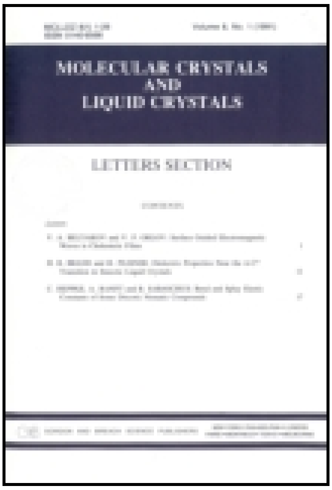

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High Reflectance of Cholesteric Liquid Crystal Reflector by Double-Layer Structure

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Cholesteric liquid crystal (CLC) has a helical structure with either of left-handedness or right-handedness. Due to the helical structure, the selective reflection occurs depending on the chrial pitch. However, the reflectance of the CLC layer is theoretically limited to 50% because only one of right- or left-handed circularly polarized light is reflected. In this paper, we demonstrate high reflectance with double layer structure for the color reflector application.

Keywords: Liquid crystals; cholesteric; reflective mode; high reflectance

1. Introduction

Recently, there are many researches about e-paper, and the one of the e-paper is using the cholesteric liquid crystal (CLC).[1–10] Due to the bistability and low power consumption, the Ch-LCD is applied to various application area. A color reflector is also a potential application area of the CLC device. Generally, when an unpolarized light is incident into a cholesteric LC layer with the right-handedness, the left-handed circularly polarized light within the bandwidth is reflected only, so the reflectance is limited to 50% [11]. In order to improving the reflective we can change the structures of Ch-LC, which can reflect the left-handed circularly polarized light and right-hand circularly polarized light. In this paper, we investigative the high reflective Ch-LCD using two layers including in right-hand Ch-LC and left-hand Ch-LC. We fabricated red, green and blue two layers' cells, and invested the optical characteristics using the measuring system.

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2. Simulation Results

From the right-handed CLC layer, Left-handed circularly polarized light is reflected. By using coupled mode analysis, optical properties of CLC layer can be calculated.[11, 12] By assuming the light propagates along the z-axis, therefore the direction for electric field of the light is located on the xy plane. The dielectric tensor of the right-handed CLC layer can be written

$$\varepsilon(z) = \varepsilon_0 \begin{pmatrix} \beta & 0 \\ 0 & \beta \end{pmatrix} + \varepsilon_0 \alpha \begin{pmatrix} \cos 2qz & \sin 2qz \\ \sin 2qz & -\cos 2qz \end{pmatrix} \tag{1}$$

where

$$\beta = \frac{1}{2}\left(n_e^2 + n_o^2\right) \tag{2}$$

$$\alpha = \frac{1}{2}\left(n_e^2 - n_o^2\right), \tag{3}$$

q is related to the chiral pitch by $q = 2\pi/P_0$.

The total electric field is represented by the sum of the field of the incident light and reflected light.

$$\mathbf{E} = A(z)\begin{pmatrix} 1 \\ i \end{pmatrix} e^{i(\omega t - kz)} + B(z)\begin{pmatrix} 1 \\ -i \end{pmatrix} e^{i(\omega t + kz)} \tag{4}$$

where A(z) is the amplitudes of the incident light and B(z) is that of reflected light. This satisfies the wave equation.

$$\frac{d^2}{dz^2}\mathbf{E} + \omega^2 \mu \varepsilon \mathbf{E} = 0 \tag{5}$$

Substituting Eq. (4) for the electric field into Eq. (5) of wave equation and by using Eq. (1) for the dielectric tensor for CLC layer, the relation between A and B is obtained:

$$\frac{d}{dz}A = -i\kappa B e^{i\Delta kz}, \quad \frac{d}{dz}B = i\kappa A e^{-i\Delta kz} \tag{6}$$

where

$$\Delta k = 2k - 2q \tag{7}$$

$$\kappa = \frac{\pi \alpha \sqrt{2}}{\lambda \sqrt{n_e^2 + n_o^2}} \tag{8}$$

From the Eq. (6), by eliminating B(z) and after a few steps, a second order differential equation is obtained. Let the light be incident at $z = 0$ and the thickness of the CLC layer be L. we can have the boundary condition of $B(L) = 0$.

