P-131: Multi-Color Cholesteric Liquid Crystal Film by Fixing Helical Pitch with Reactive Mesogen

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Abstract

We propose a multi-color cholesteric liquid crystal (CLC) film in a single-layered configuration with reactive mesogen (RM). The cholesteric pitches are controlled by temperature and memorized by photo-polymerization of the RM. Using the multi-pitch stabilization in a single layer, multicolor CLC display was obtained without any additional components.

1. Introduction

The cholesteric liquid crystal (CLC) displays have attracted much attention in electronic paper applications for their superior features such as full color capability without color filter and/or color controlling unit. Typically the CLCs are prepared by doping some chiral agent into a nematic LC. The mixed chiral dopant gives rise to a helical structure of the nematic LC forming photonic crystals. As a result, the directors of CLCs are uniformly twisted perpendicular to a helical axis [1]. Due to the helical nature of the CLC, an incident light propagating along the helical axis is selectively reflected corresponding to the helical pitch of the CLC. To perform a full color display, the CLC display with wide reflection spectrum in whole visible light should be fabricated through a CLC structure with multiple pitches. Various technologies have been proposed to control the helical pitch of the CLCs by temperature [2-4], an external electric field [5], and phototunable chiral compounds [6]. To apply these pitch-tuning methods to a multi-color CLC in a single-layered configuration, the photoreactive agents for stabilization of various pitches of the CLC were used [7,8].

In this work, we propose a technology of a multi-color CLC display in a single-layered configuration with reactive mesogen (RM). The pitch modulation in the CLC cell is controlled by temperature and memorized by polymerization of the RMs at each given temperature. The helical pitch of the CLC is typically governed by a concentration of the chiral agent and a thermo-dynamic behavior of the LC molecules. With increasing temperature, the chiral pitch and the wavelength of the selective reflection becomes short due to thermodynamic vibration [4]. The multi-pitch CLC cell is prepared with the spatially selective ultra-violet (UV) exposure through a photo-mask at several temperatures within the cholesteric phase. This is applicable to a flexible substrate and thus is expected to become a viable technology to fabricate the electronic paper displays.

2. Experiments

The CLC material used in this work was prepared by doping chiral agent, R-811 (35 wt.%, Merck Co.) into nematic LC, E7 (65 wt.%, Merck Co.). After doping R-811 into E7, the CLC material was mixed with RM monomer, RM257 (7 wt.%, Merck Co.) and photo-initiator, Irgacure651 (1 wt.%, Ciba Specialty Chemicals Inc.). Here, R-811 generates a helical structure of the LCs in right-handedness and RM257 stabilizes the helical pitch through polymerizing itself initiated by Irgacure 651.This CLC mixture was stirred at 100 °C (isotropic phase) for 24 hr to homogenize the mixture. The CLC mixture was injected into sandwiched glass substrates coated with anti-parallel rubbed polyimide layer by capillary action in the isotropic phase. The gap of the sandwiched cell was maintained with 6 μm spacers. After injecting the CLC mixture, we cooled slowly down to room temperature for obtaining a stabilized planar texture reflecting red color. Mercury lamp was exposed for 10 min through a photo-mask to fix the helical pitch even at room temperature.

The selective reflection of the CLC cell depending on temperature was measured with a polarizing optical microscope (POM) (E600 Wpol, Nikon) and a fiber optic spectrometer (S2000, Ocean Optics). A micro-furnace (FP90 and 82, Mettler Toledo) was used to control precise temperature. The morphologies of the polymerized RMs were observed with a field emissive scanning electron microscope (FESEM) (S-4800, Hitachi) after detaching the CLC cell and washing off the LC with hexane.

