Tilted photoalignment of a nematic liquid crystal induced by a magnetic field

Denis Andrienko, Yuri Kurioz, and Yuri Reznikov
Institute of Physics of National Academy of Sciences, Prospect Nauki 46, Kyiv 252022, Ukraine

Charles Rosenblatt and Rolfe Petschek[a)]
Department of Physics, Case Western Reserve University, Cleveland, Ohio 44106

Oleg Lavrentovich and Darius Subacius
Liquid Crystal Institute, Kent State University, Kent, Ohio, 44242

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Nematic liquid crystal cells with polyvinyl cinnamate coated substrates were subjected to ultraviolet light. When this was done in the presence of an oblique magnetic field the photoalignment was found to be temporally and thermally robust, with a large pretilt angle and weak polar anchoring. Moreover, two easy axes with equal and opposite pretilt angle were obtained, such that a magnetic field could switch the director from one easy axis to the other. © *1998 American Institute of Physics.* [S0021-8979(98)02901-6]

I. INTRODUCTION

The vast majority of liquid crystal (LC) displays require uniform LC molecular orientation, usually with a small angle between the director **n** and substrate; this angle is called the ''pretilt'' angle. The conventional technique to achieve oblique alignment involves deposition of a thin polymer layer on the substrate, which is subsequently rubbed. Rubbing of the polymer determines the azimuthal orientation of the LC molecular alignment, and induces a nonzero pretilt angle.

The rubbing method suffers from several drawbacks, however, especially accumulation of static charges at the thin film transistor sites and generation of dust particles. Recently, new nonrubbing alignment techniques, based on photoinduced anisotropy of the polymerizable orienting layers, have been introduced.[1–6] Typically the photosensitive polymer films are illuminated by polarized ultraviolet light, and the azimuthal orientation of the resulting planar alignment depends on the specifics of the photoinduced reaction. In contrast to the rubbing technique, neither excess charge nor dust is created on the substrates, yet control is maintained over both the tilt angle and the anchoring strength.

The traditional rubbing technique establishes a unique direction of the tilted easy axis; this direction is determined by the direction of rubbing.[7] On the other hand, for photoalignment there is a twofold degeneracy of the light-induced easy axis.[8,9] This twofold degeneracy causes poor reproducibility of the pretilt angle and, more importantly, the appearance of defects at the resulting boundaries between orientation domains. This degeneracy may be partially removed during the filling of the LC cell[9] because of the effect of flow alignment,[10] but the resulting alignment is not temporally stable.[11] To date, the most promising method to break this degeneracy involves oblique irradiation of the photoalignment layer.[4]

In a recent publication[12] we proposed use of an external magnetic field to establish a preferred direction for the oblique easy axis, and demonstrated the temporal stability of this technique. In the present article we report measurements of the primary characteristics of magnetic-field mediated alignment of a nematic LC on a polymer surface exposed to UV light. We show that a magnetic field can induce transitions between two stable directions of the easy axis.

II. MATERIALS AND TECHNIQUES

We used a fluorinated polyvinyl-cinnamate (''PVCN-F'') film as a photosensitive substrate to align the liquid crystal pentylcyanobiphenyl (''5CB'') (EM Industries). PVCN-based materials have been studied extensively as alignment materials, and have shown good promise for applications.[1–4] PVCN-F is a polyvinyl-alcohol main chain with photosensitive side groups based on fluorinated cinnamic acid. The appearance of an easy axis for liquid crystal alignment is due to the photoinduced crosslinking reaction between side groups under the influence of polarized UV light. The crosslinking of the side groups of PVCN-F induced by unpolarized UV light results in the formation of anisotropic trans-cyclobutane photoderivatives, although the PVCN itself remains isotropic.[13] Polarized UV light preferentially causes the side fragments with long axes parallel to the polarization direction **E** to undergo crosslinking. The anisotropic distribution of the side fragments of noncrosslinked cinnamic acid groups and cyclobutane photoderivatives provides a preferred axis for the LC. It is observed that the LC director orients perpendicular to the UV polarization direction.

