

Anchoring and gliding of easy axis of 5CB on photoaligning PVCN-F surface

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Abstract — The photoaligning properties of the popular photoaligning material polyvinyl-4(fluoro-cinnamate) (PVCN-F) are presented. The aligning quality and azimuthal and zenithal anchoring energy were measured and the drift of the easy orientation axis (gliding effect) on the PVCN-F surface, depending on UV exposure, was studied. Special attention is paid to unraveling the contribution of the adsorption liquid-crystal molecules onto the aligning surface to the anchoring properties of PVCN-F and measuring the drift of the easy orientation axis over the PVCN-F surface. It is shown that a relatively weak azimuthal anchoring energy ($W_{az} \approx 10^{-7} - 10^{-5} \text{ J/m}^2$) leads to strong drift of the easy axis in the azimuthal plane that was observed in a moderate ($\sim 0.1-0.3 \text{ T}$) magnetic field. A much stronger polar anchoring ($W_{zen} \approx 10^{-4} \text{ J/m}^2$) allowed us to observe the essential gliding of the easy axis in the zenithal plane in a rather strong electric field ($\sim 5 \text{ V}/\mu\text{m}$).

Keywords — ??

1 Introduction

The discovery of the alignment of liquid-crystal (LC) orientation by light in the early 1990s brought forth a great deal of expectation for applications of liquid-crystal display (LCD) technology.¹⁻⁶ The achievement of unidirectional alignment of LCs on polymer surfaces by polarized light irradiation allows for the development of advanced aligning techniques. Unlike the rubbing technique, photoalignment is a noncontact process and allows easy control of the director orientation, pretilt angle, and anchoring energy. There are no limitations in achieving homogeneous alignment over large substrates that make this method very promising for the fabrication of last generation LCDs. At the same time, the method can be effectively used for the alignment of LC in tiny telecommunication devices where the rubbing technique is very difficult to apply.

Despite advantages in photoalignment technology, some specific features of photoaligning materials (weak anchoring energy, strong sticking effect, *etc.*) prevent wide application of photoalignment in the LCD industry, and photoalignment has been used up until now in academic research. Wide application of this technology requires a deep understanding of the interaction of LC with photosensitive polymers and detailed characterization of the anchoring properties of the existing photoaligning materials.

Among the well-studied photoaligning materials are the polymers containing cinnamoyl acid derivatives in side fragments adjoined to different main chains (polyvinylalcohol, polysiloxane, cellulose).²⁻¹¹ The aligning properties of these materials are caused by anisotropic dimerization (cross-linking) of side fragments irradiated with polarized

UV light, which can be accompanied by reversible *trans-cis* isomerization of the cinnamoyl fragments. Due to the strong absorption dichroism of the cinnamoyl groups, the first process results in anisotropic angular distributions of the crossed-linked cinnamoyl groups and of the remaining cinnamoyl fragments after irradiation with polarized UV light. The second process leads to the reorientation of the cinnamoyl groups perpendicular to the polarization of UV light, resulting in additional angular anisotropy of the polymer-fragment distribution. Both processes cause the formation of an easy orientation axis perpendicular to the polarization of the UV light, and the angular distribution of the flexible fragments in the plane perpendicular to the substrate (zenithal plane) determines the pretilt angle on the polymer surface. As we recently discovered, light-induced changes of the polarity of the surface also contribute to the value of the pretilt angle.¹²

One of the typical cinnamoyl-containing photoaligning polymers is polyvinyl-4(fluoro-cinnamate) (PVCN-F), its chemical structure is depicted in Fig. 1. Our preliminary studies show that this material, along with other cinnamoyl-containing polymers, possesses a rather weak initial azimuthal anchoring energy, which can vary in the range $W_{az} = (10^{-7}-10^{-5}) \text{ J/m}^2$. In addition, effective control of the pretilt angle of LC in a wide range ($15-0^\circ$) was possible by controlling the UV exposure time. Due to a low azimuthal anchoring energy, the reorientation of the director on the PVCN-F surface in an external field is essential in promoting the drift of the easy orientation axis (easy axis gliding).¹³⁻¹⁶ For this reason, PVCN-F can be considered as a model photoaligning material to understand the basic physics of the interac-

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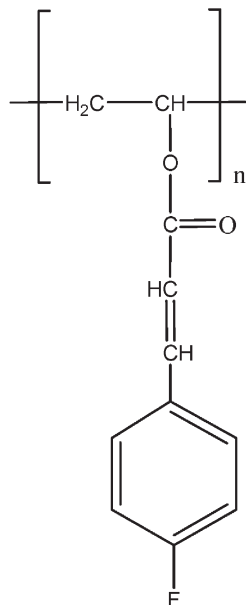


FIGURE 1 — Chemical formula of photosensitive polymer polyvinyl-4-(fluoro-cinnamate) (PVCN-F).

tion of LCs with photoaligning surfaces and to develop new competitive photoaligning materials.

