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Liquid Crystals

ISSN: 0267-8292 (Print) 1366-5855 (Online) Journal homepage: http://www.tandfonline.com/loi/tlct20

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To cite this article: Kyoung-Seok Park, Ji-Ho Baek, You-Jin Lee, Jae-Hoon Kim & Chang-Jae Yu (2016) Effects of pretilt angle and anchoring energy on alignment of uniformly lying helix mode, Liquid Crystals, 43:9, 1184-1189, DOI: 10.1080/02678292.2016.1162858

To link to this article: http://dx.doi.org/10.1080/02678292.2016.1162858

Published online: 31 Mar 2016.

LIQUID CRYSTALS, 2016
VOL. 43, NO. 9, 1184–1189
http://dx.doi.org/10.1080/02678292.2016.1162858

Effects of pretilt angle and anchoring energy on alignment of uniformly lying helix mode

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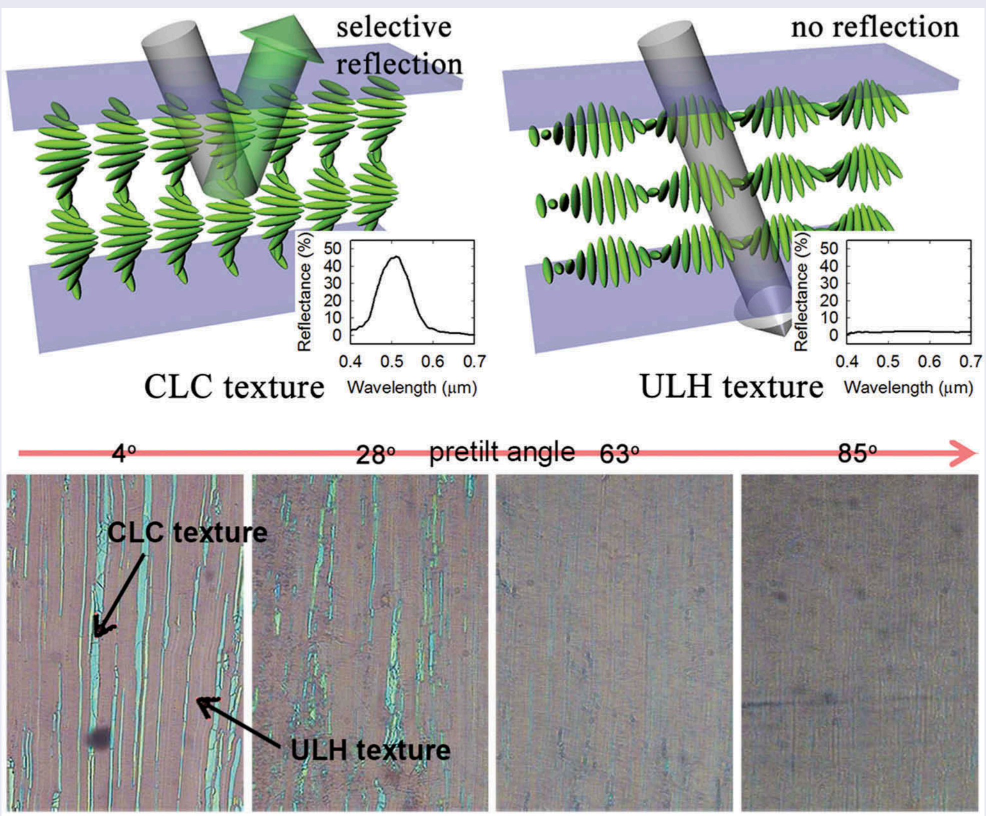
ABSTRACT

We investigated the effects of pretilt angle and anchoring energy on the formation of a uniformly lying helix (ULH) texture of cholesteric liquid crystals (CLCs). Pretilt angle was controlled by the thickness of a vertical alignment layer coated onto a planar alignment layer. In the given pretilt angle, the anchoring energy was enhanced by introducing reactive mesogen to the vertical alignment material. To characterise quantitatively the formation of the ULH texture we introduced reflectance, governed by areas of the ULH region and the planar-aligned CLC region. We found that the ULH texture was more widely formed under the condition of higher pretilt angle and weaker anchoring energy. Also, a more uniform alignment of the ULH texture was achieved with the higher pretilt angle even under the same anchoring energy condition.

