

The Dynamics of the Response of an Electro-Optic Cell Based on a Nematic Layer with Controlled Surface Anchoring

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Abstract—We investigate the electrooptical characteristics of a cell based on a nematic liquid crystal layer controlled with the use of modification of the surface anchoring by an ionic surfactant. The inverse mode of the effect is used with the nematic oriented homeotropically in the initial state and transferring to the hybrid homeoplanar structure in an applied dc electric field. We consider the applied voltage dependences of the dynamic parameters of the optical response.

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At present, liquid crystals (LCs) are among the basic functional materials used in optoelectronics, especially in the information display technics. Intense research in this field is aimed at the development of novel LC materials and LC-based devices. The traditional methods for the LC control are based on the well-known Fredericksz transition of the orientational structure under the action of an electric field aligning the LC so that to make its permittivity maximum [1]. In this case, the surface anchoring of the LC with the substrates remains invariable. The fundamentally new approach to the LC control is based on the local Fredericksz transitions [2], when, for example, an electric field modifies the boundary conditions, which leads to the reorientation of the

entire LC layer [3]. Such a transition can be implemented, in particular, by changing the surface anchoring with the use of electric-field-induced variation in the concentration of ionic surfactants [4–6]. The features of the transformations of the orientational structure of the nematic LC layer with the electric-field-controlled boundary conditions caused by the combination of several effects were described in detail in [7]. This Letter presents the results of investigations of the dynamics of the response of a nematic-layer-based optical cell controlled by an ionic surfactant method.

Planar LC cells (Fig. 1) consisting of two glass substrates with transparent ITO electrodes on the inner sides and a nematic LC layer between them were the object of study. The electrodes were preliminarily

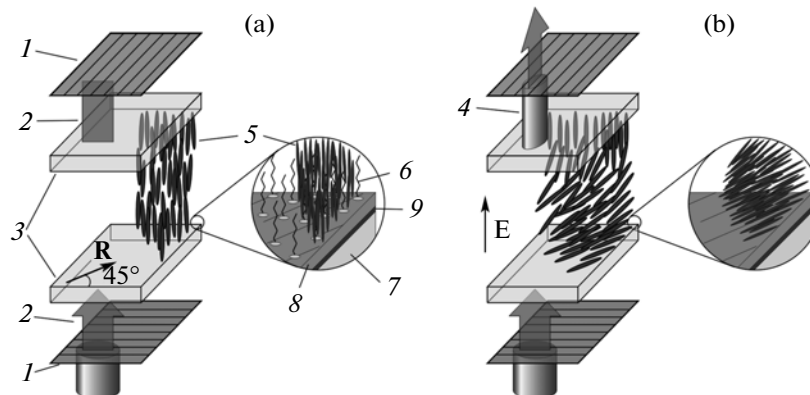


Fig. 1. Schematic of the LC cell operation in crossed-polarizers geometry. (a) Without electric field, the nematic is homeotropically aligned and light does not pass through the system; (b) in the dc electric field, the surface anchoring on the lower substrate becomes planar and a homeoplanar structure forms in the nematic layer, which allows light to pass through the structure. Crossed polarizers (1), linearly polarized light (2), substrates (3), elliptically polarized light (4), LC molecules (5), surface-active ions (6), glass substrate (7), polymer film rubbed in direction R (8), and ITO coating (9). Schema (a) should be added by R direction and angle 45 degrees at the bottom substrate as in Russian version.

the investigated LC cell. Without an electric field, the transmittance of the cell is close to zero and does not change upon azimuth rotation of the sample relative to the polarizers, which corresponds to the homeotropic orientation of the director. The situation remains invariable as the control voltage increases up to $U = 2.5$ V. When $U = 2.6$ V is attained, the variation in the transmittance of the LC cell is observed: it attains its maximum of 67% and then decreases to 29% by the time of the end of the electric pulse (Fig. 2a). This variation is explained by the transition of the director from the homeotropic orientation to the hybrid one due to the ionic modification of the surface anchoring. The presence of the threshold value of the control voltage is due to the existence of the critical density of absorbed CTA⁺ ions below which the orienting effect of the polymer surface is not blocked. An increase in the control field leads to gradual growth of the transmittance at the electric pulse finish to 64% at $U = 3.1$ V (Fig. 2b). However, with further increase in the voltage, T gradually drops to 50% (Fig. 2c). The physical mechanisms underlying the specific behavior of the curve $T(\tau)$ during the action of an electric pulse and after its switching off were described in detail in [7].

Figure 3 presents control-voltage dependences of the dynamic parameters of the optical response. Let us consider first delay τ_{del} determined as the time interval between the electric pulse switching on and the start of the variation in the LC cell transmittance (Fig. 2a). As the pulse amplitude grows from 2.6 to 3.3 V, delay time τ_{del} drops from 1.6 to 0.1 s. This correlation is explained by the diffusion character of the ion motion. The larger the field, the higher the velocity of the ion motion to the corresponding electrodes and, consequently, the smaller the time required for screening the effect of the applied electric field stabilizing the homeotropic orientation of the nematic.

