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Influence of Electric Field and Light on an Easy Axis of NLC Confined by Rectangular Channel at Weak Surface Anchoring

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S 3-4. Influence of Electric Field and Light on an Easy Axis of NLC Confined by Rectangular Channel at Weak Surface Anchoring

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Abstract: We present new experimental results on combined action of light and electric field on a nematic liquid crystal in a rectangular channel at a weak surface anchoring. The first experimental study of slow surface dynamics at combined action of electric field and polarized light in new experimental geometry was performed. Influence of polarized light on spatial twist-like deformation of a director field induced by electric field was established.

Key Words: Electric field, combined action, 3D geometry.

1 Introduction

Last decade a lot of attention was devoted to photo alignment (PA) technique due to it's perspectives for display applications [1,2]. In spite of well known advantages of such surface treatments physical processes in films of monomer or polymer photosensitive dyes resulting in overall surface orientation of liquid crystals (described in terms of an "easy axis $\mathbf{n_e}$) seem to be rather complicated and not adequately understood up to now. In particular, a specific slow rotation of an easy axis under the action of strong "in-plane" electric fields was observed experimentally [3]. A number of physical mechanisms were proposed to explain such "gliding" phenomena [4,5] but molecular nature is still under consideration. Slow surface dynamics can be of a practical importance as it defines a long term stability of liquid crystal devices. Recently [7] we established that additional action of polarized light after filling liquid crystal cells resulted in an essential intensification of electrically induced gliding which makes possible to observe such phenomena at moderate strength of electric field characteristic for operation modes of LC devices. It makes rather actual the detailed study of slow surface dynamics of liquid crystals under combined action of light and electric field. In this paper we report the first results of experimental investigations of such kind performed in new experimental geometry proposed by us previously [6]. It provides a registration of slight azimuth rotation of a director, which can be connected with an easy axis rotation. Moreover a spatial 3D distribution of the director inside LC layer can be provided in this case, which is important for better understanding of complicated phenomena under consideration.

2 Experimental

2.1 LC cell

We used LC cell construction with rectangular cannel and fixed layer thickness (b = 60 μm, d = 270 μm) similar to that described previously [8]. Two opposite surfaces of glass plates along Z direction were treated to provide a planar orientation at angles equal to 45° (on the first plate) and to zero (on the second plate) respectively to Z axis. So the initial twist geometry corresponds to that considered in the theoretical part of [8]. The first surface normal to X direction was spin-coated by the azo-dye (SD-1) and treated in a special way by UV of different dose (D_0) to obtain zones with different azimuthal anchoring strength. The opposite surface was treated by rubbing to obtain strong surface anchoring. The upper and bottom plates normal to Z direction were coated by thin layers of chromolan to produced strong homeotropic surface anchoring needed to avoid possible disclination lines. The channel was filled with a nematic 4-pentyl-4'-cyanobyphenil (5CB, Merck production) with a high positive value of Δε. Electric voltage U of a frequency f = 3 kHz was applied to avoid possible hydrodynamic instabilities.

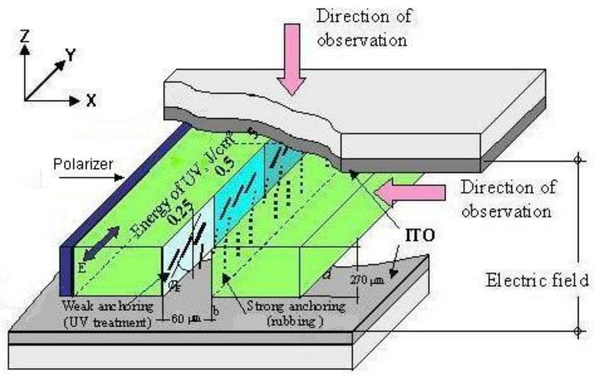

Figure 1 General scheme of LC cell

2.2 Experimental set-up

In the comparison with our previous work [8] we additionally used 1W light emitting diode (Luxeon Star/O, LXHL-NWE8) to realize combined action of light and electric field on the weakly anchoring surface (figure 2,3). The directional diagram of LED (figure 4) is rather narrow to consider light beam as a quasi parallel one. The spectrum of this light source (figure 5) shows a sharp maximum at λ = 440 nm which can be responsible for effects under consideration. It differs from the continuous spectrum of microscopic halogen lamp used in the first experiments [7] where combined action of light and electric field was detected. Both the standard microscopic illumination by halogen lamp and the special illumination by a He - Ne laser beam was used to extract more detailed information about orientational structure of LC inside the channel.

