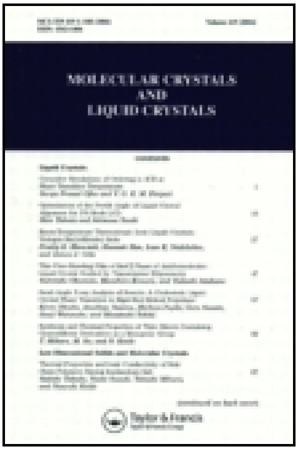

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Electro-optical Characteristics of Polymer Stabilized Vertically Aligned FLC Cell with Application of In-Plane Electric Field

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The effect of rubbing treatment on the molecular orientation is investigated for the vertically aligned ferroelectric LC (VA-FLC) cell having an inter-digit electrode to apply an in-plane electric field. The FLC material with large cone angle (CS-2005 (Chisso Co. Ltd.)) was used since a sufficient high contrast ratio is obtained due to the large effective optical retardation even if the cell thickness is thin. The E-O characteristic was measured for not only normal VA-FLC cells but also polymer-stabilized VA-FLC cells. In the polymer stabilized VA-FLC, the FLC material doped with small amount of photo-curable mesogenic monomers was used.

For the VA-FLC cell, it is effective to carry out the rubbing treatment on one side substrate or both side substrates which are assembled with the anti-parallel cell configuration. A half-V shaped T-V characteristics were obtained by implementing the polymer-stabilization technology.

Keywords: ferroelectric liquid crystal; in-plane electric field; polymer stabilization; vertical alignment

1. INTRODUCTION

It is not easy to obtain a defect free mono-domain of a ferroelectric liquid crystal (FLC) [1] using the surface stabilization method. As one of methods to avoid the occurrence of such defects, a vertical aligned FLC (VA-FLC) has been proposed by Ozaki *et al*. [2].

The chiral smectic LC exhibiting the ferroelectricity has an intrinsic spiral structure as the initial state. Ozaki *et al*. reported that although

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the chiral smectic LC aligned vertically between the substrates has the spiral structure at the initial state, the spiral is resolved by the application of an enough high electric field [2]. However, this mode has not been almost studied since Ozaki *et al.*'s study.

By the way, in this study, a new type of VA-FLC is proposed. In the initial state, a spiral structure is eliminated by the rubbing treatment. The pretilt angle of the layer normal measured from the plane parallel to the substrate surface was about 88 deg. when the rubbing treatment was conducted on the vertical alignment film. On the initial state, the c-director of FLC is oriented to the rubbing direction. When IPS [3] mode is used, an in-plane electric field was applied to the LC layer with the inter-digit electrode pattern formed on one of the substrate. An FLC material CS-2005 (Chisso Co. Ltd.) with a very large cone angle of 85.8° was used in our sample cells. Additionally, the polymer stabilizing method [4] was used.

In this report, we observe the LC molecular orientation in the VA-FLC cell and measure the T-V characteristics before and after the polymer stabilization treatment.

2. EXPERIMENTS

2.1. Materials Used in this Study

As an LC material, CS-2005 (Chisso Co. Ltd.) was used. Table 1 shows the material properties table (from data sheet). As the alignment material, a kind of polyimide SE-1211 (Nissan Chemical Ind.) for the vertical alignment was used.

2.2. Sample Cells

The sample cell was constructed using a glass substrate with the inter-digit electrode as shown in Figure 1 and a glass substrate without the electrode. The vertical alignment material SE-1211 was coated on substrates.

TABLE 1 Material Properties Table for CS-2005

Phase transition temperature	Cryst.(<−19)SmC*(64.7)N*(72.8)Iso. °C.
Cone angle	85.8°
Pitch	N*: 9 μm, SmC*: 14 μm
Response time(E = 10 V/μm, 25deg.C.)	126 μsec.

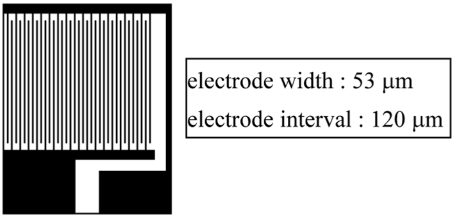


FIGURE 1 ITO Electrode pattern.

The rubbing treatment was carried out on for each sample cell of Cell-A, Cell-B, Cell-C, and Cell-D in the ways as shown in Figure 2. The rubbing treated for each sample cells are as follows;

Cell-A: both substrates were not rubbed,
Cell-B: the upper and lower substrates were rubbed in a parallel direction each other,
Cell-C: only one side substrate was rubbed. The glass substrate without ITO was rubbed along the direction perpendicular to the inter-digit electrode, and
Cell-D: the upper and lower substrates were rubbed in anti-parallel directions each other.

