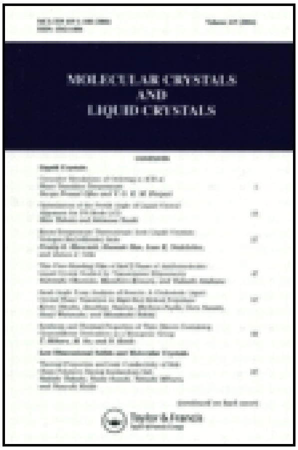

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Molecular Alignment Structure of Polymer-Stabilized Ferroelectric Liquid Crystals

Hirokazu Furue [a], Hiroaki Miyaura [a] & Jun Hatano [a]
[a] Department of Materials Science and Technology, Tokyo University of Science, Noda, Chiba, Japan

Version of record first published: 22 Sep 2010

Mol. Cryst. Liq. Cryst., Vol. 480, pp. 131–139, 2008

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400701825961

Molecular Alignment Structure of Polymer-Stabilized Ferroelectric Liquid Crystals

Hirokazu Furue, Hiroaki Miyaura, Jun Hatano
Department of Materials Science and Technology, Tokyo University of Science, Noda, Chiba, Japan

The polymer-stabilized ferroelectric liquid crystal (PS-FLC) photocured under the application of an AC electric field shows a monostable V-shaped electrooptical characteristics. However, it is not clear how the V-shaped electrooptical characteristics can be realized in the PS-FLC. In this study, we have investigated in detail the elecrooptical characteristics, microscopic texture and X-ray diffraction of PS-FLC, and the effect of the polymer stabilization on the molecular alignment structure. As a result, it is guessed that two types of domain, in which there are two alignment directions monostabilized by the polymer photocured under the application of a bipolar electric field, would coexist.

Keywords: alignment; domain; ferroelectric liquid crystal; polymer; X-ray diffraction

1. INTRODUCTION

Surface-stabilized ferroelectric liquid crystal displays (SSFLCDs) form the basis of a rapidly developing technology of significant potential impact in display applications, in particular, such as video image displays by taking advantage of their fast response speed [1–4]. However, the bistability of SSFLC is disadvantageous for LCDs that possess grayscale or full-color capability, because the size of bistable switching domains may become almost equal to the pixel size of LCDs. In previous papers we reported a polymer-stabilized (PS) FLC fabricated by a UV photocure of doped photocurable monomer, which have

We gratefully thank Dr. H. Takatsu and Dr. H. Hasebe of Dainippon Ink & Chem. and Mr. H. Fukuro and Mr. H. Endoh of Nissan Chem. Ind. for supplying photocurable mesogenic monomer and polyimide material, respectively.

Address correspondence to Hirokazu Furue, Department of Materials Science and Technology, Tokyo University of Science, 2641 Yamazaki, Noda, Chiba 278-8510, Japan. E-mail: hfurue@rs.noda.tus.ac.jp

mesogenic side chains, at a temperature where the LC medium is in the SmC* phase under the application of a DC or AC electric field [5–10]. These PS-FLCs exhibit monostable electrooptical characteristics with grayscale capability without a threshold. The PS-FLC photocured under the application of an AC electric field shows a V-shaped electrooptical characteristics [9,10]. Although an expected model of the molecular alignment in this PS-FLC was reported [10], this model is not proved definitely and thus it has been not clear yet how the monostable V-shaped electrooptical characteristics can be realized in the PS-FLC. In this study, we have investigated in detail the effect of the polymer stabilization on the molecular alignment structure. We have fabricated lots of PS-FLCs under many types of photocuring conditions such as the concentration of doped monomer and the frequency of AC electric field, and then observed microscopic textures and measured electrooptical characteristics of PS-FLCs. Especially, in order to be clear why the monostable V-shaped electrooptical effect can be obtained, in this research, we have studied the smectic layer structure and then the molecular alignment structure by the X-ray diffraction observation.

