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# Tunable colors of chiral liquid crystal displays

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## Abstract

We report a method of the color variation in the reflective CLC displays depending on thermo-dynamically and the electric field switching. The reflective wavelength can be thermodynamically switched to reflect green from a cell initially reflecting a red color. Afterwards, the reflective wavelength can be electrically switched to reflect blue color. It is found that continuous decrease of the pitch is mainly originated from the dopant solubility below the critical temperature and stepwise decrease of the pitch is dominantly affected by the thermodynamic property above the critical temperature. The blue color change is a result of the compression to the helical pitches in planar layers in response to the applied voltage.

**Keywords:** reflective CLC, color variation, helical pitche, thermo-dynamically and electrically switching.

## 1. Introduction

Cholesteric liquid crystals (CLCs) have many merits for applying to color flexible displays since the optical components such as polarizer, color filter, and backlight unit are not required in the reflective CLC displays. The reason is that CLCs, characterized by helical structures, can uniquely separate incident light into its left- and right-handed circular components by selective reflection and transmission. Planar-aligned CLCs with preselected helical pitch can only generate light at a single Bragg-reflected wavelength. CLCs have a helical structure due to the helical twisting power of the chiral dopants mixed in host nematic LC. The director of CLCs has the uniformly twisted arrangement along a perpendicular axis called the helical axis [1]. Due to the unique LC structure, CLC can induce the reflected color with a specific wavelength of the light associated with the CLCs helical pitch. The reflected color of CLCs can be changed by the pitch variation by the external factors. For the application to the electronic paper display, various technologies to diversify the reflected color of CLCs have been investigated such as varying the temperature of the cholesteric LC phase [2], adding different amounts of the chiral compounds [3], using phototunable chiral compounds [4], and applying an external field [1]. Recently, the technology of controlling the pitch by the chiral dopant solubility depending on the temperature is reported. As increasing temperature the chiral pitch decreases in the CLCs due to the effective amount of the solved chiral dopant, contributing the twisting power, increases. It was reported that applying voltage on cholesteric liquid crystal molecules enables the color tuning by extending the helical pitches or inducing tilt of helices. Although those approaches give tunable colors for reflective CLC, they require overcoming the blue color issue.

In this work, we present a technology of the color variation in the reflective CLC displays depending on the thermodynamically and electrically switching. The reflective wavelength can be thermodynamically switched to reflect green from a cell initially reflecting a red color and then electrically switched to reflect blue color. We could find that continuous decrease of the pitch is mainly originated from the dopant solubility below the critical temperature and stepwise decrease of the pitch is dominantly affected by the thermodynamic property above the critical temperature. The blue color change is a result of the compression to the helical pitches in planar layers in response to the applied voltage.

## 2. Concept

The proposed reflective colors are a two-stage process as shown in Fig. 1. First, the reflective color can be thermo-dynamically switched to reflect green color (Fig.1b) from a cell initially reflecting a red color (Fig. 1a). Afterwards, the electrically switched reflective color can be shifted to increase in applied voltage at the temperature. The switchable reflection peak occurs due to a pitch change of the cholesteric in the bulk due to the $2\pi$ twist cholesteric helix of a Helifrich Instability (Fig. 1c). In responding to an applied voltage, the liquid crystal molecules in the bulk start to tilt and squeeze the helix near the boundary layers so the effective pitch which is resulting in the reflected wavelength is shortened. Therefore, the center wavelength of the reflected light is blue-shifted corresponding to a shorter pitch.

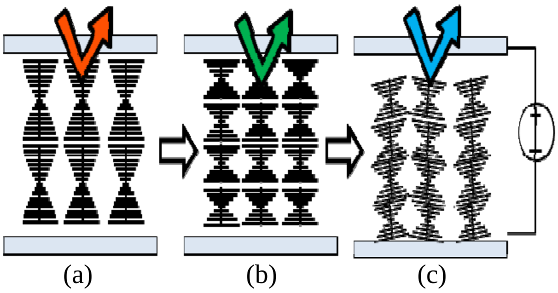


Figure 1. An illustration of tunable color in response to thermodynamically switching and the electric field switching

## 3. Experimental

The helical structure of the CLC was generated by doping R-811 (right handed chiral dopant fromMerck Co.) in the nematic LC of E7 (from Merck Co.). For making the composite uniformly and homogeneously, we stirred in an isotropic phase for 24 hours. The polyimide alignment layer was spincoated on the indium-tin-oxide (ITO) glasses and cured them in the appropriated condition on a hotplate. After rubbing the alignment layer, two rubbed substrates were assembled in anti-parallel direction. The CLC with the uniform cell gap of 5 μm was injected into the assembled cells by capillary action in the isotropic phase. Finally, the experimental cell was cooled down slowly to achieve a planar texture.

