31.3 *Invited Paper*: Single-Layer Color Cholesteric Liquid Crystal Displays

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Abstract

The authors report methods of fabrication single-layer color cholesteric liquid crystal displays (CLCDs). A single-layer CLCD has been prepared from a polymer-stabilized cholesteric liquid crystal. The unique feature of the polymer stabilization is in that the electrically switched colors preserve high reflectivity. A bistable single-layer CLCD has been prepared by the formation of polymer barrier walls and light-tuned cholesteric pitches to reflect blue, green and red color sub-pixels.

1. Introduction

Color reflective flat panel displays are desired in many portable devices ranging from electronic-papers, electronic-books, mobile displays to electronic sign displays. Among the available display technologies, cholesteric reflective displays are particular suitable for these display applications as the bistability feature enables the image to be displayed at zero voltage and the power is only needed for refreshing image.

Cholesteric liquid crystals are unique for electro-optics application in that they can be tailored to reflect light at a pre-selected wavelength and bandwidth at a planar structure arising from the helical structure. Consequently, an incident light will be circularly reflected with the same handedness as that of the cholesteric, while the opposite handedness component will be circularly transmitted.[1] The selective reflection from a cholesteric liquid crystal makes it possible to generate different color and enables vivid color images to be displayed without a color filter and crossed polarizers. In responding to a voltage pulse applied in the direction parallel to the helixes, the cholesteric can be deformed and become a focal conic state, in which incident light is transmitted or weakly scattered. With a black absorbing layer coated at the rear substrate, the display appears black. Both the planar and focal conic states are stable at zero voltage.

Color reflective cholesteric displays can be fabricated by using either a single-panel or stacked-panels method.[2-7] A high brightness color CLCD can be prepared by using stacking technique. The stacked-panels technique provides a feasible solution of reflective cholesteric LCDs to display full color. Although this approach makes maximum brightness of the color panels, volume manufacturing of color CLCDs using stacked-panel technology requires to overcome the cost and yield such as driver and pixel registration issues.

2. Electrically-Switched Colors

It was reported that applying voltage in the direction parallel to helical axis enables the color tuning in cholesteric liquid crystals by extending the helical pitches or inducing tilt of helixes.[8-12] The electric-field induced color change in cholesteric liquid crystals color can be traced back to the late 1960's. In general, the cholesteric liquid crystal in response to applied voltage by the rotation of the cholesteric helix away from normal direction of substrate surface. As a result, the reported electrically tunable color displays are high switching voltage and low reflectivity. In addition, the focal conic state is unavailable be used in which the switched color requires the voltage on to display the desired color. The other shortcoming of this approach is small color shift because of insufficient cholesteric pitches to reflect incoming light in the normal direction to surface. In this work, we present an electrically switched color cholesteric display with high reflectivity.

In reference to Fig. 1, the central reflected wavelength is switchable by an electric field applied in the direction parallel to the helical axis. Under a strong surface anchoring condition, the cholesteric pitches at the boundary are less affected by the field. However, the pitches in the bulk are deformed or unwound by the field because of weak anchoring and thus, the pitches in the middle layers are extended. Consequently, the liquid crystal molecules in the bulk start to compress the pitches near the boundary layers so the pitches near the boundary layers are shortened. Thus, the reflected wavelength is blue-shifted in corresponding to a shorter pitch.

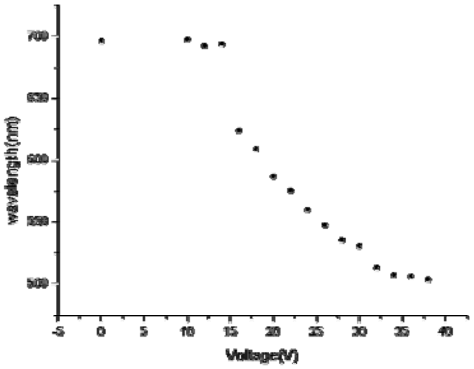

Figure 1. The reflected wavelength vs. applied voltage.

Because the oriented liquid crystal molecules are no longer in a planar structure so the number of layers contributes to the reflectance decreases. Therefore, the reflectance is significantly decreased with increasing in voltage.

