Periodic anchoring condition for alignment of a short pitch cholesteric liquid crystal in uniform lying helix texture

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Due to flexoelectricity, a cholesteric liquid crystal unidirectionally aligned in a sandwich cell, with its helix lying parallel to the confining cell substrates, exhibit a flexoelectro-optic response when subjected to an electric field applied perpendicular to the helix axis. The clarity of the flexoelectro-optic response is dependent on the quality of the uniformly lying helix texture of the cholesteric which often is difficult to achieve. Herein, a method for alignment of a short pitch cholesteric in such a texture by means of a periodic surface anchoring condition with periodicity matching that of the cholesteric liquid crystal is described.
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A thin layer of a short pitch cholesteric liquid crystal, with uniformly oriented lying helix (ULH) in the plane of the layer, behaves as a uniaxial optical plate cut along the optic axis coinciding in this case with the cholesteric helix axis [cf. Fig. 2(a)]. In this geometry, the cell may exhibit a flexoelectro-optic response when an electric field is applied perpendicular to the helix axis.[1,2] The sign and magnitude of the flexoelectric effect is described by the flexoelectric coefficients, e_s, and e_b, for splay and bend elastic deformations of the cholesteric liquid crystal, respectively.[1,2]

The flexoelectric effect in nematic liquid crystals is known. The effect is polar and linear with respect an applied electric field thus providing gray scale capability. In a cholesteric liquid crystal with ULH geometry, in-plane switching of the sample optic axis produces a linear electro-optic response with fast switching times usually in the microsecond region. The response is temperature independent as long as the pitch of the helix does not change with temperature. Cholesteric liquid crystalline mixtures with temperature independent pitch over a broad temperature interval are available.[3] For example, TI827 (Merck) is a commercially available short pitch cholesteric liquid crystal with a pronounced temperature independent flexoelectro-optic response.

However, alignment of short pitch cholesterics in a ULH geometry is problematic. The periodicity of helical molecular order of a cholesteric liquid crystal in a conventional sandwich cell does not match the substrate surface anchoring condition, which may be homeotropic, planar or tilted. Alignment of a short pitch cholesteric in a ULH texture has been achieved[4] where periodic planar/vertical surface anchoring condition having the same periodicity as the helical molecular order of the cholesteric liquid crystal bulk was employed. However, the sudden change from homeotropic to planar anchoring causes frustration in the helical molecular order of the cholesteric liquid crystal near the substrate surface, resulting in defects in its alignment.

In this paper we present a method for alignment of a short pitch cholesteric liquid crystal in ULH texture by means of a periodic surface anchoring condition with periodicity matching the helical periodicity of the cholesteric liquid crystal used. In this geometry, the achieved ULH texture is stable with respect to the time and the periodic surface anchoring condition does not generate any defects since the transition from homeotropic to planar anchoring at the substrate surface is continuous.

The experiment was carried out using conventional sandwich cells. Indium tin oxide (ITO) covered glass substrates were spin-coated with a 5% solution of an equal mixture (1:1 wt/wt) of two alignment materials SE1211 (Nissan, Japan) and SD1 (Dai Nippon Ink & Chemicals, Japan) in NMP (N-1-methyl-2-pyrrolidone). SE1211 alone promote homeotropic alignment in conventional nematic cells whereas SD1 promotes uniform planar alignment after being exposed to linear polarized UV light. The composite alignment layer was prebaked at 90 °C for 3 min, cured at 180 °C for 30 min and illuminated at 40° oblique incidence for 40 min with linearly polarized UV light ($5\ \mathrm{mW/cm^2}$) emerging from a 270 nm spectral filter. The alignment layer was found to promote large pretilt (of about 80°) from the substrate surface in a cell filled with nematic liquid crystal. Thereafter, a commercial mixture RMS03–008 (Merck, Germany), containing photoreactive cholesteric monomer with pitch 0.3 μm, was spin-coated on top, baked at 65 °C for 3 min and photopolymerized with linear polarized UV light irradiating from 270 nm spectral filter for 8 min. The polarization direction of the UV light used for illuminating both the initial alignment layer and the subsequent cholesteric layer was the same in both cases. Thus, a composite alignment layer providing uniform *periodic surface anchoring condition* was formed onto the surface of the glass substrate as shown in Fig. 1. Two such substrates oriented with their preferred direction of photoalignment parallel to each other were assembled in a sandwich cell (cell gap, ~3 μm) as depicted in Fig. 2(a). It should be mentioned here that the helix axis of cholesteric alignment layer is oriented along the preferred direction of photoalignment. Whereas the helix of the cholesteric alignment layer on both cell substrates can be easily oriented parallel to each other, it is impossible to match their phase. Such a mismatch probably is generating some defects. However, their influence on the quality of the dark state of the sample appears to be negligible. Commercial short pitch cholesteric liquid crystal, TI827 (Merck; pitch, 0.3 μm) was capillary filled from its isotropic phase

