P-169: Photoaligned Bistable FLC Displays with Birefringent Color Switching

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Abstract

In this paper, color switching bistable ferroelectric liquid crystal (FLC) displays have been studied. Memorizable colors were obtained. The spectra, chromaticity and viewing characteristics of the displays were studied in simulation. Using results of the simulations we fabricated prototypes of Black&Green, Black&Yellow, Blue&Yellow, and Green&Pink FLC displays.

1. Introduction

Recently, there is much effort to develop the low power consumption displays such as portable devices, smart card applications, information boards etc. In such cases, bistable liquid crystal displays (LCDs) become an excellent candidate owing to their superior characteristics such as light weight, low power consumption and small size [1]. Among the developed bistable LCD technologies, FLC displays are a good choice for the demands mentioned above since they own very fast response times at μs order, high contrast ratio and wide viewing angles [2].

In the traditional alignment process for FLC displays, the rubbing technique is not suitable due to the high sensitivity of FLC to mechanical shocks. Thus, our group exploits photoalignment technology to align the FLC, which enables us to avoid the mechanical brushing during the alignment process. By using this technique, our group reported recently a FLC display with remarkable bistability, wide viewing angle, unlimited memorized grayscale by forming micro-domains [3], extremely fast response time and very high contrast ratio [2].

In low power consumption devices, thin film transistor (TFT) technology is not widely used due to its relatively high power consumption and high cost. In this context, passively addressed chromatic bistable displays become more attractive and perspective in many applications. Since monochromatic displays can satisfy most of requirements of low power devices, the application of passive monochromatic bistable display can further reduce the cost of display part and provide better optical performance.

To obtain an FLC display with desirable colors, optical properties of FLC cell placed between a pair of polarizers should be studied. It is known that visual characteristics of FLC displays such as transmittance, contrast ratio and color significantly depend on display structure and configuration parameters like the optical retardation of the liquid crystal layer, the cone angle of molecules, orientations of the polarizers and the retardation film, if it is included.

In this paper, we theoretically analyze the display structure and the configuration parameters for monochromatic and dichromatic FLC displays. We focus on four regimes of the color switching: Black to Yellow, Black to Green, Blue to Yellow and Green to Pink. From simulations we find optimal configurations for FLC displays and experimentally fabricate prototypes of such FLC displays. We also present the viewing characteristics of the four color switching FLC displays in simulation.

2. Theory

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 [4].

a) Black & Yellow:
$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} \to \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \& \begin{bmatrix} R \\ G \\ B \end{bmatrix} \to \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix}, \qquad (3)$$

b) Black & Green:
$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} \to \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \& \begin{bmatrix} R \\ G \\ B \end{bmatrix} \to \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}, \qquad (4)$$

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

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ISSN0006-0966X/06/3701-0854-$1.00+.00 © 2006 SID

d) Green & Pink:
$$\begin{bmatrix}R\\G\\B\end{bmatrix}\rightarrow\begin{bmatrix}0\\1\\0\end{bmatrix}\&\begin{bmatrix}R\\G\\B\end{bmatrix}\rightarrow\begin{bmatrix}1\\0\\1\end{bmatrix}, \qquad (6)$$

The schematic structure of an FLC display is shown in Figure 1. It consists of two polarizers, an FLC cell and a retardation film.

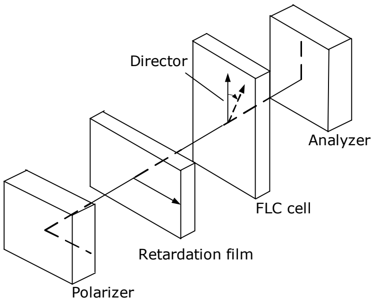


Figure 1. Schematic structure of an FLC display.

3. Results and discussion

We use conditions (3)-(6) as the criterion in simulation. The liquid crystal mixture FLC 510 (from Lebedev Physical Institute of Russian Academy of Sciences) was chosen as that possesses good bookshelf structure [2]. 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 46^o. The optimal results that we have found for normal incidence are summarized in Table 1.

