

Multicolor Cholesteric Liquid Crystal Display in a Single-Layered Configuration using a Multi-Pitch Stabilizations

Kwang-Soo Bae¹, Yeong-Joon Jang², Yeon-Kyu Moon¹, Sung-Gon Kang², Uiyeong Cha², Chang-Jae Yu^{1,2}, Jae Eun Jang³, Jae Eun Jung³, and Jae-Hoon Kim^{1,2*}

¹Department of Information Display Engineering, Hanyang University, 17 Hangdang-dong, Seongdong-gu, Seoul 133-791, Korea

²Department of Electronics and Communications Engineering, Hanyang University, 17 Hangdang-dong, Seongdong-gu, Seoul 133-791, Korea

³Display Laboratory, Samsung Advanced Institute of Technology, Yongin, Gyeonggi-do 446-712, Korea

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We report a cholesteric liquid crystal (ChLC) display with multicolor in a single-layered configuration using a multi-pitch stabilization by reactive mesogen (RM). The cholesteric pitches were modulated by temperature and stabilized at room temperature by polymerization of the RMs through ultraviolet (UV) exposure. In a single-layered ChLC display without any additional layer such as a color filter, multicolor was obtained by a multi-pitch stabilization through spatially selective UV expose at several temperatures. © 2010 The Japan Society of Applied Physics

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1. Introduction

The printed (or written) paper has been a superior display medium for a long time due to its attractive characteristics such as foldable, unbreakable, portable, and anywhere readable features. In spite of these excellent properties, the printed or written information is impossible to update new one in this paper. In addition, with increasing amount of information, the exponential increase of the paper consumption gives rise to environmental problems. In this circumstance, the electronic paper has attracted much attention for its information updatability possessing the excellent features of the classical paper. The variety of the technologies for the electronic papers have been proposed such as electrophoretic displays,¹⁻³ electrochromic displays,⁴ electrowetting displays,⁵ zenithal bistable displays,⁶ and cholesteric liquid crystal (ChLC) displays.⁷⁻⁹ Except for the ChLC displays, additional complex processes and/or color-controlling units for performing full colors are involved.

In general, the ChLC displays do not require the color filter and the polarizers due to the selective reflection of the ChLCs matching the helical pitch. The ChLCs are typically prepared by doping a chiral agent into a nematic LC and the resultant helical pitch is governed by concentration of the chiral dopant. Due to the chirality, the LC molecules are arranged in a twisted structure perpendicular to a helical axis.¹⁰⁻¹² The helical pitch and twisted sense govern the wavelength and circular polarization state of the reflected light, respectively. In principle, as a result, a full color ChLC display might be fabricated without the color filter and the polarizers. The various technologies have been used for tuning colors by controlling temperature,^{13,14} applying an external electric field,^{7,8} and using phototunable chiral compounds.⁹ The various pitches were stabilized with photopolymers in a single-layered configuration.^{9,10,15} However, these methods are limited in the number of the fixed colors and/or the switching properties of the ChLC displays.

In this work, we demonstrated a multi-color ChLC display in a single-layered configuration using multi-pitch stabilization with the reactive mesogen (RM). The various pitches were controlled by temperature and stabilized by the polymer-networks through the spatially selective exposure

of ultraviolet (UV) light. The reflected color corresponding to the helical pitch is shortened with increasing temperature due to the thermodynamic behavior of the LC molecules.¹⁴ The three different colors from red to bluish green were recorded in the single ChLC cell. In addition, this technology is applicable to the flexible displays and is expected to become a viable technology to apply the electronic paper displays.

2. Experiment

The ChLC mixture used in this work consists of a host nematic LC (62.7 wt %, Merck E7), a chiral dopant (29.5 wt %, Merck R811), RM monomer (6.4 wt %, Merck RM257), and photo-initiator (1.4 wt %, Ciba Speciality Chemicals Irgacure 651). Here, R811 generates a helical structure of the LCs in right-handedness and RM257 stabilizes the helical pitch through polymerizing itself initiated by Irgacure 651. The chemical structures of these constitutive molecules used here are shown in Fig. 1(a). The ChLC mixture was stirred in an isotropic phase for 24 h and injected between sandwiched glass substrates by capillary action in the isotropic phase. The inner surfaces of the sandwiched substrates were coated with polyimide alignment layer and rubbed antiparallely for planar alignment. Figure 1(b) shows a schematic diagram of our single-layered ChLC cell with multicolors. The cell thickness was maintained by the use of 6 μm stripe spacers formed by photolithography of SU-8 (MicroChem). After injection of the ChLC mixture, we cooled slowly down to room temperature for obtaining a stabilized planar texture reflecting red color. To fix the helical pitch (that is, fix the color), the UV light (mercury lamp) was exposed for 10 min through a photomask at different temperatures (25, 28, and 35 °C). The helical pitch was shortened with increasing temperature and fixed by polymerization of the RM through UV exposure even cooling down to room temperature.

