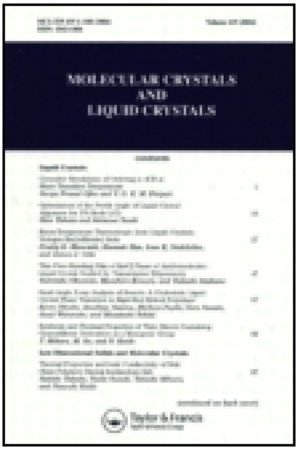

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Polymer-Stabilized SSFLCD Exhibiting Monostable Electrooptical Effect with High Contrast Ratio and Grayscale Capability

Hirokazu Furue [a] , Yasufumi Iimura [b] , Hiroshi Hasebe [c] , Haruyoshi Takatsu [c] & Shunsuke Kobayashi [a]

[a] Liquid Crystal Institute, Science University of Tokyo in Yamaguchi, 1-1-1 Daigaku-dori, Onoda, Yamaguchi, 756-0884, Japan

[b] Department of Electrical and Electronic Engineering, Faculty of Technology, Tokyo University of Agriculture and Technology, 2-24-16 Naka-machi, Koganei, Tokyo, 184-0012, Japan

[c] Dainippon Ink and Chemicals, Inc., 4472-1 Komuro, Ina-machi, Kitaadachi-gun, Saitama, 362-0806, Japan

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Polymer-Stabilized SSFLCD Exhibiting Monostable Electrooptical Effect with High Contrast Ratio and Grayscale Capability

HIROKAZU FURUE[a], YASUFUMI IIMURA[b], HIROSHI HASEBE[c], HARUYOSHI TAKATSU[c] and SHUNSUKE KOBAYASHI[a]

[a]*Liquid Crystal Institute, Science University of Tokyo in Yamaguchi, 1–1–1 Daigaku-dori, Onoda, Yamaguchi 756–0884, Japan,* [b]*Department of Electrical and Electronic Engineering, Faculty of Technology, Tokyo University of Agriculture and Technology, 2–24–16 Naka-machi, Koganei, Tokyo 184–0012, Japan and* [c]*Dainippon Ink and Chemicals, Inc., 4472–1 Komuro, Ina-machi, Kitaadachi-gun, Saitama 362–0806, Japan*

A new monostable surface stabilized ferroelectric liquid crystal display (SSFLCD) device has been fabricated by using a newly developed polyimide alignment film and adopting polymer stabilization in terms of the UV photocure of the doped monoacrylates mixture with mesogenic side chain particularly at a temperature where the liquid crystal medium is in the SmC* phase under the simultaneous application of a monopolar electric field. The device fabricated by this method exhibits monostable electrooptical characteristics with high contrast ratio (230:1) owing to freedom from defects, grayscale capability without threshold, and fast response (40 μ s). We have suggested a model for explaining the monostablity of the polymer-stabilized SSFLCD; and we obtain a fairly good agreement between experimental results and calculation using this model.

Keywords: monostability; SSFLCD; polymer stabilization; mesogenic side chain

1. INTRODUCTION

A surface-stabilized ferroelectric liquid crystal display (SSFLCD) is an attractive device because of its useful characteristics such as bistability and

fast response.[1] To fulfill these promissing features, however, it is imperative to produce a defect-free SSFLCD. The most fundamental defect in SSFLCD is a zigzag defect.[2, 3] To eliminate zigzag defects, it has been proposed to apply a low-frequency AC electric field;[4, 5] to utilize an FLC material having a naphthalene base;[6, 7] and to control a pretilt angle.[8, 9, 10] In previous papers, we reported our preliminary research on zigzag defect-free SSFLCD using a polyimide (PI) orientation film RN1199 (Nissan Chem. Ind.); at the same time, we reported a SSFLCD that exhibits a monostable electrooptical characteristics, where FLC materials used were TA-C100 (Chisso Petrochem.) and ZLI-4654-100 (Hoechst) that were stabilized by forming polymer networks having mesogenic side chains.[11, 12]

In this paper, we report the fabrication method of the monostable polymer-stabilized (PS) SSFLCD using a FLC (ZLI-4851-100, Hoechst) and the electrooptical characteristics of this device. Further, we will discuss and suggest a model for explaining the electrooptical characteristics of our monostable SSFLCD.