$$\frac{d^2A}{dz^2} - i\Delta k \frac{dA}{dz} - \kappa^2 A = 0 \tag{9}$$

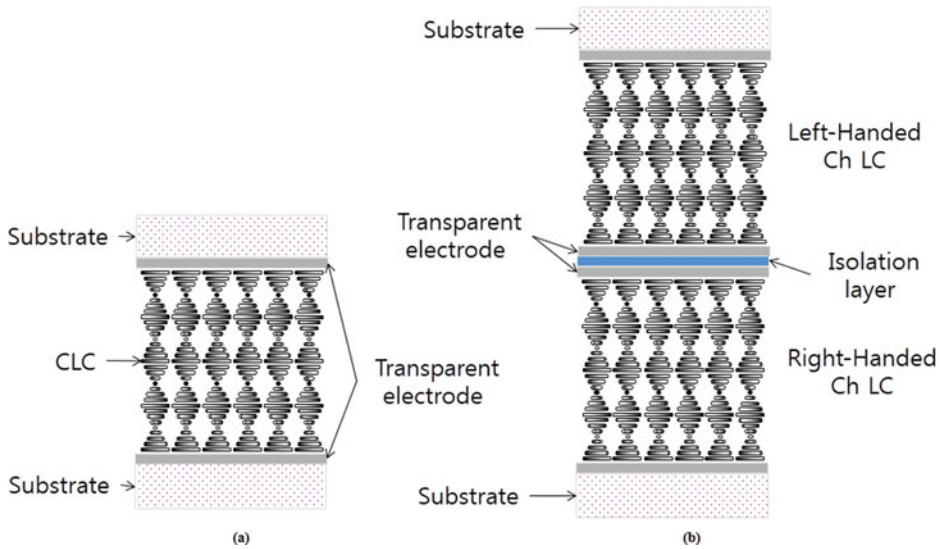

Figure 1. CLC cell structure of (a) the single layer and (b) the double layer.

After solving the second order differential equation, the expression for reflectance is obtained.

$$R = |r|^2 = \frac{\kappa^2 \sinh^2 sL}{s^2 \cosh^2 sL + \left(\frac{\Delta k}{2}\right)^2 \sinh^2 sL} \tag{10}$$

where

$$s^2 = \kappa^2 - \left(\frac{\Delta k}{2}\right)^2 = \kappa^2 - (k - q)^2 \tag{11}$$

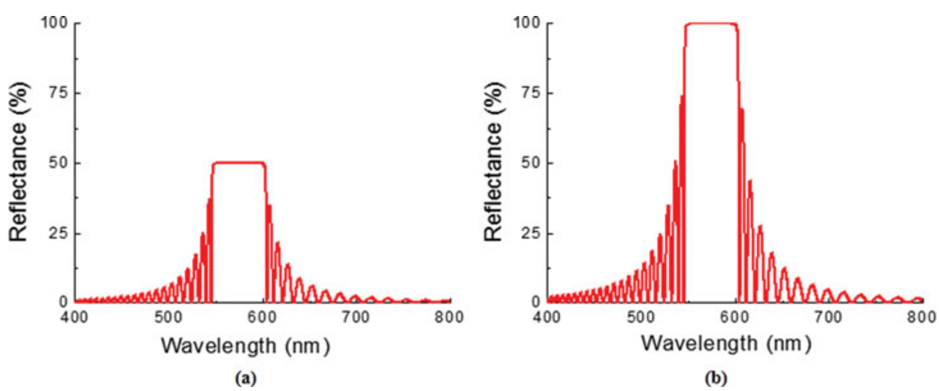

Figure 2. Calculated reflectance from (a) the single CLC layer and (b) the dual CLC layer.

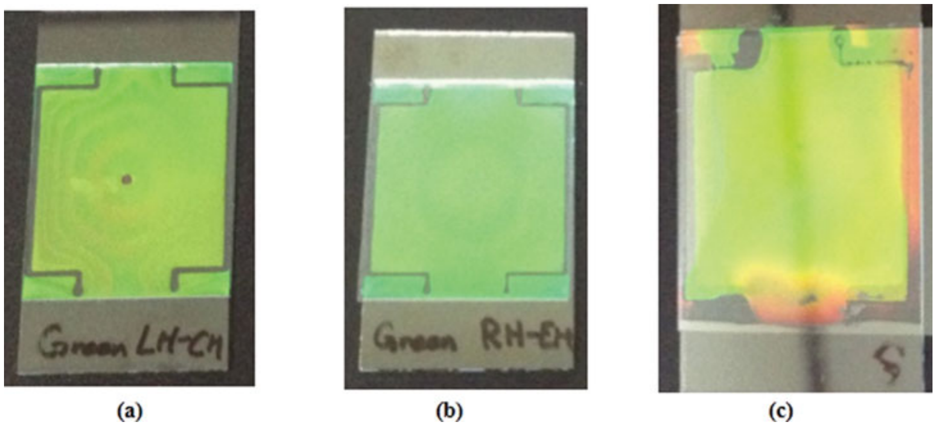

Figure 3. Fabricated test cell: (a) the LH-CLC cell, (b) the RH-CLC cell, and (c) the dual CLC cell.