ARTICLE HISTORY
Received 31 December 2015
Accepted 3 March 2016

KEYWORDS
uniformly lying helix; pretilt angle; anchoring energy; cholesteric liquid crystals



1. Introduction

The uniformly lying helix (ULH) structure in short-pitch cholesteric liquid crystals (CLCs) has attracted much attention in display applications because of its fast switching speed and continuous in-plane rotation of the optic axis based on the flexo-electro-optic effect. [1–9] However, ULH texture is not a stable

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configuration of CLCs within the sandwiched substrates with planar alignment layer, due to its energetically stable Grandjean (standing helix) configuration. To obtain stable ULH texture various approaches, such as the periodic alignment patterning on a length scale comparable to the CLC pitch, [10] unidirectional grooved surfaces, [11–13] polymer stabilisation of the ULH texture [14–16] and twisted configuration [17] were introduced. However, most approaches are impractical on a large scale except for the twisted configuration. In addition, no quantitative investigation of the formation of ULH configuration in regard to various cell conditions has yet been explored.

In this work, we quantitatively investigate the effects of pretilt angle and anchoring energy on the formation of ULH texture by introducing spatially averaged reflectance. Reflectance of the short-pitch CLC cell is mainly governed by the planar CLC texture (Grandjean configuration) due to selective reflection. [18] On the other hand, incident light passes through the ULH regions with no selective reflection. As a result, the spatial average of the reflectance directly represents the ratio of the ULH region to the planar CLC region, as shown in Figure 1. That is, the lower reflectance means that the ULH texture is formed over a larger area. It should be noted that transmission under crossed polarisers depends on the optic axis of the ULH texture, and the optic axis must be predetermined. However, in some ULH textures, two or more optic axes (the helical axes of the ULH texture) were observed. [17] Therefore, the contrast ratio based on transmission under crossed polarisers is not suitable to characterise stable ULH texture quantitatively.

In a previous work, [6] a surface pretilt angle was periodically modulated from planar to homeotropic alignment on a length scale comparable to CLC pitch. However, it is very difficult to apply sub-micron patterning on a large scale, or to guarantee proper alignment reflecting CLC pitch, due to the penetration of anchoring strength. We varied pretilt angle and anchoring energy to investigate the formation of ULH texture, which is readily applicable to large-area devices. To control pretilt angle, the stacked alignment layer coating the diluted vertical alignment materials onto the planar alignment layer was used. [19] Also, the anchoring energy was varied by introducing the reactive mesogen (RM) even at the same pretilt angle. As mentioned above, using spatially averaged reflectance we found that the higher pretilt angle and the weaker the anchoring energy, the better the ULH texture obtained. Also, better uniformity of the optic axis in ULH texture was achieved in the higher pretilt sample at the same anchoring energy.

2. Experimental

We prepared substrates with different pretilt angles and anchoring energies to investigate their effects on the formation of ULH texture. To control pretilt angle we stacked two alignment layers, which produce the planar and vertical alignment of the LC as shown in Figure 2. [19] Anchoring energy balance between the planar and vertical alignment layers and the resultant pretilt angle was governed by the thickness of the vertical alignment layer, controlled by the concentration of the vertical alignment material diluted with the solvent. First, we coated the planar alignment layer (Nissan Chem. SE7492) on the indium-tin-oxide substrate and prebaked it at 80 °C for 10 min, followed by imidisation at 210 °C for 2 h. To control the concentration of the vertical alignment material, we diluted the vertical alignment material (JSR AL60702) with a mixed solvent consisting of n-methyl-pyrrolidone, buthyrolactone and butoxyethanol. The vertical alignment mixture was spin-coated on the prepared planar alignment layer and prebaked at 80 °C for 10 min and fully

