

Light-Controlled Alignment of Cholesteric Liquid Crystals on Photosensitive Materials

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We report on investigation of photoalignment of cholesteric liquid crystal on phenylone-based photosensitive material as aligning layer. We found that reflective and electro-optical characteristics of cholesteric cells strongly depended on the dose of irradiation of a photoaligning layer with polarized UV light. Irradiation resulted in orientation of initially chaotically oriented planar domains in a direction determined with incident UV-light polarization and in narrowing of the dependence of light scattering by a planar structure on the scattering angle. The long enough exposure resulted in scattering and electro-optical characteristics not worse than obtained with standard rubbing technology. The photosensitive orientant possesses evident advantages of the effective control of cholesteric textures.

Keywords: cholesteric liquid crystals; electro-optical switching; photoalignment

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1. INTRODUCTION

Uniform orientation and reproducible pretilt of the liquid crystal (LC) director on aligning surfaces are required for application and operation of LC. Mechanical rubbing of the aligning polymer surfaces is one of the traditional methods of LCs alignment [1]. Last decade, Gibbon *et al.*, Reznikov *et al.*, and Schadt *et al.* proposed alternative, photoaligning technique [2–5]. This technique uses polarized light to induce anisotropy in a photosensitive aligning layer. The light-induced anisotropy of the irradiated layer causes appearance of the easy orientation axis \vec{e} of LC director on a photosensitive surface.

The majority of studies of photoalignment of LCs and development of photoalignment technology for mass production were concentrated on alignment of nematic LCs. As concerns other LC phases, studies of photoalignment of smectics was started just recently [6] and to our knowledge, there were no systematic studies of photoalignment of cholesteric LC (ChLC) carried out till now. At the same time, application of photoalignment technology to ChLC looks extremely promising since a possibility to control the direction of the easy axis and the anchoring energy on the surface allows, in turn, controlling scattering and electro-optical characteristics of the cholesteric textures. Here we report first investigation of photoalignment of commercial cholesteric mixtures on photosensitive polymer materials.

2. EXPERIMENTS AND DISCUSSION

We investigated photoalignment of cholesteric liquid crystal mixture BL-118 (clear point $T_c = 84^\circ\text{C}$) from Merck on several photoaligning materials (fluorinated polyvinyl-cinnamate, cellulose-cinnamate and phenylone-based polymer). The polymer solution in appropriate solvent was spin-coated on a glass substrate to produce polymer films. In particular, the phenylone-based polymer was dissolved in dimethylephormamide (weight concentration was 15 g/l), and the solution was spin-coated on a glass substrate covered with ITO at 7000 rpm speed. After spin-coating, films were cured at 120°C for 1.5 hour to remove the solvent and improve the mechanical properties of the films. The obtained films were uniform and isotropic. The aligning films of fluorinated polyvinyl-cinnamate and cellulose-cinnamate were produced analogously.

To induce anisotropy photosensitive films were exposed with linearly polarized UV light from a *Hg*-lamp at normal incidence to the film surface. A water filter was applied to cut the IR-part of the lamp irradiation. The intensity of UV I_{UV} in the plane of the polymer film was 110 mW/cm^2 .

The alignment of the cholesteric liquid crystal was tested in the parallel combined cells consisted of a reference and a tested surfaces and ChLC in between. The reference surface was coated with rubbed polyimide layer. The tested surface was covered with the studied polymer film and irradiated with different UV exposure dose. Calibrated polymer spacers set the cell thickness at $L = 5.5 \mu\text{m}$. The cell was filled at 85°C and slowly cooled down to a room temperature.

The quality of the alignment, depending on the exposure dose, was characterized by measuring the dependence of the intensity of scattering I_{scat} of the polarized beam of a YAG-laser ($\lambda = 532 \text{ nm}$) from the tested cell on the scattering angle θ (Fig. 1). For measurements the cell faced by a tested surface was set perpendicular to the laser beam, and the photodiode was rotated by a step-motor around the cell with a radius 30 cm. To prevent a parasite scattering and reflection the back reference substrate was covered by a black tape, and a lock-in modulation technique was used to collect the data.

