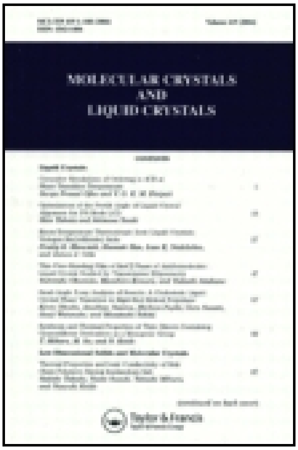

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Fabrication of Zigzag Defect-Free Bistable SSFLCD by Rubbing Method: a Material Study and Physical Modelling

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A surface-stabilized ferroelectric liquid crystal display (SSFLCD) fabricated using a developed polyimide (PI) alignment film (RN1199, Nissan chem. Ind.) demonstrates an excellent bistable memory capability with high contrast ratio owing to zigzag defect free. In order to clarify why PI-RN1199 film is so useful for fabricating defect-free SSFLCD, we have characerized PI-RN1199 film in comparison with other conventional PI films by observing the surface morphologies of rubbed PI films with an atomic force microscope (AFM). From the results of characterization of PI films, it is concluded that the formation of C2-uniform structure may be attributed to the smoothness of the surface of PI-RN1199 with a small pretilt angle.

Keywords: SSFLCD; polyimide RN1199; bistability; surface morphology

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] However, it is hard to fabricate a defect-free SSFLCD owing to the appearance of so-called zigzag defect that degrades bistable memory capability and contrast ratio of the display.[2, 3] This defect can be controlled or eliminated by the application of a low frequency AC electric field;[4, 5] the utilization of an FLC material having a

naphthalene base;[6, 7] and the adoption of the cross rubbing technique together with the control of pretilt angle.[8, 9] However, these methods are not always universally useful nor available, and there remains still a need for eliminating zigzag defects and improve the electrooptical characteristics in particular contrast ratio of a SSFLCD. In previous papers we reported our preliminary reserch on zigzag defect-free SSFLCD using a polyimide (PI) orientation film RN1199 (Nissan Chem. Ind.) together with the monostable electrooptical characteristics of this SSFLCD that was stabilized by forming polymer networks having mesogenic side chains.[10, 11]

In this paper, we report how PI-RN1199 is useful for fabricating defect-free SSFLCD by demonstraing the microscopic texture of aligned FLC and its bistable electrooptical characteristics. The nature of PI-RN1199 was characterized by comparing the surface morphology of the rubbed PI-RN1199 film with that of other conventional PI films,[12] and we suggest a model of the formation of C2-uniform state in a SSFLC cell using rubbed PI-RN1199 films.

2. EXPERIMENTALS

The PI material used in this research was RN1199 (Nissan Chem. Ind.) and, for comparison, PI-SE150 (Nissan Chem. Ind.) was also used. Both materials produce a low pretilt angle (1-5°). A solution of PI was spin-coated onto indium-tin-oxide (ITO) coated glass substrates and then baked at 180℃ for 1 hour. After the thermal treatment , the substrates were rubbed. Then an FLC was injected into an empty cell at isotropic phase temperature via capillary action. After the injection, the cell was cooled gradually to room temperature at which the FLC medium is in the SmC* phase. The inner substrates of the FLC cells were paralell rubbed PI films. The FLC used was ZLI-4851-100 (Hoechst) whose relevant properties taken from the catalogue are shown in Table I.

TABLE I Properties of ZLI-4851-100.

Property	
Phase sequence	Cryst.(<-20)SmC*(67)SmA(71)N*(76)Iso. [℃]
Spontaneous polarization	22nC/cm^2 (20 ℃)
Tilt angle	30.5 ° (20 ℃)
Switching time	38μs (E=15v/μm, 20℃)

The microscopic textures of the SSFLCD cells, whose cell gap was 2μm, fabricated using PI-RN1199 and PI-SE150 were observed with a polarizing microscope and their electrooptical characteristics were measured with a conventional measuring system.

In order to characterize PI films, the surface morphology of the rubbed PI films was observed with an atomic force microscope (AFM), SPI3700 (Seiko Instr. Inc.). A sharp Si_3N_4 tip was used to scan over the PI alignment layer.