Here, we report on the measurements of the azimuthal and zenithal anchoring energy and studies of the drift of the easy orientation axis (gliding effect) on the surface of photoaligning material polyvinyl-4-(fluoro-cinnamate) (PVCN-F).

2 Results and discussion

2.1 Aligning quality of PVCN-F films

To characterize the general quality of the LC alignment on the PVCN-F surface, we studied the alignment textures in symmetric cells made of two identical glass substrates, with the inner surfaces covered with PVCN-F film. PVCN-F film was deposited on the substrates by spin-coating of a polymer solution in dichloroethane (polymer concentration $c = 10$ g/liter, rotation speed, $v = 7000$ rpm) for about 10 sec. The substrates were then baked at 80°C during 1.2 hours to remove the residual solvent. After that, the PVCN-F film was irradiated with polarized UV light from a Hg-lamp through an IR filter (integral intensity of UV light in the plane of the substrate, $I_{UV} = 1 \pm 0.1$ mW/cm²). Different strip-like areas of the substrate were irradiated with different exposure times $t_{exp} = (0-1800$ sec). The irradiated PVCN-F films had a thickness $l \approx 100$ nm. The cell with a gap $L = 50 \pm 0.7$ μm was assembled in a manner where the projections of UV beam polarization on the substrates coincided. The cell was filled with liquid-crystal material pentyl-cyanobiphenyl (5CB, EM-Industries) by capillary effect at $T \approx 50^\circ\text{C}$ in the isotropic phase.

Observations in unirradiated areas under a polarizing microscope showed Schlieren textures typical of a degener-

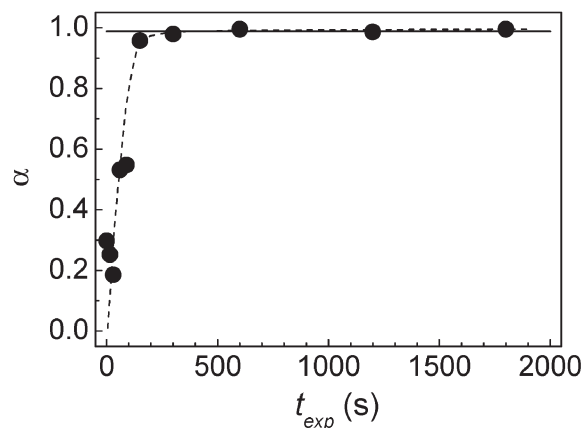


FIGURE 2 — Dependence of the aligning quality parameter α on the exposure time t_{exp} .

ated planar or tilted alignment of a nematic liquid crystal (NLC) on an isotropic surface. Irradiation with UV light resulted in an average alignment of the NLC director perpendicular to the polarization of UV light. Increase in the exposure time led to a decrease in the number of orientational defects, to thinning of the surface orientation walls separating the domains with different orientations, and to an increase of the general homogeneity of the alignment. For exposure times longer than $t_{exp} \geq 600$ sec, uniform planar alignment of the LC was observed.

To characterize the quality of the photoalignment, we placed the LC cell between crossed polarizers and adjusted the cell orientation to obtain a minimal transmitted intensity of the probe laser beam (we used a He-Ne laser, $\lambda = 0.638$ μm , spot diameter of about 1.5 mm). For this position, the average director orientation was parallel to the polarizer axis and, thus, orthogonal to the analyzer. In this configuration, we measured a transmitted intensity I_{\perp} . Then we rotated the analyzer for 90° and again measured the intensity of the probe beam, I_{\parallel} , behind the analyzer. The ratio $\alpha = (I_{\parallel} - I_{\perp}) / (I_{\parallel} + I_{\perp})$, which we call the “aligning quality parameter” is equal to zero in the case of macroscopically random alignment and approaches $\alpha = 1$ when the director is oriented unidirectional. The dependence of the quality parameter α on exposure time is presented in Fig. 2 together with the value α for the rubbed polyimide layer. Fluctuation of α at short exposures is related to the imperfect averaging of the director orientation within the laser spot. One can see that at $t_{exp} \geq 600$ sec (irradiation dose $D = It_{exp} = 0.6$ J/cm²), the parameter α almost coincides with the aligning quality parameter of rubbed polyimide.

2.2 Azimuthal anchoring of LC on PVCN-F films and the drift of the easy orientation axis

Measurement of the azimuthal anchoring energy were made in cells consisting of two substrates with different aligning surfaces: the first substrate, a test substrate, was covered with PVCN-F film and the second substrate, a ref-

erence substrate, was covered with rubbed polyimide layer that provided strong anchoring with a small pretilt angle ($<1^\circ$) of 5CB. PVCN-F film was fabricated and irradiated with *polarized* UV light as described above. The intensity of the UV light I_{UV} was 0.7 ± 0.05 mW/cm² and different strip-like areas of the substrate were irradiated with different exposure times $t_{exp} = 50\text{--}500$ sec. The cell with a thickness $L = 20 \pm 0.7$ μm was assembled in a way that the rubbing direction on the reference substrate and the projection of UV beam polarization on the test substrate constituted an angle of 45° . The cell was filled by capillary action with LC 5CB in its isotropic phase ($T \approx 50^\circ\text{C}$).

