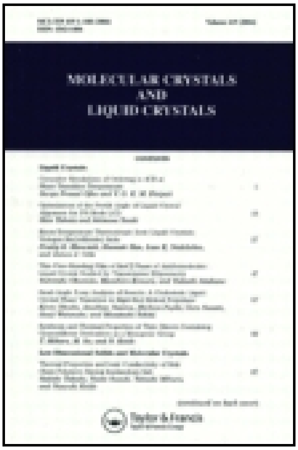

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A computer model of reorientation processes in the bipolar nematic droplets of ellipsoidal form with strong tangential anchoring has been developed. The approximate formula to estimate the Friedericksz threshold has been obtained when the operating field (electric or magnetic) is orthogonal to the bipolar axis. The dependence of the threshold field on the droplet form has been considered. The reorientation of the bipolar droplets of 5CB nematic liquid crystal dispersed in polyvinylbutyral has been studied by the magneto-optical method. The calculation data are in good agreement with measured values of the threshold field.

Keywords: Friedericksz threshold, nematic, magneto-optics, polymer dispersed liquid crystals, surface anchoring

INTRODUCTION

Polymer dispersed liquid crystal (PDLC) films [1,2] are promising materials for various electro-optical applications. They are a polymer medium where a liquid crystal is dispersed. A bipolar director configuration with two surface point defects (boojums) [3] is character for the nematic droplets with the tangential anchoring at the interface. The orientation processes in liquid crystal droplets influenced by the external field depend significantly on the boundary conditions.

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There exist two main ways to transform the bipolar orientational structure.

When the anchoring is weak the transformation of orientation structure is accompanied with the movement of the boojums [3]. This process is thresholdless for the spherical droplets. In PDLC films the transformation process has the threshold character because the droplets are ellipsoidal in such a composite. An analytical relationship for the threshold field in nematic droplets with moving poles has been derived in [3,4]. While the surface anchoring is strong the boojums are rigidly fixed and the Friedericksz transition starts with the reorientation of droplet centre thus modifying the symmetry of its bipolar structure [5,6]. Such a transformation occurs the threshold-like way inside droplets of any shape when the external field is orthogonal to the bipolar axis. The threshold value for this case has been simulated in [6], but it differs noticeably from the experimental data obtained using the electro-optical method. This discrepancy results from the imperfection of the computer model developed for the spherical LC droplets. Moreover, this model doesn't take into account the complex distribution of the electric field in a heterophase medium with a large dielectric anisotropy of the LC component. To apply the magnetic field can eliminate the latter drawback because the field is uniform in the composite material under study.

In this work the computer model will be developed for the ellipsoidal nematic influenced by the uniform external field. The data obtained by the simulation will be compared with the results of magneto-optical measurements.

THEORY

A stable director alignment for nematic droplets can be determined by using the free energy associated with the deformation of the director field [7]. The simplified free energy includes bulk elastic terms, the magnetic field coupling, and is expressed in the one-constant approximation as:

$$F = \frac{1}{2}\int \{K[(\operatorname{div}\mathbf{n})^2 + (\operatorname{rot}\mathbf{n})^2] - \Delta\chi(\mathbf{n}\cdot\mathbf{H})^2\}\mathrm{dV} \qquad (1)$$

Here $K = (K_{11} + K_{22} + K_{33})/3$ is an average elastic constant where K_{11}, K_{22}, and K_{33} are bulk elastic modules for the splay, twist, and bend deformations, respectively and $\mathbf{n}$ is a nematic director. $\mathbf{H}$ is the magnetic field strength, and $\Delta\chi$ is the anisotropy in the diamagnetic susceptibility. The simulation has been carried out using a three-dimensional model of a liquid crystal droplet with strong anchoring condition. At the temperature $T = 28°\text{C}$, $\Delta\chi = 1.085 \times 10^{-7}$ [8], $K_{11} = 4.7 \times 10^{-12}\,\text{N}$, $K_{22} = 2.45 \times 10^{-12}\,\text{N}$, and $K_{33} = 6.05 \times 10^{-12}\,\text{N}$ [9]. The used approach was offered and described in detail by Zumer in [7]. He applied the approach to simulate the orientational structure when the field acts along the bipolar axis of spherical nematic droplet. Because of symmetry of the system the simplified solution was found in the cylindrical coordinate system. In this paper the simulation method has been developed for the ellipsoidal nematic droplets with any boundary conditions at arbitrary orientation of external field using the Cartesian coordinates. Such a model allows describing the real composites more reliable as far as the nematic droplets within PDLC films are ellipsoidal, their long axes are aligned in the film plane and the operating field is usually perpendicular to the bipolar axes.

