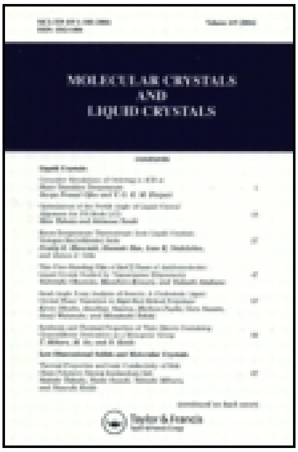

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New Method of the Threshold Voltages Determination of a Cholesteric-Nematic Transition

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We develop the method of determining the threshold voltages of a cholesteric-nematic transition which is based on the analysis of conoscopic images. To improve the measurement accuracy of the threshold voltages and to eliminate the effect of a radiation wavelength, we propose a new method which also could be efficiently used to study the influence of surface conditions on the liquid crystal texture and to obtain the additional information about the liquid crystal texture in the process of cholesteric-nematic transition.

Keywords Cholesteric-nematic transition; conoscopic images; elastic constants; threshold voltages

Introduction

Liquid crystal materials with a helical permolecular structure are widely used in reflective displays. The design of new displays based on liquid crystals requires studying their electrical and optical properties such as the dielectric anisotropy, elastic constants, viscosity, *etc*. The accuracy of measurements of these parameters has a direct influence on the operation characteristics of such devices based on liquid crystals and on the improvement of the liquid crystal properties.

The known method of determining the threshold field of the cholesteric-nematic transition (CNT) is based on the study of the dependence of the scattering of a nematic-cholesteric mixture (NCM) on the applied voltage.

In this paper, we offer methods of determination of the threshold voltage by recording a conoscopic image, which allows one to improve the accuracy.

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Theory

Measurements of the threshold voltages of the cholesteric-nematic transition such as the threshold voltages of the forward cholesteric-nematic transition U_{cn} and the threshold voltage of the backward nematic-cholesteric transition U_{nc}, allow one to determine the main physical parameters of induced cholesterics - the values of Frank elastic constants. Therefore, the development of methods for determination of these values is of importance and was carried out previously in papers [1–2].

According to the method described in [3], the critical fields of the forward and backward cholesteric-nematic transitions are:

$$Ecn = 2\sqrt{2}\left[\left[\frac{\pi}{Po}\right]^2\left(\frac{K_{22}}{\varepsilon_o\Delta\varepsilon}\right) + \frac{Fsn - Fsc}{d\varepsilon_o\Delta\varepsilon}\right]^{1/2} \tag{1}$$

$$Enc = \left[\left(\frac{\pi}{P_o}\right)^2\frac{(4K_{22} - K_{33}\frac{P_o}{d})^2}{\varepsilon_o\Delta\varepsilon K_{33}} + \frac{4Fsn}{d\varepsilon_o\Delta\varepsilon}\right]^{1/2} \tag{2}$$

where E_{cn} and E_{nc} are the fields of the forward and backward cholesteric-nematic transitions, and $E_{cn} = U_{cn}/d$, and $E_{nc} = U_{nc}/d$;

U_{cn} is the threshold voltage of the forward cholesteric-nematic transition;

U_{nc} is the threshold voltage of the backward cholesteric-nematic transition;

d is the thicknesses of the liquid crystal layer;

P_0 is the pitch of an induced spiral;

$\triangle\epsilon$ is the dielectric anisotropy;

K_{22} and K_{33} are the Frank elastic constants;

*F*sc', Fsc, and Fsn are the densities of surface free energy in planar, focal-conic and nematic states, respectively.

Other methods of determination of U_{cn} and U_{nc} are described in paper [4]. These methods are based on the study of the optical transmission of nematic-cholesteric mixtures under the influence of an applied voltage. A typical dependence of the optical intensity of a transmitted laser beam versus the applied ac voltage for a nematic-cholesteric mixture is shown in Figure 1. Increasing the applied voltage leads to changes the initial planar Grandjean texture ($U = 0$) into a scattering focal-conic texture ($U = U_{kd}$). The subsequent increase of the applied voltage forms the homeotropic nematic texture ($U = U_{cn}$). In the reverse case, if applied voltage decreases, the scattering focal-conic texture is formed ($U = U_{nc}$). The following decrease of the applied voltage leads either to the formation of a planar Grandjean texture, or the LC sample conserves a scattering focal-conic texture. This can be explained by such factors as the surface influence, speed of voltage changes, and ratio of the LC layer thickness and the spiral pitch of CNT. From such characteristics, the corresponding threshold voltages and the critical electric fields can be determined graphically.

