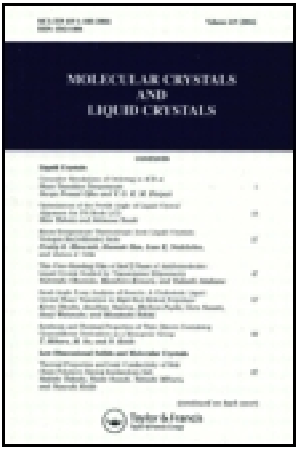

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Studies of the Polymer-Stabilized Cholesteric Texture Films Doped with SmC*

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Studies of the Polymer-Stabilized Cholesteric Texture Films Doped with SmC*

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Cells of polymer-stabilized cholesteric texture (PSCT) were fabricated by adding various ferroelectric liquid crystal (SmC*) dopant concentrations. Measuring the electro-optical characteristics of these cells indicated that adding a small amount of a SmC* could significantly improve the cells' electro-optical characteristics. Both the device's threshold voltage and the rise time were decreased, while the hysteresis width was increased. Such an improvement was attributed to the increase of the dielectric anisotropy of the liquid crystal and the modification of cells' polymer network with the addition of a small amount of SmC* in the mixture.

Keywords: Cholesteric liquid crystal; ferroelecteric liquid crystal; polymer network

INTRODUCTION

Liquid crystal (LC)-polymer composites have been extensively studied owing to their fundamental importance and potential use as displays. Two types of LC-polymer composites reported so far are polymer-dispersed liquid crystal (PDLC)[1-6] and polymer-stabilized cholesteric texture (PSCT) films.[7-10] The prepolymer concentration

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normally exceeds 20% in the former system. Upon polymerization of the LC-prepolymer mixture, micron-sized LC droplets are formed and embedded in the polymer matrix. Owing to the refractive index mismatching problem, a PDLC film is transparent only for a light incident at an angle and gradually becomes hazy for other angles. A PSCT film eliminates the haziness problem since the polymer concentration is usually below 10wt%, accounting for why the refraction index mismatching problems does not exist in it. Consequently, related investigations have conferred that PSCT films are highly promising for display application.

Depending on the surface treatment of the substrates and on the pitch length of the cholesteric LC, three different types of PSCT films can be fabricated: normal-mode, reverse-mode and color-reflective bistable mode. For a normal-mode film, the focal conic texture is stabilized at field-off condition and the cell is opaque. It is switched into homeotropic texture and becomes transparent in the field-on condition. The imperfect planar texture is stabilized at zero-field and the cell is transparent for visible light in a reverse-mode film. It is switched into focal conic texture and becomes opaque in the field-on condition. For the color-reflective bistable mode films, both the focal conic texture and the planar texture are stabilized at zero field.

PSCT films are usually fabricated using a cholesteric LC, which is a mixture of a nematic LC and a chiral dopant, In this paper, we fabricate PSCT normal-mode cells doped with various ferroelectric LC (SmC^*) concentrations. Their electro-optical (E-O) characteristics are then measured. According to those measurements, adding a small amount of SmC^* significantly improves the films' E-O characteristics, such as the reduction of both of the driving voltage and the response time. In addition, the hysteresis width increases as well. To explain these results, we measures the variations of both the dielectric constant and the pitch length in PSCT mixtures with respect to SmC^* concentration. Their polymer networks are also investigated, with those results providing a satisfactory explanation.

EXPERIMENTAL

The cholesteric LC used in this experiment was a mixture of nematic E48 (from E. Merck) with a chiral mixture by a weight ratio of ~92.0:8.0. Two sets of samples were prepared in this experiment. The first set samples were fabricated as follows. The chiral mixture was obtained from mixing a chiral CB15 (from E. Merck) and SmC^* (CS-