Observation by a polarizing microscope showed a high-quality twist structure in the irradiated areas. Our low twist conditions ensured the adiabatic regime (Mauguin regime) of the propagation of light through the cell; the polarization of the test beam followed the twisted director in the cell. This allowed us to determine the orientation of the director on the test and reference surfaces. We found that the director was parallel to the rubbing direction on the reference surface everywhere, whereas the director on the PVCN-F surface reorients toward the easy axis of the rubbed surface in a manner to reduce the twist in the cell. The longer the time of exposure to the UV beam was, the weaker the effect appeared to be. The twist angle φ_{test} between the director on the reference and the one on the PVCN-F surface is related to the value of the azimuthal anchoring energy on this latter surface by the expression¹⁰

$$W_{az}^{photo} = \frac{K_{22}}{L} \frac{2 \sin \varphi_{test}}{\sin 2(\varphi_{ref} - \varphi_{test})}, \quad (1)$$

where K_{22} is the twist elastic constant.

The obtained values of W_{az}^{photo} for 5CB twist elastic constant $K_{22} = 3.6 \times 10^{-12}$ N and cell thickness $L = 20$ μm are shown in Fig. 3 as a function of the exposure time t_{exp} and irradiation dose $D = I_{UV}t_{exp}$. The two experimental points, $t_{exp} = 400$ sec and 500 sec correspond to the angle $\varphi_{test} \approx 45^\circ$ and a strong anchoring (anchoring parameter, $\xi = W_{az}^{photo}L/K_{22} \gg 1$). For this case the experimental error of the anchoring-energy measurements is very large and we can only say that $W_{az}^{photo} \geq 15 \times 10^{-6}$ J/m² for these exposures.

The obtained values of $W_{az}^{photo}(t_{exp})$ originated just from the anchoring associated with the light-induced anisotropy of the aligning surface. An additional contribution to the anchoring of the LC is given by the adsorbed LC molecules on the aligning surface. This adsorption occurs preferably in the direction which is determined by light-induced easy orientation axis and may increase the anchoring energy value.¹⁷ To estimate the anchoring energy due to adsorption of LC molecules, we used new surfaces with an easy axis induced by the adsorption of LC molecules. The experiments were carried out in symmetric cells consisting of substrates covered with identically treated PVCN-F layers. We used PVCN-F irradiated with *unpolarized* UV light during $t_{exp} = 10, 20, 30,$ and 60 sec from a Hg UV lamp (intensity,

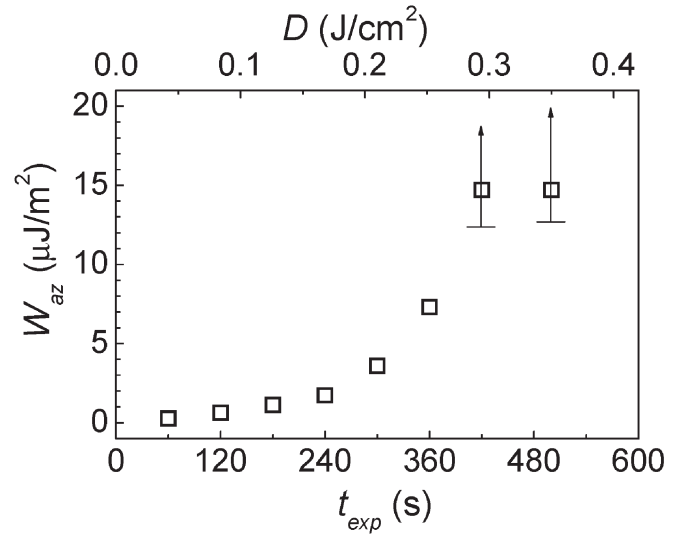


FIGURE 3 — Dependence of the azimuthal anchoring energy W_{az}^{photo} on exposure time t_{exp} .

$I_{UV} \approx 10$ mW/cm²). The 50- μm cell was filled with LC 5CB in the isotropic phase ($T \approx 50^\circ\text{C}$) and was then cooled to room temperature in an external magnetic field $\mathbf{H} = 0.3$ T at the angle between the \mathbf{H} -field and the plane of the cell, $\beta \approx 10^\circ$.

The magnetic treatment resulted in a homogeneous planar alignment of LC along the projection of the \mathbf{H} -field to the plane of the cell. It is evident that the cause of the formation of magnetically mediated easy axis is the adsorption of the LC molecules on the PVCN-F surface. Orientation of the LC molecules with an \mathbf{H} -field during the cell's cooling results in an anisotropic angular distribution of the adsorbed molecules with the maximum being parallel the projection of the \mathbf{H} -field on the cell plane. This anisotropic oriented adsorbed layer serves as an aligning coating with the easy axis parallel to the field direction.

