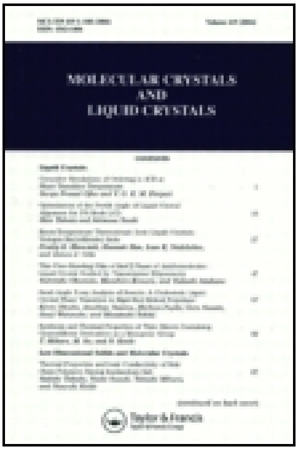

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The structural and electrooptical properties of planar-oriented films of polymer dispersed cholesteric liquid crystals with tangential orientation of molecules at the interface were investigated. It is shown, that in this medium, a great difference is observed between the threshold parameters and the form of both polarized components of the volt-contrast characteristic. This effect is due to the specific features of structural transformations of the elongated cholesteric droplets in the electric field.

Keywords: polymer dispersed liquid crystals; cholesterics

INTRODUCTION

Recently, among the heterophase polymer-liquid crystal compositions, much interest has been shown to planar-oriented films of polymer dispersed liquid crystals (PDLC)[1,2]. These films can be prepared by different methods[1,2], in particular, with the use of stretching or shear deformation. In the stretched (sheared) samples, LC droplets have an ellipsoidal form, and their long axes are parallel to each other and lie in the film plane (at a small angle to the plane) along the direction of deformation.

Apparently, the first paper devoted to the planar-oriented films of polymer dispersed cholesteric liquid crystals (PDChLC) is[3] where the optical properties (selective light scattering, spectral dependence of transmittance) of the thermochromic PDChLC films are investigated depending on the value of stretching.

The linear electrooptical effect in ellipsoidal droplets of cholesterics was studied in[4] where the light transmission of a stretched PDChLC film placed between crossed polarizers was measured. To obtain a uniform in-plane alignment of the helix axis, the authors[4] used as a polymer matrix polysiloxane or polyvinylbutyral with lecithin, which provided homeotropic conditions. The studies of the phase shift of the light transmitted through these films have shown that the helix axis was oriented perpendicular to the stretching direction inside a droplets without applied voltage.

In papers[5,6] a large anisotropy of the threshold parameters of the polarized components of the volt-contrast curves (VCC) was observed in planar-oriented PDChLC films with tangential boundary conditions. In the present paper, we study the light scattering effects, texture and orientational structure of cholesteric droplets in the same medium depending on the applied electric field.

SAMPLE PREPARATION

We used a liquid crystal consisting of a mixture of cyanobyphenyls nematic derivatives (0.7 5CB + 0.2 7OCB + 0.1 8OCB) with $\Delta\varepsilon > 0$ and cholesteric Ch3 as a chiral additive. The weight concentration of cholesteric ranged from 0 to 12%. At 5% of Ch3, the pitch of the spiral was equal to 3.5 μm. Clearing temperature T_c of the LC-mixtures was near 47^0C. The ChLC-mixture was dispersed in polyvinylbutyral at ratio 3:2 from solution in ethanol. Tangential surface condition at the polyvinylbutyral surface is characteristic of the like nematic mixtures[7].

The ordinary refractive index of the nematic mixture ($n_{\perp} \approx 1.52$) is close to the refractive index of the polymer matrix ($n_p \approx 1.51$), which provides a translucent state of the film, if the LC director in a powered state is oriented along the electric field. The cholesteric additive does not essentially change the value of the LC refractive index. The refractive index of the polymer matrix is larger than that of pure polymer ($n_{PVB} \approx 1.49$) because part of LC, approximately 23%, remains in the matrix in a dissolved state. The dissolved LC essentially plasticizes the polymer matrix. To obtain planar-oriented PDChLC samples, we stretched or sheared the film at temperatures $T > T_c$.

ANISOTROPY OF VOLT-CONTRAST CURVES

Volt-contrast characteristics of the samples under study were measured with use of a He-Ne laser ($\lambda = 0.633$ μm). A linearly-polarized laser beam passed through a cell consisting of two substrates with transparent electrodes separated by a PDChLC film, then through a pinhole and was detected by photodiode. The output signal was analyzed with the help of a XY recorder. The sample was reoriented by applying a sinusoidal signal of 1 kHz and of up to 600 V. The measurements were taken at room temperature.

First we studied the planar-oriented PDLC film prepared by shear without a cholesteric additive. In an unpowered state, this film exhibits a large anisotropy of light transmission (see Figure 1). As was shown earlier[8], in such a case, the light component polarized parallel to the direction of the film orientation (to the direction of shear deformation), appears to be strongly scattered. Oppositely, the film is translucent for the perpendicular component of light, due to the matching between the ordinary LC refractive index and polymer one.