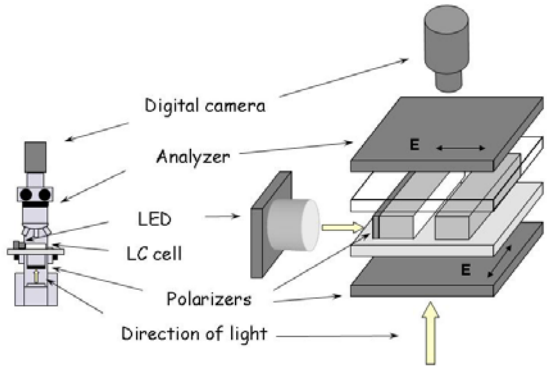

Figure 2 Experimental set-up for microscopic observations

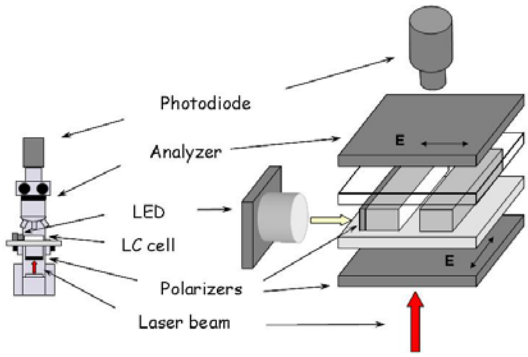

Figure 3 Experimental set-up for measurements of laser light intensity changes

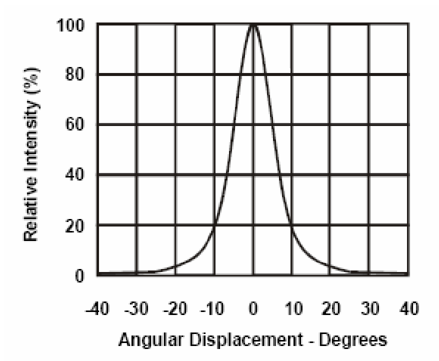

Figure 4 LED directional diagram

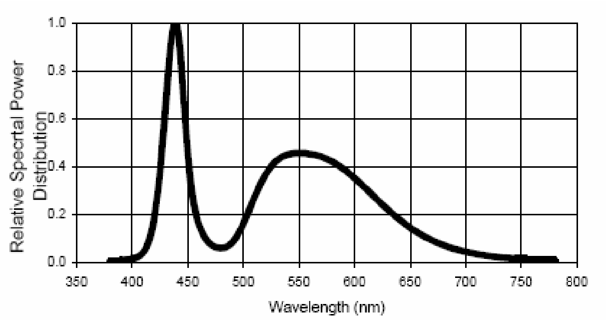

Figure 5 Spectrum of LED

3 Results and discussion

Obtained microscopic images in X direction (see figure 6) are in accordance with a twist structure of our new geometry.

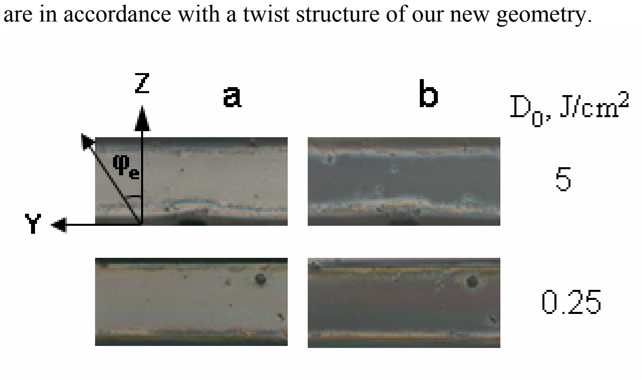

Figure 6 Microscopic images of the gap in X direction at different zones of UV dose: a) polarizers are crossed; b) parallel polarizers;

The examples of snapshots of the gap, obtained at observation in Z direction in absence of electric field and light (initial state), at turning on and off electric field without light and at the same procedure in the presence of additional light of intensity I_2 are shown in figure 7.

