Effect of Shearing Stress on Reflective Properties of Cholesteric Liquid Crystal Films

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ABSTRACT: Effect of shearing stress on reflective properties of cholesteric liquid crystal films is studied in this article. Heating up a glassy siloxane cyclic side-chain oligomer within the temperature range of the cholesteric (Ch) phase leads to the availability of its planar texture. Then, the received cholesteric liquid crystalline with planar texture is reoriented by shearing force quickly after it is taken off from the heater. The pitches change, and a pitch difference is induced by inhomogeneous distribution of stress. The SEM image indicates the pitch difference perpendicular to the substrates, and the results of transmission spectra show that the reflection bandwidth of the film obtained is broadened, and the central reflection wavelength of the reflective film moves. © 2010 Wiley Periodicals, Inc. J Appl Polym Sci 118: 1894–1897, 2010

Key words: cholesteric liquid crystal; pitch; shearing stress; reflection bandwidth; central reflection wavelength

INTRODUCTION

In a cholesteric (Ch) phase, the long axis of the liquid crystal (LC) molecules revolves around a helix. The pitch length, P, of the helix corresponds to a 2π molecular rotation. Because there is a periodic variation in the reflective index for a cholesteric liquid crystalline (Ch-LC), it can be used for optically filtering a circularly polarized incident light of the same handedness as its helix. A single-pitch Ch-LC reflects selectively the light with a wavelength between $\lambda_{min} = Pn_o$ and $\lambda_{max} = Pn_e$, here n_o and n_e are, respectively, the ordinary and extraordinary refractive indices of the locally uniaxial structure. Then, the bandwidth of the reflection spectrum, $\Delta\lambda$, is given by $\Delta\lambda = \lambda_{max} - \lambda_{min} = (n_e - n_o)P = \Delta nP$. Here, $\Delta n = n_e - n_o$ is the birefringence. Within the bandwidth, right circularly polarized light is reflected by a right-handed helix, whereas left circularly polarized light is transmitted.[1] Outside the bandwidth, both polarization states are of transmitted type. For colorless materials (typically, $n_o = 1.5$ and $n_e = 1.7$), the bandwidth in the visible region is <75 nm.[2] For some applications, such as full color displays or black and white displays, the cholesteric LC with $\Delta\lambda$ less than 100 nm is insufficient.

Broer et al. obtained a wideband polarizer from the photopolymerized composite system (cholesteric diacrylate/nematic monoacrylate/dye). In this study, because of the UV intensity gradient over the film thickness, the free radicals of the cholesteric diacrylate polymerized relatively faster on the high UV intensity side. As a result, the density of the free radicals of the cholesteric diacrylate on the high UV intensity side of the composite film was lower than that on the low UV intensity side. Then, the molecules of the cholesteric diacrylate diffused from the low UV intensity side of the composite film into the high UV intensity side during photopolymerization, and a pitch gradient was formed in the photopolymerized composite system.[3] A pitch gradient could also be successfully induced by thermal diffusion between the two layers of ChLCPs with different pitches.[4] Kreuzer et al. obtained a polarizer from a composite system (polymer network/LC/chiral dopant), the bandwidth of which increased with temperature.[5]

In this article, effect of shearing stress on the reflective properties of a glassy siloxane cyclic side-chain oligomer (GSCSO) film is studied. Pitches change because of the shearing stress, and a pitch difference is induced by an inhomogeneous distribution of stress.

EXPERIMENTAL

Preparation

A GSCSO with mole ratio of chiral and nonchiral mesogens of 3/1 was chosen.[5] The glass transition

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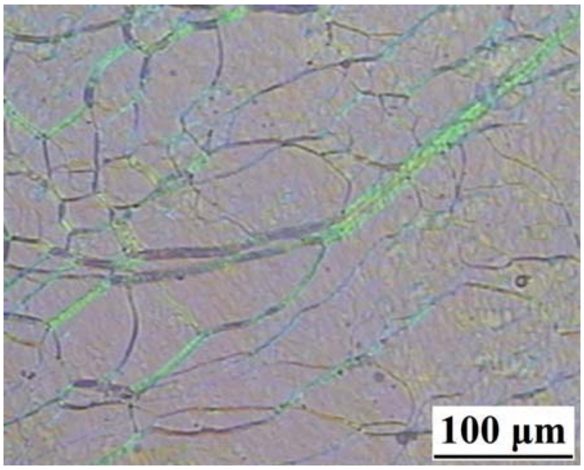

Figure 1 Polarized optical microphotograph of the planar texture of the cholesteric liquid crystal. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

temperature and clearing point of the GSCSO are 320.9 and 465.1 K, respectively.

