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The Cholesteric-Nematic Transition in Thin Layers of Nematic-Cholesteric Mixtures

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In this article the investigation of the cholesteric-nematic transition in thin layers of nematic-cholesteric mixtures is carried out. Nematic-cholesteric mixtures based on a nematic matrix MLC-1 with a low concentration (up to 2%) of an optically active dopant were the object of this investigation. The dependencies of threshold voltages of focal-conic deformation and forward cholesteric-nematic transition for different thicknesses of a liquid-crystal layer are obtained. It was demonstrated that the twist effect in induced cholesterics can be considered as a simple case of a cholesteric-nematic effect in thin liquid-crystal layers.

Keywords Cholesteric-nematic transition; focal-conic deformation; liquid crystal mixtures

Introduction

In the present day liquid-crystal information displays are most used in comparison with other technologies of display systems. The majority of liquid-crystal information displays are based on the using of twist or super-twist effects in nematic liquid crystals (NLC). However industrially produced liquid-crystal materials are not pure nematics. It is necessary to use nematic liquid-crystal materials with low concentrations (up to 0.1%) of chiral dopants as an active medium to provide the high quality and homogeneity of a displayed image (absent of structural defects of nematic texture). In this case, the active medium is the induced cholesteric [1,2]. Because of above-stated circumstances it is necessary to revise the physical process that occurs in layer of liquid-crystal material when an external electrical field is applied. So, if the chiral dopant is added into a nematic liquid crystal, the character of the twisted structure in the liquid crystal (LC) layer is changed. In case of pure nematic LC, the twisted structure is created only under the influence of surface boundary conditions. In twist indicators the nematic LC twist structure is archive by means of different orientation of azimuthal component of director on the opposite surfaces of the LC cell. But in case

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of adding the chiral dopant into the nematic LC a permolecular twisted structure occurs. This is explained by the presence of chiral molecules in the LC layer. Such a structure can exist without surface influence. We propose to review the twist or super-twist effects in nematic liquid-crystal materials with a low concentration of chiral dopant described by theoretical modeling of cholesteric-nematic transition.

Theory

Before describing the special feature of cholesteric-nematic transition effect in thin films, we review the twist effect under the same conditions. The director orientation in the twist effect depends on the coordinate z not only for the slope angle of molecule $\theta(z)$ but for the azimuthal angle $\varphi(z)$.

This type of deformation is not identical to the clear twist deformation and consists of three possible types of deformation [1]: *S, B*, and *T*. The director deviation from the initial state in this case is characterized by two angles $\theta(z)$ and $\varphi(z)$ (Fig. 1). Thus, the minimum of functional can be described by systems of two equations. The threshold field of deformation of the NLC layer is equal to:

$$E_0 = \frac{\pi}{d}\sqrt{\frac{4\pi}{\Delta\varepsilon}\left[K_{11} + \frac{1}{4}(K_{33} - 2K_{22})\right]} \tag{1}$$

