequential FLC display. Except the top and the bottom polarizers, two neutral polarizers are inserted between the three FLC cells. The liquid crystal mixture we used in our simulation is FLC 510 (from Lebedev Physical Institute of Russian Academy of Sciences) since it has good bookshelf structure [10]. The measured birefringence of the FLC 510 is described by the following empirical analytical form: $\Delta n(\lambda) = 0.1707 - \frac{0.00198}{\lambda^2} + \frac{0.00269}{\lambda^4}$. The cone angle of FLC 510 is 54^o. The optimal parameters that we have found for reproducing the three subtractive primary colors are summarized in Table 1. The optical performance and the output color coordinates have been examined using MOUSE-LCD [12].

The output spectra of each stage are shown in Fig. 2. Very bright white state can be observed from the spectra. Also, transmission for the three subtractive primary colors is still good. Figure 3 shows the corresponding chromaticity diagrams of the three subtractive primary colors. From the CIE chart, we can see the saturation for Magenta and Yellow is very good. After combining three stages together, the chromaticity diagrams for the subtractive primary colors are almost unchanged. Only slight decrease in the output transmission could be observed.

Further, the saturation of the primary colors could be improved by using uniaxial compensation film. Besides, the additive mode color sequential can also be obtained based on this theory, which could have higher color saturation.

CONCLUSION

A new color sequential display based on stacked bistable FLC has been proposed in this paper. The parameters of the configuration have been optimized for the color sequential display. The optical performance and color coordinates of the output of the system have been examined in simulation. The results show that bistable FLC has a good potential in color sequential display applications.

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Table 1: Optimal parameters of the configuration for the color sequential display.

FLC layer	Orientation	Cell gap (μm)
Layer 1(top)	36°	4.0
Layer 2	42.5°	3
Layer 3(bottom)	26.7°	4.65
Polarizers	Orientation	
P1 (top)	-45°	
P2	-45°	
P3	-45°	
P4(bottom)	-71.4°	

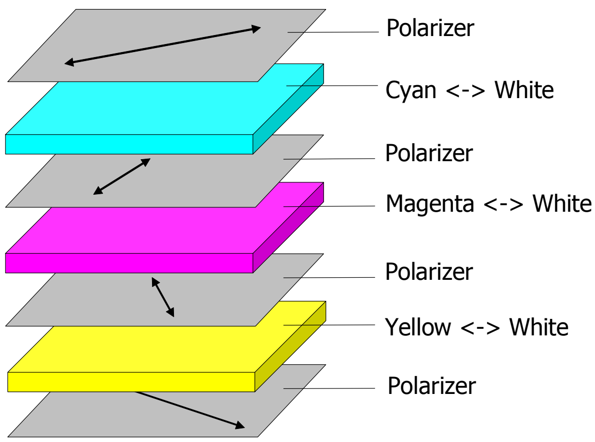
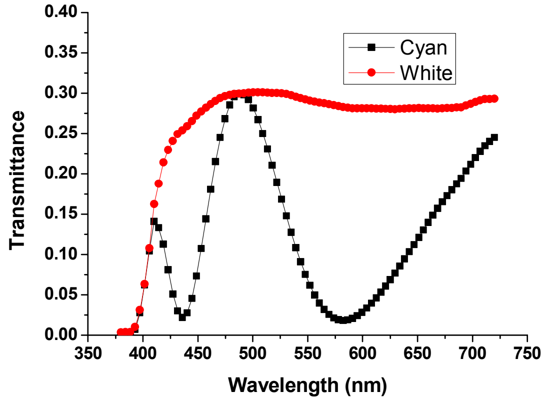
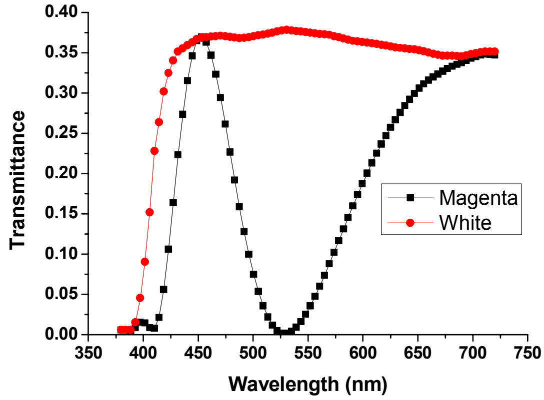


Fig. 1 Schematic structure of the stacked FLC display.



