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Texture evolution of cholesteric liquid crystal driven by a thermal process

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ABSTRACT

Cholesteric liquid crystal displays (Ch-LCDs) have potential as screens in portable readers. In the present study, it is demonstrated that a Ch-LCD can be driven by a thermal process at a temperature of 90 °C. At a suitable temperature, the texture of the cholesteric liquid crystal will be transferred from planar to focal conic. The experimental results show that the reflectance of a Ch-LCD is influenced by texture after the thermal process. After thermal treatment at 90 °C, the periodicity was reduced from 63 nm to 55 nm. A chain tilting angle of ~29° was estimated.

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1. Introduction

Bistable flexible displays have recently become important for portable devices. Electronic displays with paper-like features such as high visibility, high resolution, and flexibility have been proposed. Due to their paper-like appearance and low power consumption, cholesteric liquid crystal (Ch-LC) material is attractive for inexpensive and rugged e-book displays. Cholesteric liquid crystal displays (Ch-LCDs) have been widely investigated in recent years [1–5]. Ch-LCDs with bistability exhibiting two stable states can display information for a long time without an applied electric field. One of the bistable states is the reflecting planar state and the other is the non-reflecting focal conic state. Disordered LC molecules scatter incident light in focal conic textures. By applying a large enough electric field, the planar and focal conic textures of a Ch-LC can be switched to the homeotropic texture. If the electric field is quickly released, the homeotropic texture of the Ch-LC relaxes to the planar texture through a transient planar texture. If a low electric field is subsequently applied, the planar state transforms into the focal conic state. The necessary applied voltages for the state transitions can be determined from the reflectance voltage (R - V) curve of the Ch-LCD. For the homeotropic texture, all molecules are vertical

to the surface, allowing incident light to pass through the system [6–8].

Many drive schemes for Ch-LCD addressing have been proposed in recent years [9–14]. With the photo-addressing method, the driving electronics can be completely separated from Ch-LCD panels. The Ch-LCD structure can also be simplified because of un-patterned upper and lower electrodes. Because the conductors of Ch-LCD panels are un-patterned and can be fabricated using the roll-to-roll process, the panels have high yield and low cost. Resolution and contrast ratio are the basic parameters of e-paper. With an electronic driving method, it is very difficult to achieve the required high resolution [15]. Therefore, thermal and photo addressing have been proposed for driving a Ch-LCD.

Few studies have investigated the texture of cholesteric liquid crystal in various states. In the present study, the texture evolution of cholesteric liquid crystal driven by a thermal process is investigated. The molecular configuration change of a Ch-LCD with the focal conic or planar texture was examined using wide- and small-angle X-ray scattering (WAXS/SAXS) techniques.

2. Experimental method

Ch-LC is a mixture of nematic liquid crystal (Merck BL118) and a chiral dopant which provides strong twisting. Fig. 1 shows a sectional diagram of a Ch-LCD panel structure. The flexible Ch-LCD is composed of a polymer-dispersed Ch-LC layer and a dark layer sandwiched between the top and bottom electrodes on a polyethylene terephthalate (PET) substrate. The panel was treated by a thermal process at temperatures of 60–120 °C for 30 min

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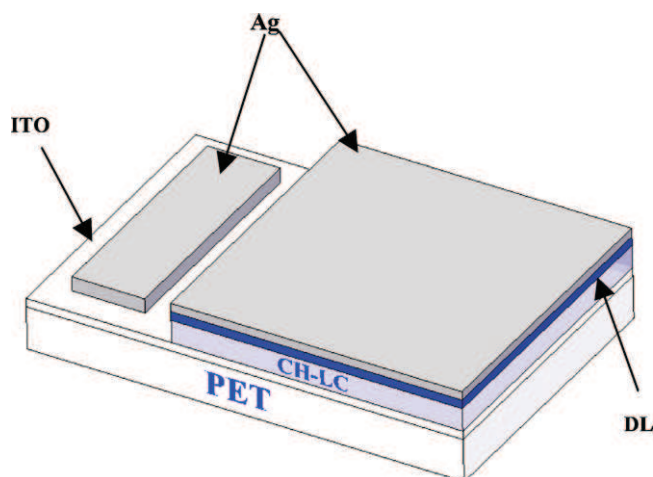


