Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Patterning Properties of Liquid Crystal Alignment by Anchoring Control

Rumiko Yamaguchi [a], Yusuke Goto [a] & Susumu Sato [a]

[a] Department of Electrical and Electronic Engineering, Akita University, Akita City, Japan

Version of record first published: 18 Oct 2010

To cite this article: Rumiko Yamaguchi, Yusuke Goto & Susumu Sato (2004): Patterning Properties of Liquid Crystal Alignment by Anchoring Control, Molecular Crystals and Liquid Crystals, 412:1, 285-292

To link to this article: http://dx.doi.org/10.1080/15421400490439950

Mol. Cryst. Liq. Cryst., Vol. 412, pp. 285/[1895]–292/[1902], 2004

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400490439950

Taylor & Francis
Taylor & Francis Group

PATTERNING PROPERTIES OF LIQUID CRYSTAL ALIGNMENT BY ANCHORING CONTROL

Rumiko Yamaguchi, Yusuke Goto, and Susumu Sato
Department of Electrical and Electronic Engineering, Akita University, Tegata gakuencho 1-1, Akita City, 010-8502 Japan

A patterning method of the liquid crystal (LC) alignment by controlling a polar or an azimuthal anchoring energy of the alignment surface is proposed. The LC cell is assembled with a patterned substrate with strong and weak anchoring. We can experimentally control the azimuthal anchoring of the uniformly rubbed polyvinyl cinnamate (PVCi) surface by irradiating with a non-polarized UV light. The domain on the PVCi surface without the UV irradiation shows the homogeneous alignment of which direction is determined by the easy axis of the counter substrate, even if the easy axes of two substrates are perpendicular to each other. On the other hand, the surface with the UV irradiation shows a strong anchoring and TN orientation can be obtained in that domain.

Keywords: alignment surface, alignment patterning, anchoring control, anchoring energy, liquid crystal, photo-reactive polymer, PVCi

INTRODUCTION

A patterning of the liquid crystal (LC) alignment is a very interesting technique for wide viewing angle LC displays, molecular micro-assembly, and the application for the optical LC devices such as gratings and optical waveguides. The patterning of the LC alignment has been so far formed due to the initial LC molecular alignment on the substrate by controlling the direction of an easy axis. Some techniques have been proposed to obtain the LC alignment pattern. One is a multiple rubbing technique which is carried out using a photolithography on the substrate to form a mask for the next rubbing process [1,2] or using an atomic force microscope rubbing [3–5]. Another technique is a photo-induced alignment using a linearly polarized

Address correspondence to Rumiko Yamaguchi, Department of Electrical and Electronic Engineering, Akita University, Tegata gakuencho 1-1, Akita City, 010-8502 Japan.

UV light [6–9]. These LC alignment techniques are the patterning of the anisotropies of a dispersed force and/or a surface topography.

In this paper, the patterning method by controlling the anchoring energy of the alignment surface is proposed. Domains with a different azimuthal anchoring energy are optically written on one side or both substrates, though easy axes of two substrates are uniformly formed by using conventional rubbing machine.

RELATIONSHIP BETWEEN THE LC ALIGNMENT AND ANCHORING ENERGY

In the conventional LC cell, the bulk LC alignment is controlled by easy axes on two substrates with the premise that the surfaces have strong anchoring. When the weak anchoring surface is used to assemble the cell, LC director on its surface deviates from the easy axis due to the elastic power of the LC in the bulk. Figure 1 shows the principle of the LC alignment patterning by the control of the anchoring. The anchoring of the

