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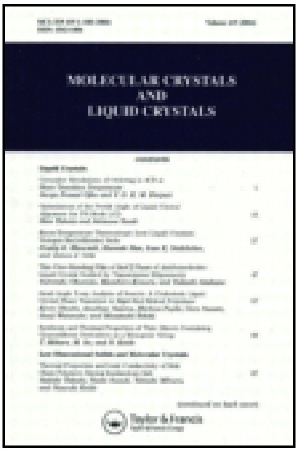

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Switching Behavior of Surface Stabilized Ferroelectric Liquid Crystal Devices with Chevron Layer Structure

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SWITCHING BEHAVIOR OF SURFACE STABILIZED FERROELECTRIC LIQUID CRYSTAL DEVICES WITH CHEVRON LAYER STRUCTURE

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Abstract The switching behavior in the C1-uniform (C1U), C1-twisted (C1T) and C2-uniform (C2U) states, which were observed in surface-stabilized ferroelectric liquid crystal (SSFLC) devices with the chevron layer structure, were investigated. The voltage dependence of the extinction angle was investigated in the C1U and C2U states and was discussed in terms of the switching model of these states. The boat-shape disclination loops were observed in the C1U, C1T and C2U states, suggesting that they were attributed to the molecular switching at the chevron interface. In addition, this paper describes a gray scale with smooth voltage-transmission characteristic, which were induced by the voltage dependence of the extinction angle.

INTRODUCTION

It is known that surface-stabilized ferroelectric liquid crystal (SSFLC)[1] devices usually have the chevron layer structure[2] in which the smectic layer is not perpendicular to the substrates. The molecular orientational states with the chevron layer structure can be classified to four states, which are C1-uniform (C1U), C1-twisted (C1T), C2-uniform (C2U) and C2-twisted (C2T) states.[3] These states, having different director profile,[3,4] show different thermal stability,[5,6] different shock stability,[5] different memory angle,[3,4,6] different contrast ratio,[7] different memory pulse width[8] and different $\tau - V_{min}$ characteristics.[9]

In this paper, the switching behavior in the C1U, C1T and C2U states was investigated under square wave voltage. The voltage dependence of the extinction angle[10,11] and the appearance of the boat-shape disclination loops[12,13] were examined in these states and discussed in terms of the director profile and the switching model of these states. In addition, this paper describes a gray scale with smooth voltage-transmission characteristic[14,15,16] induced by the voltage dependence of the extinction angle.

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EXPERIMENTAL

Table I shows FLC materials used in this study and their physical properties. SCE-8 was supplied by E. Merck. SF-0731 was prepared in our laboratory. Both materials have the INAC phase sequence with a nematic pitch that is sufficiently long.

Two FLC cells No. 1 and No.2 were prepared. The construction of the cells No. 1 and No.2 are summarized in Table II. The FLC cells No.1 and No.2 were constructed with two glass plates coated with an ITO electrode, an insulating film (SiO_2) and a polyimide. The rubbing directions on the two glass surfaces were parallel. The cell spacing was 1.5μm. The pretilt angles of liquid crystal molecules on the aligning films were determined by using the capacitance-magnetic field curves (C-H curves) of antiparallel thick (50μm) cells filled with nematic liquid crystal E-8 (supplied by E. Merck).

The extinction angle was determined by the angle between the layer normal, which was determined by the extinction angle in the smectic A phase, and the extinction position when a square wave voltage was applied at 25℃.

TABLE I Physical properties of FLC materials.

FLC Material	Transition Temp.(℃) C S_C S_A N I	Ps[b)] (μC/m²)	τ[c)] (μs)
SCE-8[a)]	• -20 • 59 • 79 • 100 •	+ 63	294
SF-0731	• <RT • 58 • 71 • 87 •	-145	64

a) Supplied by E. Merck.

b) Spontaneous polarization measured by the triangular wave method at 25℃.

c) Response time at 25℃. V=±5V/μm, 0→50% transmission change.

TABLE II Construction of FLC cells No.1 and 2.

Cell No.	Aligning film	LC material	Observed states
No.1	PI-A(θ_P= 5°)	SCE-8	C1U, C2U
No.2	PI-B(θ_P= 3°)	SF-0731	C1T, C2U

Cell thickness: 1.5μm

Rubbing: parallel

RESULTS AND DISCUSSION

The observed states in the FLC cells No.1 and No. 2 were shown in Table II. The molecular orientational model of the C1U, C1T and C2U states is illustrated in Figure 1.[3,4] The FLC cells No.1 and No.2 showed bistability.

