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Experimental studies of the dynamics of jumps of the period of stripes (PS) for the electrically induced 'fingerprint' texture of thin planar cholesteric layers are carried out for various values of the anchoring energy of substrates of liquid crystal (LC) cells. The nematic LC E7 doped by ZLI-3786 (R-811, Merck, Darmstadt, Germany) at a concentration 1.5 wt.% was used as the induced cholesteric with the helix pitch 5 μm. The ratio between the cell thickness and the cholesteric pitch was approximately 1.6. To study the influence of the anchoring energy W on jumps of the PS in the electric field, two polymers (oxidianiline-polyimide and polyvinyl-cinnamate) for the planar alignment of cholesterics were used. The anchoring energy of surfaces of polymers changes under the exposure to UV light. Experimentally, it was shown that jumps of the PS significantly depends on the value of the anchoring energy: (a) for the strong surface anchoring, jumps of the PS are observed; (b) for the sufficiently weak anchoring, no jumps are observed. The phenomenon of hysteresis of jumps of the PS is experimentally found when the electric field changes in the opposite direction.

Keywords: hysteresis; cholesteric liquid crystals; diffraction gratings; anchoring energy

Introduction

It is known that the addition of chiral dopants to nematic liquid crystals (LCs) leads to the formation of the helical structure in which the director n is twisted uniformly along the helical axis. Cholesteric liquid crystals (CLCs) are characterised by a pitch p and handedness of the helix. Due to the helical structure of CLCs, a phenomenon of the selective reflection of light (Bragg diffraction at the maximum wavelength $\lambda_{max} = \tilde{n}\cdot p$, where $\tilde{n}$ is the average refractivity index) is observed for the *planar* texture of cholesteric layers, where the helical axis is perpendicular to the plane of the LC cell.[1,2] When the helical axis is parallel to substrates of the LC cell, the *homeotropic* texture of CLCs (or the so-called 'fingerprint' texture) can be obtained on a condition that the chiral torque is strong enough with respect to the elastic torque determined by the orientational elasticity and anchoring.[1,3] It is well known that a pitch of the cholesteric helix p can be sensitive to various external fields (temperature, electric or magnetic fields and light).

Recently, detailed studies of thin planar layers of CLCs indicate great interest not only from the viewpoint of theoretical investigations but also because of their practical applications. For example, planar layers of CLCs have been considered for various applications (displays, thermometers and sensors for visualisation of temperature, optical elements for lasers, mirrors, light shutters and reflectors).[4–9]

In addition, specific modulated fingerprint textures (a high uniformity of the structure of the stripe pattern or the so-called undulation texture) were obtained by applying the alternating electric field parallel to the helical axis of the planar texture of CLCs.[10–13] On the basis of the formation of stripes, authors classified two types of fingerprint textures: (a) the so-called developable modulation (DM) and (b) growing modulation (GM), depending on the ratio between the thickness d of the LC cell and pitch p of the cholesteric helix.[11,12,14] It was shown that for the ratio range $0.5 < d/p < 1$, the DM type of the cholesteric grating is formed with periodic stripe patterns, which are perpendicular to the rubbing direction, and their contrast increases with time. For the ratio $d/p \geq 1.5$, two types of patterns (DM and GM) are formed simultaneously, but the GM type dominates as shown in [14]. The usage of the modulated fingerprint structure for switchable cholesteric gratings of the Raman–Nath type [15,16] with the electrically controlled period of stripe patterns, the dynamics of the formation of patterns and the beam-steering characteristics of diffraction gratings were described in [11,12,14]. Recently, photoswitchable cholesteric gratings were studied in [17].

It was noted experimentally that for thin planar layers with a whole number of half-pitches across the thickness of the LC cell, having strong anchoring conditions on the surface of substrates, the so-called jumps of the cholesteric pitch could be observed when

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the temperature changed.[18,19] It was shown that photoinduced jumps of the cholesteric pitch depend on the value of the anchoring parameter [20]:

$$\xi = W \cdot d / K_{22} \tag{1}$$

where W is the anchoring energy, d is the thickness of the LC cell and K_{22} is the twist elastic constant of LC. For sufficiently great values of the anchoring parameter ξ = 2 and 5 jumps of the cholesteric pitch were observed. When ξ is sufficiently small, the cholesteric pitch is monotonically unwinding with an exposure dose (or with the temperature for homeotropic boundary conditions [19]) and no jumps were observed.[20]

The fact that the phenomenon of jumps of the cholesteric pitch in thin planar layers could be observed due to the competition between the twist energy and surface-anchoring energy was theoretically described.[21–26] It was also shown that when an external field (temperature, electric or magnetic field [26]) changed in the opposite direction, hysteresis of jumps of the cholesteric pitch in thin cholesteric layers could be observed.[21,22]

