Alignment Peculiarities of Cholesteric Liquid Crystals on the Surfaces Processed by Plasma Beam

Ruslan Kravchuk, Oleg V. Yaroshchuk
Institute of Physics, NAS of Ukraine, Kyiv, Ukraine

Abstract
It is demonstrated that plasma beam alignment process allows one to combine uniformity of planar texture and stability of focal conic texture of cholesteric liquid crystals (CLC) and thus obtain highly contrast and truly bistable samples. It provides suitable anchoring conditions for ULH texture. It can also be readily applied for the alignment patterning that opens new prospects for CLC devices.

Author Keywords
liquid crystal alignment; ion beam alignment; plasma beam alignment; cholesteric liquid crystal; reflective display, ULH texture.

1. Introduction
Reflective cholesteric liquid crystal (CLC) displays have aroused great interest due to number of benefits such as high brightness, high contrast ratio at a wide viewing angle, image memory and low power consumption. These unique features are suitable for public information displays, mobile displays, signboards, e-papers and PDAs, characterized by ruggedness in handling and low cost.

Unlike the conventional LCDs containing nematic liquid crystals (LCs), the CLC based LCDs do not need polarizers and color filters. This is due to their unique working principle based on electric switching between planar (P) and focal conic (FC) texture of CLC, both of which are stable in a zero field. In the planar state, the helical axes of CLC are aligned normally to the substrates and the selected wavelength of incident light is reflected in accordance with Bragg law. In the focal conic state the helical axes of CLC are aligned randomly and the light is weakly scattered and absorbed by black background of the display cell. Therefore, display pixels with a CLC in the P texture look bright and in the FC texture look dark [1].

The alignment layer plays a crucial role in obtaining a higher quality CLC displays. The planar- aligning layers providing stable planar texture are most commonly used. To enhance reflectivity, which determines brightness of the display, the alignment layers are usually rubbed. This procedure reduces number of CLC domains separated by specific line defects – oily streaks. However, increasing the selectivity of reflection reduces the viewing angle. Besides, rubbing of alignment layers weakens stability of FC texture. On the other hand, non-rubbed layers for planar alignment provide stable FC texture and wide viewing angle, but insufficiently bright planar state due to big number of CLC domains. Thus, there is an urgent need for such an alignment process, which can combine the advantages of rubbed and non-rubbed aligning layers. In present study this is achieved by using plasma beam (PB) alignment technique earlier adopted for nematic [2,3] and ferroelectric [4] thermotropic LCs, reactive mesogens [5], and lyotropic chromonic LCs [6]. Good potential of this technique for alignment patterning and formation of uniform and stable ULH textures of CLC is also demonstrated.

2. Experimental part
Plasma Setup for Alignment Processing: The films were obliquely treated by the beam of Ar plasma from anode layer source using in-house made processing tool described in our previous papers [2,3]. The processing scheme is presented in Fig. 1a. The sheet-like beam of particles (Fig. 1b) was directed onto substrate at an angle $\alpha=65^o$ with respect to the normal to the substrate. During the exposure, the glass slides were periodically shifted back and forth with a speed ~ 2 cm/min, to ensure multiple exposures of the sample and to achieve a better homogeneity of surface treatment. The working pressure was $6\text{-}8*10^{-4}$ torr and the anode potential was 600 V that corresponded to the current density in the plasma beam of about 6 $\mu A/cm^2$. The exposure time was set at 5 or 15 min, which produced the so-called 1st and 2nd alignment modes, respectively. In the 1st mode, the alignment direction is towards the propagation direction of the plasma beam and in the 2nd mode, it is perpendicular to this beam.