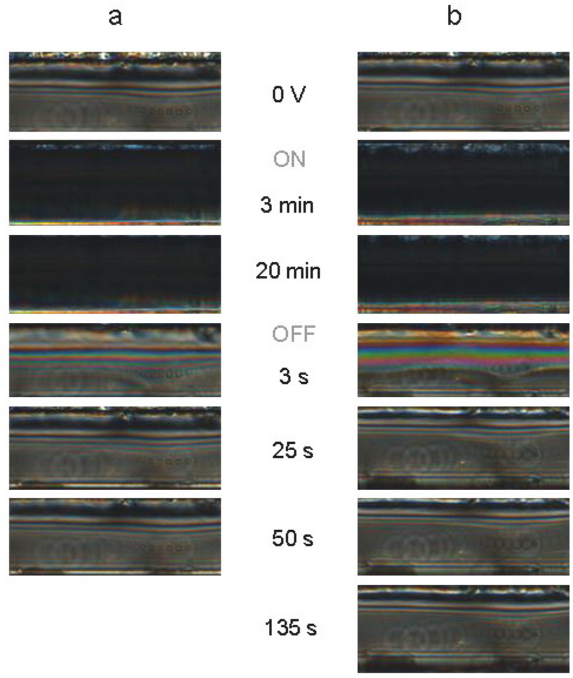

Figure 7 Microscopic images of the gap in Z direction before applying voltage, switching on and switching off the electric field, U = 300V, t_{exp} = 20 min D_0 = 0.25 J/cm^2: a) without light; b) combined action.

At the initial state one can see the dark stripe (no birefringence) near the surface with strong planar anchoring corresponding to the orientation of a director along Z axis stabilized both by surfaces with strong planar orientation and by surfaces with a homeotropic orientation. A number of interference stripes arising at approaching to the opposite surface with a weak planar anchoring is connected with a rotation of a director resulting in birefringence for this direction of observation.

After turning on electric field of high enough strength the orientation becomes close to Z direction practically inside all parts of a gap and so it looks as a dark stripe.

The most interesting effects were observed after turning off electric field (or electric field and light). In this case one can see the difference between spatial distribution of a light intensity inside the gap obtained without preliminary additional action of light and with combined preliminary action of electric field and light. This difference exists both for a stage of a relatively quick relaxation (with a characteristic time $\tau = (\gamma_1 b^2/K_{22})$ ~80s) and for a stage of slower process presumably connected with a reversal gliding of an easy axis. Previously [7] we observed a slowing down of this process at combined action of electric field and light. The time dependences of intensity of laser light presented in figure 8,9 confirm the existence of slow surface relaxation slowed by the additional action of light at presented experimental conditions.

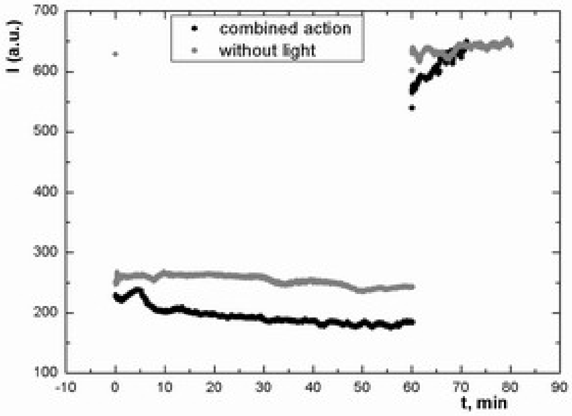

Figure 8 Time dependence of light intensity before applying voltage, switching on, switching off the electric field U = 200V t_{exp}= 60 min, D_0 = 0.5 J/cm^2 with combined action and without light

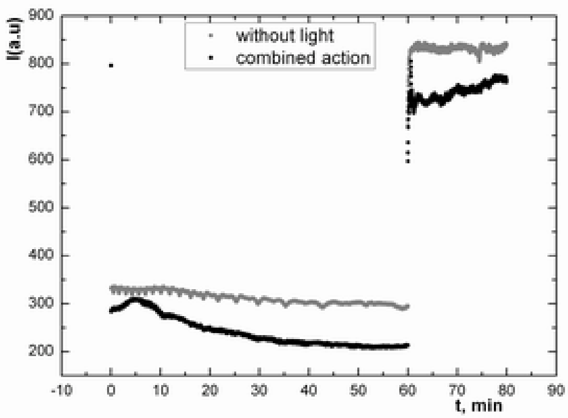

Figure 9 Time dependence of light intensity before applying voltage, switching on, switching off the electric field U = 200V t_{exp} = 60 min D_0 = 0.25 J/cm^2 with combined action and without light

We didn't find influence of light on the layer of NLC in the absence of electric field (see figure 12).