The first hysteresis effects in LC cells were experimentally obtained for the optical transmission of thick planar layers of CLCs (around 20–25μm) in the electric field,[27] and under the relatively low intensity of the light excitation (the laser pumping power was about 1 kW) with the small radiation pulse duration (about 8 ns).[28] For thick LC cells with the homeotropically aligned cholesteric–nematic mixture based on nematic E7 doped with various concentrations of cholesteric C15, the optical Freedericksz transition (birefringence jumps under the laser intensity), accompanied by a very large hysteresis, has been observed.[29]

It was described theoretically that hysteresis of pitch jumps is related to the surface anchoring W and cell thickness d.[20–22,24] When the twist energy dominates over the anchoring energy in the thick LC cell, then the director rotation at the surface is a completely reversible process and no hysteresis can be observed. For thin cholesteric layers, when the anchoring energy is more than the twist energy, the electric field dependence of pitch jumps is different with the increase and decrease of voltage, and hysteresis can be well observed.[21,22]

By measuring the selective reflection of the wavelength, thermal jumps of the cholesteric pitch was experimentally found for the thin planar alignment of the cholesteric layer (about 5 μm), where the pitch decreases with the increase of the temperature.[19] For LC cells with homeotropic boundary conditions, the monotonic change of the helix pitch under the temperature was found. It is shown that planar and homeotropic surface alignment layers have a different effect and mechanisms of changes of the helical pitch under the temperature. It should be noted that for thin cholesteric layers with various boundary conditions, the phenomenon of hysteresis of changes of the helix pitch has not been experimentally studied in [19].

By using the phenomenon of the selective reflection of light, hysteresis of jumps of the helix pitch p under the temperature was experimentally investigated for thin planar cholesteric layers with strong boundary conditions.[18] Here, authors chose samples with a pitch, sensitive to the temperature, and used the high-resolution reflection spectra technique to provide accurate measurements of pitch changes (selective reflection wavelength λ_{max}) during the heating or cooling of LC cells. It was concluded that during jumps of the helix pitch, surface directors changed in a manner consistent with coiling or uncoiling a spring.

In this article, the dependence of jumps of the period of stripes (PS) for the electrically induced 'fingerprint' texture (undulation texture) in thin cholesteric layers on various values of the anchoring energy W will be experimentally described.

Experiment

To study hysteresis of jumps of the PS in the electric field, the induced CLC, based on the right-handed chiral dopant (ChD) ZLI-3786 (R-811, Merck, Darmstadt, Germany) at concentration $C_{R\text{-}811}$ = 1.5 wt.% dissolved in the nematic LC E7 (a mixture of cyano-biphenyl and terphenyl molecules, Merck), was used. The nematic E7 has a positive dielectric anisotropy $\Delta\varepsilon$ = + 13.8, elastic constant $K_{22} = 5.82 \cdot 10^{-12}$ N and the isotropic transition temperature T_{iso} = 59.8°C.

To measure the length of the cholesteric pitch, the Grandjean–Cano method was used.[30,31] In all experiments, the cholesteric helix pitch p was fixed and equal to 5 μm.

To study the influence of changes of the anchoring energy W on jumps of the PS in the electric field, two types of polymers for the planar alignment of CLC were used. To ensure the strong anchoring energy of alignment layer, the polymer oxidianiline-polyimide (ODAPI) (Kapton from Dupont is a commercial analog of ODAPI) was used. For the achievement of the low anchoring energy W, the photo-polymer polyvinyl-cinnamate (PVCN) was also used.

ODAPI solution in dimethylformamide was spin coated (7000 rpm, 5 s) on glass substrates, covered with transparent indium tin oxide electrodes and further annealed for 90 min at a temperature of

190°C, as described in [32]. Thereafter, thin films of ODAPI were unidirectionally rubbed. To decrease the anchoring energy of ODAPI layers, rubbed films were additionally irradiated by depolarised UV light from 450W Xenon lamp (Oriel, model 6266), as it was early proposed by the authors in [33].

PVCN solution in dichloroethane was spin coated (4000 rpm, 30 s) and annealed at 80°C for 90 min in order to evaporate the residual solvent. To increase the anchoring energy of PVCN layers, polymer films were irradiated through the Glan–Thompson prism by ensuring polarised UV light from Hg-lamp (the integral intensity in the plane of the substrate was 20 mW/cm^2).[34,35]

To measure the anchoring energy W on irradiated polymer films, as a characteristic of the LC alignment, twist LC cells constructed from two substrates (reference and tested) were prepared. The reference substrate was a non-irradiated rubbed ODAPI film, ensuring the strong planar anchoring of the nematic LC E7. The easy axis of the reference substrate with ODAPI film was given by the direction of rubbing. Substrates with tested polymer films were irradiated with a different exposure time in a range 0–15 hours for ODAPI and 0–30 min for PVCN, through a special mask to ensure areas with a different value of the anchoring energy W. The easy axis of the tested substrates (irradiated ODAPI or PVCN films) is given by the direction of rubbing or the angle of polarisation of UV light, respectively. The angle between the easy axis of the reference substrate and the tested substrate for ODAPI and PVCN films was 90° and 45°, respectively. The thickness d of twist LC cells was in a range around 22–24 μm and controlled by spherical spacers. LC cells were filled with E7 in the isotropic phase and slowly cooled to the room temperature to avoid the possible flow alignment.