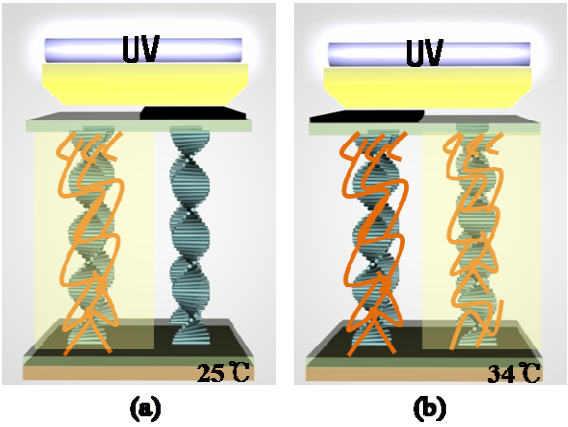

Figure 1. The schematic diagram of fabrication process to achieve the multi-color in a single-layered CLC cell. UV light is selectively exposed through a photo-mask at (a) 25 °C and (b) 34 °C and fixes the chiral pitches in each region even at room temperature.

Figure 1 shows the schematic diagram to fabricate multi-color CLC display using spatially selective UV exposure at different temperatures. At room temperature (25 °C), the CLC cell initially reflects reddish color and is fixed by polymerization of the RM

under UV exposure passing through a photo-mask as shown in Fig. 1(a). Next, we increase slowly temperature up to 34 °C and expose selectively UV light to fix the chiral pitch, corresponding to greenish color, even as room temperature. Here, the chiral pitch of the CLC decreases with increasing temperature.

3. Results and Discussion

Figure 2 shows the color variation of the CLC cell before exposing UV light depending on the temperature. The images were observed by the POM under a reflective mode. The central wavelengths corresponding to the chiral pitch of the CLC cell were determined from reflectance spectra for each temperature. In our CLC cell, the central wavelength initially started 775 nm at 20 °C and moved to a short wavelength up to 560 nm with increasing temperature within a cholesteric phase. This means that the chiral pitch of the CLC cell becomes short with increasing temperature. Above a certain critical temperature (~22 °C), the chiral pitch goes down stepwise due to the competition between the LC molecular thermodynamics and boundary effects [2,9]. The thermodynamic vibration induces the twisting angle variation between nearest neighboring molecules and thus the chiral pitch gradually decreases. However, the boundary condition at both substrates hinders continuous reduction of the chiral pitch. Therefore, the chiral pitch of the CLC cell goes down stepwise with increasing temperature. Below the critical temperature, on the other hand, the central wavelength was rapidly decreased [4]. In this regime, the wavelength variation was influenced by not only the aforementioned molecular thermodynamics but also the solubility of the chiral dopant contributing its helical twisting power [9]. As a result, the concentration of the chiral dopant has a strong effect on the color variation in the solubility-dominated regime.

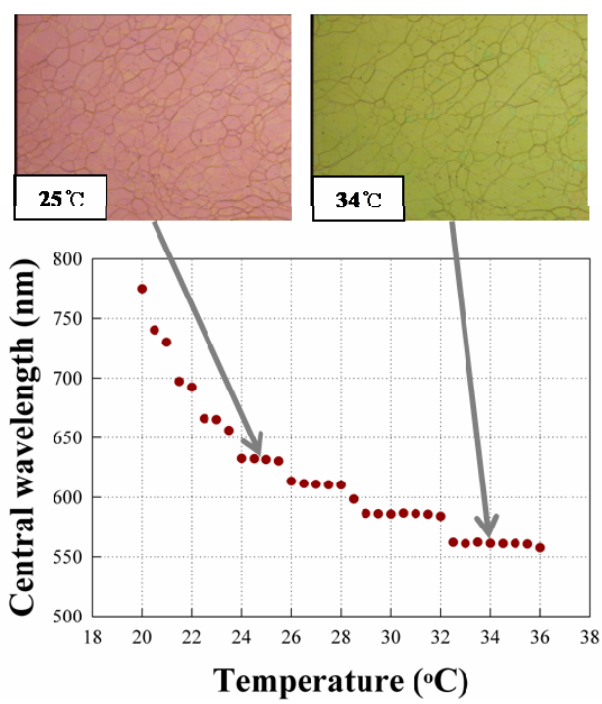

Figure 2. The POM textures at 25 and 34 °C, and the central wavelength of the reflectance spectra as a function of temperature.

To memorize various helical pitches corresponding to different temperatures at room temperature, the multi-pitch stabilization should be involved in a single-layered configuration. We fixed two helical pitches by forming the polymer-network structure through UV illumination to the RMs after the pitch variation by the temperature control. Here, the polymer-network structure acts as the microscopic boundaries to maintain the helical structure formed at the given temperature and thus the helical pitches are kept even at room temperature.

