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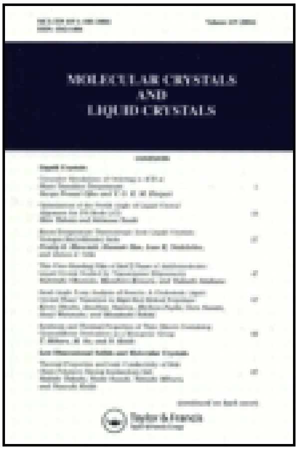

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The Optical Element Based on a Planar Waveguide with Liquid Crystal Core

Z. Mykytyuk [a] , A. Fechan [a] , O. Sushynskyy [a] & V. Gural [a]
[a] Lviv Polytechnic National University, Lviv, Ukraine

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The Optical Element Based on a Planar Waveguide with Liquid Crystal Core

Z. Mykytyuk
A. Fechan
O. Sushynskyy
V. Gural
Lviv Polytechnic National University, Lviv, Ukraine

One of the important disadvantages of information display devices based on the cholesteric-nematic effect is a low contrast level. We propose a new constructive decision to solve this problem. The classic sandwich cell is a planar waveguide taking into account the correlation between the glass refraction index and the liquid crystal layer refraction index. Therefore, in a liquid crystal layer (at the homeotropic texture) the minimum amount of light radiation propagates along the planar waveguide and is scattered perpendicularly to the propagation direction. However, in the liquid crystal layer, the confocal texture is obtained due to a voltage change, and it leads to the light scattering. This constructive solution provides the increase in the contrast level.

Keywords: cholesteric-nematic transition; optical element; planar waveguide

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INTRODUCTION

The cholesteric-nematic transition (CNT) effect has a technical favour to be used in optoelectronic devices. The interest in it is determined by the texture and the field hysteresis. The main interest is determined by simple constructive decisions in the optoelectronic device design. This liquid crystal (LC) effect expands the sphere of applications of optoelectronic devices because of changing the main laser radiation parameters. The most important way of the development of image devices based on a liquid crystal material is the use of the selective reflection effect. In this aspect, the planar waveguide structure with liquid crystal optical active core is very perspective. The main problem

Address correspondence to Z. Mykytyuk, Lviv Polytechnic National University, 12 Bandery Str., Lviv 79013, Ukraine. E-mail: zmykytyuk@polynet.lviv.ua

of liquid crystal devices based on the scattering effect is a low contrast level.

The present work is devoted to the electrooptical investigation of the cholesteric-nematic transition. We tried to improve the contrast level of optical elements based on a planar waveguide with liquid crystal core.

THEORY

The destruction of a supermolecular spiral structure underlies the cholesteric-nematic transition. This scattering effect changes the transparency of a liquid crystal layer. The typical dependence of the liquid crystal layer transparency on the applied voltage is shown in Figure 1. By varying the electrical field at the range from zero to the focal-conic deformation voltage (UCD), the reorientation of the axis spiral is occurred. The further increase of the electrical field to the Ucn value destroys the supermolecular spiral structure. And then the nematic phase is formed. The Ucn value is the threshold value of the cholesteric-nematic transition. The decrease of the electrical field to the inverse CNT voltage (Unc) saves the nematic phase. This leads to the hysteresis of electrooptical properties of CNT.

In our work, we use the theoretical model of Kawachi–Kogure to determine the critical voltage of the CNT effect [1,2]:

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

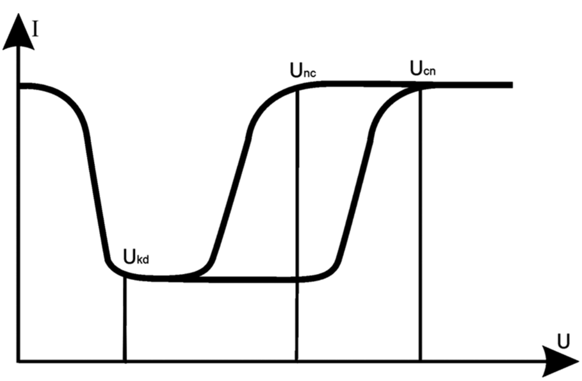

FIGURE 1 Typical dependence of the liquid crystal layer transparency on the applied voltage due to CNT.