The diversification of the reflected color depending on temperature was observed using a microscope mounting on a micro furnace. To confirm the variation of the reflectance spectra of the CLC samples, we measured varying temperature from 25°C to a phase transition temperature of CLC cell with different concentrations of the chiral dopant. The applied voltage is a square wave with a frequency of 1 kHz. As a ramification, the cholesteric liquid crystal in a planar state exhibits a blue shift in reflected wavelength with increasing voltage.

## 3. Results and Discussion

Figure 2 shows the reflected microscopic color of the CLC samples. At room temperature, the ChLC cell reflects red color. With increasing temperature, the helical pitch is shortened due to the thermodynamic behavior as [5]

$$\lambda = A(1+\frac{\beta}{T-T_0})^2 \quad (1)$$

where A, β, and $T_0$ are a molecular thermodynamic factor, an empirical thermal sensitivity, and phase transition temperature, respectively. Therefore, the reflected color varied from initial red to green as shown in Fig. 2(a)~(c).

The cholesteric phase was shown in range from 25 °C to 34°C where perfect planar textures were observed because the substrates with a low pretilt angle and a strong anchoring strength produced a uniform helical structure whose axis was perpendicular to the substrates. However, as shown in figure 2(a) ~ (c), the reflected color was slightly shifted from red to bluish green color under whole temperature range showing the cholesteric phase. This can be explained due to not enough cholesteric pitches held in the planar texture of the cell to obtain reflective blue color. Therefore, the reflected blue color was obtained when the 6.5 voltage was applied at the 34 °C, as shown in Fig 2(d).

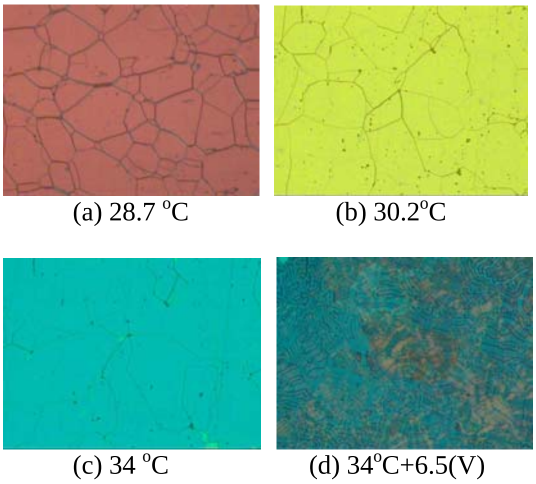


Figure 2. Microscopic textures of the change in reflected colors at different temperatures of the CLC samples; (a) 28.7 °C, (b) 30.2 °C, (c) 34 °C (d) 34 °C when 6.5(V) was applied

Figure 3 shows the resultant reflectance spectra at three different temperatures (28.7 °C, 30.2 °C, 34 °C) and applied field of 6V, 8V and 10V. First, the reflective wavelength can be thermodynamically switched to reflect green from a cell initially reflecting a red color. The reflectance spectra were measured using the spectrometer with varying temperature and the resultant central wavelengths were evaluated in the cholesteric phase as shown in Fig. 3.

The wavelength-tuning range was to be measured from 480 to 650 nm. With increasing temperature, the corresponding helical pitch goes stepwisely down due to the surface boundary conditions against the thermodynamic behavior of the LC molecules. In this condition, the pitch variation by increase of the helical twisting power of the chiral dopant within the cholesteric phase just depends on the thermodynamic properties of the CLC molecules [6].

Afterwards, the electrically switched reflective wavelength is linearly proportional to the applied voltage beyond 10V with a maximum alteration range of 450 nm from the original planar state at 34 °C. Therefore, we are able to shift the reflection peak toward blue for about 450nm with the increase in applied voltage.

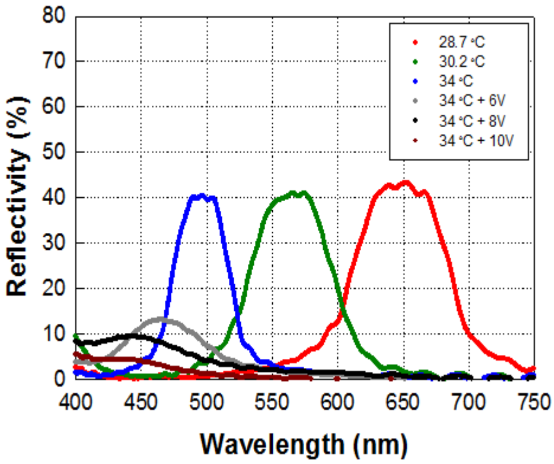


Figure 3. The reflected wavelength as a function of temperature and applied voltage at 34 °C

## 4. Conclusion

In this work, we have proposed a technology for expanding the range of color variation of CLC cell by controlling the temperature and applied voltage. The corresponding wavelength rapidly goes down due to both contribution of the thermodynamic behavior. The helical pitches were controlled by temperature based on the thermodynamic behavior of the ChLCs. The reflection blue color is tunable after the electric field is switched on. We are able to shift the reflection peak toward blue for about 450nm with the increase in applied voltage.

## Acknowledgements


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