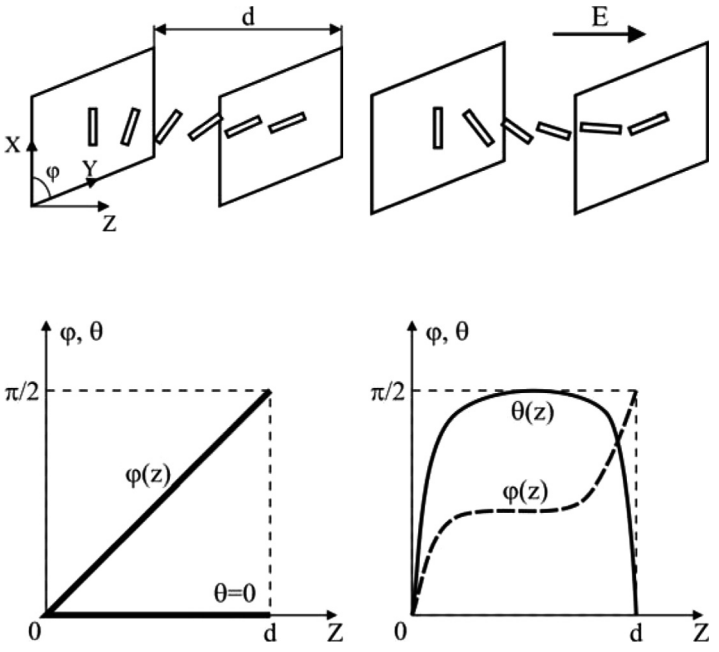

Figure 1. Molecular orientation in the twist cell and the dependencies of the angles $\theta(z)$ and $\varphi(z)$ *versus* coordinate without the electrical field influence (a) and with the electrical field influence (b).

If the voltage on the electrodes of the LC cell is more than the threshold voltage, then the director gradually changes from a twisted state ($\theta = 0$) into a state like homeotropic ($\theta \to \pi/2$), and the azimuth angle φ in the center of the layer changes very sharply.

The optical properties of a twisted structure are characterized by birefringence. Another optical activity of this twisted structure explained by defined of polarization direction by rotation of liquid crystal director, when the Mogen's proportion is used [1]:

$$\Delta n P_0/\lambda >> 1 \tag{2}$$

where P_0 is the spiral pitch of the twisted structure. This condition is correct if the NLC layer thickness is equal to several micrometers for all wavelengths of the visible range.

At voltage increase on cell, as a result of sharpen of azimuth angle φ jump in the center of NLC layer, the Mogen's condition is break, and this leads to modulation of cell transparency. The threshold of optical response is not equal to the threshold voltage of deformation and depends on the wavelength of modulated light. In accordance with condition (2), the threshold voltage of the optical response decreases if the layer thickness d and optical anisotropy $\Delta n = n_{\perp} - n_{\parallel}$ decrease. The parameters of NLC also affect the characteristics of the twist effect. Therefore, the steepness of electrooptical characteristics depends on correlation between the value of bend elastic constant and the value of splay elastic constant K_3/K_1. If the correlation K_3/K_1 is small, then the steepness of the electrooptical characteristic is large. The steepness of modulation characteristic can be increased and the threshold voltage can be decreased by decreasing the bonding between the molecules of the liquid crystal and cell substrate.

But the above-stated is correct in case of a pure nematic, because in induced cholesterics the formation a of twisted (chiral) structure is caused not only by the influence of orientation of the surface, which limits the LC layer (the single factor in case of classic nematic). The formation of twisted structure in an induced cholesteric is also caused by presence of chiral molecules in LC layer, which cause the torsion field deformation of the nematic layer director. Therefore, the increasing electrical field in this case leads to the destruction of the twist structure in the center in the LC layer (twist effect) and also leads to molecular reorientation, keeping the spiral structure and formation of divergent focal-conic structure with further destruction of spatial spiral and formation of homeotropic nematic structure (cholesteric-nematic transition effect). So, the physical processes that occur in the induced cholesteric layer during the twist effect are very similar to processes during the cholesteric-nematic transition effect in thin films.

Such similarity permits combining those processes within the theory of Kawachi-Kogure et al. [3] and also analyzed in our article [4]. This theory is select the three basic states in cholesteric-nematic effect at the external electrical field influence (Fig. 2) and the equations for the free energy for all states is determinate (3).

$$F_{C'} = \frac{1}{2} \cdot \varepsilon_0 \cdot \Delta\varepsilon \cdot E^2, F_C = \frac{1}{4} \cdot \varepsilon_0 \cdot \Delta\varepsilon \cdot \mathrm{E}^2, F_N = \frac{1}{2} \cdot K_{22} \left(\frac{2\pi}{P_0}\right)^2 \tag{3}$$

When we calculate the free energy as the E function and plot the graphic dependencies the threshold field of cholesteric-nematic transition as the cross-point of curves