The X is aligned on the lateral a axis of droplet, and the Z-axis coincides with the bipolar c axis (Fig. 1). The axis ratio is equal to $a/c = 0.7$. That is close to the average experimental value. The vector **H** lies generally at the ϕ angle to the X-axis in the XZ plane. The coordinate origin is placed in the droplet center. Such boundary conditions and the field direction correspond to the experiment. Indeed, the angle φ specifies the deviations of the bipolar axes from the film plane because the **H** vector is perpendicular to the PDLC film plane.

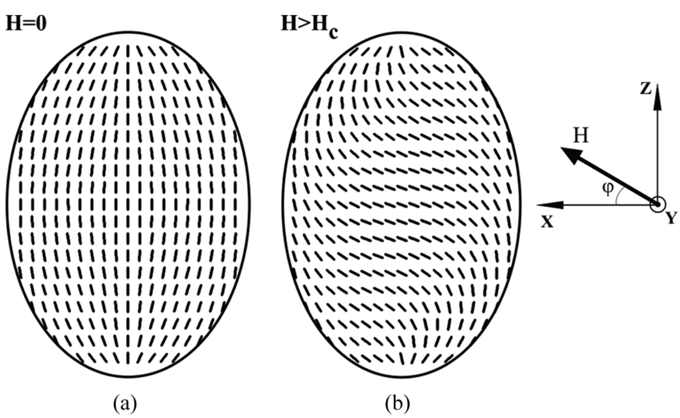

FIGURE 1 Director-field distribution calculated in the central section XZ of the bipolar nematic droplet (a) in off-state and (b) under the influence of magnetic field exceeding the threshold value $H > H_c$.

RESULTS

The typical curves characterizing the director reorientation in the center of droplet are presented in Figure 2. Here D_x is a director projection at the X-axis. The abscissa axis shows the normalized values of magnetic field strength

$$A = HR\sqrt{\frac{\Delta\chi}{K}}, \tag{2}$$

where $R = c/2$.

As seen the reorientation process makes the threshold character evident when the **H** vector is perpendicular to the bipolar axis ($\varphi = 0$). In the case of $\varphi \neq 0$, the threshold behavior vanishes and the more deviation angle, the less sharp curve. In practice, it can result in corresponding smoothing of the threshold break at the oersted-transmittance curve.

The threshold field depends strongly on the droplet a/c anisometry. For example, the threshold value for the spherical droplet differs from the ellipsoidal ($a/c = 0.5$) one in 1.38 times. We have simulated such curves for the set of the value of a/c and plotted a corresponding graph (see Fig. 3) describing the dependence of the threshold value of A_c on the a/c ratio. It should be noted that this simulation has been carried out at the same value of c.

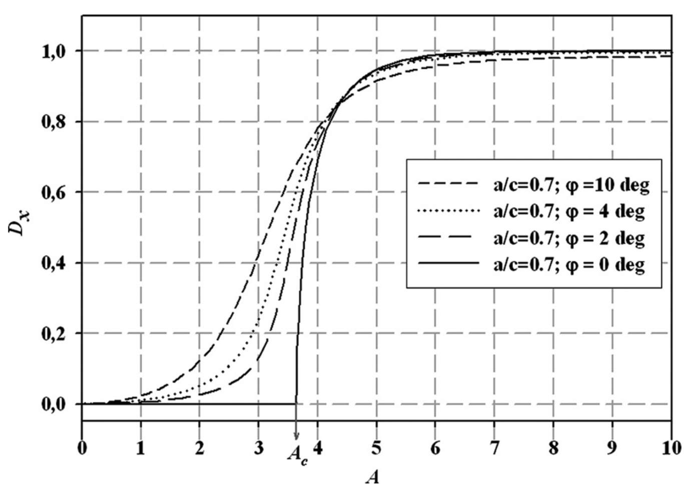

FIGURE 2 The calculated projection D_x of director on X-axis in the droplet center vs. the normalized field value of $\boldsymbol{A}$ at the different deviation φ angle of the bipolar axis from the film plane.