In this article we report on two types of LC cells, which we refer to as ''mixed'' and ''symmetric.'' Both cells had one glass and one quartz substrate, separated by spacers. The cell spacing was determined by the interference method,[14] and found to be (65 ± 1) μm. Mixed cells were constructed by spincoating a PVCN solution onto the quartz substrate to a thickness of approximately 0.1–0.5 μm and baking at 70 °C for 1 h. The glass substrate was coated with DuPont polyimide 2555 (PI) and then rubbed. This polyimide provides a small pretilt angle $\theta_{PI}\approx 2-4°$ and a strong anchoring

a)Electronic mail: rpetsche@mrg.phys.cwru.edu

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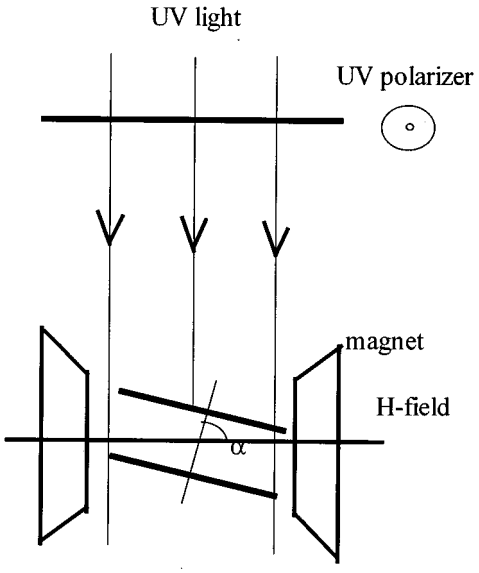

FIG. 1. Experimental setup.

potential for the LC. The cell was filled with 5CB in the isotropic phase at $\sim 50\,^{\circ}\mathrm{C}$, placed in a magnet field of approximately 8 kG which was at an angle α (Fig. 1) to the cell normal, and cooled to room temperature under continuous exposure to polarized UV illumination from a mercury vapor lamp; the lamp's intensity $I \approx 0.1\ \mathrm{mW\,cm^{-2}}$ (Fig. 1). Symmetric cells were constructed as above except that both the quartz and the glass substrates were treated with PVCN and neither substrate coated with polyimide or rubbed. The pretilt angle in the symmetric cells was measured by the ''magnetic null'' method. The cell was rotated between the poles of the electromagnet until an orientation was found at which the phase retardation of the light passing through the cell did not depend on the strength of the applied magnetic field. This corresponds to a director orientation along the magnetic field, i.e., the pretilt angle. We note that the variation of the beam direction helps to verify the uniformity of the cell. If the cell is truly uniform, the null position is preserved for all directions of the probing laser beam.

For the mixed cells the pretilt angles at the two substrates were different. This resulted in an inhomogeneous director distribution in the cell, and makes the magnetic null method unproductive. Therefore, the tilt angle was measured using the traditional rotation method.[15] In this technique the cell is placed between crossed polarizers so that the plane of the director—this is effectively the rubbing direction—makes an angle of 45° with respect to the polarization axes. The beam from a weak He-Ne laser passes through the first polarizer and has normal incidence on the cell. The cell is then rotated about an axis perpendicular to the director by an angle β, and the transmission $I(\beta)$ through the crossed polarizer is measured. For symmetric pretilt angles at the two surfaces, the intensity profile I vs β is symmetric about $\beta = 0$; if the pretilt angles differ, the symmetry axis of $I(\beta)$ is shifted by an angle $\Delta\beta$ such that,[8]

TABLE I. Measured parameters for various cells.

Cell number	Type of the cell	α (°)	Pretilt θ_{PVCN} (°)	Cell thickness, μm
1	mixed	80	20 ± 5	65
2	symmetric	71	17	68
3	mixed	70	20 ± 5	65
4	mixed	60	20 ± 5	65
5	symmetric	50	22	56
6	mixed	45	20 ± 5	65
7	mixed	45	16 ± 2	23

$$\frac{\theta_1+\theta_2}{2} \approx \frac{\Delta\beta}{n_e+n_0}, \tag{1}$$

where θ_1 and θ_2 are the pretilt angles at the surfaces, and n_0 and n_e are the refractive indices of ordinary and extraordinary light, respectively. Thus, a measurement of $\Delta\beta$ in the mixed cells allows a determination of the pretilt angle at the PVCN-F surface as the tilt angle on the reference polyimide surface is known. It should be noted that the accuracy of this method decreases with increasing pretilt angle. For pretilt angles $\geqslant 15°$, only rough estimates of the pretilt angle can be made.