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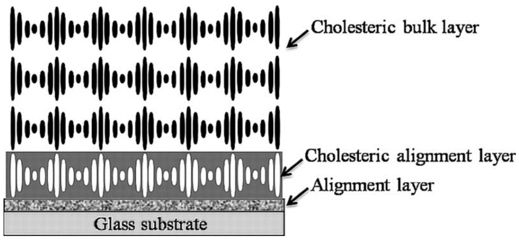

FIG. 1. Schematic presentation of the periodic surface anchoring condition achieved by means of alignment layer made from photopolymerized cholesteric liquid crystal aligned in ULH texture. The pitch of the helical molecular order of the cholesteric alignment layer is chosen to match the one of the cholesteric liquid crystal bulk.

in to the sandwich cell. The polymerized cholesteric layer, according to the data from the producer, has helical molecular periodicity of 0.3 μm thus matching well the helical pitch of TI827.

To explore the differences between photoalignment (noncontact) versus mechanical rubbing (contact), a second sandwich cell was made in which the initial alignment layer comprised SE1211 alone (promotes homeotropic alignment). The cholesteric alignment layer in this cell was deposited on top of the initial alignment layer as described previously and uniformly rubbed before curing. The cell was also filled with TI827. The orientation of the helix axis of the ULH texture in this case is perpendicular to the rubbing direction.

After filling, all cells were cooled from the isotropic phase at a rate of 0.2 °C/min and the optical texture was examined using a polarizing optical microscope equipped with image acquisition system. However, despite having a periodic surface anchoring condition, in the most of the experimental cells, the bulk cholesteric liquid crystal layer (T1827) did not align completely in ULH texture on cooling from the isotropic liquid. However, if at a temperature of about 2 °C below the clearing point an electric field of sufficient strength for complete unwinding of the molecular helical order of the cholesteric liquid crystal bulk was applied, then the cholesteric liquid crystal layer in both type of cells relaxed to the desired ULH texture as applied field strength was reduced slowly coupled with very slow cooling of the

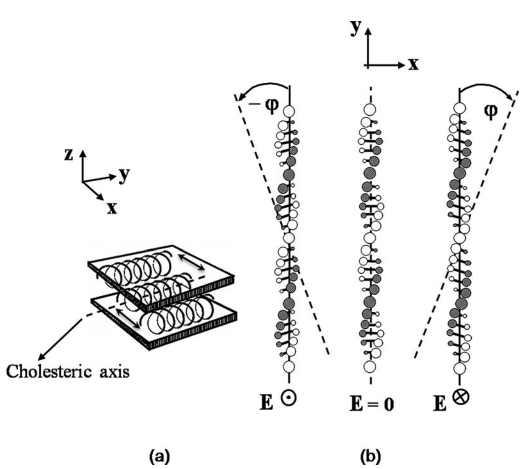

FIG. 2. (a) Schematic presentation of a sample containing a short pitch cholesteric liquid crystal aligned in ULH texture (the preferred direction of alignment produced by rubbing or photoalignment method is shown by the arrows). (b) When an electric field is applied across the sample, i.e., along the z-axis, a field-induced in–plane deviation of the sample optic axis takes place thus giving rise to a linear electro-optic response (cf. Fig. 3).

