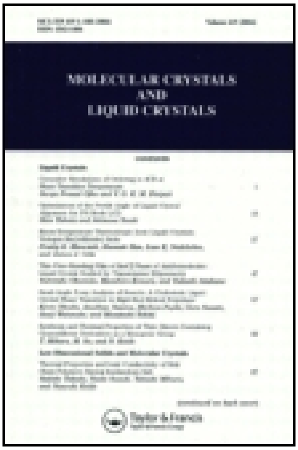

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The volt-contrast characteristics of the scattering indicatrix of induced cholesterics depending on the chiral dopant concentration have been investigated.

The dependences of the view angle on the sizes of focal conic domains which can be changed by changing the intensity of an electric field applied to the cell are explored.

We have obtained the dependences of the intensity of reflected radiation on the view angle for a uniformly illumunated cell, in which a focal conic texture is created under the action of the electric field. We have also shown that the effect of radiation reflection can be successfully used in the information reflection displays in order to create a white background with a wide view angle and with uniform intensity of the reflected light.

Keywords: cholesteric-nematic transition; liquid crystal mixtures; scattering

INTRODUCTION

The cholesteric-nematic transition (CNT) can be used in optoelectronic devices because it has texture and field hysteresis, and the devices using CNT have a simple design. This effect strongly affects the parameters of irradiation that allows expanding the usage of liquid crystal (LC) devices.

The CNT effect has advantage when used in the display devices with an LC-electrochromic layer structure. Such active optical medium allows the independent control of the electrochromic layer transparency and scattering properties of LC [1,2]. In this structure,

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the electrochromic layer allows one to change its transparency, and the liquid crystal layer set the white background and also changes the view angle in a wide range.

This approach makes it possible to use the scattering electrooptical effects in LCs for the designing of display information devices, which can work in both the transmission and reflection modes. This method removes the main problem of these LC devices, namely the low contrast level.

THEORY

The electric field applied to a cholesteric LC destroys its helical structure and changes the transparency of an LC layer. Figure 1 shows the typical dependence of the liquid crystal layer transparency on the applied voltage. The electric field less than the voltage of forming the focal conic deformations (U_{cd}) reorients the helical axis and causes the formation of a scattering focal conic texture. Let the voltage U_{cn} destroy the helical cholesteric structure completely inducing the nematic phase oriented homeotropically. The U_{cn} value is the threshold value of the cholesteric-nematic transition. The nematic phase will appear when decreasing the electric field to the inverse CNT voltage (U_{nc}). This corresponds to the hysteresis of electrooptical properties of CNT.

In our work, we use the theoretical model developed in [3–5] to determine the critical voltage of the CNT effect:

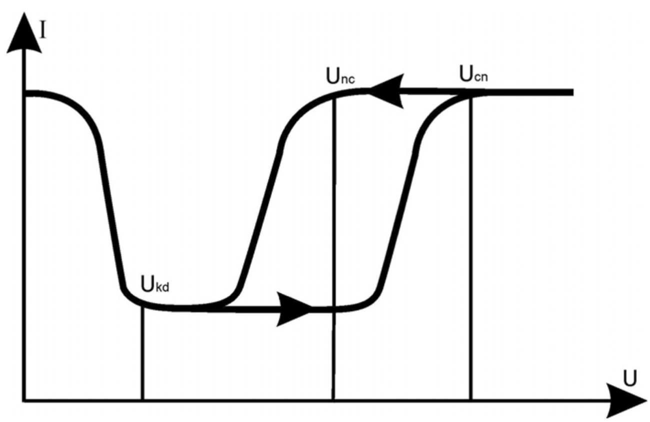

FIGURE 1 Typical dependence of the liquid crystal layer transparency on the applied voltage due to CNT.

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

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

where K_{22} and K_{33} are the Frank elastic constants; $F_{\mathrm{sc'}}$, F_{sc}, and F_{sn} are the densities of surface free energy in the planar, focal conic, and nematic states, respectively; d is the thickness of an LC layer; and P_0 is the intrinsic pitch of a cholesteric LC.

Close to the cholesteric-nematic transition, the sample of the induced cholesteric has a focal conic texture. Moreover, the size of focal conic domains depends on the applied voltage. The increase in the applied voltage leads to a decrease in the size of domains in the focal conic texture [4].