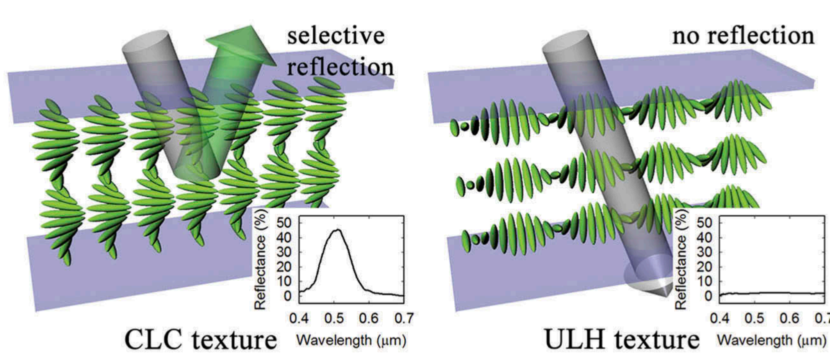

Figure 1. (color online) Concept of the quantitative description of ULH aligning properties. At a region of CLC texture, selective reflection was measured. On the other hand, no selective reflection was observed at a region of ULH texture. Insets represent reflection spectra for each sample.

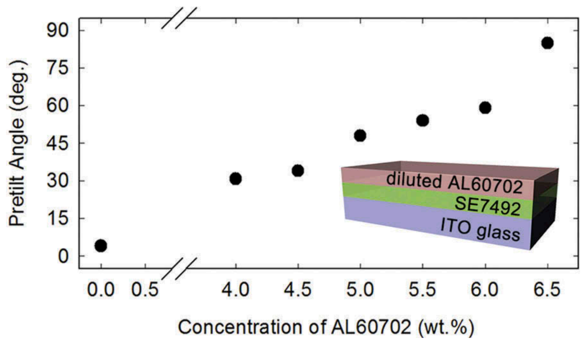

Figure 2. (color online) Pretilt angles as a function of concentration of AL60702 diluted with the mixed solvent stacked on SE7492.

cured at 180 °C for 1 h. The pretilt-controlled substrates were rubbed and assembled in an anti-parallel direction. The resultant pretilt angles of the stacked alignment layers were measured using the polariser rotation method [20] for MLC-0643 (Merck) and are shown in Figure 2. The cell thickness was maintained using glass spacers of 3 μm.

The CLC of MDA-13–953 (Merck) was injected by capillary action in the CLC phase just below the isotropic-CLC transition temperature under an applied voltage to produce the ULH texture. The pitch and isotropic-CLC transition temperature of MDA-13–953 were 308 nm and 88 °C, respectively. The bipolar square waveform at 1 Hz was applied by an arbitrary waveform generator (Stanford Research Systems DS345). To change the anchoring energy of the substrates, the RM was mixed into the diluted vertical alignment layers and the assembled cells were exposed to ultra-violet (UV) light for polymerisation of the RM. [21–23] The vertical alignment mixture contained 3 wt.% RM-257 (Merck) and 0.6 wt.% photo-initiator (Ciba Speciality Chemicals Igacure651) with respect to AL60702. To control the pretilt angle in the RM mixed alignment layer, the same method of stacking the diluted vertical alignment layer with the RM was used on the planar alignment layer mentioned above. Polar anchoring energy was measured by the electro-optical phase retardation technique. [24] The reflective and transmissive textures were observed using a polarising optical microscope (Nikon E600 W POL) with a frame-grabber (Samsung SDC-450), and the reflective spectra were measured by using a fibre-optic spectrometer (Ocean Optics S2000).

3. Results and discussion

Figure 3 shows the reflective textures and spectra of the various sample cells without polariser at different pretilt angles and the electric field conditions during the injection of the CLC. Here, the cyan or yellow regions represent the planar textures of the CLC and the other regions represent the ULH textures. The cyan or yellow regions of the sample under the applied electric field of 2.5 V/μm were more clearly delineated than under the applied electric field of 3.0 V/μm, as shown in Figure 3(a) and 3(b). The ULH texture was demonstrated well when a high-electric field was applied during the injection of the CLC to the sandwiched cell. Under electric field conditions of both 2.5 and 3.0 V/μm, the cyan or yellow regions were gradually reduced with increasing pretilt angle. Low pretilt angle strongly enhanced the planar alignment of the CLC, which gave rise to the selective reflection of the sample.

