Rollable multicolor display using electrically induced blueshift of a cholesteric reactive mesogen mixture

Haiqing Xianyu, Tsung-Hsien Lin, and Shin-Tson Wu[a)]
College of Optics and Photonics, University of Central Florida, Orlando, Florida 32816

(Received 17 April 2006; accepted 13 July 2006; published online 1 September 2006)

Electrically controllable blueshift of the reflection band in a planar cholesteric reactive mesogen cell is observed. The responsible mechanism is electric-field-induced Helfrich deformation [J. Chem. Phys. **55**, 839 (1971)]. The modified director configuration can be solidified by photopolymerizing the reactive mesogens when a voltage is applied. The correlation between the director configuration and optical properties is validated by the scanning electron microscope photos and the transmission spectra of a planar and an undulated cholesteric film. With masked curing at different voltages, a rollable multicolor display is demonstrated. © *2006 American Institute of Physics*.
[DOI: 10.1063/1.2345597]

The selective Bragg reflection from cholesteric liquid crystal (CLC) has been exploited in devices such as reflection display,[1,2] color filter arrays,[3] and mirrorless lasing.[4,5] The reflection color of the CLC can be tuned by varying the device temperature or by applying an external field.[6] Pitch elongation by in-plane electric field perpendicular to the helical axis has been utilized to induce a redshift of the reflection band.[7,8] *Redshift* of the reflection band can also be realized by applying an electric field across a polymer-stabilized CLC cell and such devices have been utilized in tunable filters and lasers.[9]

Reactive mesogens are photopolymerizable monomers that have LC phase in certain temperature range. The director configuration in reactive mesogen can be manipulated using the same methods for manipulating liquid crystals and the resulted configuration can be fixed by photopolymerization. Particularly, a stable film with selective reflection can be fabricated by curing the cholesteric reactive mesogen mixtures at cholesteric phase.[10] Broadband reflective polarizers were developed by introducing pitch gradient along the helical axis.[11,12] Pixelated color filters were fabricated using photochemically isomerizable cholesteric compounds and patterned masked curing to generate and consolidate pixelated pitch variation in cholesteric polymer films.[13]

In this letter, we present a *blueshift* of the reflection band in a planar cholesteric reactive mesogen cell driven by an electric field. The color of the cell can be tuned by varying the voltage across the cell. The change in optical properties originates from the electric-field-induced Helfrich deformation. The undulated director configuration can be recorded by UV curing and the resulted change in optical properties is recorded simultaneously. By photopolymerizing different areas of the film at different voltages with the help of appropriate photomasks, a multicolor pattern can be generated in a single cell. A rollable multicolor display is obtained by peeling off the cured cholesteric film from the glass substrates.

In our experiment, cholesteric reactive mesogen mixtures consisting of RMM254 (reactive mesogen mixture, Merck), RM82 (reactive mesogen, Merck), and CB 15 (chiral dopant, Merck) are prepared. The reactive mesogen mixtures were filled into indium tin oxide (ITO) glass cells in isotropic phase and then cooled down slowly to achieve a planar texture. The inner side of each ITO glass substrate was overcoated with a thin polyimide alignment layer and rubbed in antiparallel directions. The reflection wavelength of the cells can be engineered by modifying the ratio of the components in the mixture. An ac electric field (~100 Hz) was applied to a cholesteric reactive mesogen cell. When the voltage exceeds a threshold value, the planar structure is deformed. Keep on increasing voltage leads to a continuous blueshift in the cell's appearance color.

Figure 1 shows the photos and their corresponding reflection spectra of a 5 μm cholesteric reactive mesogen cell under different voltages. A crossed polarizer setup was utilized to eliminate the specular reflection from glass sub-

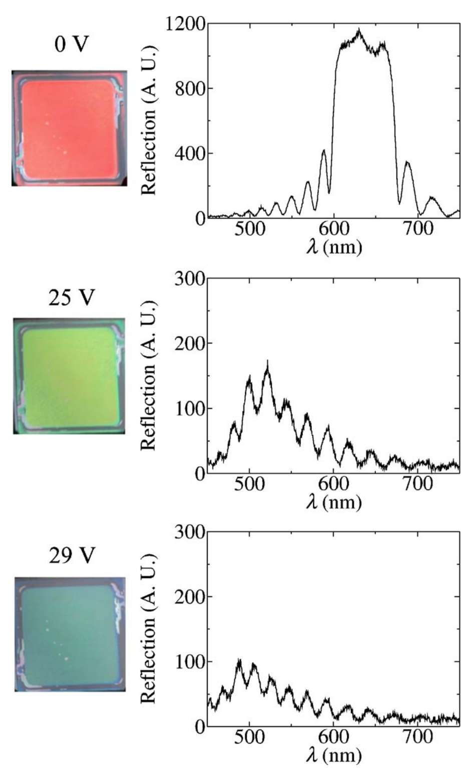

FIG. 1. (Color online) Left: Photos of a 5 μm cholesteric reactive mesogen cell under different voltages. Right: measured reflection spectra of the cell under different voltages.

