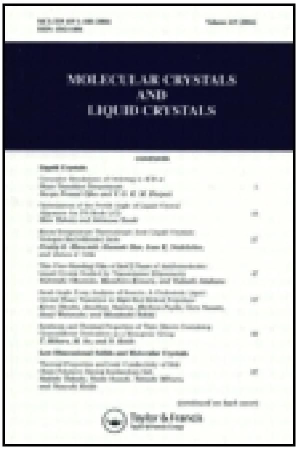

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Alignment Control of Rubbed Polyimide Layers by UV-Irradiation

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This investigation demonstrates the feasibility of re-aligning the assembled liquid crystal cells based on rubbed substrates with photoalignment treatment. A pre-exposure process is proposed to achieve the photo-reorientation effectively. This study shows that the fine-tuning on the LC alignment after a cell is assembled by adjusting UV irradiation conditions can be obtained easily.

Keywords: anchoring strength; liquid crystal photoalignment; photo-reorientation; pre-exposure process; twist angle

I. INTRODUCTION

Aligning liquid crystal (LC) molecules uniformly on a substrate is essential in producing LC displays and other LC devices. A conventional method to align LC molecules is rubbing polyimide (PI) films on substrates [1]. However, many non-contact alignment techniques have also been extensively studied. Among them, photoalignment technique has attracted much attention, because it can provide multi-domain alignment with high quality and high resolution. Several studies have reported the achievements of photoalignment technique. Schadt *et al*. have proposed using the photoalignment to achieve multi-domain aligned display to widen the viewing angles [2]. The author's previous work have reported the photoalignment patterns with sizes of 2 μm, and the mixed alignment patterns was

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obtained with double exposures [3]. Kawatsuki *et al*. fabricated a durable photoalignment layer with high azimuthal anchoring strength and controllability of the tilt angle [4]. Fuh *et al*. have taken dye-doped LC with photoalignment technique to fabricate several optic devices such as holographic gratings and Fresnel lens [5,6]. Multidirectional aligned liquid crystal cells with rubbing treatment have been examined and applied to fabricate IPS LC devices with lower threshold voltage and faster response time [7,8]. Many similar properties of multidirectional aligned with doubly treated photoalignment method are also interested and have been reported. These investigations include controlling the anchoring energy of rubbed PI layers by irradiation with depolarized UV light [9] and re-aligning LC directors by multiple linear polarized UV light irradiation treating method [10]. These studies are all relate to doubly treated substrates before the cells were assembled. In this work, we study the photo-realignment effect on the assembled LC cells.

In this work, we have also employed a particular surface treatment process – pre-exposure, in which the rubbed substrate is irradiated with UV light before being assembled. The twist angle and anchoring strength at various irradiation energy densities have been measured for cells prepared with varies conditions. We have found out that it is easier to achieve the reorientation of LC director in the assembled cells with soft rubbed PI than hard rubbed PI. Furthermore, the reorientation range of LC director is larger with a pre-exposure process. Because of these particular characteristics, fine-tuning the LC alignment by adjusting UV irradiation conditions can be achieved.

In the following contents, we report our experimental methods in section II, and the results with discussion in section III. In the last section, a conclusion and the possible applications are presented.

II. EXPERIMENT METHODS AND PRINCIPLES

The schematic diagram of the LC alignment in the cell is shown in Figure 1. The top and bottom substrates were coated with PI films. The alignment material employed in this investigation was photosensitive PI, RN-1349 (Nissan). After hard baking, the substrates were rubbed by a cotton velvet roller. Controlling the rubbing conditions, various anchoring strength could be obtained. The anchoring strength measured by double-cell method [11] were $5.54 \times 10^{-5}\,\mathrm{J/m^2}$ and $1.13 \times 10^{-5}\,\mathrm{J/m^2}$ for a hard rubbing and a soft rubbing, respectively. The rubbed substrates were assembled anti-parallelly with a $6\,\mu\mathrm{m}$ thick Mylar. The nematic liquid crystal utilized was E7 from Merck. After the cells were assembled, the cells were then illuminated by