The cell thickness is approx. 4 μm. FLC material CS-2005 was injected into the cell in the isotropic phase. The intrinsic pitch in the SmC* phase of CS-2005 is 14 μm as shown in Table 1, and the spiral structure is eliminated at the cell thickness of 4 μm. It is possible to cause a twist alignment of about 1/4 pitch if a spiral structure remains. Under the application of the triangular-wave voltage, the situation of LC molecular orientation was observed by a polarizing optical

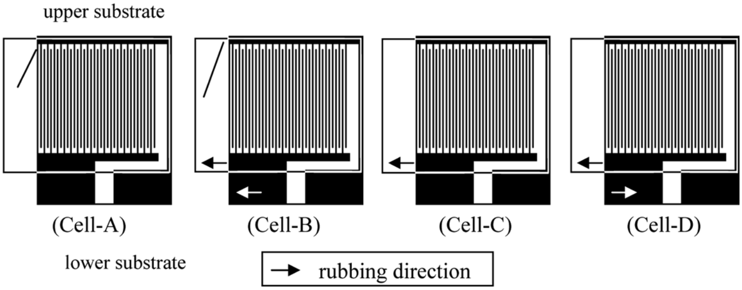


FIGURE 2 Rubbing directions in Cell-A, Cell-B, Cell-C, and Cell-D.

microscope under the crossed Nicol condition. In addition, a mixture of CS-2005 and a UV curable LC monomer UCL-001 (DIC Ind.) including a small amount (4 wt%) of photo-initiator were injected in the cell. And, the polymer stabilization treatment was conducted for cells, and the electro-optical characteristics of those cells were measured.

2.3. UV Light Irradiation System

The triangular-wave voltage was applied to the cell, and the UV light with a wavelength: of 365 nm was irradiated by using a UV-LED (Nichia Chemical Ind.). The UV irradiation condition was as follows; the UV irradiation energy: 90 mJ/cm^2, the applied voltage: +/− 10–50 V_p, the frequency: 100–500 Hz.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1. In the Cell-A

The cell indicated as Cell-A was made using two glass substrates without the rubbing process on the vertical alignment film. Figure 3 shows the situation of the molecular orientation in the cell before carrying out the polymer stabilizing. The LC molecular orientation was observed using a polarizing optical microscope. The optical response for the applying voltage was very poor, and the single domain was not obtained. The optical extinction state did not appear when the cell was rotated. Thus, it is thought that the spiral structure was not eliminated.

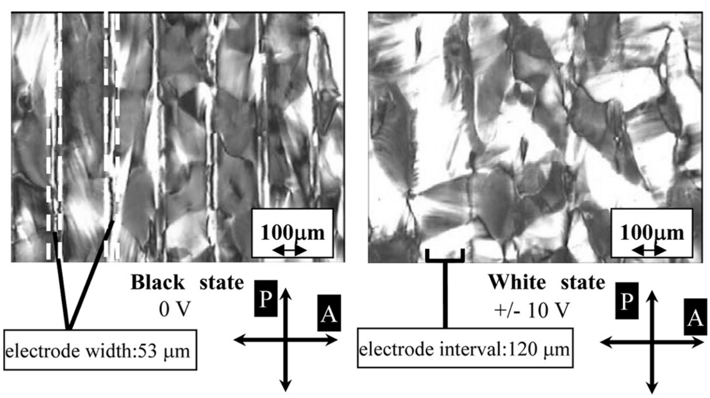


FIGURE 3 Observed results for the state of LC orientation in the Cell-A (Black state and White state).

3.2. In the Cell-B

The cell indicated as Cell-B was made using two glass substrates with the rubbing process on the vertical alignment film. Figure 4 shows the situation of the LC molecular orientation of the cell before carrying out the polymer stabilizing. The triangular-wave voltage $25\,V_p$ was applied to the cell and the situation of the LC molecular orientation was observed using a polarizing optical microscope. The optical response for the applying voltage was good, but the orientation defect was observed. Additionally, the optical extinction state appeared when the cell was rotated.

Based on the principle of the retardation compensation, it was confirmed that the direction of projection of director onto the plane parallel to the substrate agrees with the rubbing direction. Therefore, it is thought that the director oriented completely in the direction of the rubbing, and the spiral structure was eliminated.

The polymer stabilization treatment was not carried out for cell B, because a lot of orientation defects were observed in the cell. And, it was decided that this cell was not suitable in the polymer stabilization treatment.