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$$U_{nc} = \frac{1}{d}\left[\left(\frac{\pi}{P_0}\right)^2 \frac{\left(K_{22} - K_{33}\frac{P_0}{d}\right)^2}{\varepsilon_0 \Delta\varepsilon K_{33}} + \frac{4F_{sn}}{d\varepsilon_0 \Delta\varepsilon}\right]^{1/2},$$

where K_{22} and K_{33} are the Frank elastic constants; $F_{sc'}$, F_{sc}, and F_{sn} are the densities of surface free energy in the planar confocal and nematic state, correspondingly; d is the LC layer thickness; and P_o is the free induced helix pitch.

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THE EXPERIMENT

The induced cholesteric mesophase with high pitch structure is the object of our investigation. It consists of the nematic matrix with low concentration (up to 2%) of an optical active dopand (OAD). Mixtures of strong polar cyanobipheniles are characterized by a high value of dielectrical anisotropy $\Delta\varepsilon - +13.5$ (at 293 K), $\Delta n - 0.22$, and has a wide temperature range of the mesophase existence, 263–328 K. With the aim to create an induced spiral structure, the non liquid crystal optic active dopand (BIXH-3) was used. The value of the induced helix pitch was determined by the Cano-Grandjan method and by the diffraction of a laser beam on the “finger print” texture. In Figure 2, the dependence of the inverse induced helix pitch on the concentration of OAD is shown.

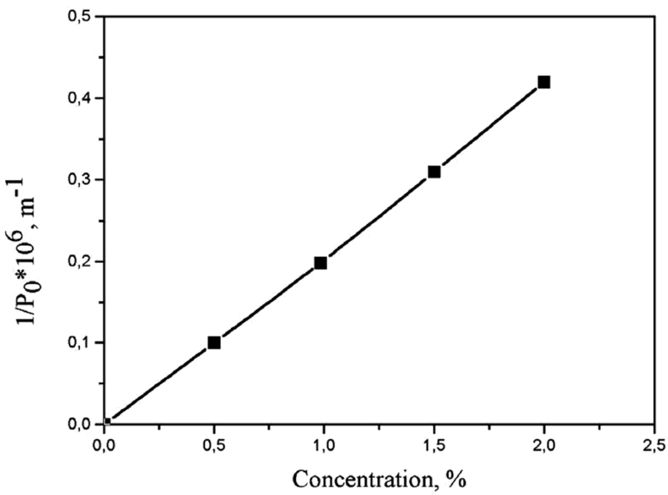

FIGURE 2 Dependence of the inverse induced helix pitch value on the concentration of OAD.

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The electrooptical investigations were carried out in sandwich cells with planar boundary conditions at room temperature: the LC layer thickness was 100 μm. In our investigation, the scattering behavior of the CNT effect is considerable. We use a He–Ne laser with a wavelength of 0.63 μm as a source of radiation. The electrooptical investigation was carried out at the normal incidence of a laser beam on the LC layer and at the input by a prism. In the second case, the liquid crystal cell is a planar waveguide structure. The experimental block-diagram is shown in Figure 3.

The results of our investigation of the optical transparency of an LC cell on the applied voltage at the normal introduction of laser radiation and the planar waveguide structure are shown in Figure 4.