To study the hysteresis of jumps of the PS in the electric field, plane-parallel symmetrical LC cells were prepared. LC cells with unidirectionally rubbed ODAPI films were assembled using substrates, which had opposite rubbing on both aligning surfaces. In case of LC cells, which were assembled using both substrates with irradiated PVCN films, the polarisation axis during UV light exposure had the identical direction.

To determine the thickness of LC cells, the interference method of measuring the transmission spectra of empty cells was used. The LC cell thickness d was about 8 μm. For all studies, the ratio between the cell thickness and cholesteric pitch was around $d/p \approx 1.6$.

To observe stripes of the pattern (the PS) of the undulation texture forming by AC field, the polarising microscope Biolar (PZO, Poland), equipped with the digital camera Nikon D80 (Nikon, Japan) with the close-up attachment KO-H/52 (Arsenal, Ukraine) for the macroscopic survey, was used. AC voltage with a frequency 10 kHz was applied to samples by using the frequency generator GZ-109 (Pskov Region, Russia).

Results and discussion

Measurement of the azimuthal anchoring energy W of polymer films

First of all, the dependence of the azimuthal anchoring energy of PVCN film on the exposure time was studied. The photograph (Figure 1) shows a general top view of the twist LC cell of 24 μm thickness, consisting of the reference substrate (rubbed ODAPI) and tested substrate (non-irradiated and irradiated areas of PVCN), between crossed polarisers.

The background of the LC cell, around the area with stripes, which is depicted in the photograph (Figure 1) by a rectangle with a red dashed line, corresponds to the non-irradiated area of PVCN film. For this area, no transmission of light is observed, because the twist angle φ = 0. Owing to the low anchoring energy of the non-irradiated area of PVCN film, the strong planar orientation in one direction of the nematic E7 is specified exclusively by orientation, which is formed at the reference substrate

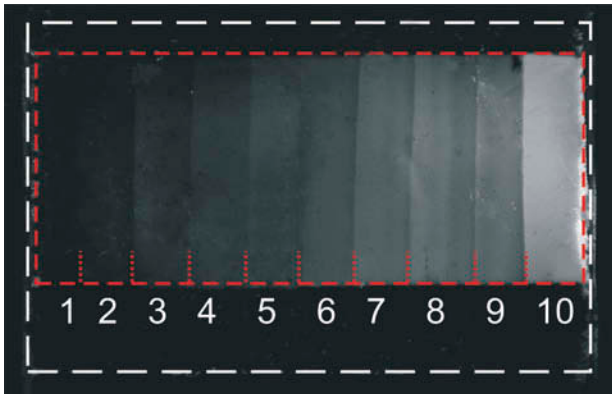

Figure 1. (colour online) Photograph of the twist LC cell (d = 24 μm) between crossed polarisers. The LC cell consists of the reference substrate (rubbed ODAPI film) and tested substrate (PVCN film). The contour of the LC cell is depicted by a rectangle with a white dashed line. The tested substrate with PVCN film is irradiated through a proximity mask so that the exposure time is 5, 10, 15, 20, 25, 30, 60, 90, 120, 300 s in areas 1, 2, …10, respectively. During the exposure of PVCN film, the UV light is linearly polarised at an angle of 45° to the horizontal plane (a long side of the LC cell). The contour of irradiated areas with various exposure times is indicated by a rectangle with a red dashed line. The background of the LC cell corresponds to the non-irradiated area of PVCN film.

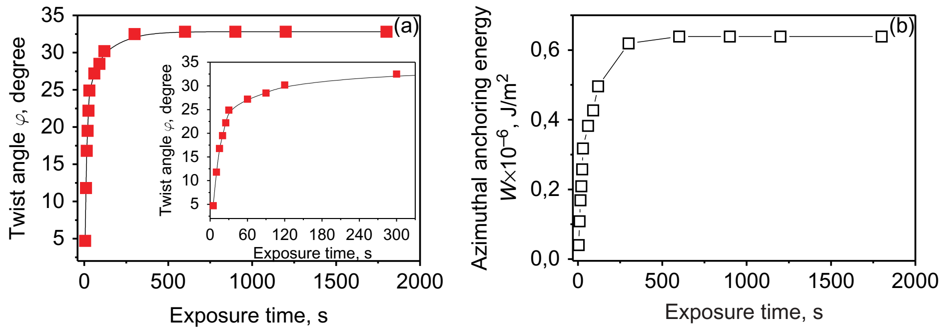

Figure 2. (colour online) Dependencies of the twist angle φ (a) and calculated azimuthal anchoring energy W (b) on the exposure time for the twist LC cell (d = 24 µm). The LC cell was constructed from the reference substrate with rubbed ODAPI film and tested substrate with PVCN film, which is irradiated with various exposure times, forming narrow areas. The inset depicts the dependence φ–(t) in the enlarged scale.