We analysed the spectra of reflection and reflectance for the various sample cells under different pretilt angles and electric fields to characterise the ULH texture/CLC texture quantitatively. As shown in Figure 3(c), the central wavelengths of reflection for various samples were similar since the reflection mainly originated from the planar texture of the CLC, and the CLC materials used here were identical. Subtle variation in the central wavelengths may be attributed to cell-gap variation rather than tilting of the helical axis by pretilt angle. However, the reflectance was gradually reduced with increasing pretilt angle under both electric field conditions, as expected from the reflection textures. As a result of our approach, the reflectance analysis is confirmed to be relevant to quantitative characterisation of the formation of the ULH texture. A more stable ULH texture was obtained under the higher pretilt angle since the low pretilt angle strongly enhances planar alignment of the CLC. However, when no electric field was applied during CLC injection, stable ULH texture was not achieved even at the vertical alignment shown in Figure 3(a).

In our experiments, polar anchoring was gradually reduced with increasing pretilt angle. We then investigated the effect of anchoring energy on the formation of ULH texture at the same pretilt angle. Previously we found that surface anchoring energy was enhanced by introducing the RM into the alignment layer. [25,26] First, we prepared the diluted vertical alignments mixed with the RM, and then coated them onto the planar alignment layer to control the pretilt angle. Figure 4 shows the pretilt angle and polar anchoring energy for the stacked alignment layers with/without the RM as a function of the concentration of AL60702 diluted with the solvent. The pretilt angles in both stacked alignment layers with and without the RM were similar at the same concentration of AL60702, as shown in Figure 4(a). At the same concentration, however, the polar anchoring energy of the RM mixed alignment layers was greater than that of the alignment layer without the RM, as shown in Figure 4(b). Also, the anchoring energy