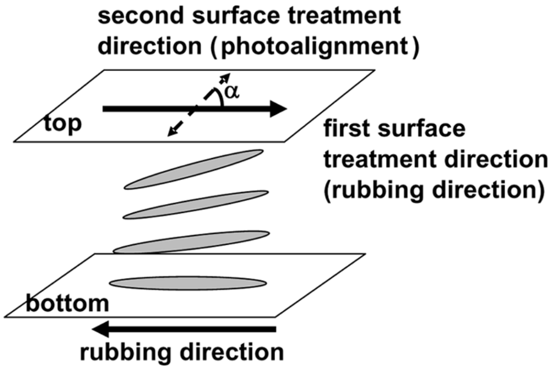

FIGURE 1 Sample structure of photo-reorientation cell.

UV light with a two-step 45° incident angle, double exposure method [12]. The UV light was generated from an ultrahigh pressure xenon arc lamp (Oriel). No any optical filter was used besides the water filter to remove infrared light. The first step, the exposure used S-polarization light, which caused LC molecules aligned perpendicular to the polarization. The second step, unpolarized UV light exposure was utilized to eliminate tilt angle degeneracy. The average light intensities irradiated onto the substrate were $40\,mW/cm^2$ and $180\,mW/cm^2$ for polarized and unpolarized UV light, respectively. The ratio of the first and second-step exposure time was 4:1.

We call the substrate facing the incident UV light the top substrate. Setting an angle α of rubbing direction with respect to the incident plane, the UV light led to a re-orientation of the surface alignment. Two values of α, 90° and 60°, have been investigated in this work. A particular process we proposed in this work was "pre-exposure". One of the substrates (the top substrate) was exposed with UV light before a cell was assembled. The exposure conditions for the pre-exposure process were equal to the corresponding treatment steps of the filled cells. The same incidence angle, same angle α, and same intensities for the polarized and unpolarized UV light for the pre-exposure process illuminated on the top substrate before cells assembled. The irradiation times were 20 min and 5 min for the two exposure steps, respectively. Four cases for photo-reorientation have been studied: (a) soft rubbing with pre-exposure (S-P), (b) hard rubbing with pre-exposure (H-P), (c) soft rubbing without pre-exposure (S-N), and (d) hard rubbing without pre-exposure (H-N). The twist angle and the anchoring strength with various irradiation energy densities were measured.

The azimuthal anchoring strength was determined from measuring the deviation angle, ϕ_s, between the surface alignment direction and the LC director on the surface of the cell. The investigations of multi-direction rubbing on the alignment had shown that the last rubbing determined the alignment of the LC and that the LC molecules would be aligned along the direction of the last rubbing [7,13]. We therefore assume that the second alignment treatment dominated the LC director and the easy direction of the top substrate was parallel to the UV incident plane. The relationship among the deviation angles ϕ_{st}, ϕ_{sb}, and the twist angle ϕ together with angle α, is shown in Figure 2. For the nematic LC in the cell, the energy per unit area (F) was given as a sum of the surface anchoring energies ($F_{surface}$) and the elastic energy (F_{bulk}) as following:

$$F = F_{surfance} + F_{bulk}, \tag{1}$$

and

$$\begin{aligned} F_{surface} &= \frac{1}{2}A_t \sin^2 \phi_{st} + \frac{1}{2}A_b \sin^2 \phi_{sb}, \\ F_{bulk} &= \frac{1}{2d}K_2\phi^2, \end{aligned} \tag{2}$$

where K_2 is the twist elastic constant of E7, d is the cell thickness, A_t, A_b, ϕ_{st}, and ϕ_{sb} are the anchoring strengths and deviation angles of the top and the bottom substrates, respectively. Substituting Eq. (2) into Eq. (1), and minimizing the free energy in the Eq. (1), with respect to ϕ_{st} and ϕ_{sb} leads to a torque balance condition and gives the anchoring strengths as