(rubbed ODAPI film). As it can be seen from Figure 1, the twist angle from the area 1 to 10 is increased and the transmission of light is observed.

The dependence of the twist angle φ (between the director of the reference ODAPI and tested PVCN surfaces) on the exposure time is shown in Figure 2(a). The maximal twist angle φ = 33° was observed for the area 10, which corresponds to the long exposure time (t_{exp} ≥ 300 s) of PVCN film, as can be seen from Figure 2(a). According to [34,36], the twist angle φ is related to the value of the azimuthal anchoring energy W as:

$$W = K_{22} \cdot 2sin\varphi/d \cdot sin2(\varphi' - \varphi) \qquad (2)$$

where d is the thickness of the LC cell, φ' = 45° is the fixed angle of the linearly polarised UV light and φ is the measured twist angle.

The dependence of the calculated azimuthal anchoring energy W on the exposure time, by using Equation (2), is shown in Figure 2(b). For these experimental conditions, the maximal value of the anchoring energy $W \sim 0.6 \cdot 10^{-6}$ J/m^2 is observed for the prolonged exposure time t_{exp} ≥ 300 s.

As it was shown in [33], the irradiation of the rubbed ODAPI film leads to the decrease of the anchoring energy W. This idea was used for the study of jumps of the PS in the electric field depending on various values of the anchoring energy W. At the beginning, the dependence of the anchoring energy W on the exposure time was studied. Finally, few values of the anchoring energy W were used to investigate jumps of the PS in the undulation texture.

The dependence of the twist angle on the exposure time for the twist LC cell, assembled from the reference (non-irradiated rubbed ODAPI film) and tested (rubbed ODAPI film, irradiated by non-polarised UV light) substrates, is shown in Figure 3(a).

For the non-irradiated area of ODAPI film (t_{exp} = 0 hours), where the twist angle φ = 89°, the maximal transmittance of the LC cell between crossed polarisers was observed. In this case, the anchoring energy W, calculated by Equation (2), has the maximal value around $15 \cdot 10^{-6}$ J/m^2. The further illumination of

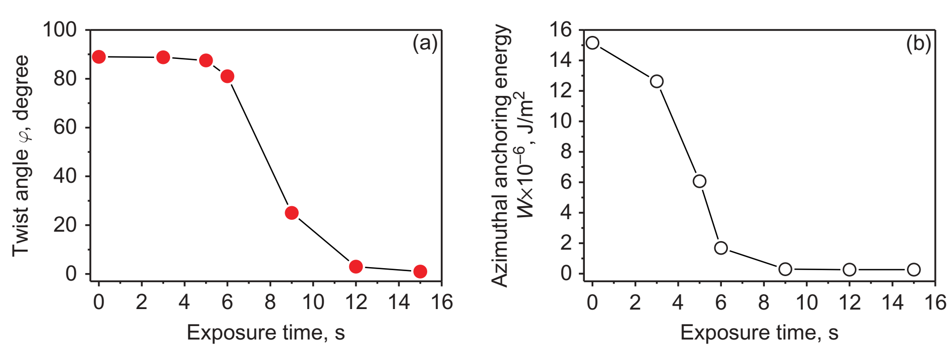

Figure 3. (colour online) Dependencies of the twist angle φ (a) and calculated azimuthal anchoring energy W (b) on the exposure time for the twist LC cell (d = 22 µm). The LC cell was constructed with the reference substrate with the rubbed ODAPI film and tested substrate with the rubbed ODAPI film, which is irradiated by non-polarised UV light from the Xenon lamp under various exposure times, forming narrow areas.

ODAPI film leads to photodestruction of polymer chains,[33] and the anchoring energy W and transmittance of the LC cell are decreased. The dependence of the azimuthal anchoring energy W on the exposure time is shown in Figure 3(b). As it can be seen from Figure 3, the prolonged exposure leads to the decrease of the twist angle φ, transmittance of the LC cell and the anchoring energy W of the polymer film. Minimal values of the anchoring energy $W \sim 0.3 \cdot 10^{-6}$ J/m^2 are observed for the exposure time range t_{exp} = 9–15 hours.

Hysteresis of jumps of the PS

Here, hysteresis of jumps of the PS for symmetrical LC cells, assembled from two substrates with ODAPI (or PVCN) films, will be described.