3.3. In the Cell-C

The cell indicated as Cell-C was made using the glass substrate with the rubbing processing and the glass substrate without the ITO film rubbed along the direction perpendicular to the inter-digit electrode

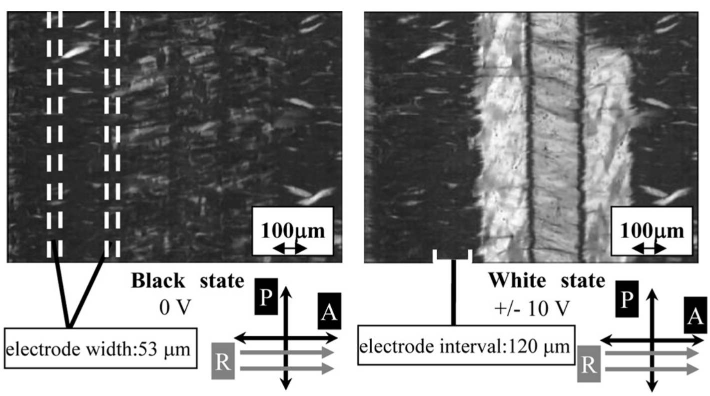


FIGURE 4 Observed results for the state of LC orientation in the Cell-B (Black state and White state).

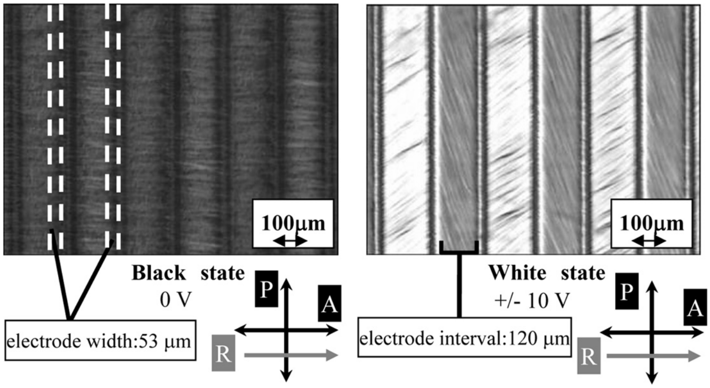


FIGURE 5 Observed results for the state of LC orientation in the Cell-C before polymer stabilization (Black state and White state).

on the other side. Figure 5 shows the situation of the molecular orientation of the cell before carrying out the polymer stabilizing. The triangular-wave voltage $25\,V_p$ was applied to the cell and the LC molecular orientation was observed using a polarizing optical microscope. The optical response for the applying voltage was good, but the orientation of FLC director was not uniform between electrodes. It is thought that this is affected by the direction of the intrinsic twist, the direction of the rubbing treatment and the material.

Moreover, the optical extinction state appeared when the cell was rotated, as well as the Cell-B. From this fact, it is thought that the c-director oriented completely in the direction of the rubbing, and the spiral structure was eliminated. It seems that the twist orientation was almost eliminated because the director orientation is regulated by the rubbed one side substrate and the spiral axis has inclined a little. In addition, because the rubbing treatment is not carried out in the opposing substrate, it is thought that the FLC director might be uniformly oriented between the substrates without any restraining force for the azimuth direction.

Figure 6(a) shows the T-V characteristic (hysteresis characteristic) measured by applying the triangular wave voltage to the VA-FLC cell in one cycle. The transmitted light intensity through only one inter-electrode region was measured using a polarizing optical microscope. The change of transmittance with the increase of voltage is different from that with the decrease of voltage. Figure 6(b) shows the corresponding T-V characteristic (hysteresis characteristic) for the PS-VA-FLC (polymer stabilized vertical aligned FLC) cell. The polarizer

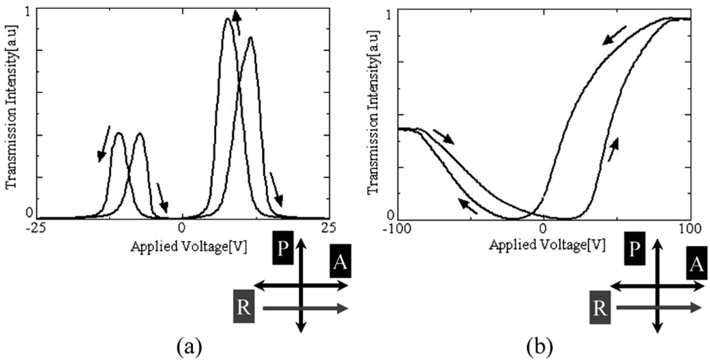


FIGURE 6 T-V characteristic of the Cell-C: (a) before carrying out the polymer stabilizing, (b) after carrying out the polymer stabilizing.

and the analyzer were set in similar way for the VA-FLC and the PS-VA-FLC. The T-V characteristic changed before and after carrying out the polymer stabilization. The driving voltage became higher (form ±25 V to ±100 V) by the polymer stabilization. An electro-optical characteristic near the half-V characteristic [5] of PS-FLC was obtained.