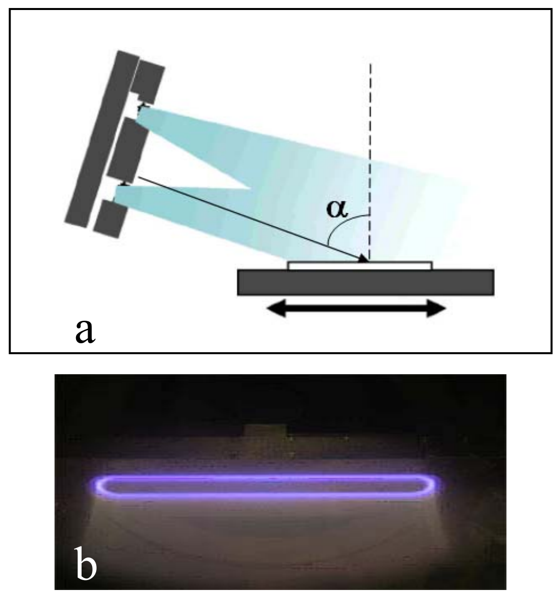

Figure 1. (a) Schematic of plasma beam processing. (b) Gas discharge and plasma beam formed by anode layer source.

Samples: CLC BL118 from Merck with a clearing temperature T_c=84°C was used. Polyimide (PI) precursors for alignment layers were AL1051 from JSR and SE1211 from Nissan designed for planar and homeotropic (H) alignment of nematic LCs, respectively. The polyimide films were spin coated (3000 rpm, 30 s) on ITO/glass substrates and properly backed (AL1051 at 210°C for 40 min and SE1211 at 180°C for 30 min). Non-treated and directionally treated PI films have been used for alignment of CLC. Two kinds of treatment were compared: (1) manual unidirectional rubbing with velvet cloth and (2) plasma beam alignment using the above mentioned tool.

Testing Methods: Polarizing microscopy was used to examine alignment quality. Textures of CLC cells were captured by using

CCD camera attached to Olympus polarizing microscope. Additionally, the cells were observed in reflected light. Reflection ability of the cells, as a measure of alignment quality, was examined by measuring the transmittance spectra of the cells at normal incidence of testing light using a UV/Vis spectrometer from Ocean Optics. In electro-optic tests, the intensity of reflected light at the wavelength of the reflectance maximum was measured as a function of applied electric voltage. The incidence angle of collimated testing beam was about 15^o. The light reflected at -15^o was experimentally detected. The measurements were made in the following manner. The sharp pulse of sine-line voltage (50 Hz) was applied for 5 s and subsequently power of reflected light was measured. After that, refreshing pulse of high voltage (60 V) was applied for 5 s to return the sample to its original planar state. Upon transition from one measuring cycle to another, the applied voltage was stepwise increased. In the measuring process, the voltage was ramped up from 0 to 60 V.

3. Results and Discussion

Quality of Planar Alignment: Preliminary alignment tests allowed us to reduce the number of samples for further research. The results of these tests were as follows. (1) The uniformity of Grandjean (planar) texture is much better in case of filling of CLC at the temperatures below T_c. Because of this, only the cells filled in mesophase were further tested in this section. (2) In contrast to nematic LCs, the alignment of CLC on the plasma processed PI substrates does not essentially depend on whether 1st or 2nd mode processing was applied. Taking this into account, the samples processed for 5 and 15 min are not further differentiated.

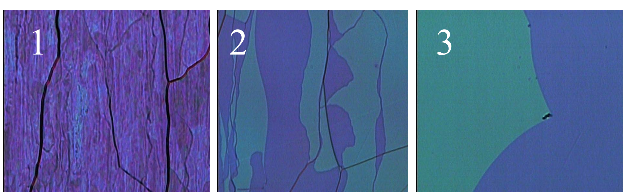

Figure 2. Microscopic images of the CLC cells based on non-treated (1), PB treated (2) and rubbed (3) layers of PI AL1051. X200 magnification.

Fig. 2 shows microscopic pictures of the cells based on untreated (UT), PB treated and rubbed (R) PI films. Despite the fact that our eyes detect only slight difference in light reflection from these cells, the samples have quite different micro-structure. The CLC layer aligned between unprocessed PI films consists of many micro-domains separated by thick and thin linear defects. The planar texture is dramatically improved in the R-cell. In this case, only small number of defects, limiting large domains with highly uniform alignment, is visible. The CLC texture in the PB-cell is rather similar to the rubbing case, except somewhat bigger number of domains and defect lines. This might be explained by weaker azimuthal anchoring on plasma beam processed films.