(a)



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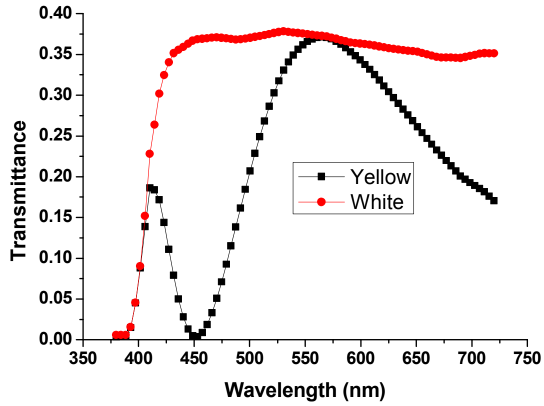
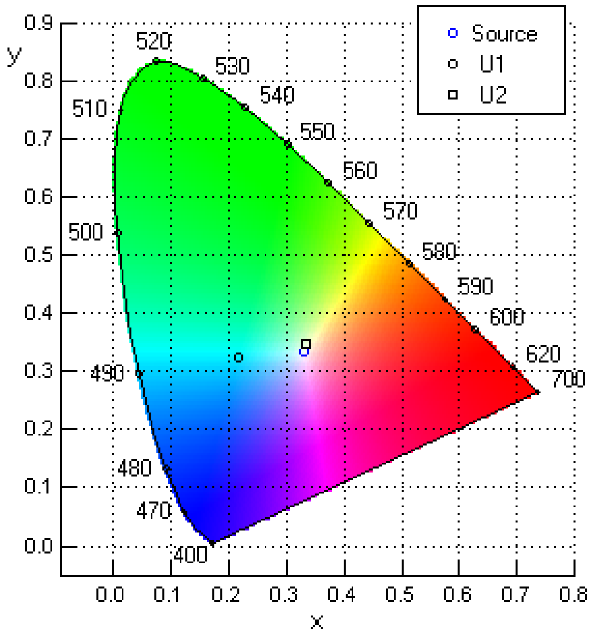
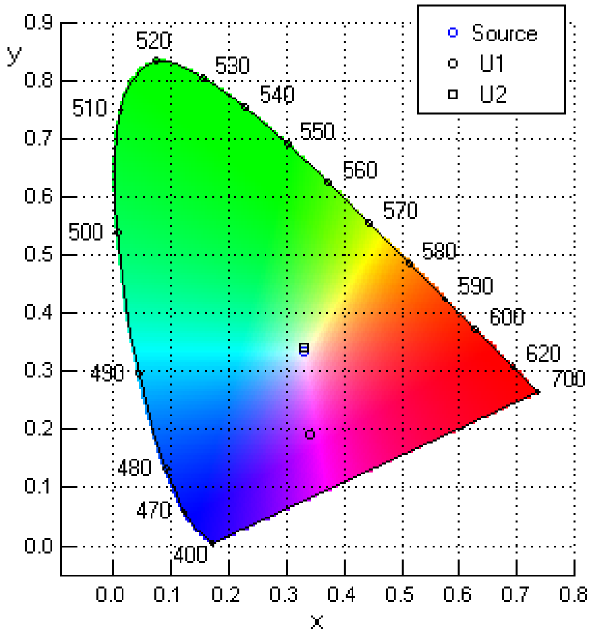


(c)

Fig. 2 Spectra of three color switching stages. (a) Cyan; (b) Magenta; (c) Yellow.



(a)



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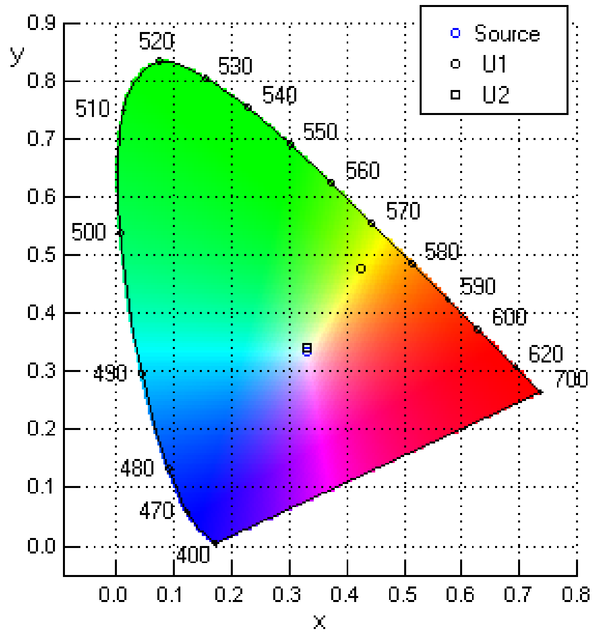

(c)

Fig. 3 Color coordinates of three color switching stages. (a) Cyan; (b) Magenta; (c) Yellow.