3. RESULTS AND DISCUSSION

3.1. Microscopic textures

Figures 1(a) and 1(b) demonstrate the microscopic textures of SSFLCD cells fabricated using PI-SE150 and PI-RN1199, respectively. In Fig. 1(a), zigzag defects and reverse domains are observed as dark parts in the light state; on the other hand, in Fig. 1(b), neither zigzag defects nor reverse domains are observed, and this medium is identified as C2-uniform state. The zigzag defect-free medium is realized in terms of the favorable nature of PI-RN1199. This defect-free situation results in a very good dark state in the SSFLC cell at quiescent condition because optical leakage is negligible, as shown in the dark state of Fig. 1(b). A uniform light state is also obtained in a cell using PI-RN1199 as shown in Fig. 1 (b).

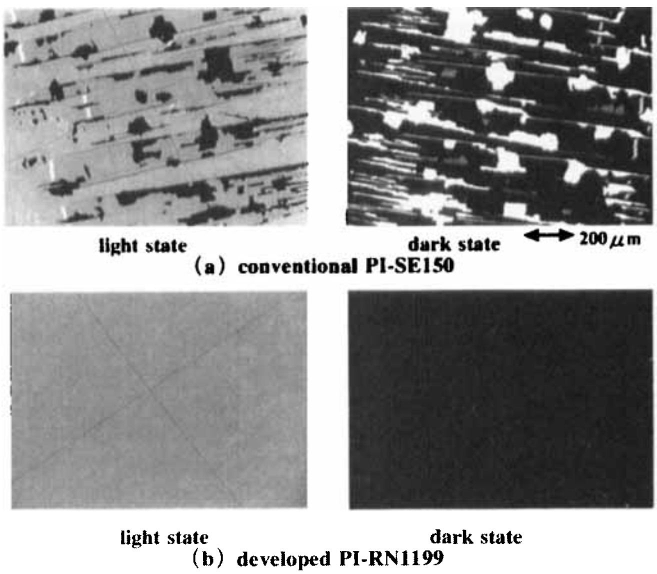

FIGURE 1 Microscopic textures of SSFLCs aligned on (a) conventional PI-SE150 and (b) developed PI-RN1199 films.

See color plate VII at the back of this issue.

3.2. Electrooptical characteristics

The electrooptical contrast ratio (CR) between bistable memory states in the SSFLCD cell with RN1199 is about 60, which is much higher than that in the SSFLCD cell with SE150 (CR=4), as shown in Figure 2. Fig. 2 also demonstrates microphotographs of textures corresponding to a series of memory states in SSFLCD cell using PI-RN1199 films for the ampiltudes of applied voltages corresponding to points (a) through (f), where the dark state is indicated by (a) and the light state by (f); grayscale capability is demonstrated by points (b) through (e) as an average CR throughout the aperture. It is shown that switching is being done accompanying switching domains even though the SSFLCD cell has no zigzag defects that provide domain switching nuclei.[13, 14]

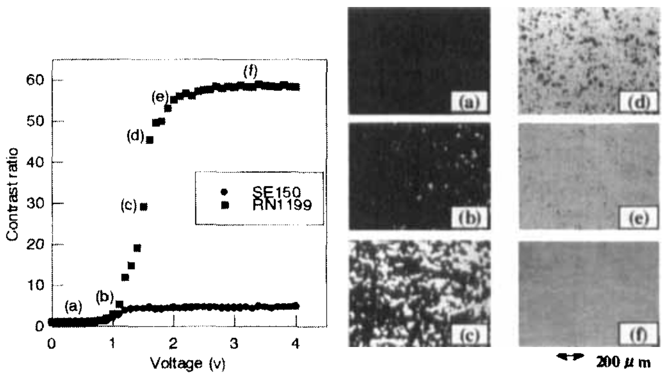

FIGURE 2 Contrast ratios vs. applied voltages for SSFLCDs with PI-RN1199 or PI-SE150. The contrast ratio was calculated from measured data of bistable memory state. Microscopic textures correspond to a series of memory states designated by the point (a) through the point (f) in the SSFLCD with RN1199 films.

See color plate VIII at the back of this issue.

