Blue-white Reflective Cholesteric Liquid Crystal Displays by Single Liquid Crystal Layer

Woon-Seop Choi[a]
School of Display Engineering, Hoseo University,
165 Sechul-ri, Baebang-myeon, Asan-si, Chungnam 336-795, Korea

Hee-Jeong Lee
Samsung SDI, CRD Center,
428 Gongse-dong, Giheung-gu, Yongin-si, Gyeonggi 449-577, Korea

[a]E-mail : wschoi@hoseo.edu

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Blue-white reflective cholesteric liquid crystal display was prepared by a unique method of single liquid crystal layer, the combination of yellow color liquid crystal and blue color backplane. The dopant and host combination of chlolesteric liquid crystal affects the color spectrum. The CIE chromaticity coordinates of blue and white are (0.10, 0.16) and (0.29, 0.30), respectively. The relatively low driving voltages of 32 V for blue-white display are obtained.

Keywords : Refelctive display, Ch-LCD, Blue-white display

1. INTRODUCTION

Reflective cholesteric liquid crystal displays (Ch-LCD) with bistability are very attractive because of their excellent readability, low power consumption with image memory, high reflectivity, high contrast ratio at a wide viewing angle, and a low manufacturing cost[1]. A cholesteric liquid crystal is similar to a nematic liquid crystal since it has a long-range orientational order but no a long-range positional order. The Ch-LCD, however, has a helical structure due to the dopants in the cell. Cholesteric liquid crystal displays use two stable states at zero field; in the planar state the helical axes of LC align perpendicular to the substrate surface and a selected wavelength of incident light is reflected by Bragg reflection. In the focal conic state the helical axes of LC align more or less parallel to the substrate surface, and the cell is weakly scattering the incident light without Bragg reflection[1]. Cholesteric liquid crystal displays have several unique features suitable for mobile displays, public information displays, signboard applications, and future e-books. However, such technical problems as high operation voltage and full-color capability should be enhanced to yield a robust product. Especially, low operation voltage is very important in cost and power consumption. Driving cholesteric liquid crystal displays using conventional STN drivers have the advantage of a cheaper cost and lower power consumption. In general, the ideal liquid crystal mixture for low driving voltage should have a high birefringence, high dielectric anisotropy, and low viscosity[2]. In addition, the panel structure and alignment layer of the display would be crucial factors for obtaining a higher quality display. We reported on the initial work of the driving techniques related to Ch-LCD[3]. There are different types of color combination with Ch-LCD such as green/black and red/green/blue color. It is interested for the combination of blue and yellow colors to make white display.

In this work, we achieved the optimized cholesteric liquid crystal mixture and tried to obtain white color display with only one type of liquid crystal usage. We have demonstrated blue-white reflective cholesteric liquid crystal display by a unique method of single liquid crystal layer, the combination of yellow color liquid crystal and blue color backplane.

2. EXPERIMENTAL

The molecules of liquid crystals, MDA 1444 and BL 087, as host components were obtained from liquid crystal companies. We formulated different liquid crystal with dopants to demonstrate different colors in our laboratory. LCD panels as empty cells were fabricated in the STN liquid crystal production line at our facility. The size of the test cell was 2" and it was pixellized into 150X150. The VGA panel was 5.7" diagonally and had a VGA (640X480) resolution. The small molecules were added into the cholesteric mixture at slightly elevated temperatures. The empty panels were filled with this cholesteric mixture in a vacuum environment. The different pigments were coated on the backplane of LCD to show the desirable colors. The optical characterizations such as reflectivity and spectrum analysis were carried out by LCD evaluation system, LCD 5000 (Otsuca, Japan) calibrated with $BaSO_4$. The driving test was performed with an electro-optical measuring system assembled in our laboratory.

3. RESULTS AND DISCUSSION

Chlesteric liquid crystal can be formulated by various dopants to show different types of colors. The pitch size in the chloresteric texture is controlled by dopants type and contents.

$$\lambda = pn$$

where λ is the central reflection wavelength, p is the pitch length, and n is the average refractive index. In this equation, if the cell gap was fixed, the color was shifted to red to blue when the dopant was added due to the shortening the pitch length. Therefore, one can control the different colors by adjusting the dopants contents such as yellow-black, yellow-green, white-green combinations. Two types of liquid crystal combination are necessary to make white as shown in Fig. 1. The blue and yellow combination can make white color. If that the case, what happen to off state. It is not easy to make blue to white conversion with only two colors, and more colors and stacked panels are needed.

