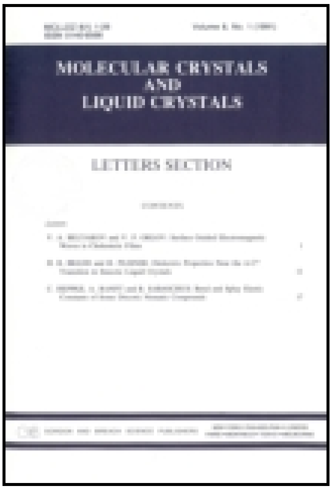

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Fabrication of Uniformly Vertical Alignment FLC Cell

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We focus on vertical alignment ferroelectric liquid crystal (FLC) cells fabricated without the rubbing technique to realize FLC displays having high contrast ratio. In this study, we research the conditions for the fabrication of uniformly vertical alignment FLC cells in terms of the tilt angle of FLC and the anchoring strength of alignment film materials.

As a result, the uniformly vertical alignment of FLC can be obtained in the case of the small tilt angle and the strong anchoring strength. Furthermore, we investigate the effect of the application of electric field on the vertical alignment.

Keywords Ferroelectric liquid crystal; vertical alignment; tilt angle; anchoring strength

1. Introduction

Currently, liquid crystal display (LCD) devices have been widely put to practical use such as smart phones and televisions. The current LCDs are fabricated by using nematic LCs (NLCs). NLCs respond to the electric field by the torque due to the dielectric anisotropy. On the other hand, ferroelectric LCs (FLCs) have a spontaneous polarization, and respond to the electric field by the force based on the interaction of the electric field and the spontaneous polarization [1–6]. Therefore, the response speed of FLC is much faster than that of NLC [7–11]. Thus, FLCs are attractive for a next generation of LCD having high performances such as high-quality moving video image and very low power consumption. FLCs are usually handled with a homogeneous alignment cell, in which FLC molecules align parallel to the cell substrate surface and the smectic layer is normal to that surface, fabricated by using parallel rubbing alignment films. In the rubbing cells, a non-uniformity of LC molecular orientation due to the rubbing groove and scratch appears even in NLCs. In FLCs, the non-uniformity becomes more remarkable because of the crystallic smectic layer structure. The large optical leakage and low contrast ratio due to the non-uniformity of FLC molecular alignment are one of the problem for the application of FLC to the display devices. Therefore, we focus on the vertical alignment FLC (VA-FLC) [12–16]

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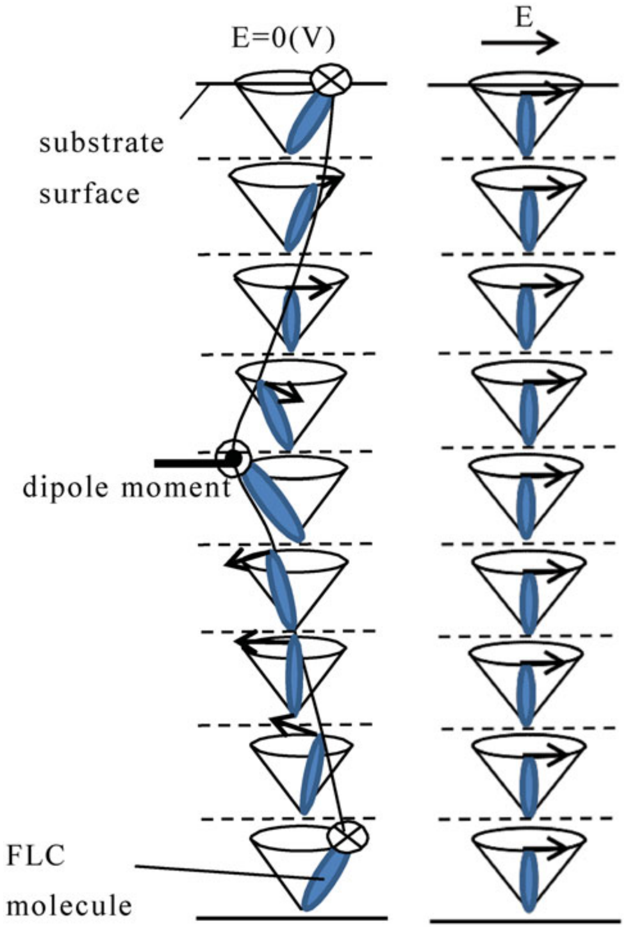