2003, from Chisso). The SmC* concentration in the chiral mixture was varied from 0~100 wt%. ~2.7wt% of the laboratory-synthesized monomer BAB-6 (4,4'-Bis[6-(acryloyloxy) hexyloxy] biphenyl) was then added to the cholesteric LC. Finally, a small amount of photoinitiator BME (~10wt% of the monomer) was added in the mixture to initiate polymerization. Under UV irradiation, the monomer was polymerized to form a polymer network that stabilized the focal conic LC domains in PSCT normal-mode cells. In the following, the first set samples are said the PSCT cells having x wt% SmC* concentrations. It means they were fabricated using above mixing ratio with x wt% SmC* in the mixtures. In order to investigate the sole role which SmC* plays, the second set samples were fabricated. A PSCT compound having CB15 content ~ 8 wt% (which corresponds to the device having 0 wt% SmC* in the first set samples) was prepared. It was then used to fabricate PSCT cells with the addition of 0, 0.5, 1 and 1.5 times of SmC* as much as CB15 (8 wt%). In the following, we call the second set samples to be the PSCT cells having y-times SmC* concentration in the mixtures (i.e., y is the amount ratio of SmC* to CB15) to distinguish them from those having x wt% SmC* in the first set samples.

The sample cell used in our experiment was fabricated with two indium-tin-oxide (ITO)-coated glass slides, separated by a 12 μm plastic spacer. The surfaces of ITO glass slide were untreated. The final mixture was vacuum filled into an empty cell. The filled cell was cured using a UV lamp provided by a Phillips model 400/300S metal halide lamp for ~30minutes. The UV light intensity was about 3 mW/cm^2. During curing, the cell was aligned homeotropically by applying an AC voltage across the ITO electrodes.

Details of the apparatus used to perform the electro-optical measurements can be found in Ref.11. For scanning electron microscope (SEM) study of the polymer network, details on how to prepare the sample can be found in Ref.12. Briefly, the cell was put in hexane to remove LCs. The cell was then splitted and placed in a vacuum chamber to evaporate hexane in which LCs were dissolved. Finally, the polymer network was coated with a thin film of gold (~40 nm) and investigated using SEM.

To measure the pitch length, a cholesteric planar cell having a thickness of 12 μm was measured using a FTIR spectroscopy. Finally, an impedance analyzer was used to measure the dielectric constant of cholesteric LC mixtures having SmC* concentrations, 0, and 50 wt% in the chiral dopant.

RESULTS AND DISSCUSSIONS

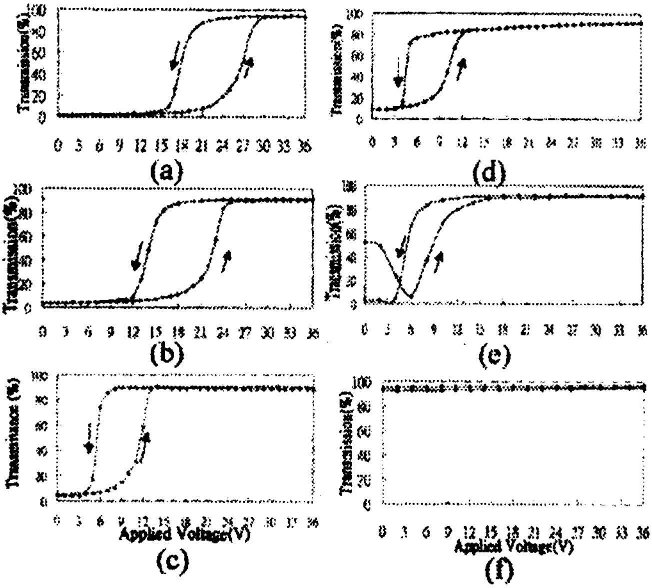


Figure 1 shows the measured transmissions of the PSCT normal-mode (the first set) cells having x wt% (x=0-100) SmC*