[a)]Electronic mail: swu@mail.ucf.edu

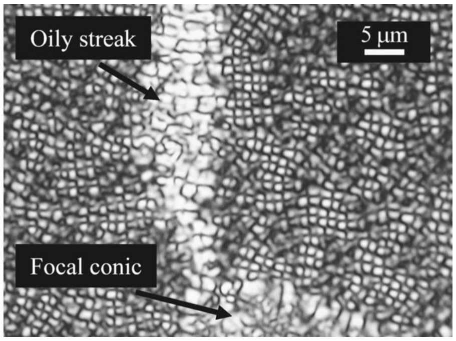

FIG. 2. Microscope photo of an electrically undulated cholesteric reactive mesogen cell between crossed polarizers.

strates when we measured the reflection spectra. The incident angle is at 16°. The cell reflects red light when no field is applied. When the voltage is greater than $22V_{\rm rms}$, the reflection from the cell begins to deviate from that of a perfect planar texture. As the voltage increases, the color of the cell evolves from red to green and then to blue. Moreover, the reflection band is broadened but the peak reflectance is decreased. Keep on increasing voltage would bring the cell into focal conic texture and then to homeotropic state, neither of which maintains the selective reflection.

We observed the cholesteric reactive mesogen cells under microscope. Figure 2 shows the transmission microscope photo of a cholesteric reactive mesogen cell between crossed polarizers with the undulated texture. When the applied voltage exceeds the threshold, a two dimensional periodic structure begins to appear in the cell. Observation from reflection microscope confirms that this structure contributes to the blueshift. At the same time, oily streak expands slowly along defect lines and brings part of the cell into focal conic texture.

The observed periodically undulated structure originates from the electric-field-induced Helfrich deformation.[14] It happens when the voltage exceeds a critical voltage[14]

$$V_{\rm Helfrich} = \frac{4\pi(2K_{22}K_{33})^{1/2}}{\Delta\varepsilon\varepsilon_0}\frac{h}{P_0}, \tag{1}$$

where K_{22} and K_{33} are the twist and bend elastic constants of the cholesteric liquid crystal, h is the cell gap, and P_0 is the pitch length at zero field. In the first order perturbation, the pitch undulation is described by[14]

$$2\pi\left(\frac{1}{P} - \frac{1}{P_0}\right) = \tau_0 \sin\left(\frac{\pi z}{h}\right)\cos\left(\frac{\pi x}{\lambda}\right), \tag{2}$$

where P is the local pitch length, z axis is the cell normal direction, x axis is parallel to the cell surface, and τ_0 is the perturbation amplitude which depends on the electric field. The period of the undulation λ is given by[14]

$$\lambda = (2K_{33}/K_{22})^{1/4}(P_0 h)^{1/2}. \tag{3}$$

The pitch inhomogeneity in Helfrich deformation, as described in Eq. (2), broadens the reflection band and decreases the peak reflectance as the voltage increases. Due to the undulated nature of the Helfrich deformation, light scattering of the cell increases with the increased applied voltage, which also contributes to the decreased reflectance.

The electrically induced director reconfiguration can be recorded by photopolymerizing the cholesteric reactive mesogen. Figures 3(a) and 3(b) show the scanning electron microscope (SEM) images of the cross section of an UV-cured cholesteric cell at $V=0$ and $V=45V_{\rm rms}$, respectively. In Fig. 3(a), the pitch distribution of a cholesteric film cured without an external field is rather uniform. While Fig. 3(b) clearly reveals the spatial pitch variation and distortion due to the electric-field-induced Helfrich deformation. The recorded variation in texture leads to the difference in optical properties, as presented in Fig. 3(c). The film cured at $V=0$ exhibits a transmission notch typical for a planar cholesteric cell. On the other hand, the transmission spectrum of the undulated cholesteric texture shows not only a blueshift but also a broadened bandwidth as compared to that cured without an external field. Therefore, the correlation between the cholesteric texture and its optical properties is established. We noticed that the undulated texture does not exactly follow the first order sinusoidal perturbation form suggested by Helfrich. The variation in cholesteric pitch and tilt angle of cholesteric layer is not always minimized at the cell substrates, which is indicated by Eq. (2). A more precise mathematical description of the undulated director field distribution and the optical properties of such distribution are under investigation.