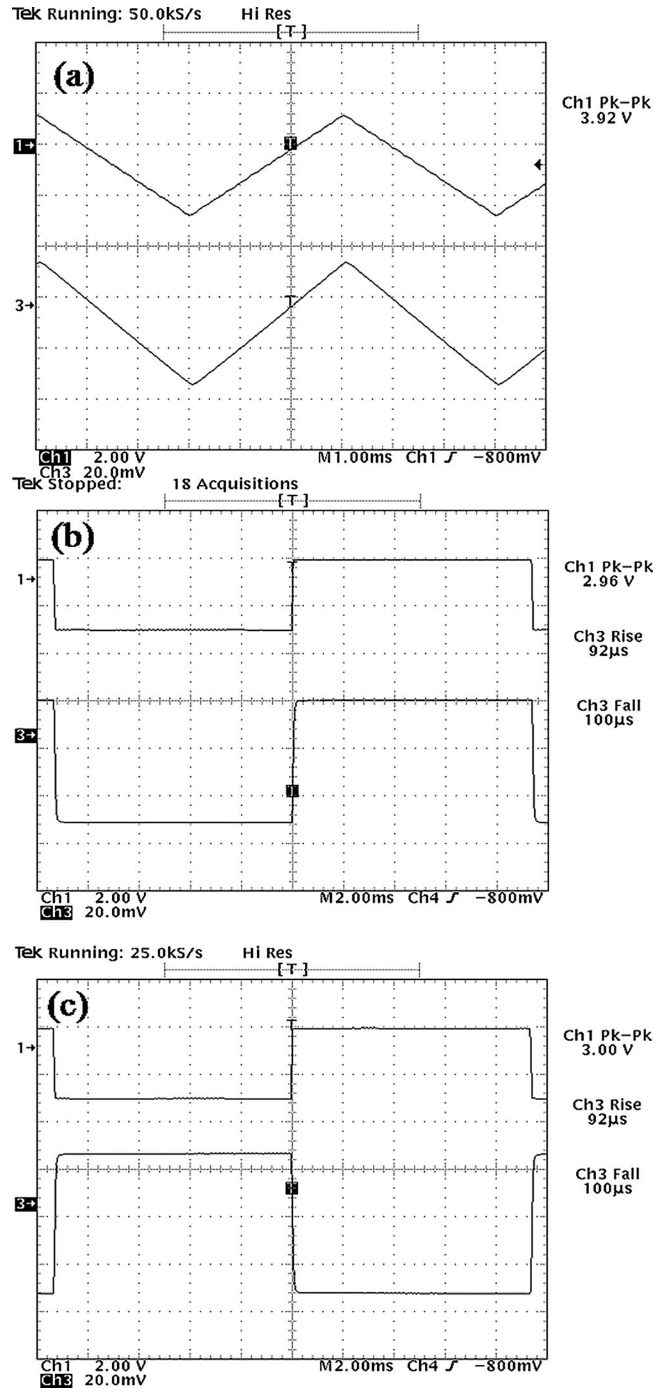

FIG. 3. Electro-optic response of a sample (lower curve) containing a short pitch cholesteric liquid crystal aligned in ULH texture by means of a photopolymerized cholesteric liquid crystal alignment layer. The preferred direction of alignment of the cholesteric alignment layer in the sample is produced by the photoalignment method. (a) Linear electro-optic response detected under application of an electric field with triangular form (upper curve). [(b) and (c)] Rotation of the sample 45° results in 180° phase shift of the response providing thus a clear indication of the in-plane switching of the sample optic axis possible only in a sample with ULH texture.

sample. This texture remained in all samples after the applied field was removed, being uniform and stable over time. In both cases, non-contact and contact method for achievement of ULH texture, the dark state found when the cell is placed between crossed polarizers, with its optic axis parallel to the polarizer, was of very good quality. This indicates that the ULH texture in the cells is of high quality without defects causing light scattering. It should be noted here that in the cells where the noncontact photoalignment method was employed, the quality of ULH texture seemed to be much better. Thus from this point onwards, we present only the results obtained with such type of cells.