III. EXPERIMENT

A. Tilted alignment

The cells were examined by means of polarizing optical microscopy. For all UV exposure times the cells exhibited good unidirectional alignment, provided a magnetic field $H > 7$ kG was applied during the cooling. Textures in the irradiated and nonirradiated parts of the cell were found to be similar, differing slightly only in their brightness. When the magnetic field was not applied during the cooling, planar alignment was realized after 1 min of UV exposure.

Simultaneous action of the magnetic field and UV illumination is crucial for tilted director alignment. In the nonirradiated parts of the cell a small pretilt $\theta_{\mathrm{PVCN}} = 2-4°$ at the PVCN-F surface was observed just after cooling in a magnetic field. This pretilt was unstable and rapidly decayed to zero. If the magnetic field was not applied during the cooling, no pretilt ($\theta_{\mathrm{PVCN}} = 0$) was observed at the PVCN-F surface. Thus, zero pretilt is associated with a PVCN-F surface cooled from the isotropic phase. We conclude that the simultaneous action of the magnetic field and UV light results in the desired oblique orientation of LCs. The pretilt angle θ_{PVCN} versus the orientation of magnetic field α is shown in Table I. Within experimental error the pretilt does not depend strongly on the orientation of the magnetic field. Additionally, we found that θ_{PVCN} does not correlate well with exposure time: exposure times ranging from 10 to 240 min resulted in pretilt angles θ_{PVCN} varying between 15 and 25°.

From a practical standpoint, the most important physical parameters are the temporal and thermal stability of the pretilt angle and the anchoring energy of LC at the alignment surface. These are discussed below.

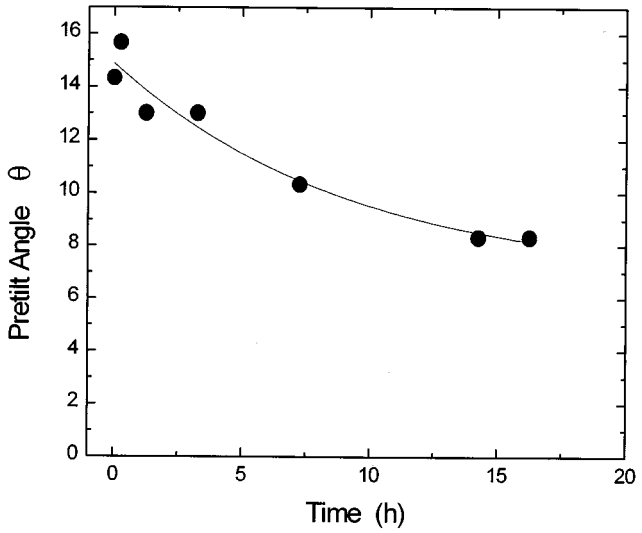

FIG. 2. Pretilt angle vs time for cell elevated to 90 °C after irradiation in the presence of a magnetic field. The last point corresponds to the pretilt angle after this treatment followed by increasing the temperature to 145 °C for 2 h.

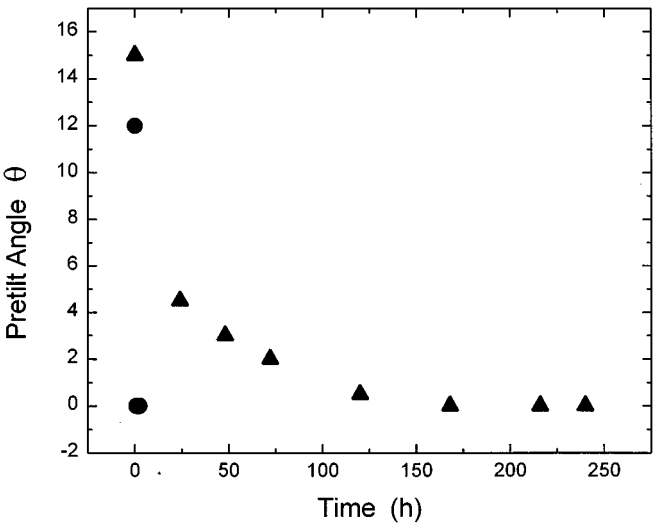

FIG. 3. Pretilt angle vs time for cell at room temperature (triangles) after irradiation in the absence of the magnetic field. Circles indicate pretilt relaxation under same condition, except at 40 °C.