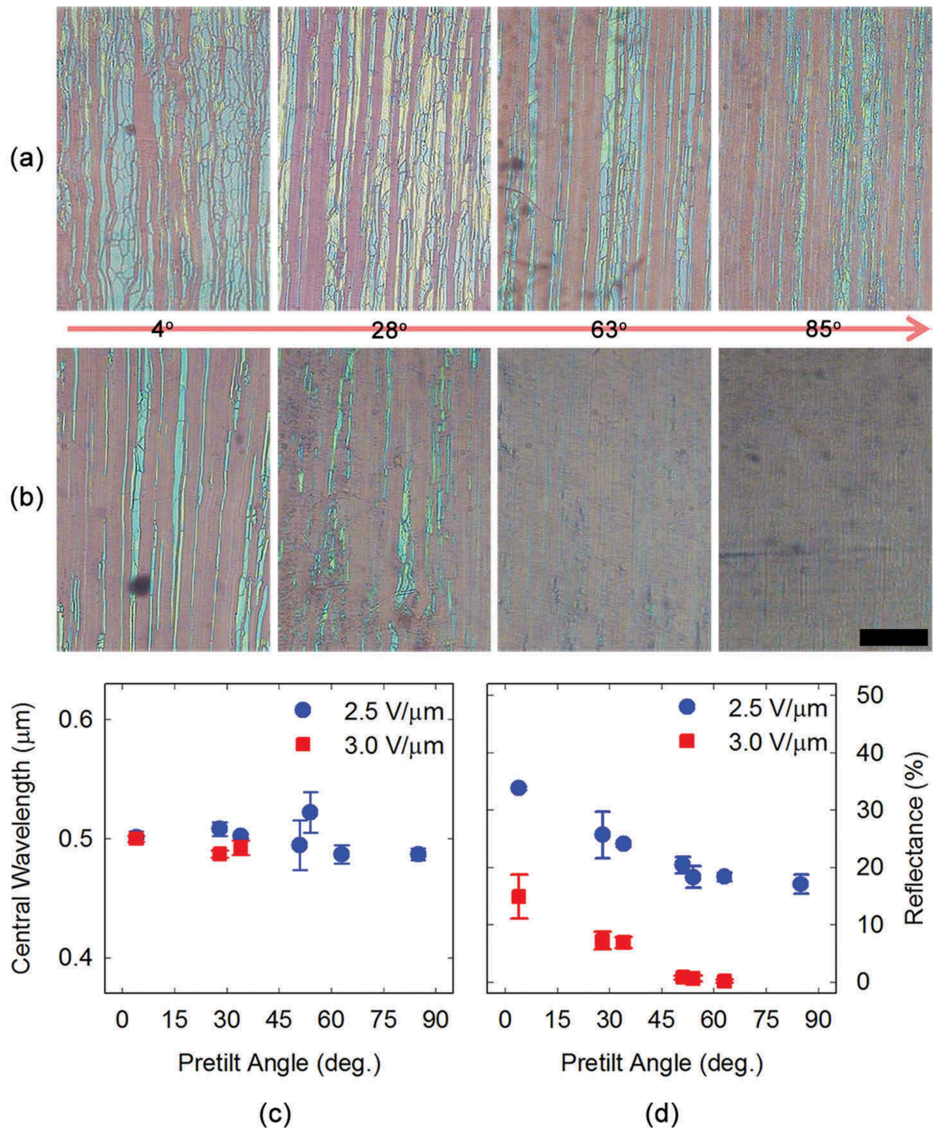

Figure 3. (color online) Reflective textures, prepared by injecting LC mixtures by capillary action at 85 °C under the applied fields of (a) 2.5 V/μm and (b) 3.0 V/μm, and (c) the central wavelength and (d) the reflectance of the corresponding reflections as a function of the pretilt angle. All textures were taken at the same scale (scale bar represents 100 μm) .

gradually decreased with increasing AL60702 concentration and the resultant pretilt angle. It should be noted that the two samples denoted by 'A' and 'B' in Figure 4(b) exhibited similar anchoring energy, of about 12 $\mu J/m^2$, but different pretilt angles – 30° for 'A' and 62° for 'B'. As shown in Figure 4(c), the reflectance of both samples measured was found to be almost equivalent, implying that the spatial distribution of the ULH texture is equivalent. As a result, we found that ULH texture was more widely formed at higher pretilt angle and weaker anchoring energy. In addition, even at two different pretilt angles, the reflectance of both samples was almost identical when they exhibited the similar anchoring energy. We can conclude that anchoring energy is more relevant effect to the formation of ULH texture.

Next, we investigated the uniformity of the optic axis of ULH texture relative to the pretilt angle at the same anchoring energy condition. The transmissive texture of samples "A" and "B", with the same anchoring energy under crossed polarisers, is shown in Figure 5. It should be noted that the rubbing direction is parallel to horizontal and perpendicular to the optic axis of the ULH texture. Here, the horizontal blue stripes represent the planar textures of the CLC. In sample "A" at lower pretilt angle (30°), stripe domains (bright and dark strips in the vertical direction) with two optic axes were observed at the ULH regions, but in sample 'B" with higher pretilt angle (62°), a relatively uniform domain was observed. As a result, under the same anchoring condition, better uniformity of the

