

# Transformation of Cholesteric Orientational Structures and Optical Textures Induced by the Electric Field–Driven Ionic Modification of Surface Anchoring

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**Abstract**—The reorientation of a cholesteric liquid crystal with a large helical pitch induced by the electric field–driven modification of surface anchoring is investigated. In the initial state, the liquid crystal cell has a homeotropic alignment of the director. An applied dc electric field produced a twisted homeoplanar structure of the cholesteric.

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## INTRODUCTION

Cholesteric liquid crystals (CLCs) exhibit specific optical properties caused by the helical ordering of the director [1]. This means CLCs can be used in different devices, including displays, optical modulators, controlled diffraction gratings, and liquid-crystal lasers. The operation of these devices is based on variations in the orientational structure of the cholesteric. This is normally a direct effect of an electric field on the bulk of a liquid crystal (LC). During reorientation of the director in the bulk of a cell, the conditions for LC anchoring at the interface remain invariable.

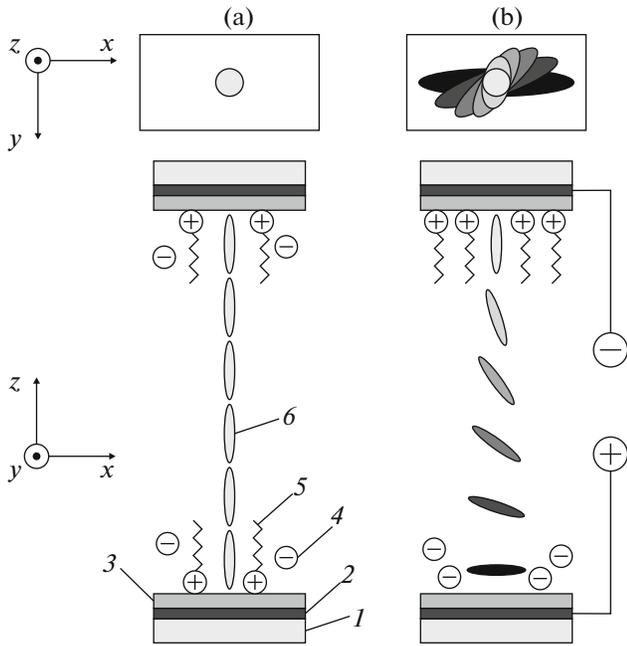
However, an LC can also be reoriented by changes in surface anchoring as a result of such external factors as temperature, ultraviolet radiation, or an electric field [2–4]. Studies of director reorientation induced by the modification of surface anchoring are of interest to both fundamental research and application, since it allows to realize the orientational structural transitions in an LC that cannot occur owing to the Frederiks effect. We have developed a technique for the electric field–driven modification of LC surface anchoring with ion surfactants, which was used earlier to control the orientational structure of nematics in droplets [5] and layers [6]. The aim of this work was to extend our LC orientation control technique to cells filled with a cholesteric having a large helical pitch.

## EXPERIMENTAL

Our objects of study were flat LC cells consisting of two glass substrates with transparent indium tin oxide (ITO) electrodes on their inner sides and a cholesteric

LC layer between them. The aligning coating was formed via the preliminary deposition of polyvinyl alcohol (PVA) films plasticized by a glycerin compound (GI) in a weight ratio of PVA : GI = 1 : 0.383 onto the electrodes. The polymer films were deposited by spin coating and the easy orientation axis was specified through mechanical rubbing of the polymer surface. Spacing width  $d$  in a cell was ensured using teflon spacers and measured on a spectrometer by means of interference technique. The CLC used was 4-*n*-pentyl-4'-cyanobiphenyl (5CB) nematic doped with a chiral additive cholesteryl acetate in weight ratios of 1 : 0.0030 to 1 : 0.0155. The nematic was preliminarily added with cation surfactant cetyltrimethylammonium bromide (CTAB) in the weight ratio 5CB : CTAB = 1 : 0.002. When dissolved in an LC, CTAB dissociates into positively charged surface-active CTA<sup>+</sup> ions and negative Br<sup>−</sup> ions. In the mixtures we used, cholesteric pitch  $p$  varied from 10 to 51  $\mu\text{m}$ , and the  $d/p$  ratio was from 0.16 to 0.85. The LC cell samples were experimentally investigated using polarization microscopy and electro-optical measurements.