3.3. Characterization of polyimide alignment films

In order to clarify why PI-RN1199 film is useful for fabricating a defect-free SSFLCD, we characterized PI films by observing the surface morphologies of rubbed polyimide films with an AFM. Figures 3(a) and 3(b) show the surface morphologies of the rubbed PI films of RN1199 and SE150, respectively. Figure 4 also illustrates the schematic surfaces in cross section where the average size of undulations were derived from the data given in Fig. 3. It is found that the height of the undulation and its spatial frequency in the surface of RN1199 are much less than that of SE150; that is, the surface of RN1199 is much smoother and flatter than that of SE150.

First of all, it is thought that the generated bulk pretilt angle may be

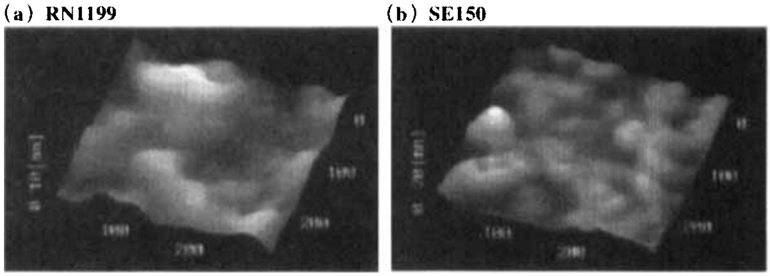

FIGURE 3 Surface morphologies of rubbed PI films of (a) RN1199 and (b) SE150. (See Color Plate IX at the back of this issue)

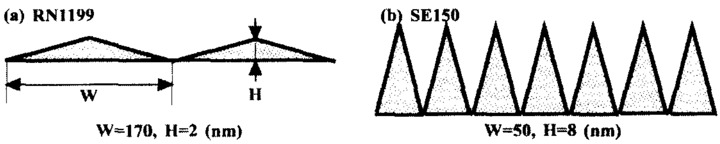

FIGURE 4 Schematic illustrations of cross sections of (a)RN1199 and (b)SE150 surfaces.

commonly small even though there is a difference in the surface smoothness as depicted in Figure 5. However, an irregular local surface pretilt may exist on a rough surface. An typical example is PI-SE150. Regarding the formation of a C2 structure, there occurs a transition from the C1 structure to the C2 structure due to an increase in the tilt angle of FLC molecules during the cooling process;[15] in this process, an FLC (such as ZLI-4851-100) hardly forms the C2 structure in the case where the surface has an irregularity that gives rise to local surface pretilt, because an alignment film with high pretilt angle prohibits an SSFLC from the formation of the C2 structure even at a room temperature. Therefore, even in the case where an FLC medium has a low bulk pretilt alignment film like SE150, a high pretilt angle may occur locally on the surface because of the rugged surface; and then zigzag defects may appear in such an SSFLCD cell. It may be concluded that the smooth enough surface favors to form zigzag defect-free

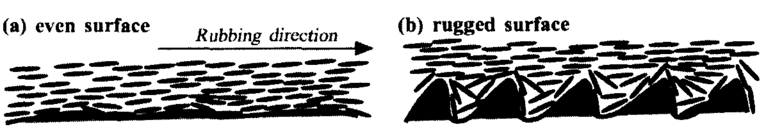

FIGURE 5 Schematic illustrations of the alignment of FLC molecules on low pretilt films having (a) an even surface and (b) a rugged surface.

C2 uniform state of SSFLCD; PI-RN1199 may have this favorable feature. This conclusion is in agreement with that by Watson *et al.*[16]

In order to confirm the above discussion, we have tried a theoretical explanation, where we investigated the surface-pretilt-angle dependence of the free energy of SSFLCs using the equation given by[17]

$$f = \int_0^d (f_b + f_s)\, dY. \tag{1}$$

In eq.(1), f, f_b and f_s are the total free energy, the bulk free energy and the surface anchoring energy, respectively, and the Y-axis is taken along the cell normal (the cell thickenss is d). We assume that an n-director of FLC molecule is parallel to the boundary plane such as substrate surface and chevron interface, and the azimuthal angle of c-director, ϕ, depends only on Y. In the quiscent condition,