The transmission spectra of the UT-, PB- and R-cells are presented in Fig. 3. It can be seen that the spectra of samples based on rubbed and plasma beam processed substrates are similar. In contrast, the sample based on untreated PI films shows much broader spectrum due to essential scattering loses. This is consistent with microscopic observations.

Electro-optic Response of Grandjean Textures: The reflectance vs. applied voltage curves are presented in Fig. 4. These curves consist of three parts. At the beginning, the voltage is weak to induce structural changes and so sample remains in an initial planar state. After reaching some threshold voltage, the curve abruptly decreases to the bottom level because of transition from P to FC texture characterized by low reflectance. The following sharp increase in reflectance to upper level is associated with the P-H transition in an electric field and subsequent H-P transition after the field is off. Due to essential scattering from the planar texture, these changes in the NT-cell are quite small. However, they are big in the R- and PB-cells. It can also be seen that the curves corresponding to R- and PB-cells are similar with only difference in somewhat lower initial reflectance of the PB processed cell. However, the bottom reflectivity level for the PB-cell is also lower that even results in some enhancement of switching contrast comparing to the R-cell. The latter may reflect the fact that FC texture is more efficiently formed in the PB-cell.

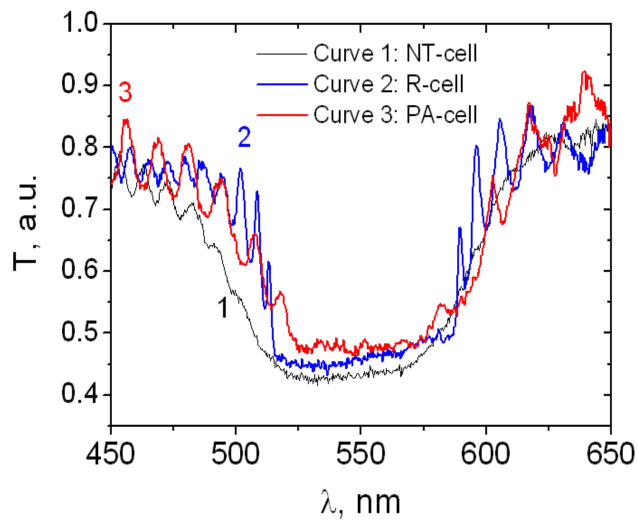

Figure 3. Transmittance spectra of the studied cells

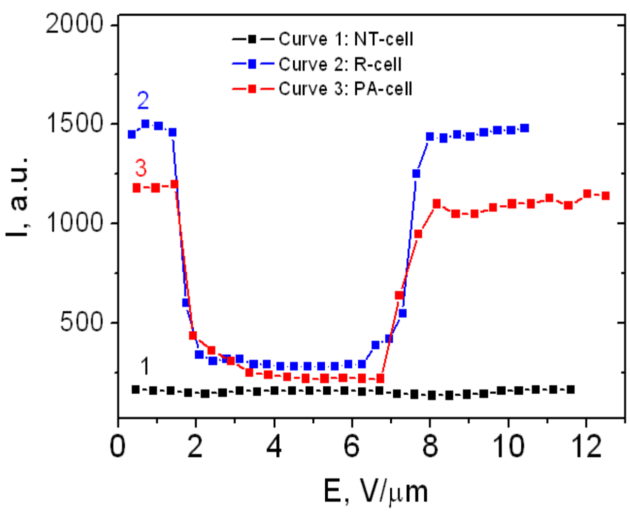

Figure 4. Intensity of reflected light as a function of applied voltage.

The next experiments have also revealed that the FC textures are much more stable in the PA-cells. Fig. 5 shows that the bottom reflectivity level in the R-cell is unstable because the FC texture gradually relaxes to the P texture. We attribute this to strong azimuthal anchoring that restores P texture. In contrast, the bottom reflectivity level in the PB-cell is highly stable. It appears that the weaker anchoring attained in case of PB processing suits better for the reflective CLC displays.