Figure 1 shows a schematic of the orientational structural transition in an LC cell based on the cholesteric doped with the ion surfactant in an applied dc electric field. As a result of the adsorption of surface-active cations in the LC, they formed layers on the upper and lower cell substrates at a certain concentration. This screened the planar-aligning influence of the polymer coatings and ensured normal (homeotropic) anchoring conditions for the LC. The formation of a uniform homeotropic or twisted structure in



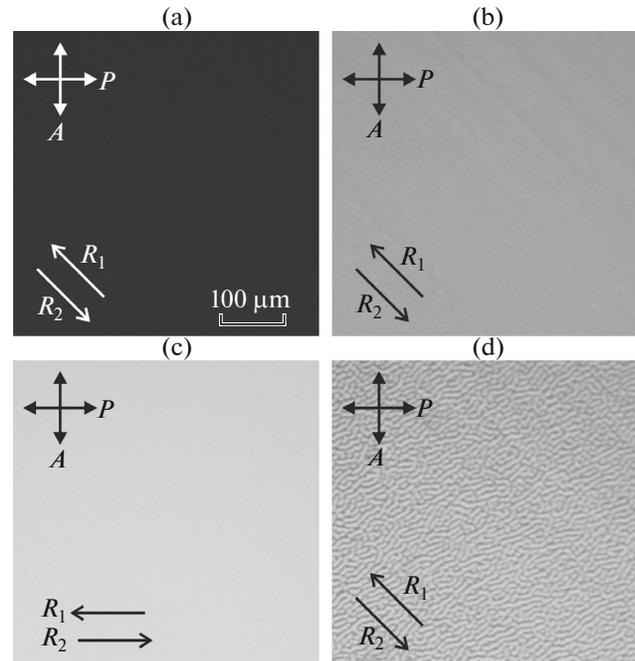
**Fig. 1.** Schematic of the orientational structural transition induced by a dc electric field in an LC cell filled with a cholesteric added with the ion surfactant. Glass substrate 1, ITO 2, polymer film 3,  $\text{Br}^-$  ions 4,  $\text{CTA}^+$  ions 5, and LC 6. (a) A homeotropically aligned LC layer in a zero electric field and (b) a hybrid-aligned cholesteric layer formed by changing homeotropic surface anchoring to planar anchoring on a substrate with an anode. The director configuration in the LC cell is shown in the  $xy$  plane (upper row) and the  $xz$  plane (lower row).

a cholesteric layer with rigid normal anchoring conditions depends on the  $d/p$  ratio between the LC layer thickness and cholesteric pitch. The threshold value  $(d/p)_{\text{thresh}}$  of a transition is determined as [7]

$$(d/p)_{\text{thresh}} = K_{33}/(2K_{22}), \quad (1)$$

where  $K_{33}$  and  $K_{22}$  are the elastic moduli of the bend and twist deformations, respectively. At  $d/p < (d/p)_{\text{thresh}}$ , the cholesteric helix in an LC cell with rigid normal anchoring conditions is completely untwisted, and a twisted orientational structure forms at  $d/p > (d/p)_{\text{thresh}}$ . In typical materials, threshold value  $(d/p)_{\text{thresh}}$  is around unity [8]. In the LC cell samples under study, we had  $d/p < 1$ , so the cholesteric helix in the initial state was completely untwisted (Fig. 1a).

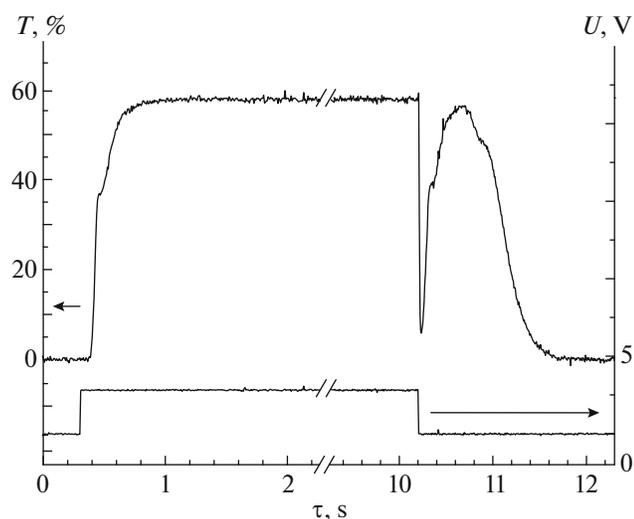
In an applied dc electric field, ions moved toward the corresponding electrodes and the concentration of surface-active cations on the substrate with the anode fell. As a result, the planar anchoring conditions typical of the aligning coating were restored on this substrate and the LC cell transformed to the twisted hybrid (homeoplanar) director configuration (Fig. 1b). This orientational structural transition changed the optical texture of the LC cell located between crossed polarizers (Fig. 2). The  $d/p$  ratio in