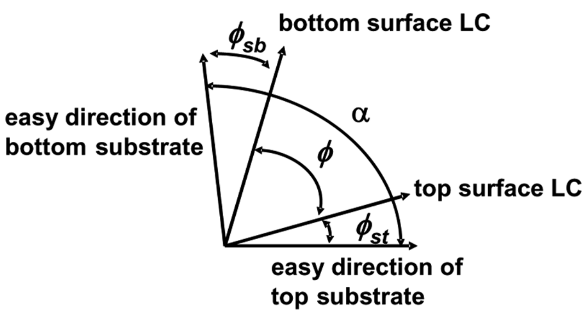

FIGURE 2 Relationship among ϕ, ϕ_{st}, ϕ_{sb}, and α.

$$A_t = \frac{2K_2\phi}{d\sin 2\phi_{st}}, \tag{3a}$$

$$A_b = \frac{2K_2\phi}{d\sin 2\phi_{sb}}. \tag{3b}$$

In Eq. (3b), the parameter 6.0×10^{-12} N was used for K_2 of E7. The anchoring strength of the bottom surface, A_b, was measured independently using another cell with the double cell method. After the twist angle ϕ was measured, so the deviation angle of bottom substrate ϕ_{sb} could be obtained from Eq. (3b). From Figure 2, we can see $\alpha = \phi + \phi_{st} + \phi_{sb}$ and obtain ϕ_{st}. The anchoring strength of the top substrate A_t can then been obtained from Eq. (3a).

III. RESULTS AND DISCUSSIONS

Figure 3 shows the photographs of the photo-reoriented samples under a pair of crossed polarizer. The rubbing direction of the samples was parallel to one of the polarizers. The left parts of the photographs are UV irradiated areas, which were re-orientated and became twisted nematic cells, while the right parts are the un-exposed anti-parallel cell. The reorientation direction was set 90° with respect to the rubbing direction, i.e., $\alpha = 90°$. For the four cases we investigated, the change in alignment can be seen clearly for the S-P and H-P

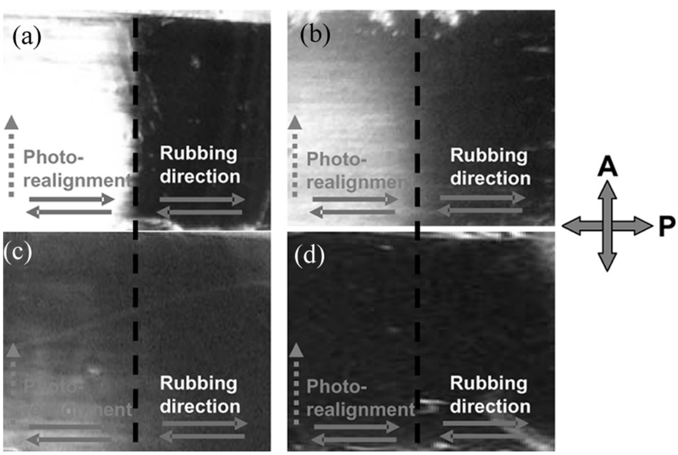

FIGURE 3 Photographs of photo-reorienting samples under crossed polarizers. (a) S-P (b) H-P (c) S-N (d) H-N.

samples. That is, the pre-exposure helps the reorientation for both hard and soft rubbing surface.

The reorientation result expressed in terms of twist angle as a function of irradiation energy density is shown in Figure 4. It is obviously that the twist angle was increased with the increasing irradiation energy density in all cases, but the soft rubbed cells were easier to achieve reorientation than the hard rubbed cells. Moreover, pre-exposure process increased the twist angle dramatically. The twist angle would saturate with increasing irradiation for the S-P and H-P cells reached 71° and 44°, respectively.

The anchoring strength of the reoriented substrate, A_t, as a function of irradiation energy density is shown in Figure 5. The anchoring strengths also increased with increasing irradiation for the pre-exposed samples, but for the samples without pre-exposed, the anchoring strengths remained on smaller values. The changing range of anchoring strength were from $0.90 \times 10^{-6}\,J/m^2$ to $3.29 \times 10^{-6}\,J/m^2$ for the S-P sample, and from $0.65 \times 10^{-6}\,J/m^2$ to $0.98 \times 10^{-6}\,J/m^2$ for the H-P sample.