Analyzing the previously developed methods, we met some problems that can affect the accuracy of measurements of the threshold voltages. By definition, the threshold field of the cholesteric-nematic transition (E_{cn}) is the value of the electric field strength in a liquid crystal layer with a helical permolecular structure, when the homeotropic nematic texture is formed. However, as is shown in paper [5], the value of the electric field corresponding to the disappearance of a focal-conic texture

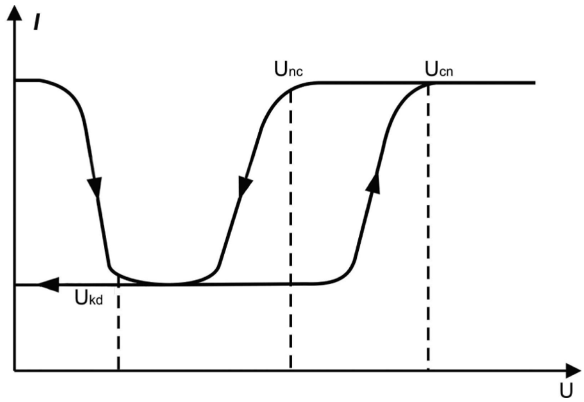

Figure 1. Typical dependence of the optical transmission on the applied alternating voltage for a nematic-cholesteric mixture.

of the cholesteric depends strongly on the radiation wavelength. The dependences of the transmitted laser radiation intensity versus the applied alternating voltage for a nematic-cholesteric mixture based on cyanobiphenyl mixtures with the 5% cholesterin dekanoate ($T_i = 54°C$, $\Delta\varepsilon = 10$, $P_0 = 4.6\,\mu m$) experimentally obtained by authors are shown in Figure 2. The discrepancies between the results obtained at different wavelengths can exceed 30%. It is also well known that, under some conditions, the cholesteric-nematic transition takes place without formation of a focal-conic scattering texture. In such cases, the measurement of threshold voltages of the cholesteric-nematic effect based on the above-mentioned methods becomes impossible.

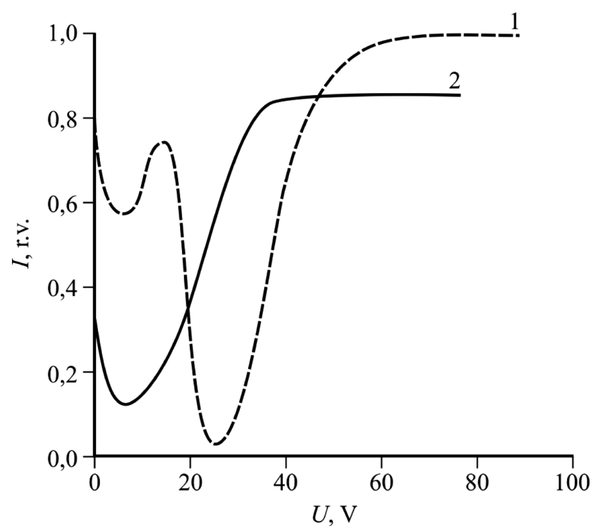

Figure 2. Transmitted laser radiation intensity *versus* the applied alternating voltage at: 1 – $\lambda = 0.63\,\mu m$; 2 – $\lambda = 10.6\,\mu m$ (d = 50 μm).

To improve the accuracy of measurements of the threshold voltages and to eliminate the effect of a radiation wavelength, we propose our new method. This method is based on studies of changes in the conoscopic image, when the alternating voltage is applied to the liquid crystal cell. The technique is based on the observation of the interference image of a beam which passes through a liquid crystal cell placed between crossed polarizers. For the first time, this method of study of nematic LCs was proposed in [6], and the authors of work [8] developed the scheme of the experiment which allows one to observe conoscopic images using a laser radiation. They also obtained a series of conoscopic images for different orientations of a nematic LC. However, this method was not used for the study of cholesteric LCs.

Experiment

Nematic cholesteric mixtures based on nematic liquid crystal SP-92 (the melting temperature < 243 K, isotropic temperature is equal to 333 K, $\triangle\epsilon = 9.88$) with chiral dopant HDN-1 were used in the present investigation ($P_0 = 4.2\,\mu$m for the mixture 1%HDN-1 + n-pentylcyanobiphenyl (5CB).