B. Stability of the pretilt

We found that the magnetic field-mediated photoalignment was very stable. Measuring the tilt angle approximately 1700 h (2 1/2 months) after the initial measurement was made, we obtained the same values of θ_{PVCN} within experimental error; no decay of the tilt angle was observed.

In addition to the temporal stability, we have investigated the thermal stability of the tilt. A mixed cell that was subsequently elevated to 90 °C for some time and then quickly cooled back into the nematic phase for a measurement of θ_{PVCN}. This was done repeatedly with the sample quickly reheated and held at 90 °C until the next measurement. The tilt angle was observed to decay (Fig. 2) from its initial value. After 14 h, the temperature was instead elevated to 145 °C for an additional 2 h. On cooling the cell back into the nematic phase, it was found that the tilt angle was relatively unaffected, although there was a change in the $I(\beta)$ curve and a decrease in contrast.

The symmetric cells filled with nematic LC after irradiation without magnetic field exhibited an initial tilt. We believe this is due to flow alignment. The tilt decayed to zero within 15 min at $T=40°$ (Fig. 3, Ref. 11). In Fig. 3 we also show the degradation of the tilt angle at room temperature after irradiation in the absence of a magnetic field (triangles). Although the room temperature decay is much slower than the decay at 40 °C, the pretilt of this cell is clearly far less temporally robust than that of the cell that was irradiated in the presence of the magnetic field; recall that that cell was unchanged after 2 1/2 months.

C. Anchoring energy

Phase retardation measurements for the symmetric cells under the action of a magnetic field were used to define the polar anchoring strength coefficient W. [W is defined such that there is an energy $F_S=-1/2W(\mathbf{n}\cdot\mathbf{e})^2$ associated with the orientation θ of the director ($\mathbf{n}$) and orientation θ_{PVCN} of the easy axis $\mathbf{e}$.[10] For small $\theta-\theta_{\mathrm{PVCN}}$, the physically relevant part of F_S corresponds to the energy cost $1/2W(\theta-\theta_{\mathrm{PVCN}})^2$.] The orientation of the magnetic field was varied from the easy axis direction, and the phase retardation was measured as a function of the magnetic field strength and angle of the magnetic field (see Ref. 16 for details). All phase retardation measurements were performed with a He-Ne laser beam directed perpendicular to the cell. For small deviations of the magnetic field from the easy axis, the director profile in the cell, and therefore the phase retardation, can be calculated analytically. The measured phase retardation $\Delta\Phi(\alpha,H)$ was fitted to the analytical expression to obtain W. For cell 2 (cf. Table I) we obtained $W\approx 2.6\times10^{-3}$ erg/cm^2, and for cell 5 we obtained $W\approx 1.7\times10^{-3}$ erg/cm^2. Figure 4 illustrates the experimental data and fitted curves. Similar measurements for PVCN-F substrates

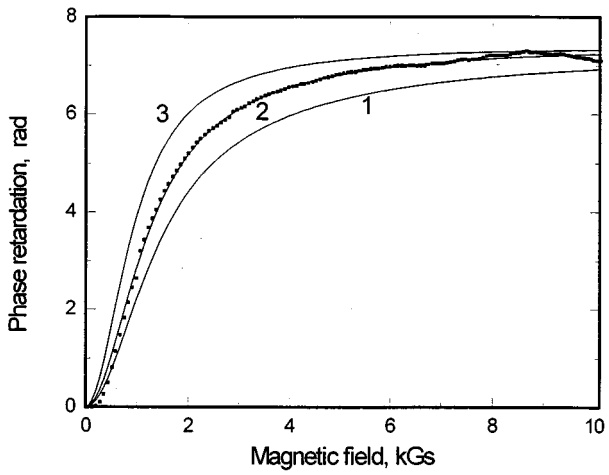

FIG. 4. Phase retardation vs magnetic field (circles—experimental points, curve 1—fitting for anchoring energy $W=10^{-3}$ erg/cm^2, curve 2—fitting for $W=2.6\times10^{-3}$ erg/cm^2, curve 3—fitting for $W=10^{-2}$ erg/cm^2).