The typical dependence of the optical transparency on the applied voltage in case of the normal radiation introduction is observed (Figures 4,5). The increase of the OAD concentration leads to the increase of the threshold voltage in both cases. Such a behaviour has been explained by the decrease of a helix pitch of the spiral structure. In the case of a planar waveguide structure, at the first region of the dependence, the high intensity of laser radiation, which goes out of the liquid crystal cell with the scattering on the confocal texture of the

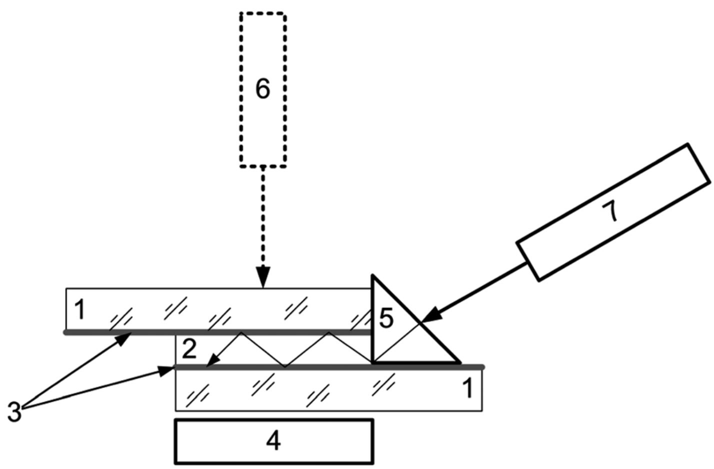

FIGURE 3 Experimental block-diagram: 1-glass substrate; 2-induced cholesteric layer; 3-transparent conductive electrodes; 4-photosensitive element; 5-the prism for the introduction of laser radiation into the induced cholesteric layer; 6-position of a He–Ne laser at the normal introduction; 7-position of a He−Ne laser for the introduction of radiation into the induced cholesteric layer (the waveguide mode).

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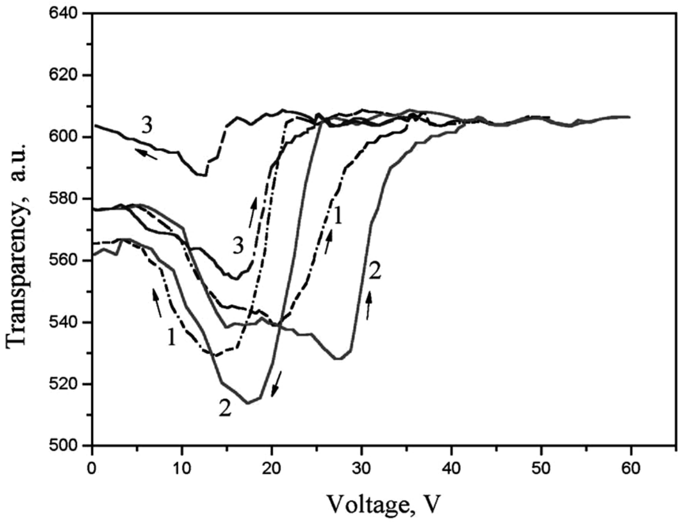

FIGURE 4 Dependences of the optical transparency of an LC cell on the applied voltage at the normal introduction of laser radiation at different concentrations of OAD: 1–1%; 2–1.5%; 3–0.5%.

induced cholesteric, is observed. The increase of the applied voltage leads to the CNT effect in a liquid crystal, and the nematic homeotropic texture is formed. The optical properties of the LC change in such a way that, in the structure Glass-LC-Glass, the condition of complete internal reflection takes place. The liquid crystal cell is become a planar waveguide. Such a change of the optical properties leads to a sharp decrease of the intensity of the laser radiation which falls on a photosensitive element. This sharp decrease of the laser radiation intensity has been explained by the implementation of the condition of complete internal reflection. Thus, the laser beam spreads throw the LC layer in parallel to the photosensitive element.

The dependence of the contrast value of the LC cell on the OAD concentration is shown in Figure 6. The contrast value was determinated [3] as

$$K = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$

where $I_{\max}$, $I_{\min}$ are the maximum and minimum values of the intensities of the laser radiation which goes from the LC cell.