Qualitative observations of the cholesteric structures in polarized microscope shown that irradiation of the polymer with UV light resulted in orientation of initially chaotically planar-oriented domains in a direction determined with the incident UV light polarization. Increase of the exposure results in improvement of the domain ordering. For phenylone-based polymer the irradiation with the exposure $t_{\text{exp}} > 20 \text{ min}$ resulted in a high-quality mirror reflection in a green part of visible spectrum. Irradiation of the other studied polymers brought similar results but the quality of the photoalignment was

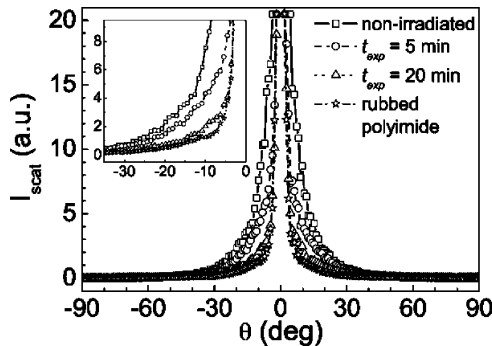


FIGURE 1 Dependence of the intensity of scattering I_{scat} from the planar cholesteric texture on the scattering angle θ at irradiation of phenylone-based polymer surface with different exposure times t_{exp} . 0° -angle corresponds to the scattering being normal to the cell. The experimental points around 0° -angle are not showed because of a large scale of the plot.

not so impressive. Therefore, below we focus attention on the results obtained for phenylone-based material.

For quantitative characterization of photoalignment on phenylone-based surface we introduced *angular selectivity* of the planar texture determined as a width of the angular distribution I_{scat} (Fig. 1) at 1/40 of the distribution maximum. The dependence of the angular selectivity of the planar photoaligned cholesteric structure on the exposure is depicted in Figure 2.

The data for standard rubbed polyimide cell are also presented in the figure. One can see that increase of the exposure time t_{exp} , that is equivalent to increase of the irradiation dose $D = It$, results in an essential contraction of the angular selectivity approaching to one of the texture on the rubbed polyimide surface at $t_{\text{exp}} > 20$ min.

The quality of the alignment of the planar ChCL cell is mainly determined with an angular distribution of LC director on the aligning surface. It is reasonable to suggest that orientation ability of a ChLC mixture consisted of a nematic matrix and a chiral dopant is close to the orientation ability of nematic matrix. Therefore, we investigated alignment of nematic LC, which was a matrix of ChLC BL-118, on UV-exposed phenylone-based polymer surface, non-irradiated polymer surface, and rubbed polyimide surface. The experiments were performed with light transmission polarimetry method, which is based on analysis of the polarization characteristics of light passed through the cell.

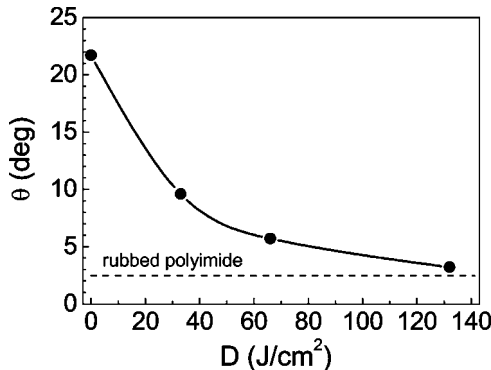


FIGURE 2 The angular selectivity θ dependence of cholesteric texture aligned with phenylone-based polymer surface on the UV light irradiation dose D . Dashed line — angular selectivity of the cholesteric planar structure aligned with rubbed polyimide surface. The planar texture angular selectivity was determined as a width of the angular distribution I_{scat} (Fig. 1) at 1/40 of the distribution maximum.

The experimental set-up consisted of consecutive elements: He-Ne laser ($\lambda = 633 \text{ nm}$), polarizer, collimating lenses, tested liquid crystal cell, quarter-wave plate, analyzer, zooming lens, CCD camera, and a computer. Linear polarized laser beam passed through the tested planar symmetrical cell, which both substrates were covered with the same aligning layers, (cell thickness $\sim 50 \mu\text{m}$). The polarization vector was set parallel to the director on the aligning surfaces. The light passed through the cell was detected with CCD camera and digitized at different orientation of polarizers and quarter-wave plate. Measurements of the Stokes parameters S_i [7,8] of the transmitted light in each pixel of the CCD camera finally allowed obtaining a spatial distribution of orientation of a big axis of elliptically polarized transmitted light, and an ellipticity:

$$\psi = 0.5 \arctan\left(\frac{S_2}{S_0}\right),$$

$$\frac{b}{a} = \tan\left(0.5 \cdot \arcsin\left(\frac{S_3}{S_0}\right)\right),$$

where ψ is the azimuth angle between the big axis of the polarization ellipse of transmitted light and polarization vector of incident light, b – small axis of polarization ellipse, and a – big axis of polarization ellipse.