Considering that the 90° re-orientation setting angle α could cause the twist angle degeneration, we chose another setting angle of 60° for α and repeated the experiments. The results for twist angle and the anchoring strength as functions of irradiation energy density are shown in Figures 6 and 7. They show similar features as for $\alpha = 90°$. The twist angle shifting ranges were from 35° to 58° for the S-P sample, from 12° to 31° for the H-P sample. The reorientation for

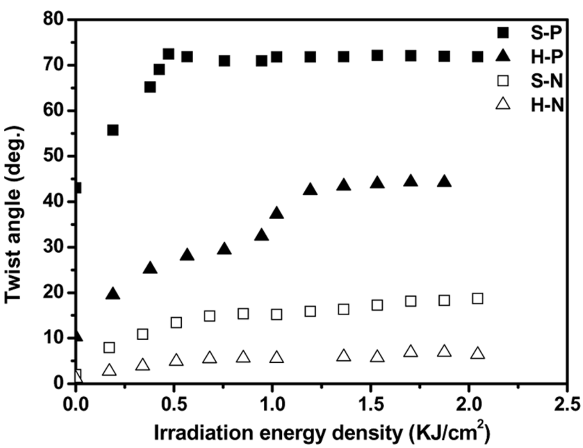

FIGURE 4 Twist angle as a function of irradiation energy density. ($\alpha = 90°$).

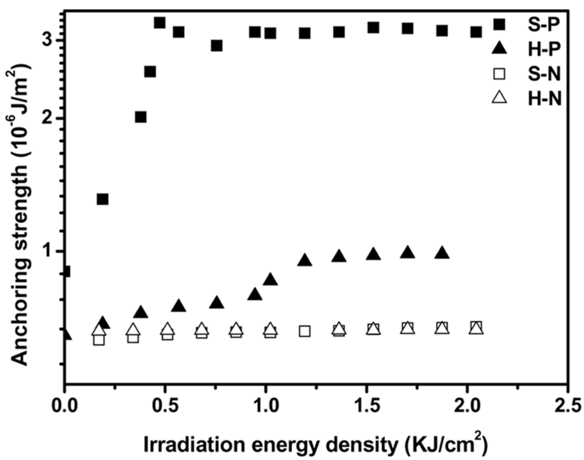

FIGURE 5 Anchoring strength as a function of irradiation energy density. ($\alpha = 90°$).

non-pre-exposed samples remained small. The changing range of anchoring strength were from $0.93 \times 10^{-6}\,\mathrm{J/m^2}$ to $26.6 \times 10^{-6}\,\mathrm{J/m^2}$ for the S-P sample, from $0.22 \times 10^{-6}\,\mathrm{J/m^2}$ to $0.68 \times 10^{-6}\,\mathrm{J/m^2}$ for the H-P sample, from $0.23 \times 10^{-6}\,\mathrm{J/m^2}$ to $0.46 \times 10^{-6}\,\mathrm{J/m^2}$ for the S-N sample, and from $0.11 \times 10^{-6}\,\mathrm{J/m^2}$ to $0.33 \times 10^{-6}\,\mathrm{J/m^2}$ for the H-N sample. In summary, we found that the pre-exposure process made photo-realignment effect efficient for both hard rubbing and soft

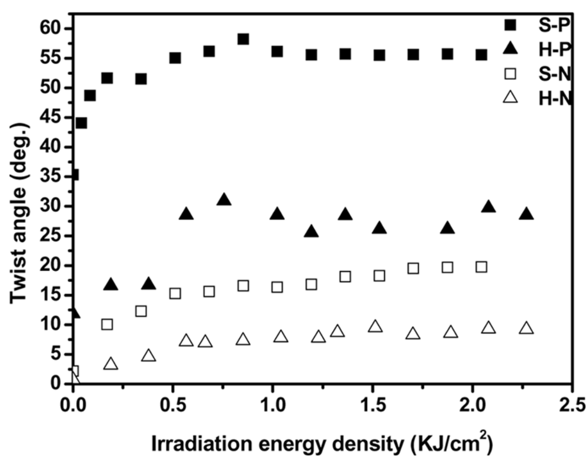

FIGURE 6 Twist angle as a function of irradiation energy density. ($\alpha = 60°$).