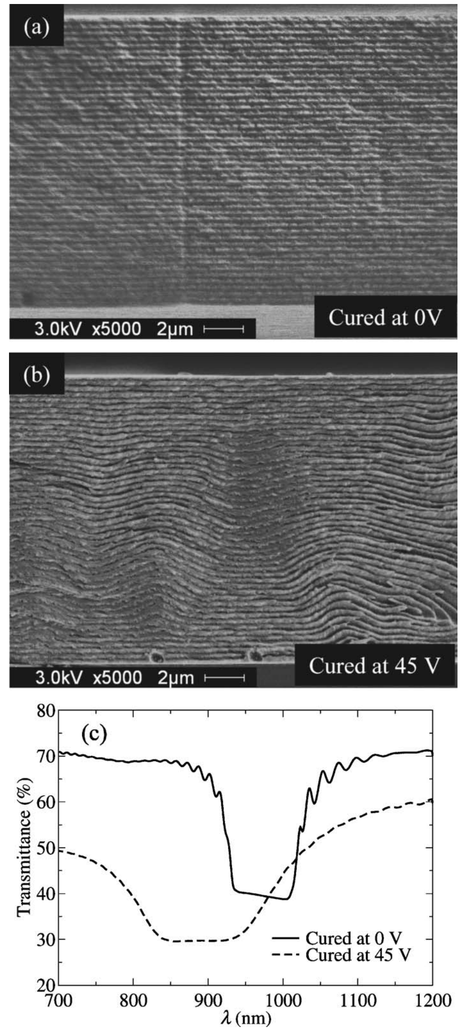

FIG. 3. SEM images of the cross section of a cholesteric film cured at (a) $V=0$ and (b) $V=45V_{\rm rms}$. (c) The transmission spectra of the films shown in (a) and (b).

By masked curing at different voltages, we are able to record multiple color patterns into a single cell. A flexible

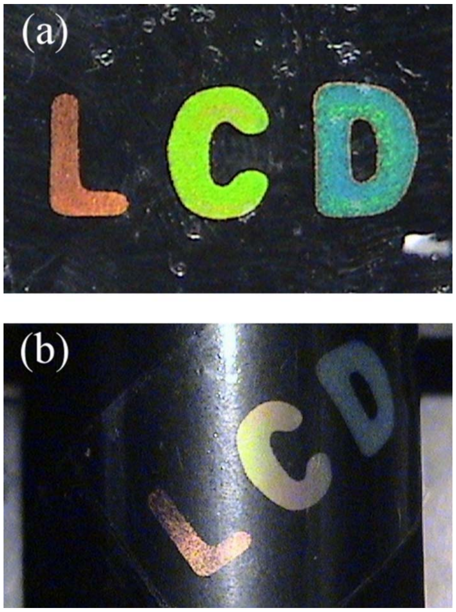

FIG. 4. (Color online) Three-color rollable cholesteric polymer film: (a) before bending and (b) the film is attached to a cylindrical post holder. The "LCD" characters were exposed when different voltages were applied. The film thickness is 8 μm.

film with multiple color patterns was acquired by peeling off the film from the glass substrates. The film thickness is controlled by the cell gap which is 8 μm in our experiment. Thus, it is highly flexible and can be bent to a circle easily. Figure 4(a) shows a polymer film with three characters LCD written in on a black background. The orange, green, and blue colors are displayed. To demonstrate its flexibility, we laminated the film onto a transparent Scotch tape and wrapped it on a black cylindrical post holder, as Fig. 4(b) shows. The film is highly flexible and rollable. Potential applications of this film for rollable color display are promising.

In conclusion, we have demonstrated a controllable electrically driven blueshift of the reflection band in cholesteric reactive mesogen cells. The change in optical performance is accomplished by a two dimensional undulation of the director configuration induced by electric field. The deformed director configuration and the resulted color shift can be fixed by photopolymerizing the reactive mesogens when the electric field is applied. The undulated texture is clearly observed by the SEM images. Flexible and rollable polymer films with multiple color patterns can be fabricated with masked curing at different voltages and can be used as color filters, decoration films, and security prints.

The authors are indebted to Yung-Hsun Wu for his help in photography.

[1] D. K. Yang, J. L. West, L. C. Chien, and J. W. Doane, J. Appl. Phys. **76**, 1331 (1994).
[2] S. T. Wu and D. K. Wu, *Reflective Liquid Crystal Displays* (Wiley, New York, 2001).
[3] A. Hochbaum, Y. Jiang, L. Li, S. Vartak, and S. Faris, SID Tech. Digest **30**, 1063 (1999).
[4] B. Taheri, A. F. Munoz, P. Palffy-Muhoray, and R. Twieg, Mol. Cryst. Liq. Cryst. Sci. Technol., Sect. A **358**, 73 (2001).
[5] Y. Huang, Y. Zhou, and S. T. Wu, Appl. Phys. Lett. **88**, 011107 (2006).
[6] P. G. de Gennes and J. Prost, *The Physics of Liquid Crystals*, 2nd ed. (Clarendon, Oxford, 1993).
[7] Z. Li, P. Desai, R. B. Akins, G. Ventouris, and D. Voloschenko, Proc. SPIE **4658**, 7 (2002).
[8] H. Xianyu, S. Faris, and G. P. Crawford, Appl. Opt. **43**, 5006 (2004).
[9] H. P. Yu, B. Y. Tang, J. H. Li, and L. Li, Opt. Express **13**, 7243 (2005).
[10] J. Lub, D. J. Broer, R. A. M. Hikmet, and K. G. J. Nierop, Liq. Cryst. **18**, 319 (1995).
[11] D. J. Broer, J. Lub, and G. N. Mol, Macromol. Symp. **117**, 33 (1997).
[12] D. J. Broer, J. Lub, and G. N. Mol, Nature (London) **378**, 467 (1995).
[13] J. Lub, D. J. Broer, and P. van de Witte, Prog. Org. Coat. **45**, 211 (2002).
[14] W. Helfrich, J. Chem. Phys. **55**, 839 (1971).