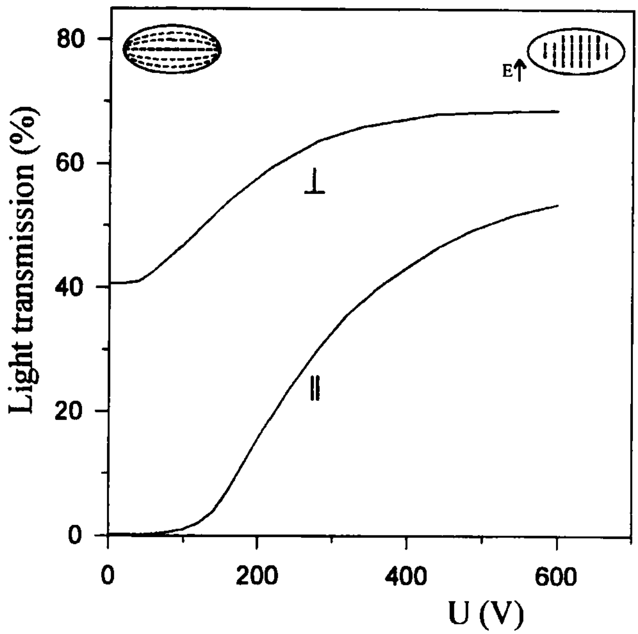

FIGURE 1 Polarized components of light transmission of the sheared PDNLC films as a function of the applied voltage. The film thickness is 36 μm. The shearing is 0.45 mm. Average size of droplets - 2×9 μm. In the inset at the top, the director configuration inside nematic droplets in an unpowered state (on the left) and at saturation voltage (on the right) is schematically shown.

Under applied voltage, transmission of the both light components increases to converge in the field of VCC's saturation. It should be noted, that both the threshold parameters, and the forms of VCC's are approximately identical.

A different situation is observed for sheared PDLC film, prepared with a cholesteric additive (see Figure 2). In the absence of voltage, both light components are strongly scattered, however the parallel one scatters more intensively.

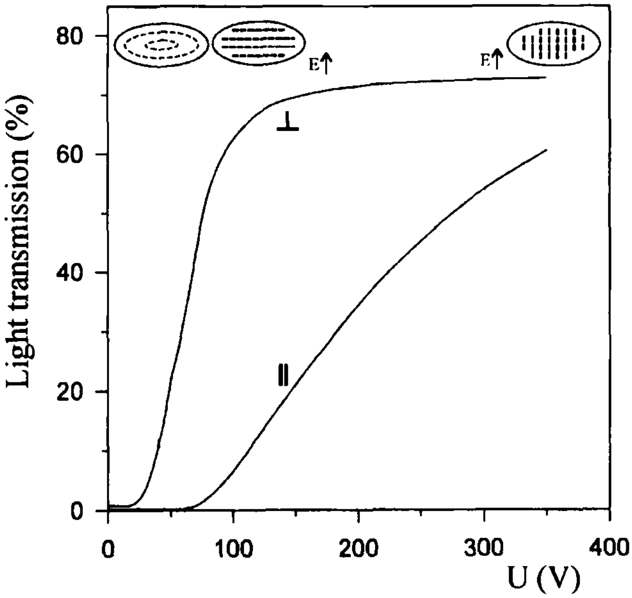

FIGURE 2 Polarized components of light transmission of the sheared PDChLC films as a function of the applied voltage. Cholesteric concentration is 5%. Film thickness is 45 μm. Shearing is 0.5 mm. Average size of droplets - 4×16 μm. In the inset at the top, the director configuration inside cholesteric droplets in an unpowered state (on the left), under the saturation voltage (on the right) and the intermediate structure (in the middle) are schematically shown.

At an increased voltage of up to U ≈ 20V, the perpendicular component of the light transmission begins to grow fast and saturates at U ≈ 120V. The parallel component only begins to go up at U ≈ 70V and reaches saturation at U ≈ 400V. At higher voltages, the both curves, like in the case of nematic LC, converge. Anisotropy of VCC's parameters strongly depends on the cholesteric concentration and the value of deformation. Figure 3 shows, that at the increased shear and concentration of the cholesteric additive, the difference between the two components of the light transmission becomes even more apparent.