We also established that the change of dose D_0 of preliminary UV treatment can modify the distribution of light intensity inside the gap. It takes place both in the absence and in the presence of electric field (see figure 10) and can be attributed to the influence of weak anchoring effects.

So we hope that the high sensitivity of the optical picture to small azimuthal angle variations characteristic for new geometry will make possible to propose new ways to extract information about azimuthal anchoring strength and Frank's module K_{22}.

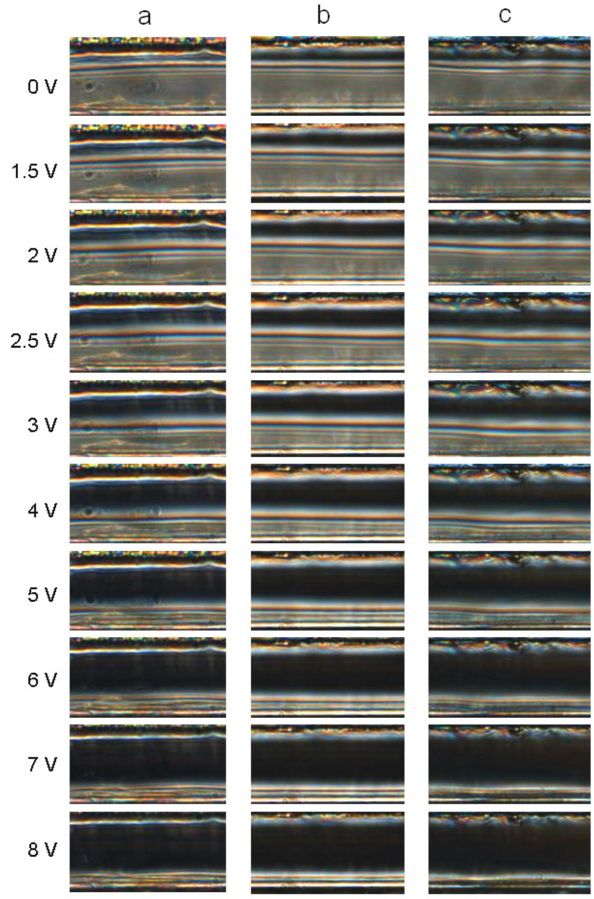

Figure 10 Microscopic images of the gap in Z direction before and after turning on the electric field: a) D_0 = 5 J/cm^2, D_0 = 0.5 J/cm^2, D_0 = 0.25 J/cm^2.

Figure 11 describes the changes in a reorientation of a director under the action of electric field and correspondent light intensity variations I(t).

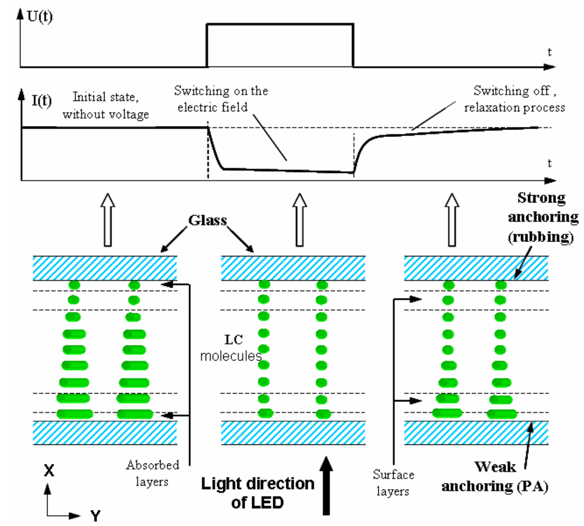

Figure 11 Distribution of director of NLC in the gap before, after switching on and switching off the electric field