The GSCSO was molded on a glass substrate. Another plastic substrate was put on it. Then, the GSCSO was sandwiched between two substrates, of which the inner surfaces had been treated for planar orientation of the LC molecules. The GSCSO was first oriented at a higher temperature between the glass transition temperature and the isotropic transition temperature of the GSCSO. The received Ch-LC with planar texture was then reoriented by pulling the bottom substrate by a force of about 0.5 N quickly after it was taken off from the heater. The molecular arrangement obtained was fixed by rapid cooling. The thickness of the LC film was about 12 μm.

Measurements

The spectral characteristics of the films were obtained by an LCT-5016C LCD Parameters Tester at room temperature. The reflection wavelength λ and reflection bandwidth $\Delta\lambda$ were measured from the spectrum by considering the wavelength for the minimum of transmitted light inside the peak and the peak bandwidth at half-height, respectively.

The morphologies of freeze-fractured surfaces of samples perpendicular to the plates were observed by scanning electron microscopy (SEM) after coated with carbon in a sputtering coater.

RESULTS

A selective reflective film from the GSCSO

When the GSCSO was heated to the temperatures between glass transition temperature and the clearing temperature, the energy of disorientation of the mesogens was low because of the highly flexible siloxane backbone, coupled with flexible spacers separating the mesogens from the backbone. So, the mesogens attaching to the cyclic siloxane LCs were easy to orient along a certain direction.[6]

In this article, the GSCSO sandwiched between two substrates, of which the inner surfaces had been treated for planar orientation was first oriented at a higher temperature between the glass transition temperature and the isotropic transition temperature of the GSCSO. Then, the mesogens attached to the cyclic siloxane can be aligned parallel to the substrates, and the axis of the cholesteric helix is preferentially perpendicular to the substrates at last. The molecular arrangement can be easily fixed by rapid cooling because of the freezing of the chain segments for the glassy materials.[7–9]

Figure 1 is polarized optical microphotograph of the film fabricated from the GSCSO by the process mentioned above. Figure 1 shows the network of oily streaks in the cholesteric planar texture, when the axis of the cholesteric helix is preferentially perpendicular to the substrates and the directors are parallel to the plates. Then, selective Bragg reflection occurs because of the periodic helical molecular structure in the cholesteric planar texture.

A solid reflective film with a constant reflection wavelength can be fabricated when the planar texture of the GSCSO is fixed by rapid cooling below the glass transition temperature. Figure 2 is the SEM

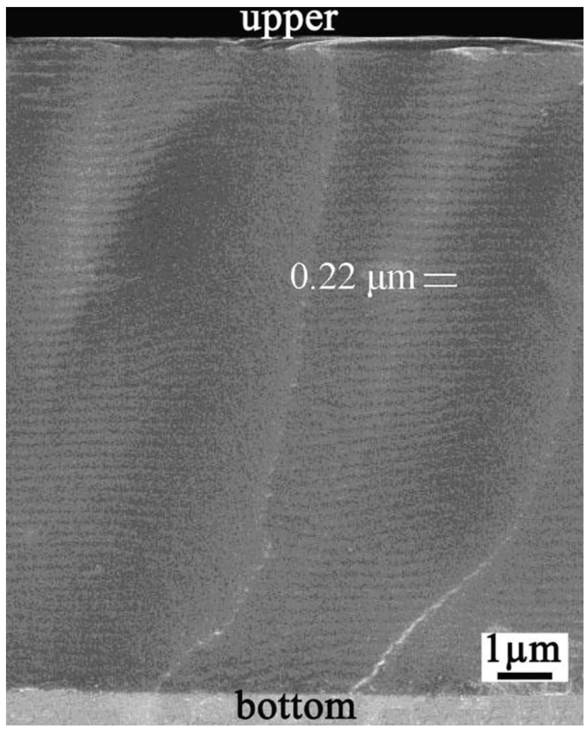

Figure 2 Scanning electron micrograph of the freeze-fractured surface of the specimen oriented at 105°C.