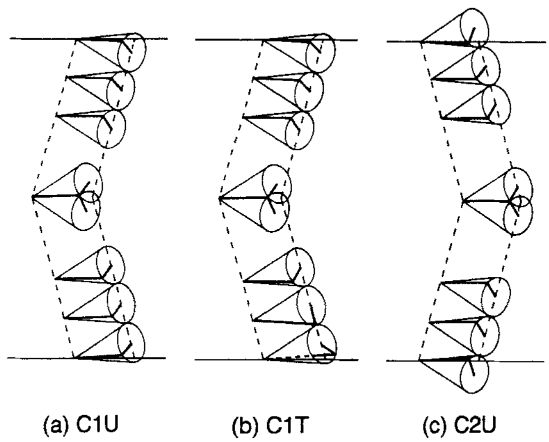

FIGURE 1 The molecular orientational model of the C1U, C1T and C2U states.

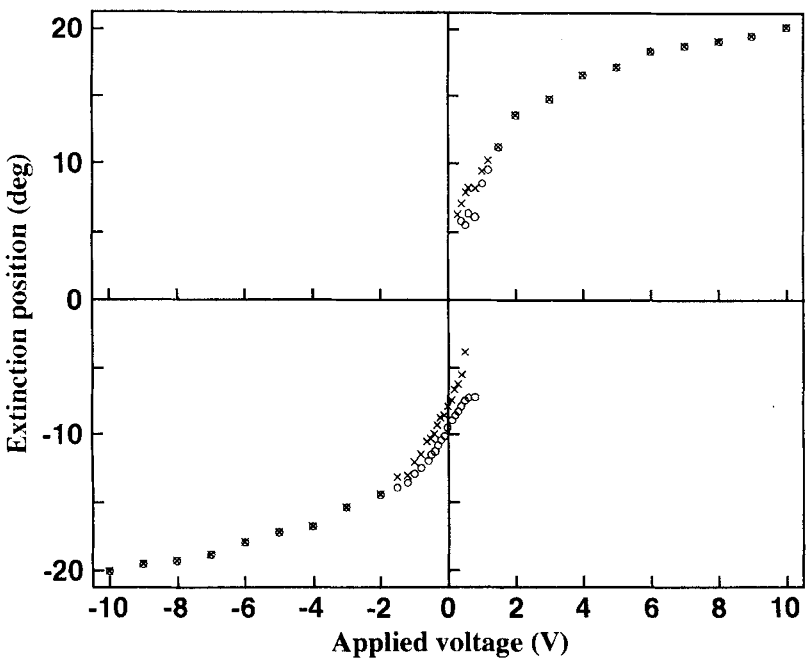

FIGURE 2 The voltage dependence of the extinction angle in the FLC cell No. 1 under square wave voltage with 0.1Hz at 25℃.
○; C1U state, ×; C2U state

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Voltage dependence of extinction angle

The FLC cell No.1 showed the C1U and the C2U states. Figure 2 shows the relationship between the extinction angle and the square wave voltage of 0.1Hz in the C1U and C2U states of the FLC cell No.1. The initial memory state was obtained by applying a negative pulse voltage with sufficient strength and width for bistable switching. The sign of the extinction angle in the initial state was defined as negative. The absolute value of the memory angle, which is an extinction angle under 0V, is larger for the C1U state than for the C2U state, as is consistent with the previous results.[3,4,6]

When negative voltages were applied, the sign of the extinction angle did not change and the absolute value of the extinction angle increases with increasing the absolute value of voltage. In this case, no boat-shape disclination loop[12,13] was observed. The absolute values of the extinction angles were larger for the C1U state than for the C2U state when the absolute value of voltage was low (-0.1～-1.5V). When the absolute value of voltage increases (-2～-10V), the difference in the extinction angle between the C1U and the C2U states disappeared.

When very low positive voltages (+0.1～+0.2V) were applied, the absolute value of the extinction angle decreases in the C1U and C2U states. The sign of the extinction angle was still negative. In this case, no boat-shape disclination loop was observed. The absolute value of the extinction angle was larger for the C1U state than for the C2U state.