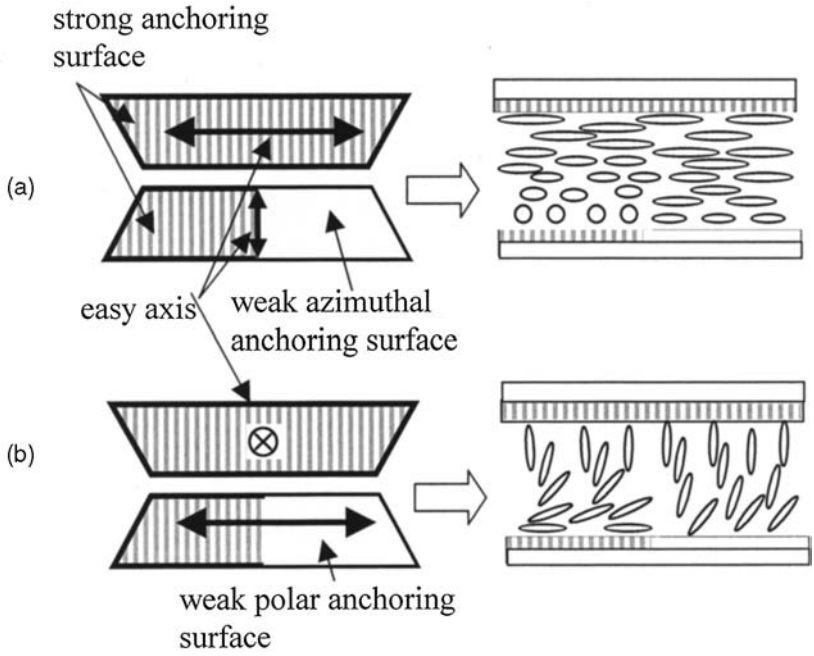

FIGURE 1 The principle of the LC alignment patterning by the control of (a) the azimuthal anchoring and (b) the polar anchoring strength.

alignment surface on the upper substrate is uniformly strong and that on the lower substrate is partly weak in the azimuthal and polar direction, respectively shown in Figure 1(a) and (b). Easy axes of two substrates are perpendicular to each other in the in-plane or out of plane. In Figure 1(a), the twist angle of LC director is almost 90° between strong anchoring surfaces. However the twist angle on the surface with the weak azimuthal anchoring becomes small. When the anchoring is very weak, the twist angle decreases to 0°. Moreover, a hybrid alignment and a homeotropoic alignment could be obtained on the strong and extremely weak polar anchoring surfaces, as shown in Figure 1(b) by the same mechanizum.

The free energy per unit area in the twisted LC cell which is prepared using alignment substrates with a finite and an infinite anchoring is expressed as

$$F = \frac{1}{2}K_{22}(\Phi_t - 2\pi d/p)^2/d + \frac{1}{2}Wa\sin^2(\Delta\Phi), \tag{1}$$

where K_{22} is the twist elastic constant, Φ_t is the twist angle, d is the thickness of the LC layer, p is the chiral pitch of the LC, W_a is the azimuthal anchoring energy and $\Delta\Phi$ is the angle between the easy axis and the LC director on the alignment surface. The relationship between W_a and Φ_t can be obtained by minimizing the free energy F. When the angle between two easy axes of the alignment surfaces is perpendicular to each other, that is $\Phi_t + \Delta\Phi = 90°$, and the pitch is infinite, W_a *vs* Φ_t curves are calculated with the parameter of the cell thickness and shown in Figure 2. This theoretical result suggests that the twist angle can be changed from 0° to 90°, if

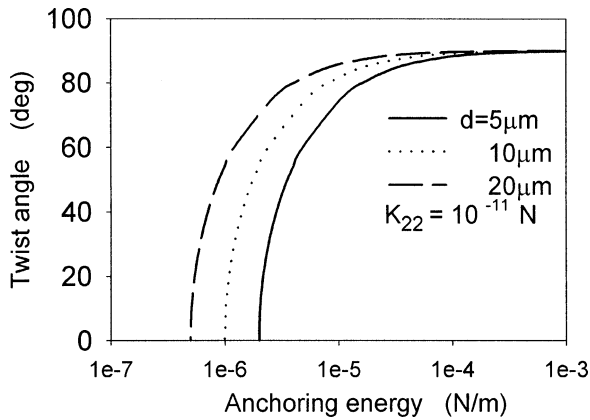

FIGURE 2 The theoretical relationship between W_a and Φ_t with the parameter of cell thickness. The angle between easy axes of alignment substrates is 90°.