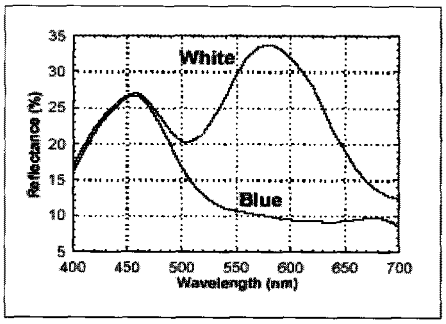

Fig. 1. Schematic diagram of the concept to make white color with two different liquid crystal colors.

We prepared blue and white combination with very simple and unique method. The yellow liquid crystal was prepared and injected in to the cell gap and the blue color was coated on to the backplane. White color can be obtained with on state due to the blue and yellow combination by Bragg reflection. The blue state can also be obtained with off state due to the focal conic state of chloresteric liquid crystal. In the focal conic state the helical axes of liquid crystal align more or less parallel to the substrate surface, and the cell is weakly scattering the incident light. To develop such device, the color match is important. Because the blue color is critical to display, blue coloring material was intensively searched. The criteria for choosing blue were color coordinate, contrast ratio and transparency for reflectivity. In order to select liquid crystal, wide spectrum liquid crystal was chosen due to broad reflection area and to display white color. The large birefringence liquid crystal is necessary because it gives broad band spectrum because the spectrum bandwidth is proportional to the birefringence.

$$\Delta\lambda = p\Delta n$$

where $\Delta\lambda$ is the spectral band width, p is the pitch length, and $\Delta n = n_e - n_o$ is the birefringence. We selected liquid crystal with high Δn and adjusted the color pitch by adding suitable dopant. Host liquid crystal MDA-1444 and BL-087 were chosen with dopants. The birefringence and dielectric constant of above two liquid crystals were 0.1774 and 0.2362, and 31.0 and 20.6, respectively. To obtain central wavelength max around

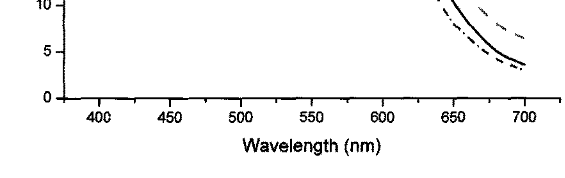

Fig. 2. Spectrum for white–blue display with different types of liquid crystals. (wavelength 400-700 nm).

580 to 600 nm, the dopant were added to the host. The cell gap was 4 μm and homeotropic alignment layer was used to make a LCD cell. Fig. 2 shows the spectrum result of blue-white reflective liquid crystal display. Comparing reference, MDA-1444 and BL087 show high

reflectivity, however, the spectrum widths are relatively narrow. BL087 shows better performance than MDA1444. The CIE chromaticity coordinates for both displays were characterized as shown in Fig. 3. The CIE chromaticity coordinates of blue are similar, however, the white is different. The white are (0.27, 0.26) for MDA144 and (0.29, 0.30) for BL087, respectively. Even though the whiteness of blue-white display is a little difference from the NTSC white index, the whiteness of BL087 is the closest one and enough to display white.

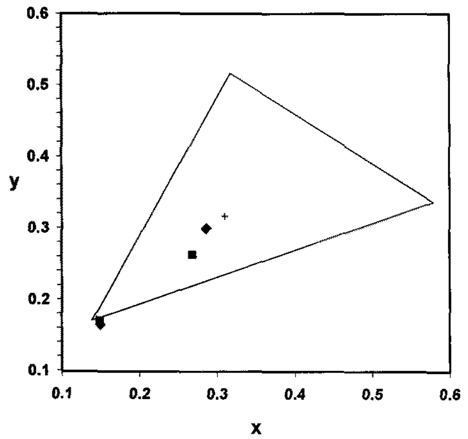

Fig. 3. The CIE chromaticity coordinates of blue and white for MDA1444 (rectangular) and for BL087 (diamond), respectively(a center cross is reference white of NTSC).