2. EXPERIMENTALS

The materials used in this research were as follows: the FLC was FELIX-M4851/100 (Clariant Japan); the photocurable mesogenic diacrylate was 2A363 (Dainippon Ink and Chemicals) which was doped 1 wt% photoinitiator; and the LC alignment film was polyimide RN-1199 (Nissan Chemical Industries) which induced a defect-free FLC alignment with the C2-chevron structure [11,12]. The relevant properties of FELIX-M4851/100 given by the catalogue are shown in Table 1.

A solution of polyimide was spun on glass substrates coated with indium-tin-oxide (ITO) and then baked. After the thermal treatment, the substrates were rubbed. Then the FLC, which was doped with the photocurable mesogenic monomer, was injected in the isotropic

TABLE 1 Properties of FELIX-M4851/100

Properties	
Phase sequence	Cryst. (<-20)SmC*(67)SmA(71)N*(76)Iso. [°C]
Spontaneous polarization	22.8 nC/cm^2 (20°C)
Tilt angle	30.5° (20°C)
Switching time	38 μs (E = 15 V/μm, 20°C)

phase via capillary action into an empty 2 μm-thick cell, in which the rubbing directions were set parallel. Next, the cell was cooled gradually to the temperature where the LC medium is in the SmC* phase. After that, the LC medium was photocured with a UV light source (365 nm, 2 mW/cm^2) under the application of a bipolar square-pulsed AC electric field in which the amplitude was 5 V/μm.

The microscopic textures of the PS-FLCs fabricated by this method were observed with a polarizing microscope and their electrooptical characteristics were measured with a conventional measuring system and by applying a 10–30 Hz triangular AC electric field.

3. RESULTS AND DISCUSSION

3.1. Concentration of Polymer

Figure 1 shows the dependence of the electrooptical characteristics of PS-FLCs photocured under the application of 100 Hz AC electric field at the temperature of Tc-20°C (Tc: the phase transition temperature from SmA to SmC* phase), in which the FLC director at the quiescent condition was set parallel to the polarized direction of incident light in the cross-Nichol situation and the measurement was done at the temperature of Tc-20, on the polymer concentration. We confirmed that the monostable V-shaped electrooptical characteristics can be realized over 4 wt% concentration of polymer and then a relatively high contrast ratio, which was the ratio of transmittance between in the light state under the application of 10 V voltage and the dark state at the quiescent condition, can be obtained over

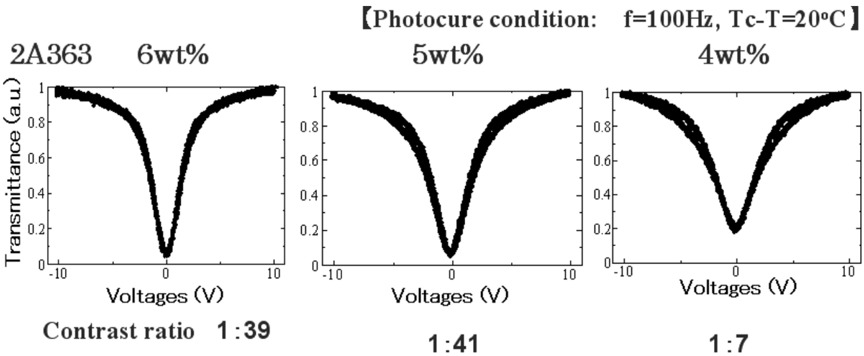

FIGURE 1 Electrooptical characteristics of PS-FLCs with 4, 5 or 6 wt% polymer concentration.