the azimuthal anchoring energy increases by a factor of two, for example from 10^{-6} to 10^{-4} N/m with the cell thickness of 10 μm and the twist elastic constant of 10^{-11} N. Moreover, we see that the LC can not twist any longer if the cell thickness becomes less than the extrapolation length K_{22}/W_a of the weak anchoring surface. In the hybrid aligned cell, splay angle can be calculated in the same manner if K_{22} is replaced by K ($= K_{11} = K_{33}$) and the pitch is infinite.

RESULTS AND DISCUSSION

In this study, the control of the azimuthal anchoring energy is investigated. It is well known that the azimuthal anchoring energy depends on the rubbing strength on the rubbed polyimide (PI) surface or the amount of the linearly polarized UV irradiation on the photo-aligned PI surface [10,11]. However, PI surfaces without alignment treatment usually have a strong surface memory effect. Therefore, it might be difficult to change the anchoring energy over a wide range by controlling the rubbing strength.

We tried the photo-decomposition of the PI to change the anchoring energy. The PI (AL-2154, JSR Corp.) surface is irradiated with the UV light ($\lambda = 254$ nm, 3 mW/cm^2 × 1 hour) and rubbed. Figure 3 shows the TN cell with and without the UV irradiation surface. The twist angle on the surface with the UV irradiation was about 86°, compared to 88° on the surface without the UV irradiation. The LC of 4-cyano-4′-n-pentylbiphenyl (5CB) was used and the cell thickness was 5 μm. It is indicate that the photo-decomposition of the PI molecules results in the decrease of the azimuthal anchoring energy of the PI surface. However, the anchoring energy becomes only half and that change is insufficient to control the LC alignment.

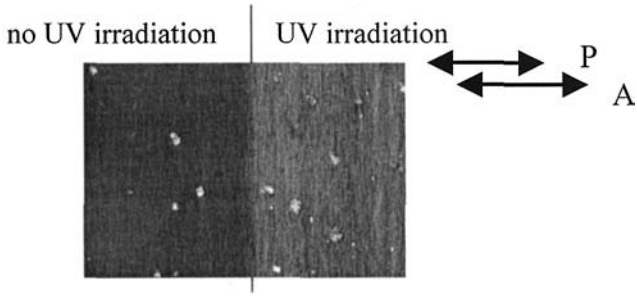

FIGURE 3 The effect of the photo-decomposition on the anchoring energy of the rubbed PI surface in the TN LC cell.

Next, we remarked the polyvinyl cinnamate (PVCi) which shows a photo-dimerization [7] and/or a photo-isomerization reaction [12] by the UV irradiation. It also is well known to be utilized as a LC photo-alignment material with the linearly polarized UV light irradiation. The PVCi surface was irradiated with the non-polarized UV light ($\lambda = 365\,\text{nm}$, $30\,\text{mW/cm}^2 \times 2$ minutes) and rubbed. Figure 4 shows the homogeneous cell with and without the UV irradiation surface. Schlieren textures appeared on the surface without the UV irradiation, when the LC cell was heated up to the isotropic phase and cooled to the nematic phase. Moreover, different schlieren textures were observed by the subsequent heat treatment, which showed the extremely weak adsorption strength of the LC molecules on the PVCi surface. On the other hand, the uniform alignment was obtained on the photo-reacted PVCi surface. Neel wall defects were observed and the defects appeared just under the phase transition temperature from the isotropic to nematic phase. Moreover, their width became narrow when the UV irradiation time was 5 minutes. These results indicate that it is possible to control the anchoring energy over the wide range by irradiating the UV light on the PVCi surface.