2. EXPERIMENTALS

The materials used in this research were as follows: the FLC was ZLI-4851-100 (Hoechst); the mixture of photocurable mesogenic monoacrylates was UCL-001 (Dainippon Ink and Chem., Inc) that was doped with 1 wt% photoinitiator; and the LC alignment layers were polyimide RN-1199 (Nissan Chem. Ind.). The relevant properties of FLC (ZLI-4851-100) given in the catalogue are shown in Table I.

TABLE I Properties of ZLI-4851-100.

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

The FLC was doped with a mixture of photocurable monomers (2 wt%) and injected into an empty cell, whose cell gap was 2 μm and

inner substrates were parallel rubbed PI-RN1199 films, at isotropic phase temperature via capillary action. After that, the cell was cooled gradually to room temperature at which the FLC medium is in the SmC* phase, and then the medium was photocured with UV light source at 365 nm for 30 s under the simultaneous application of a monopolar electric voltage of 4 volts at the UV light intensity level of 2 mW/cm^2.

The microscopic textures of the SSFLCD cells fabricated by this method before and after UV photocure were observed with a polarizing microscope and their electrooptical characteristics were measured with a conventional measuring system.

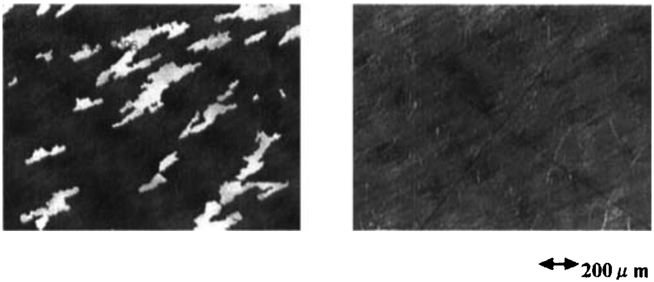
3. RESULTS AND DISCUSSION

3.1. Microscopic textures

Figures 1 (a) and 1 (b) show the microscopic textures of an SSFLCD cell before and after the photocure, respectively. No zigzag defects in C2 uniform state are observed in both photographs. However, the appearance of switching domains is observed as light parts or spots in Fig. 1 (a) ; on the other hand, in Fig. 1 (b) , no switching domains are observed, indicating that switching is being done with grayscale capability. Continuous switching without accompanying switching domains is confirmed in our monostable SSFLCD. The zigzag defect-free medium is realized in terms of the favorable nature of the polyimide RN1199.[13] This defect-free situation results in a very good dark state at the quiescent condition. For convenience, in Figs. 1 (a) and 1 (b) we show a slightly light state by adjusting the angle of polarizers to demonstrate the defect-free state, otherwise the dark state yields completely black photographs. Moreover, in Fig. 1 (a) we show a partial memory state for comparison with the texture in Fig. 1 (b) . We succeeded in fabricating defect-free monostable SSFLC media using available FLCs such as TA-C100, CS-1014, CS-1017 (Chisso Petrochem.) and ZLI-4654-100 (Hoechst) as well as ZLI-4851-100.

3.2. Electrooptical characteristics of PS-SSFLCD

Figure 2 demonstrates an example of electrooptical characteristics, as contrast ratio vs. applied voltage, of the PS-SSFLCD cell at different temperatures. The PS-SSFLCD exhibits monostable electrooptical character-



(a) SSFLCD (b) PS-SSFLCD

FIGURE 1 Microscopic textures of an SSFLCD cell (a) before and (b) after photocuring.

istics without threshold and with a fairly high contrast ratio of 230:1 at an amplitude voltage of about 4 volts with a pulse width of 1 ms. The temperature dependence of the electrooptical performance of this PS-SSFLCD is fairly small as shown in Fig. 2. The measured response time of this device is about 40 μs at room temperature. We confirmed that it is possible to fabricate two kinds of monostable PS-SSFLCDs, each of which has a different stable molecular direction by applying either +V or -V during the photocure.

