

Black-white Reflective Liquid Crystal Display Prepared with Two Color Reflective Layers

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Black-white reflective cholesteric liquid crystal display was prepared with two color liquid crystal layers, the combination of yellow color liquid crystal and blue color liquid crystal. The rubbing of cholesteric liquid crystal panel affects the brightness and color spectrum due to increase the planar domain texture. The CIE chromaticity coordinate of white is (0.31, 0.31).

Keywords: Reflective display, Ch-LCD, Black-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]. 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. 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]. Especially, low operation voltage is very important in cost and 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] and blue-white cholesteric displays by single layer[4].

There are different types of color combination with Ch-LCD such as green/black and red/green/blue color. Technically, black-white cholesteric liquid crystal display is not simply obtained due to the reflectivity characteristic of cholesteric texture. In general, white color can be made by

the mixture of three colors, red, green and blue. Therefore, it is very interested to make white color display by the combination of blue and yellow colors

In this work, we achieved the optimized cholesteric liquid crystal mixture and tried to obtain white color display with two types of liquid crystal panels, blue and yellow. We have demonstrated black-white reflective cholesteric liquid crystal display.

2. EXPERIMENTAL

The molecules of liquid crystals, MDA 2124 and MDA 3667, as host components were obtained from a liquid crystal company. 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 pixelized into 150X150. The VGA panel was 5.7" diagonally and had a VGA (640X480) resolution. The liquid crystal molecules were added into the cholesteric mixture at slightly elevated temperatures. The empty panels were filled with this cholesteric mixture in a vacuum environment. Blue color was obtained by the combination of MDA 2124 and MDA 3667, while the yellow was MDA 3667 with dopant. Two panels were stacked to demonstrate white color. The rubbing was performed conventional rubbing machine in the lab. The optical characterizations such as reflectivity and spectrum analysis were carried out by LCD evaluation system, LCD 5000 (Otsuca, Japan) calibrated with BaSO₄.

3. RESULTS AND DISCUSSION

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

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$$\lambda = pn, \tag{1}$$

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, red-black, blue-black and green-black combinations.

In general, white color can be made by the mixture of three colors, red, green and blue in display areas. There are three cholesteric color panels are stacked to display white color. It is not a good idea to have such stacked product because of the thickness, weight and lose reflectivity. There is another way to make white color reflective display by using the white color spectrum technology such as color combination of broad band spectrums. That is the blue and yellow combination to make white color. Only two panels are necessary instead of three. This process can improve reflectivity, give light weight and low production cost.

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:

$$\Delta\lambda = p\Delta n, \tag{2}$$

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-2124 and MDA 3667 were chosen with dopants. To obtain central wavelength max around 470 nm and 580 nm for blue and yellow, the dopants were added to the host. In order to obtain suitable reflectivity of each color panel and white color chromaticity, cell gap was controlled. The cell gaps were 3.3 μm and 5.2 μm for blue and yellow color panel, respectively. The homo-tropic alignment layers were used to make blue and yellow LCD cells.

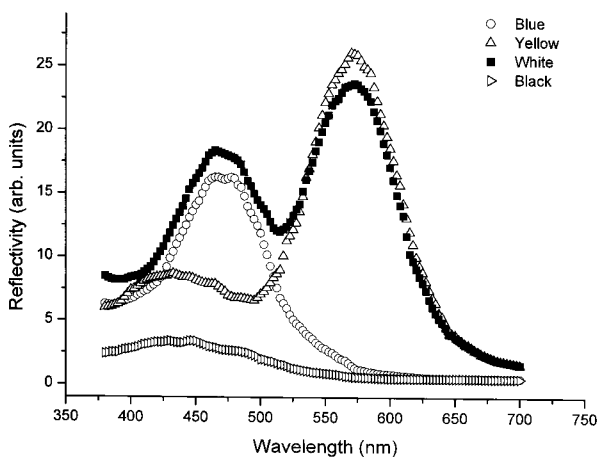


Fig. 1. Spectrum for white-black display with yellow and blue color liquid crystals (wavelength 380-700 nm).