Figure 5(a) shows the stripe patterned photo-mask used in this study. The line width is 100 μm. The uniformly rubbed PVCi surface was irradiated with the non-polarized UV light (365 nm, $30\,\text{mW/cm}^2$, 5 minutes) through the photo-masks. LC molecules tend to align perpendicular to the rubbing direction on the PVCi surface. Uniformly rubbed polyimide (PI) surface with strong anchoring of more than $1 \times 10^{-4}\,\text{N/m}$ was prepared as a counter alignment surface. The rubbing directions were parallel to each other in the LC cell. The patterned LC alignment was observed by using a polarization microscope, and is shown in Figure 5(b). The cell thickness was 11 μm. LC molecules were twisted at about 87 and 0° in the TN and homogeneous

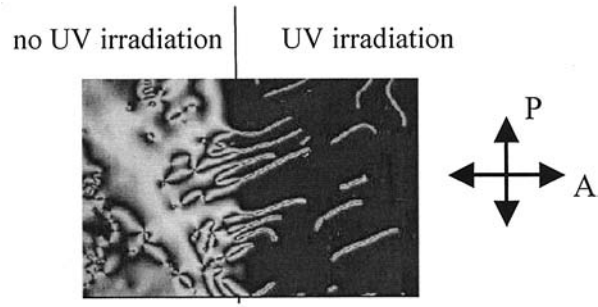

FIGURE 4 The effect of the photo-reaction on the anchoring energy of the rubbed PVCi surface in the homogeneous LC cell.

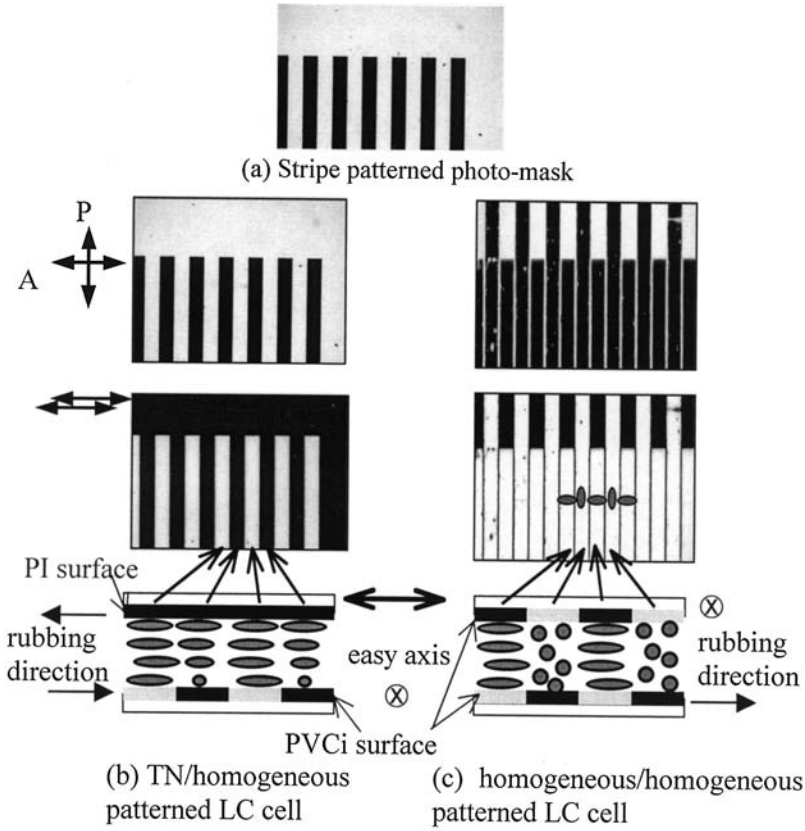

FIGURE 5 Microphotographs of (a) the photo-mask and (b), (c) the patterned LC cell. The line width of the stripe patterned photo-mask is 100 μm.

domains, respectively. When both substrates with PVCi surface are used, homogeneous aligning domains where LC directions are perpendicular to each other are successfully demonstrated, as shown in Figure 5(c).