Figure 7 shows the state of the orientation in the PS-VA-FLC cell. The un-uniformity of the molecular orientation in the inter-electrode region was solved by using the polymer stabilizing treatment. It was thought that the driving voltage became higher by the polymer

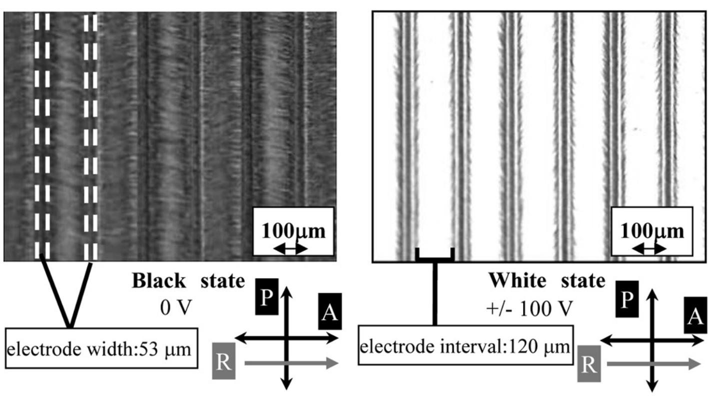


FIGURE 7 Observed results for the state of LC orientation in the Cell-C after polymer stabilization (Black state and White state).

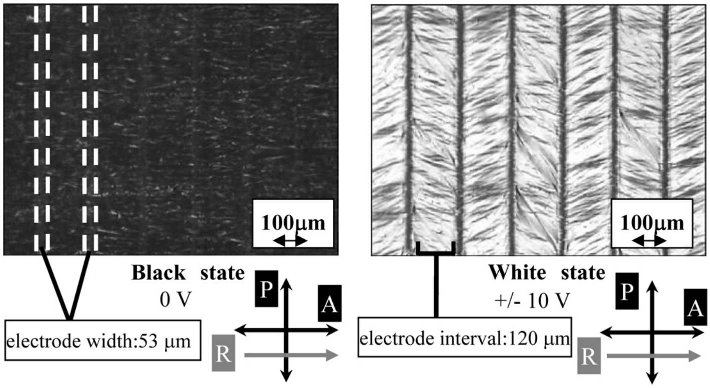


FIGURE 8 Observed results for the state of LC orientation in the Cell-D before polymer stabilization (Black state and White state).

stabilization treatment since the movement of director was limited due to the polymer network formed by the polymer stabilization treatment.

3.4. In the Cell-D

The Cell-D was made using two glass substrates both of which were rubbed. Figure 8 shows the state of the orientation of the cell before

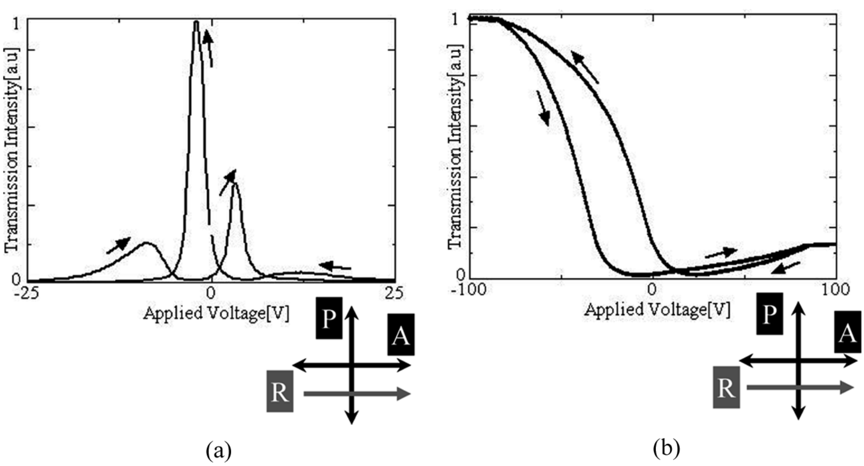


FIGURE 9 T-V characteristic of the Cell-D: (a) before carrying out the polymer stabilizing, (b) after carrying out the polymer stabilizing.

