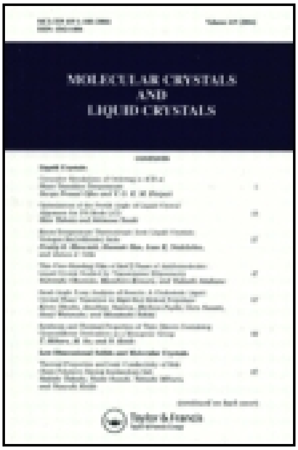

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The Effect of Polymer Stabilization on the Alignment Structure of Surface-Stabilized Ferroelectric Liquid Crystals

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The Effect of Polymer Stabilization on the Alignment Structure of Surface-Stabilized Ferroelectric Liquid Crystals

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It has been shown that a polymer network, formed in the SmA phase by UV photocure of photocurable liquid crystalline monoacrylates that are doped in a surface-stabilized ferroelectric liquid crystal (SSFLC), eliminates zig-zag defects in the SmC* phase, since a chevron layer structure is transformed into a quasi-bookshelf layer structure by the polymer main chain. In this study, we have observed the electrooptical (EO) effect of this polymer-stabilized SSFLC (PS-SSFLC) with the aim of exploring the effect of the liquid crystalline polymer network on the alignment structure of FLC molecules. As experimental results, it was found that liquid crystalline side chains bond strongly with a main chain and attract FLC molecules in the rubbing direction. Furthermore, we propose and demonstrate a new PS-SSFLC fabricated also by UV photocure of doped monoacrylates particularly at a temperature where the LC medium is in the SmC* phase under the simultaneous application of a monopolar electric field. This device exhibits monostable EO characteristics with a high contrast ratio owing to being defect free, having grayscale capability without threshold, and a fast response speed.

Keywords: PS-SSFLC; liquid crystalline side chain; SmA; SmC*; monostable EO characteristics

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1. INTRODUCTION

A surface-stabilized ferroelectric liquid crystal (SSFLC) display is an attractive device because of its bistability, fast response speed, and wide viewing angle [1]. However, they have a serious problem of the appearance of zig-zag defects that degrades the contrast ratio of the display due to the formation of the so-called chevron layer structure [2, 3]. This defect can be controlled or eliminated by several techniques, such as the utilization of a special FLC material having a naphthalene ring core [4, 5]; the application of a low-frequency AC electric field [6, 7]; and the adoption of the high pretilt technique together with the cross rubbing treatment [8, 9]. However, these methods are not always universally useful nor available, and there remains still a need for eliminating zig-zag defects and improving the electro optical (EO) characteristics, in particular the contrast ratio, of a SSFLC.

In a previous paper, we (S. Kataoka *et al.*) reported a liquid crystalline polymer-stabilized (PS) SSFLC that was fabricated by UV photocure of doped photocurable monoacrylates with a liquid crystalline side chain at a temperature where the FLC medium is in the SmA phase in which it forms a bookshelf layer structure [10]. This PS-SSFLC is devoid of zig-zag defects, because the chevron layer structure is transformed into a quasi-bookshelf layer structure by the network of a polymer main chain. Recently, we published preliminary results of PS-SSFLC that exhibits a monostable electrooptical (EO) characteristics [11, 12].

In this paper, we will report the results of a detailed research on both bistable and monostable PS-SSFLC in comparison with previous results.

2. EXPERIMENTAL

The materials used in this research were as follows: the FLC was TA-C100 (Chisso Petrochemical Co. Ltd.) [10]; the mixture of photocurable mesogenic monoacrylates was UCL-001 (Dainippon Ink and Chemicals) that was doped with 1 wt% photoinitiator [10, 13]; and the LC alignment layers were polyimide RN-1199 (Nissan Chem. Ind.). The fabrication process of the PS-SSFLC cell was as follows: first, the FLC doped with the mixture of photocurable monomers (2 wt%) was injected into an empty cell, where the inner substrate surfaces were coated with rubbed polyimide films, in the isotropic phase viá a capillary action; second, the cell was cooled down and kept at an appropriate temperature, and illuminated with a UV light source (2 mW/cm^2 at 365 nm) for photocure of doped photocurable monoacrylates; finally, the cell was set at a measurement temperature where the LC medium was in the SmC* phase. In this study, we fabricated the following two types of experimental PS-SSFLC cells:

(A) PS-SSFLC (SmA+UV) [10]

The PS-SSFLC cell was fabricated by UV photocure of doped monomers at a temperature where the LC medium was in the SmA phase for 30 or 90 seconds. The cell gap was 2 or 5.4 μm.