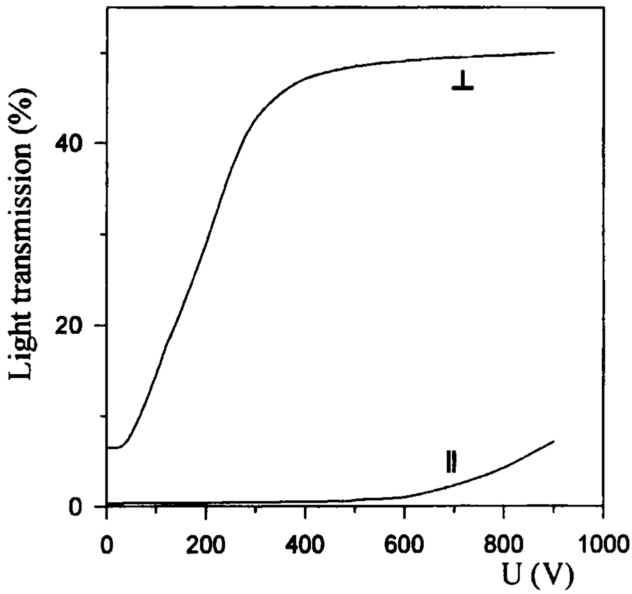

FIGURE 3 Polarized components of light transmission of the sheared PDChLC films as a function of the applied voltage. Cholesteric concentration is 12%. Film thickness is 65 μm. Shearing is 1.2 mm. Average size of droplets - 1.5×12 μm.

For this sample, the perpendicular component of VCC saturates at U ≈ 350V, while the parallel one only begins to appreciably grow at U ≈ 600V. However in this case it was difficult to achieve saturation of the parallel component because of the electric destructions of sample.

TEXTURE AND ORIENTATIONAL STRUCTURE OF LC DROPLETS

To study the orientational structure, thinner samples of PDChLC films with just one layer arrangement of droplets were prepared which allowed to identify precisely the texture of droplets and its change under the applied electric field. The observations were carried out both in the geometry of crossed polarizers and without the analyzer. In an undeformed PDChLC film, the droplets have a round form (see Figure 4). A typical[9] spiral shaped texture with a radial disclination is observed inside the droplets.

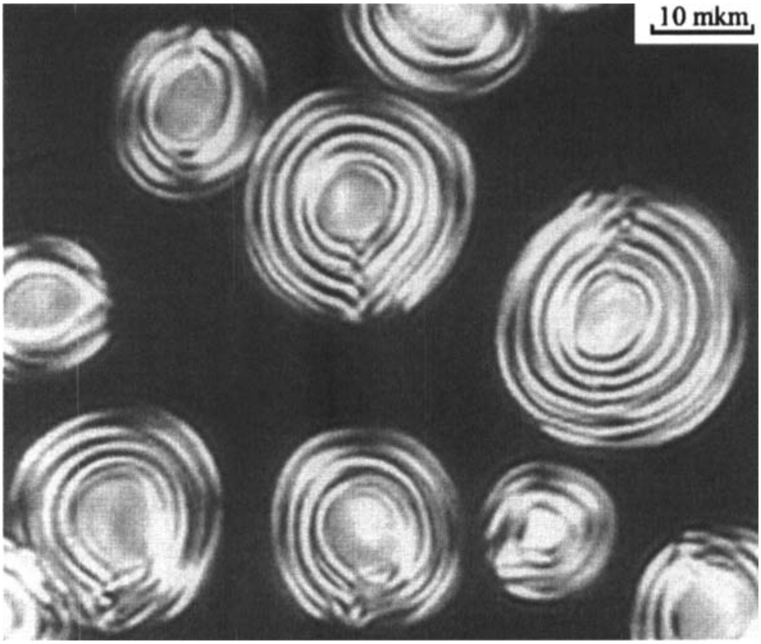

FIGURE 4 A texture of cholesteric droplets in the undeformed sample. Polarizers are crossed.

The axis of the cholesteric spiral is perpendicular to the surface of the droplet and is directed along the radius towards the center. The only distinction is in the central part, where, as we believe, in our case the cholesteric is in an unwound state; i.e., where a nematic core appear.

After stretching of the sample, the structure of droplets is mainly preserved but the spiral rings are transformed into ellipses (see Figure 5a).