The alignment of the cholesteric liquid crystal in ULH texture was checked also by studying the electro-optic response of the samples. As known, when a cholesteric liquid crystal is oriented in ULH texture, an electric field applied normal to the helix axis, along z axis, causes simultaneous rotation of the liquid crystal molecules around the direction of the applied field, i.e., in xy plane [Fig. 2(b)]. Such a rotation of the liquid crystal molecules results in an in-plane deviation of the sample optic axis whose magnitude, φ, is linearly dependent on the applied electric field according to,[1,2]

$$\varphi \approx e^{*}Ep/2\pi, \tag{1}$$

where $e^{*}=e/K$ and $e=(e_s+e_b)/2$, where e_s and e_b are the splay and bend flexoelectric coefficients and $K=K_{11}=K_{33}$ is the average elastic constant of the liquid crystal. E and p are the applied electric field and the helical pitch, respectively.

This field-induced in-plane deviation of the sample optic axis, however, will give rise to an electro-optic response when the cell is placed between two crossed polarizers. If, the cell, satisfying the half-wave plate condition $(d\Delta n/\lambda = 1/2)$, is inserted between two crossed polarizers with its optic axis oriented at 22.5° with respect to transmission direction of the polarizer, and applying a moderate electric field $E=E_0 \sin \omega t$ across the sample, then the transmitted light through the sample will be modulated according to,[2]

$$I \approx I_0\left\{\frac{1}{2} - 2\varphi(E_z)\right\} = I_0\left\{\frac{1}{2} - \frac{e^{*}}{\pi}\mathrm{pE}_0 \sin \omega t\right\}. \tag{2}$$

From Eqs. (1) and (2) it follows that the flexoelectro-optic response is polar, i.e., will change its sign when the applied electric field changes its polarity, and it will be linear with the field at moderate applied field. These features are known to be characteristic of the flexoelectro-optic response associated with a short pitch cholesterics aligned in ULH texture.

Figure 3 shows the flexoelectro-optic response of an experimental cell in which the photoalignment method was employed. As shown, the detected electro-optic response of the cell is linear with the field [Fig. 3(a)]. The response time, both rise τ_r and fall τ_f, is below 1 ms [Figs. 3(b) and 3(c)]. Moreover, there is 180° phase shift of the response at rotation of the sample at 45° which is a clear indication that the electro-optic response of the cell arises from the in-plane switching of the sample optic axis. Such an electro-optic response, however, is only possible if the short pitch cholesteric in the cell is aligned in a ULH geometry. Consequently, the study of the experimental cells by means of polarizing microscopy and electro-optical response proved unambiguously that a short pitch cholesteric liquid crystal confined in the experimental cells is aligned in a ULH geometry defined by the periodic surface anchoring conditions due to the periodic helical molecular structure of the cholesteric alignment material.

In this work we have demonstrated that when an alignment layer made from a reactive cholesteric material, either oriented by photoalignment or mechanical rubbing to give a uniform lying helix texture, this alignment may be transferred further to the bulk cholesteric material. However, in order to make it possible, the bulk cholesteric material has to be unwound by an applied electric field and then the helix is reformed slowly by reducing the strength of the field while slow cooling. Since this process starts from the substrates' surface therefore the presence of the periodic surface anchoring condition is a necessary condition for aligning the bulk cholesteric layer in ULH texture. Importantly, in the presence of periodic anchoring condition, the ULH texture is very stable with time. However, to stabilize the ULH texture against the possible damages due to the driving process, a stabilization of the ULH texture by means of polymeric network is needed.[5]

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