Fig. 1. Sectional diagram of Ch-LCD panel structure.

under a nitrogen environment. The reflectance measurements were performed using an X-Rite 938 spectrodensitometer. After the thermal process, the dark layer and Ag film were peeled off from the Ch-LCD panel structure. The cholesteric layer on the flexible substrate was examined using a Bruker AXS NANOSTAR universal system at a wavelength of 0.154 nm and sample-to-detector distances of 9.7 and 112 cm for wide- and small-angle detection, respectively. Data were recorded by a VANTEC-2000 CCD system. The diffraction peak positions and widths were calibrated with a silver behenate standard. The 2-D wide-/small-angle X-ray scattering patterns were taken by orienting the incident beam along the film normal (z -axis) and film lateral (x -axis) directions, respectively.

3. Results and discussion

When the temperature was changed from 60 to 120 °C, the reflectance of the Ch-LCD changed. The image results after the thermal process for various temperatures are shown in Fig. 2(a). The results show that the Ch-LCD was driven when the temperature was over 90 °C. Fig. 2(b) shows the reflectance of the Ch-LCD for various thermal conditions. The textures of the Ch-LCD changed after the thermal process, especially for temperatures over 90 °C. At 550 nm, the reflectance changed from 15% to 2% when the temperature was increased from 60 °C to 90 °C. 90 °C is thus the threshold temperature for driving a Ch-LC.

To clarify the molecular morphology, a Ch-LC film without the thermal process and one with a thermal process at 90 °C for 30 min were analyzed. Fig. 3(a) shows the WAXS pattern in the x direction for the pristine film without thermal treatment. The anisotropic pattern reveals the preferred molecular packing in this direction. Along the equator, the scattering profile (see Fig. 3(b)) is similar to the results for the z direction, but it is anisotropic, implying that the molecular packing is twisting along the z direction. Along the meridian (see Fig. 3(c)), the sharp arc (d-spacing of 3.25 nm) and its second-order reflection (d-spacing of 1.60 nm) correspond to a layer stacking periodicity. Except for alkyl chain packing (d-spacing of 0.42 nm), there is a sharp arc at $2\theta \sim 27^\circ$ corresponding to the d-spacing of 0.32 nm. This packing might be due to the π - π stacking including the complexes between -CN and phenyl groups or other molecular packing related to the 3.25 nm-thick layered packing. In addition, the diffused diffraction arcs at $2\theta \sim 20^\circ$ and 31° are quite broad regarding to spatial correlations spread around 0.42 nm (and 0.28 nm) separation, and thus can be related to lateral (face-to-face) stacking among backbone and -CN groups.

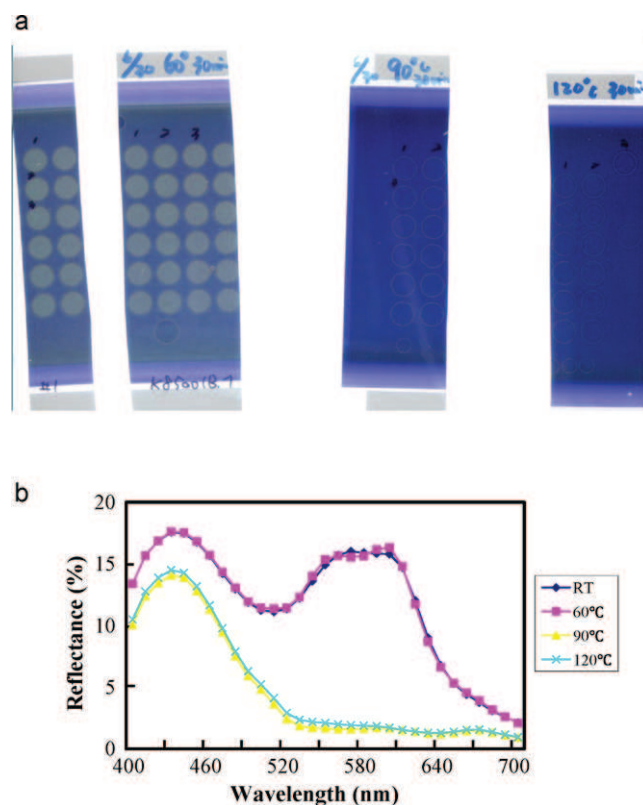


Fig. 2. (a) Image and (b) reflectance of Ch-LCD annealed under various thermal conditions.