(B) PS-SSFLC (SmC*+UV)

The LC medium was photocured with a UV light source under the simultaneous application of a monopolar electric voltage of 4 volts, particulary at a room temperature where the LC material was in the SmC* phase. The thickness of the FLC medium was 2 μm.

The microscopic textures of the SSFLC cell before and after UV photocure were observed with a polarizing microscope (BH2, Olympus) and their EO characteristics were measured with a conventional measuring system. The cell was placed on a hot stage (FP82HT, Mettler), and the temperature was controlled within ±0.1°C. The temperature dependence of contrast ratio and memory ratio [14] was derived by processing the EO data.

3. RESULTS AND DISCUSSION

3.1. PS-SSFLC (SmA+UV)

Figure 1 shows the temperature dependence of the memory ratio in the PS-SSFLC cell. Since the phase transition temperature shifts due to doping mesogenic monoacrylates and/or UV irradiation, we adopted the SmA-SmC* transition temperature (T_c) as a reference point. In conventional SSFLCs (0 wt% and 2 wt% + UV0 sec.), the value of the memory ratio is about 60% at a temperature far from T_c. Moreover, no zig-zag defects and no switching domains in the C2-uniform memory state were observed even in the microscopic textures of these SSFLCs; the zig-zag defect-free SSFLC medium was realized in terms of the favorable nature of the polymide RN-1199 used. Therefore, it may be concluded that this value of 60% is caused

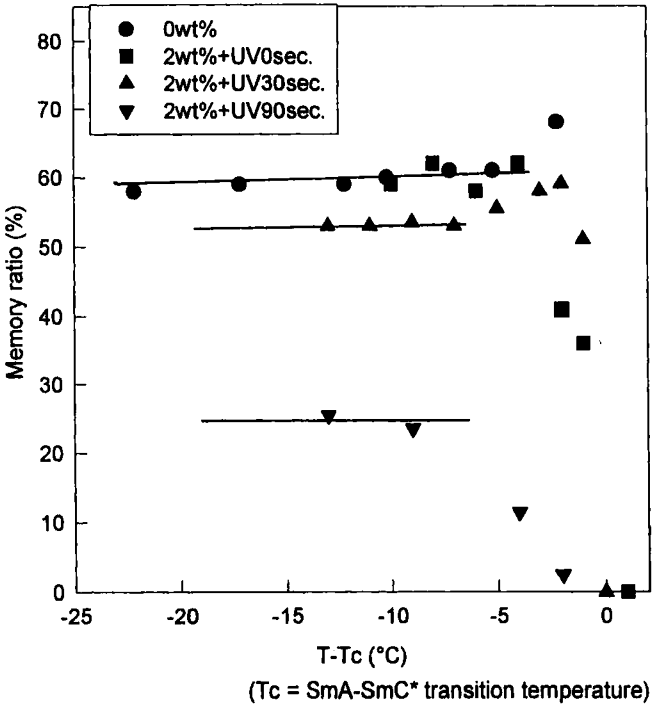


FIGURE 1 Temperature dependence of memory ratio in PS-SSFLCs (SmA + UV).

by the difference between the cone angle and the memory angle. In PS-SSFLC (2 wt% + UV30 sec. and + UV90 sec.), it is found that the memory ratio is a smaller value in comparison with a conventional SSFLC and decreases with increasing UV irradiation time. Since the smaller the memory angle is, the smaller the memory ratio is, if the memory angle of PS-SSFLCs was smaller than that of conventional SSFLCs, the memory ratio of PS-SSFLCs was smaller. In the measurement of the memory angle, however, its variation was not observed approximately between before and after UV photocure, as shown in Figure 2. Therefore, it has been found that this decrease of the memory ratio is not caused by the decrease of the memory angle, but by the appearance of switching domains that were observed in the microscopic texture of PS-SSFLC (SmA + UV) in quiescent condition, as shown in Figure 3. As a result of the appearance of switching domains, a memory state of PS-SSFLC (SmA + UV) may not yield black photographs, and so Figure 4 shows that the contrast ratio between bistable memory states decreases drastically due to UV photocure in the SmA phase.

