

# Bistable transfective cholesteric light shutters

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**Abstract:** We have studied a bistable transfective cholesteric light shutter. The shutter contains dual-frequency cholesteric liquid crystals that incorporate a photocurable monomer. The electro-optical properties and optical microscope images of the shutter were examined. Good correlations between the cholesteric textures and optical properties of the shutters were obtained. The shutter was switched into a wide-band homogeneous transmission mode by a low frequency voltage pulse, and into a selective reflection mode using a high-frequency voltage pulse. The concentration of the monomer apparently affected the electro-optical characteristics of the shutter.

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**OCIS codes:** (230.2090) Electro-optical devices; (230.3720) Liquid-crystal devices

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## 1. Introduction

Electrically controlled liquid crystal-polymer dispersion (LCPD) films have recently attracted increasing interest, due to not only their potential application in flat-panel displays, but also the interesting physical phenomena that they exhibit [1-6]. The potential application of LCPD films in flat-panel applications has been the main motivation for intense research into the structure and morphology of the liquid crystal-polymer composite system. Liquid crystal (LC) polymer dispersions are divided into two types according to the concentration of polymer in the mixture. Polymer-dispersed liquid crystals (PDLCs) constitute one type of LCPD film [7-9]. They contain approximately equal quantities of LCs and polymer, and form micron-sized LC droplets in the polymer matrix. However, they exhibit a strong haze in the transparent state, because of serious refractive index mis-matching of the refractive indices of LCs and the polymer matrix [9].

Another LCPD material, called the Polymer-Stabilized Cholesteric Texture (PSCT)[10-11], has been developed to solve the problem of refractive index mis-matching in the PDLC films. In such a system, a little monomer (typically less than 10wt%) dissolves in a cholesteric LC medium. Fiber-like anisotropic polymer networks form after the monomer is polymerized. The surface alignment, or the external electric field determines the orientation of the LCs, which, in turn, determines the direction of the polymer networks [6,12]. In such a system, the polymer network exerts an aligning force on the LC molecules, but this force can be overcome by an external electric field. The problem of mis-matching refractive indices is eliminated because PSCTs use a low concentration of polymers. Therefore, PSCTs are haze-free at wide viewing angles in the clear state. They have been reported to be a strong contender in display applications.

Liquid crystal light shutters have been intensely studied and used in many applications in the last two decades. They can be operated in transmission or reflection mode, according to their structure and purpose. However, in some applications, transfective display devices, when used in the transmission mode, partly transmit light from a backlight behind the display devices; when used in the reflection mode, the incident ambient light is reflected. Such display devices have found increasingly wide range of applications, including for example, cellular telephones, personal digital assistants and automotives. This work presents a new transfective cholesteric light shutter. The shutter is bistable and made from a mixture of dual-frequency cholesteric liquid crystal and photocurable monomer mixture. The cholesteric textures, the optical properties, the concentration of the monomer and the electrooptical characteristics of the shutters were examined.

## 2. Experiments

The dual-frequency cholesteric liquid crystal (DFCLC) mixture used in this paper was a mixture of ZLI-2806 (from E. Merck), DF-02XX (from Chisso) and chiral dopant R1011 (from E. Merck). DF-02XX was a dual-frequency nematic liquid crystal with a crossover frequency of  $f_c \sim 1\text{kHz}$ . The dielectric anisotropies of DF-02XX at frequencies 100Hz and 5kHz were 1.4 and  $-0.5$ , respectively. ZLI-2806 ( $\sim 40\text{wt}\%$ ) was added to increase the absolute value of the dielectric anisotropy of the DFCLC mixture at high frequency, due to its negative dielectric anisotropy. Therefore, the driving voltage of the cell at 5kHz was reduced. A laboratory-synthesized monomer Bis [6 - (acryloyloxy) hexyloxy]-1, 1'-biphenylene (BAB6) and photoinitiator Benzyl methylether (BME, from Polyscience) were added to the DFCLC to generate the DFCLC-monomer mixture. The purpose of the photoinitiator was to initiate the polymerization of the monomer BAB6. The amount added to the mixture was around 10wt% of the monomer BAB6. Each end of monomer BAB6 had a reactive double bond. UV radiation polymerized the monomer into a cross-linked anisotropic polymer network [12].