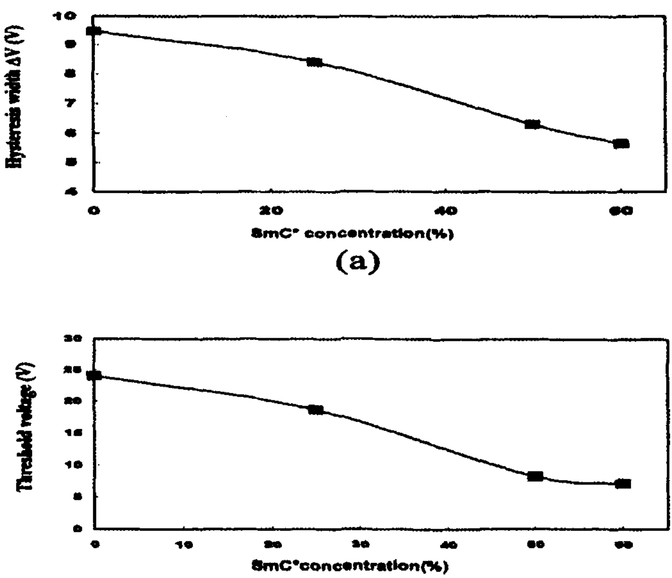
FIGURE 1: Measured transmissions of the PSCT normal-mode cells having x wt% SmC* concentrations in the chiral mixture as a function of the applied voltage. x equals to (a) 0, (b) 25, (c) 50, (d) 60, (e) 75, (f) 100.

concentrations as a function of the applied voltage. This figure clearly indicates that the curve of the transmission versus applied voltage systematically shifts towards lower voltages with an increasing SmC* concentration. Meanwhile, the hysteresis width decreases. Notably, the cells become unstable if the SmC* concentration exceeds 60%.

Let the hysteresis width ΔV be defined as the voltage difference at the mid-point of the ramp-up curve (voltage increase) and the rampcells become unstable if the SmC* concentration exceeds 60%.

Let the hysteresis width ΔV be defined as the voltage difference at the mid-point of the ramp-up curve (voltage increase) and the ramp-down curve (voltage decrease) between the maximum and minimum transmission in Fig. 1. In addition, threshold voltage V_{th} is defined as the voltage of the light transmission to increase 10% from the minimum transmission in the ramp-up curve. Figure 2 shows he variations of the measured hysteresis width ΔV and threshold voltage V_{th} given in Fig. 1 as a function of the SmC* concentration.

Figure. 3 shows the variations of the measured rise-time τ_{on} and fall-time τ_{off} of the PSCT cells having x wt% SmC* (x=0-100) concentrations with respect to the applied voltage. In this experiment,



(b)

FIGURE 2: Variations of (a) the measured hysteresis width ΔV, and (b) the threshold voltage V_{th} with respect to SmC* concentration derived from Fig. 1

a DC voltage pulse having a width of 165ms was applied to a cell. The rise-time is defined as the time elapsed for the light transmission to reach 90% of the maximum from its 10% while applying the voltage pulse. Similarly, the fall-time is defined as the time elapsed for the transmission to reach 10% from its 90% while the voltage

