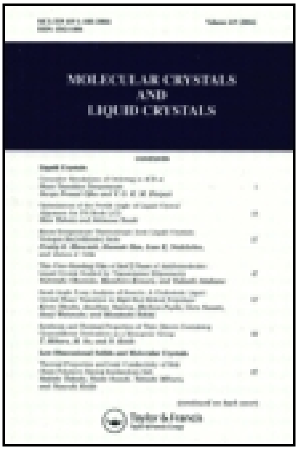

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Control of Pretilt Angle and its Direction in Homeotropic Alignment of Liquid Crystals Using Photoalignment Technique

Hai Feng Li [a] , Eung Jin Kim [b] , Hirokazu Furue [c] , Yasufumi Iimura [d] & Shunsuke Kobayashi [c]

[a] The State Key Laboratory of Modern Optical Instrumentation, Zhejiang University, Hangzhou, 310027, P. R. China

[b] Korea Advanced Institute of Science and Technology, Taejon, 305-701, Korea

[c] Liquid Crystal Institute, Science University of Tokyo in Yamaguchi, Onoda, Yamaguchi, 756-0884, Japan

[d] Faculty of Technology, Tokyo University of Agriculture and Technology, Koganei, Tokyo, 184-0012, Japan

To cite this article: Hai Feng Li, Eung Jin Kim, Hirokazu Furue, Yasufumi Iimura & Shunsuke Kobayashi (1999): Control of Pretilt Angle and its Direction in Homeotropic Alignment of Liquid Crystals Using Photoalignment Technique, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 326:1, 249-257

To link to this article: http://dx.doi.org/10.1080/10587259908025418

Mol. Cryst. Liq. Cryst., Vol. 326, pp. 249-257
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Control of Pretilt Angle and its Direction in Homeotropic Alignment of Liquid Crystals Using Photoalignment Technique

HAI FENG LI[a], EUNG JIN KIM[b], HIROKAZU FURUE[c,*],
YASUFUMI IIMURA[d] and SHUNSUKE KOBAYASHI[c]

[a] *The State Key Laboratory of Modern Optical Instrumentation, Zhejiang University, Hangzhou, 310027, P. R. China;*
[b] *Korea Advanced Institute of Science and Technology, Taejon 305-701, Korea;*
[c] *Liquid Crystal Institute, Science University of Tokyo in Yamaguchi, Onoda, Yamaguchi 756-0884, Japan;*
[c] *Faculty of Technology, Tokyo University of Agriculture and Technology, Koganei, Tokyo 184-0012, Japan*

(Received 14 August 1998; In final form 14 October 1998)

We have investigated the control of the pretilt angle and its direction appearing in the tilted homeotropic alignment of nematic liquid crystals oriented on polyimide films that are irradiated with an unpolarized obliquely incident UV light. As a result, it is shown that the pretilt angle is well controlled and its value is shown to be determined by the irradiation energy where the direction of pretilt is governed by the temperature of polyimide films during the course of UV irradiation.

Keywords: Photoalignment; tilted homeotropic alignment; polyimide; nematic liquid crystal

1. INTRODUCTION

In the fabrication of liquid crystal (LC) cells, photoalignment technology has been regarded as a hopeful substitute for the traditional rubbing method for its contact-free characteristics [1].

The methods of photoalignment for producing a homogeneous alignment of nematic liquid crystal (NLC) that are reported in literature are as follows:

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[*] Corresponding author. Tel.: 0836-88-4540, Fax: 0836-88-4540.