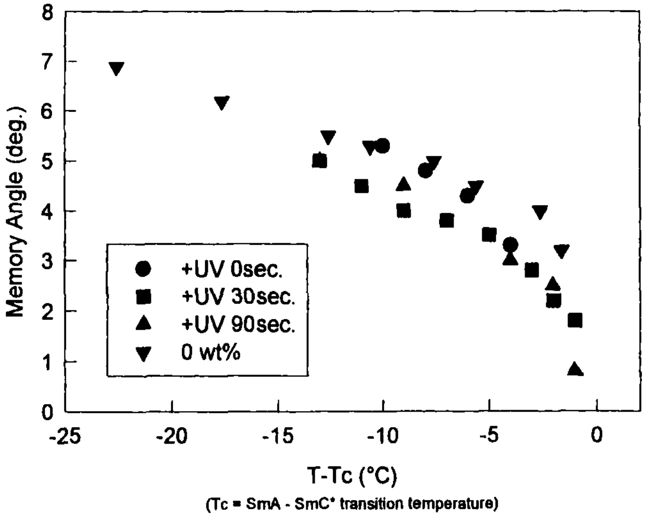


FIGURE 2 Temperature dependence of memory angle in PS-SSFLCs (SmA + UV).

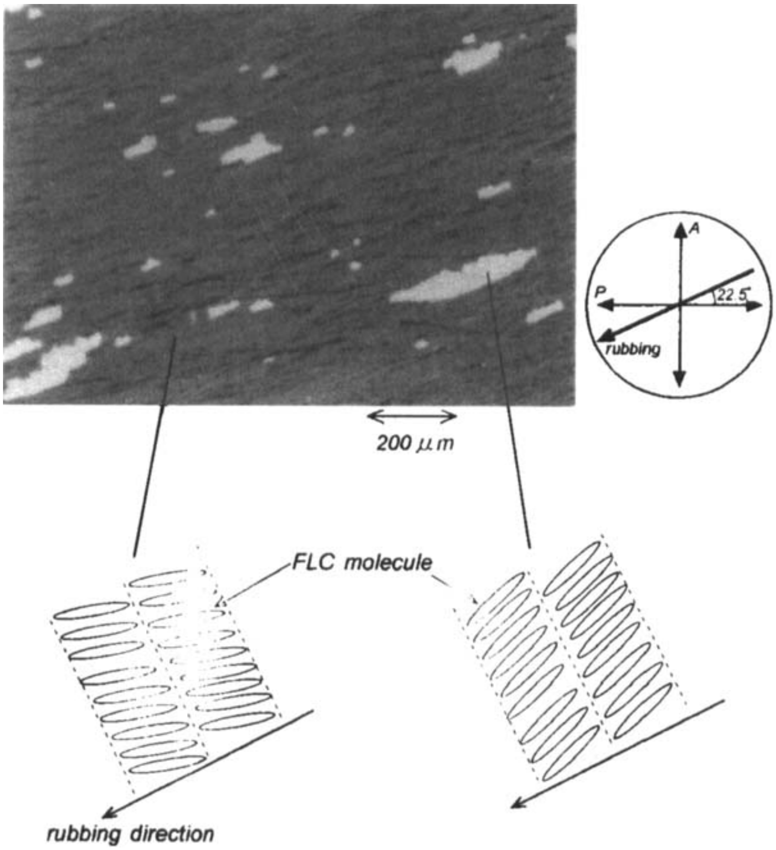


FIGURE 3 Microscopic texture of a PS-SSFLC (SmA + UV). (See Color Plate VIII).