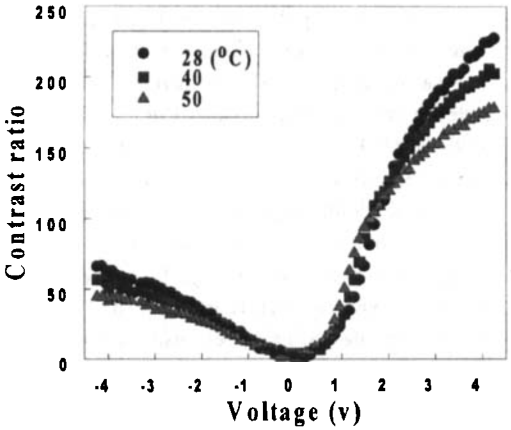


FIGURE 2 Contrast ratio vs. applied pulse voltage for the PS-SSFLCD.

3.3. Theoretical consideration of the transformation from bistability to monostablity

We investigate the director of SSFLC molecules in order to understand the transformation from bistability to monostability due to the polymer stabilization.

Assuming that the layer structure of SSFLC is bookshelf structure, and further the FLC molecules align uniformly all over the inside of the cell, then the free energy of SSFLC before the photocure can be written as

$$f_{SS} = \sum\{\gamma_n(\hat{n}\cdot\hat{g})^2 + \gamma_p(\hat{p}\cdot\hat{g})\}, \qquad (1)$$

where $\sum$ is the summation of the free energies of the interaction between FLC and surface of upper or lower substrate; $\hat{n}$, $\hat{p}$ and $\hat{g}$ are unit vectors of director, spontaneous polarization and normal of substrate surface, respectively, as shown in Figure 3; and γ_n and γ_p represent the strength of director-surface interaction and polar-surface interaction, respectively. The sign of $\gamma_p(\hat{p}\cdot\hat{g})$ is different between upper and lower surface for the polar-surface interaction, and then

$$\sum\gamma_p(\hat{p}\cdot\hat{g}) = 0. \qquad (2)$$

Therefore, the free energy of a SSFLC is expressed by

$$f_{SS} = 2\gamma_n \sin^2\theta\sin^2\phi, \qquad (3)$$

where θ and ϕ are the cone angle and the azimuthal angle of the c-vector, respectively.

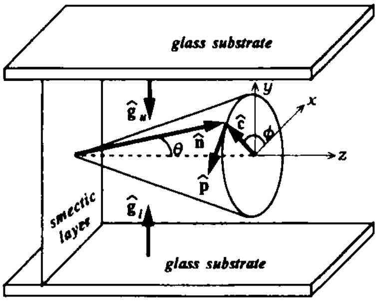


FIGURE 3 Relationship of unit vectors: $\hat{n}$, $\hat{c}$ and $\hat{p}$ represent director, c-vector and spontaneous polarizaition of FLC, and each of $\hat{g}_u$ and $\hat{g}_l$ stands for the normal vector to the upper and the lower substarates, respectively.

In the bookshelf structure, mesogenic side chains, which bond rigidly to polymer networks, are directed to the FLC molecules with $\phi = 0$ or π according to the sense of applied voltage during the photocure. Now if we assume that this direction corresponds to $\phi = 0$, as shown in Figure 4, then the free energy in terms of the interaction between FLC and side chain may be written as

$$\begin{aligned} f_{PS} &= -K_{PS}(\hat{c} \cdot \hat{s}) \\ &= -K_{PS} \cos\phi, \end{aligned} \tag{4}$$

where $\hat{c}$ and $\hat{s}$ represent the c-vector of FLC molecule and the direction vector of mesogenic side chain, respectively. When the $\hat{c}$ is parallel to the $\hat{s}$, f_{PS} results in a minimum value. Therefore, the free energy of PS-SSFLC is

$$\begin{aligned} f &= f_{SS} + f_{PS} \\ &= K_{SS} \sin^2\phi - K_{PS} \cos\phi, \end{aligned} \tag{5}$$

where $K_{SS} = 2\gamma_n \sin^2\theta$.