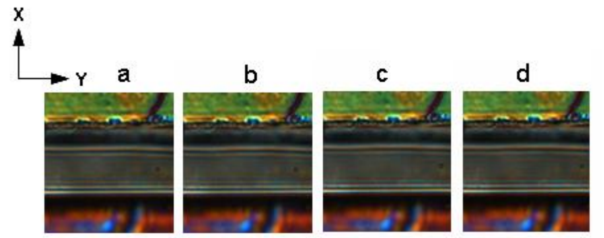

Figure 12 Microscopic images of a gap under the action of light of LED: a) before applying light; b) switching on- 1 min, c) switching on- 30 min; d) 3s after switching off light

We would like to focus in more details on slow surface dynamics at combined action of electric field and light, as this effect is quite new.

Previously [8] we have shown that the new geometry realized in experiments under consideration can be useful for a study of weak anchoring effects such as slow relaxation of an easy axis to the initial state after turning off electric field responsible for breaking of weak anchoring. Indeed, due to essential difference in characteristic time scales for bulk (fast) and surface (slow) dynamical processes it is possible to use stationary solutions of the problem with boundary conditions slowly varying with time. In this case after short period of fast relaxation the space distribution of a director described by the azimuthal angle $\varphi(x)$ will be slow changed with time accordingly to the reversal gliding of an easy axes from the stationary state induced by field to un pertrurbated by the initial boundary angle $\varphi_0(t)$. It is obvious that the same situation will take place in the case of combined action of electric field and light after turning off both factors. The difference between two cases mentioned above is completely described in terms of the boundary angle $\varphi_0(t)$ determined by a number of control parameters such as strength and duration of electric and light fields which produced gliding phenomena and by the anchoring strength of the surfaces [7]. So one can wait that the simplest stationary distribution of a director [8]:

$$\varphi(x) = C_1 x + C_2 \quad (1)$$

will be valid for slow gliding process too. In the latter case the parameters C_1 and C_2 determined by boundary conditions have to be considered as functions of time.

$$C_1 = -\varphi_0(t)/(b-\xi_s^{(2)}) \quad (2)$$

$$C_2 = [\varphi_0(t)/2][b/(b-\xi_s^{(2)})] \quad (3)$$

where

$$\xi_s^{(2)} = K_{22}/W^{(2)} \quad (4)$$

the characteristic length inversely proportional to the azimuth anchoring strength at weakly anchoring surface, K_{22}- the Frank's elastic module. The slow time variations of the angle $\varphi(x,t)$ will result in changes of the phase difference $\delta(x,t)$ between an ordinary and an extraordinary rays passing through the cell in Z direction:

$$\delta(x,t) \approx (2\pi d\Delta n/\lambda)\sin^2[\varphi(x,t)] \quad (5)$$

where Δn – the anisotropy of a refraction index.
So one has to observe (in Z direction) slow time variations of space distribution $I(x,t)$:

$$I(x,t) = I_0 \sin^2[\delta(x,t)/2] \quad (6)$$

which is in a qualitative agreement with experimental results presented above. Recently [7] we have shown that the simple exponential law:

$$\varphi_0(t) = A\exp(-t/\tau) \quad (7)$$

describes the final stage of gliding of an easy axes after turning off electric field and light. So the detailed analysis of time dependent images presented above makes it possible to extract the relaxation time τ which can be connected with complicated physical processes responsible for combined action of light and electric field on the boundary orientation of a liquid crystal. Such analysis is under progress now and the results will be reported elsewhere. In this paper we want to emphasize that the new geometry used in our investigations provides essentially higher sensitivity (in the comparison with the traditional geometry) to the small variations of the twist angles (including boundary angle $\varphi_0(t)$) which makes it perspective for further investigations of complicated surface phenomena mentioned above.

4 Conclusion

The first experimental study of slow surface dynamics at combined action of electric field and polarized light in new experimental geometry was performed. Influence of polarized light on spatial twist-like deformation of a director field induced by electric field was established. It was shown that the optical images, obtained in experiments could be connected with a boundary orientation of a liquid crystal. So such geometry turned out to be useful for detailed study of gliding phenomena. The practical importance of presented results is briefly discussed.

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