To reach the equilibrium alignment, we kept the cell during 40 min between the magnetic poles. After that, the cell was tilted to set the angle $\beta = 0^\circ$ and then the cell was rotated for $\varphi_0 = 45^\circ$ around the normal to \mathbf{H} . In this geometry, the bulk director is parallel to the magnetic field and a twist distortion close to the two surfaces appears. The elastic torque associated to this distortion caused the reorientation of the director \mathbf{d} on the aligning surfaces toward the magnetic field direction. To follow the director reorientation in the cell, we placed it between two polarizers and we probed the director orientation by rotating the polarizers. The measurements showed that the Mauguin regime was valid in our case as expected. The value φ_{surf} was measured in a few tens of seconds after the rotation of the cell in the magnetic field set $\varphi_0 = 45^\circ$. The dependence of the reorientation angle φ_{surf} on exposure time and irradiation dose is presented in Fig. 4. The evident decrease of the angle φ_{surf} with the exposure time is a consequence of the increase of the anchoring energy due to LC molecules adsorption W_{az}^{ad} .

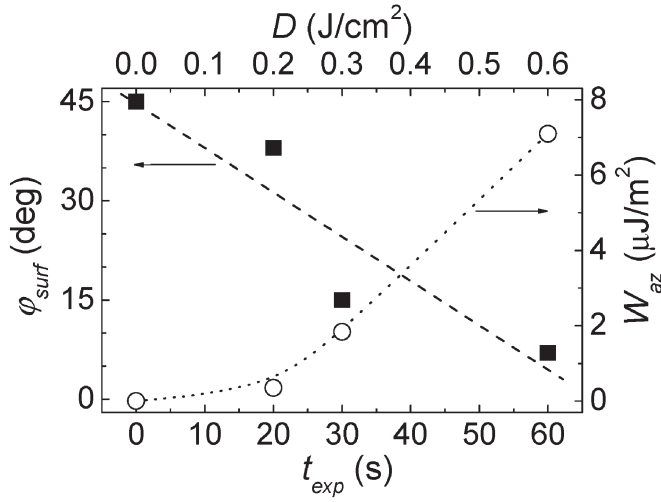


FIGURE 4 — Dependences of the reorientation angle φ_{surf} and anchoring energy W_{az}^{ad} on exposure time t_{exp} .

To estimate the values of W_{az}^{ad} , we use the balance of the surface and bulk torques, which act on the surface director¹⁸:

$$\frac{\partial W_{az}}{\partial \varphi_{surf}} = \sqrt{K_{22}\chi_a} H \sin^2(\varphi_0 - \varphi_{surf}) \quad (2)$$

and

$$W_{az} \approx \frac{\sqrt{K_{22}\chi_a} H \sin^2(\varphi_{surf})}{\varphi_{surf}}. \quad (3)$$

Replacing the known values $\chi_a = 1.76 \times 10^{-7}$, $\varphi_0 = 45^\circ$, and $\mathbf{H} = 0.3$ T and the experimental values of φ_{surf} into Eq. (3), we obtain $W_{az}^{ad}(t_{exp})$ as depicted in Fig. 4 together with $\varphi_{surf}(t_{exp})$.

Comparing Figs. 3 and 4, one can see that the anchoring energy due to the LC adsorption is weaker than the one induced by the photoalignment. Both anchoring values W_{az}^{ad} and W_{az}^{photo} are relatively weak and the associated surface director reorientation is on the order of tens of degrees. These large deviations of the director from the equilibrium position may result in a strong azimuthal drift of the easy axis.

We explored the gliding effect in the symmetric cell used for the measurement of W_{az}^{ad} . The experiment was analogous to the experiment of the anchoring measurements with the difference that it was carried out in a much longer time scale, up to 250 min. We found that the initial quick director reorientation (~ 1 sec) is followed by a much slower director reorientation toward \mathbf{H} . The dependence of the reorientation angle φ_{surf} on time is presented in Fig. 5. The characteristic reorientation times (tens and hundreds of minutes) are incomparably larger than the typical bulk reorientation time of the director in a magnetic field (~ 1 sec). The interesting feature of the observed drift is that the characteristic times of the gliding increases with increasing UV exposure.

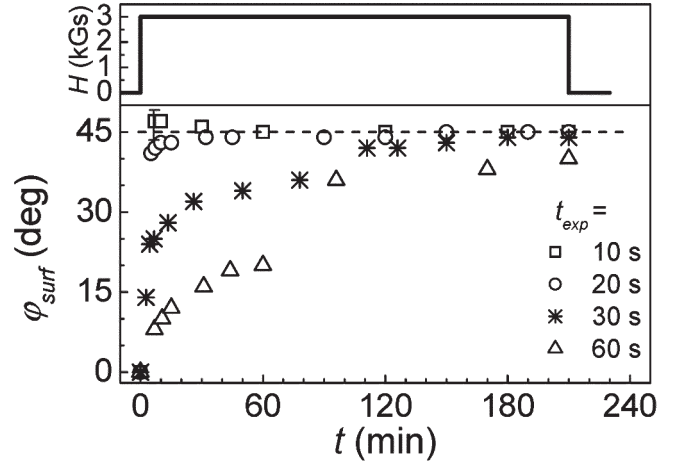


FIGURE 5 — Drift of the easy axis in azimuthal plane.