We introduce a low concentration of polymer networks to stabilize more helices in a planar state to avoid the significant decrease in reflectance with increasing voltage. In Fig. 2a, it is shown that the reflectance after the application of the field is improved. In the meantime, the reflected central wavelengths are still electrically tunable. The reflected central wavelength is linearly tunable by a range as much as 135nm as shown in Fig. 2b.

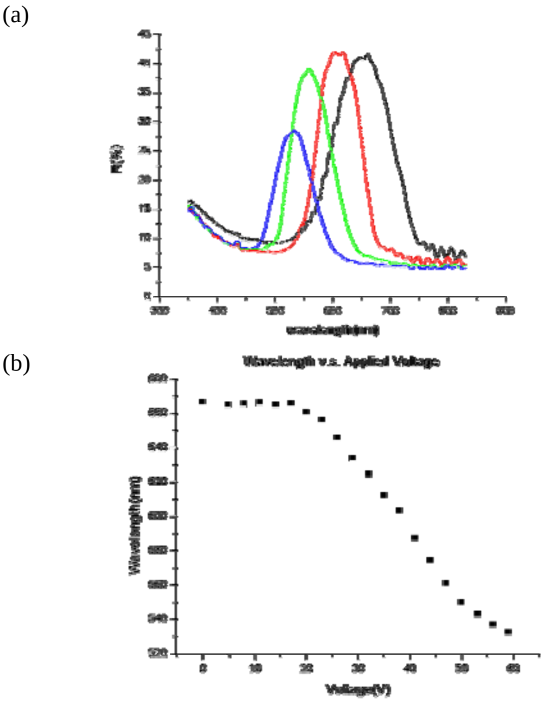

Figure 2. (a) The reflectivity of electrically switched color and (b) the reflected central wavelength vs. applied voltage.

Figure 3 shows the chromaticity diagram calculated according to CIE 1931 of electrically-switched colors of a polymer stabilized cell. The color change with the increase in applied voltage can be easily observed from the pictures taken directly from the cell as shown in Fig. 4.

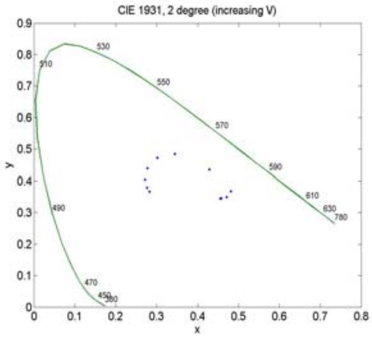

Figure 3. 1931 CIE Chromaticity diagram from reflection of polymer stabilized cholesteric liquid crystals.

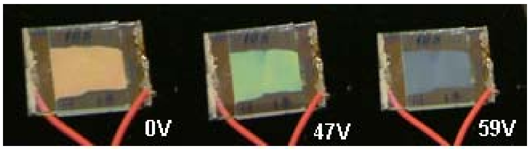

Figure 4. Photos of single-layer electrically switched colors.

At zero applied voltage, the cell shows a good thermal stability in both heating and cooling process. Unlike the variation of pitch with temperature change in cholesteric liquid crystals, the cell with polymer network suppresses the pitch elongation as the temperature increased. As shown in Fig. 5, the deviation in reflected wavelength from room temperature up to 60°C is negligible. The decrease in reflected wavelength beyond 60°C is because of the liquid crystal approaching the isotropic transition temperature, in which the extended helical pitches in mid layers compress those at the boundary layers.

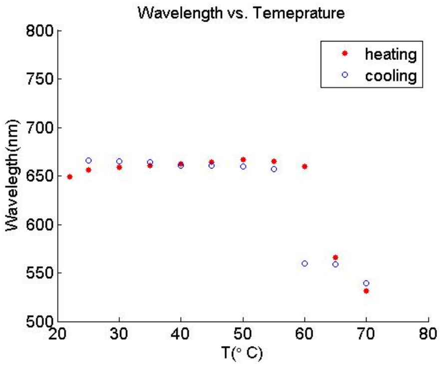

Fig. 5 Thermal stability of a single-layer color CLCD.