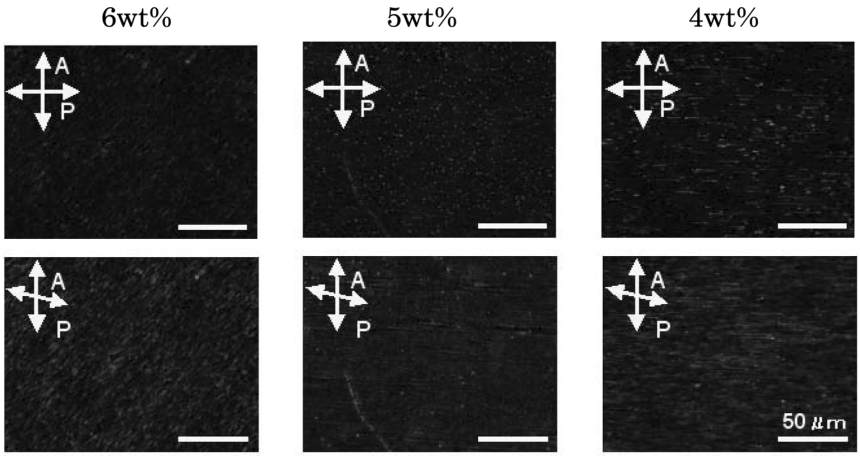

FIGURE 2 Microscopic textures of PS-FLCs with 4, 5 or 6 wt% polymer concentration.

5 wt% polymer, even though the high contrast ratio utilizable for a display device was not obtained because the LC cells could not be fabricated well fine due to the laboratory level of the fabricating condition. Figure 2 shows microscopic textures of PS-FLCs with the polymer concentration of 4, 5 and 6 wt%, which were observed at the quiescent condition. It is found that PS-FLCs possess a domain structure and the texture of PS-FLC with 4 wt% polymer is rougher than that with 5 or 6 wt% polymer because the domain size of PS-FLC fabricated using 4 wt% diacrylate 2A363 is larger than that of the other. Thus, the optical leakage of PS-FLC with 4 wt% polymer is stronger in the dark state at the quiescent condition, and then the contrast ratio is degraded.

3.2. Frequency of AC Electric Field

Figure 3 demonstrates the dependence of the electrooptical characteristics of PS-FLCs fabricated using 5 wt% diacrylate at the temperature of Tc-20 on the frequency of AC electric field at the photocure stage. It is found that the transmittance in the dark state decreases and the contrast ratio increases as the frequency increases except for the case of 100 kHz. Figure 4 shows the microscopic textures of the PS-FLCs. It is confirmed that the domain size decreases except for 100 kHz as the frequency increases and then the domain structure is hardly observed in a case of high frequency such as 1 kHz and

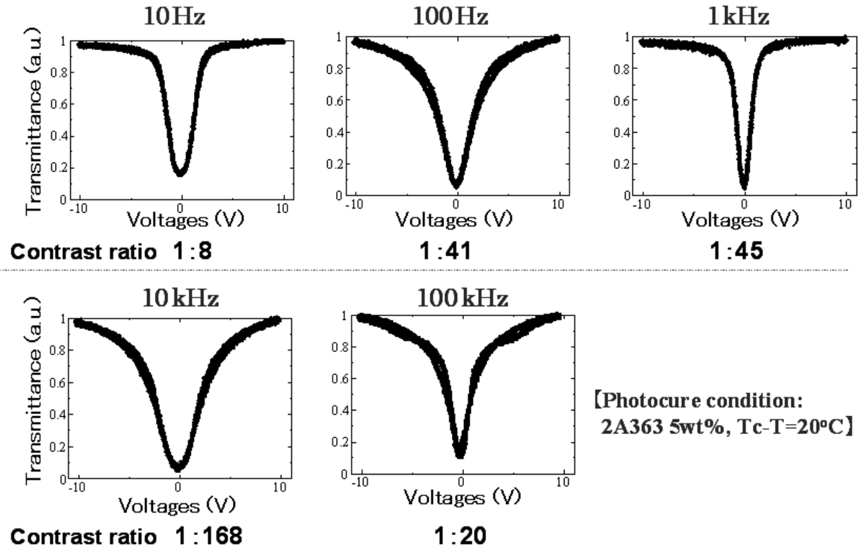

FIGURE 3 Electrooptical characteristics of PS-FLCs photocured under the application of AC electric field with 10, 100, 1 k, 10 k or 100 kHz frequency.