The drift might also be observed when we switched off the field during reorientation – the surface director did not return to the initial position $\varphi_{surf}(t = 0) = 0$ but relaxed to some intermediate angle between the current value $\varphi_{surf}(t)$ and $\varphi_{surf} = 0$.

Switching off the field after achievement of the stationary reorientation angle $\varphi_{surf} \approx 45^\circ$ led to a small-amplitude relaxation of the director [$\Delta\varphi_{surf} = 2.5^\circ$ ($t_{exp} = 20$ sec) and $\Delta\varphi_{surf} = 5^\circ$ ($t_{exp} = 30$ sec)]. The characteristic time of this relaxation was much longer (hundreds of seconds) than both the relaxation time of the magnetic field due to the inductivity of the magnet (~ 5 sec) and the relaxation of the bulk elastic deformation (~ 0.25 sec). Thus, long-term application of the magnetic field resulted in a huge azimuthal drift of the easy orientation axis from the initial orientation to the direction of the applied field \mathbf{H} . Occurring after the field cut off, a weak drift of the LC director toward its initial orientation points to the presence of an additional surface torque deviating from the new easy axis orientation. This observation implies that despite the effective azimuthal drift of the easy axis, the surface “remembers” its initial position.

2.3 Zenithal anchoring of LC on PVCN-F films and the drift of the easy orientation axis

The measurements of the zenithal anchoring and gliding were carried out in a cell made of PVCN-F and SiO-coated glass plates. The glass plates were first coated with ITO electrodes. The 300-Å-thick SiO layer was evaporated at an oblique incidence (60°) to obtain planar anchoring. For the anchoring measurements, PVCN-F layers were irradiated with polarized UV light ($I_{UV} = 0.7 \pm 0.05$ mW/cm²) with different UV exposure times ranging from 10 to 1200 sec. The cell was filled with 5CB in the isotropic phase. After quenching in the nematic phase, the sample was kept at room temperature for about 48 hours. The method used for the measurement of the polar anchoring energy is based on the “anchoring breaking” phenomenon under a strong electric field and allows the measurement of the anchoring

strength for the surfaces with planar or low-pretilt easy axis orientation.¹⁹ The values of the polar-anchoring strength measured by this technique for PVCN-F polymer subjected to UV irradiation in the range 10–1200 sec were $W_{zen} \sim 0.25 \times 10^{-3} \text{ J/m}^2$ which is larger than W_{az} . This value is comparable with the typical values of rubbed polyimide surfaces $W_{zen} \sim 0.33 \times 10^{-3} \text{ J/m}^2$.¹⁴

Due to a rather strong zenithal anchoring energy, one can expect that the drift of the easy orientation axis in the zenithal plane can only be observed in a rather strong external field. In addition, the amplitude of the zenithal gliding is also expected to be much smaller than its azimuthal counterpart. To measure the expected weak zenithal gliding of the surface director, a new high-resolution optical method has been developed. This method, derived from the one in Ref. 20, is based on the measurement of the optical path difference when an amplitude modulated ac (100 kHz) electric field is applied to the nematic cell. The rms (root mean square) value of the field is fixed to half of the Fredericks threshold to compensate for the geometric splay elastic torque, induced by different director orientations on the two boundaries (planar and weak pretilt), with the field dielectric torque. The chosen value of the field then corresponds to a null total torque on the PVCN-F surface director. As a consequence, the measured pretilt angle coincides with the pretilt angle of easy axis (no contribution of the zenithal anchoring in this case). The electric-field amplitude is modulated at a relatively low frequency (1 Hz) to allow for the modulation of the director orientation. The optical path difference is then modulated at the same frequency and a lock-in technique can be used to measure it. The experimental setup is fully automated allowing an easy data acquisition on very long time scales (days). For pretilt angles larger than 1° , the angular resolution is about 0.05° with a long-term stability greater than 0.5° . More details about this method will be published in a forthcoming paper.