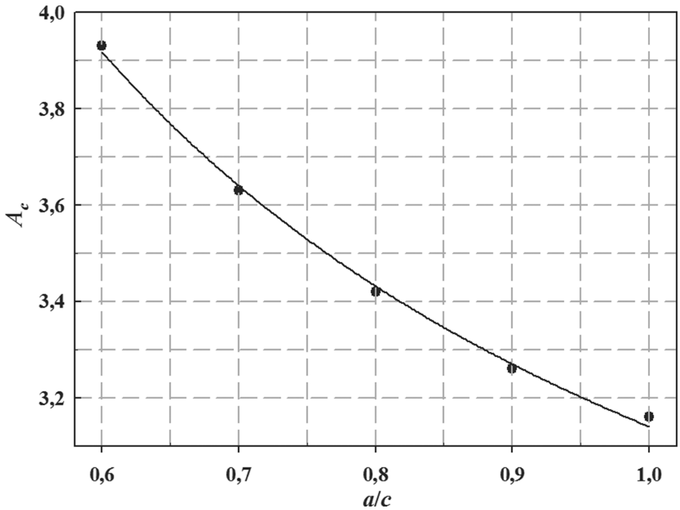

FIGURE 3 The values of A_c reduced field vs. the a/c ratio of droplet axis. The circles are the simulated data, and the line is approximation function according to formula (3).

For the case of a small deviation of droplet form from the spherical one (within $0.6 \div 1.0$ range of a/c ratio) the data of A_c presented in Figure 3 can be approximately described by the inverse polynomial function:

$$A_c \cong \pi - B + \frac{B}{a/c}, \tag{3}$$

where $B = 1.165$ is a calculated coefficient. The error of this approximation of A_c within the indicated range does not exceed 0.6%.

Inserting Eq. (3) into Eq. (2) we express the threshold magnetic field:

$$H_c \cong \frac{2\pi}{c}\sqrt{\frac{K}{\Delta\chi}} + \frac{2B(c-a)}{ca}\sqrt{\frac{K}{\Delta\chi}} \tag{4}$$

Thus for spherical droplets ($a/c = 1$) taking into account $R = c/2$, Eq. (4) is reduced to the simple relationship:

$$H_c \cong \frac{\pi}{R}\sqrt{\frac{K}{\Delta\chi}} \tag{5}$$

EXPERIMENT

PDLC samples are prepared by the solution method [1,2] on the base of nematic LC 4-n-penthyl-4′-cyanobiphenyl (5CB) and polyvinylbutyral (PVB). This composition is characterized by a strong tangential anchoring at the interface [5]. The size and shape of LC droplets depend on the composition, film thickness and solvent evaporation rate.

As seen in Figure 4a the LC droplets are circular in the film plane. The boojums of the bipolar structure are localized on the opposite sides of droplets and revealed as dark spots. In the cross section of composite film (Fig. 4b) the LC droplets are ellipsoidal with the average ratio $a/c = 0.7$. It should be noted that there are deviations of the long droplet axis from the film plane.

The magneto-optical measurements have been carried out at the temperature of $T = 28°C$, using He–Ne laser and the magneto-static field in the range $0 \div 24$ kOe. The experimental setup was described in detail in [10]. Figure 5a presents a typical oersted-transmittance

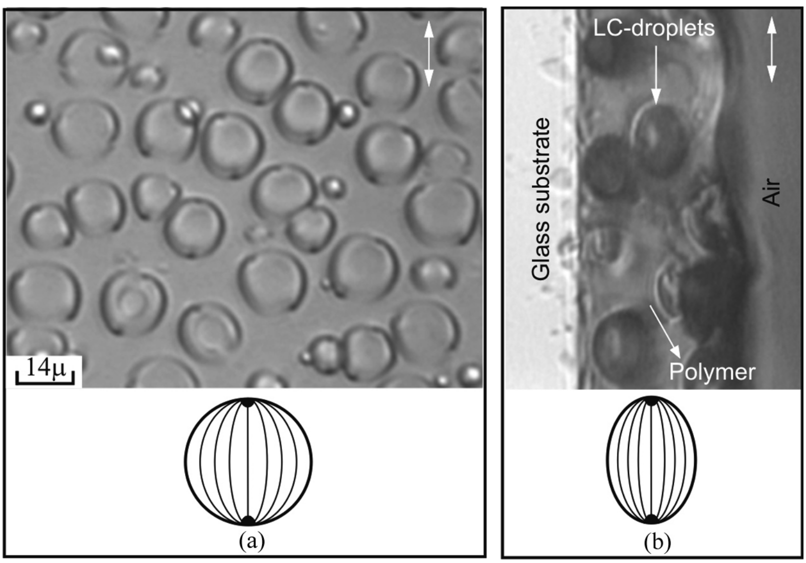

FIGURE 4 (a) The texture of PDLC film in polarized microscope (top) and the scheme of the bipolar orientational structure of nematic droplets in the film plane (bottom). (b) The cross section of the film (top) and the corresponding section of the director configuration (bottom). The double arrows show the polarization direction.