The theory of scattering by the focal conic texture in induced cholesterics is absent, and we take the Rayleigh–Gans scattering theory into account. It is necessary to consider many parameters while investigating the scattering effect in induced cholesterics. The resulting scattering of an optical beam passing through a cholesteric LC is determined by the scattering by a focal conic texture, selective scattering by a cholesteric helical structure, and anisotropic molecular scattering. Usually, their contributions to the total scattering are different. The models describing the scattering effect are developed using some assumptions. Some approaches take only the selective scattering into account, and the others consider the scattering by a focal conic texture without the anisotropic scattering. Our model of the scattering of a laser radiation by a focal domain texture is based on the Rayleigh–Gans one. In the first approximation, we take the scattering particle as a spherical one and consider the single reflection of light. To determine the angular distribution of the scattering light intensity, we use the expression

$$I(\beta, R) = I_0\alpha^2\frac{16\pi^4}{\lambda^4}v^2\;\frac{1+\cos^2\beta}{2}f^2(q), \tag{3}$$

where I_0 is the initial intensity; λ is the wavelength; n is the reflection coefficient; v is the volume of a scattering particle, β is an angle of scattering,

$$\alpha = \frac{3}{4} \cdot \pi \cdot \frac{n^2 - 1}{n^2 + 2}; \quad f(q) = \frac{3}{q^2}(\sin q - q \cos q); \quad q = 2 \cdot \rho \cdot \sin\frac{\beta}{2}. \quad (4)$$

$$\rho = \frac{2\pi R}{\lambda}, \quad (5)$$

where R is the radius of a scattering particle.

The use of the angular distribution of scattering light intensity (Fig. 2) normalized by the intensity of light scattered forward allows the direct comparison with experimental data.

Changing the size of scattering particles allows us to change diagram's direction in a wide range, as seen from the theoretical curves in Figure 2. In the case of cholesteric LCs, the scattering centers are domains of a focal conic texture, and their size can be controlled by an applied electric field. During the textural changes under the applied electric field, the size and concentration of scattering centers vary, which causes the multiple light scattering. When the electric field increases to U_{cn}, the multiple light scattering is ignored.

We have investigated the possibility to use the LC doped with ionic dopant as the electrolytic medium for the electrochromic devices based

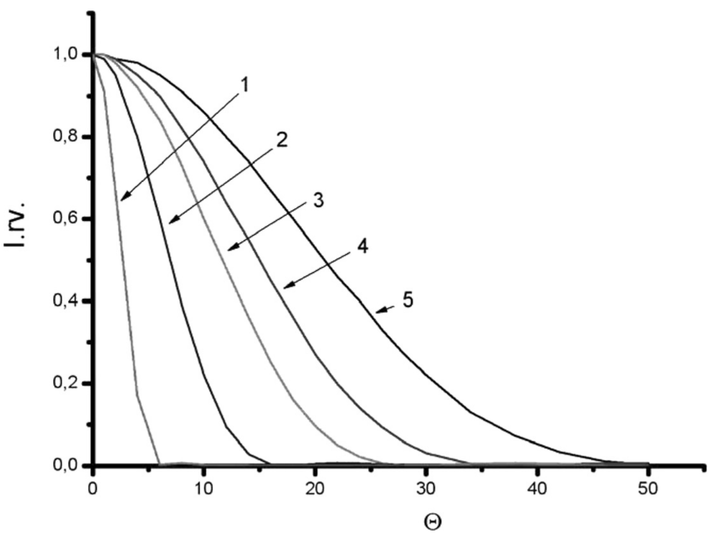

FIGURE 2 Angular distribution of the scattering light intensity from the scattering particles of different sizes: 1–10 μm; 2–4 μm; 3–1.5 μm; 4–1 μm; 5–0.5 μm.

on polyaniline [1]. It is not possible to use pure liquid crystals for this purpose because of their low conductivity. The conductivity of liquid crystals can be increased by adding an ionic dopant. Therefore, at the thickness of a liquid crystal layer of 20 μm, the conductivity can change from $5 \cdot 10^{-11}$ to $10^{-7}\,\mathrm{Ohm}^{-1} \cdot \mathrm{cm}^{-1}$ in our experiments. The description of the light scattering by an LC-layer in the LC-electrochromic layer structure is not possible, because the electrohromic layer changes the optical characteristics of the liquid crystal when the voltage is applied to this structure. Therefore, we will investigate the light scattering only in the LC-layer.

The induced cholesteric mixture consists of the nematic matrix doped with an optically active dopant (OAD) at a concentration of 3–17%. The used nematic LC SZK-1 has the following parameters: the dielectric anisotropy $\Delta\varepsilon = 13.5$ (at 293 K), optical anisotropy $\Delta n = 0.22$, temperature range where the mesophase exists is 263–328 K. We used OAD BIXH-3 to create a helical structure. The tetrabutylammonium chloride was used to obtain the ionic conductivity.