For measuring the reflectance of the ChLC cells at different temperatures, a polarizing optical microscope (Nikon E600 Wpol), a fiber optic spectrometer (Ocean Optics S2000), and a microfurnace (Mettler Toledo FP90 and 82) were used. The polymer-networks were observed by a field emissive scanning electron microscope (FESEM; Hitachi S-4800) after detaching the sandwiched cell and washing off the LC with hexane for 10 min.

*E-mail address: jhooon@hanyang.ac.kr

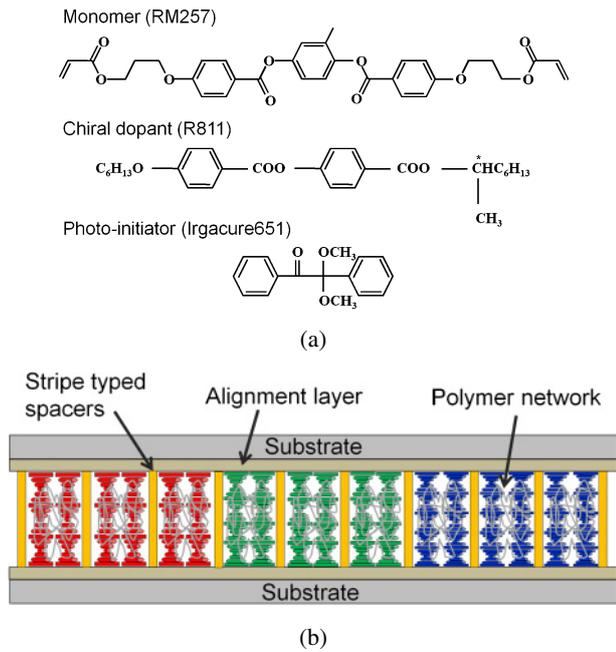


Fig. 1. (Color online) (a) The chemical structure of the constitutive molecules used here and (b) the schematic diagram of the our single-layered ChLC cell with multi-colors.

3. Results and Discussion

Figure 2 shows a color variation of the ChLC cell depending on temperature without the RM and photo-initiator. At room temperature, the ChLC cell reflects red with the central wavelength of 620 nm. With increasing temperature, the helical pitch is shortened due to the thermodynamic behavior as¹⁴⁾

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

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 and bluish green as shown in Fig. 2(a). In our cell, the cholesteric phase was shown in range from 25 to 35 °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. 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. 2(b). The wavelength-tuning range was to be measured from 520 to 800 nm. With increasing temperature, as shown in Fig. 2(b), the corresponding helical pitch goes stepwisely down due to the surface boundary conditions against the thermodynamic behavior of the LC molecules.^{12,13)}

Next, we stabilized the helical pitch even at room temperature with polymerization of the RMs by UV exposure through an amplitude photomask at different temperatures (25, 28, and 35 °C). Figure 3 shows the reflected microscopic textures and the resultant reflectance spectra obtained at three different areas corresponding to UV