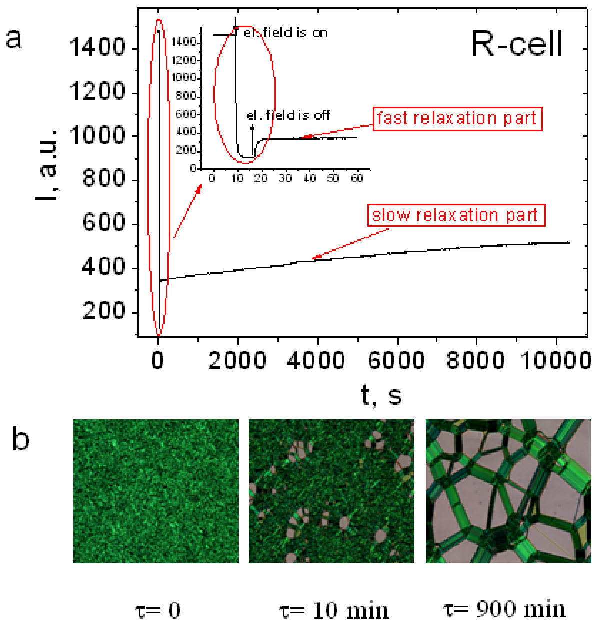

Figure 5. (a) Changes in intensity of reflected light of R-cell after switching on and off the electric field. (b) The microphotographs (x200) corresponding to different times of relaxation, started after the field is off.

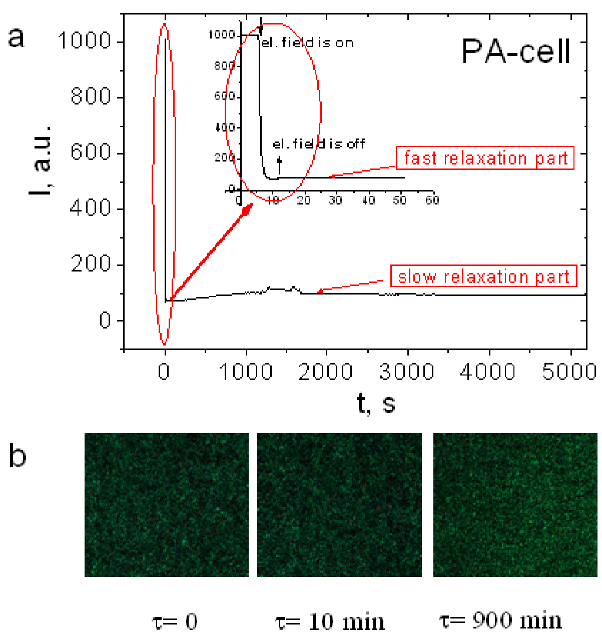

Figure 6. (a) Changes in intensity of reflected light of PB-cell after switching on and off the electric field. (b) The microphotographs (x200) corresponding to different times of relaxation, started after the field is off.

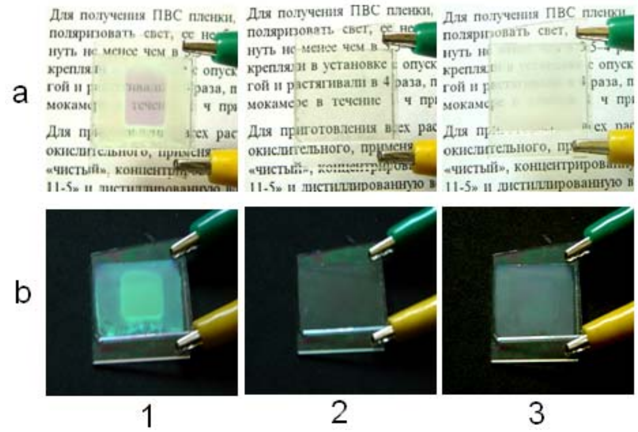

Figure 7. LC cell based on patterned PI SE1211 alignment layers viewed (a) without polarizers and (b) between two crossed polarizers (b). The only central rectangular area was processed by plasma beam (5min, 6 μA/cm^2). Pictures 1, 2, and 3 correspond to the initial state, field on state (50 V) and the field off state, respectively.

