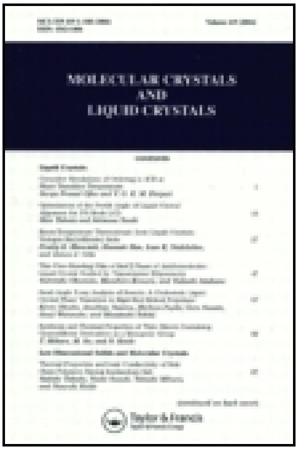

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Latent Image Forming by Exposure, Development and Fixing on Liquid Crystal Cells

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Twisted and nontwisted liquid crystal (LC) orientation domains can be formed on crosslinkable polymer surfaces. The latent image is written by exposing the LC cell with non-polarized UV light. The image is immediately developed by heating the LC cell up to an isotropic phase and cooling to a nematic phase. The image also gradually appears when the LC cell is in the nematic phase at a certain temperature. Thermal writing and UV fixing can also be demonstrated in the same LC cell.

Keywords: alignment patterning; photo alignment; thermal development; thermal writing; UV exposure; UV fixing

INTRODUCTION

Some techniques for a liquid crystal (LC) alignment patterning have been proposed up to this point. One is a multiple rubbing using a photolithography technique or an atomic force microscope [1–5]. Another technique is a photo-induced alignment using a polarized light [6–9]. These LC alignment techniques are based on controlling an easy axis of the alignment surface on which anisotropies of a dispersed force and/or a surface topography generate. Recently, we have reported that an azimuthal anchoring energy of the alignment surface of the crosslinkable polymer increases by exposing the polymer surface with an unpolarized UV light [10,11]. We have also reported another photo-crosslinkable polymer surface which exhibits two easy axes

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induced by unidirectional rubbing treatment [12]. Using these surfaces, the alignment patterning with twisted and non-twisted nematic domains can easily be made in the LC cell.

In this study, using the anchoring controllable polymer substrate, the LC alignment patterning is successfully demonstrated by exposing the LC cell with the unpolarized UV light and thermally developing. A thermal writing and a UV fixing techniques in the LC cell are also reported.

ALIGNMENT PATTERNING PRINCIPLE

The relationship between the twist angle and the azimuthal anchoring energy on one substrate in the TN LC cell whose another alignment surface has a finite anchoring energy is estimated from the following torque valance equation

$$K_{22}(\Phi_t/d) = \frac{1}{2} Wa \sin(2\Phi_t), \quad (0 \leq \Phi_t \leq \pi/2), \tag{1}$$

where K_{22} is the twist elastic constant, Φ_t is the twist angle, d is the thickness of the LC layer, and W_a is the azimuthal anchoring energy. The two easy axes of opposite substrates are crossed at right angles. Figure 1 shows a relationship between W_a and Φ_t, ($K_{22} = 5{\times}10^{-12}$ N and $d = 10\,\mu$m). The weak anchoring surface less than 5×10^{-7} N/m ($=K_{22}/d$) can not keep the twisted LC alignment and the LC should take the homogeneous alignment. On the other hand, the 90° twisted nematic (TN) orientation can be obtained on the strong anchoring surface of more than 5×10^{-5} N/m.

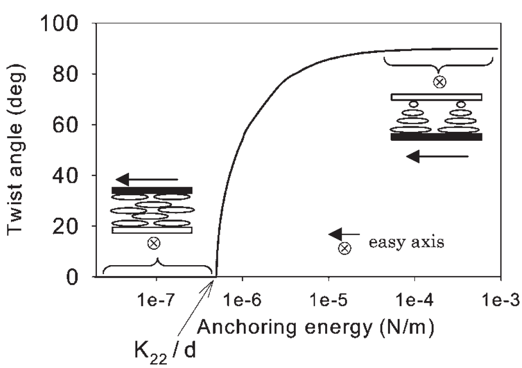


FIGURE 1 A theoretical relationship between a twist angle and an azimuthal anchoring energy in the TN cell. The black and white substrates have an infinite and a finite anchoring energies, respectively.

EXPERIMENTAL

Photo crosslinkable polymer materials, polyvinyl cinnamate (PVCi) is used in this study. The substrate covered with PVCi film was rubbed and assembled with another substrate covered with rubbed polyimide (PI) film. The azimusal anchoring of the non-crosslinked PVCi surface is about $8 \times 10^{-8}\,\mathrm{N/m}$ and that of the crosslinked surface is about $2 \times 10^{-5}\,\mathrm{N/m}$. PI surface has the anchoring of about $4 \times 10^{-4}\,\mathrm{N/m}$. The easy axis perpendicular to the rubbing direction is generated on the rubbed PVCi surface. Therefore the rubbing directions of two substrates were assembled parallel. The cell gap is about $11\,\mu\mathrm{m}$.