Figure 3 shows the microscopic images and the corresponding transmittance spectra at 25 and 34 °C. The central wavelengths of the spectra in the regions polymerized at 25 and 34 °C were measured to be 620 and 565 nm, respectively. The change of the central wavelength by polymerization is negligible but the spectrum edges are not too steep due to the disorder of the helical structure originated from the boundary effects of the polymer-network.

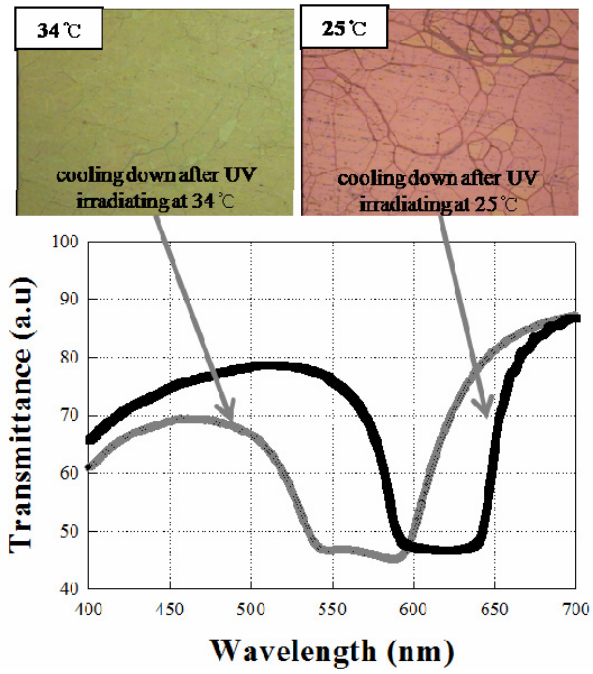

Figure 3. The POM textures and the transmittance spectrum of the single-layered CLC cell at room temperature after selective UV illumination at different temperatures.

Figure 4 shows the FESEM images of the polymer-network of the CLC cell prepared by UV illumination. The CLC cell was gently detached and the LC was carefully washed off with hexane to observe the morphologies of the polymerized RMs. The network morphology in the polymer-stabilized LC structure is strongly correlated with the solubility [10]. In general, the coarse network structure results from low solubility, while the fine network structure is formed in a well-dispersed mixture. With increasing temperature, the monomer solubility gradually increases and thus the finer network is formed as shown in Fig. 4. The rice grain-like morphology of the polymer-network produces strong anchoring force in the bulk region of the CLC cell. Such local anchoring force maintains the helical pitches, determined at different temperature, even at room temperature.

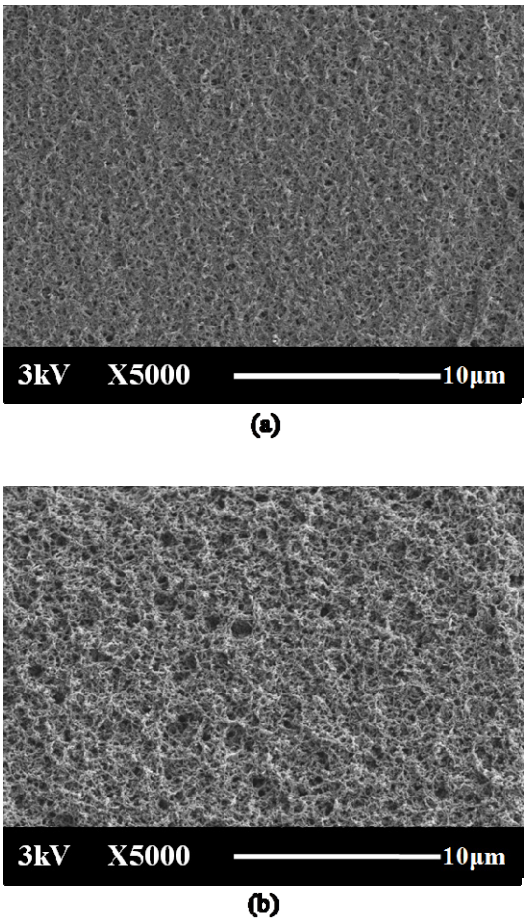

Figure 4. The FESEM images of the polymer-networks polymerized at (a) 34 °C and (b) 25 °C.