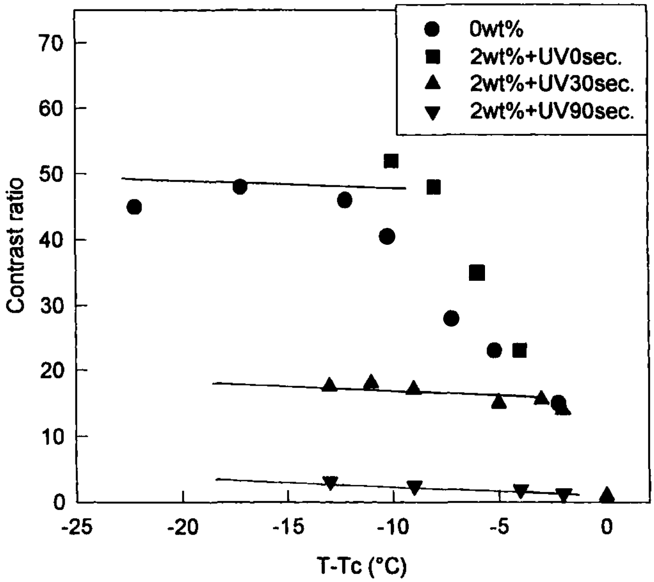


FIGURE 4 Temperature dependence of contrast ratio in PS-SSFLCs (SmA + UV).

The schematic model of the LC alignment in the PS-SSFLC (SmA + UV) is shown in Figure 5. In the PS-SSFLC fabricated by UV photocure of doped monoacrylates in the SmA phase, FLC molecules are attracted locally in the rubbing direction by a liquid crystalline side chain, which bonds strongly with a main chain, in the SmC* phase, and the local areas around the side chains become the core of switching of FLC molecules and facilitate the switching for opposite electric fields that occur due to ions of impurities. Namely, it is found that FLC molecules are held in the direction of a memory angle by surface stabilization (SS) or in the direction of side chains by polymer stabilization (PS); the direction determined by PS is different from that by SS in PS-SSFLC (SmA + UV), as shown in Figure 6.

We observed also the EO performance of the PS-SSFLC (SmA + UV) cell in which the cell gap was 5.4 µm and the effect of SS was reduced. Figures 7(a) and (b) show the wave forms of optical transmission for pulsed voltage before and after UV photocure, respectively. It is found that the bistability due to SS remains still before the photocure, but the bistability vanishes completely after the photocure. This result supports the above consideration.

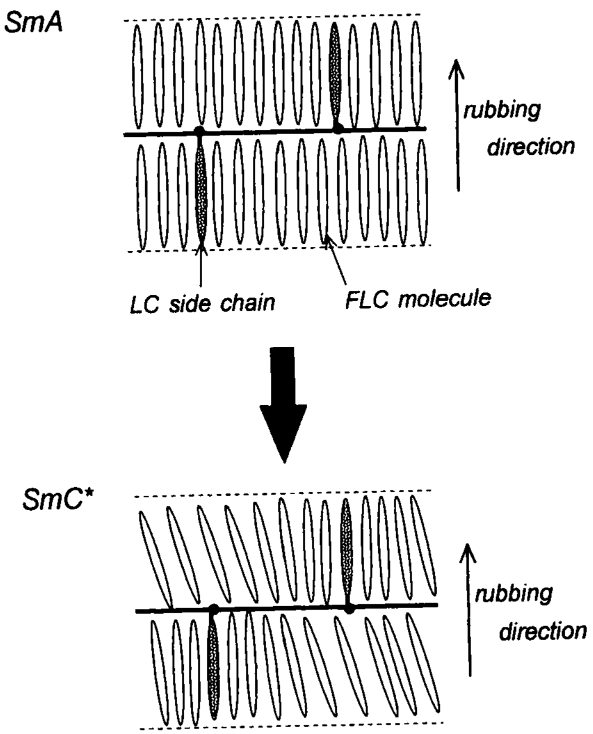


FIGURE 5 Schematic model of the LC alignment in a PS-SSFLC (SmA + UV).

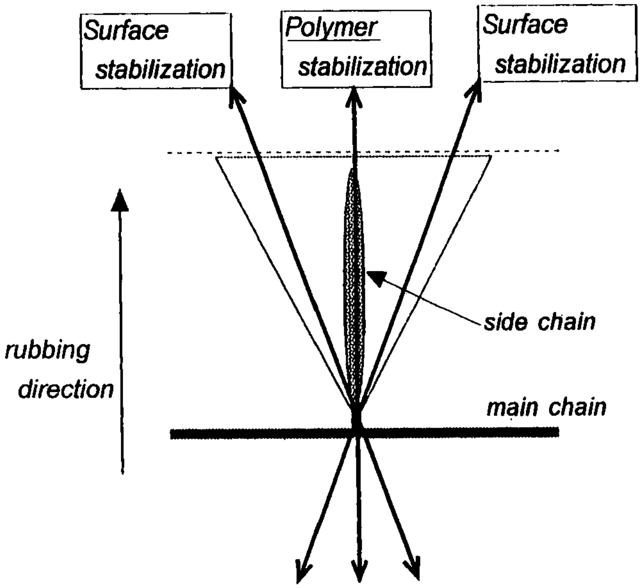


FIGURE 6 The alignment directions of FLC molecules determined by PS or SS in PS-SSFLC (SmA + UV).