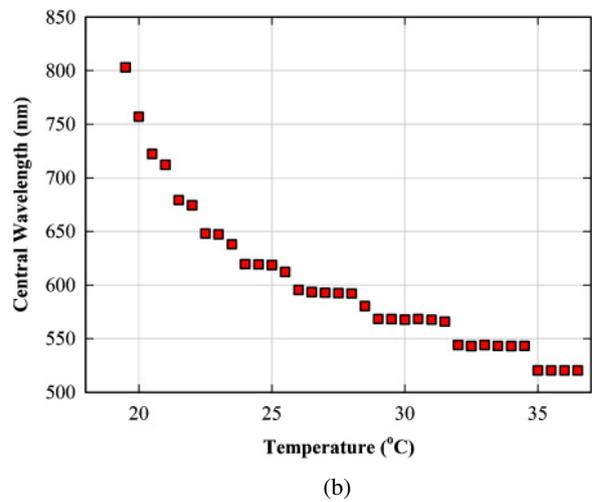
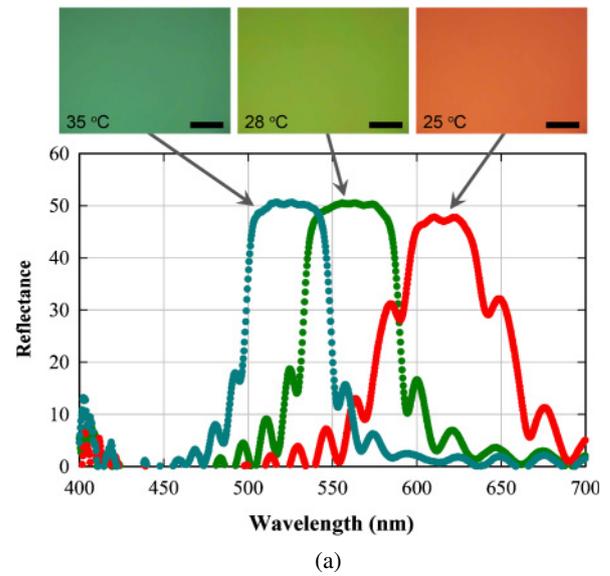


Fig. 2. (Color online) The reflective color variation of the ChLC cell without the RM and photo-initiator depending on temperature. (a) The microscopic textures and the corresponding reflectance spectra at 25, 28, and 35 °C. (b) the central wavelength of the reflectance spectra as a function of temperature. Here, the black scale bars in the textures are 200 μm.

exposed regions at three different temperatures in a single cell. Here, black lines in the textures represent the stripe-typed spacers fabricated with SU-8 to maintain the cell thickness. All textures and spectra were obtained at 25 °C. At a given temperature, the spatially selective UV exposure generates polymerization of the RM and forms polymer-networks in the ChLC cell. The polymer-networks act as micro-structural boundaries in a bulk region and thus the helical pitch was fixed against thermal relaxation even cooling down. From the reflectance spectra, the corresponding central wavelengths in the UV exposed regions at 25, 28, and 35 °C were measured to be 630, 560, and 525 nm, respectively. However, broadening of the reflectance spectrum in Fig. 3 was originated from the helical pitch broadening and the helical axis disordering of the ChLC due to the polymer-networks. As a result, the uniformity of the helical structure was slightly disturbed by the polymer-networks and thus the fabric textures were observed.

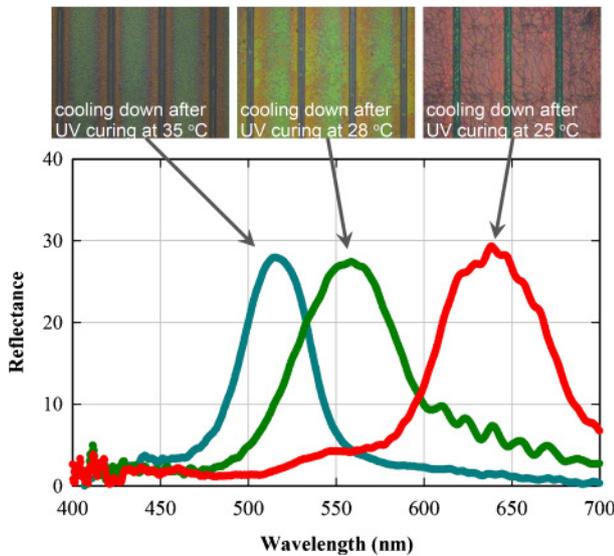


Fig. 3. (Color online) The microscopic images and the corresponding reflectance spectra of the different regions exposed UV light at three different temperatures, 25, 28, and 35 °C. All textures were obtained at room temperature (25 °C). The black stripes in the textures represent stripe-type SU-8 spacers with 30 μm wide. The interval between the stripe spacers is 300 μm.

