

The active medium scattering characteristics of liquid crystal displays

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A new design has been proposed for the liquid crystal displaying element to enhance the view angle and the contrast level. The laser radiation scattering process in nematic-cholesteric mixtures has been simulated mathematically. The dependences of scattering intensity on the scatter angle have been studied in experiment taking into account the laser radiation incidence angle on the scattering structure. The contrast value as a function of the optically active dopant concentration in the nematic matrix has been determined.

Предложено новое конструктивное решение элемента жидкокристаллического дисплея с целью увеличения угла зрения и контрастности. Выполнено математическое моделирование процесса рассеивания лазерного излучения в нематико-холестерических смесях. Экспериментально исследована зависимость интенсивности рассеивания от угла рассеяния с учетом угла падения лазерного луча на рассеивающую структуру. Определена величина контрастности как функция концентрации оптически активной добавки в нематической матрице.

The cholesteric-nematic transition (CNT) effect is of a technical interest defined by the presence of both texture and field hysteresis as well as by possible simple design of optoelectronic devices based thereon. This liquid crystal (LC) effect expands the sphere of optoelectronic device applications because of changing the main laser radiation parameters. The most important way to imaging devices based on liquid crystal materials with helical supramolecular structure is to make use of selective reflection effect. The planar waveguide structures with liquid crystal optically active core is of good promise, too [1]. The scattering electrooptical effects in liquid crystals are useful in such devices, provided that the main problem thereof, the low contrast level, is eliminated.

The cholesteric-nematic transition essence consists in degradation of supramolecular spiral structure due to an external electric field. This effect changes the transparency of the liquid crystal layer. A typical dependence of the liquid crystal layer transparency on the applied voltage is shown in Fig. 1. In the electrical field, the reorientation of axis spiral occurs within the range extending from zero to focal-conic straining voltage (U_{kd}). The further electrical field increase up to the U_{cn} value causes degradation of the supramolecular spiral structure formation of the homeotropically oriented nematic phase. The U_{cn} value is the threshold of cholesteric-nematic transition. The nematic phase remains at the decrease of electrical field value down to the inverse CNT voltage (U_{nc}) saves. This results in a hysteresis of the CNT electrooptical properties.

In this work, the Kawachi-Kogure theoretical model has been used to determine the critical voltages of CNT effect [1, 2]:

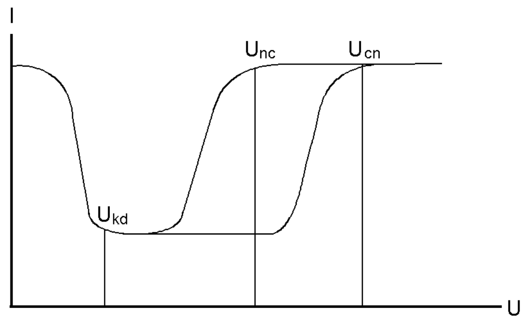

Fig. 1. A typical dependence of liquid crystal layer transparency on the applied voltage due to CNT.

$$U_{kd} = \frac{2\sqrt{2}}{d}\left[\frac{F_{sc} - F_{sc'}}{d\varepsilon_0\Delta\varepsilon}\right]^{1/2},$$

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

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

where K_{22}, K_{33} are Frank elastic constants; $F_{sc'}$, F_{sc}, F_{sn}, the surface free energy densities in planar, confocal, and nematic state, respectively; d, thickness of LC layer; P_0, free induced helix pitch.

The study of scattering effect in induced cholesterics is associated with numerous aspects of laser radiation scattering. When the laser radiation incides the induced cholesteric layer, the resulting scattering diagram will be defined by scattering on confocal domains, selective scattering on the cholesteric spiral and anithotropic molecular scattering. The general model of laser radiation scattering in induced cholesterics is based on several approximations. Some of those have considered only the selective scattering component, while other took into account the scattering in confocal domains but not the anisotropic scattering. Our model of laser radiation scattering in a planar waveguide is based on the Rayleigh-Gans scattering in single approximation, the full internal reflection conditions being taken into account (Fig. 2). The angular distribution of the scattered light intensity based on Rayleigh-Gans approximation is described as