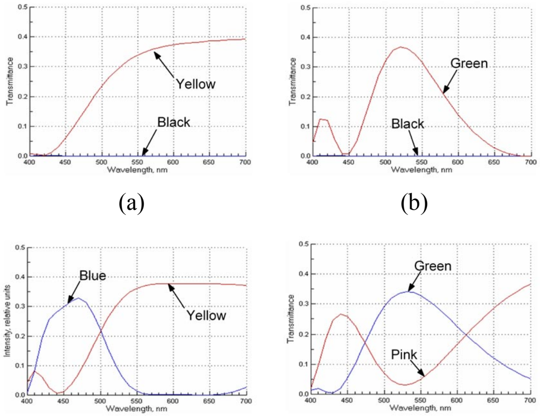
A D65 lamp was used as light source in calculation. The data of polarizers and all the retardation films came from Nitto-Denko.

To confirm the simulation results, we chose one set of configuration for each color switching. We use azo-dye SD1 from DIC as the photoalignment material [2].

Table 1. Color Coordinates change during color switching with and without phase retarder.

	Black & Yellow	Black & Green	Blue & Yellow	Green & Pink
No phase retarder	No retarder: (0.27, 0.25) →(0.43, 0.45)	No retarder: (0.19, 0.16) →(0.30, 0.51)	-	-
Single phase retarder	Z537: (0.34, 0.35) →(0.44, 0.46)	Z585: (0.32, 0.32) →(0.31, 0.54)	Z580: (0.15, 0.11) →(0.44, 0.48)	Z537: (0.33, 0.46) →(0.40, 0.28)
	R550: (0.27, 0.27) →(0.44, 0.47)	Z570: (0.34, 0.34) →(0.29, 0.54)	Z617: (0.14, 0.13) →(0.44, 0.47)	R550: (0.37, 0.49) →(0.34, 0.20)
Double phase retarder	Z537 & Z570: (0.18, 0.09) →(0.36, 0.37)	Z560 & Z537: (0.21, 0.25) →(0.32, 0.57)	Z617 & Z585: (0.15, 0.08) →(0.46, 0.44)	Z617 & Z617: (0.27, 0.49) →(0.40, 0.30)
	Z617 & Z560: (0.18, 0.08) →(0.42, 0.44)	Z580 & R550: (0.30, 0.29) →(0.29, 0.51)	Z585 & Z585: (0.16, 0.20) →(0.39, 0.43)	Z537 & Z537: (0.29, 0.41) →(0.36, 0.24)

Fig. 2 shows the simulated spectra of bistable FLC displays for normal incidence. From the spectra, we can predict clearly that at these configurations, color switching can be in principle realized very well in bistable FLC displays. Moreover, the Black & Yellow and the Black & Green modes have a very high contrast compared with the other two modes.



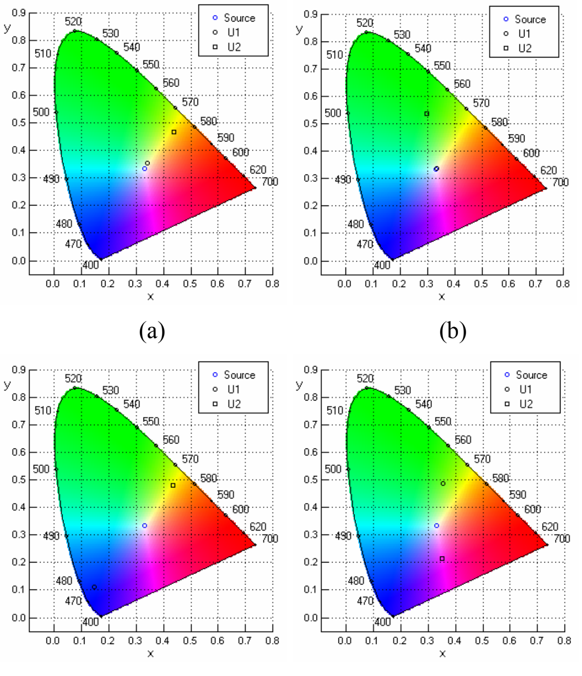
(a) (b)

(c) (d)

Fig. 2 Spectra of chromatic bistable FLC displays for normal incidence. (a) Black & Yellow; (b) Black & Green; (c) Blue & Yellow; (d) Green & Pink.