In contrast to the voltage dependence of τ_{del} , the dependence of the on time τ_{on} determined as the interval between the electric pulse start and the start of transmittance saturation (Fig. 2c) is nonmonotonic (Fig. 3). It can be seen that τ_{on} rapidly decreases from 4.8 to 0.8 s in the control voltage range 2.6–2.8 V. This drop of τ_{on} is caused by the acceleration of the modification of the surface anchoring on the substrate with the anode. However, at $U = 2.9$ V, the value of τ_{on} jumps from 0.8 to 3.4 s and then the on time smoothly decreases again to 2.1 s at $U = 3.3$ V. It should be noted that an analogous anomaly was observed earlier in the film of the polymer-encapsulated nematic LC controlled by the ionic surfactant method [11]. This gives us grounds to suggest that the investigated transformations of the orientational structure are driven by at least two physical mechanisms. At small voltages $U \leq 2.8$ V, ionic modification of the surface anchoring is dominant; at $U > 2.9$ V, a competing mechanism prevails, the nature of which requires special investigations.

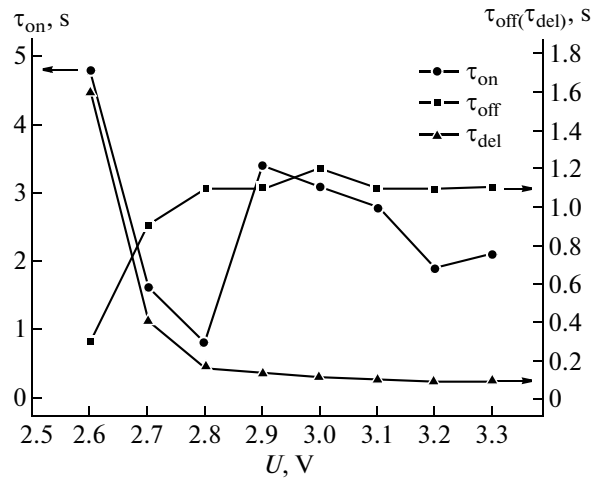


Fig. 3. Control voltage dependences of delay times τ_{del} , on times τ_{on} , and relaxation times τ_{off} of the LC cell.

Off time τ_{off} is determined as the interval between the end of the electric pulse and the transmittance relaxation to the initial zero level (Fig. 2c). In the range 2.6–2.8 V, τ_{off} grows from 0.3 to 1.1 s and then remains almost invariable up to 3.3 V. Such a behavior is typical of many relaxation processes occurring, in particular, in LC cells with the classical Fredericksz transition [12].

Thus, we analyzed oscillograms of the optical response of the LC cell controlled by the electric-field-induced ionic modification of the surface anchoring. The threshold value of the control voltage is 2.6 V; the maximum transmittance of 64% in the saturation mode is reached at $U = 3.1$ V. For the investigated cell, the minimum values of the dynamic parameters are noticeably higher than those for traditional LC devices: the optical response delay time is $\tau_{\text{del}} = 0.1$ s, the on time is $\tau_{\text{on}} = 0.8$ s, and the off time is $\tau_{\text{off}} = 1.1$ s. However, we do not exclude the possibility of significant improving of the operating speed by changing the material composition, control field parameters, and structural schemes of the implemented effect.

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REFERENCES

1. V. K. Fredericksz and V. Zolina, *Trans. Faraday Soc.* **29**, 919 (1933).
2. E. Dubois-Violette and P. G. De Gennes, *J. de Phys. Lett.* **36** (1975).

3. L. Komitov, B. Helgee, J. Felix, and A. Matharu, *Appl. Phys. Lett.* **86**, 023 502 (2005).
4. A. G. Petrov and G. Durand, *Liq. Cryst.* **17**, 543 (1994).
5. V. Ya. Zyryanov, M. N. Krakhalev, O. O. Prishchepa, and A. V. Shabanov, *JETP Lett.* **86**, 383 (2007).
6. V. Ya. Zyryanov, M. N. Krakhalev, and O. O. Prishchepa, *Mol. Cryst. Liq. Cryst.* **489**, 273 (2008).
7. V. S. Sutormin, M. N. Krakhalev, O. O. Prishchepa, and V. Ya. Zyryanov, *JETP Lett.* **96**, 511 (2012).
8. J. Cognard, *Alignment of Nematic Liquid Crystals and Their Mixtures* (Gordon and Breach Science Publishers, London, New York, Paris, 1982).
9. V. Ya. Zyryanov, M. N. Krakhalev, O. O. Prishchepa, and A. V. Shabanov, *JETP Lett.* **88**, 597 (2008).
10. M. N. Krakhalev, O. O. Prishchepa, and V. Ya. Zyryanov, *Mol. Cryst. Liq. Cryst.* **512**, 152 (2009).
11. M. N. Krakhalev, V. A. Loiko, and V. Ya. Zyryanov, *Tech. Phys. Lett.* **37**, 34 (2011).
12. L. M. Blinov, *Structure and Properties of Liquid Crystals* (Springer, Dordrecht, Heidelberg, London, New York, 2011).

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