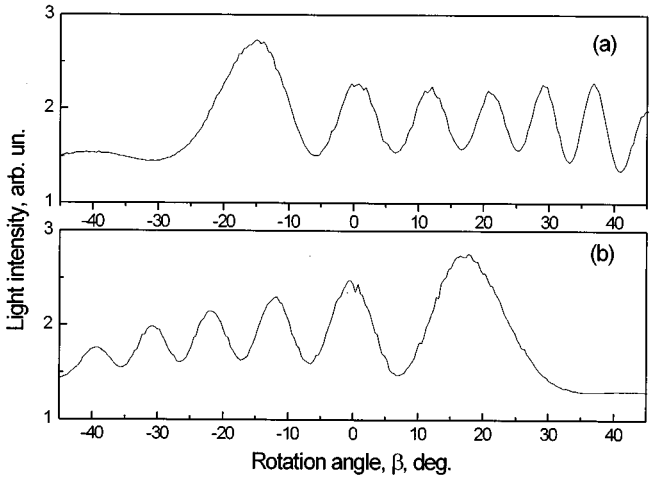

FIG. 5. Intensity traces vs rotation angle. (a) just after field-mediated photoalignment, (b) after application of field.

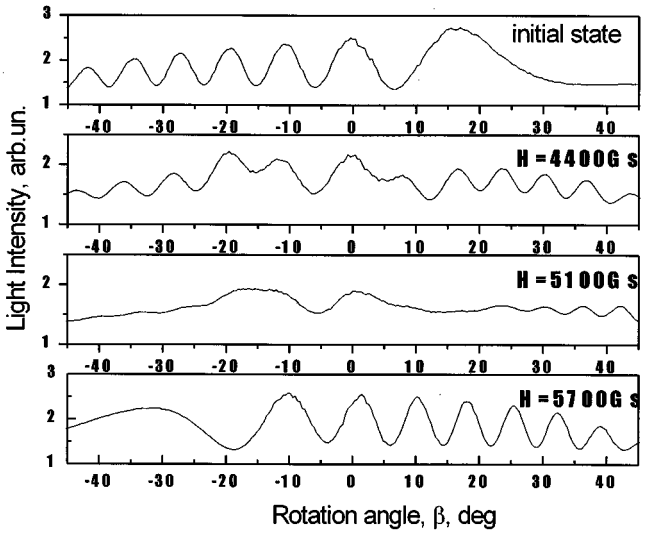

FIG. 6. Intensity traces vs rotation angle for the different values of a magnetic field.

that have been photoaligned without a magnetic field gave values of the same order of magnitude for W.

D. Easy axis bistability

As mentioned above, in the absence of a magnetic field the photoinduced easy axis is, in principle, twofold degenerate. Therefore a transition should exist between the two equivalent directions of the easy axis. The energy barrier between these states depends on the microscopic nature of the easy axis, and could hardly be known in advance. This raises an interesting question: If the cell is initially treated with the magnetic field oriented at angle α, and then is reheated into the isotropic phase and cooled with the field oriented at some new angle α^* (for example, $\alpha^* = -\alpha$), will the pretilt switch from θ_{PVCN} to $\pi - \theta_{\mathrm{PVCN}}$?

We performed this experiment in the mixed cell, and the results obtained are presented in Fig. 5. The upper plot represents the experimental curve $I(\beta)$ obtained after the initial magnetically-mediated phototreatment. The bottom plot was obtained after the subsequent heating up to 50 °C and slow cooling to room temperature in the magnetic field oriented at $\alpha^* = -\alpha$. One can see the obvious switching of the pretilt angle from θ_{PVCN} to $\pi - \theta_{\mathrm{PVCN}}$. This switching was possible not only at $\alpha^* = -\alpha$, but at other magnetic field orientations α^* as well. We observed the transition at the angles $\alpha^* = -80$; -70; $-60°$ and $-45°$, for the initial process at $\alpha = 45°$. For $\alpha^* = 0$ and 90°, an irregular dependence $I(\beta)$ was obtained, i.e., the initial pretilt alignment was destroyed.