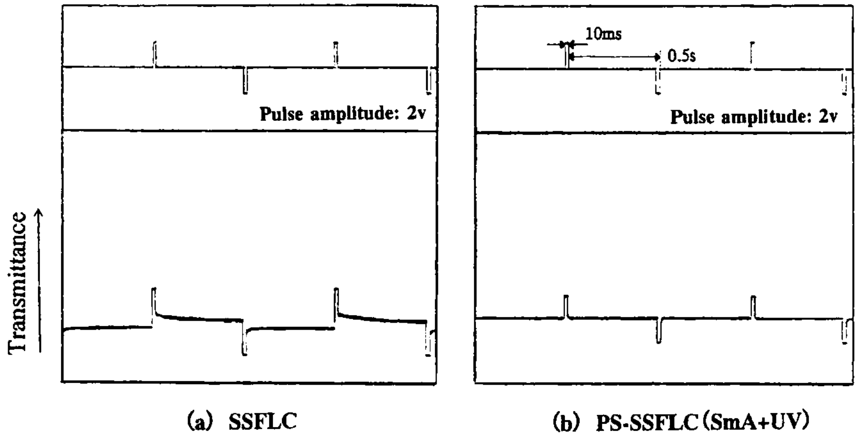


FIGURE 7 The wave forms of optical transmission for pulsed voltage before and after UV photocure at the SmA temperature in a SSFLC cell where the cell gap is 5.4 μm.

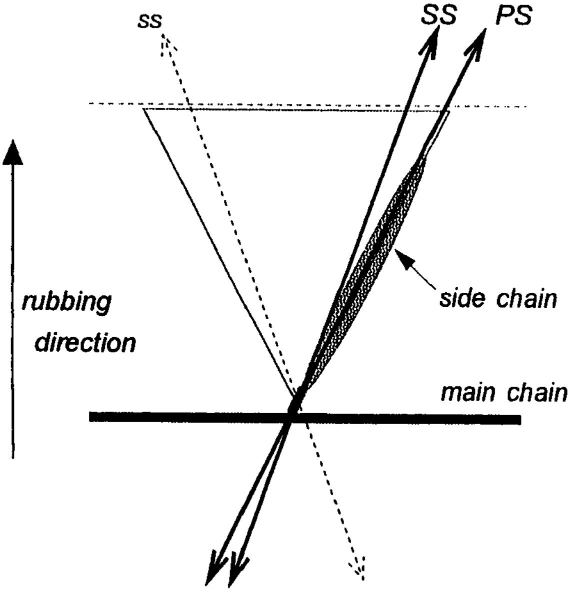
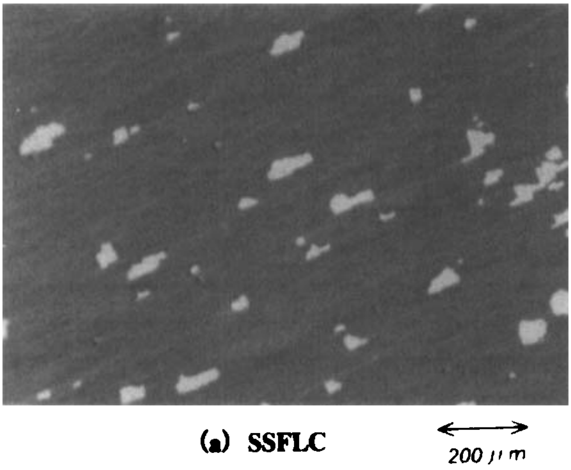


FIGURE 8 The alignment directions of FLC molecules determined by PS or SS in PS-SSFLC ($SmC^* + UV$).