When positive voltages increased (+0.3～+0.8V), the boat-shape disclination loops[12,13] appeared. The outside of the boat-shape disclination loops showed the negative extinction angle but the inside of the boat-shape disclination loops showed the positive extinction angle. With increasing voltage, the inside area grew and the outside area disappeared finally. The absolute value of the extinction angle in the outside of the disclination loops decreases with increasing voltage. The extinction angle in the inside of the boat-shape disclination loops increases with increasing voltage. With further increasing the voltage, the difference in the extinction angle between the C1U and the C2U states disappeared.

When the applied voltage was high enough (～±10V), the absolute values of the positive and negative extinction angles were the same. On the other hand, when the applied voltage was not so high, the absolute values of the positive and negative extinction angles were not the same in each voltage. No texture change and no roof-top texture

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was observed in this experiment, suggesting no change in the layer structure.

Boat-shape disclination loops

The boat-shape disclination loops, which are usually observed in SSFLC devices,[12, 13] were observed in the FLC cells No.1 and No.2. Figure 3 shows a micrograph of switching with the boat-shape disclination loops in the FLC cell No.2, which showed the C1T and C2U states. The internal boat-shape disclination loops point in the opposite direction on the C1 and C2 states, as was reported previously.[12, 13] Since the switching of the C1T state does not require any switching at the interface of the substrates, the boat-shape disclination loops are attributed to the switching of molecules at the chevron interface.

Switching model

The switching behavior described above can be understood as change in the director profile of molecules. As is illustrated in Figure 1, the direction of the C-director of molecules in SSFLC cells changes with changing distance from the substrates. The molecular orientations can be illustrated by the director profile of molecules in SSFLC cells. Figure 4(a) shows the director profile of the initial state of the C2U state,[3, 4] which is supposed to be one memory state initialized by a negative voltage. In this model the director twist angle at the chevron interface (ϕ_{IN}) is larger than the director twist angle at the surface (ϕ_0).

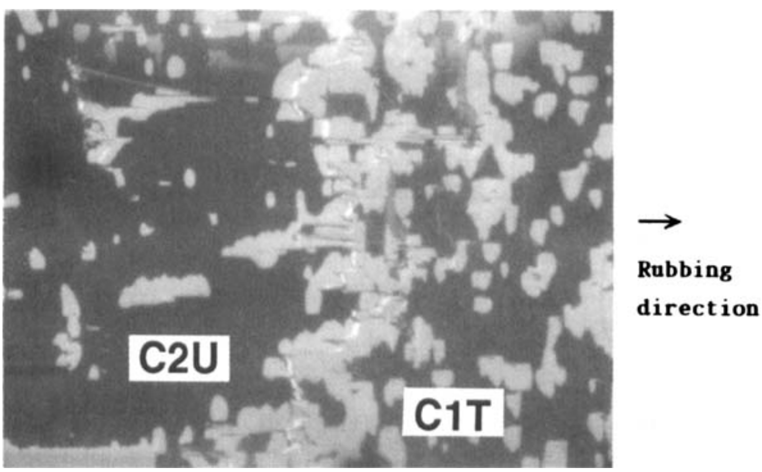

FIGURE 3 A micrograph of switching in the FLC cell No.2 at 25℃, when voltage of +0.2V was applied to the memory state initialized by applying a negative pulse voltage.

When voltages are applied, the interaction between the spontaneous polarization and the electric field induces the fluctuation of the azimuthal angle ϕ (Goldstone mode) and then changes the director profile. The change of the director profile under applied voltages are illustrated in Figures 4(b) and 4(c). In the experiment of this study, no change of layer structure was considered because no texture change was observed. Therefore, no change in the director twist angle at the chevron interface was supposed.

When negative voltages are applied, the interaction between the spontaneous polarization and the electric field changes the director profile as shown in Figure 4(b). In this process no change in the director twist angle occurs at the chevron interface, giving rise to no boat-shape disclination loop. Since the extinction angle is correlated to the integration of ϕ, it is understood that an increase in the electric field gives rise to an increase in the absolute value of the extinction angle.