By this way we obtained a “map” of polarization state of the light after the cell. The spatial resolution of the map, $4 \mu\text{m}$, was determined by a CCD resolution and the software. The accuracy of the measurements of azimuth angle ψ was 0.7° , and the ellipticity b/a was determined with the accuracy 0.008).

Spatial distribution of the azimuth angle and ellipticity of light polarization are showed on Figure 3. Standard deviation σ of polarization parameters of transmitted light from the mean values $\psi(d)$ and $b/a(d)$ characterizes a quality of the LC orientation on the studied surfaces.

The values $\sigma_{ph}^\psi = 0.047$, $\sigma_{ph}^{b/a} = 0.1$ were obtained for non-irradiated phenylone-based material, and $\sigma_{ph,UV}^\psi = 0.017$, $\sigma_{ph,UV}^{b/a} = 0.011$ we determined for UV-irradiated phenylone-based polymer. For comparison, the rubbed polyimide surface gave the values $\sigma_{PI}^\psi = 0.014$, $\sigma_{PI}^{b/a} = 0.022$. One can see that the spatial standard deviation for non-irradiated surface is much bigger than for UV-irradiated surface, which standard deviation value approaches to one of rubbed polyimide surface.

To clear up an affect of photoalignment on the electro-optical switching of the ChLC cell we studied the dependencies of planar-homeotropic transition of cholesteric mixture on the exposure time. Ac-voltage (50 Hz) of different values U was applied to the planar cell during 1 s. After 3 s the voltage was switched off and the reflection

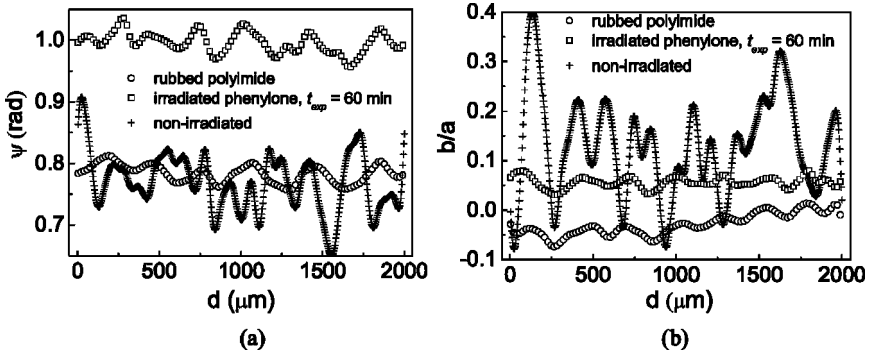


FIGURE 3 Spatial dependences of azimuth angle ψ (a) and ellipticity b/a (b) of light transmitted through symmetrical planar cell filled with nematic matrix of BL-118. Aligning layers of the cells were rubbed polyimide (\circ), irradiated (\square) and non-irradiated ($+$) phenylone-based polymer. d – location in the laser spot.

intensity I_{ref} was measured. Application of 45 V for 1 s recovers the initial planar structure of ChLC cell and the next measurement cycle could be carried out. We found that at $t_{\text{exp}} > 10$ min the transitions virtually did not differ from the characteristics of the rubbed-aligned planar structures. Shorter exposure times resulted in decrease of the textures' reflectivity but the driving voltages characteristics of planar – focal-conic – homeotropic texture transition remained constant (Fig. 4).

We found that irradiation of phenylone-based layer with unpolarized UV light also influenced on characteristics of cholesteric textures.

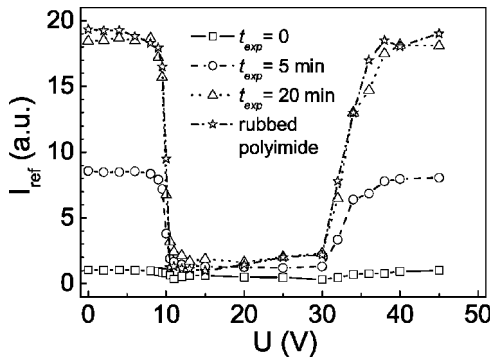


FIGURE 4 Dependencies of the intensity of the light reflection I_{ref} from the cholesteric structure aligned with phenylone-based polymer surface on applied voltage U .