10 kHz since the domain size may be less than the wavelength of visible light. As a result, the PS-FLC photocured under the application of AC electric field with a high frequency can show excellent black with no optical leakage in the dark state. In the PS-FLC photocured under the application of AC electric field with an extremely high frequency such as 100 kHz, the domain size cannot decrease because FLC molecules would be hard to reorient for the electric field due to slower response time of FLC than the frequency of AC field and thus the application of the electric field might not be effective. Therefore, the performance of PS-FLC photocured at the extremely high frequency may deteriorate.

3.3. X-Ray Diffraction

Figure 5 shows the measurement results of X-ray diffraction. In the conventional FLC cell before the photocure, the double peaks are observed due to the chevron layer structure and then the layer tilt angle (chevron angle) δ is 27.5°. It is well known from experience that δ is almost equal to 0.8θ in conventional FLC cells (θ: the tilt angle of FLC molecules). In the case of this study, the tilt angle is 22.5° before the photocure and therefore this relation stands up. If $\delta = \theta$, the FLC

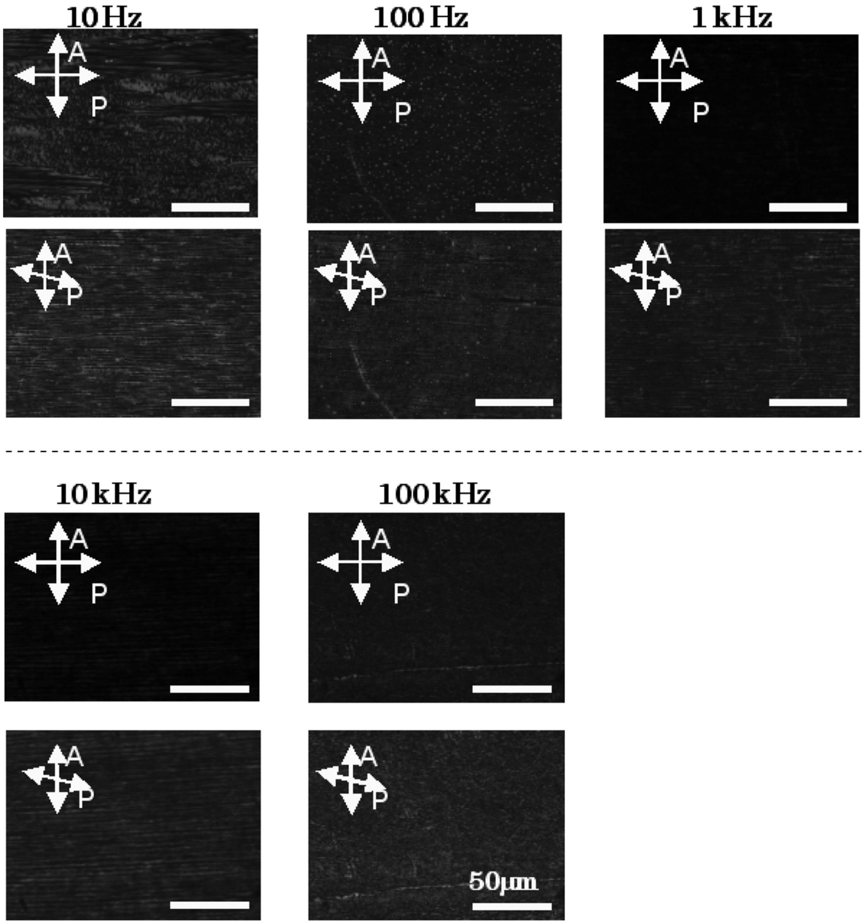

FIGURE 4 Microscopic textures of PS-FLCs photocured under the application of AC electric field with 10, 100, 1 k, 10 k or 100 kHz frequency.

medium may show the monostability such as a PS-FLC photocured at a temperature where the LC medium is in the SmA phase [13]. However, in the PS-FLC photocured at the SmC* phase under the application of AC electric field, $\delta \neq \theta$ but $\delta = 0$, as shown in Figure 5(b). Thus the smectic layer forms a quasi-bookshelf structure with a smeared-out distribution of chevron angle. Therefore, it is proved definitely from the X-ray diffraction results in this study, for the first time, that the origin of the monostable V-shaped electrooptical characteristics in this PS-FLC is different from that in the PS-FLC photocured at the SmA phase.