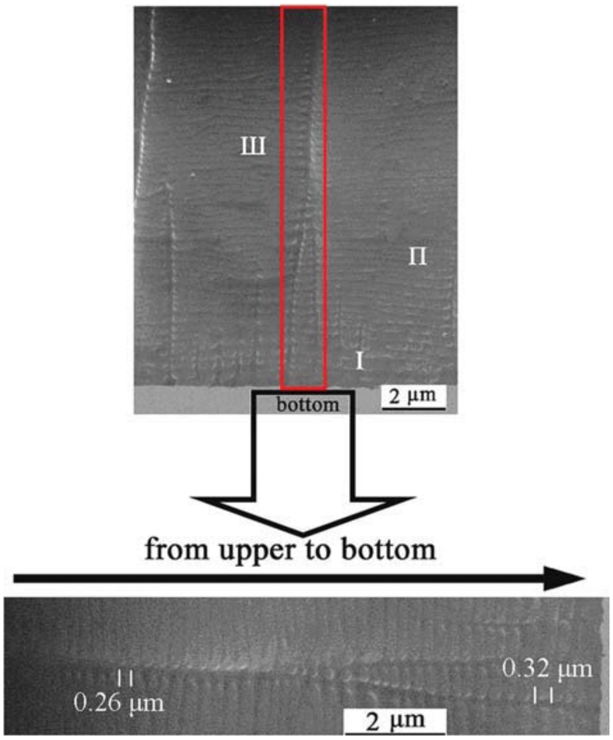

Figure 3 Scanning electron micrograph of the freeze-fractured surface of the specimen reoriented quickly after oriented at 105°C for planar texture. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

of freeze-fractured surface (cross section perpendicular to the plates) of a solid GSCSO reflective film with planar texture after orienting at 105°C and then quenching. The periodic helical molecular structure is along the transverse direction. The pitch of the helix corresponds to a 2p molecular rotation.

Shearing stress dependence of the reflection properties

When a GSCSO is heated to a temperature above its glass transition temperature, more free room for the motion of the chain segments is obtained because of the highly flexible siloxane backbone, coupled with flexible spacers separating the mesogens from the backbone. Then, the mesogens can orient easily. Certainly, the mesogens can also rearrange easily when the obtained LC with planar texture is reoriented above its glass transition temperature. Figure 3 is the SEM of a freeze-fractured surface (cross section perpendicular to the plates) of the specimen, which is reoriented by pulling the bottom substrate quickly after it is taken off from the heater with the temperature of 105°C. It is clear that pitch difference is induced in the specimen. The reason that a pitch difference is formed when the specimen is reoriented by pulling the bottom substrate quickly after it is taken off from the heater can be explained as follows. Figure 4 presents a schematic representation of the method used to prepare a reflective film in this study. At first, the LC is oriented for planar texture at 105°C, and uniform pitches are formed [referring to Fig. 4(I)]. It can be seen from Figure 2 that the pitches are nearly uniform from upper to bottom for the reflective film orienting at 105°C and then quenching. Selective Bragg reflection happens because of the periodic helical molecular structure (referring to the thinner curve in Fig. 5). While as the bottom substrate is pulled quickly after the