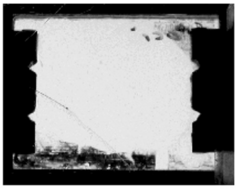
We used nematic LCs with various structures, 4-cyano-4′-n-pentyl-biphenyl (5CB), and ZLI-1083 (cyano-phenylcyclohexane compounds mixture), ZLI-4792 (three rings and fluorine end compounds mixture) and E44 (cyano-triphenyl and -biphenyl compounds mixture). Clearing temperatures (Tc) of those LCs are respectively 35.3°C, 52.3°C, 92.5°C and 100°C. A super high pressure mercury lamp was utilized as a UV light source for the crosslinking reaction. The power of the UV light was about $10\,\mathrm{mW/cm^2}$. The exposure time was $200 \sim 300\,\mathrm{ms}$.

RESULTS AND DISCUSSION

UV Exposure/Thermal Development

When the LC in the isotropic phase was injected to the empty cell which was assembled using the PVCi substrate without the UV exposure and cooled to the nematic phase, homogeneously aligned LC cell was observed. On the other hand, when the LC was injected into the cell in the nematic phase, the TN orientation of about 90° was observed. We subsequently heated the cell to the isotropic phase, the twist angle became zero after cooling the cell to the nematic phase. If we used the UV exposed surface of PVCi, the twisted alignment was obtained in both cases.

Next, we partly exposed the PVCi surface using the photomask and assembled the empty LC cell. When the LC in the nematic phase was injected into the cell, the uniform TN orientation was observed, as shown in Figure 2(a). However, the image was latent and appeared by heating the cell to the isotropic phase and cooling to the nematic phase, as shown in Figure 2(b). In the LC cell, the background area takes TN orientation since the area exposed with the UV light. The LC orientation changes from TN to homogeneous orientation on the character parts where without the UV light exposure.



(a) latent image

(b) developed image

FIGURE 2 Photographs of the LC cell (a) after the LC injection in the nematic phase and (b) after heating up to the isotropic phase and cooling to the nematic phase. The cell is set between crossed polarizers.

The orientation change also takes place in the nematic phase. The LC of 5CB was injected into the empty cell and the cell was kept at different temperature. The twist angle gradually decreased and the decreasing rate became faster with increasing the temperature of the LC cell, as shown in Figure 3. However, the twist angle did not decrease at 25°C when using LCs of ZLI-1083, ZLI-4792 and E44. We measured the twist angle in these LC cells which were kept at 40°C. Figure 3 shows that the twist angle of E44 gradually decreases. In contrast, the decreasing angle of ZLI-1083 is very small even if the Tc of ZLI-1083 is much lower than that of E44. On the other hand, ZLI-4792 (Figure 4) has the close Tc value to E44, however the twist angle of ZLI-4792 orientation hardly changes at 40°C. The twist angle immediately decreases when the cell temperature is heated at 80°C. These LC materials have different chemical structures of core and end groups. Therefore, it is considered that the decreasing property of the twist angle depends on the LC materials strongly.

Next, the UV exposure to the PVCi substrate after the LC injection was investigated. As shown in Figure 5(a), rubbed PVCi and PI substrates are prepared and the LC is injected in the nematic phase. The LC cell takes the uniform TN orientation. Then the LC cell is exposed with the UV light from the side of the PVCi substrate, as shown in Figure 5(b). At this time, the latent image is formed in the cell. The image gradually appears when the cell is heated up near

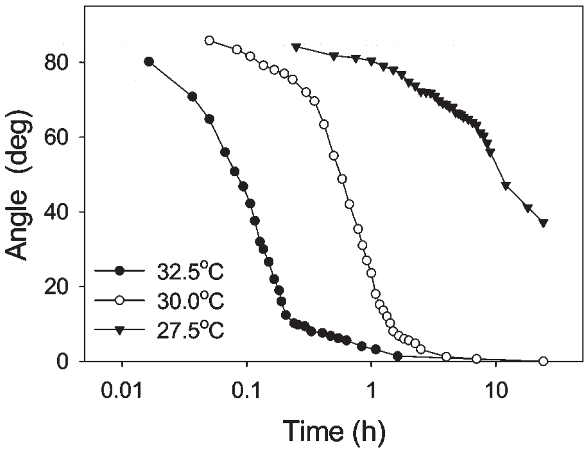


FIGURE 3 Time dependences of twist angles after the 5CB injection at different temperatures.

the Tc and the development completely finishes, as shown in Figures 5(c) and 5(d). The image also immediately appears by heating the LC cell up to the isotropic phase and cooling to the nematic phase.