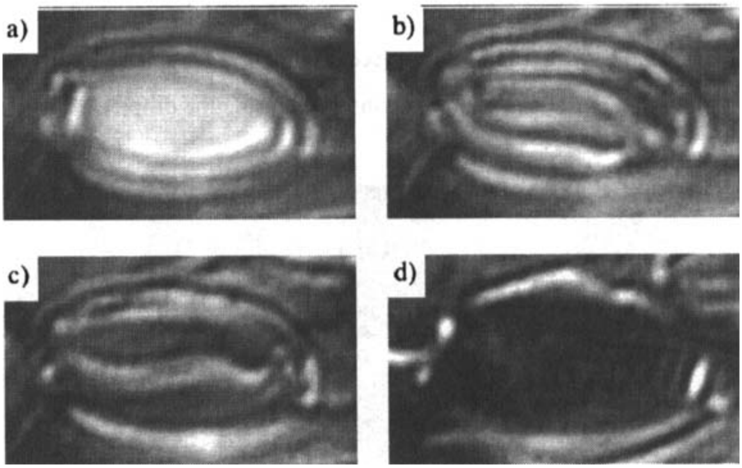

FIGURE 5 The texture of a cholesteric droplet in a stretched film under the effect of the electric field: a) U = 0; b) U = 4V; c) U = 5V; d) U = 30V. Polarizers are crossed.

Here disclination is localized at the left end of the long axis of a droplet. The spiral axis remains perpendicular to the droplet surface. It should be noted, that the size of nematic core increases relative to the size of the whole droplet. Apparently, in this case, the effect of deformation is similar to the effect of a magnetic field[9].

In the electric field (see Figure 5b), a dramatic change of the droplet structure with the formation of "finger print" texture is observed. The central core disappears. The spiral axis is oriented perpendicularly to the long axis practically in the whole of droplets volume. A similar picture is observed in the entire ensemble of LC droplets (see Figure 6). Here a polymer matrix in the crossed polarizers looks brighter compared to the air bubble (see Figure 6, top left). It occurs due to the appearance of an essential birefringence in the stretched matrix, while in the undeformed sample (see Figure 4) the polymer matrix is optically isotropic.

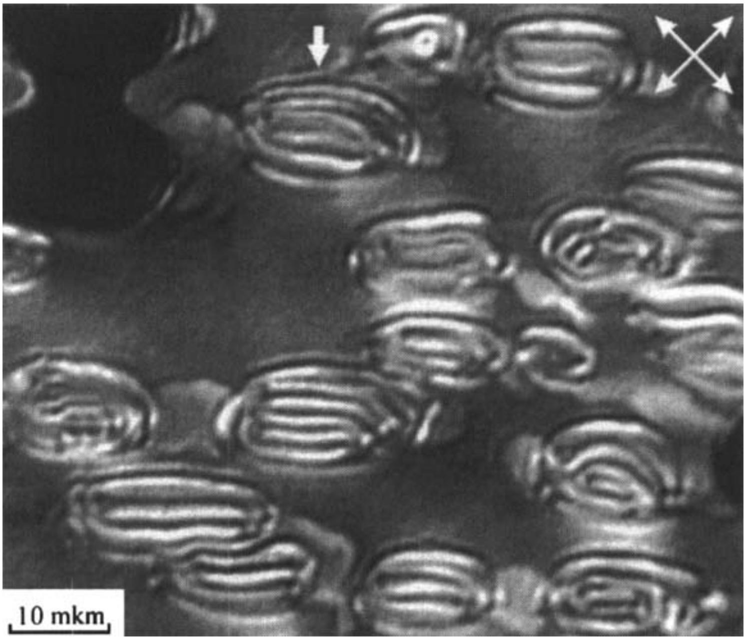

FIGURE 6 The texture of a droplet ensemble in the stretched film at voltage U = 4V. The thick arrow indicates the droplet shown in Figure 5. Polarizers are crossed (thin arrows show the orientation of the polarizers).

The voltage increase results in the unwinding of the cholesteric spiral (see Figure 5c) and in the decrease of the a number of stripes in the texture pattern. In this case, the bright stripes correspond to the local orientation of the LC director in the film plane and parallel to the long axis of droplets. The dark areas inside droplets correspond to the perpendicular orientation of the director relative to the film plane. Figure 7 illustrates schematically the orientational structure of such cholesteric droplet. The same orientational structure was predicted early[4] for stretched PDChLC films with homeotropic anchoring condition, but in a field-off state.

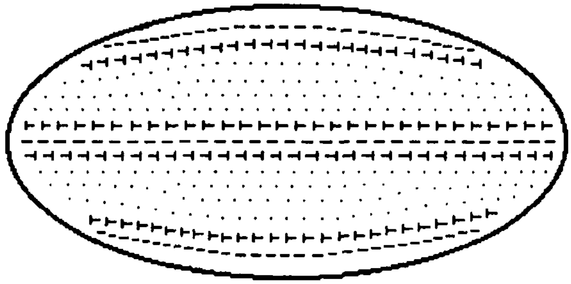

FIGURE 7 Top-view of the orientational structure in the ellipsoidal cholesterics droplet (see Figure 5c).