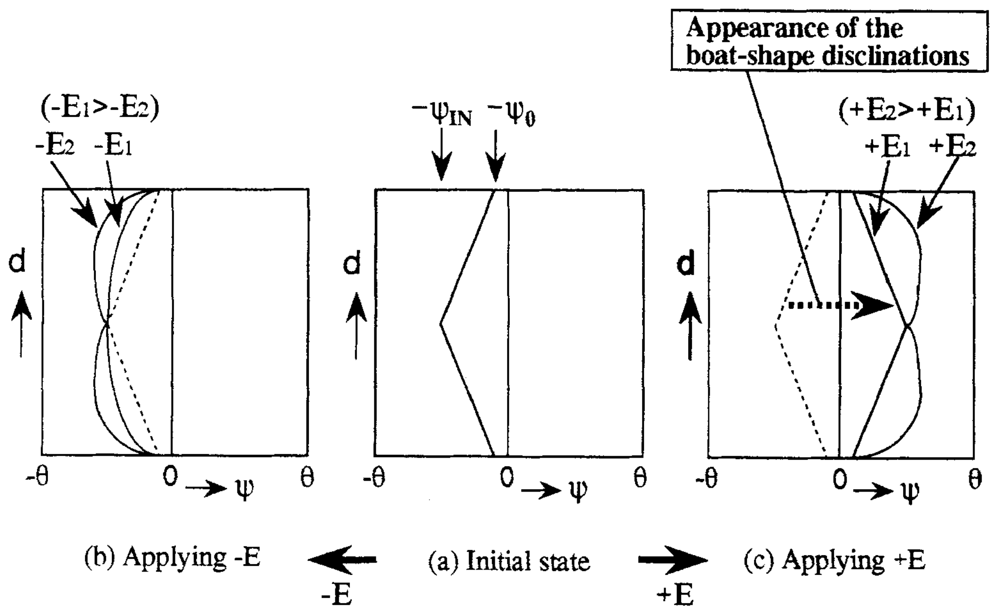

FIGURE 4 The director profiles in the C2U state. (a) The initial state with no electric field. (b) Applying negative voltages. (c) Applying positive voltages.

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On the other hand, when positive voltages are applied, the director twist angle at the chevron interface changes from $-\phi_{IN}$ to $+\phi_{IN}$ along with a small change in the director twist angle at the substrates, as shown in Figure 4(c). This is consistent with the appearance of boat-shape disclination loops. With further increase in voltage, the director profiles would change as shown in Figure 4(c), giving rise to an increase in the extinction angle.

Voltage-transmission curves

The voltage dependence of the extinction angle indicates that FLC molecules in FLC cells have intermediate states in which the energy induced by the interaction between voltage and spontaneous polarization is balanced with the energy induced by the cell surface. Using the voltage dependence of the extinction angle, a gray scale with smooth voltage-transmission characteristic can be obtained. Figure 5 shows the voltage-transmission characteristic of the FLC cell No. 2 when square wave voltages of 60Hz was applied at 25℃. In this measurement the polarizing axis was set to the extinction position of the initial state. Therefore, the transmission under the positive voltage is different from that under the negative voltage. The transmissions in Figure 5 are the average values.

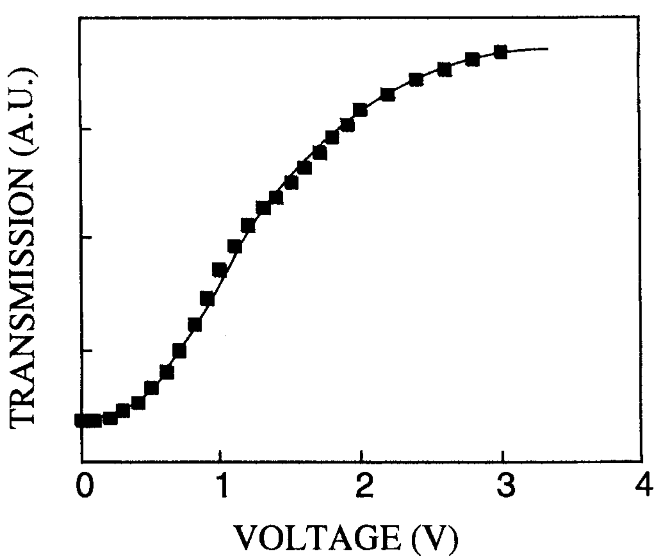

FIGURE 5 The voltage-transmission characteristics in the cells No.2 under square wave voltages with 60Hz at 25℃.

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