cis – trans transformation of azodye mixed or bonded with polymer films such as polyimide (PI) and poly(vinyl alcohol) [2–5]; photo-dimerization of poly(vinyl cinnamate) [6, 7]; and undoped polyimide irradiated with a polarized UV light [8]. Originally, this research was conducted for fabricating an LC cell with a uniform planer LC molecular conformation called homogeneous monodomain. Later the photoalignment is particularly appreciated for fabricating a multidomain cell with four divisions called super multidomain [1, 9] and also for a tilted homeotropically aligned cell [1], because it is hard to fabricate these kinds of cells with the conventional rubbing method. Along with this research, it is necessary to develop a method for generating and controlling the pretilt angle. The generation of pretilt angle is necessary to fabricate a defect-free cell by eliminating the appearance of reverse tilt disclinations [1, 10]. Hashimoto *et al.* succeeded in generating a pretilt angle in an NLC cell by adopting oblique irradiation of polarized UV light onto PVCi films and demonstrated a defect-free TN-matrix LCD with four domain pixels, where the first vertical irradiation was done prior to the second oblique irradiation [1, 8]. Soon after, Schadt *et al.* demonstrated a pretilt angle generation by adopting PVCi with a coumarin side chain [11], and Han *et al.* also reported polyimide with a cinnamoyl side chain [12]. Further, Saitoh *et al.* [13] and Hashimoto *et al.* [14] succeeded in fabricating LC media with any pretilt angle ranging from 90° (homeotropic alignment) to 0° (homogeneous alignment) by using PI with alkyl sidechains that were irradiated with polarized obliquely incident UV light. Regarding the obliquely incident UV irradiation, Iimura *et al.* [15] and Yoshida *et al.* [16] discussed and actually demonstrated that an unpolarized obliquely incident UV light is also useful to align an LC molecule to form a uniform alignment with a pretilt angle, where the s-component of the incident light contributes to the uniform alignment and the p-component to the pretilt angle generation.

In this paper we will report a method for fabricating a uniform NLC medium with a small pretilt angle deviation from homeotropic vertical conformation and describe some results, where we utilized a PI material with alkylchains that were irradiated with an unpolarized obliquely incident UV light.

2. EXPERIMENTAL

The polyimide material used in this research, which was synthesized by Nissan Chem. Ind., was mixed with a compound having alkyl chains of which the chemical structure is shown in Figure 1, and then produces a

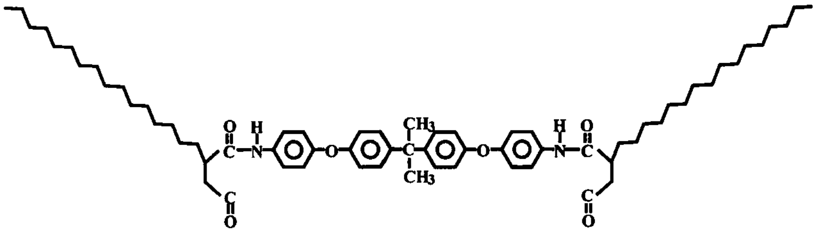

FIGURE 1 The chemical structure of a compound included in polyimide material.

homeotropic alignment. This material was spincoated on two ITO glass substrates at a speed of 4000 r/min for 20 seconds and then baked at about 180°C for one hour. These two substrates were then irradiated by a parallel unpolarized UV light at an incident angle of about 45°. The UV light coming from a super-high-pressure Hg lamp was passed through an optical interference filter that has maximum transmission at about 254 nm. When being cured with a UV light, a hot plate was used to control the substrates at a certain temperature. The purpose of this is to control the speed of certain reactions in the material.

After cured by the UV light, a pair of substrates was used to make an LC cell with their alignment direction antiparallel. The cell gap was about 5.4 μm. A liquid crystal was injected in the cell at its clearing point and then cooled down gradually to room temperature. We used several kinds of NLCs with negative dielectric anisotropy, such as ZLI-4792, ZLI-4318 (Merck), MBBA, and other NLCs for comparison.

The pretilt angle of the LC cell was then measured by the conventional crystal rotation method. In order to present the tilt direction in the pretilt angle, we define the angle θ as the pretilt angle shown in Figure 2, where in the case of (A) $\theta < 90°$ and $\theta > 90°$ in the case of (B). The value of θ will change from 90° to 0° when the LC molecule inclines to the opposite side of the UV light irradiation, and 90° to 180° when on the same side of the UV light.

3. RESULTS AND DISCUSSION

First we irradiated the substrates with an unpolarized UV light at room temperature. We found that the LC molecule tilts to the opposite side of the UV light. The tilt angle is dependent on the energy of the exposure of unpolarized UV light. However, the tilt angle changes with different LC materials. The measured pretilt angles for different exposure energy and different liquid crystal materials are shown in Figure 3. In our experiment

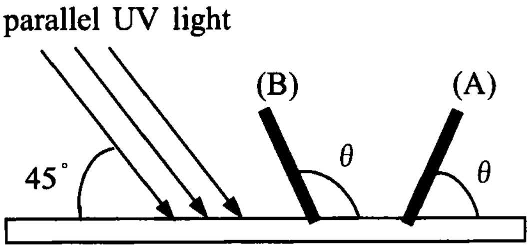

FIGURE 2 The definition of the pretilt angle θ.