Cleaned indium tin oxide (ITO) glass substrates were coated with polyvinyl alcohol (PVA), and then rubbed with a cloth to promote homogeneous alignment. Homogeneous cells were

made using two identical but anti-parallel homogeneous alignment substrates. Untreated cells were fabricated using two untreated ITO glass substrates. The dimension of the cells was about 2.5 cm x 3cm, and the gap of the cells was controlled by an 8 $\mu$ m thick plastic spacer. The homogeneous cells were filled with DFCLC mixture to generate surface-stabilized films. The filled samples underwent thermal annealing, involving heating the samples into an isotropic state and then slowly cooling them to room temperature. The untreated cells were filled with the DFCLC-monomer mixture to generate the polymer-stabilized films. The filled samples underwent thermal annealing, followed by UV polymerization without an external field. The UV light was provided from a Philips model 400/30S metal halide lamp. The wavelengths used was 350~400nm, the curing intensity was 2.5 mW/cm<sup>2</sup> and the curing time was ~ 40 minutes. Several cells of each type were constructed and tested in this experiment.

Figure 1 depicted the experimental setup for measuring the cells' electro-optical characteristics. Monochromatic light emerged from a combination of quartz tungsten halogen (QTH) lamp and monochromator was incident normal to the sample. The light transmitted through the sample was collected at a photodiode (PD). The distance from the sample to the lens F was about 20cm. The focal length of F was 100mm. The pinholes P1 and P2 were placed adjacent to the sample and the lens F. The combination of a function generator (FG) and a high voltage amplifier (AMP), providing a continuous square wave voltage (CSV) or a single pulse square wave voltage (SPV), was connected to the sample. The electrical signal from the PD was fed to a photometer (PM) and then to a PC for analysis.

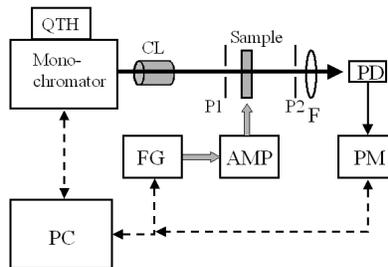


Fig. 1. Experimental setup for measuring electro-optical characteristics of cells. QTH indicates the quartz tungsten halogen lamp, CL the collimator, P1 and P2 the pinhole, F the lens, FG the function generator, AMP the high voltage amplifier, PD the photodiode and PM the photometer.

### 3. Results and discussion

Figures 2(a) to 2(c) present optical microscope images of the surface stabilized film after annealing in the  $V=0$  (ANN) state, after 100Hz 50V SPV and after 100Hz 80V SPV, respectively. As shown in the figure, in the ANN state, the texture of the DFCLC is clear; however, after the application of 100Hz SPV, the DFCLC exhibits Grandjean textures. When a low-frequency SPV (below  $f_c$ ) is applied, the LC molecules are subject to a positive torque and unwind toward the homeotropic state, before relaxing back into an imperfect planar state. The density of the Grandjean textures increase with the amplitude of the low frequency SPV.

Figure 3 displays the spectral characteristics of the surface-stabilized film, under 100Hz 50V CSV, under 100Hz 80V CSV, after 100Hz 50V SPV and after 100Hz 80V SPV. In this paper, the selective reflection region of the DFCLC mixture was chosen in the red, thus, we measure the transmission of the cell from 550nm~750nm. As shown in the figure, when the 100Hz CSV is applied, the DFCLC molecules unwind toward the homeotropic texture; therefore, the transmission increases with the applied voltage. Also, the films exhibit homogeneous wide-band transmission in the visible spectrum. After 100 Hz SPV is applied, the LC molecules unwind toward the homeotropic state, before relaxing back into the imperfect planar state. The density and the domain size of the Grandjean texture increases and

decreases with increasing amplitude of the low frequency SPV, respectively. Therefore, the number of the scatters in the cell increases. Accordingly, as shown in the figure, applying higher amplitude of low frequency SPV generates more Grandjean texture, reducing the reflectivity of the selected reflection. It is noted that with the application of high voltage CSV, the cell becomes hazy. After the application of high voltage SPV, the cell appears reddish. In this experiment, the dielectric anisotropies of the DFCLC mixture at low frequency and high frequency are small; the driving voltage becomes high. In addition, the viscosity of the mixture is large and the miscibility of DF02XX, ZLI-2806, R1011 and BAB6 are not excellent. Therefore, the transmission and other electro-optical characteristics of the cell are limited in operation.