To obtain the detailed chromatic information for these four color switching FLC displays, we calculated the corresponding color coordinates. From Fig. 3, we can see that these all four color switching FLC displays have good chromaticity except that the color in Green & Pink mode is less saturate than the other three modes. It is reasonable because the data of phase retarders used in calculation are all real commercial products and not optimized for our color switching bistable FLC displays. The color saturation will be definitely much better if fully optimized phase retarders used.

To study the chromaticity shift characterized for polar viewing angles, we calculated the change of chromaticity of the four monochromatic FLC displays when the polar viewing angles varying from -50^o to 50^o along the two directions that azimuthal angle ϕ equals to 45^o and 135^o (relative to the orientation of input director) respectively.



(a) (b)

(c) (d)

Fig. 3 Color coordinate of chromatic bistable FLC displays for normal incidence. (a) Black & Yellow; (b) Black & Green; (c) Blue & Yellow; (d) Green & Pink.

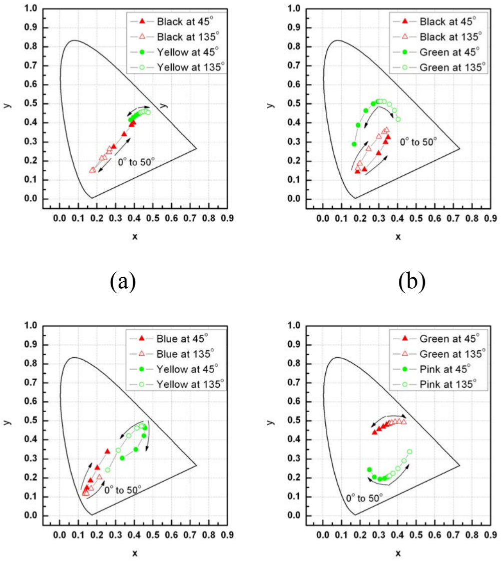
From Fig. 4(a) and (b), we can see that chromaticity does not change substantially especially for the polar angle less that 30°. The color shift in dark state is larger in bright state. But the monochromatic contrast can still be high since the dark state is black state and transmittance is very low.

The chromaticity shifts in Blue & Yellow and Green & Pink modes are shown in Fig. 4(c) and (d). For these two modes, the color saturation has larger impact in the appearance of displays since the two switching states are both chromatic. But we still can find good chromaticity for polar viewing angles less than 40°. In this group figures, we study the viewing characteristics only for 45° and 135° relative to the input director (equivalent to 225° and 315° since polar viewing angles are extended to negative values), and no other azimuthal preference of viewing direction is considered.

Based on the optimized configuration we have obtained, we fabricated four prototypes using photoalignment technology. The appearances of the four monochromatic color switching bistable FLC displays are shown in Fig. 5. Since the cell gaps in Black & Yellow and Black & Green modes are smaller, the uniformity of the two displays is also better. After proper electric treatment, the perfect bistable states can be achieved.

5. Conclusion

We have studied color switching bistable FLC displays in this report. We theoretically investigated how to find optimal configurations for color switching in FLC displays for normal incidence. The spectra, chromaticity and viewing characteristics of the displays are studied in simulation. Prototypes that show good monochromatic color in perfect bistable state have been demonstrated. This technique can be used for any low power consumption displays which need low cost monochromatic colors.



(a) (b)

(c) (d)

Fig. 4 Shift of chromaticity as a function of polar viewing angle for monochromatic bistable FLC displays. (a) Black & Yellow; (b) Black & Green; (c) Blue & Yellow; (d) Green & Pink.

(a) (b) (c) (d)

Fig. 5 Appearance of monochromatic bistable FLC displays. (a) Black & Yellow; (b) Black & Green; (c) Blue & Yellow; (d) Green & Pink.

6. Acknowledgements

This research was supported by ITF grant ITS/111/03 and RGC 6149/04E.

7. References

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