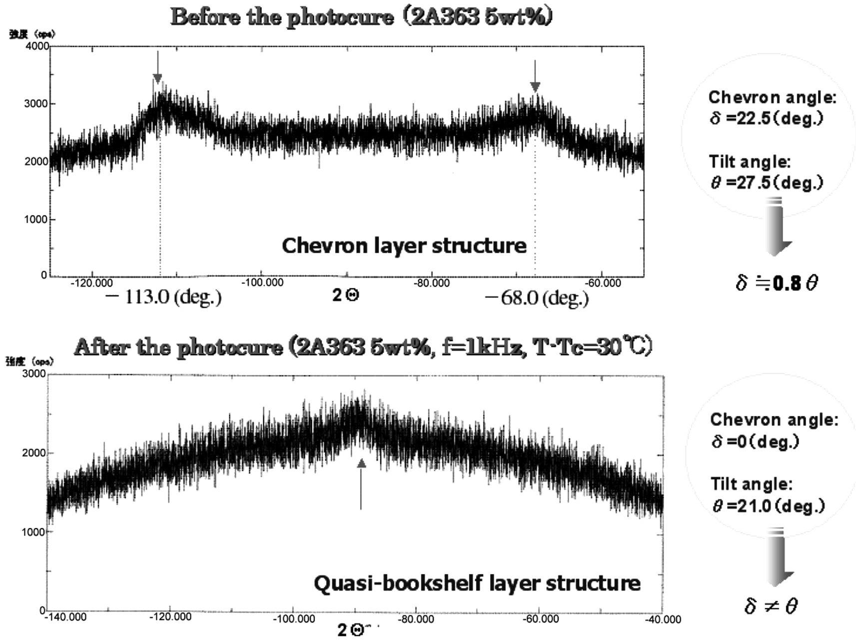

FIGURE 5 The results of the layer tilt angle measurement with X-ray diffraction.

3.4. Molecular Alignment Structure

Since Figures. 2 and 4 indicate the existence of domain structure and moreover Figure 5 means δ is not equal to θ in the PS-FLC photocured under the application of an AC electric field, it is guessed that the FLC molecules near a polymer are monostabilized to either tilt direction determined by the polarity of the AC electric field and then there coexist three-dimensionally two types of monostable domains in the PS-FLC medium, as shown in Figure 6 which is illustrated two-dimensionally. As the frequency of the AC electric field increases at the photocure stage, the polymerization progresses with faster orientational change of the mesogenic side chains and then the domain size may decrease. As a result, the monostable PS-FLC with V-shaped electrooptical characteristics may be realized because the optical axis of this medium is directed to the average molecular alignment direction of the two types of monostable domains due to the domain size being less than the wavelength of visible light.