As shown on Figure 6, the use of the planar waveguide structure allows one to increase the contrast value of optical elements. This

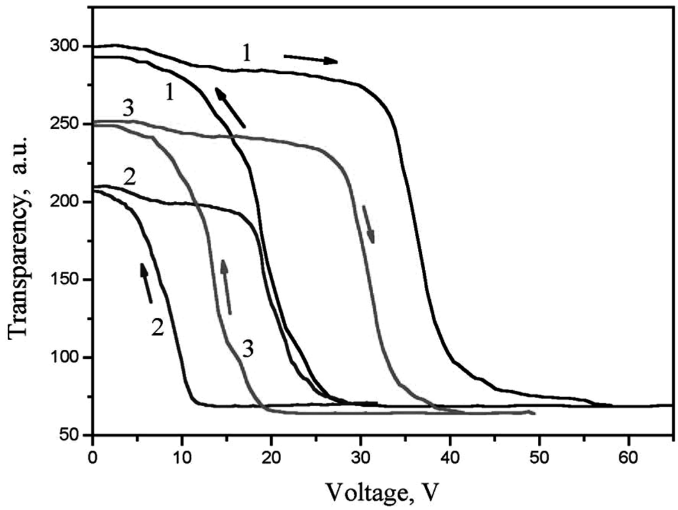

FIGURE 5 Dependences of the optical transparency of an LC cell on the applied voltage for a planar waveguide structure at different concentrations of OAD: 1–1.5%; 2–0.5%; 3–1%.

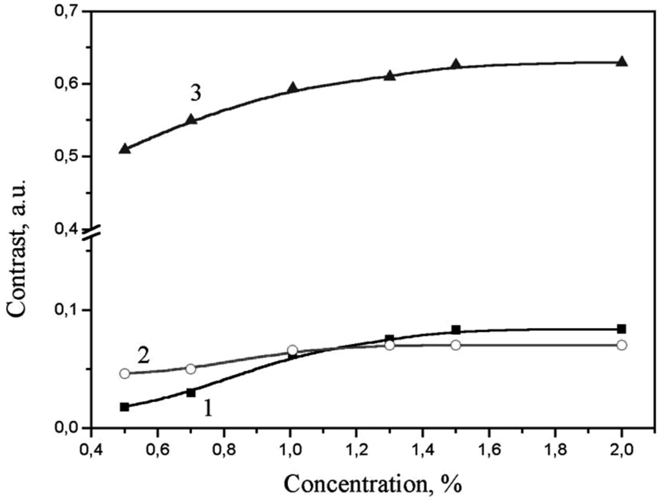

FIGURE 6 Dependences of the contrast values of an LC cell on the OAD concentration in the case of the normal introduction of laser radiation at the texture (curve 2) and the cholesteric-nematic transition (curve 1) and for a planar waveguide structure (curve 3).

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occurs due to a change of the distribution direction of a laser beam relatively to the view point. The increase of a contrast with increase in the OAD concentration occurs by means of the increase of the scattered laser radiation on the confocal cholesteric structure. This increase is caused by a change of the linear size of the confocal domain of the cholesteric structure because of a decrease of the helical pitch of the supermolecular spiral structure.

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CONCLUSION

We have established the correlation between the physical parameters of nematic-cholesteric mixtures and the electrooptical properties of the cholesteric-nematic transition effect.

We offer a new construction of optical elements based on the planar waveguide with a LC core, which allows one to increase the contrast by means of a change of the distribution direction of laser radiation.

The scattering effect of the cholesteric-nematic transition leads to the design of optical elements with higher contrast characteristics and a wider angle of observation.

The scattering behavior of the cholesteric-nematic transition allows the creation of optical elements with improved contrast parameters and a wide observation angle.

We show that the critical fields of the CNT effect and the steepness of the dependence of light transmission of an LC cell on the applied voltage can be controlled in a wide range by the change in the percentage of components of cholesteric-nematic mixtures.

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