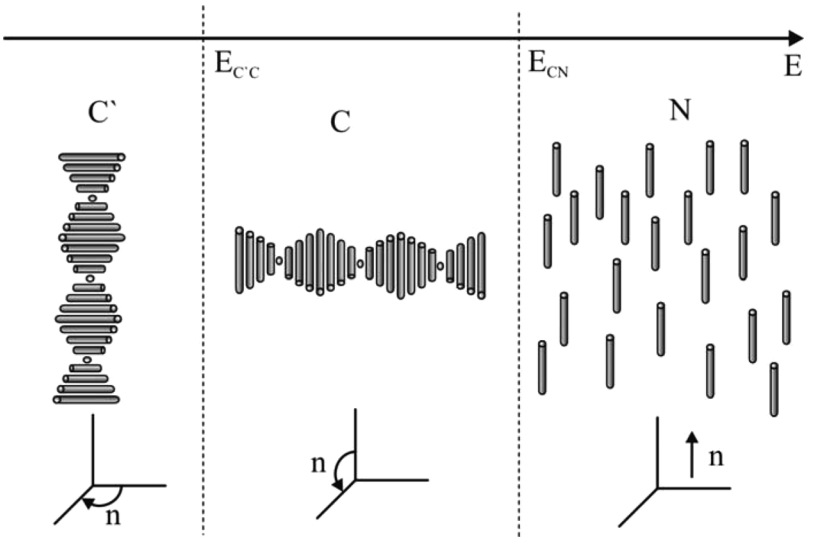

Figure 2. Three basic states in cholesteric-nematic effect with external electrical field influence.

of dependences of free energy and corresponding states versus electrical field values are obtained. Using the equations for free energy, Sprang and Van de Venne [5] added new values $F_{SC'}$, F_{SC}, and F_{SN}:

$$F_{C'} = \frac{1}{2}\cdot\varepsilon_0\cdot\Delta\varepsilon\cdot E^2 + 2\frac{F_{SC'}}{d}, F_C = \frac{1}{4}\cdot\varepsilon_0\cdot\Delta\varepsilon\cdot E^2 + 2\frac{F_{SC}}{d}, F_N = \frac{1}{2}\cdot K_{22}\left(\frac{2\pi}{P_0}\right) + 2\frac{F_{SN}}{d} \tag{4}$$

where $F_{SC'}$, F_{SC}, F_{SN} are the density of surface energy for $C^{'}$, C, N states, and $F_{SC} > F_{SC'}$ are supposed. For the planar boundary conditions $-F_{SC'} = 0$, and for the homeotropic boundary conditions $-F_{CN} = 0$.

$$E_{cn} = 2\sqrt{2}\left[\frac{\pi^2}{P_0^2}\left(\frac{K_{22}}{\varepsilon_0\Delta\varepsilon}\right) + \frac{F_{sn} - F_{sc'}}{\mathrm{d}\varepsilon_0\Delta\varepsilon}\right]^{1/2}, E_{c'c} = 2\sqrt{2}\left[\frac{F_{sc} - F_{sc'}}{\mathrm{d}\varepsilon_0\Delta\varepsilon}\right]^{1/2} \tag{5}$$

where E_{cn} is threshold field of cholesteric spiral destruction (cholesteric-nematic transition) and $E_{c'c}$ is threshold field of homeotropic nematic texture creation (texture transition).

Regardless of the inaccuracy of this theory and suggestions, in our opinion, this theory correctly describes the cholesteric-nematic effect.

Experimental

The nematic-cholesteric mixtures based on nematic matrix MLC-1 with low concentration (up to 2%) of optical-active dopant are the objects of investigations. The cholesterol ether of monoatomic carbon acids miristate (X-15), undecilate (X-18),

propionate (X-10), and nonmethohen dopant BIXH-3 are used as optical-active dopants.

The investigations were performed on a "sandwich"-type cell with thickness of the LC layer of 20 μm using standard optical methods at room temperature. As the source of radiation we used an HeNe laser with wavelength of $\lambda = 0.63$ μm.

The dependencies of focal-conic deformation voltage on d/P_0 correlation are shown in Fig. 3. As shown, the U_{cn} does not change much with increasing d/P_0. This is in a good correlation with the theoretical model, as long as the equation (for Ec′c) dependence $U_{c'c}$ *versus* d/P_0 is linear. For different chiral dopants this dependence is different as much as $\Delta\varepsilon$ and F_{sc}, $F_{sc'}$.