For this purpose, the electric field-induced texture of the planar cholesteric structure, the so-called undulations, [11,12,14] was used. It is known that this texture strongly depends on the ratio between the cell thickness and cholesteric pitch (d/p). These undulations form the unidirectionally oriented fingerprint texture of cholesteric (or so-called stripes of the diffraction grating). As mentioned in [14] when the ratio $d/p \geq 1.5$, then stripes of the undulation texture are always parallel to the rubbing direction.

According to [14], the PS of the undulation texture progressively changes due to the application of the electric field to a sample. As a result, the fingerprint texture of cholesteric can be unwound to the homeotropic texture of nematic with an increase of the applied field.

Typical sequential changes of the PS of the undulation texture in thin cholesteric layers (d = 8 μm) during the increase of the value of the applied field at a frequency 10 kHz are shown in Figure 4. The increase of the applied electric field leads to the

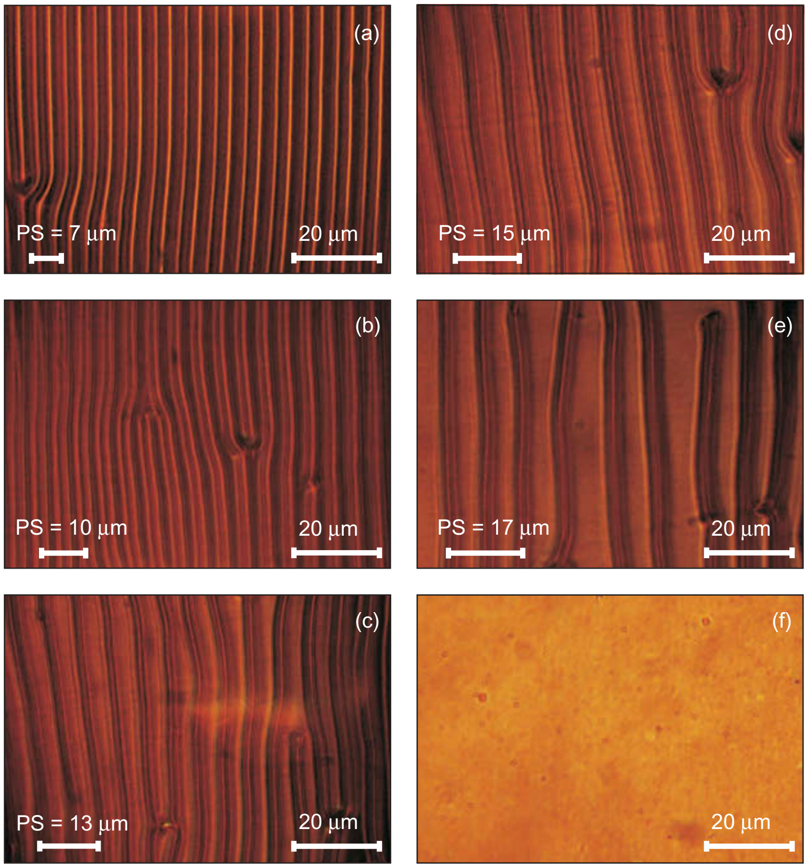

Figure 4. Photographs of the sequential changes of the PS of the undulation texture in thin cholesteric layers during the increase of the value of the applied field at the frequency 10 kHz. The 8.2 μm LC cell based on the rubbed ODAPI alignment layers and filled with CLC E7 + 1.5% R-811 is viewed between parallel polarisers. The cholesteric pitch is 5 μm. The ratio between the cell thickness and cholesteric pitch is $d/p \approx 1.64$. The azimuthal anchoring energy W of ODAPI films is $15 \cdot 10^{-6}$ J/m^2. (a) The first appearance of the undulation texture at the U = 2 V. The period of stripes is 7 μm. The undulation textures at the electric fields U = 3.2 V (b), U = 3.9 V (c), U = 4.4 V (d) and U = 4.7 V (e) with the period of stripes 10, 13, 15 and 17 μm, respectively (f). The cholesteric–nematic transition under the electric field with U = 4.8 V.

increase of the PS, as it can be seen from Figure 4(b)–(e). This fact was used to study the dependence of changes of the PS under the increase and decrease of the electric field.

In Figure 5, changes of the PS are depicted for symmetrical LC cells, constructed from two substrates coated by PVCN film, having certain values of the anchoring energy W (0.2 J/m^2 and 0.6 J/m^2). In a case of the non-irradiated PVCN film, non-uniform stripes of the undulation texture were obtained, which is similar to the fingerprint texture of homeotropically oriented CLCs.[37] For this case, non-uniform stripes of the undulation texture can be steered by the electric field, and monotonic changes of the PS and cholesteric–nematic transition were observed (results are similar to Figure 5(a)).