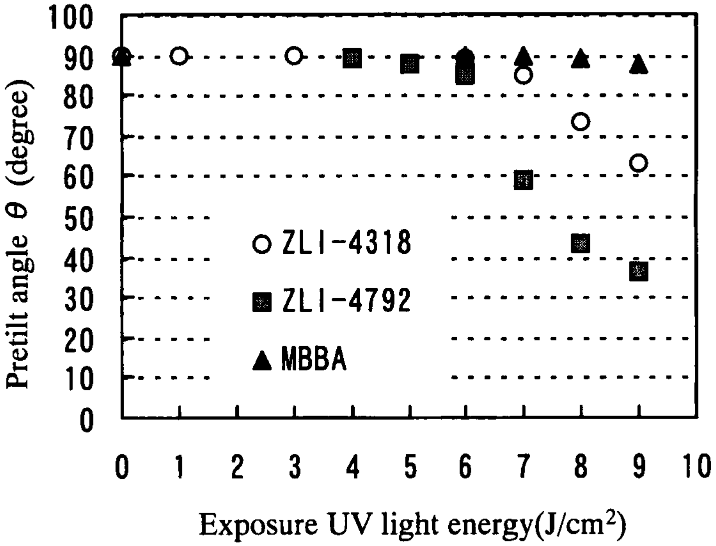

FIGURE 3 The pretilt angle θ measured for different exposure of unpolarized UV light energy.

NLC ZLI-4792 seems more sensitive to the UV exposed polymer surface. But it is also easy to produce defects in our case. All the materials seem to generate defects in small tilt angles. We found that the MBBA is more uniform in a wide range of pretilt angles although it needed higher UV energy. A uniform alignment with a large tilt angle can be obtained easily by controlling the exposure UV light energy for all the LC materials we used. Figure 4 demonstrates a multidomain LC cell with different pretilt angles generated by different exposure UV energy for MBBA. Figures 5(a) and (b) are the microphotographs of the microscopic textures of MBBA and ZLI-4792 at their pretilt angle of about 88°.

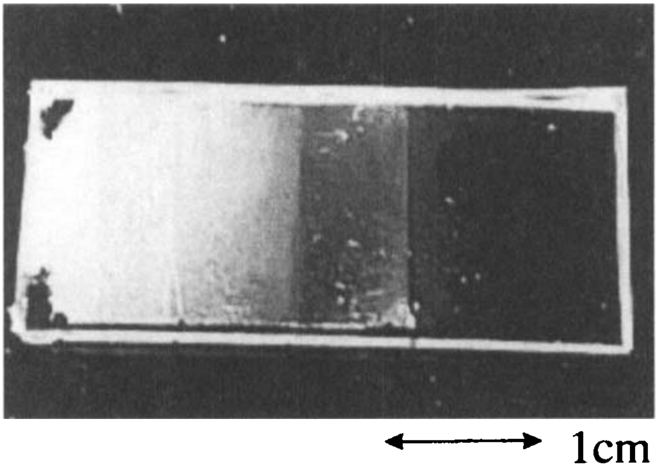

FIGURE 4 Multi-domain LC cell with different pretilt angles, where a shield was used to control the exposure energy. LC material is MBBA.

Next we irradiated the substrates with an unpolarized UV light at a high temperature. We found that the reaction was significantly accelerated at a high temperature. Meanwhile we found that the direction of the pretilt angle will change from the normal to the opposite as the substrate temperature increased from room temperature to about 120°C. The variation of pretilt angle for longer exposure time was also observed in both higher temperatures and lower temperatures. Figure 6 shows the measured data for different substrate temperature and exposure energy for MBBA. We found that there exists a certain temperature at which the director of an NLC will change from normal to the opposite side when the exposure UV energy increases. As a typical example the sign of the pretilt angle turns over at about 100°C as shown in Figure 6, where MBBA was used. Similar results were also obtained for some other liquid crystals such as 5CB (with a positive dielectric anisotropy $\Delta\varepsilon$), ZLI-4318, and other NLCs regardless of the sign of $\Delta\varepsilon$.