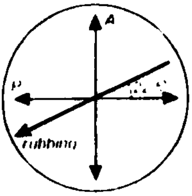
3.2. PS-SSFLC (SmC*+UV)

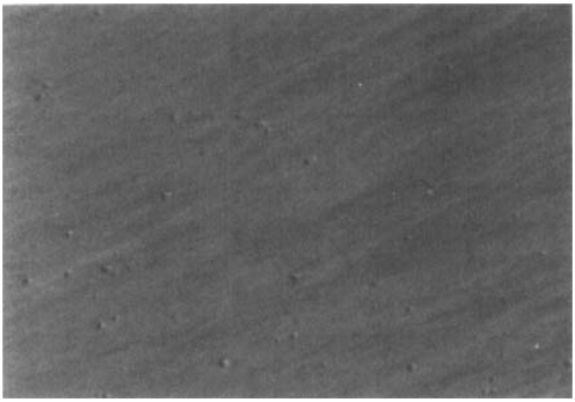
It has been found that the alignment direction of FLC molecules determined by PS is different from that by SS in PS-SSFLC (SmA + UV). So, we tried to coincide these two directions, as shown in Figure 8. A new PS-SSFLC has been fabricated by UV photocure of doped monoacrylates with a mesogenic side chain, particularly at a temperature where the LC medium is in the SmC* phase under the simultaneous application of a monopolar electric field.

Figures 9(a) and (b) show the microscopic texture of a SSFLC cell before and after UV photocure, respectively. No zig-zag defects in the C2-uniform state are observed in either photograph. In Figure 9(a), the appearance of



(a) SSFLC





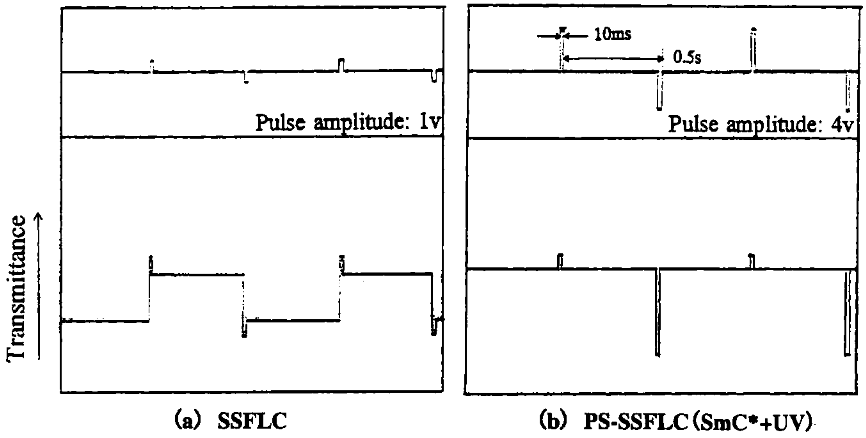
(b) PS-SSFLC (SmC*+UV)

FIGURE 9 Microscopic texture of a SSFLC cell before and after UV photocure at the SmC* temperature. (See Color Plate IX).

switching domains is observed at a partial memory state as light parts or spots; on the other hand, in Figure 9(b), no switching domains are observed. It is confirmed that the PS-SSFLC (SmC* + UV) exhibits monostable EO performance and continuous switching without accompanying switching domains. This defect-free situation with no switching domains results in a very good dark state always in the quiescent condition.

Figures 10(a) and (b) show the wave forms at optical transmission for pulsed voltage before and after UV photocure, respectively. It is found that bistability due to SS is transformed completely into monostability by PS. Figures 11(a) and (b) show a suggested potential energy model for the conventional bistability and the monostability, respectively. This monostability of FLC molecules may be produced by the fairly strong interaction between the FLC molecules and mesogenic side chains in polyacrylate and the coincidence of the alignment direction determined by PS and SS. We confirmed that it is possible to fabricate two kinds of monostable PS-SSFLC cells, each of which has a different stable molecular direction by applying either +V or −V during the photocure.

Figure 12 demonstrates an example of EO characteristics, as contrast ratio *vs.* applied voltage, of PS-SSFLC (SmC* + UV) at different temperatures. The temperature dependence of the EO performance is fairly small. This PS-SSFLC exhibits monostable EO characteristics with a high contrast ratio and grayscale capability without threshold, and then makes possible a LC display with a fast response and wide viewing angle.



(a) SSFLC (b) PS-SSFLC (SmC*+UV)

FIGURE 10 The wave forms of optical transmission for pulsed voltage before and after UV photocure at the SmC* temperature.