Alignment Patterning: On the H-type polyimide the studied CLC showed stable FC texture non-transformable to the P texture with an electric field. Based on the fact that PB processing causes anchoring transition from H to P alignment [3], patterning of the aligning layers of H-PI was realized. For this purpose, H-type polyimide films were exposed through the mask, which was a sheet of perforated paper. The exposed areas acquired the properties of P-type PI, while the protected area kept properties of H-type PI. These areas respectively provided P and FC textures. The P texture demonstrated P-FC transformation after pulse of electric field, while no textural transition was observed for the area with H anchoring. According to Fig. 7, the area with planar texture contrasts well with the surrounding area being in a FC state. After application of electric field, this difference disappears due to the P-FC transition in the plasma exposed area. This suggests energy-saving method for concealment of optical images and configurable smart windows. Also, the method gives new options for manufacturing of miniature switchable optical devices such as mirrors, reflective polarizers, shutters, etc.

CLC Alignment in ULH configuration: As a last stage, we studied capability of the PB alignment technique for getting texture of uniform lying helix (ULC), in which the helix axis is uniform and parallel to the cell walls [7-9]. In optic sense, the ULH layer is equal to the positive A anisotropic film, with optical axis associated with the helix axis of the structure. The short-pitch (p = 0.3–0.6 μm) structures of this type demonstrate the flexoelectric effect, which manifests itself in the fast in-plane deviation of the optical axis under the electric field applied across the cell. This linear, fast (submillisecond) and temperature independent effect is of great practical interest as a possible alternative to the essentially slower electro-optical effect, associated with dielectric coupling, which is commonly used in LCD industry. However, practical application of the flexoelectro-optic effect is complicated by the difficulty of obtaining highly uniform and stable ULH structures on the essential areas. This is mainly due to the fact that the ULH texture is not compatible to strong uniform anchoring, either planar or homeotropic. So, non-standard anchoring conditions are needed to be involved to solve this problem.

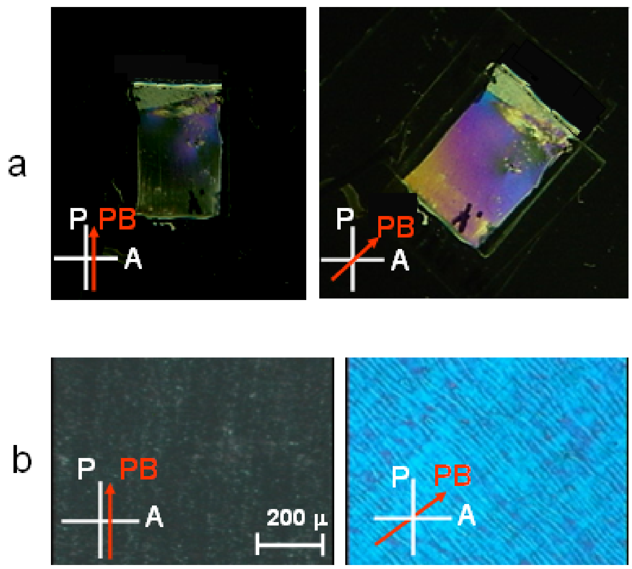

Figure 8. (a) CLC cell (d=5.5 μm) with ULH texture based on the PB processed films of H-PI viewed between a pair of crossed polarizers. (b) Microscopic images corresponding to the cell shown in Fig. 8a.

To clarify capability of PB technique for this issue, alignment layers of P- and H-type PIs were used. The ULH structure was attained by (1) pressing the cell after filling the LC in nematic phase and (2) application of electric field during cooling the LC from isotropic phase. The best result was obtained for the H-type PI gently processed by plasma beam. This kind of treatment provided highly tilted alignment for the nematic LCs in our earlier studies [10]. The ULH texture is this case was achieved without any mechanical stress. According to Fig. 8, the obtained cells demonstrated sufficiently good macroscopic and excellent microscopic uniformity. The cells uniformly switched in an electric field, Fig. 9, before the electric voltage exceeded critical value needed for unwinding of cholesteric helix and ULH-H transition, occurring due to dielectric coupling.