When the anchoring energy is strong and the LC director non-monotonically slips at the surface of the alignment film, jumps of the cholesteric pitch can be observed as it was theoretically described.[21,22]

The experimental dependence of changes of the PS on the applied alternating electric field is shown in Figure 5(a) for the symmetrical LC cell, which was assembled from two substrates with PVCN films, which were irradiated during 15 s. As it can be seen from Figure 2(b), for the exposure time 15 s, the anchoring energy of PVCN film is sufficiently small ($W \sim 0.2 \cdot 10^{-6}$ J/m^2). Due to the weak value of the anchoring energy W, the PS monotonically increases with the increase of voltage U, as shown by solid symbols in Figure 5(a). The decrease of voltage U leads to the monotonic decrease of the PS as shown in Figure 5(a) by open symbols.

In a case of the weak value of the azimuthal anchoring energy W, jumps of the PS were not found experimentally. This fact is in a good agreement between experimental observations (Figure 5(a), [19]) and the theory.[21,22] However, the phenomenon of hysteresis of monotonic changes of the PS is observed when the electric field changes in opposite directions (Figure 5(a)).

It should be noted that in a case of the homeotropic orientation of the cholesteric layer, when the value of the azimuthal anchoring energy is insufficient, it was experimentally found that the PS of the undulation texture monotonically changes with the increase (or decrease) of voltage. In this case, the phenomenon of hysteresis is also observed. This result is similar to the study of the dependence of changes of the helix pitch of thin homeotropically oriented cholesteric layers on the temperature.[19] Authors obtained that the peak wavelength of the spectrum for the homeotropically oriented chiral–nematic mixture (E44 + 76 wt.% BL061) decreased continuously when the temperature increased. It was shown that the pitch of the cholesteric phase in the homeotropic cell did not jump with the temperature as it did in the planar cell.

A different situation observed with the LC cell constructed from substances with PVCN films, which were irradiated by UV light during 300 s. In this case, as it can be seen from Figure 2(b), the maximal anchoring energy $W \sim 0.6 \cdot 10^{-6}$ J/m^2 was reached. In contrast to the previously described case, when the anchoring energy W was weaker (Figure 5(a)), the director of the CLC is forced to obey surface boundary conditions, which leads to discontinuous changes of the PS with the applied electric field, as can been see from Figure 5(b). As it can be observed, the value of the PS is a bit changing, forming a single domain, over a small range of voltage. Further changes in voltage lead to the jump of the PS and a new domain will appear, when the voltage range changes insignificantly. In addition, as it can be seen from Figure 5(b), hysteresis of jumps of the

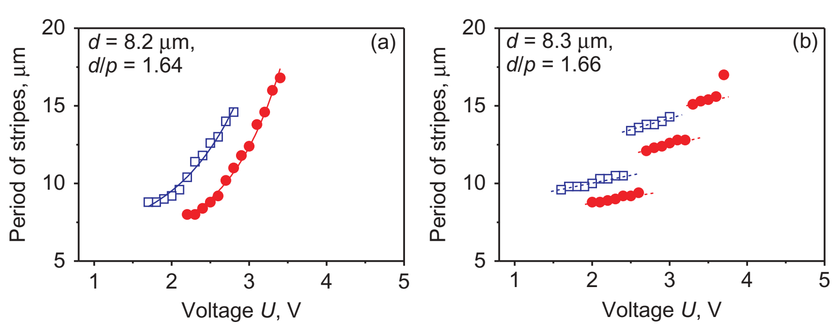

Figure 5. (colour online) Dependencies of the period of stripes in the electric field on the value of the anchoring energy W. Changes of the period of stripes during the increase (solid symbols) and decrease (open symbols) of the electric field with hysteresis: (a) monotonic dependence for the weak anchoring energy $W \sim 0.2 \cdot 10^{-6}$ J/m^2 and (b) discontinuous dependence for the strong value of the $W \sim 0.6 \cdot 10^{-6}$ J/m^2. The symmetrical LC cell with thickness 8.2 µm (a) and 8.3 µm (b) is constructed from two substrates with PVCN film, which were irradiated during 15 and 300 s, respectively. The pitch of the cholesteric helix p is 5 µm.

PS when voltage of the electric field changes in opposite directions (solid, open squares) was experimentally found. The fact that the anchoring energy W is not too strong when the director was strongly anchored with substrates of the LC cell explains slight changes of the PS in a range of a single domain.

Because of this, the study of the dependence of jumps of the PS on voltage of the electric field by the usage of ODAPI layers, which ensure a stronger anchoring energy W (Figure 3(b)) than for the irradiated PVCN layers (Figure 2(b)), will be considered below.

In Figure 6, dependencies of jumps of the PS on voltage of the electric field are shown for planar LC cells, assembled from substrates with ODAPI films, which previously were irradiated at a certain dose to change the value of the anchoring energy W.