Analyzing the dependencies of light transmission intensity of laser radiation on applied voltage, we observed the abrupt increasing in minimum transmission value of scattering focal-conic texture with decreasing concentration of optical active dopant. A decrease in focal-conic deformation threshold steepness was also observed. Such behaviors of these dependencies are caused basically by increasing of cholesteric spiral pitch, which leads, on the one hand, to partial destruction of focal-conic texture, and on the other hand, the spiral structure with large pitch has greater ability to deform when the external electric field is applied. The dependencies of correlation of cell light transmission minimum in focal-conic texture (I_{min}) to the transmission of cell in nematic state (I_{max}) on d/P_0 correlation are shown in Fig. 4. Analyzing these dependencies, we have observed that in the mixtures based on one nematic matrix with different cholesterol ethers the increase of sequence number of the cholesterol ether leads to an increase in minimum transmission.

The calculated dependencies of threshold voltages of focal-conic deformation and forward cholesteric-nematic transition on the d/P_0 correlation are shown in Figs. 5–8.

As it comes from dependencies, at the definite critical value of d/P_0 the voltage of texture transition is higher than the voltage of the cholesteric-nematic transition.

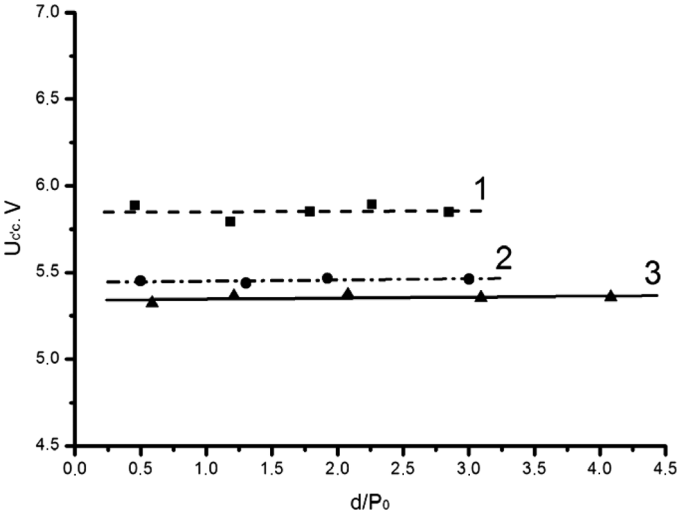

Figure 3. Dependencies of focal-conic deformation voltage on d/P_0 correlation for the mixtures based on nematic matrix MLC-1 with ethers of cholesterol: 1, X-15; 2, X-18; 3, X-10.

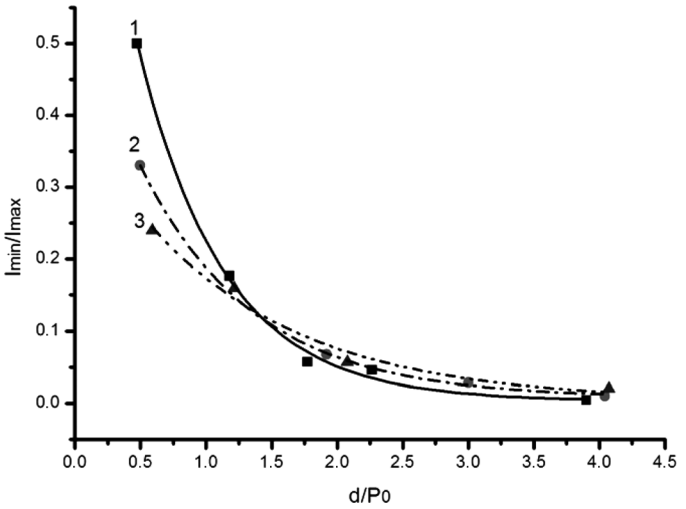

Figure 4. Dependencies of $I_{\min}/I_{\max}$ correlation on d/P_0 correlation for the mixtures based on nematic matrix MLC-1with ethers of cholesterol: 1, X-15; 2, X-18; 3, X-10.