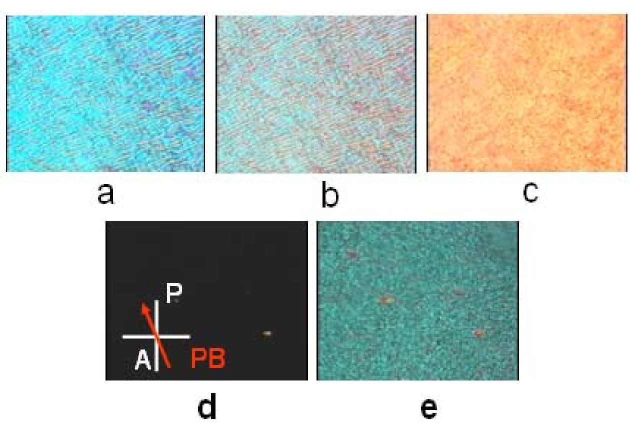

Figure 9. Microphotographs of the CLC cell with ULH texture shown in Fig. 8a. (a) Initial state, (b) and (c) under voltage of 15 V and 25 V, respectively, (d) H texture under voltage of 55 V, (e) FC texture formed after the voltage is off.

4. Conclusions

With this study we extend the field of application of plasma beam alignment to CLC. This technique allows one to get number of benefits. It gives anchoring conditions, which seem to be well optimized from the viewpoint of brightness, electro-optic contrast and viewing angle. Furthermore, it allowed us to achieve real bistability of CLC in a zero field. Another strong point of this method is possibility of alignment patterning. This suggests unique approaches to recording of hidden images, fabrication of miniature optical elements, such as mirrors, shutters, etc.

The method is also effective for the alignment of CLC in ULH configuration. The developed approach is rather similar to that in [11], where a weak homeotropic anchoring and anisotropic relief of the aligning layers are combined. Macroscopically and microscopically uniform ULH textures stable over long period of time are obtained.

5. Acknowledgment

These studies were partially supported with Fulbright Program through Dr. Yaroshchuk's personal research grant.

6. References

[1] S.T. Wu and D.K. Yang. Reflective LCD (Wiley, New York, 2001).

[2] O. Yaroshchuk, Yu. Zakrevsky, A. Dobrovolsky, S. Pavlov, "Liquid crystal alignment on the polymer substrates irradiated by plasma beam", Proc. SPIE **4418**, 49-53 (2001).

[3] O.V. Yaroshchuk, R.M. Kravchuk, A.M. Dobrovolskyy, P.C. Liu, C.D. Lee, "Plasma beam alignment for the large area substrates: equipment and process", J.Soc.Inf.Display **13** (4), 289-294 (2005).

[4] G. Hedge, O. Yaroshchuk, R. Kravchuk, A. Muravskii, V. Chigrinov, H.S. Kwok, "Plasma beam alignment technique for ferroelectric liquid crystals", J.Soc.Inf.Display **16**(10), 1075-1079 (2008).

[5] O. Yaroshchuk, O. Parri, R. Kravchuk, S. Satayesh, M. Reijme, "Plasma-beam alignment of passive liquid crystals", J.Soc.Inf.Display **16**(9), 905-909, (2008).

[6] O. Yaroshchuk, R. Kravchuk, S. Gubarev, A. Golovin and O. Lavrentovich, "Plasma beam alignment of lyotropic chromonic liquid crystals", SID'11 Digest, 1627-1629.

[7] J.S. Patel and R.B. Meyer, "Flexoelectric electro-optics of cholesteric liquid crystal", Phys. Rev. Lett. **58**(15), 1538-1540 (1987).

[8] L. Komitov, G. P. Bryan-Brown, E. L. Wood, and A. B. Smout, "Alignment of cholesteric liquid crystals using periodic anchoring", J. Appl. Phys. **86,** 3508-3511 (1999).

[9] B. J. Broughton, M. J. Clarke, S. M. Morris, A. E. Blatch, and H. J. Coles, "Effect of polymer concentration on stabilized large-tilt-angle flexoelectro-optic switching", J. Appl. Phys. **99**, 023511 (2006).

[10] O.V. Yaroshchuk, A. D. Kiselev, and R. M. Kravchuk, "Liquid-crystal anchoring transitions on aligning substrates processed by a plasma beam", Phys.Rev. E **77**, 031706 (2008).

[11] B.I. Outram and S.J. Elston, "Spontaneous and stable uniform lying helix liquid-crystal alignment", J. Appl. Phys. **113**, 043103 (2013).