As shown in Figure 6(a) for the LC cell, consisting of the rubbed ODAPI layers, which ensure the maximal value of the azimuthal anchoring energy $W \sim 15{\cdot}10^{-6}$ J/m^2 (Figure 2), hysteresis of jumps of the PS in the electric field is experimentally observed. In contrast to LC cells, assembled with ODAPI layers irradiated at a certain dose, ensuring the anchoring energies $W \sim 12{\cdot}10^{-6}$ J/m^2 and $6{\cdot}10^{-6}$ J/m^2 (Figure 6 (b) and (c), respectively), the PS in a single domain remains constant over a small range of voltage changes. These results qualitatively agree with theoretical [20–24] and experimental studies,[19] for changes of the value of the helix pitch in a thin layer with the temperature, when planar boundary conditions are very strong.

The irradiation of the rubbed ODAPI films leads to the decrease of the anchoring energy, and as a result the weakening of planar boundary conditions is attained as it is seen from Figure 3(b).

To study the phenomenon of hysteresis of jumps of the PS depending on various powers of the weakening, three different values of the anchoring energy W were chosen, which correspond to the exposure times t_{exp} = 3, 5 and 9 hours in Figure 3(b).

As it can be seen from Figure 6(b), (c), only for two values of the anchoring energy $W \sim 12{\cdot}10^{-6}$ J/m^2 and $6{\cdot}10^{-6}$ J/m^2, hysteresis of jumps of the PS is observed. The value of the PS in a single domain is not constant and a bit changing with the increase (or decrease) of voltage. These results are in a qualitative agreement with results, obtained for the irradiated PVCN film (t_{exp} = 300 s, $W \sim 0.6{\cdot}10^{-6}$ J/m^2) as it is shown in Figure 5(b). In a case that the anchoring energy is sufficiently weak ($W \sim 0.2{\cdot}10^{-6}$ J/m^2), no jumps are observed, and the PS monotonically

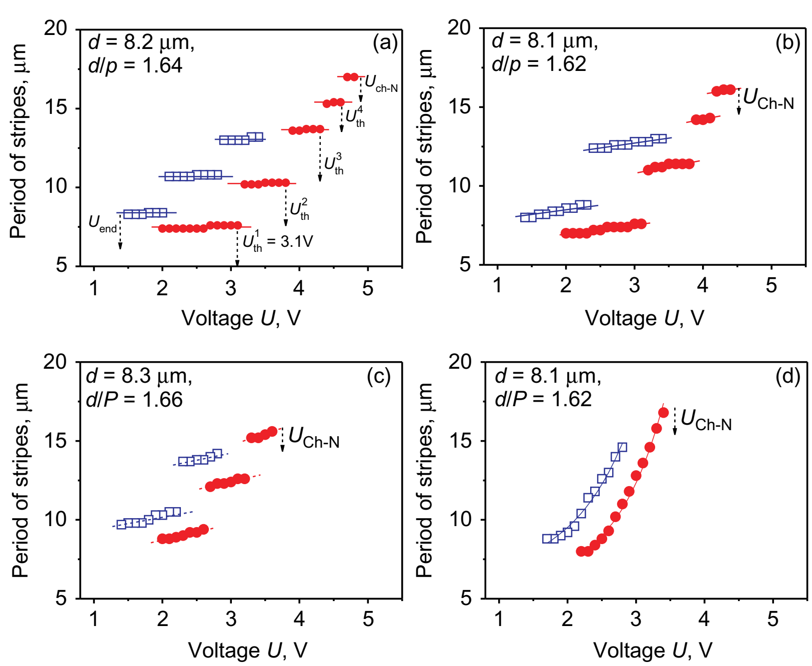

Figure 6. (colour online) Dependencies of the PS in the electric field on various values of the anchoring energy W. Changes of the PS during the increase (solid symbols) and decrease (open symbols) of the electric field with hysteresis and discontinuous dependencies for: (a) the strong anchoring energy $W \sim 15{\cdot}10^{-6}$ J/m^2, (b) for $W \sim 12{\cdot}10^{-6}$ J/m^2 and (c) for $W \sim 6{\cdot}10^{-6}$ J/m^2. (d) Hysteresis of monotonic changes of the PS in the electric field for a weak value of the anchoring energy $W \sim 0.3{\cdot}10^{-6}$ J/m^2. The LC cell with thickness 8.2 μm (a) was constructed from two substrates with the non-irradiated rubbed ODAPI film. The 8.1 μm (b), 8.3 μm (c) and 8.1 μm (d) LC cells were constructed from two substrates with the rubbed ODAPI film, which were irradiated during 3, 5 and 9 hours, respectively. The pitch of the cholesteric helix p is 5 μm.

changes with the applied electric field, and hysteresis is observed when the electric field changes in opposite directions (Figure 6(d)).