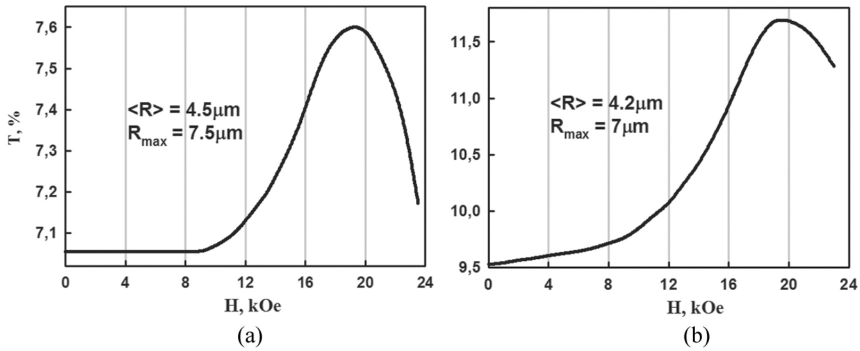

FIGURE 5 Oersted-transmittance curves of PDLC films with monolayer droplet arrangement (a), and multilayer one (b). $\langle R \rangle$ is the ensemble-mean radius of the droplets. R_{max} is the radius of the largest droplets.

curve for the PDLC film. The threshold behavior of such curves allows determining the values of H_c to within ± 1 kOe. The oersted-transmittance dependences with smoothing threshold break are character for the PDLC films with multilayer droplet arrangement (Fig. 5b). As mentioned above, such a feature is explained by a deviation of bipolar axis from the film plane in these PDLC samples. A decrease

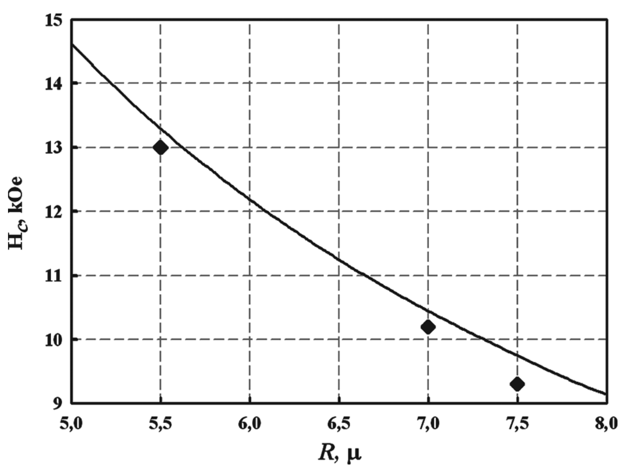

FIGURE 6 The dependences of threshold field on the R_{max} droplet radius. The points are the experimental data. The line is simulated by Eq. (4) for $a/c = 0.7$.

of transmittance at a high magnetic field results from the interference effect having been considered in detail earlier [5,6,11].

The results of magneto-optical measurements of threshold field and the data simulated by Eq. (4) at the ratio $a/c = 0.7$ are presented in Figure 6. As seen, the calculation data are in good agreement with measured values of the threshold field. The high estimation values of threshold field are explained by a small deviation ($<1^\circ$) of the droplet long axis from the film plane which takes place in the films with monolayer arrangement too. This deviation causes the undervalueing of measured data.

CONCLUSION

In conclusion, the developed model allows calculating the threshold magnetic field for the bipolar nematic droplets within a wide range a/c parameter. The obtained results can be applied for PDLC films only with a strong anchoring at the LC-polymer interface. To determine experimentally the threshold value, the magnetic field must be aligned strictly orthogonal to the bipolar axis of LC droplets. Any deviation from the orthogonal conditions results in the smoothing of threshold break and, consequently in the decrease of threshold field. The developed approach is applicable not only for polymer-dispersed liquid crystal films but also for droplet LC dispersions in other solid and liquid matrixes.

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