On the other hand, from the Left-handed CLC layer, the reflectance for right-handed polarized light can be calculated by the similar way. From the Eq. (10), we can expect there is no difference between the reflectance from the cholesteric layer the left-hand sense, if the chiral pitch of two CLC layers is the same. In the case of stacking CLC layer with the opposite chiral sense. The reflectance can be maxized because the CLC layers reflect both the circularly polarized light.

We have calculated the reflectance from each CLC layer with opposite chiral sence and that from the stacking CLC layer with opposite chiral sence which is shown in Fig. 1.

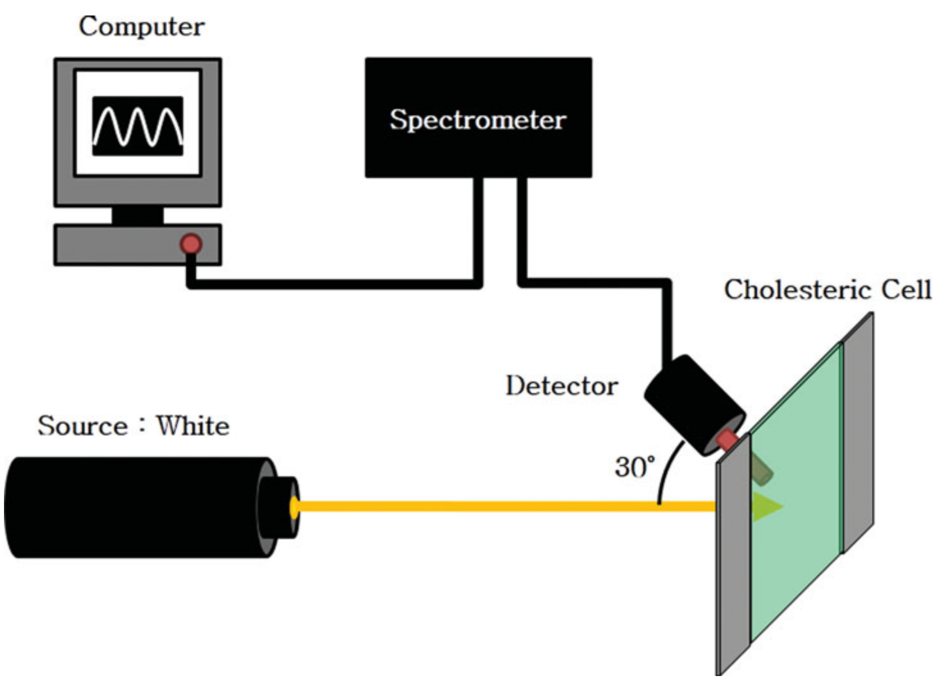

Figure 4. Schematic diagram of the measuring system for reflectance.