To measure the easy-axis zenithal gliding, we used PVCN-F layers exposed 1200 sec to polarized UV. A combined PVCN-F/SiO cell of $10 \mu\text{m}$ thickness was filled with 5CB in the isotropic phase. After filling, the temperature was quenched in the nematic phase and the cell was kept at $T = 25^\circ\text{C}$ for 48 hours. In this condition a pretilt angle $\psi_0 \approx 0.8^\circ$ was measured. Thereafter, a strong disorienting electric field (perpendicular to the PVCN-F easy axis) is applied to the cell. Under the field action, the director on the PVCN-F plate reorients toward the normal to the plates by reaching the orientation where the dielectric torque is exactly counterbalanced by the anchoring torque. After 16 hours, the curing field is removed and the zenithal gliding of the easy axis is measured by the technique described above. In Fig. 6, we show a typical curve obtained for a cell just after curing with an electric field of $1 \text{ V}/\mu\text{m}$. The director on the PVCN-F surface during the application of the field was oriented at 60° with respect to the plate. The time origin corresponds to switching off the curing electric field. The first 3 minutes of the relaxation has been removed from the Fig. 6

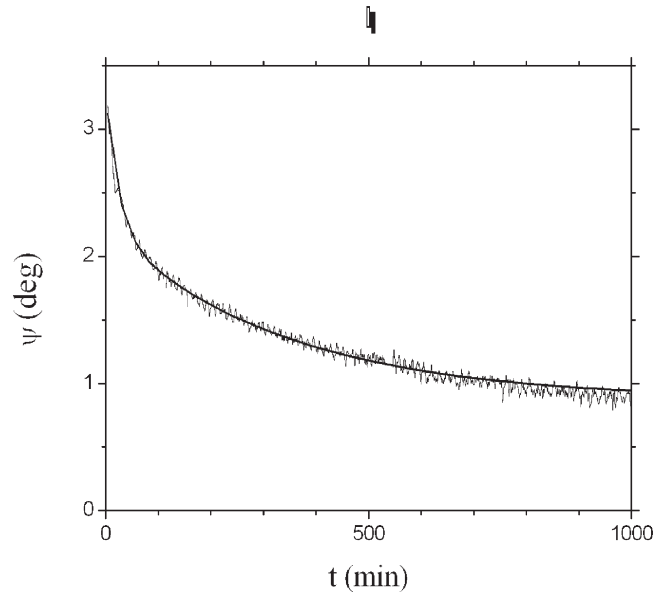


FIGURE 6 — Drift of the easy axis in zenithal plane.

because they corresponded to the electronic relaxation of the lock-in setup. One can see that the easy axis relaxes back to its initial orientation on very long time scales on the order of hours. The best fit for a bi-exponential function $\psi = \psi_0 + \psi_1 \exp(-t/\tau_1) + \psi_2 \exp(-t/\tau_2)$, where $\psi_0 = 0.87^\circ$, $\psi_1 = 1.05^\circ$, $\psi_2 = 1.35^\circ$, and $\tau_1 = 23.5 \text{ min}$, $\tau_2 = 337 \text{ min}$, is also shown in Fig. 6. These characteristic times are more than five orders of magnitude larger than the elastic relaxation time of the bulk distortion. The total amplitude of the easy-axis gliding results in $\psi_{tot} = \psi_1 + \psi_2 = 2.4^\circ$. A similar behavior, namely, very long relaxation times of the easy axis and ψ_{tot} on the order of few degrees, have been measured for curing fields of different amplitudes and for different temperatures. Even in the case of a saturated surface angle under a curing field (director parallel to the plate normal), ψ_{tot} remains on the order of a few degrees.

Let us describe, briefly, the easy-axis drift after quenching from the isotropic phase and before the curing-field application. In Fig. 7, a typical behavior of the pretilt angle versus time is reported. The time origin marks the nematic–isotropic transition. The pretilt angle increases in the first 3 hours after quenching, but decreases to a value of 0.8° in the following 10 hours. Similar nonmonotonic behavior has been observed for PVCN-F layers with different UV doses. More-detailed experimental analysis will be devoted to this intriguing behavior.

The results obtained clearly show that a weak azimuthal anchoring energy for the PVCN-F surface results in a strong drift of the easy axis (gliding effect) in a moderate magnetic field ($\mathbf{H} \geq 0.1 \text{ T}$). The drift of the easy axis in the zenithal plane is also observed, but it requires a rather strong electric field ($E \geq 1 \text{ V}/\mu\text{m}$) due to strong zenithal anchoring. The adsorption–desorption of LC molecules on the aligning surface and collective reorientation of flexible polymer fragments and LC molecules may be considered as possible

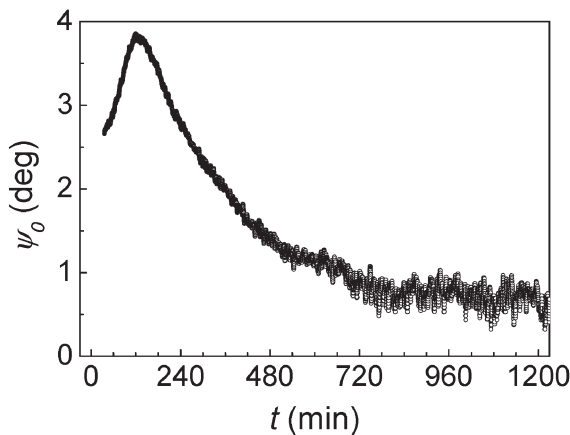


FIGURE 7 — Dependence of the tilt angle on time, $t_{exp} = 20$ min.