$$f_b = \frac{1}{2}\{(B_1 sin^2\phi + B_2 cos^2\phi)cos^2\delta + B_3 sin^2\delta - 2B_{13} sin\delta\, cos\delta\, sin\phi\}\left(\frac{d\phi}{dY}\right)^2$$
$$+ D_1 cos\delta\, sin\phi \frac{d\phi}{dY} - D sin\delta\, sin\phi, \tag{2}$$

$$f_s = \gamma\, sin^2\psi, \tag{3}$$

where δ and ψ are the chevron angle (C1: δ<0, C2: δ>0) and the in-plain tilt angle, respectively, as shown in Figure 6, and

$$\frac{d\phi}{dY} \doteqdot \frac{\phi_s - \phi_c}{d/2}, \tag{4}$$

$$tan\psi = \frac{sin\theta\, cos\phi_s}{sin\delta\, sin\theta\, sin\phi_s + cos\delta\, cos\theta}. \tag{5}$$

In eq.(4) and (5), ϕ_s and ϕ_c are the azimuthal angle ϕ of FLC molecules on the substrate surface and on the chevron interface, respectively, and

$$sin\phi_s = \frac{tan\delta}{tan\theta} + \frac{sin\alpha}{sin\theta\, cos\delta}, \tag{6}$$

$$sin\phi_c = \frac{tan\delta}{tan\theta}, \tag{7}$$

where α is surface pretilit angle. The parameters used in the calculations are as follows; θ=30°, $|\delta|$=25°, d=2μm, B_1=B_2=5pN, B_3=B_{13}=D=D_1=0 and γ=5mJ/m^2. Figure 7 shows the results for C1 and C2 structure. It is found that C2 structure may be rather stable and occur for a few degrees or less of the surface pretilt angle, that is very smooth surface. The average angle of inclination in the surface undulations of PI-RN1199, which was measured with AFM, was about 1°. Therefore, it may be concluded that the

uniform C2-structure or zigzag defect-free situation is realized for the SSFLCD cell with PI-RN1199.

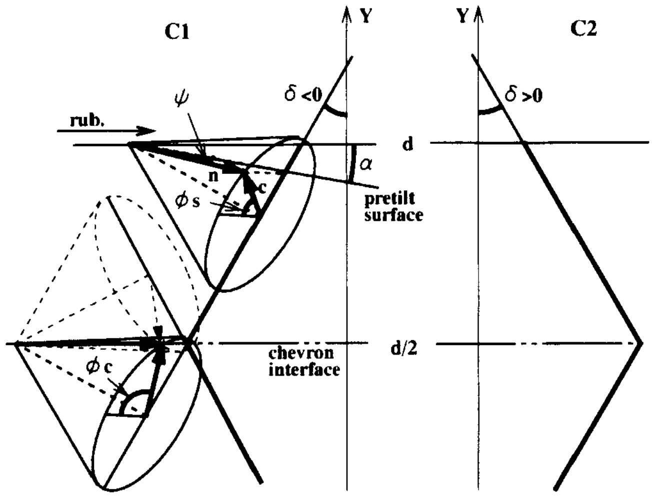

Figure 6 Schematic alignment structures of SSFLC for C1 and C2 states.

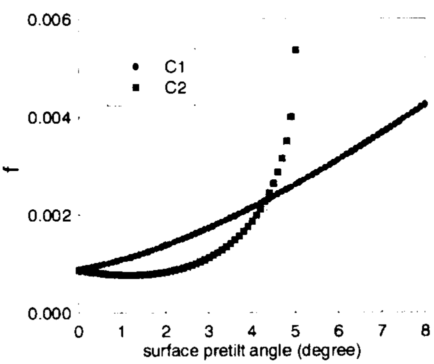

Figure 7 Free energy vs. surface pretilt angle for C1 and C2 structure.

4. CONCLUSIONS

It is shown that an SSFLCD cell fabricated by utilizing a developed polyimide RN1199 as alignment film shows excellent electrooptical performance with high contrast ratio (CR=60) for use as a bistable electrooptical device

because of its zigzag defect-free and reverse domain-free features in the dark and light states. The mechanism for producing defect-free conformation called C2-uniform state of SSFLCD fabricated particularlly using rubbed RN1199 films has been investigated in terms of surface morphology of RN1199. It is concluded that the formation of C2-uniform state may be attributed to the smoothness of the rubbed surface of PI-RN1199 film.

Acknowledgements

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