It can be seen from Figure 6(a)–(c) that depending on the value of the anchoring energy of ODAPI films, the line segment of a single domain (jump of the PS) is inclined with respect to the voltage axis at a certain fixed angle. It is seen that the decrease of the anchoring energy leads to the increase of the tilt angle. For $W \sim 15{\cdot}10^{-6}$ J/m^2, $12{\cdot}10^{-6}$ J/m^2 and $6{\cdot}10^{-6}$ J/m^2, the tangent of the tilt angle is around 0.22, 0.67 and 1, respectively. (For comparison, it should be noted that in a case of the irradiated PVCN film (t_{exp} = 300 s) for the maximal value of the anchoring energy $W \sim 0.6{\cdot}10^{-6}$ J/m^2 the tangent of the tilt angle is equal 2.) This also confirms the fact that during the irradiation of ODAPI film the decrease of the anchoring energy W results in a strong slip of the LC director at the surface of the alignment film with the increase of voltage.[21, 22] For a certain threshold value of voltage U_{th} (for example, as denoted in Figure 6(a) U_{th}^1 = 3.1 V and so on), a jump of the PS can be observed. Under the increase of voltage, jumps of the PS will be observed as long as there is no cholesteric–nematic transition in the electric field. It should be noted that when the value of voltage $U = U_{Ch\text{-}N}$ (as denoted in Figure 6), the cholesteric–nematic phase transition is observed. For instance, in a case of the anchoring energy $W \sim 15{\cdot}10^{-6}$ J/m^2, the homeotropically alignment layer of the nematic phase in the electric field is shown in the photograph in Figure 4(f)). As it can be seen from Figure 7, the increase of the value of the anchoring energy W results in the increase of the value of voltage $U_{Ch\text{-}N}$ of the cholesteric–nematic transition due to the fact that the director weakly slips at the surface of the alignment layer.

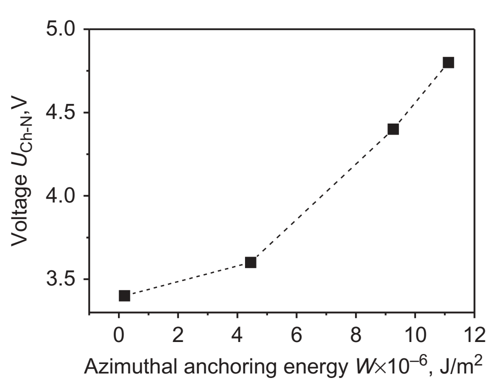

Figure 7. Dependence of voltage of the applied electric field of the cholesteric–nematic phase transition on the value of the azimuthal anchoring energy W of the ODAPI alignment layers.

As it can be seen from Figure 6(a)–(c), hysteresis of jumps of the PS is observed when voltage changed in opposite directions. With the decrease of voltage (open symbols), tilt angles for the single domain (where the PS a bit changes) are approximately equal in value with angles, which were defined when voltage increases (solid symbols) as it is seen in Figure 6. When the anchoring energy W is sufficiently weak (Figure 6(d)), hysteresis of continuous changes of the PS (without any jumps) is also observed.

As it can be seen from Figures 5 and 6, there is a slight difference between initial and final values of the PS. By the decrease of voltage to U_{end} < 1.5 V, the transition from the unidirectional fingerprint texture (undulation texture, induced by the electric field) to the planar texture of cholesteric is observed for examined samples.

Conclusion

Thin planar cholesteric layers with a ratio between the thickness d of the LC cell and pitch p of the cholesteric helix $d/p \approx 1.6$, recently proposed for the usage of cholesteric diffraction gratings, were studied. The unidirectional fingerprint texture (well known as a GM type of the fingerprint texture [11,12,14,38]) with the direction of stripes along the LC director was received by applying the electric field to the LC cell. Hysteresis of jumps of the PS of the undulation texture in the electric field was experimentally studied for various values of the azimuthal anchoring energy W, which can be modified by illumination of the rubbed ODAPI or photosensitive PVCN films, used as alignment layers. It was also shown that jumps of the PS and changes of the PS for a range of a single domain essentially depend on the value of the azimuthal anchoring energy W. In addition, it has been found experimentally that no jumps of the PS are observed, as in a case of the long exposure of ODAPI or non-irradiated PVCN films, because the anchoring energy W between LC molecules and the alignment layer is sufficiently weak.

The comparison of obtained results, when jumps of the PS for two different alignment layers were studied, leads to the conclusion that the usage of photo alignment layers is less efficient to ensure the strong anchoring energy W than the application of ODAPI layers. These results show that for the practical application of thin cholesteric layers, for example, as diffraction gratings with a period steered by the electric field, it is necessary to take into account the value of the anchoring energy W of alignment layers and the phenomenon of hysteresis of jumps of the PS.

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