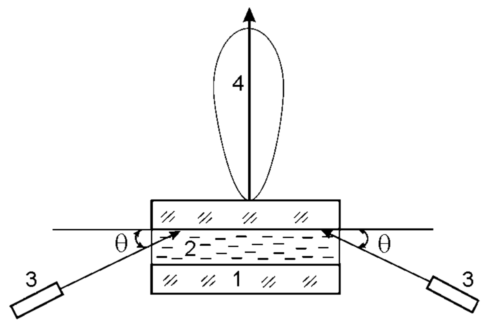

Fig. 2. Mathematical simulation scheme of laser beam scattering at the two ways of the beam incidence: *1*, glass surface; *2*, induced cholesteric layer; *3*, He–Ne-laser directing the beam to induced cholesteric (planar waveguide mode); *4*, the distribution directions of scattered radiation.

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

$$\alpha = \frac{3}{4}\pi\frac{n^2-1}{n^2+2};$$

$$f(q) = \frac{3}{q^3}(\sin q - q\cos q); \quad q = 2\rho\sin\frac{\beta}{2}.$$

The light scattering when the radiation is introduced directly into a liquid crystal layer under single approximation for the beam incidence from two sides at various particle radius and various incidence angles was simulated according to the scheme shown in Fig. 2. The mathematical simulation results of laser beam scattering process are shown in Fig. 3.

The increasing the radiation incidence angle on liquid crystal layer results in increasing effective cross-section of the active medium scattering layer and, correspondingly, in increasing scattering on the confocal domains. However, the maximum radiation incidence angle is defined by the internal reflection angle. The decreasing size of scattering particles causes increasing uniformity of the radiation intensity. The use of planar wave guide mode makes it possible to increase considerably not only the contrast value [3] but also the view angle, since this is caused by changes in the light flow spreading direction with respect to the view point.

We have studied in experiment also the scattering intensity dependences on the view angle at the laser beam normal incidence to establish the correlation between the laser beam scattering, physical proper-

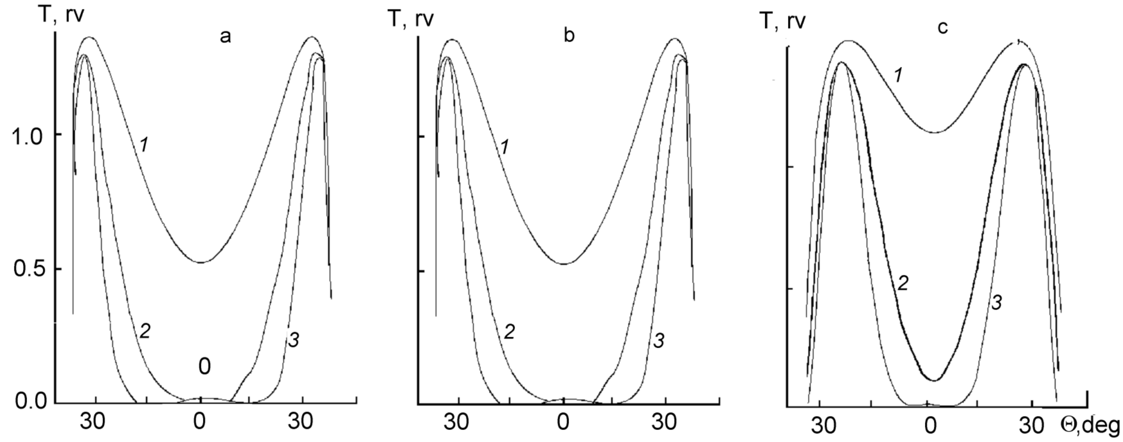

Fig. 3. Light scattering on confocal domains at cholesteric-nematic transition at the incidence angle of laser beam 0° (a), 20° (b), 40° (c) and particle size 0.2 (*1*), 0.4 (*2*), and 0.63 μm (*3*).