**Fig. 2.** Photographs of the optical textures of a cholesteric layer doped with ion surfactant at different control voltages  $U$  and angles  $\alpha$  between the directions of rubbing the lower substrate ( $R_1$ ) and polarizer ( $P$ ): (a)  $U = 0$  V and  $\alpha = 45^\circ$ , (b)  $U = 2.8$  V and  $\alpha = 45^\circ$ , (c)  $U = 2.8$  V and  $\alpha = 0^\circ$ , and (d)  $U = 3.7$  V and  $\alpha = 45^\circ$ . The LC layer was  $8.1 \mu\text{m}$  thick. The cholesteric pitch was  $21 \mu\text{m}$ .  $A$  and  $R_2$  are the directions of the analyzer and upper substrate rubbing, respectively.

this cell was 0.4. In a zero external electric field, the optical texture of the LC layer in crossed polarizers was a uniformly dark area (Fig. 2a) regardless of the angle of sample rotation on the microscopic stage, indicating there was homeotropic director alignment in the cell (Fig. 1a). This optical texture remained up to a dc voltage of  $U = 2.3$  V, at which the optical transmittance started to grow. At control voltages  $2.3 \text{ V} \leq U \leq 3.4 \text{ V}$ , the optical texture of the cell was a uniformly bright area (Fig. 2b), and rotating the sample on the microscopic stage with respect to the crossed polarizers did not reveal a dark optical texture. This was demonstrated by the optical textures shown in Figs. 2b and 2c, where angles  $\alpha$  between the direction of rubbing and polarizer were  $45^\circ$  and  $0^\circ$ , respectively. This indicates a twisted director configuration in the cell (Fig. 1b). In addition, when  $\alpha = 0^\circ$  (Fig. 2c), rotation of the analyzer did not reveal a dark optical texture. This means the light passing through the layer of the hybrid-aligned cholesteric was no longer linearly polarized. When  $U = 3.5$  V, domains began to form in the LC cell; these are clearly seen in Fig. 2d at  $U = 3.7$  V.

Similar changes in optical texture at approximately the same control voltages were observed in the LC cells with  $d/p = 0.16$  and  $0.85$ . It should be noted that the observed changes in the optical texture could not



**Fig. 3.** Oscilloscope of the electro-optical response of an LC cell filled with a cholesteric added with the ion surfactant in crossed polarizers. The direction of substrate rubbing coincides with that of the polarizer. The electric pulse amplitude was 2.8 V. The  $d/p$  ratio between the LC layer thickness and cholesteric pitch was 0.4.

have been due to the Frederiks effect, since we used an LC with the positive dielectric anisotropy in the experiment. The Frederiks effect could in this case only stabilize the initial homeotropic director configuration.

Figure 3 shows an oscilloscope of the LC cell's optical response to a rectangular electric pulse with an amplitude of 2.8 V and a duration of 10 s. The LC cell was in this case placed between crossed polarizers so that the direction of substrate rubbing coincided with the polarization of the incident light ( $\alpha = 0^\circ$ ). The optical transmittance was determined as  $T = I_t/I_0$ , where  $I_0$  is the intensity of the radiation passing through the first polarizer and  $I_t$  is the intensity of the radiation passing through the second polarizer. In the initial state, the optical transmittance of the system is almost zero, due to the homeotropic alignment of the director. When an electric pulse was applied, the optical transmittance of the system grew, due to the formation of the hybrid-aligned cholesteric structure in the LC cell, and the saturated optical transmittance reached 59%. Switching-on time  $\tau_{on}$ , defined as the interval between the start of the electric pulse and reaching an optical transmittance of 90% of the saturated value, was 0.3 s. Switching-off time  $\tau_{off}$ , defined as the interval between the end of the electric pulse and a drop in optical transmittance to 10% of the sat-

urated value, was 1.21 s. At control voltages  $2.6 \text{ V} \leq U \leq 3.2 \text{ V}$ , switching-on time  $\tau_{on}$  was virtually invariable, and switching-off time  $\tau_{off}$  grew from 0.51 to 1.75 s. When  $\alpha = 45^\circ$ ,  $\tau_{on}$  was around 0.13 s, and  $\tau_{off}$  grew from 0.59 to 1.75 s.

## CONCLUSIONS

An orientational structural transition in a cholesteric liquid crystal layer with a large helical pitch, induced by the electric field-driven ionic modification of surface anchoring, was described for the first time. It was shown that applying a dc electric field results in a transition from a homeotropic director configuration to a twisted hybrid structure in LC cells. The reorientation process has a threshold character and, in a certain range of control voltages, occurs without electrohydrodynamic instabilities. The switching-on time for the investigated LC cells was tenths of second, while the switching-off time was around one second.

## ACKNOWLEDGMENTS

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