mechanisms for the gliding. The first mechanism was proposed by Vetter *et al.*²¹ and studied in Refs. 14, 15, and 22. In this proposed mechanism, the drift of the easy axis is caused by the rotation of the symmetry axes of the distribution function of the adsorbed LC molecules under the influence of a reorientation torque. It is suggested that adsorbed molecules are oriented preferably along the initial direction of the director in the cell. Application of the torque reorients the director near the surface and results in the adsorption of molecules along this new direction. As a consequence, the symmetry axes of the angular distribution function of the adsorbed molecules reorients as well as the associated easy axis. The model of cooperative reorientation of the director and polymer fragments was first proposed by Kurioz *et al.*²³ It was suggested that very slow relaxation of the director in the zenithal plane after application of an electric field to the cell with a PVCN-F surface is caused by realigning flexible fragments on the polymer. Owing to the weak anchoring, the electric field reorients the director on the polymer surface, which, in turn, drags the flexible fragments of the polymer surface. As a result, the electric field orients both the LC molecules and flexible fragments in a direction which is determined by the anchoring parameter and LC – flexible fragments interaction. Later on, Janossy¹⁶ explained the drift of the easy axis in the azimuthal plane over PMMA surface in a similar way. His interpretation of the azimuthal gliding observations is based on the assumption that the polymer main chains can undergo conformational transitions under the influence of the anisotropic potential of the liquid crystal. The induced structural changes in the polymer decrease the interfacial energy between the liquid crystal and the polymer; hence, self-strengthening of the surface anchoring of the liquid crystal takes place. The change in the director position at the surface initiates conformational changes in the polymer, and, as a result, the easy axis rotates towards the director. This latter rotation, in turn, decreases the anchoring torque; therefore, the director can rotate further towards the external field. The process ends when both surface torques become zero, *i.e.*, the twist deformation is zero at the surface and the easy

axis coincides with the director at the soft plate. Similar argumentation was used to explain the director gliding in lyotropic LCs.²⁴ Both considered mechanisms may be realized on PVCN-F surface because this material contains revolvable cinnamoyl fragments and effectively adsorbs molecules from the LC bulk.^{25,26} Therefore, the microscopic mechanism of the gliding over the PVCN-F surface requires additional studies to be elucidated. At the same time, the increase in the drift characteristic times with an increase in the UV exposure makes the mechanism of cooperative reorientation of the director and polymer fragments most probable since the exposure depletes the revolvable fragments. It should be noted that both models are described by the same equations (see Ref. 22), and the difference is just in the physical meaning of these equations. Thus, to settle between these two alternative mechanisms is a rather difficult task.

3 Conclusion

PVCN-F provides a very good planar alignment of LC 5CB with the same quality as rubbed polyimide layers after UV exposure with a dose $D \sim 0.2$ J/cm². The measurement of the azimuthal anchoring energy shows that the anchoring caused by photoinduced anisotropy ($W_{az}^{photo} = 10^{-6}$ – 10^{-5} J/m²) is comparable with that due to magnetically mediated adsorption of 5CB molecules onto a PVCN-F surface ($W_{az}^{ad} \sim 10^{-6}$ J/m²). A relatively small anchoring energy results in a very effective drift of the easy axis in the azimuthal plane under a moderate magnetic field of ~ 0.3 T. A much larger zenithal anchoring energy ($W_{zen} \sim 0.25 \times 10^{-3}$ J/m²) allows the essential gliding of the easy axis in a zenithal plane only in a rather strong electric field (~ 3 V/μm). The obtained results can be described in the frames of models, suggesting that the gliding of the easy axis is governed by adsorption/desorption of LC molecules onto PVCN-F surface or/and realignment of flexible fragments of the polymer during LC director reorientation. We believe the results of this study have a rather general essence and can be applied for any aligning material providing weak azimuthal anchoring.

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References

- 1 A Dyadyusha, V M Kosenkov, T Ya Marusii, V Yu Reshetnyak, Yu A Reznikov, and A I Khizhnyak, *Ukr J Phys* **36**(7), 1059–1061 (1991).