Fig. 4(a) shows the WAXS pattern in the x direction for the film annealed at 90 °C for 30 min. The arc of 0.42 nm in d-spacing in Fig. 3(a) becomes an isotropic ring. The scattering peaks at the equator and meridian are similar to those of the pristine film but have some differences in intensity. Fig. 4(b) shows the diffraction pattern along the equator; the intensities of the two tetragonal diffractions are weaker than those for the pristine film. In addition, the peak of 0.32 nm in d-spacing becomes obvious at the equator. Along the meridian (see Fig. 4(c)), the relative intensity of the peak of 0.32 nm in d-spacing decreased after the thermal process. The changes after 90 °C thermal treatment imply a tilting of molecular chains, which reduced the layer thickness to 64 nm. In other words, the layered structure was reorganized due to the chain tilting.

Fig. 5(a) shows the SAXS profile of the pristine film with the incident beam along the z direction. The obtained SAXS pattern is also isotropic. The corresponding one-dimensional scattering profile shows a peak at $q \sim 0.22 \text{ nm}^{-1}$ with its second-order scattering at $q \sim 0.44 \text{ nm}^{-1}$, indicating the existence of a correlation of larger d-spacing of $\sim 30 \text{ nm}$, which can be considered as the grain size. Fig. 5(b) shows the SAXS patterns of the film annealed at 90 °C for 30 min with the incident beam in the z direction. The phase behavior is similar to that of the pristine film except for the peak of 0.32 nm in d-spacing. The annealed film shows a relatively clear peak, implying that molecular chains may tilt after heat treatment.

Fig. 6(a) shows the results of SAXS measurement in the x direction. The corresponding scattering profile at the meridian indicates a long-range-order molecular packing with a d-spacing of $\sim 63 \text{ nm}$ in this direction, as shown in Fig. 6(b). The second (d-spacing of 31.4 nm) and third-order (d-spacing of 20.9 nm) reflections of the long-range-order molecular packing were observed. The first-order reflection is unclear because the scattering peak is very