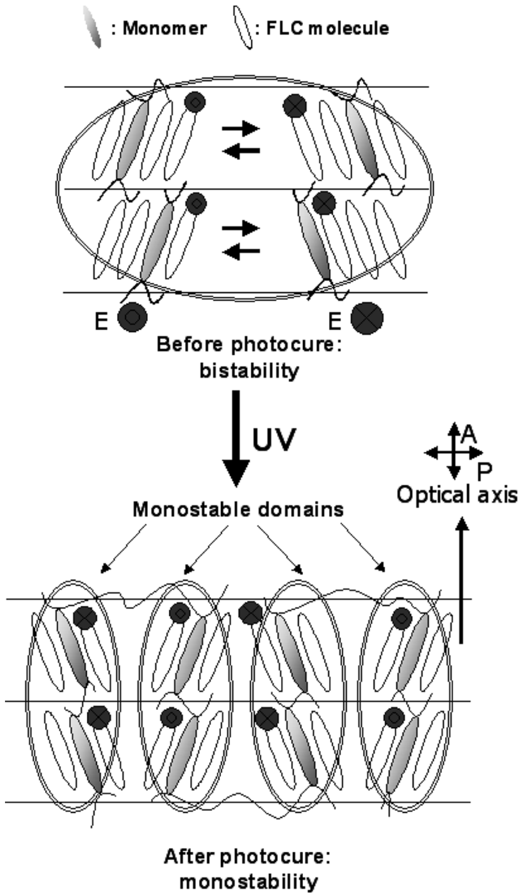

FIGURE 6 Molecular alignment structure model of PS-FLCs fabricated by a UV photocure of doped photocurable mesogenic monomer, at a temperature where the LC medium is in the SmC* phase under the application of an AC electric field.

4. CONCLUSIONS

The PS-FLC photocured under the application of an AC electric field shows a V-shaped electrooptical characteristics. However, it is not clear how the monostable V-shaped electrooptical characteristics can be realized in the PS-FLC. In this study, we have investigated in detail the effect of the polymer stabilization on the molecular alignment structure. Electrooptical characteristics and microscopic textures of PS-FLCs, which were photocured under lots of conditions such as the concentration of doped monomer and the frequency of AC electric field, were measured. Furthermore, we studied the smectic layer structure by the X-ray diffraction observation. Since the existence of domain structure and quasi-bookshelf layer structure is confirmed in the PS-FLCs, it is concluded that two types of domain, in which there are two alignment directions monostabilized by the mesogenic side chains of polymer photocured under the application of a bipolar square-pulsed AC electric field, would coexist.

REFERENCES

[1] Clark, N. A. & Lagerwall, S. T. (1980). *Appl. Phys. Lett.*, *36*, 899.
[2] Skarp, K. & Handschy, M. (1988). *Mol. Cryst. Liq. Cryst.*, *165*, 439.
[3] Armitage, D., Thackara, J. I., & Eades, W. D. (1988). *Ferroelectrics 85*, 29.
[4] Matsumoto, S., Hatoh, H., & Murayama, A. (1989). *Liq. Cryst.*, *5*, 1345.
[5] Furue, H., Miyama, T., Iimura, Y., Hasebe, H., Takatsu, H., & Kobayashi, S. (1997). *Jpn. J. Appl. Phys.*, *36*, L1517.
[6] Furue, H., Iimura, Y., Hasebe, H., Takatsu, H., & Kobayashi, S. (1998). *Mol. Cryst. Liq. Cryst.*, *317*, 259.
[7] Furue, H., Takahashi, T., & Kobayashi, S. (1999). *Jpn. J. Appl. Phys.*, *38*, 5660.
[8] Takahashi, T., Furue, H., Shikada, M., Matsuda, N., Miyama, T., & Kobayashi, S. (1999). *Jpn. J. Appl. Phys.*, *38* L534.
[9] Shikada, M., Tanaka, Y., Xu, J., Furuichi, K., Hasebe, H., Takatsu, H., & Kobayashi, S. (2001). *Jpn. J. Appl. Phys.*, *40* 5008.
[10] Furue, H., Yokoyama, H., & Kobayashi, S. (2001). *Jpn. J. Appl. Phys. 40*, 5790.
[11] Furue, H., Iimura, Y., Miyamato, Y., Endoh, H., Fukuro, H., & Kobayashi, S. (1998). *Jpn. J. Appl. Phys.*, *37*, 3417.
[12] Furue, H., Takahashi, T., & Kobayashi, S. (2000). *Ferroelectrics*, *244*, 75.
[13] Furue, H., Koizumi, Y., Hatano, J., & Yokoyama, H. (2005). *Mol. Cryst. Liq. Cryst.*, *437*, 195.