The investigations were carried out in sandwich-type cells with liquid crystal thicknesses of 20 and 50 μm. A He-Ne laser with the operating wavelength $\lambda = 0.63\,\mu$m and light emitting diode LXHL-NM98 (LEDs Luxeon) (the operating wavelength $\lambda = 0.53\,\mu$m, angle of scattering $-10°$, brightness -30 Lm, and supplied voltage -3.42 V) were used as the optical sources.

To verify the effect of a wavelength on the accuracy of measurements of the threshold voltages, we studied the light transmission intensity at different wavelengths for sample SP-92 + 1% HDN-1. As shown in Figure 3, the effect is significant. A decrease in the wavelength of the optical source leads to a shift of the maximum of the light transmission intensity to a higher voltage. Such a behavior can be explained by the influence of the ratio of the size of scattering domains of a cholesteric focal-conic texture, which is stable in this case, and the radiation wavelength [7].

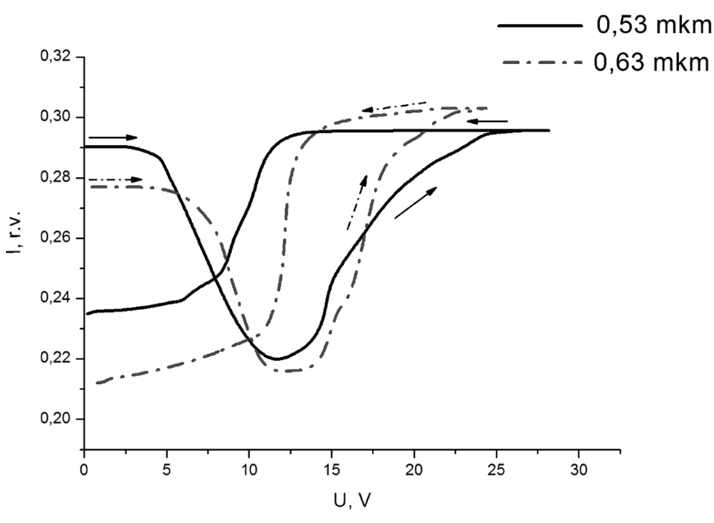

Figure 3. Light transmission *versus* the applied alternating voltage for SP-92 + 1% HDN-1 at different wavelengths (liquid crystal layer thickness is 50 μm).

Studies of conoscopic images were carried out, by using the technique described in [8]. The light transmission intensity *versus* the applied voltage obtained by the previously known methods, as well as the corresponding conoscopic images obtained with the use of the proposed method at the wavelength $\lambda = 0.63\,\mu\text{m}$, are shown in Figure 4.