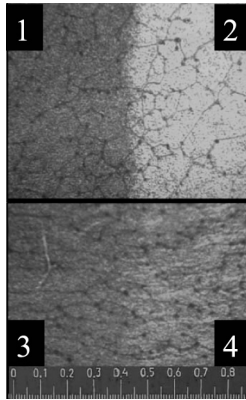


FIGURE 5 Planar cholesteric textures on phenylone-based polymer aligning surface: (1) – non-irradiated area; (2) – area irradiated with polarized light, $t_{\text{exp}} = 30$ min, $I_{UV} = 110 \text{ mW/cm}^2$; (3) – non-irradiated area; (4) – irradiated with unpolarized light area, $t_{\text{exp}} = 30$ min, $I_{UV} = 110 \text{ mW/cm}^2$. Width of the photos is 0.9 mm.

The polarizing microscopy images of planar textures of ChLC cell, which different areas of aligning layer were non-irradiated and irradiated with polarized and unpolarized light during $t_{\text{exp}} = 30$ min at $I_{UV} = 110 \text{ mW/cm}^2$, are presented in Figure 5. One can see that the area irradiated with unpolarized light looks brighter than non-irradiated area and polarization of UV irradiation improves the reflectivity of the textures drastically.

The characteristics of the light scattering from the non-irradiated textures and textures produced by irradiation with polarized and unpolarized UV light are presented in Figure 6. One can see that

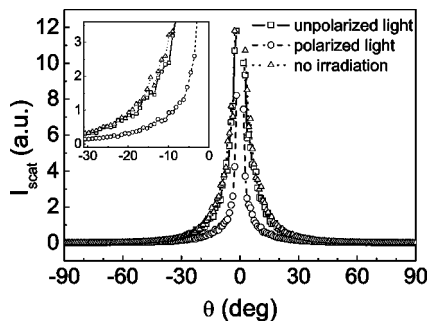


FIGURE 6 Dependencies of light scattering intensity I_{scat} from the cholesteric texture aligned with phenylone-based polymer surface on the scattering angle θ .

the angle dependencies of reflection for non-irradiated surface and for the surface irradiated with unpolarized light are virtually the same at the reflection angle $\theta > \pm 2^\circ$, and the angle range of the reflection are much wider than for polarized irradiation in both cases. At the same time, the scattering at the small angles $-2^\circ < \theta < 2^\circ$ are different for unpolarized irradiation and “no”-irradiation cases. For instance, at $\theta = 1.5^\circ$ the ratio of the scattering intensity for different treatment $I_1:I_2:I_3 = 1:1.8:122$ (where $I_1; I_2; I_3$ are the scattering intensity in the case of “no”-irradiation, irradiation with unpolarized light and irradiation with polarized light, correspondingly).

Angle dependence of scattering in a planar texture of ChLC is determined mostly by the angular dependence of the axes of cholesteric spirals in domains and by the size distribution of cholesteric domains. We did not find essential changes in the domains sizes on the polymer surface after irradiation. Therefore, the difference in the scattering is determined mostly by the difference in the angular distribution of the orientation of the cholesteric spirals. Decrease of the pretilt angle of the director on the polymer surface after irradiation might cause the observed constriction of the angular dependence of scattering, but the pretilt angle of the nematic component of cholesteric mixture was found to be zero for both surfaces. We believe that the difference in angular scattering dependence is caused by changes in efficiency of adsorption of LC molecules after irradiation of the polymer surface. It is a layer of adsorbed LC molecules that plays a role of the aligning layer stabilizing the distribution of cholesteric spirals in a LC cell. Irradiation of the polymer is supposed to encourage a formation of this adsorbed layer, which promotes a planar alignment of the director. It should result in increase of the anchoring energy of ChLC that, in turn, encourages planar orientation of the spirals and constriction of the angular scattering dependence.

Obtained results showed that photoalignment technology can be successfully applied to align cholesteric liquid crystals. Strong dependence of the width of the angular selectivity of the planar textures on the exposure dose allows controlling the reflectivity of the cholesteric cells effectively. Low-temperature photoalignment process makes this technology very promising for plastic LCD applications.

3. CONCLUSIONS

Our results showed that photoalignment technology can be successfully applied to align cholesteric liquid crystals. Reflective and electro-optical characteristics of cholesteric cells strongly depended on UV exposure dose that allowed controlling the cholesteric cells reflectivity

effectively. The optimized UV polymer treatment allowed obtaining the same quality of alignment as the one provided by standard polyimide orientants. At the same time, the photosensitive orientant possesses evident advantage of the effective control of cholesteric textures. Low-temperature photoalignment process makes it very promising for plastic LCD applications. A possibility of fabrication of multi-domain cholesteric structures revealing improved scattering characteristics was demonstrated.

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