For this characteristic, we were able to fabricate a double-domain LC cell which has opposite tilt directions just in one exposure without changing the incident direction. The temperature was controlled accurately at about 100°C. During the irradiation a shield was used to control the exposure energy for one domain at about $2\,J/cm^2$ and another at $3.5\,J/cm^2$, where corresponding pretilt angles were 89° and 90.6°, respectively. The photographs of the LC cell are shown in Figure 7, where (a) is viewed from the top without applying the electrical field; it is totally black because

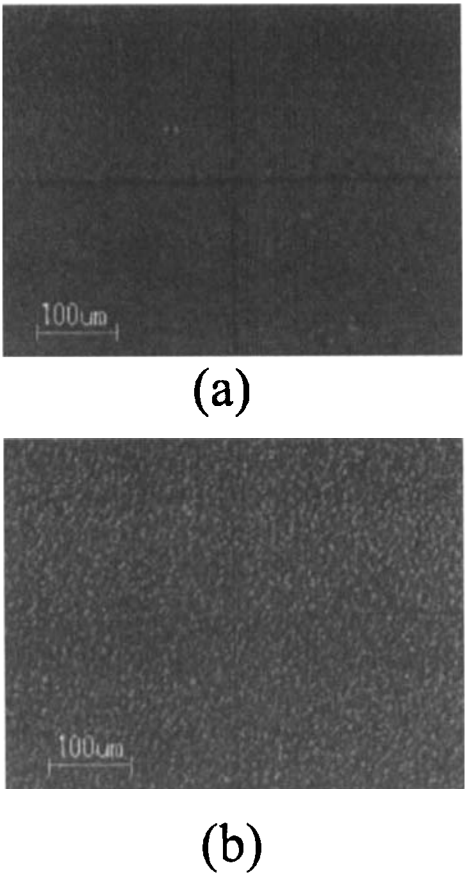

FIGURE 5 The microscopic texture of the inclined homeotropic alignment for different LC materials with its pretilt angle about 2 deg. (a) MBBA and (b) ZLI-4792, respectively.

the pretilt angle is near 90°, where as (b) and (c) are viewed from two opposite azimuth directions with an applied voltage of about 2 volts on the cell. The two domains show their opposite tilt directions.

Now, we will suggest a model for explaining the observed phenomena. First of all, we assume that the photoalignment in the UV light-irradiated PI may occur as a result of a photo depolymerization where a special moiety in the backbone of the compound mixed with PI is destroyed by UV light absorption. Based on this assumption, we proceed with our explanation as follows: Figure 8(a) depicts a homeotropic alignment of LC molecules using alkyl sidechains where we assume that there is an equal probability in the slanted alkyl branches as distinguished by the letter L (that stands for left)

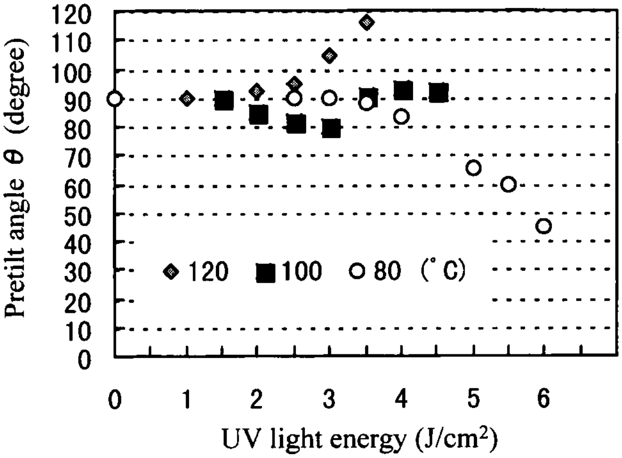

FIGURE 6 Pretilt angle θ for different substrate temperature and exposure energy for MBBA.