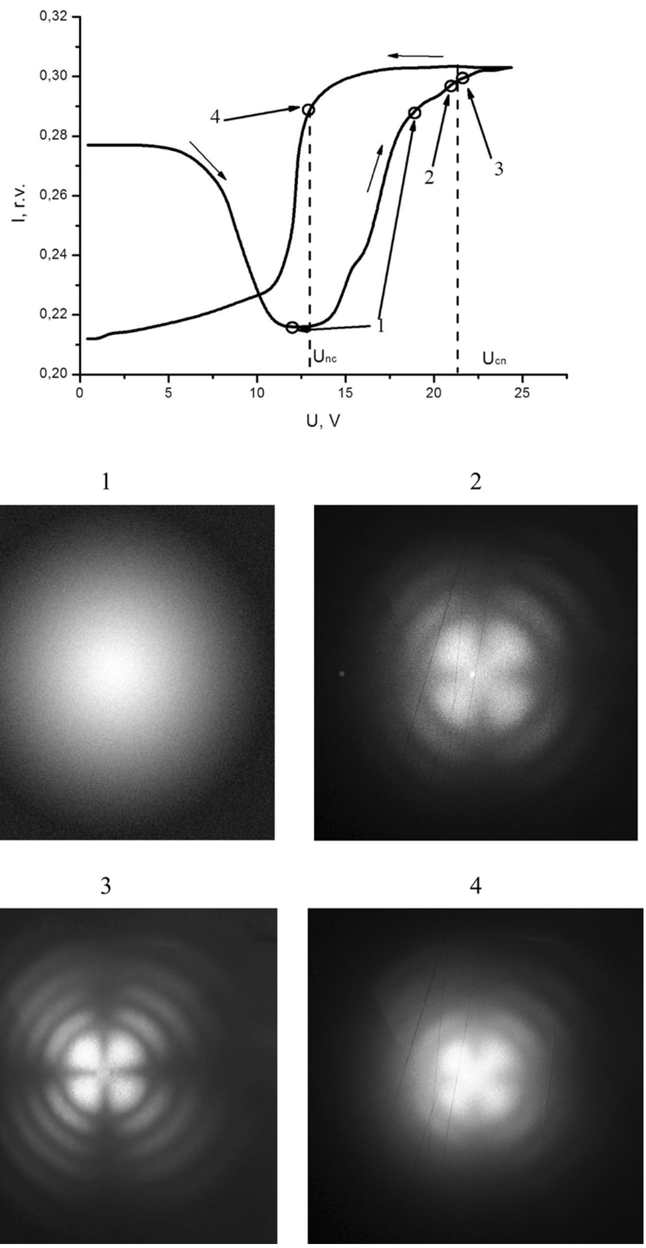

Figure 4. Light transmission intensity *versus* the applied alternating voltage for SP-92 + 1% HDN-1 and corresponding conoscopic images (liquid crystal layer thickness is 50 μm).

As seen from photo 1 (Fig. 4), no conoscopic images appeared for the initial planar cholesteric texture. This view of a conoscopic image remains the same until reaching the voltage of the cholesteric-nematic transition. An increase in the applied voltage leads to the formation of a conoscopic image, which corresponds to the homeotropic alignment of the liquid crystal layer (Fig. 4, photo 2). This conclusion can be drawn because of the dark cross formed by isogyres at the center of the interference image. Isochromic circles surrounding the cross can be seen, and the interference image has rotational symmetry around the optical axis. The illumination of the central part of the image in a vicinity of the isogyre intersection shows the ellipticity of the light output from the cell. In turn, this indicates that the more intense the illumination, the larger the director deviation from a homeotropic orientation. As was expected, the illumination is significantly decreased at higher voltages. A rotation of the sample in the plane perpendicular to the light propagation direction does not lead to any changes in the conoscopic image. This means that the initial slope of the optical axis of a nematic sample is absent. A further increase in the applied voltage leads to an improvement of the quality of a homeotropic nematic texture, which is accompanied by an increase of the brightness of isochromic circles of the conoscopic image (Fig. 4, photo 3). Photo 3 corresponds to the CNT threshold voltage. The formation of a conoscopic image, which corresponds to the homeotropic orientation of a LC layer, occurs in a narrow range of voltage changes that can improve an accuracy of the determination of the CNT threshold voltage. The determination of the time moment, when the homeotropic nematic texture is formed, can be made visually and by using a dot photodetector registering a variation of the intensity of the region at the dark cross of a conoscopic image. When the homeotropic nematic texture is formed, the intensity of a conoscopic image in this region is changed sharply.

We also estimated the influence of the radiation wavelength on the behavior of conoscopic images. This study was carried out for two wavelengths: $\lambda = 0.63\,\mu m$ and $0.53\,\mu m$. The corresponding conoscopic images are shown in Figure 5.

As shown in Fig. 5, the shape of a conoscopic image is not changed, and a change in the brightness is caused by different intensities of the optical sources used in this study. Therefore, it can be concluded that the radiation wavelength does not

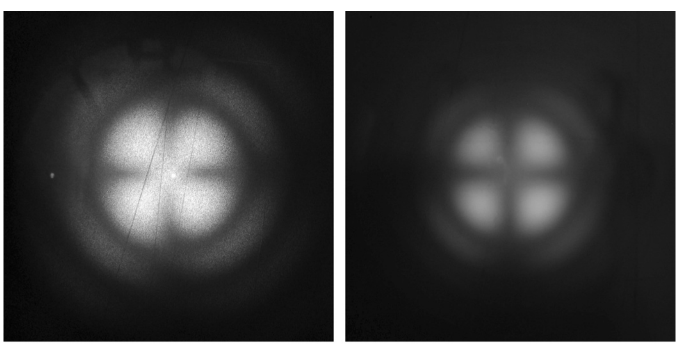

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Figure 5. Conoscopic images for a homeotropic nematic texture at different wavelengths: 1—$\lambda = 0.63\,\mu m$; 2—$\lambda = 0.53\,\mu m$ (liquid crystal layer thickness is $20\,\mu m$).

Table 1. Values of the threshold voltages obtained by the known methods and by proposed conoscopic technique.