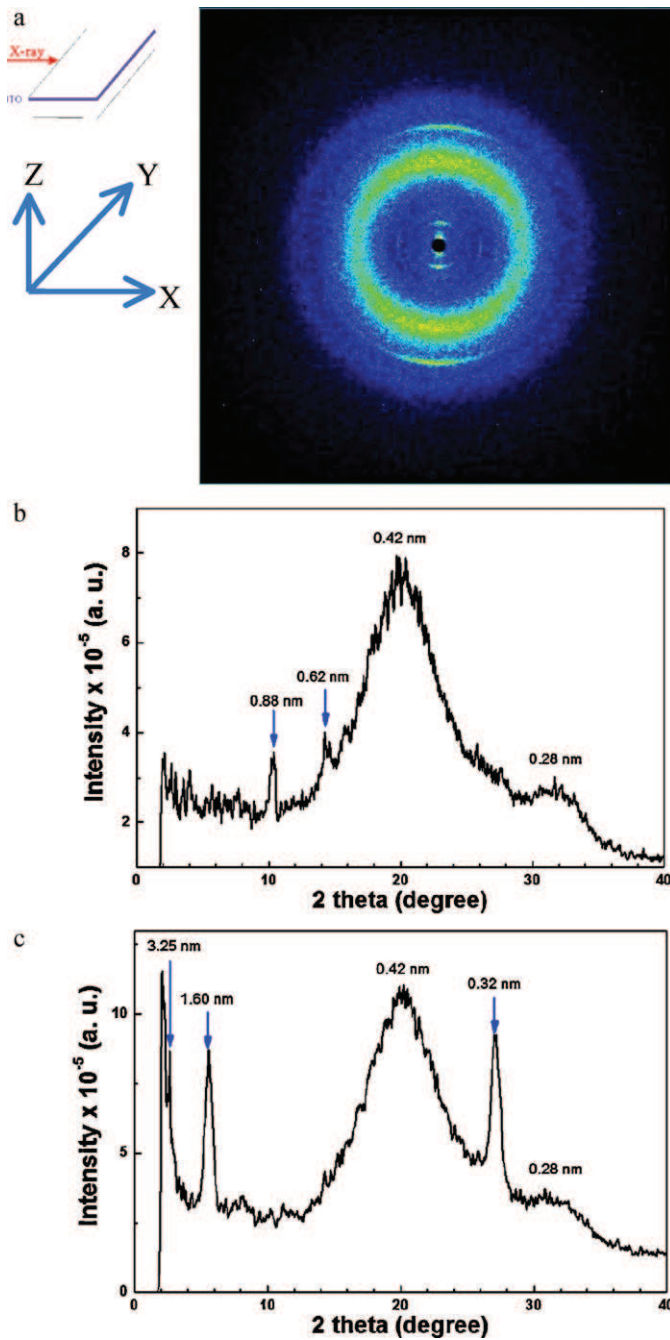


Fig. 3. (a) WAXS pattern, (b) diffraction profile along the equator, and (c) diffraction profile along the meridian in the x direction for pristine film without thermal treatment.

close to the beam-stop for such a large d-spacing. The SAXS results (Fig. 6) in the x direction for the film annealed at 90 °C for 30 min show the long-range order reduced to ~55 nm in this direction (of note, the grain size did not change in the z direction). This also supports the assumption of chain tilting within each layer.

Using the results obtained under various conditions, a preliminary model is proposed to describe possible molecular packing and to classify the formation of the liquid crystalline phase within the sample. In the X-ray scattering measurements, the scattering patterns along the z direction were always isotropic, whereas the patterns obtained using incident X-ray along the

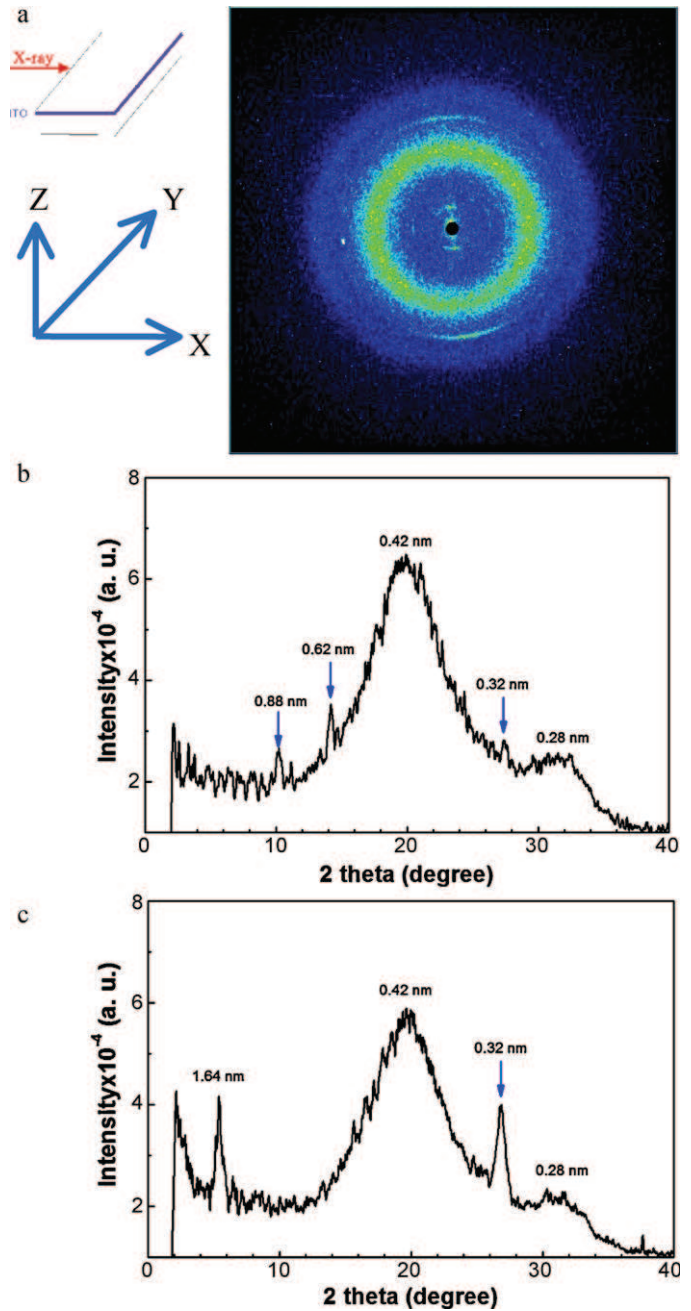


Fig. 4. (a) WAXS pattern, (b) diffraction profile along the equator, and (c) diffraction profile along the meridian in the x direction for the film annealed at 90 °C for 30 min.