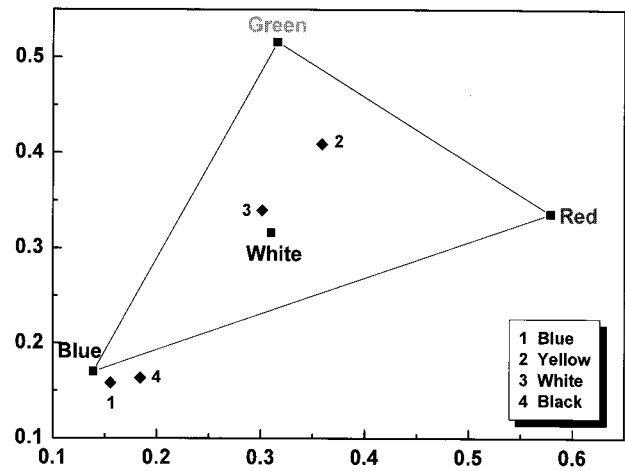


Fig. 2. The CIE chromaticity coordinates of blue (1), yellow (2), white (3) and black (4), respectively, (a center rectangular is reference white of NTSC).

We prepared white-black color display with the combination of very simple method of a blue and a yellow color matching as shown in Fig. 1. The blue liquid crystal panel was prepared and stacked the yellow color panel with suitable adhesive layer. White color can be obtained with on state due to the blue and yellow combination by Bragg reflection. The black state can also be obtained with off state due to the focal conic state of cholesteric 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. Figure 2 shows the CIE chromaticity coordinates of blue (1), yellow (2), white (diamond) and black (4), respectively. (a center rectangular is reference white of NTSC) The CIE chromaticity coordinate of white is (0.31, 0.34).

To minimize the loss of light and to raise the reflection rate of the panel, one should control the chirality of the liquid crystal of each layer. That is, it should differ depending on whether the dopant is a (S)-compound or a (R)-compound. Therefore, in order to reduce loss of light, one must control the chirality of the blue and the yellow layers differently from one another[5].

Ch-LCD with surface treatment or polymer treatment into liquid crystal has the effect to stabilize the planar texture or the focal conic texture at zero field. The choice of alignment layer is very important and the rubbing method is another factor to be considered in the domain texture. The homogeneous alignment layer provides a higher reflective panel because the layer stabilizes the planar structure of the cholesteric mixture, while the homeotropic alignment layer provides a higher contrast ratio due to stabilizing focal conic texture.

Figure 3 shows improved reflectivity of black-white

cholesteric panel after rubbing of homeotropic alignment layers inside the cells. The improvement of the reflectivity of blue region helps better white spectrum as shown in the Fig. 3 and Fig. 4. The CIE chromaticity coordinates of white and blue are (0.30, 0.32) and (0.15, 0.17), respectively, approaching the NTSC coordinate. The cholesteric liquid crystal has tendency to align with the rubbing state and this causes a more planar preferred structure with a higher reflectivity performance[6]. When both sides of the alignment layers in the cell are rubbed, mirror-like appearance there is from viewing side. This is due to the almost perfect planar texture with very large domain sizes.

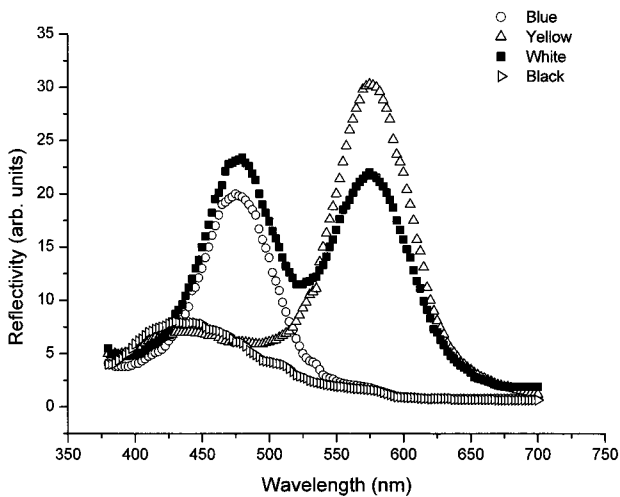


Fig. 3. Spectrum for white-blue display with different types of liquid crystals (wavelength 380-700 nm).