Our experiments have shown the existence of the electrochromic effect in the LC-electrochromic layer structure.

To find the connection between the scattering of a laser beam, optical parameters of the LC layer, and a driving signal, we experimentally determined how the intensity of light scattering depends on the view angle at the normal incidence of a laser beam.

We investigated the transparence of a cholesteric mixture depending on the applied voltage in standard cells with the thickness of an LC layer of 25 μm at room temperature. The scattering effect in CNT was taken into account during the experiment. The experimental scheme for the investigations of scattering characteristics is shown in Figure 3. The construction of this experimental setup was developed by using all methods for the investigation of display information devices [5].

The experimental dependence of the optical transparence of an LC cell on the view angle is shown in Figures 4–6.

From the experimental curves (Figs. 4–6), it is clear that the increase in the driving voltage results in narrowing the direction diagrams and increasing the intensity of the central peak due to a larger size of scattering domains of the focal conic texture (Fig. 4). The greater the concentration of OAD, the more the intensity of the light transmitted at large angles due to a smaller size of scattering domains (Figs. 4, 5). These experimental data are in good agreement with the theoretical curves (Fig. 2).

In the reflective mode (Fig. 6), the direction diagram is wider than that in the transmission mode and does not depend on the applied

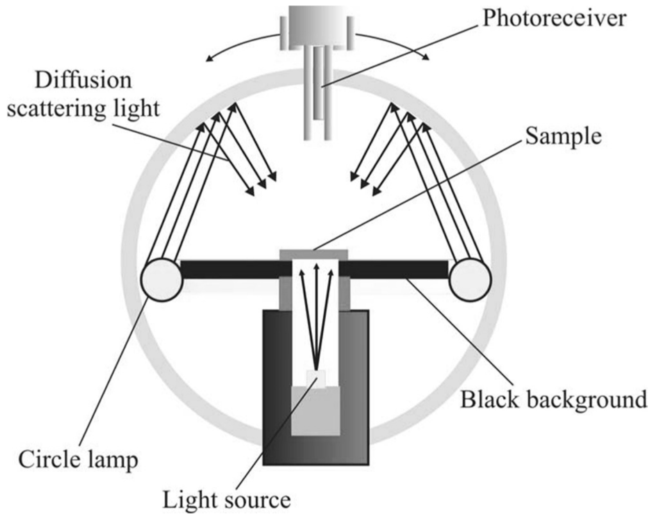

FIGURE 3 Scheme of the experimental setup for the investigation of scattering characteristics.

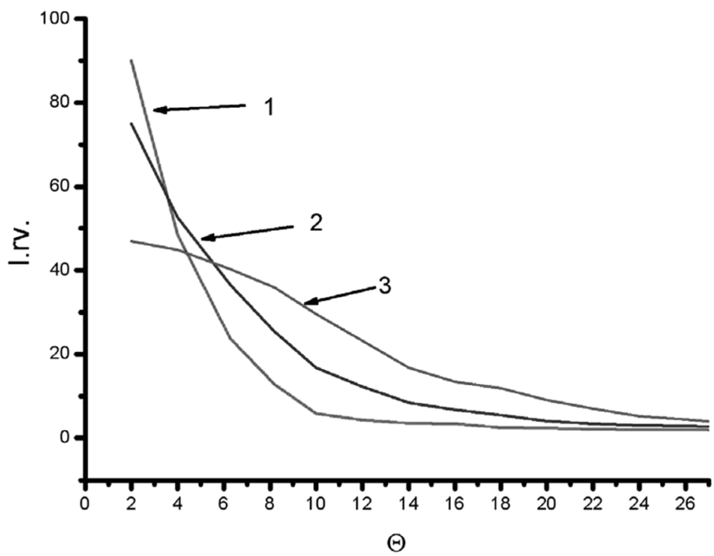

FIGURE 4 Experimental dependences of the optical transparency of an LC cell on the view angle for the mixtures SZK-1 + 3.5 BIXH-3 at various applied voltages: 1) 25 V ($U < U_{cn}$); 2) 1 V ($U < U_{cd}$); 3) 4.6 V ($U_{cd} < U < U_{cn}$), (transmission mode).