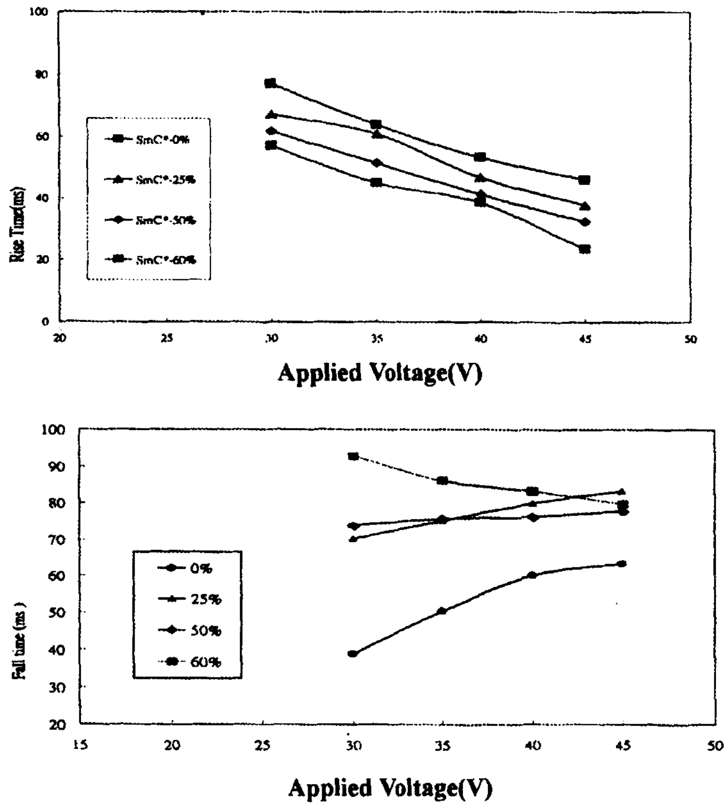


FIGURE 3: Variations of the measured (a) rise time τ_{on} and (b) fall time τ_{off} of the PSCT normal-mode cells having x wt% SmC* concentrations with respect to voltage.

turned off. Notably, the amplitudes of the voltage pulse applied in this case are greater than the saturation voltages shown in Fig. 1 in each case. According to Fig. 3(a), the rise-time decreases with an increasing voltage. Also, the rise-time decreases as the SmC* concentration increases under the same applied voltage.

However, Fig. 3(b) reveals that the fall-time of the cells with the addition of SmC* are higher than those without SmC*. At higher voltages, the fall times of these cells with SmC* are approximately equal, which are independent of the SmC* concentration.

Applying an electric field indicates that the helical structure of a cholesteric LC can be unwound to become a pesudo-nematic homeotropic state. The threshold voltage V_{th} is [13]

$$V_{th}=\frac{2\pi d}{p}\sqrt{\frac{\pi k_{22}}{\Delta\varepsilon}}\ , \qquad (1)$$

where p denotes the pitch length, $\Delta\varepsilon$ represents the dielectric anisotropy, k_{22} is the twist elastic constant and d denotes the cell's thickness.

The measured pitch lengths of planar cells made from the cholesteric mixtures having x wt% SmC* concentrations (x= 0, 5, 10, 1.5) are 1.7μm, 1.8μm, 1.85μm, 2.1μm, respectively. Also, the measured dielectric anisotropy $\Delta\varepsilon$ for the cholesteric LC having 0, 50wt% of SmC* are 14.9 and 15.99, respectively. Restated, the pitch length of the cholesteric LC having a higher SmC* content is larger. In addition, the dielectric anisotropy increases with an increasing SmC* concentration as well. The increase of the pitch length when adding SmC* in the cell may be due to a decrease of CB15 component in the mixture. This was further verified in the pitch-length measurements of PSCT cells having y-times SmC* concentration which is given latter. Based on these results, Fig. 2(b) that shows V_{th} decreases with an increasing SmC* concentration is consistent with the theory (Eq.(1)).

The threshold voltage and the hysteresis width ΔV of a PSCT normal-mode cell are also known to be affected by its polymer network morphology.[8] In a PSCT normal-mode cell, the formed polymer network aligns perpendicularly to the cells' surfaces. As a result, the polymer network induces an alignment force on LC molecules which helps a PSCT cell to transit from its off-state (focal-conic state) to on-state (homeotropic alignment). Thus, a denser polymer network induces a stronger alignment force, resulting in a lower V_{th} and a larger ΔV. In order to explain the result shown in Fig. 2(a), we investigated the polymer network formed in PSCT cells having x wt% SmC* concentrations (x = 0, 25, 50). The observed SEM images are shown in Fig. 4. It clearly indicates that the morphology of the polymer network

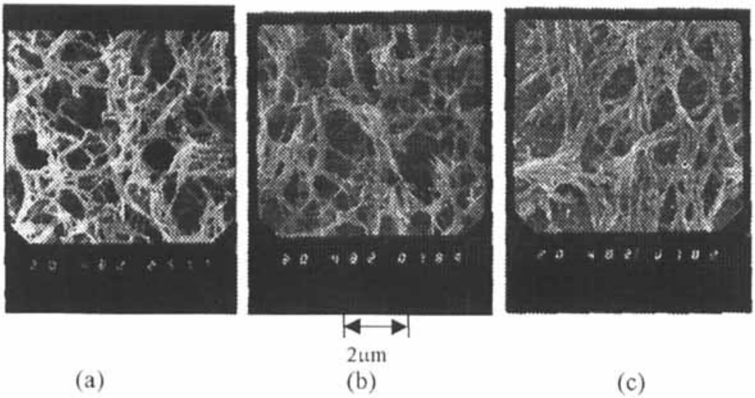


FIGURE 4: Top-view SEM images of the polymer network formed in the PSCT normal-mode cell having x wt% SmC* concentrations, (a) x=0, (b) x=25, (c) x=50.