The transition between the two directions θ_{PVCN} and $\pi - \theta_{\mathrm{PVCN}}$ of the easy axis was found to be possible only if the magnetic field was rather strong and if the sample was first reheated to, and subsequently cooled from, the isotropic phase. The form of the resulting $I(\beta)$ essentially depended on the value of the magnetic field strength (Fig. 6). On cooling from the isotropic to the nematic phase in a relatively weak field $H \leqslant 4.4$ kG we found that $I(\beta, \theta_{\mathrm{PVCN}})$ was typical for multidomain structures with two opposite directions of tilt. Larger magnetic fields caused ''development'' of the curve $I(\beta; \pi - \theta_{\mathrm{PVCN}})$, i.e., to favor a complete reversal of the pretilt direction. At $H > 5.7$ kG the profile of $I(\beta)$ was found to be symmetric with respect to the initial curve, i.e., there was a complete transition from the initial pretilt angle θ_{PVCN} to the symmetric one, $\pi - \theta_{\mathrm{PVCN}}$.

Attempts to switch between the two easy axis directions θ_{PVCN} and $\pi - \theta_{\mathrm{PVCN}}$ by the magnetic field while in the isotropic state failed, i.e., we did not find any changes in the initial curve $I(\beta)$ after the cell was cooled to room temperature. We conclude that the action of the elastic torque of the bulk LC is necessary for the transition between the θ_{PVCN} and $\pi - \theta_{\mathrm{PVCN}}$ orientations.

To realize this transition solely in the nematic phase (without cooling from the isotropic phase) it is necessary to overcome not only the local intermolecular forces at the PVCN-F surface, but also orientational elastic forces. These elastic forces can prevent the transition to another direction of the easy axis. For example, the orientational states in the mixed cell characterized by the angles (θ_{PVCN}, θ_{PI}) and ($\pi - \theta_{\mathrm{PVCN}}$, θ_{PI}) are not topologically equivalent to each other, and disclination lines appear during the transition. As a result, the barrier between equivalent states is extremely high. Actually, we could not realize the transition in the mixed cells at any field (up to 8 kG); the initial orientational state of the cells was restored when this field was turned off.

We were, however, able to achieve the transition within the nematic phase using a ''hybrid cell.'' We used a cell ($L = 65$ μm) with one substrate covered with a homeotropically orienting polymer (azo-containing acrylate) and the other substrate with PVCN-F. In this cell the states with pretilt angles θ_{PVCN} and $\pi - \theta_{\mathrm{PVCN}}$ are topologically equivalent. The cell was treated to obtain the pretilt angle on the PVCN-F surface as described above. Unfortunately, we could not measure the pretilt angle at the PVCN-F surface because of the large average tilt in the cell. Nevertheless, the cell obviously demonstrated homogeneous tilted alignment: Between crossed polarizers it displayed clear asymmetric changes of brightness while the cell was rotated about the

axis perpendicular to the director (the director made the angle 45° to the axes of polarizers). For example, the cell became more transparent while it was rotated clockwise, and became darker under counterclockwise rotation. In this kind of hybrid cell the director distributions for both easy axes are topologically equivalent and orientational defects do not appear during the reorientation.

To switch the easy axis direction in the hybrid cell, the cell was placed between the magnet poles so that the angle α between **H** and the cell normal was -2 to $-5°$. Assuming a pretilt angle $\theta_{\mathrm{PVCN}} \sim 20°$ with respect to the cell plane, the angle between the easy axis direction and the magnetic field was 72–75°. In this geometry a rather strong magnetic field in the nematic phase reorients the bulk director along **H**, and the system may undergo a transition to the state given by the angle $\pi - \theta_{\mathrm{PVCN}}$. Experimentally, a transition was indeed obtained in the nematic phase at temperatures $T_{\mathrm{NI}} - T \approx 2-5\,°\mathrm{C}$ at a field $H = 7-8$ kG. Subsequent rotation of the cell between crossed polarizers revealed behavior similar to that observed before, although with the opposite sense. The change of the rotation asymmetry can be also observed from the experimental curves $I(\beta)$. We could not realize the field-induced transition at lower temperatures, however.