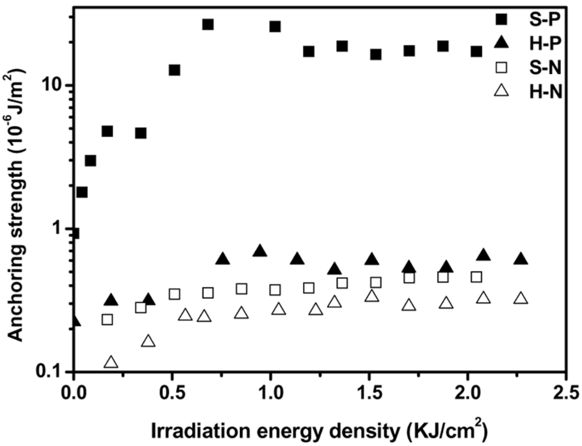

FIGURE 7 Anchoring strength as a function of irradiation energy density. ($\alpha = 60°$).

rubbing substrates. Moreover, the hard rubbing substrates were more difficult to reorient comparing to the soft rubbing substrates.

IV. CONCLUSIONS

Our work showed the feasibility of reorient the assembled cells with photoalignment treatment. A particular process, the pre-exposure process, proposed in this study can make the photo-reorientation much efficient. With these features, fine-tuning on the LC alignment by adjusting UV irradiation conditions can be achieved. With the present results, the re-alignment is realized in the cell based on rubbed PI substrate with UV irradiation. Therefore, the rubbed cells may be used to design optically rewritable devices with this achievement in future.

REFERENCES

[1] Mauguin, C. (1911). *Bull. Soc. Fr. Min.*, *34*, 71.
[2] Schadt, M., Seiberle, H., & Schuster, A. (1996). *Nature*, *381*, 212.
[3] Pan, R.-P., Chiu, H.-Y., Lin, Y.-F., & Huang, J. Y. (2003). *Chinese J. Phys.*, *41*, 177.
[4] Kawatsuki, N., Hamano, K., Ons, H., Sasaki, T., & Goto, K. (2007). *Jpn. J. Appl. Phys.*, *46*, 339.
[5] Lee, C. R., Mo, T. S., Cheng, K. T., Fu, T. L., & Fuh, A. Y.-G. (2007). *Appl. Phys. Lett.*, *83*, 4285.
[6] Lin, L. C., Jau, H. C., Lin, T. H., & Fuh, A. Y. -G. (2007). *Optics Express*, *15*, 2900.

[7] Huang, C. Y., Lin, C. H., Wang, J. R., Huang, C. W., Tsai, M. S., & Fuh, A. Y.-G. (2002). *J. Appl. Phys.*, *92*, 7231.
[8] Huang, C. Y., Hsieh, C. T., & Tina, J. R. (2006). *Optics Express*, *14*, 9931.
[9] Andrienko, D., Kurioz, Y., Nishikawa, M., Reznikov, Y., & West, J. L. (2000). *Jpn. J. Appl. Phys.*, *39*, 1217.
[10] Chung, D. H., Takanishi, Y., Yu, C. J., Lee, S. D., & Takezoe, H. (2003). *Jpn. J. Appl. Phys.*, *42*, 1686.
[11] Saitoh, Y. & Lien, A. (2000). *Jpn. J. Appl. Phys.*, *39*, 1743.
[12] Iimura, Y., Kobayashi, S., Hashimoto, T., Sugiyama, T., & Katoh, K. (1996). *IEICE Trans ELECTRON*, *E79-C*, 1040.
[13] Kim, Y. J., Zhuang, Z., & Patel, J. S. (2000). *Appl. Phys. Lett.*, *77*, 513.