in PSCT mixtures changes when adding SmC* in the cell. For a mixture having a higher SmC* concentration, more polymers were separated to form network. But the polymer stripes seem to be less rigid, and they tend to stick together. Thus, the space (LC domains) between polymer fibers is larger. The observed result depicted in Fig. 2(a) that shows the decrease of ΔV with an increasing SmC* concentration is should be connected mainly with this morphology change.

The rise time τ_{on}[14] and fall time τ_{off}[15] of a PSCT normal-mode cell can be described by the following equations:

$$\tau_{on}=\frac{\eta}{\Delta\varepsilon\frac{V^2}{d^2}-\frac{k_{22}}{p^2}}, \text{ and} \quad (2)$$

$$\tau_{off}=\frac{\eta p^2}{k_{22}}, \quad (3)$$

where V denotes the applied voltage and η represents the viscosity of the cholesteric LC. Based on the measured results of Δε and p for PSCT mixtures having x% SmC* concentrations and on the equations (2) and (3), our results that the rise time decreases, and that the fall time increases with an increasing SmC* concentration shown in Fig. 3 are reasonable. We then moved to investigate the electro-optical characteristics of PSCT cells having y-times SmC* concentrations (the second set samples). Notably, the amount of the chrial dopant CB15 added in these cells is same (~ 8 wt%). The difference is that the added SmC* concentration in the cells varies.

The pitch lengths of these y-times SmC* PSCT cells were found to be approximately unchanged. It indicates that the twist power of CB15 is much stronger than that of the SmC*. The measured E-O characteristics of these cells are shown in figures 5 and 6. It is seen that

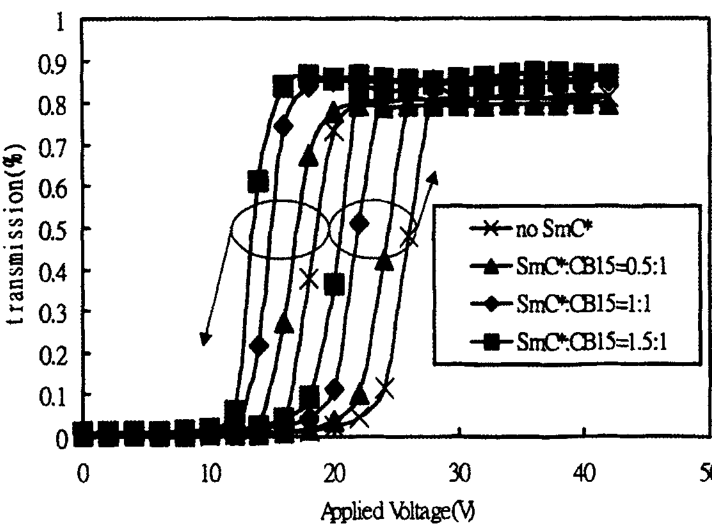


FIGURE 5: Measured transmissions of the PSCT cells having y-times SmC* concentrations.

the threshold voltage of these y-times SmC* PSCT cells decreases, while the hysteresis width increases, with an increasing SmC* concentration. In addition, the rise-time (fall-time) is decreasing (increasing) with an increasing SmC* concentration. In order to explain these results, the morphologies of the cells' polymer networks were examined. The result is depicted in Fig. 7 . It clearly indicates that adding a small amount of a SmC* in the cell significantly modifies the morphology of the cells' polymer network. As the SmC* concentration