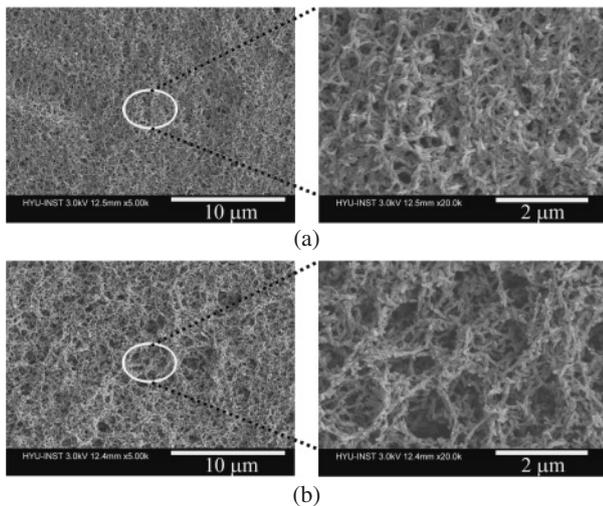


Fig. 4. The FESEM images of the polymer-networks formed by UV exposure at (a) 35 and (b) 25 °C.

Figure 4 shows the FESEM images of the polymer-networks formed by UV exposure at 25 and 35 °C. To observe the polymer-networks, the sandwiched cell was detached and the LC molecules were washed off with hexane for 10 min. From Figs. 4(a) and 4(b), it was found that the network structure formed at low temperature (25 °C) was more coarse than that formed at higher temperature (35 °C). In general, the morphology of the polymer-networks is correlated to the monomer solubility within the host materials.¹⁷⁾ In the case of low solubility, the LC-monomer mixture is locally phase-separated and thus the coarse network is formed during polymerization of the monomers. On the other hand, in the case of high solubility, the monomers are well-dispersed in the host LC and the fine network is formed. With increasing temperature, in our

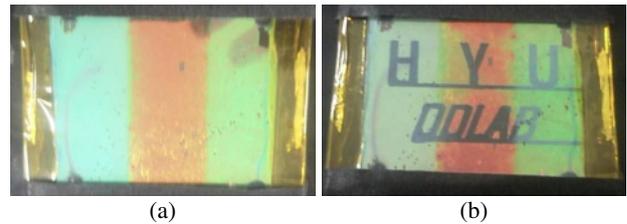


Fig. 5. (Color online) Prototypes of our single-layered ChLC cell with different colors (a) in the absence of an applied voltage and (b) in the present of the voltage (applying only characters part).

case, the monomer solubility gradually increases and thus the finer network is obtained as shown in Fig. 4. It should be noted that the grain size of the network does not directly correspond to the helical pitch. These polymer-networks give rise to local anchoring force in bulk regime of the sandwiched ChLC cell. Therefore, the helical pitches determined by UV exposure at higher temperatures (28 and 35 °C) could be fixed even cooling down to room temperature.

The multi-color ChLC display can be demonstrated in the single-layered configuration by the multi-pitch stabilization using the temperature control and the spatially selective UV exposure. A prototype of a 2-in. ChLC display with multi-colors (red, green, and bluish green) in a single-layered configuration was shown in Fig. 5. Each pixel with the different reflective colors has 1.5 cm in width and 3 cm in length. In the absence of an applied voltage, the selective colors corresponding to the stabilized helical pitches in a planar texture were reflected at each region as shown in Fig. 5(a). When the external voltage (40 V) was applied, the transition from the planar to the focal conic textures was occurred and the reflectance was reduced to dark state. As shown in Fig. 5(b), the electric field was just applied to the electrode-patterned characters showing a logo of “HYU” and “DDLAB” and thus the only characters were turned off.

4. Conclusions

We demonstrated the multicolor ChLC display in a single-layered configuration without any additional layers such as a color filter. Our ChLC display was fabricated with the ChLC and RM mixture for multipitch stabilization in the single cell. The helical pitches were controlled by temperature based on the thermodynamic behavior of the ChLCs and memorized by the polymer-networks of the RM through the spatially selective UV exposure. In this work, wide color range from red to bluish green was demonstrated in a single ChLC cell without any additional processes and components. In addition, this technology is applicable to the flexible displays due to the ChLC stabilization of the polymer-networks. This single-layered multicolor ChLC display by multi-pitch stabilization is expected to become a viable display to apply the electronic paper.

Acknowledgment

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