x direction were anisotropic. This indicates that the formation of the liquid crystalline phase inside the film should be classified as the twist grain boundary (TGB) phase, as shown in Fig. 7. Within each grain, the LC molecules packed within a tetragonal scheme with $a = 0.88$ nm. The lamellar thickness is estimated to be ~3.2 nm. Each grain in the TGB phase is ~30 nm in size, and therefore is composed of 3–4 layers of lamellae. The long-range-order scattering resulted from the average periodicity (~63 nm for the pristine film) of one helical turn in the TGB phase. After heat treatment at 90 °C, this periodicity was reduced from 63 nm to 55 nm. Thus, a chain tilting angle of ~29° was estimated.

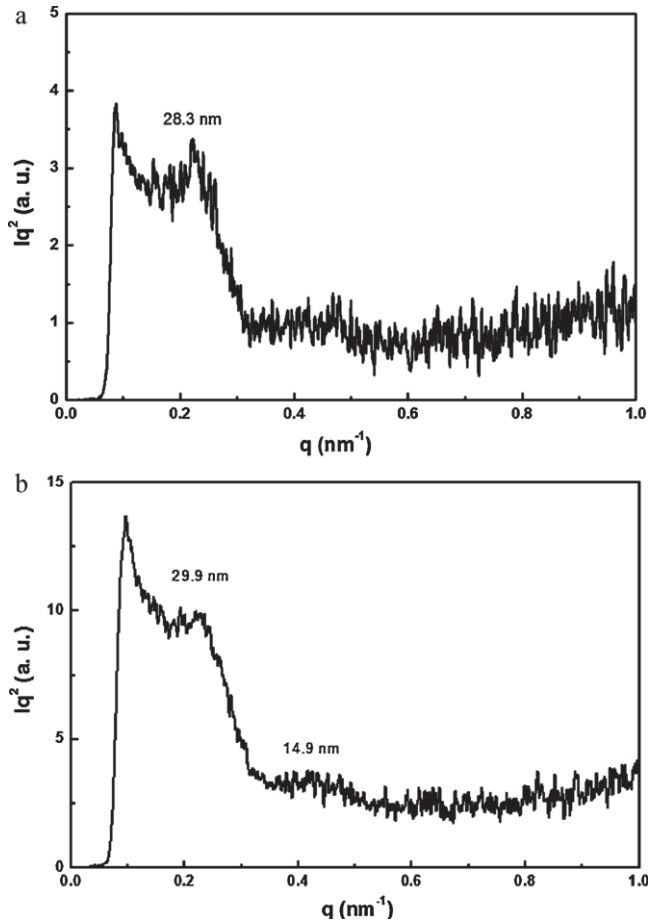


Fig. 5. SAXS profile with the incident beam along the z direction for film (a) without thermal process and (b) annealed at 90°C for 30 min.