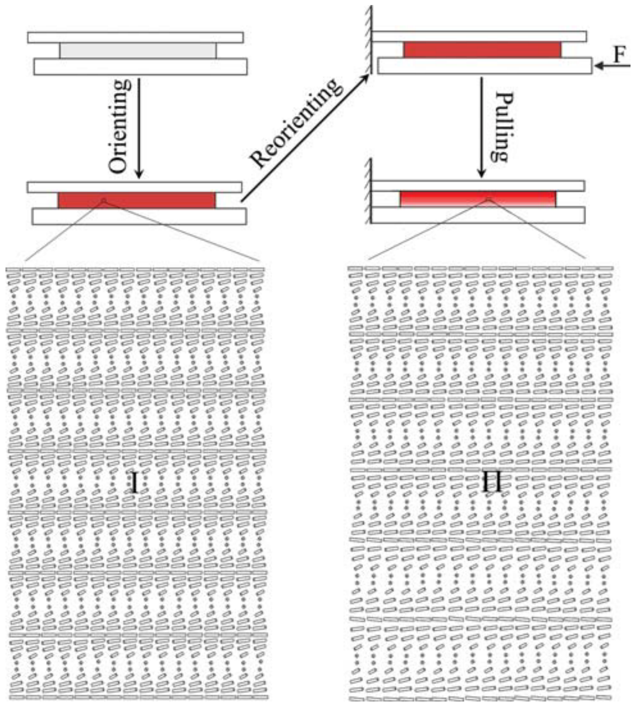

Figure 4 Schematic representation of the sample preparation method. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

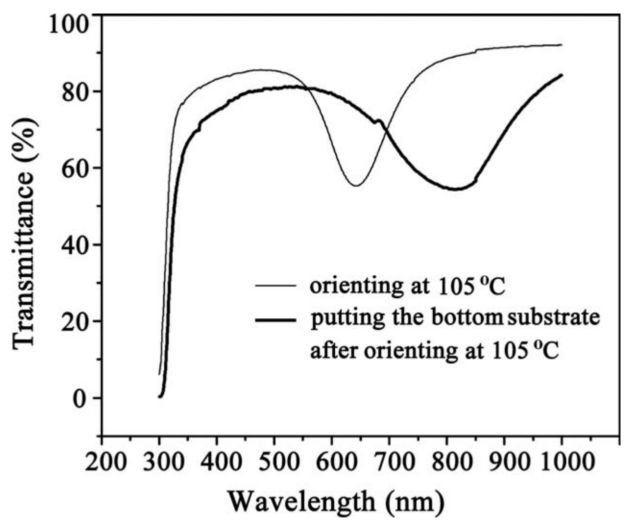

Figure 5 Transmission spectra of the reflection films.

specimen is taken off from the heater of 105°C, the viscosity of the LC is low enough for the mesogens to adjust under the shearing stress. That is, when the bottom substrate is pulled by a force *F* above the glass transition temperature quickly after the cholesteric LC is oriented for planar texture, the mesogens can rearrange under shearing stress.[10,11] So, the pitches can be adjusted [referring to Fig. 4(I)]. It is clear that the pitches change when the bottom substrate is pulled above the glass transition temperature after the specimen is taken off from the heater of 105°C (referring to Figs. 2 and 3). Of course, the central reflection wavelength of the reflective film moves (referring to Fig. 5). On the other hand, the pulling force is inhomogeneous, so the distribution of stress is inhomogeneous. Then, the pitches are different because of the inhomogeneous distribution of stress [referring to Fig. 3(I–III)].[12] At the same time, the stress attenuates step by step along the transverse direction because of the influence of viscosity.[13] So, in some places, pitch gradients will be formed (referring to the magnifying part in Fig. 3). Then, the reflection bandwidth is broadened because of the pitch difference (see the thicker curve in Fig. 5).

As the temperature continues decreasing, energy becomes lower and viscosity becomes higher. At last, the residual stress cannot make the mesogens to bend around from their point of attachment. So, the pitches and the pitch difference are finally restored because the mesogens cannot reorient further under the stress.

CONCLUSIONS

When a GSCSO is heated to a temperature above its glass transition temperature, more free room for the motion of the chain segments is obtained because of the highly flexible siloxane backbone, coupled with flexible spacers separating the mesogens from the backbone. Then, the mesogens can rearrange easily above its glass transition temperature. When the planar cholesteric LC film is reoriented by force quickly after it is taken off from the heater with a higher temperature, pitches can change and a pitch difference can be induced because the mesogens rearrange. The central reflection wavelength of the reflective film moves because of the changed pitches, and the reflection bandwidth is broadened because of the pitch difference formed.

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