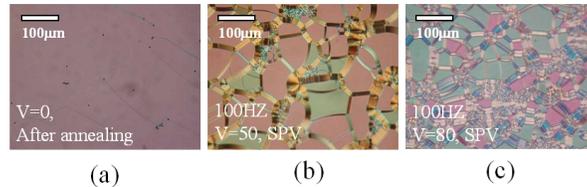


Fig. 2. Optical microscope images of the surface-stabilized film (a) after annealing in the V=0 (ANN) state, (b) after 100Hz 50V SPV and (c) after 100Hz 80V SPV.

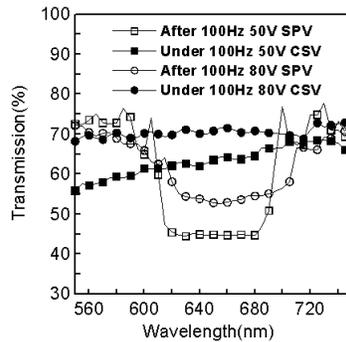


Fig. 3. Spectral characteristics of the surface-stabilized films under 100Hz 50V CSV, under 100Hz 80V CSV, after 100Hz 50V SPV and after 100Hz 80V SPV.

Figure 4 displays the optical microscope images of the polymer-stabilized film in the ANN state, after 5kHz 80V SPV, after 5kHz 120 V SPV, after 100Hz 80V SPV and after 100Hz 120 V SPV. The concentration of monomer added in this experiment is around 1wt%. As shown in the figure, in the ANN state, the DFCLC molecules exhibit the focal conic texture, and the film is in the scattering state, the transmission is low, as shown in Figs. 5(a) and 5(b). After high-frequency SPV is applied, the stable stripe patterns appear. The stripes group into pairs and become sparse and indistinct as the amplitude of the high frequency SPV is increased [13]. Therefore, the selective reflection state appears, as shown in Fig. 5(a). The selective reflection curve and the efficiency are similar to those of surface-stabilized films since only a little small monomer is added to the film. The transmission of the selective reflection region of the selective reflection curve is found to be the same as that in the ANN state, and the transmission in the unselective reflection region exceeds that obtained in the ANN state. However, after low-frequency SPV is applied, the DFCLC molecules unwind toward the homeotropic texture, and the focal conic domains combine and are enlarged. Accordingly, the transmission increases with the amplitude of the low frequency SPV and is homogeneous across the visible spectrum, as depicted in Fig. 5(b).

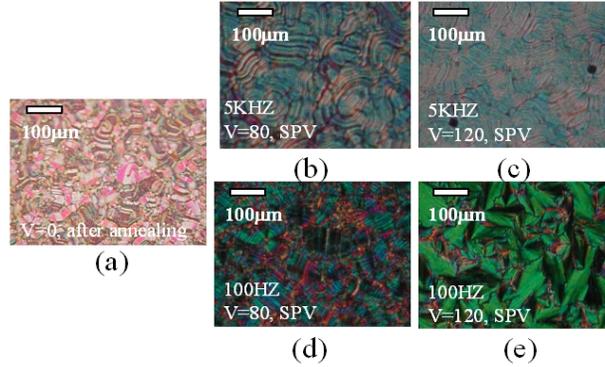


Fig. 4. Optical microscope images of the polymer-stabilized film (a) in the ANN state, (b) after 5kHz 80V SPV, (c) after 5kHz 120 V SPV, (d) after 100Hz 80V SPV and (e) after 100Hz 120 V SPV. The concentration of the monomer added in this experiment is approximately 1wt%.

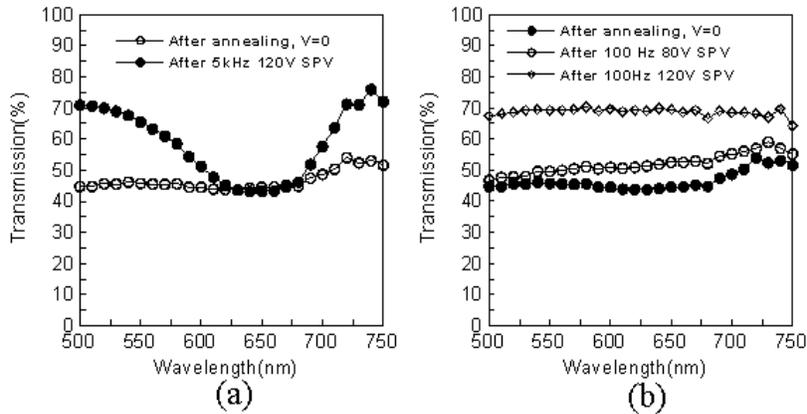


Fig. 5. (a) Spectral characteristics of the 1wt% polymer stabilized film in the ANN state and after the application of 5kHz 120 V SPV. (b) Spectral characteristics of the 1wt% polymer-stabilized film in the ANN state, after 100Hz 80 V SPV and after 100Hz 120 V SPV, respectively.