3. Color Pixelation

A single-layer color reflective CLCD also can be made by a color pixelation method. The display has three sequential color stripes with different cholesteric pitches reflecting blue, green and red from a single cholesteric liquid crystal. Building polymer walls between the color pixel stripes are necessary to prevent color diffusion. In general, the fabrication of a color-pixelated CLCD includes two steps. First, the polymer walls have to formed at the inter-pixel area via photopolymerization-induced phase separation through a photomask. Subsequently, color pixelation is achieved by light-induced pitch change in desired color stripes using appropriate masks. Upon interacting with light the tunable chiral dopant in the cholesteric mixture undergoes a photo-racemization and changes the total chirality of the mixture depending on the light doseage. In general, a cholesteric mixture for color pixelation comprises of a commercially available photomonomer (19%) and a cholesteric liquid crystal (81%). The cholesteric liquid crystal consists of 75.5% of cholesteric liquid crystal and 5.5% of a tunable chiral dopant to give a reflected wavelength λ_R = 440 nm. The mixture is loaded into an electro-optical cell with homogeneous alignment layers and five-micron cell gap. The method of the formation of polymer walls and a color pixelation CLCD illustrated in Figure 6.

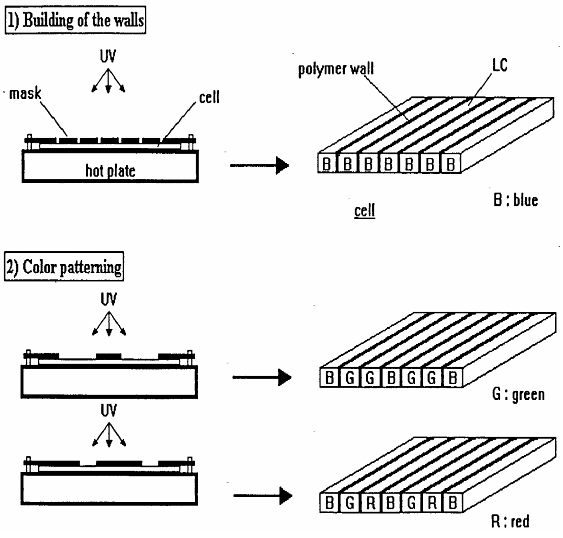

Figure 6. The graphic illustration of polymer walls formation and color piexlation of a CLCD with photomasks.

The reflection wavelength of the cholesteric material is then controlled by the amount of UV exposure, which allows the selective adjustment of the pitch of a cholesteric pixel stripe. The photo-induced pitch change is UV dose dependent. Photo-induced racemization of chiral dopants resulted in the reduction in chirality and thus, the reflective color.

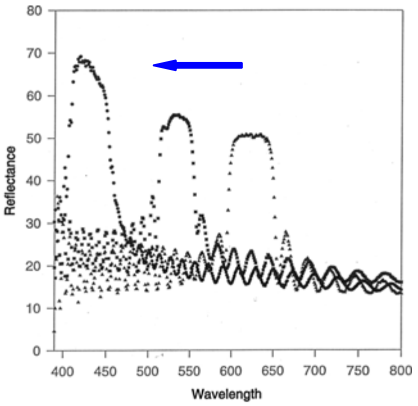

Figure 7. The the reflectance vs. wavelength of a pixilated color CLCD. The arrow represents the color change with increase in UV dosage.

The progressive blue-shift in reflection wavelength is because of the extension of cholesteric pitch as the increase in UV dosage. The reflectance of the CLCD with photo-tuned color, measured under diffuse illumination in an integrated sphere, is around 35%. Figure 7 shows the center reflection wavelengths for the three photo-tuned colors at 440 nm, 540 nm, and 635 nm. The calculated color coordinates, base on the 1976 CIE chromaticity chart, for the blue, green and red are (0.1846, 0.2037), (0.2855, 0.4628), and (0.4897, 0.3669), respectively.