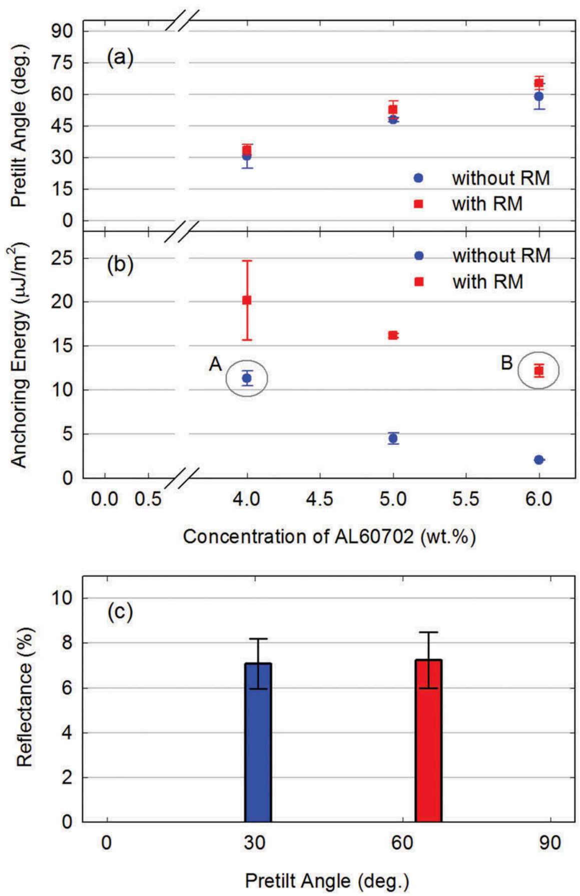

Figure 4. (color online) (a) Pretilt angle and (b) polar anchoring energy as a function of concentration of AL60702 diluted with the mixed solvent stacked on SE7492. (c) The reflectance of the samples with similar anchoring energies (about 12 μJ/m^2) but different pretilt angles (about 30° for the RM free sample and 62° for the RM sample) denoted by A (blue) and B (red) .

optic axis was achieved in the higher pretilt sample since two helical axes formed from the two substrates with the low pretilt differed from each other. Note that such stripe domains as shown in sample "A" with low pretilt angle were usually observed in the planar alignment of the short-pitch LC materials, such as a short-pitch ferroelectric liquid crystal at a given azimuthal direction. [27,28]

4. Conclusion

We quantitatively investigated the effects of pretilt angle and anchoring energy on the formation of ULH texture by introducing the spatial average of reflectance. The reflectance was governed by the ratio of planar CLC texture to ULH texture, and lower reflectance consequently implied a wider area of ULH texture. To control the pretilt angle, the stacked alignment layer coating the diluted vertical alignment materials onto the planar alignment layer was used. In addition, the anchoring energy was varied by introducing the RM even at the same pretilt angle. In conclusion, under higher pretilt angle and weaker anchoring energy, the ULH texture was more widely formed. In addition, even in samples with different pretilt angles, reflectance was similar when they exhibited the similar anchoring energy. Formation of the ULH texture is expected to be more correlated to anchoring energy. Under the condition of the same anchoring energy, however, the uniformity of the optic axis was enhanced in the higher pretilt sample.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work is supported by the MOTIE (Ministry of Trade, Industry & Energy) (project number 10052268) and KDRC (Korea Display Research Corporation), and LG Display Co. Ltd.

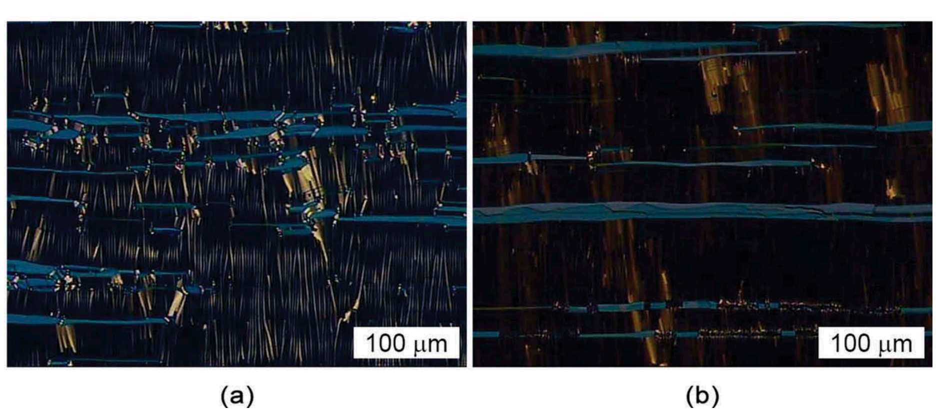

Figure 5. (color online) Polarising microscopic textures of (a) Sample A (without RM at 30° pretilt angle) and (b) Sample B (with RM at 62° pretilt angle) in Figure 4 under crossed polarisers.

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