- 2 W M Gibbons, P J Shannon, S T Sun, and B J Swetlin, "Surface-mediated alignment of nematic liquid crystals with polarized laser light," *Nature* **351**, 49 (1991).
- 3 A Dyadyusha, T Ya Marusii, V Yu Reshetnyak, Yu A Reznikov, and A I Khizhnyak, "Orientational effect due to change in the anisotropy of the interaction between a liquid crystal and a bounding surface," *JETP Lett* **56**, 17 (1992).
- 4 M Schadt, K Schmidt, V Kozenkov, and V Chigrinov, "Surface-induced parallel alignment of liquid crystals by linearly polymerised photopolymers" *Jpn J Appl Phys* **31**(7), Part 1, 2155 (1992).
- 5 T Ya Marusii and Yu A Reznikov, "Photosensitive orientants for liquid crystal alignment," *Mol Mater* **3** 161–176 (1993).
- 6 K Ichimura, Ya Akita, H Akiyama, Yu Hayashi, and K Kudo, "Role of E/Z photoisomerization of cinnamate side chains attached to polymer backbones in the alignment photoregulation of nematic liquid crystals," *Jpn J Appl Phys* **35**(8A), Part 2, L992–L995 (1996).
- 7 F Barbet, D Bormann, M Warengem, Yu Kurioz, Yu Reznikov, and B Khelifa, "Raman spectroscopy evidence of phototransformation in poly(vinyl-para-fluorocinnamate)," *Mol Cryst Liq Cryst* **320** 405–415 (1998).
- 8 O Yaroshchuk, G Pelzl, G Pirwitz, Yu Reznikov, H Zschke, J H Kim, and S B Kwon, "Photosensitive materials on a base of polysiloxane for the alignment of nematic liquid crystals," *Jpn J Appl Phys* **36**(9), 961 (1997).
- 9 A Duadyusha, A Khizhnyak, T Marusii, V Reshetnyak, Yu Reznikov, and W S Park, "Peculiarity of an oblique liquid crystal alignment induced by a photosensitive orientant," *Jpn J Appl Phys* **34**, 566–571 (1995).
- 10 D Andrienko, A Dyadyusha, A Iljin, Yu Kurioz, and Yu Reznikov, "Measurements of controllable azimuth anchoring energy of liquid crystal on a photoaligning polymer surface," *Mol Cryst Liq Cryst* **321**, 271–281 (1998).
- 11 I Gerus, A Glushchenko, Yu Kurioz, Yu Reznikov, and O Tereshchenko, "Sticking of liquid crystal on photosensitive polymer layers," *Opto-Electron Rev* **12**(3), 281 (2004).
- 12 L Bugayova, I Gerus, A Glushchenko, A Dyadyusha, Yu Kurioz, V Reshetnyak, Yu Reznikov, and J West, "Non-monotonic exposure dependence of the pretilt angle and surface polarity of the photo-orientant F-PVCN," *Liq Cryst* **29**(2), 209–212 (2002).
- 13 V P Vorflusev, H-S Kitzerow, and V G Chigrinov, "Azimuthal surface gliding of a nematic liquid crystal," *Appl Phys Lett* **70**, 3359 (1997).
- 14 S Faetti, M Nobili, and I Raggi, "Surface reorientation dynamics of nematic liquid crystals," *Eur Phys J B* **11**, 445 (1999).
- 15 D N Stoenescu, I Dozov, and Ph Martinot-Lagrade *Mol Cryst Liq Cryst Sci Technol, Sect A* **351**, 427 (2000).
- 16 I Jánossy and T I Kósa, "Gliding of liquid crystals on soft polymer surfaces," *Phys Rev E* **70**, 052701 (2004).
- 17 K Okubo, M Kimura, and T Akanane, "Measurement of genuine azimuthal anchoring energy in consideration of liquid crystal molecular adsorption on alignment film," *Jpn J Appl Phys* **42**(10), Part 1, 6428 (2003).
- 18 S Faetti, G C Mutinati, and I Gerus, "Measurements of the azimuthal anchoring energy at the interface between a nematic liquid crystal and photosensitive polymers," *Mol Cryst Liq Cryst* **421**, 81 (2004).
- 19 I Dozov (unpublished results).
- 20 M Nobili *et al* (unpublished results).
- 21 P Vetter, Y Ohmura, and T Uchida, "Study of memory alignment of nematic liquid crystals on polyvinyl alcohol coatings," *Jpn J Appl Phys* **32**(9A), Part 2, L1239–L1241 (1993).
- 22 A Romanenko, I Pinkevich, V Reshetnyak, I Dozov, and D Stoenescu, "Director reorientation in a cell with time-dependent anchoring due to adsorption/desorption of LC molecules," *Mol Cryst Liq Cryst* **422**, 173[443] (2004).
- 23 Yu Kurioz, V Reshetnyak, and Yu Reznikov, "Orientation of a liquid crystal on a soft photoaligning surface," *Mol Cryst Liq Cryst* **375**, 535 (2002).
- 24 E A Oliviera, A M Fugueredo Neto, and G Durand, "Gliding anchoring of lyotropic nematic liquid crystals on amorphous glass surfaces," *Phys Rev A* **44**(2), R825 (1991).
- 25 E Ouskova, Yu Reznikov, S V Shiyankovskii, L Su, J L West, O V Kuksenok, O Francescangeli, and F Simoni, "Photo-orientation of liquid crystals due to light-induced desorption and adsorption of dye molecules on an aligning surface," *Phys Rev E* **64**, 051709 (2001).
- 26 Yu Reznikov, O Ostroverkhova, K Singer, J-H Kim, S Kumar, O Lavrentovich, B Wang, and J L West, "Photoalignment of liquid crystals by liquid crystals," *Phys Rev Lett* **84**(9), 1930 (2000).



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