So, the destruction of the chiral texture of the induced cholesteric takes place without the previous texture transition (without formation of scattering focal-conic textures) and the effect of the cholesteric-nematic transition degenerates into the twist effect. The critical value of d/P_0 can be determined by the correlation of values of density of surface energies of corresponding to director states F_{sc}, F_{sn}. In this case, the scattering character of this effect disappears. The critical field of spiral destruction is determined as the point of disappearance of the optical activity of the liquid crystal layer.

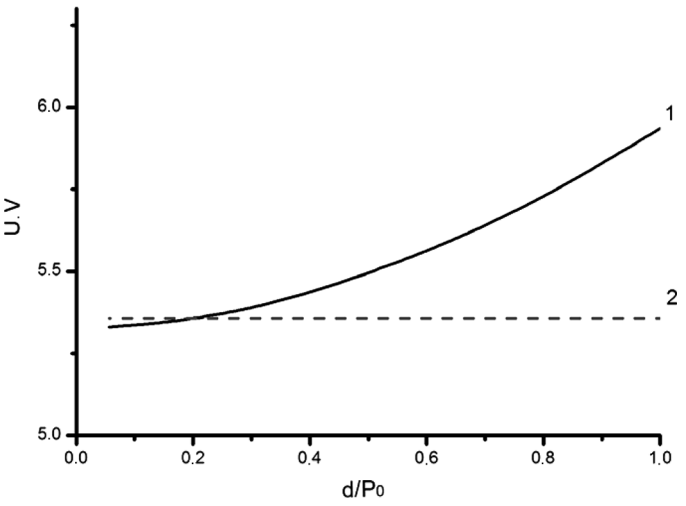

Figure 5. Threshold voltages of cholesteric-nematic 1 ($U_{c'c}$) and texture 2 (U_{cn}) transitions in thin liquid-crystal layers for the MLC-1 mixture with cholesterylpropionate.

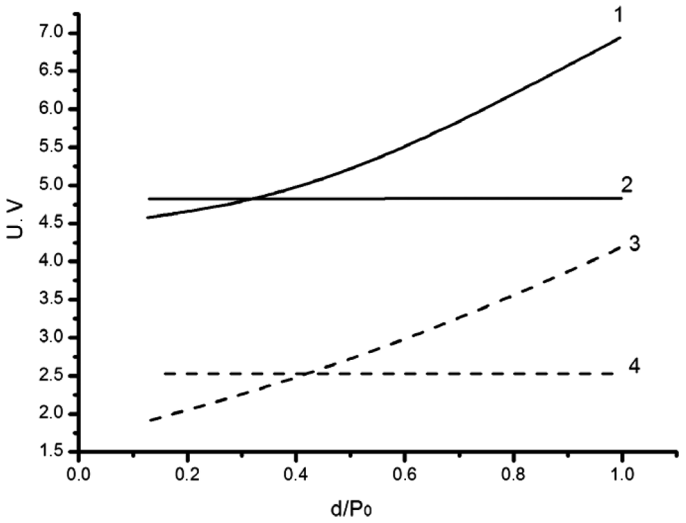

Figure 6. Threshold voltages of cholesteric-nematic 1, 3 ($U_{c'c}$) and texture 2, 4 (U_{cn}) transitions in thin liquid-crystal layers for the MLC-1 mixture with cholesterylundecylate: 1, 2, $d = 25\,\mu m$; 3, 4, $d = 10\,\mu m$.

In the mixtures based on one nematic matrix with ether of cholesterol, an increased critical d/P_0 value and voltage of focal-conic deformation with increased number of homologous series is observed. This behavior can explained by the increased F_{sc} value.