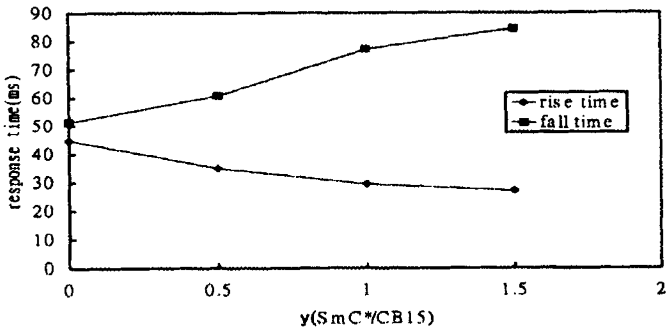


FIGURE 6: The measured (a) rise-time τ_{on} and (b) fall-time τ_{off} of PSCT cells having y-times SmC* concentrations (y=SmC*/CB15).

increases, the formed polymer network becomes denser. As a result, the induced alignment force increases with an increasing SmC* concentration for these PSCT cells having y-times SmC*. The stronger alignment force helps to reduce both the threshold voltage and the rise-time, but to increase the hysteresis width and the fall-time. Thus, the observed results shown in Figs. 5 and 6 are understandable.

In conclusion, this work has demostrated that adding a small amount of a PSCT mixture could result in a lower threshold voltage, a faster rise-time and a larger hysteresis width of the device. From the perspective of PSCT display applications,[8] these features are desired. Such an improvement is due to the modification of the cells' polymer network and the increase of the dielectric anisotropy of the liquid crystal with the addition of a small amount of SmC* in the mixture. Notably, that the pitch length of the cholesteric mixtures having y-times SmC* concentrations does not change.

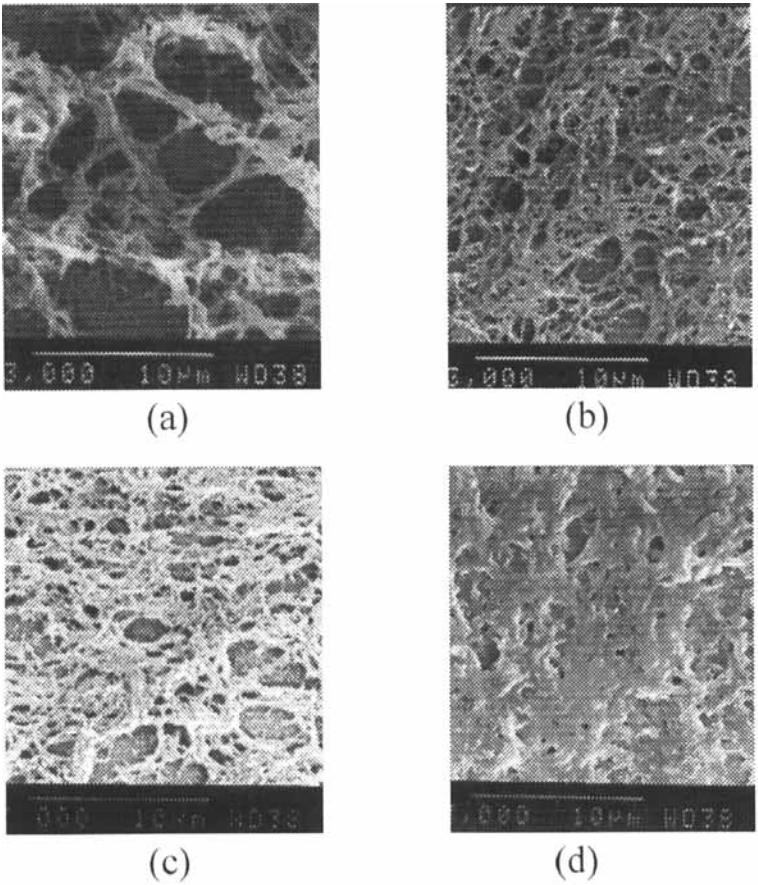


FIGURE 7 Top-view SEM images of the polymer network formed in the PSCT cells having y-times SmC* concentrations (second set samples), (a) y=0, (b) y=0.5, (c)y=1, (d) y=1.5.

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