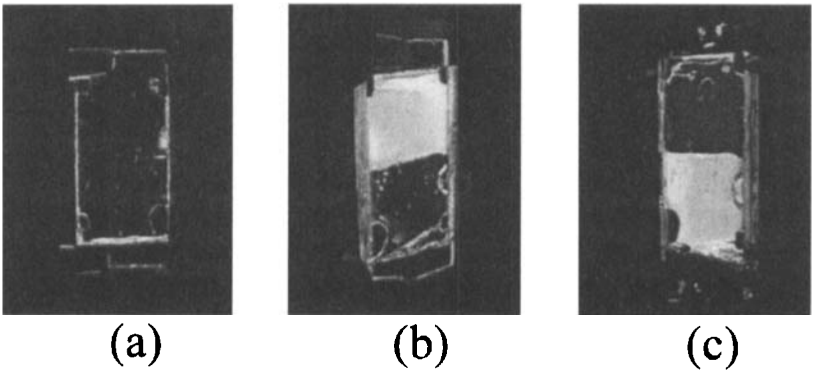

FIGURE 7 Two-domain LC cell with opposite tilt directions obtained by controlling the exposure of unpolarized UV light energy without changing the incident direction. (a) Viewed from top, off state; (b) from left, on state and (c) right, on state.

and by R (right), respectively; this situation may produce an ideal homeotropic alignment. On the left part of Figure 8(a) necessary notations for the incident UV light beam are those such as the propagation vector k and the components of the electric field of the UV light, p and s.

If the left-slanting alkyl branches disappear, then the LC molecules tend to incline to the right side, where the pretilt angle is $\theta < 90°$, as shown in Figure 8(b). In this case the disappearance of the left alkyl branches may be caused by the UV light absorption of the p component by the b_L component of the dipoles in the backbone. Furthermore, the s component is absorbed

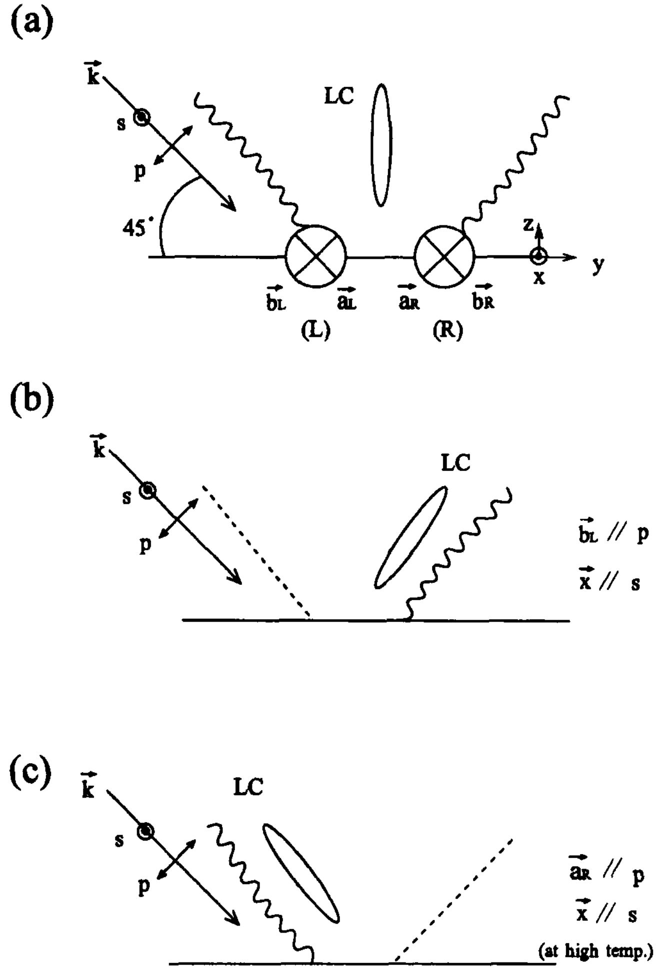

FIGURE 8 A model for explaining the mechanism of the formation of the inclined homeotropic alignment of liquid crystals by photoalignment using unpolarized obliquely irradiated UV light. (a) depicts homeotropic alignment before UV irradiation, where a_R, b_R, a_L and b_L stand for the directions of dipole moments existing in the back bone of the compound mixed with PI, each dipole moment absorbs UV light for depolymerization; (b) the s component of UV light contributes to aligning LC molecules in the y direction, and if the p component is absorbed by the b_L component, then the left alkyl branches lose the aligning capability and only the right branches become capable of aligning LC molecules and LC molecules inclining toward the right direction, where the pretilt angle is $\theta < 90°$; (c) if the p component is absorbed by the dipole a_R and depolymerization occurs, then the pretilt angle is $\theta > 90°$. Generally, the b case is likely to occur, but depending on the material the c case occurs at an elevated temperature.