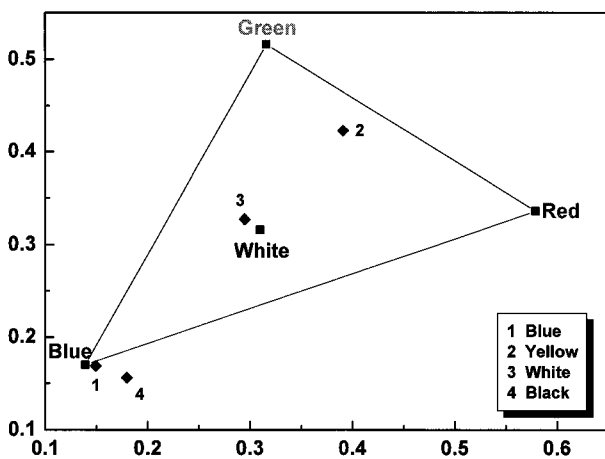


Fig. 4. The CIE chromaticity coordinates of reflective Ch-LCD; blue (1), yellow (2), white (diamond) and black (4), respectively (a center rectangular is reference white of NTSC).

The target of this research is black and white display with relatively simple structure. Even though we found that white spectrum could be obtained in two stacked blue and

yellow panel, the whiteness was not sufficiently approached NTSC standard. The process was optimized with each step according to whiteness. The cell gap was adjusted, and the liquid crystals and dopants were controlled, and the alignment layer and rubbing effect were controlled to obtain whiteness. Figure 5 shows the spectrum result of black-white reflective liquid crystal display. The CIE chromaticity coordinates for optimized black-white reflective cholesteric liquid crystal display was characterized as shown in Fig. 5. The CIE chromaticity coordinates of white is (0.31, 0.31) very close to the NTSC white index. Even though the blue coordinate shows deep blue and yellow shows a little more greenish yellow, the whiteness of black and white display is enough to display white. This black-white display has a potential to low-end e-paper applications.

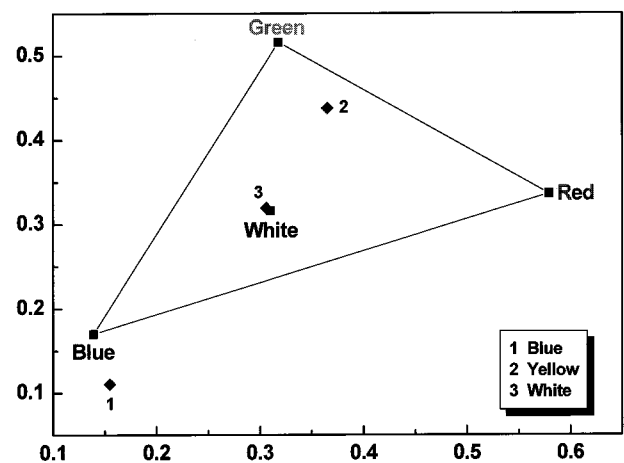


Fig. 5. The CIE chromaticity coordinates of optimized black-white Ch-LCD; blue (1), yellow (2), and white (3), respectively (a center rectangular is reference white of NTSC).

4. CONCLUSION

Black-white reflective cholesteric liquid crystal display was successfully fabricated by the combination of blue and yellow color liquid crystal panels. The cholesteric liquid crystal has tendency to align with the rubbing state, and this causes a more planar preferred structure with a higher reflectivity performance. The panel was optimized by cell gaps, liquid crystals, dopants, alignments, rubbing, and process parameters. The CIE chromaticity coordinates for optimized black-white reflective cholesteric liquid crystal display is (0.31, 0.31) very close to the NTSC white index. The whiteness is enough to display white. This black-white display has a potential to low-end e-paper applications.

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