IV. DISCUSSION

The nature and mechanism of magneto-UV induced alignment deserves further study. Although a complete picture is still lacking, in this section we shall consider several of the observed phenomena and conjecture about their significance. We speculate that the underlying mechanism for the effect is the tilted arrangement of the photosensitive side fragments of PVCN-F induced by LC molecules under the action of the magnetic field. Application of the magnetic field during UV irradiation while cooling from the isotropic phase leads to alignment of the bulk nematic phase along the field direction. Although anchoring may inhibit the director at the surfaces, the elastic torque from the bulk interior still results in a significant pretilt—with the same orientational sense as the magnetic field—at the surfaces. The aligned LC, interacting with the side fragments of the polymer, in turn orients the polymer. The crosslinking between the oriented side fragments ''freezes in'' this structure. The resulting anisotropic polar distribution of the side fragments and their photoderivatives provide the tilted LC alignment which is stable in time and temperature. In the absence of the magnetic field the resulting distribution is isotropic and the easy axis is in the plane of the substrate.

To estimate the magnetic field needed to induce a pretilt angle θ_{PVCN} on the PVCN substrate, we recall that, in the absence of a magnetic field, the easy axis on the PVCN is planar. For a magnetic field **H**, when the magnetic coherence length $\xi_H = [K/(\chi_a H^2)]^{1/2} \ll L$, the director in the interior of the cell is virtually parallel to **H**. Within a magnetic coherence length ξ_H of the surface the orientation is determined by a competition between the surface anchoring and the elastic torque. Here K is an appropriate elastic constant and χ_a is the magnetic susceptibility anisotropy. From the development in Ref. 17 one can show that, for a cell with thickness $L \gg \xi_H$ and in the equal elastic constant approximation, the tilt angle θ_{PVCN} at the surface is given by the implicit equation

$$\tfrac{1}{2}\, W \sin(2\theta_{\mathrm{PVCN}}) = (K\chi_a H^2)^{1/2} \cos(\theta_{PVCN} + \alpha), \qquad (2)$$

For the material 5CB, $K = 6\times10^{-7}$ dyne and $\chi_a = 1.8 \times 10^{-7}$ cgs; we therefore find $\xi_H = 3\,\mu\mathrm{m} \ll L$ at $H = 7$ kG. Substituting $\alpha = 45°$ and the value $W = 2\times10^{-3}$ erg/cm^2, corresponding to the polar anchoring energy at the room temperature, we find a pretilt angle $\theta_{\mathrm{PVCN}} \sim 25°$. This indicates that the magnetic field can induce a significant tilt at the surface, which may be locked in upon polymerization. We note that this value for W corresponds that obtained after alignment in the field. A smaller or larger value of W for the initial magneto-UV alignment process would correspondingly increase or decrease θ_{PVCN}. Nevertheless, the important point is that we may obtain significant pretilt angles with readily available magnetic fields.

We could achieve only poor alignment in a magnetic field when the sample was not first heated into the isotropic phase, but kept only in the nematic phase. We also could not achieve uniform tilted UV-magneto alignment under these conditions. We believe that this is due to the alignment memory effect,[18] which is very strong for the pair PVCN-F-5CB and results in poor alignment during the crosslinking. The correspondences between poorly alignment during crosslinking and the poor final alignment confirms the hypothesis that the effect of liquid crystal alignment on the photoreaction causes the UV-magneto alignment.