We studied the optical responses as function of applied voltage pulses of a color pixilated CLCD. The results of electro-optical measurement are shown in Figure 8. The pixilated color CLCD is a bistable reflective display, which means the switched color or dark state is stable at zero voltage. Depending on the addressed voltage, the display can be either at the reflective state (planar texture) or at the transmission state (focal-conic texture). The pulse width and frequency of applied voltage are 40 ms and 1 kHz, respectively. The reflectance is measured after the applied pulse in an integrated sphere calibrated with MgO coated substrate as standard white state.

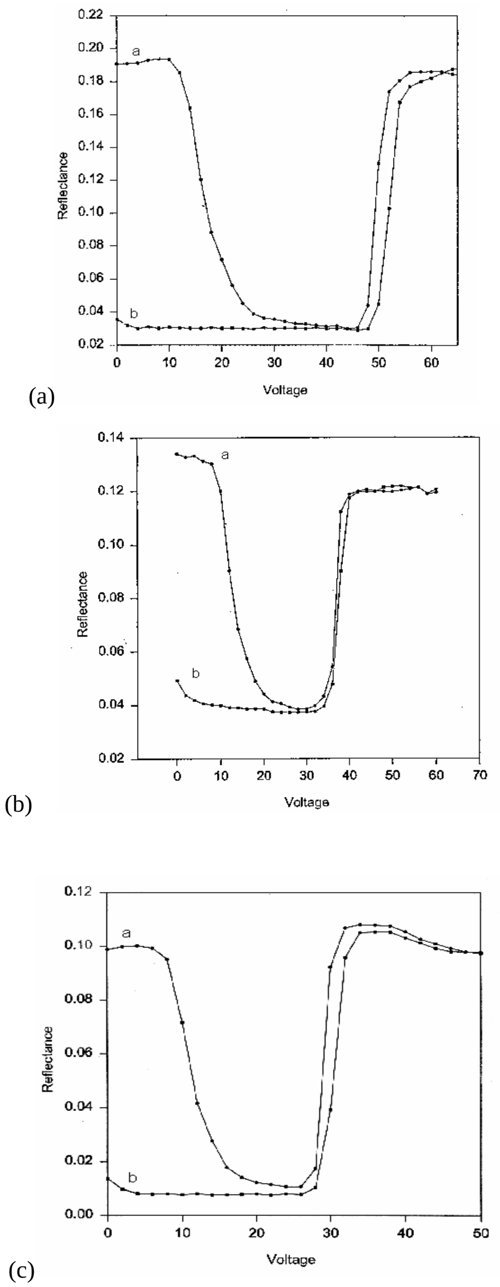

Figure 8. The responses of the three photo-tuned colors, (a) blue, (b) green and (c) red, to applied voltage pulses: curve a, planar texture at zero field; curve b, focal-conic texture at zero field.

As the increase in applied voltage, the cholesteric initially at the planar state (curve a) is switched to focal conic state at voltages of 24V, 20V, and 16 V for the blue, green, and red pixels, respectively. The cholesteric stays at the focal-conic texture until the applied voltage pulses exceed the voltages of unwinding helix. At voltage pulses of 52V, 42V, and 32V, the cholesteric is switched to homeotropic texture. Quickly turned off the voltage pulse, the cholesteric relaxes into planar texture. In case of the cholesteric initially at the focal-conic texture (curve b), at applied voltage pulses of 52V, 42V, and 32V for blue, green and red, respectively, the pixels are switched to planar texture. A bistable single-layer color CLCD is shown in Fig. 9.

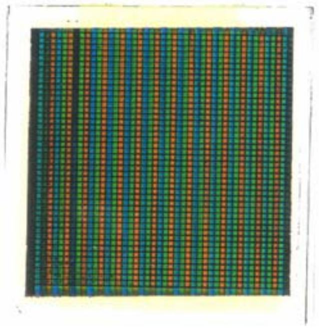

Figure 9. A 2”x2”, 22 dot-per-inch color-pixelated CLCD.

4. Conclusion

We have demonstrated methods of fabricating single-layer color cholesteric liquid crystal displays. A single-layer color reflective cholesteric display with polymer network enables the high color reflectivity of electrically-switched color and good thermal stability. Bistable single-layer color cholesteric displays can be prepared by color pixelation of a single color mixture and formation of polymer walls at inter-pixel area.

5. References

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