In a stronger electric field, a transition "cholesteric-nematic" occurs. The central bright stripe disappears, and the entire volume of the droplet becomes dark (see Figure 5d). It corresponds to the orientation of the LC director in the entire volume of the droplet along the field.

Observation in the geometry with just one polarizer allows to analyze the scattering efficiency of LC droplets. Figures 8a, 8b illustrate, that in an field-off state, the optical inhomogeneity of the interface and the spiral structure inside a droplet are clearly visible for the light of both polarization. It explains equally strong scattering of the both light components (see Figure 2). For a droplet under the effect of the field, the optical inhomogeneity shows itself mainly for the light polarized parallel to the long axis (see Figures 8c, 8e). For a perpendicular component, the optical inhomogeneity is hardly visible (see Figures 8d, 8f). This pattern corresponds to a translucent state of the PDChLC film for perpendicularly polarized light (see Figure 2, at U ≈ 120V). After full unwinding of the chiral structure, the defects inside a droplet disappear, and the boundaries become hardly visible for light of both polarization.

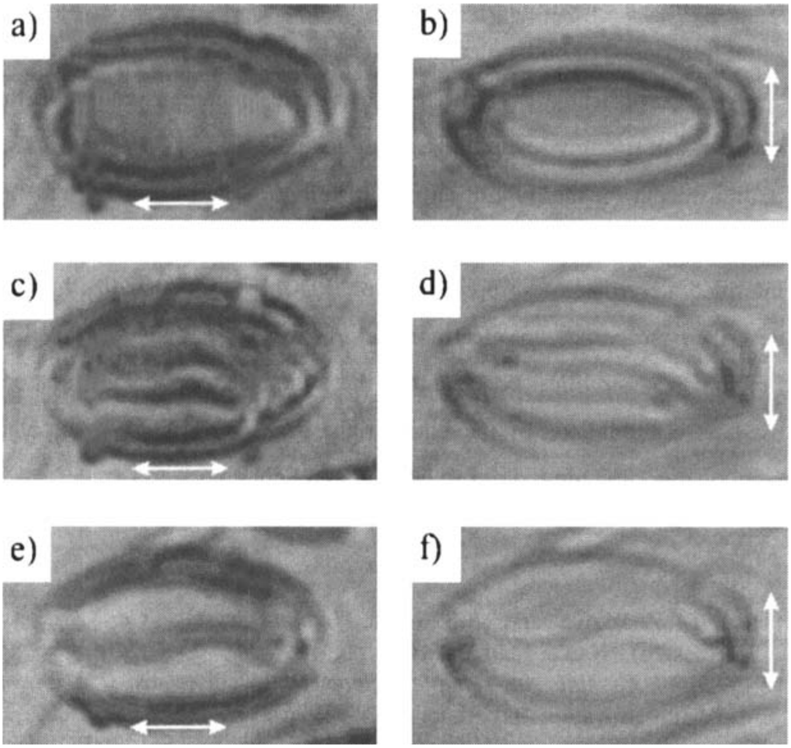

FIGURE 8 The texture of the same droplet, as in Figure 5, in the geometry of just one polarizer. a), b) - U = 0; c), d) - U = 4V; e), f) - U = 5V. Thin arrows show the orientation of the polarizer.

CONCLUSION

We have studied the volt-contrast curves anisotropy of planar-oriented PDChLC films and transformation of the orientational structure of ellipsoidal cholesteric droplets with tangential conditions at the LC-polymer interface. The texture analysis has convincingly shown a possibility of the formation of an intermediate orientational structure inside cholesteric droplets in the electric field. The spiral axis in such droplets lies in the film plane and is oriented perpendicularly to the long axis. With the consideration of these results, the great difference between the parameters (threshold fields, saturation fields) of both polarized VCC's becomes clear.

A planar-oriented PDChLC film can exist in three, essentially different states: it can strongly scatter the light of any polarization (in a field-off state), be translucent for the light of any polarization (at the saturation field); or be translucent only for one linearly-polarized component of the light (at some intermediate voltage). Application of PDChLC films with the above-described properties in electrooptical devices essentially improves their functional possibilities. For example, the same electrooptical element can be used as a modulator of the entire light beam or of only one polarized component of the light, or it can be used as a light polarizer.

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