As discussed above, it's possible to switch the director orientation in the hybrid cell between distributions with the tilt angles θ_{PVCN} and $\pi - \theta_{\mathrm{PVCN}}$ on application of a suitable magnetic field. This suggests that the PVCN-F surfaces treated in the magnetic field possess two possible directions of the tilted easy axis, i.e., a doubly-degenerate easy axis. Recall that the initial pretilt angle θ does not seem to depend on the orientation α of the magnetic field during the magneto-photoalignment (Table I). Moreover, we found that the second preferred pretilt angle is symmetric to the first, viz., $\theta_{\mathrm{PVCN},2} = \pi - \theta_{\mathrm{PVCN},1}$. This would suggest that the direction of the easy axis induced by magneto-phototreatment is a feature of the PVCN-F-5CB interface. In particular, the liquid crystal, when oriented by the magnetic field, orients the side fragments of PVCN-F, resulting in an arrangement of LC molecules and side-fragments of PVCN-F which is apparently independent of α. When the magnetic field is turned off, the LC molecules and side units come to their equilibrium orientations. Experimentally, the pretilt angle θ does not depend on the direction of the magnetic field during the treatment. From these observations we surmise that the role of the magnetic field is only to form the ordered structure on the surface in polar plane. Since there are two equilibrium directions of the pretilt, a transition from the tilt θ_{PVCN} to the symmetric value $\pi - \theta_{\mathrm{PVCN}}$ should be possible. The reason for this apparent independence of θ_{PVCN} on α needs further investigation.

Based upon these observations, we assume a pair of symmetric easy axes $\mathbf{e}_+$ and $\mathbf{e}_-$. The effective pretilt axis may then be written $\mathbf{e} = \mathbf{e}_+ \Theta(\pi/2 - \theta_{\mathrm{PVCN}}) + \mathbf{e}_- \Theta(\theta_{\mathrm{PVCN}}$

$-\pi/2)$, where $\Theta(x)$ is the Heaviside step function. Since the surface energy in the Rapini approach is $F=-1/2W(\mathbf{n}\cdot\mathbf{e})^2$, two minima as a function of director orientation exist. In this formalism we see that, if the tilt angle θ_{PVCN} exceeds $\pi/2$, the LC molecules may reorient the easy axis direction to the state with the angle $\pi-\theta_{\mathrm{PVCN}}$.

We can now estimate the magnetic field necessary for the transition between equivalent easy axis directions. Equation (2) can be generalized to the case of an initial easy axis at orientation θ_{PVCN} and a subsequent magnetic-field-induced orientation (in the absence of UV) to angle θ. We then have $1/2W \sin 2(\theta-\theta_{\mathrm{PVCN}})=(K\chi_a H^2)^{1/2}\cos(\theta+\alpha)$. Because of the large angles involved, this expression is clearly approximate, however it is useful to obtain orders of magnitude. For a transition to the opposite easy axis orientation to occur, the field must induce a director orientation from θ_{PVCN} to angle θ, where θ must be slightly larger than 90°. (If $\theta<90°$, the director would fall back to the initial pretilt on removal of the field; for $\theta>90°$, the director goes to $\pi-\theta_{\mathrm{PVCN}}$ on removal of the field.) Thus, on substituting into Eq. (2) room temperature values of the magnetooptically induced easy axis angle $\theta_{\mathrm{PVCN}}=20°$, $\alpha=-10°$, $\theta=90°$, and $W=2\times10^{-3}$ erg/cm^2, we find $H\sim11$ kG. Since the upper limit of our field is 8 kG, it is reasonable that we could not observe switching at room temperature. At the same time it is reasonable that the critical magnetic field decreases near the clearing point where this transition was observed.

V. CONCLUSIONS

Magneto-optical alignment of the nematic liquid crystal 5 CB leads to a bistable tilted orientation of the easy axis on the PVCN-F surface. The alignment is characterized by high temporal and thermal stability, weak polar anchoring ($W\approx2\times10^{-3}$ erg/cm^2) and a large barrier between equivalent directions of the easy axis ($H\approx6-8$ kG). The induced tilt angle $\theta_{\mathrm{PVCN}}=(15-25)°$ does not depend on the direction of the magnetic field over a wide range of magnetic field orientations α.

The results are examined in terms of a model for the formation of an anisotropic spatial distribution of the side fragments of PVCN-F and their photoderivatives on the polymer surface. These interact with, and are oriented by, the LC molecules, which in turn are oriented by a magnetic field. The structure of the oriented side fragments is fixed with the UV light due to their crosslinking, thereby determining the easy axis direction. Reorientation of the director with a magnetic field can apparently switch the easy axis to the symmetric tilted direction, although the mechanism for this behavior requires further elucidation.

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