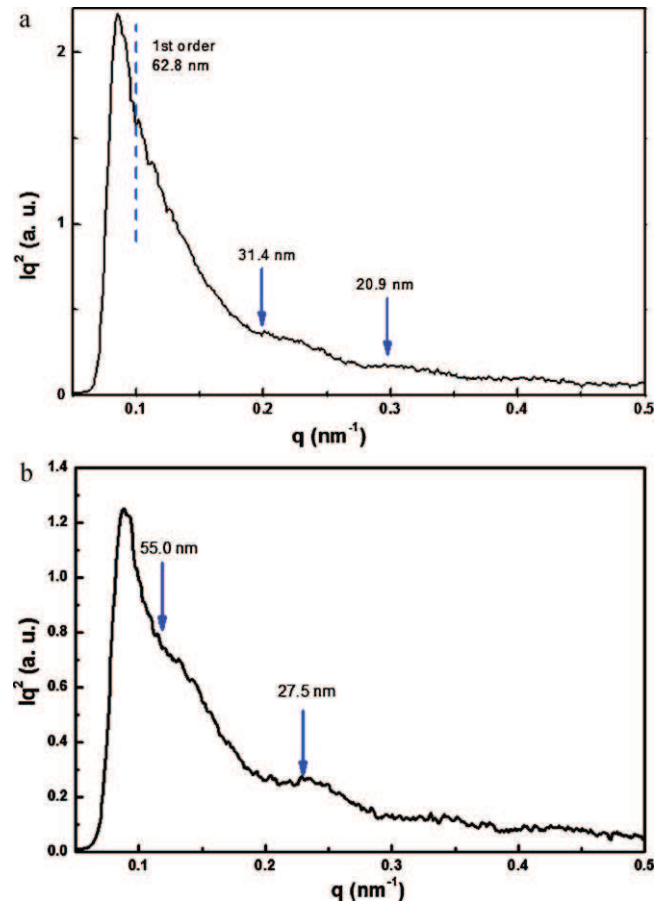


Fig. 6. SAXS profile with the incident beam along the x direction for film (a) without thermal process and (b) annealed at 90°C for 30 min.

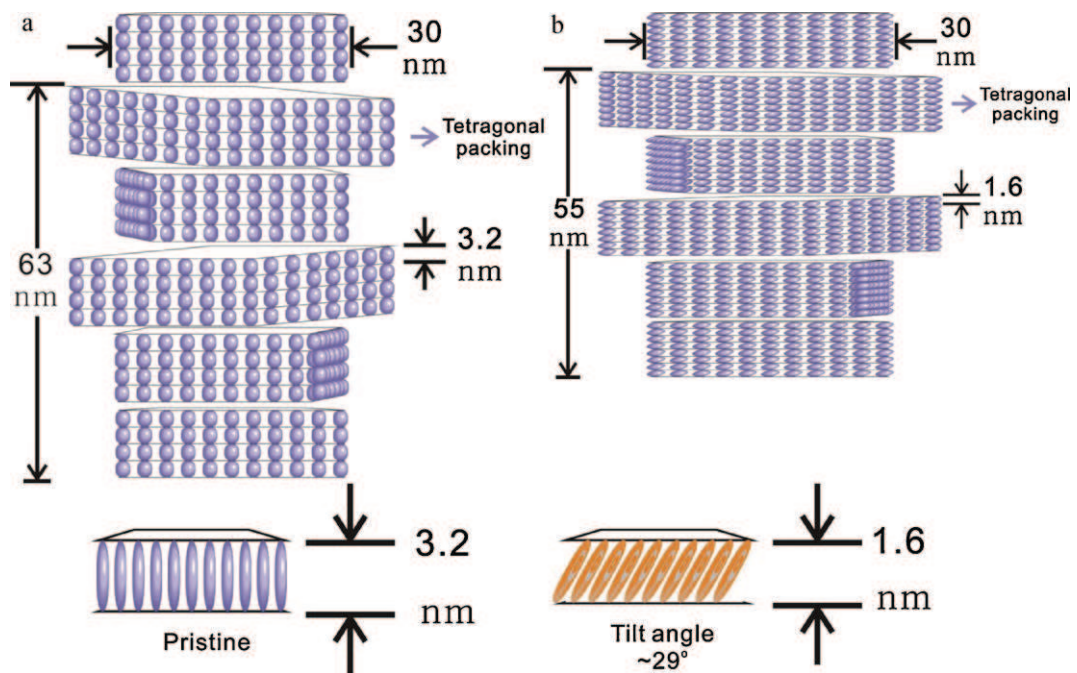


Fig. 7. Schematic illustration of the twist grain boundary phase for film (a) without thermal process and (b) annealed at 90°C for 30 min.

4. Conclusion

A Ch-LCD was driven by a thermal process. A detailed investigation revealed that the reflectance and texture of the Ch-LCD depend on the thermal conditions. After heat treatment at 90 °C, the periodicity was reduced from 63 nm to 55 nm. A chain tilting angle of ~29° was estimated.

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