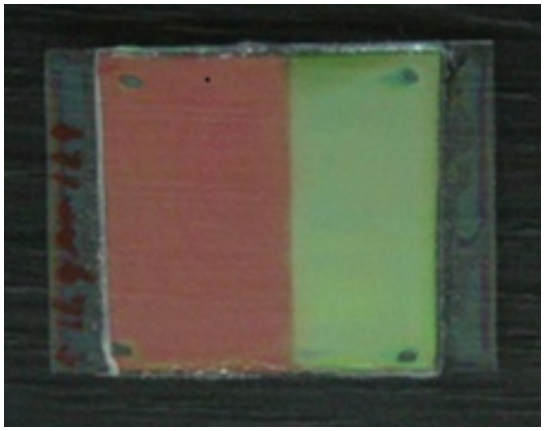

Figure 5. The prototype of our 2-inch single-layered CLC film with two of different colors.

Finally, we fabricated a 2-inch two-color CLC cell in a single-layered configuration without any additional color controlling unit as shown in Fig. 5. Red and green colors were stabilized by UV exposure at 25 and 34 °C, respectively. When temperature increases to obtain blue color, the phase transition occurs to isotropic phase in our CLC mixture. Optimizing the CLC mixture, the full color CLC display can be fabricated in a single-layered configuration.

4. Conclusion

In this work, we demonstrated the multi-color CLC display in a single-layered configuration using a multi-pitch stabilization with the RMs. The chiral pitch in the CLC cell was controlled by temperature and memorized by polymerization of the RMs. The multi-color CLC cell in a single-layered configuration was fabricated with the spatially selective UV exposure through a photo-mask at several temperatures directly corresponding to the chiral pitches. This technology presented here is expected to become a viable technology to fabricate the electronic paper displays.

5. Acknowledgements

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6. References

[1] N. Tamaoki, "Cholesteric Liquid Crystals for Color Information Technology," Adv. Mater. **13**, 1135-1147, (2001).

[2] P. N. Keating, "A Theory of the Cholesteric Mesophase," Mol. Cryst. Liq. Cryst. **8**, 315-326, (1969).

[3] J. V. Gandhi, X.-D. Mi, and D.-K. Yang, "Effect of surface alignment layers on the configurational transitions in cholesteric liquid crystals," Phys. Rev. E. **57**, 6761-6766, (1998).

[4] Y. Huang, Y. Zhou, C. Doyle, and S.-T. Wu, "Tuning the photonic bandgap in cholesteric liquid crystals by temperature-dependent dopant solubility," Opt. Express **14**, 1236-1242, (2006).

[5] H. Xianyu, T.-H. Lin, and S.-T. Wu, "Rollable multicolor display using electrically induced blueshift of a cholesteric reactive mesogen mixture," Appl. Phys. Lett. **89**, 091124, (2007).

[6] G. D. Filpo, F. P. Nicoletta, and G. Chidichimo, "Cholesteric Emulsions for Colored Displays," Adv. Mater. **17**, 1150-1152, (2005).

[7] J. Chen, S. M. Morris, T. D. Wilkinson, and H. J. Coles, "Reversible color switching from blue to red in a polymer stabilized chiral nematic liquid crystals," Appl. Phys. Lett. **91**, 121118, (2007).

[8] S.-Y. Lu, and L.-C. Chien, "A polymer-stabilized single-layer color cholesteric liquid crystal display with anisotropic reflection," Appl. Phys. Lett. **91**, 131119, (2007).

[9] K.-S. Bae, Y.-J. Jang, J.-H. Kim and C.-J. Yu, "Wavelength-Selective Reflection of Cholesteric Liquid Crystals Depending on Temperature and Dopant Concentration," Proceedings of the 16th International Display Workshop, 55-58, (2009).

[10] I. Dierking, L. L. Kosbar, A. Afzali-Ardakani, A. C. Lowe, and G. A. Held, "Network morphology of polymer stabilized liquid crystals," Appl. Phys. Lett. **71**, 2454-2456, (1997).