In this UV exposure/thermal development process, the LC orientation changes from TN to homogeneous one in the area without the UV light exposure. The LC orientation in the area with the UV light exposure is still twisted. If the homogeneously aligned surface is

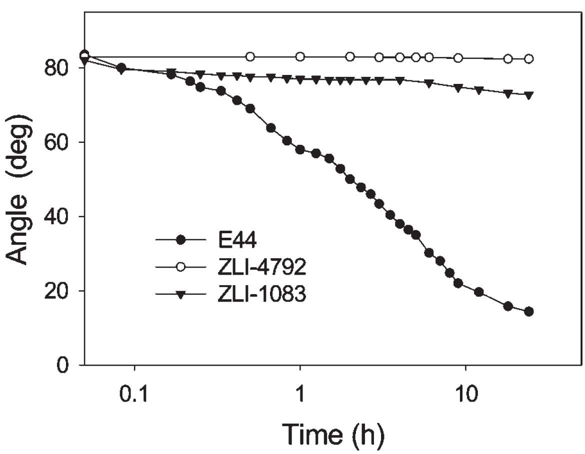


FIGURE 4 Time dependences of twist angles of E44, ZLI-14792 and ZLI-1083 at 40°C.

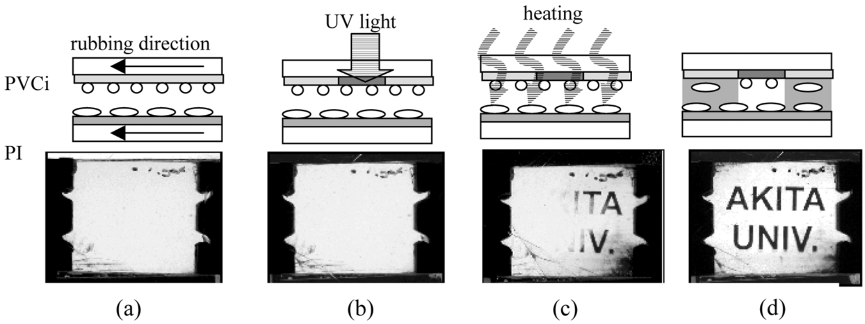


FIGURE 5 Schematic models of UV exposure/thermal development process in the LC cell and polarized photographs between crossed polarizers. (a) LC cell after the nematic LC injection (TN orientation), (b) after the UV exposure (latent image formation), (c) halfway thermal development and (d) end of development.

exposed with the UV light after the thermal development, the LC orientation did not change to the TN state, nevertheless the anchoring energy of PVCi surface increases by the crosslinking reaction. This result shows that the image is fixed after the development.

Thermal Writing/UV Fixing

Next, a thermal writing and a UV fixing (Figure 6) was demonstrated in the LC cell. The mixture LC of 5CB and E44 (Tc $\approx$ 60°C) was used.

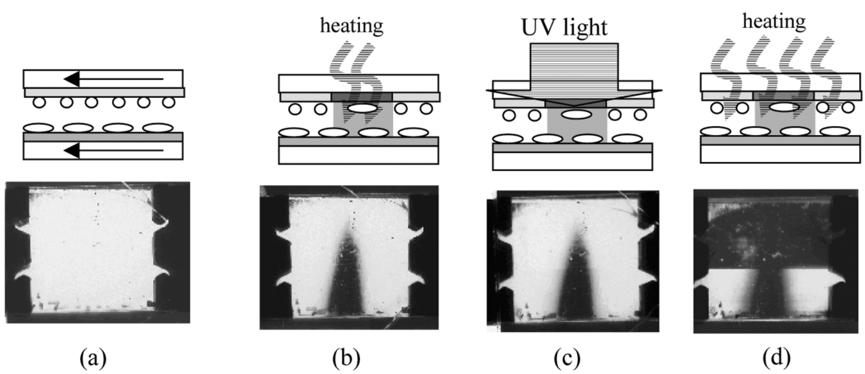


FIGURE 6 Schematic models of thermal writing/UV fixing process in the LC cell and polarized photographs between crossed polarizers. (a) LC cell after the nematic LC injection (TN orientation), (b) thermal writing, (c) UV fixing at the lower half side of the cell and (d) after re-heating of the whole cell.

The LC cell with the uniform TN orientation shown in Figure 5(a) was prepared using the unexposed PVCi substrate. The LC cell was partly heated up to the isotropic phase. When the cell is cooled to the nematic phase, the LC orientation changed from TN to homogeneous state in the heated area, as shown in Figure 5(b). This thermally written image is stable at room temperature if we select the suitable LC material. When the whole cell is heated up near the phase transition temperature or higer, the written image naturally disappears. Then, the cell is exposed with the UV light to fix the image. Figure 5(c) shows the LC cell that we expose the lower half side of the cell has been exposed and the written image hardly changes. When the whole cell was heated up to the isotropic phase, the image was successfully stored at the lower half side of the cell, as shown in Figure 5(d).

SUMMARY

Alignment properties of LC molecules on the PVCi surface rubbed and exposed with unpolarized UV light have been investigated. UV exposure/thermal development and thermal writing/UV fixing are successfully demonstrated in the LC cell. The thermal conditions for the development and writing process strongly depend on the chemical structure of the LC materials. The mechanism of the LC alignment on the crosslinkable polymer surfaces will be studied more in detail.

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