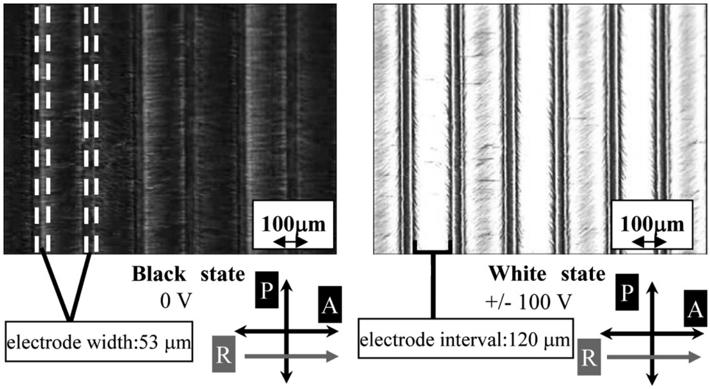
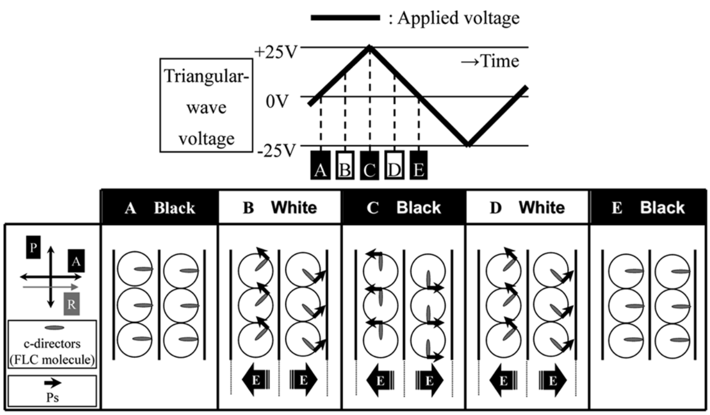


FIGURE 10 Observed results for the state of LC orientation in the Cell-D after polymer stabilization (Black state and White state).

carrying out the polymer stabilization (VA-FLC). The LC orientation in the Cell-D was observed under the condition of the application of triangular-wave voltage $25\,V_p$ using a polarizing optical microscope. The optical response for the applying voltage was good, and the orientation defect was not observed. The orientation of the FLC director was uniform between electrodes. Moreover, optical extinction state appeared when the cell was rotated, as well as the Cell-B and Cell-C.



<top view>

FIGURE 11 Qualitative explanation for the operation of the VA-FLC with the application of a triangular-wave voltage.

Thus, it is thought that the director oriented completely in the direction of the rubbing, and the spiral structure was eliminated.

Figures 9(a) and 9(b) show the T-V characteristic for the Cell-D before and after the polymer stabilization treatment, respectively. They were measured under the application of the triangular wave voltage. Similar tendencies are observed for the Cell-C and Cell-D.

Figure 10 shows the state of the orientation in the PS-VA-FLC cell. It was thought that the driving voltage became higher by the polymer stabilization treatment since the movement of director was limited due to the polymer network formed by the polymer stabilization treatment.

A qualitative model for this mode is shown in Figure 11. When a triangular-wave voltage is applied between the inter-digit electrodes, if the voltage is 0 V, the c-director of the FLC is uniformly oriented in the rubbing direction and the black state was displayed. If the voltage is relatively low (2–10 V), the c-director begins to move due to a torque acting on the spontaneous polarization Ps from the electric field. And a white state (bright state) is displayed because the projection of the FLC director on the plane parallel to the substrate has an angle with respect to the transmission axis of the polarizer. When the angle is 45 deg. the brightest state was displayed. If the voltage was high enough (more than 20 V), the c-director is uniformly oriented in a direction perpendicular to rubbing direction because Ps is oriented to the parallel direction to the electric field. Then, a black state (dark state) is displayed.

4. CONCLUSIONS

The new type of VA-FLCs was proposed in this study. A spiral structure in the FLC molecular arrangementwas eliminated when the rubbing treatment was carried out on the vertical alignment film. It is thought that the cells treated by one side rubbing (Cell-C) and anti-parallel rubbing (Cell-D) results in the good characteristics. In this time, the detailed consideration was not done for this experimental. Because, the mechanism or structure of molecular orientation for the VA-FLC cell with parallel rubbing and also anti-parallel rubbing has not been clarified yet, the mechanism and structure of orientation have been researched now.

Moreover, the T-V characteristic has changed by the polymer stabilization. In the near future, we will discuss in more detail the FLC director orientation model and the influence of the polymer stabilization condition on the electro-optical properties.

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