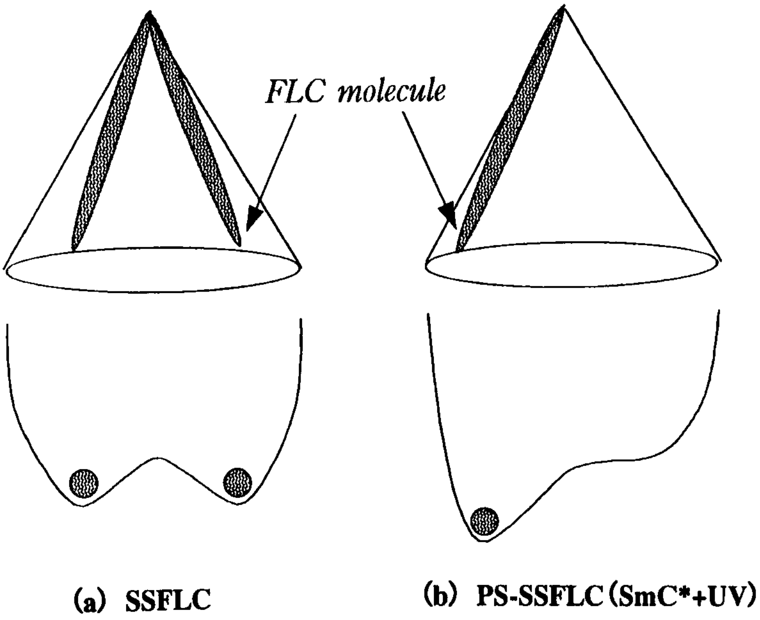


FIGURE 11 Potential energy model for (a) conventional bistability and (b) monostability.

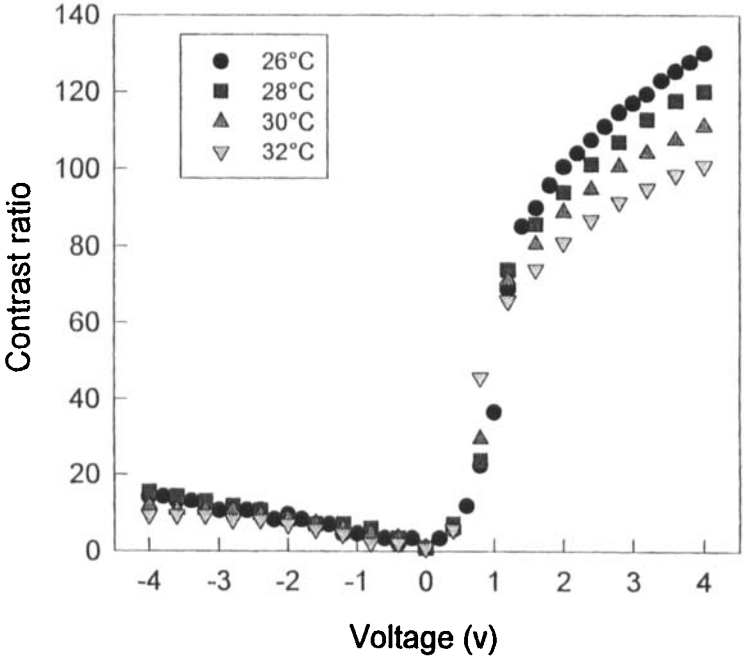


FIGURE 12 Contrast ratio *vs*. applied voltage for the PS-SSFLC (SmC* + UV).

4. CONCLUSIONS

We studied the alignment structure of FLC molecules in PS-SSFLCs. It is found that the liquid crystalline side chain bonds strongly with polyacrylate main chain, and attracts FLC molecules in the direction of the side chain. In PS-SSFLC (SmA + UV), the side chain attracts FLC molecules in the rubbing direction; the direction of FLC molecules determined by PS is different from that by SS. As a result of this difference, the switching domains occur in quiescent condition, and the memory ratio and contrast ratio decrease in comparison with a conventional SSFLC. So, we tried to coincide the two directions of PS and SS, and fabricated a new PS-SSFLC by UV photocure, particularly at the SmC* temperature under the application of a monopolar electric field. PS-SSFLC (SmC* + UV) exhibits monostable EO characteristics with a high contrast ratio owing to being defect-free and switching domain-free and having grayscale capability without threshold.

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