by the dipole moments parallel to the x direction; this may contribute to aligning LC molecules in the y direction. On the other hand, if the p component is absorbed by the a_R component of dipoles in the backbone, then right-slanting alkyl branches may disappear resulting in the pretilt angle of $\theta > 90°$, as shown in Figure 8(c).

4. CONCLUSION

We have studied the inclined homeotropic alignment by irradiation of obliquely incident unpolarized UV light. Uniform alignment for large pretilt angles (near 90°) can be obtained by irradiation of the unpolarized UV light. We have found that both the pretilt angle and the azimuth direction are dependent on the exposure energy and substrate temperature. It seems possible to fabricate an LC cell having double domains with opposite tilt directions in one exposure without changing the incident direction of UV light.

Acknowledgements

The authors thank H. Fukuro and H. Endoh of Nissan Chem. Ind. for supplying polyimide materials.

References

[1] S. Kobayashi and Y. Iimura, *Proc. SPIE*, **3015**, 40 (1997).

[2] W. M. Gibbons, P. J. Shannon, S. T. Sun and B. J. Swetlin, *Nature*, **351**, 49 (1991).

[3] Y. Iimura, J. Kusano, S. Kobayashi, Y. Aoyagi and T. Sugano, *Jpn. J. Appl. Phys.*, **32**, Pt. 2, L93 (1993).

[4] H. Akiyama, K. Kudo, K. Ichimura, S. Yokoyama, M. Kakimoto and Y. Imai, *Langmuir*, **11**, 1033 (1995).

[5] H. Akiyama, M. Momose, K. Ichimura and S. Yamamura, *Macromolecules*, **28**, 288 (1995).

[6] A. G. Dyadyusha, T. Ya. Marusii, Yu. A. Resnikov, A. I. Khizhuyak and V. Yu. Reshetnyak, *JETP Lett.*, **56**, 17 (1992).

[7] M. Schadt, H. Seiberle, A. Schuster and S. M. Kelley, *Jpn. J. Appl. Phys.*, **34**, Pt. 2, L764 (1995).

[8] M. Hasegawa and Y. Taira, *J. Photopolymer Sci. and Tech.*, **8**, 257 (1995).

[9] T. Hashimoto, T. Sugitama, K. Katoh, T. Saitoh, H. Suzuki, Y. Iimura and S. Kobayashi, *Digest of Tech. Papers, 1995 SID Int'l. Symp.*, **26**, 877 (1995).

[10] A. Miyaji, M. Yamaguchi, A. Toda, H. Mada and S. Kobayashi, *IEEE Tr. Elect. Dev.*, **ED-24**, 811 (1977).

[11] M. Schadt and H. Seiberle, *J. SID*, **5**, 367 (1997).

[12] K. Y. Han, S. H. Yu, B. H. Chae, J. K. Song, Y. K. Jang and H. S. Yu, *IDRC97* (Toronto), p. 81 (1997).

[13] T. Saitoh, Y. Iimura, M. Nishikawa and S. Kobayashi, *22nd Jpn. Conf. on Liquid Crystals* (*Kyushu Univ.*), p. 19 (1996).

[14] T. Hashimoto, K. Katoh, Y. Iimura and S. Kobayashi, *22nd Jpn. Conf. on Liquid Crystals* (*Kyushu Univ.*), p. 167 (1996).

[15] Y. Iimura and S. Kobayashi, *Digest of Tech. Papers, 1997 SID Int'l. Symp.*, **28**, 311 (1997).

[16] H. Yoshida and Y. Koike, *Jpn. J. Appl. Phys.*, **36**, Pt. 2, L428 (1997).