For a cholesteric liquid crystal display with uniform pitch size, the threshold voltage is expressed as

$$V_{th} = \frac{\pi^2 d}{p}\sqrt{\frac{K_{22}}{\Delta\varepsilon}} ,$$

where d is the cell gap, K_{22} is the twist elastic constant, and p is the pitch size, and $\Delta\varepsilon$ is the dielectric anisotropy[4]. As presented in above equation, the threshold voltage is proportional to the cell gap. Although, a thinner cell gap yields a lower threshold voltage, it leads to a smaller number of helical structures in the cell and thus causes a reduction in reflectance[5]. After several tests on the reflectivity and driving voltage of cholesteric liquid crystal, we decided that the optimal cell gaps of Ch-LCD should be around 4-5 μm. Liquid crystal with a large Δn and $\Delta\varepsilon$ is desirable because of the thin cell gap which can be used with a large Δn, and because of lower driving voltage with a large $\Delta\varepsilon$ and Δn. We have focused on the increase of the dielectric anisotropy of liquid crystal for reducing operation voltage. Cholesteric liquid formulations from MD1444 and BL087 were prepared for panel preparation.

There are several driving regions for Ch-LCD such as planar reset, focal-conic reset, and homeotropic reset due to the bistability of Ch-LCD. We have proposed a delayed-homeotropic (DH) reset for the normal driving of Ch-LCD and other fast driving methodologies[6,7]. The liquid crystal was formulated in our Lab to make it possible for the driving voltage to be lower than 30 V[8]. What we found is that lower threshold voltage suitable for conventional passive matrix driving can be realized by the cholesteric mixtures as a potential commercial display product. The line scan rate was 4 ms/line with 16 gray by using the STN driver IC as a delayed-homeotropic (DH) reset driving method. The driving measurements were performed at two different liquid crystal formulations. MDA1444 shows a little lower driving voltage around 24 V than that of BL087 around 30 V. Because the whiteness for BL087 from CIE chromaticity diagram and contrast ratio data shows better property, BL087 is tested for real driving condition for a panel. By applying real driving pulses to the cholesteric display, the driving voltage became higher than that of the cell, as shown in Fig. 4. When the selection time was 8ms, the driving voltage is around 32 V that might be possible for driving STN IC.

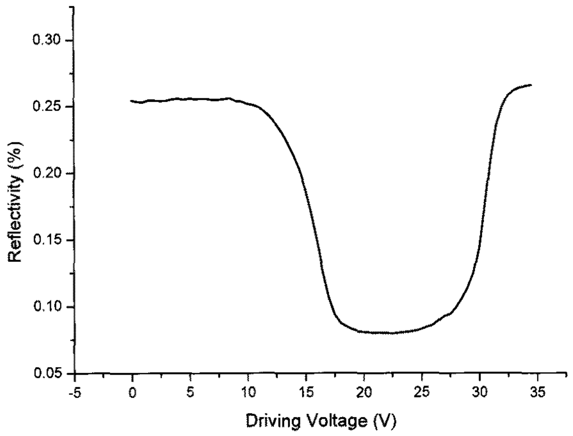

Fig. 4. Driving characteristic of white-blue reflective liquid crystal display(BL087).

When the driving temperature increases, the driving voltage decreases due to the lower viscosity of liquid crystal. A driving voltage change and small color shift were detected when the measurements were performed under different temperatures. The liquid crystal materials should be chosen such that the dependence on temperature in the cholesteric phase is not so critical and the pitch does not change much with the temperature. The temperature dependence of the cholesteric panel will require a temperature compensation circuit system in the driving system. This white-blue display may be used as low-end e-paper applications

4. CONCLUSION

Blue-white reflective cholesteric liquid crystal display was successfully fabricated by a unique structure of single liquid crystal layer, the combination of yellow color liquid crystal and blue color backplane. The dopant and host combination of chlolesteric liquid crystal affects the color spectrum. The CIE chromaticity coordinates of blue and white for BL087 are (0.10, 0.16) and (0.29, 0.30), respectively. Even though the whiteness of white-blue display shows a little difference from the NTSC white index, the whiteness of BL087 is the closest one and enough to display white. The relatively low driving voltages of 32 V for blue-white display are obtained. This white-blue display may be used as low-end e-paper applications.

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