Such LC cells with a stripe patterned alignment can be applied to the polarization-independent LC grating [13]. When the cell thickness is 5.4 μm, the line and space of above 2 μm can be observed in the LC cell. If the PVCi surface is rubbed after the UV irradiation, almost the same alignment property can be obtained. On the other hand, the patterning can also be attained when the non-rubbed PVCi surface is irradiated with a linearly polarized UV light at one time to make TN domains. However, the anchoring of the domain irradiated with the linearly polarized UV light is weak ($Wa = 2 \sim 5 \times 10^{-6}$ N/m), therefore the twist angle becomes small and the patterning space resolution might be lower.

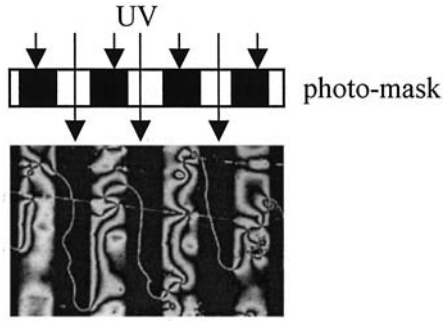

FIGURE 6 The microphotograph of the hybrid aligned LC cell with the patterned PVCi and homeotropic alignment substrate.

Next, the hybrid aligned LC cell is assembled using the PVCi and the homeotropic alignment substrates. The microphotograph of the cell are shown in Figure 6. Uniform hybrid aligned domains are obtained on the PVCi surface with the UV irradiation. Reverse tilt discrination lines are also shown in the domains, since the pretilt angle does not generate on that surface. On the other hand, schlieren textures appear on the PVCi surface without the UV irradiation, and the polar anchoring change of the PVCi surface is not clearly observed.

CONCLUSIONS

A novel patterning technique of the LC alignment by controlling the anchoring energy has been proposed. It is clarified that the azimuthal anchoring energy of the PVCi surface increases by the non-polarized UV irradiation. The patterned LC cell has successfully been demonstrated by using the photo-mask, and twisted and non-twisted orientations can be obtained on the PVCi surface with and without the UV irradiation, respectively. The homogeneously aligned pattern where LC directions are perpendicular to each other can also be assembled by a very simple method.

REFERENCES

[1] Takatori, K., Sumiyoshi, Hirai, Y., & Kaneko, S. (1992). *Proc. IDRC*, Hiroshima, Japan, 591.
[2] Chen, J., Bos, P. J., Vithana, H., & Johnson, D. L., (1995). *Appl. Phys. Lett.*, *67*, 2588.
[3] Ruetschi, M., Grutter, P., Funfschilling, J., Guntherodt, H.-J., (1994). *Science*, *265*, 512.
[4] Pidduck, A. J., Haslam, S. D., Bryan-Brown, G. P., Bannister, R., & Kitely, I. D. (1997). *Appl. Phys. Lett.*, *71*, 2907.

[5] Rastegar, A., Skarabot, M., Blij, B., & Rasing, Th. (2001). *J. Appl. Phys.*, *89*, 960.
[6] Gibbons, W. M., Shannon, P. J., Sun, S.-T., & Swetlin, B. J. (1991). *Nature*, *351*, 49.
[7] Schadt, M., Schmitt, K., Kozinkov, V., & Chigrinov, V. (1992). *J. J. Appl. Phys.*, *31*, 2155.
[8] Iimura, Y., Kusano, J., Kobayashi, A., Aoyagi, Y., & Sugano, T. (1993). *J. J. Appl. Phys.*, *32*, L93.
[9] Seki, T., Sakuragi, M., Kawanishi, Y., Tamaki, T., Fukuda, R., & Ichimura, K. (1993). *Langmurar*, *9*, 211.
[10] Seo, D.-S. (2000) *Liquid Crystals*, *27*, 1539.
[11] Hasegawa, M. (1999). *Jpn. J. Appl. Phys.*, *38*, L457
[12] Ichimura, K., Akita, Y., Akiyama, H., Hayashi, Y., & Kudo, K. (1996). *Jpn. J. Appl. Phys.*, *35*, L992.
[13] Titus, C. M. & Bos, P. J. (1997). *Appl. Phys. Lett.*, *71* , 2239.