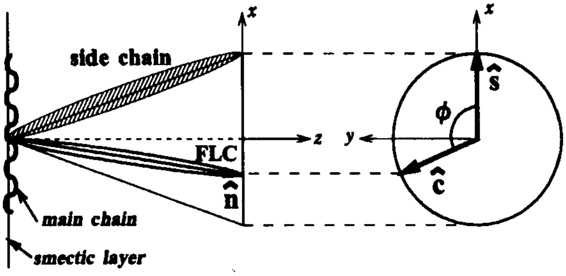


FIGURE 4 Relationship of unit vectors for PS-SSFLCD, where $\hat{s}$ represents mesogenic side chain which is in the direction of $\phi = 0$.

Figure 5 shows the free energies for PS-SSFLC as a function of ϕ that are plotted with $K_{SS}=1$ and changing K_{PS} from 0 to 5. It may be claimed that the PS-SSFLCD has bistability for $K_{PS}<2$ and monostability for $K_{PS}>2$, and further that the bistability transfers into monostability where $K_{PS}=2$ because the minimum appearing at $\phi = 180°$ disappears. Experimental data of the angle ϕ dependence of the free energy is derived from the data shown in

Fig. 2 in such a way that the energy is expressed by eV, where e is the electronic charge, and the contrast ratio (CR) is expressed by the apparent tilt angle θ.(11) which is given by the angle ϕ and the cone angle θ using

$$\tan\theta_a = \cos\phi\tan\theta. \qquad (6)$$

It is considered that the electrooptical behavior is simulated by the movement of a particle confined in a potential shown in Fig. 5. In Fig. 5 (f), we show the fitting of experimental data obtained in this way to the free energy. When $K_{SS}=1$ and $K_{PS}=5$, the simulation results in a good coincidence with the experimental free energy for the PS-SSFLCD fabricated in this research.

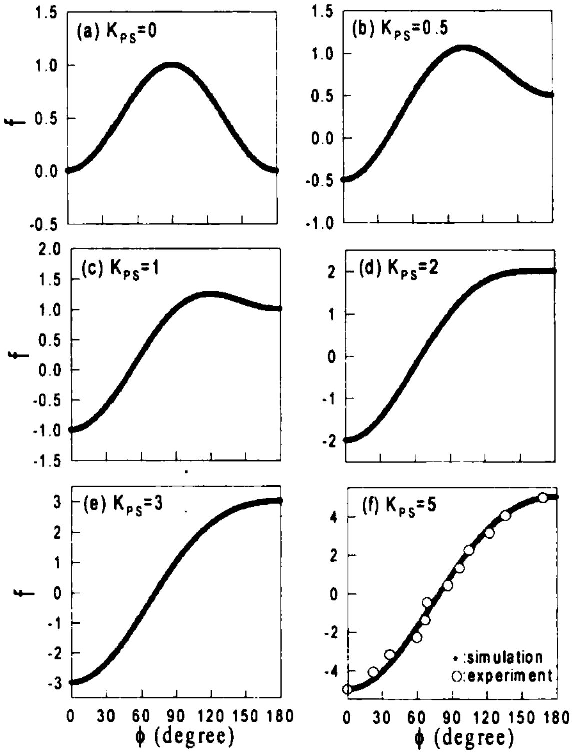


FIGURE 5 Free energies for PS-SSFLCD. K_{SS} is commonly taken as $K_{SS}=1$; and the parameter K_{PS} is varied by choosing it from 0 to 5.

4. SUMMARY

We have fabricated a new SSFLCD that exhibits monostable electrooptical characteristics with grayscale capability without threshold, high contrast ratio (230:1) due to freedom from defects, and fast response (40 μ s) using an FLC (ZLI-4851-100, Hoechst) that has been stabilized by the UV photocure of doped photocurable mesogenic monomers at the SmC* temperature under the application of a monopolar electric field. Further, We discussed the transformation from bistability into monostability due to the polymer stabilization, based on a theory of free energy developed by ourselves.

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