Samples		$\lambda = 0.53\,\mu m$		$\lambda = 0.63\,\mu m$	
		U_{cn}, V	U_{nc}, V	U_{cn}, V	U_{nc}, V
Known methods	SP-92 + 1% HDN-1 $Po = 4.67\,\mu m$, $d = 50\,\mu m$	24.1	12.6	22.6	14.1
	SP-92 + 2% HDN-1 $Po = 3\,\mu m$, $d = 20\,\mu m$	34.2	28.8	33.1	27.6
Proposed method	SP-92 + 1% HDN-1 $Po = 4.67\,\mu m$, $d = 50\,\mu m$	21.2	12.7	21.2	12.7
	SP-92 + 2% HDN-1 $Po = 3\,\mu m$, $d = 20\,\mu m$	31.2	27.3	31.2	27.3

affect the accuracy of the results obtained by the proposed conoscopic method of measurement of the threshold voltage.

For comparison, values of the threshold voltages obtained by different methods are shown in Table 1.

The indisputable advantage of the conoscopic method is the possibility to identify a deformation of the director field of a homeotropic texture caused by reasons other than an applied external electrical field. Figure 6 shows the conoscopic images obtained for the samples with different surface conditions: without additional treatment (1) and a cell with alignment polymer layer PI 2555 (2). The conoscopic image obtained for the second sample is typical of the existence of a non-aligned planar layer near the surface. The subsequent increase of the applied voltage leads to the alignment of layers near the surface. A difference between the field, when a homeotropic nematic texture is formed, and the field, when the layers near the surface are aligned, allows us to determine the cohesion energy with the surface. We note that the conoscopic studies could be a promising technique to study the alignment efficiency and to determine the parameters of aligned layers such as, for example, the cohesion energy.

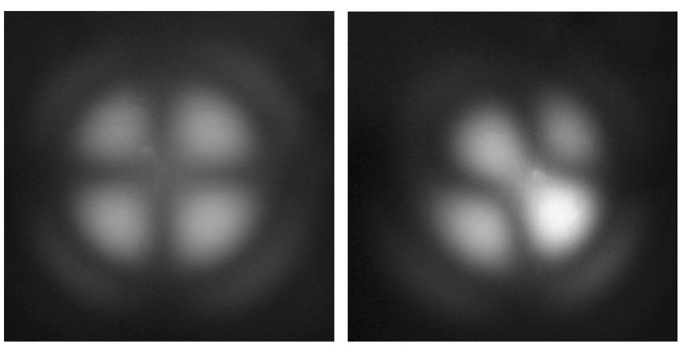

Figure 6. Conoscopic images of a homeotropic nematic texture at the wavelength $\lambda = 0.53$ μм: 1—without alignment layer; 2—with alignment layer. (liquid crystal layer thickness is 20 μm).

Conclusion

Our investigation has demonstrated both the efficiency of the use of the conoscopic method for measurements of the threshold voltage of the cholesteric-nematic transition and the improved accuracy of such measurements.

The proposed method allows one not only to determine the threshold voltage, but also it can be efficiently used in studies of the influence of surface conditions on the texture of samples.

Thus, the conoscopic studies are found to be a promising technique to investigate the alignment efficiency and to determine the parameters of aligned layers such as, for example, the cohesion energy.

References

[1] Mykytyuk, Z., & Nevmerzhitska, O. (1993). *European Conference on Liquid Crystals (ECLC-93), Flims, Switzerland.*

[2] Mykytyuk, Z., Fechan, A., Gural, V., Shymchyshyn, M., & Yasynovska, O. (2008). *Molecular Crystals and Liquid Crystals*, *493*, 3.

[3] Kawachi, M., Kogure, O., Yoshii, B., *et al.* (1975). *Jap. J.of Appl. Phys.*, *14*, 1063.

[4] Mikityk, Z., Semenova, O., Sushinsky, O., & Nutskovsky, M. (1998). *Molecular Crystal and Liquid Crystals*, *317*, 93. de Gennes, P. G., The Physics of Liquid Crystals, Oxford Univ. Press, London (1974)

[5] Danilov, V. V., & Saveljev, D. A. (1986). *Trudy GOI*, *60*, 81.

[6] de Gennes, P.- G. (1974). *The Physics of Liquid Crystals*, Oxford Univ. Press: London.

[7] Mykytyuk, Z., Fechan, A., Sushynskyy, O., Shymchyshyn, M., & Levenets, V. (2008). *Molecular Crystals and Liquid Crystals*, *496*, 230.

[8] Nastishin, Ya., Dovgyj, O. B., & Vlokh, O. G. (2001). *Ukr. J. Phys. Optics*, *2*, 98.