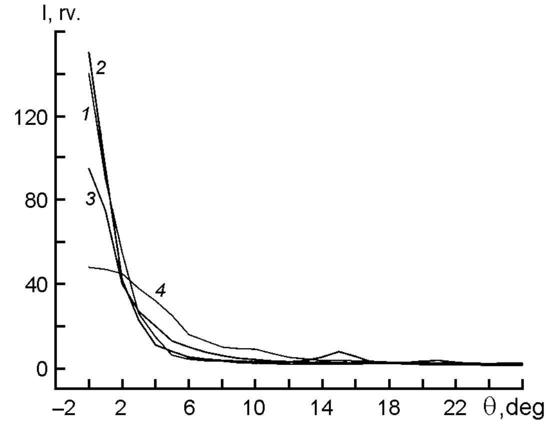

Fig. 4. Experimental dependences of the LC cell scattering intensity on the view angle for СЖК–1+3.5 % BIXH-3 mixture at at various applied voltage values: 32.5 V (*1*); 43 V (*2*); 4.6 V (*3*); 1 V (*4*).

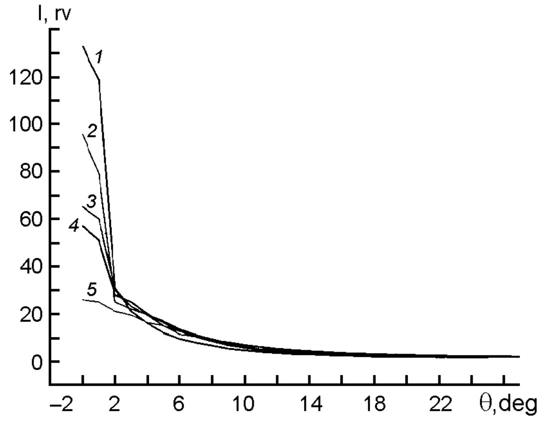

Fig. 5. Experimental dependences of the LC cell scattering intensity on the view angle for СЖК–1+17 % BIXH-3 mixture at at various applied voltage values: 50 V (*1*); 25 V (*2*); 13 V (*3*); 6 V (*4*); 1 V (*5*).

ties of liquid crystal layer and parameters of control signal.

The induced cholesteric mesophases consisted of a nematic matrix with low concentrations (from 3–17 %) of optical active dopants (OAD). Mixtures of strong polar cyanobiphenyls are characterized by high value of dielectrical anisotropy $\Delta\varepsilon = +13.5$ (at 293 K), $\Delta n = 0.22$, the temperature range of mesophase existence is 263 to 328 K. To induce the spiral structure, the non-mesomorphic optically active dopant (BIXH-3) was used. The electrooptical investigations were carried out in sandwich cells with planar boundary conditions at room temperature, the LC layer was 25 μm thick. The scattering character of CNT effect was taken into account. A He–Ne laser (the radiation wavelength 0.63 μm) was used as the radiation source. The optical transparency characteristics of LC cell as functions of the applied voltage at the normal incidence of laser beam and planar waveguide structure are shown in Figs. 4 and 5.

The increasing applies voltage is seen to narrow the directional diagrams on confocal nematic textures and increase the central peak intensity. This is caused by increasing size of scattering confocal domains [3]. The increasing OAD concentration results in increasing intensity of radiation passing through the liquid crystal cell due to decreasing size of confocal domains. The experimental results agree well with theoretical relationships.

Thus, the use of the proposed structures makes it possible to vary the directional diagrams within a wide range by varying the applied voltage and concentration of opticallyactive dopant at retaining high contrast level. The increasing light incidence angle on the liquid crystal layer results in increasing effective cross-section of the scattering layer active medium and, correspondingly, in increasing scattering on the confocal domains, that is, in enlarging directional diagram width. However, the maximum light incidence angle is limited to the internal reflection angle. The increasing applied voltage causes a narrowing scattering directional diagrams on confocal nematic textures and increasing intensity of the central peak. This is caused by increasing size of scattering confocal domains.

References

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Характеристики розсіювання активною речовиною рідкокристалічних дисплеїв

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Запропоновано нове конструктивне рішення елемента рідкокристалічного дисплею з метою збільшення кута огляду і величини контрасту. Проведено математичне моделювання процесу розсіювання лазерного випромінювання у нематик-холестиричних сумішах. Експериментально досліджено залежність інтенсивності розсіювання від кута розсіяння із врахуванням кута падіння лазерного променя на структуру, що розсіюється. Визначено величину контрасту як функцію концентрації оптично-активної домішки у нематичній матриці.