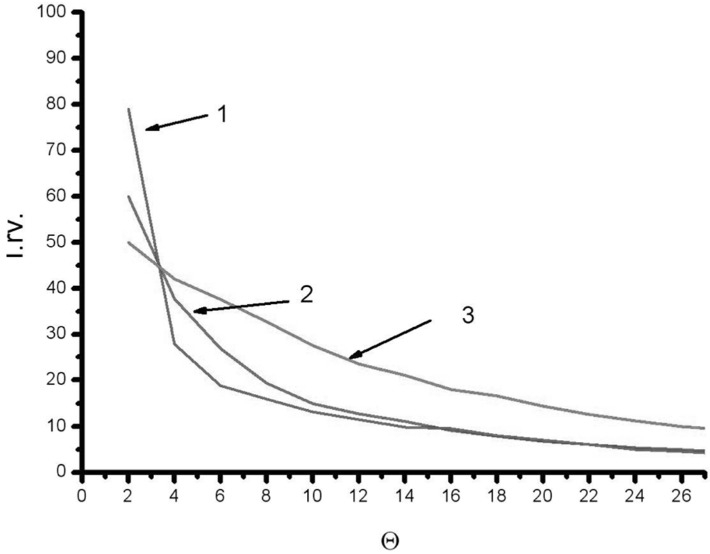

FIGURE 5 Experimental dependences of the optical transparency of an LC cell on the view angle for the mixtures SZK-1 + 17 BIXH-3 at various applied voltages: 1) 54 V ($U < U_{cn}$); 2) 1 V ($U < U_{cd}$); 3) 13 V ($U_{cd} < U < U_{cn}$), (transmission mode).

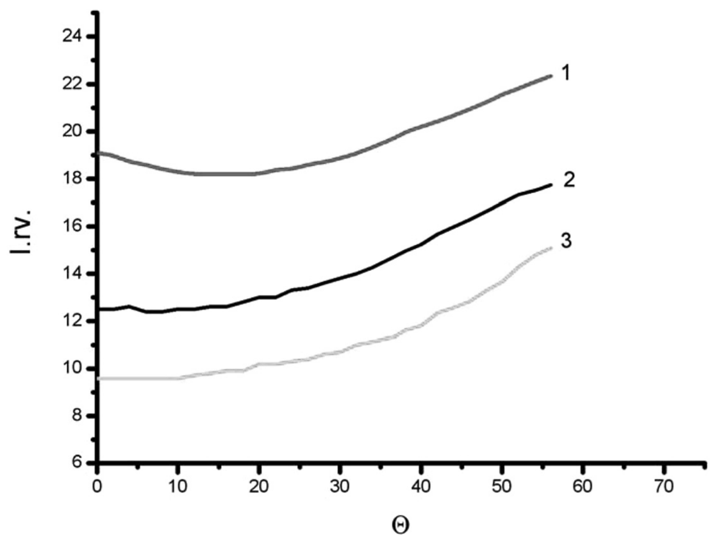

FIGURE 6 Experimental dependences of the optical transparency of an LC cell on the view angle for the mixtures SZK-1 + 17 BIXH-3 at various applied voltages: 1) 13 V ($U_{cd} < U < U_{cn}$); 2) 1 V ($U < U_{cd}$); 3) 54 V ($U < U_{cn}$), (reflection mode).

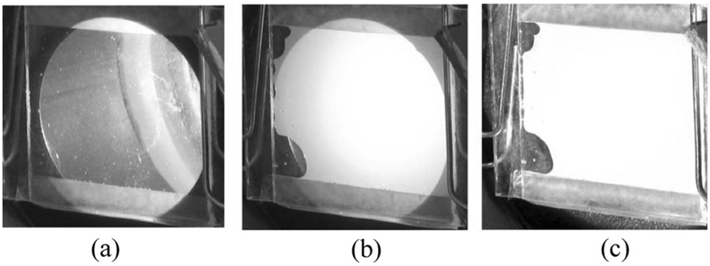

FIGURE 7 Photos of the investigated samples at the different modes of flash and different control voltages: (a) the transmission mode, $U = 60\,\mathrm{V}$; (b) the transmission mode, $U = 9.6\,\mathrm{V}$; (c) the reflection mode, $U = 9.6\,\mathrm{V}$.

field. The increase of the reflective radiation intensity at the large view angles particularly can be explained by the influence of the parasitic radiation reflected from glass substrates [6]. The maximum intensity of the reflected light and the maximum width of the direction diagram of transmitted light are obtained at the same control voltage.

The photos of the investigated sample for the different modes of flash are shown in Figure 7.

CONCLUSION

1. Using the proposed structure allows one to change the direction diagrams, by changing the applied voltage and the concentration of an optically active dopant.
2. The increase of the driving voltage results in narrowing the direction diagrams and increasing the intensity of the central peak due to a larger size of scattering domains of a focal conic texture in cholesteric LC.
3. Our investigation has shown the feasibility to develop the display devices using the LC – electrochromic polymer structure operating in the transmissive and reflective modes.

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