Figure 6 presents optical microscope images of the polymer-stabilized film in the ANN state, after 5kHz 80V SPV, after 5kHz 120 V SPV, after 100Hz 80V SPV and after 100Hz 120 V SPV. The concentration of monomer added in this experiment is approximately 3wt%. The observed images are similar to those in Fig. 4. However, the stripes are denser and thinner, because a higher concentration of monomer is added to the films. The denser and thinner stripes cause very different electro-optical characteristic from those exhibited by the 1wt% polymer stabilized film. As displayed in Fig. 7(a), after the high-frequency SPV is applied, the selective reflection appears. However, the transmission of the reflection region of the selective reflection spectrum is much smaller than that in the ANN state, and the transmission of the non-reflecting region is the same as that in the ANN state because increasing the concentration of the monomer strengthens the scattering effect in the 3wt% polymer-stabilized films. Figure 7(b) presents the transmission of the 3wt% polymer-stabilized film after the low-frequency SPV is applied. Comparing Figs. 5(a) and 7(a) indicates that the transmission of the 3wt% film is more homogeneous than that of the 1wt% polymer-stabilized film in the visible region.

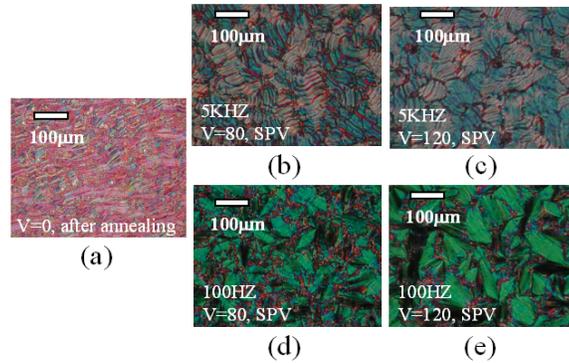


Fig. 6. Optical microscope images of the polymer stabilized film (a) in the ANN state, (b) after 5kHz 80V SPV, (c) after 5kHz 120 V SPV, (d) after 100Hz 80V SPV and (e) after 100Hz 120 V SPV. The concentration of the monomer added in this experiment is about 3wt%.

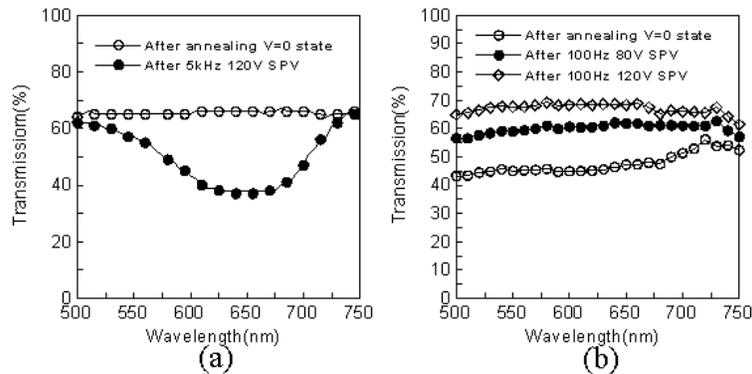


Fig. 7. (a) Spectral characteristics of the 3wt% polymer-stabilized film in the ANN state and after 5kHz 120 V SPV, respectively. (b) Spectral characteristics of the 3wt%-polymer stabilized film in the ANN state, after 100Hz 80 V SPV and after 100Hz 120 V SPV.

#### 4. Conclusions

We have presented a bistable transfective cholesteric light shutter. The shutter contains dual-frequency cholesteric liquid crystals that incorporate a photocurable monomer. The electro-optical characteristics and optical images of the shutter were investigated. Good correlations between the cholesteric textures and the optical properties of the shutter were obtained. The concentration of the monomer apparently affected the electro-optical characteristics of the shutters. The shutter was switched into a wide-band homogeneous transmission mode by a low-frequency voltage pulse, and into a selective reflection mode by a high-frequency voltage pulse. The concentration of the monomer added to the mixture could be adjusted to control the transmission of the selective reflection band above or below the transmission of the original after annealing,  $V=0$  (ANN) state. More detailed work on optimization and applications is being conducted.

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