The dependencies of threshold voltage of focal-conic deformation and forward cholesteric-nematic transition voltages at the different thicknesses of liquid crystal layer are shown in Fig. 6. The obtained results show that the decreased liquid crystal

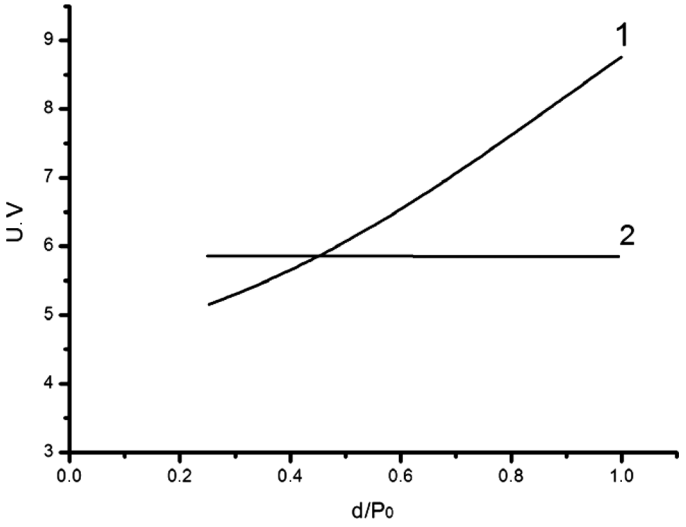

Figure 7. Threshold voltages of cholesteric-nematic 1 ($U_{c'c}$) and texture 2 (U_{cn}) transitions in thin liquid-crystal layers for the MLC-1 mixture with cholesterylmiristate.

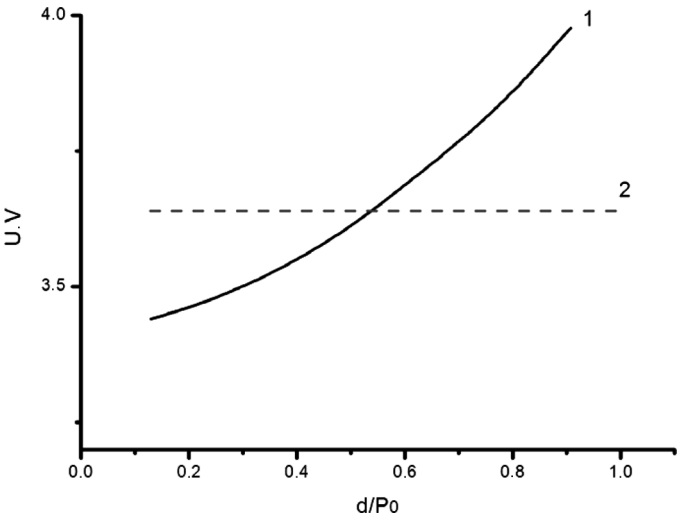

Figure 8. Threshold voltages of cholesteric-nematic 1 ($U_{c'c}$) and texture 2 (U_{cn}) transitions in thin liquid-crystal layers for the MLC-1 mixture with non-liquid-crystal dopant BIXH-3.

thicknesses leads to the increased d/P_0 values as a result of the influences of surface effects.

In the boundary condition of the chosen theoretical model, we equal the expressions of threshold fields of texture ($E_{c'c}$) and cholesteric-nematic (E_{cn}) transitions and we define the critical d/P_0 value when the effect of cholesteric-nematic transition occurs with the formation of focal-conic scattering texture:

$$\frac{d}{P_0} = \frac{2F_{sc} - F_{sn}}{\pi^2 K_{22}} \tag{6}$$

This expression allows declaring a definite recommendation for the composition of nematic-cholesteric mixtures. In particular, to avoid the scattering focal-conic texture formation we propose using the nonmethohen dopants because their use does not lead to essential increasing of Franc elastic constant [4,6].

Conclusions

In nematic liquid crystal layers the twist structure is formed by means of boundary surface influence or by the addition of a low concentration of chiral dopant in the nematic matrix. In the second way we obtain the induced cholesteric. Therefore, we can investigate the twist effect using cholesteric-nematic transition effect theory.

The limit to using theory for the cholesteric-nematic transition effect as the twist effect is the d/P_0 parameter. At this parameter the threshold voltages of texture transition are greater than the critical voltage of the forward cholesteric-nematic transition effect. In practice it is accompanied by disappearance of the focal-conic texture, which transforms the planar cholesteric texture directly into a homeotropic nematic texture.

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