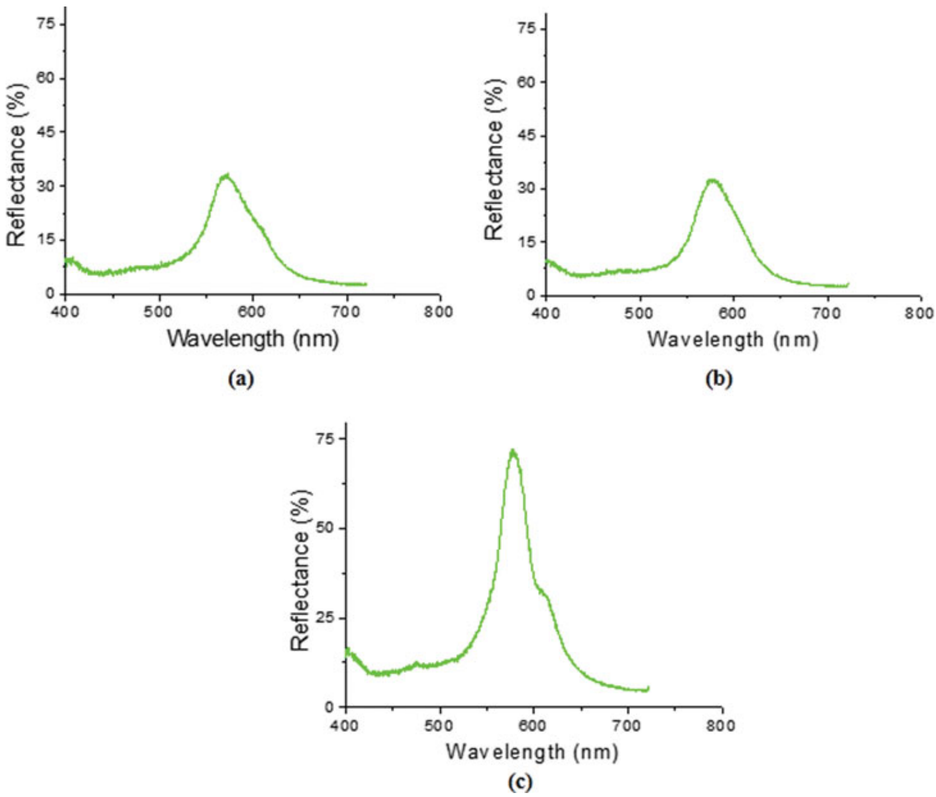

Figure 5. Measured reflectance of (a) the LH-CLC cell, (b) the RH-CLC cell, and (c) the dual CLC cell.

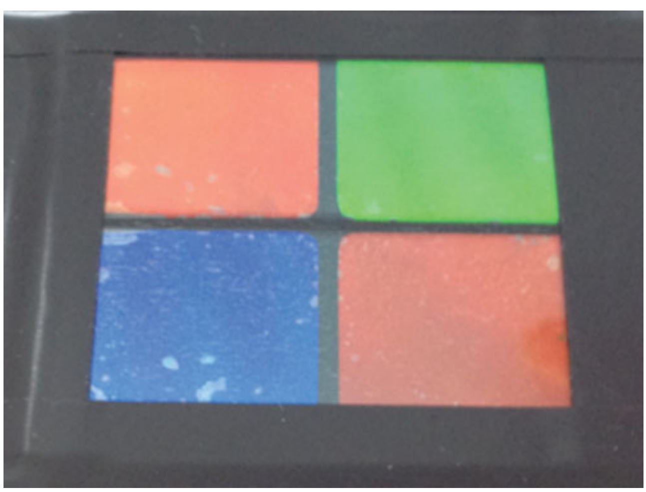

Figure 6. Color reflector with double layer structure by the pixel division method.

The parameters used in the numerical calculation are as follows: liquid crystal MLC-6650; Optical anisotropy n = 0.1498, $n_e = 1.6495$, $n_o = 1.4997$, the chiral pitch = 365.2 nm. The reflectance of the single CLC layer was 50% and with the dual structure, we can obtain the reflectance of 100% as shown in Fig. 2. When unpolarized light is incident into the 7single CLC layer, although one of the circularly polarized light is only reflected, both the circularly polarized light can be reflected from the two CLC layers with the opposite chiral sense.

3. Experimental Results

To clarify the effect of the dual structure, we fabricated several test cells. The structure of the test cell is shown in Fig. 1. Two substrates sustained by the spacer with the diameter of 9 um. Each test cell was filled with the LC material MLC-6650 whose optical anisotropy is 0.1498 as mentioned before. For the dual structure, we used isolation layer. The thickness of the isolation layer, which is made of PET film, is 200 um. The transparent electrode is coated on the both surfaces which can be used as ground electrode.

The schematic diagram of the measuring system for reflectance is described in Fig. 4. The halogen lamp was used for the white light source. The light source was incident to the cell in normal direction. Detector is located at the angle of 30 to the normal direction. Reflectance was measured by the spectrometer as shown in Fig. 5. The measured reflectance was normalized by the incident luminance, Halogen lamp produces a yellowish-white light. With the single CLC layer, the peak reflectance was about 33%. The peak reflectance of 75% was obtained with double CLC layer.

By using the pixel division method, color reflector with the dual structure can be fabricated. The glass substrate and the isolation layer are sustained by the spacer with the diameter of 9 um. It is divided into four sub pixels. The different color CLCs with the right-handedness are respectively filled into each of the color sub-pixel. Another glass substrate and the isolation layer of the fabricated CLC cell are sustained by the same spacer. It is divided into sub pixels again. The color CLCs with the left-handedness are respectively filled into each of the same color sub-pixel. The fabricated color reflector with dual structure with four pixels as shown in Fig. 6.

4. Summary

The reflectance in the single cholesteric liquid crystal layer is theoretically limited to 50% because with the right-hand CLC layer, Left-handed circularly polarized light is reflected and vice versa. To improve the reflectance, we proposed the double CLC device which including the isolation layer. With our device, not only the right-handed circularly polarized light, but also the left-handed circularly polarized light is simultaneously reflected. Therefore, we obtained the reflectance of about 75%. We also fabricated color reflector with double layer structure by the pixel division method.

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