Figure 1. Schematic model of vertical alignment in FLC.

fabricated without the rubbing technique. High contrast ratio is expected, and moreover, the fabrication process can be simplified because of rubbing-less. Figure 1 shows the FLC molecular alignment structure that we want to obtain. Although the normal of the smectic layer is vertical to the substrate surface, the director of FLC molecules have to tilt to the substrate surface by the tilt angle of FLC molecule itself. Furthermore, the smectic layer spacing decreases due to the LC molecular tilting from SmA to SmC* phase. As a result, the structural change and non-uniformity of the smectic layers may easily occur at the phase

Table 1. Properties of FH8002N

Properties	
Phase sequence	SmC*(62)SmA(76)N*(82)Iso. [°C]
Spontaneous polarization	25nC/cm^2
Tilt angle	22° (at room temp.)

Table 2. Properties of FH8006N

Properties	
Phase sequence	SmC*(77)SmA(83)N*(96)Iso. [°C]
Spontaneous polarization	50 nC/cm^2
Tilt angle	30° (at room temp.)

transition. Thus, it is much more difficult to obtain the uniformly vertical alignment in FLC than that in NLC. In this study, we research the conditions for the fabrication of uniformly vertical alignment FLC cells in terms of the tilt angle of FLC and the anchoring strength of vertical alignment film materials.

2. Experimentals

The materials used in this research were as follows: the FLCs were FH8002N and FH8006N (DIC), and the vertical alignment films were polyimide JALS204 (JSR), SE1211, SE7511L, and RN2803 (Nissan Chemical Industries). Tables 1 and 2 show physical properties of FH8002N and FH8006N listed in the catalogues, respectively. A solution of polyimide was spun on glass substrates and then baked. Then, the FLC was injected in the isotropic phase via capillary action into an empty cell in which the cell gap was set 10μm. Next, the cell was cooled gradually to 30°C which is in the SmC* phase. The FLC cells fabricated by above method were observed with a conventional polarizing microscope. In the crossed Nichol situation, the dark or black texture can be obtained if FLC molecules are vertically oriented. To evaluate quantitatively the degree of the vertical orientation, the transmitted light intensity was measured.

Further, to investigate the anchoring strength of the vertical alignment films used in this research, the threshold voltage was measured by utilizing the nematic liquid crystals of ZLI2806 and MLC2039 (Merck) having a negative dielectric anisotropy. We defined the threshold voltage as the voltage at which the transmitted light intensity begins to respond to the triangular waveform voltage (0.1Hz, ±10 V), as shown in Fig. 2. It is thought that the anchoring strength is stronger as the threshold voltage is higher.

3. Results and Discussion

Figure 3 shows the microscopic textures observed in the cells fabricated using FH8002N. Since the textures in the cells fabricated using the alignment film of SE1211, RN2803, or JALS204 are dark, it is found that an almost uniform vertical alignment is obtained.

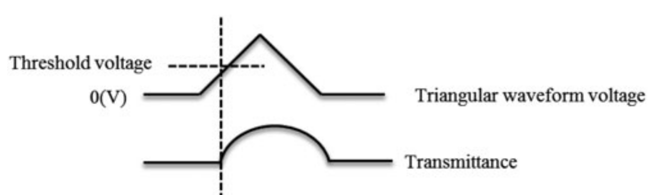

Figure 2. Definition of threshold voltage.

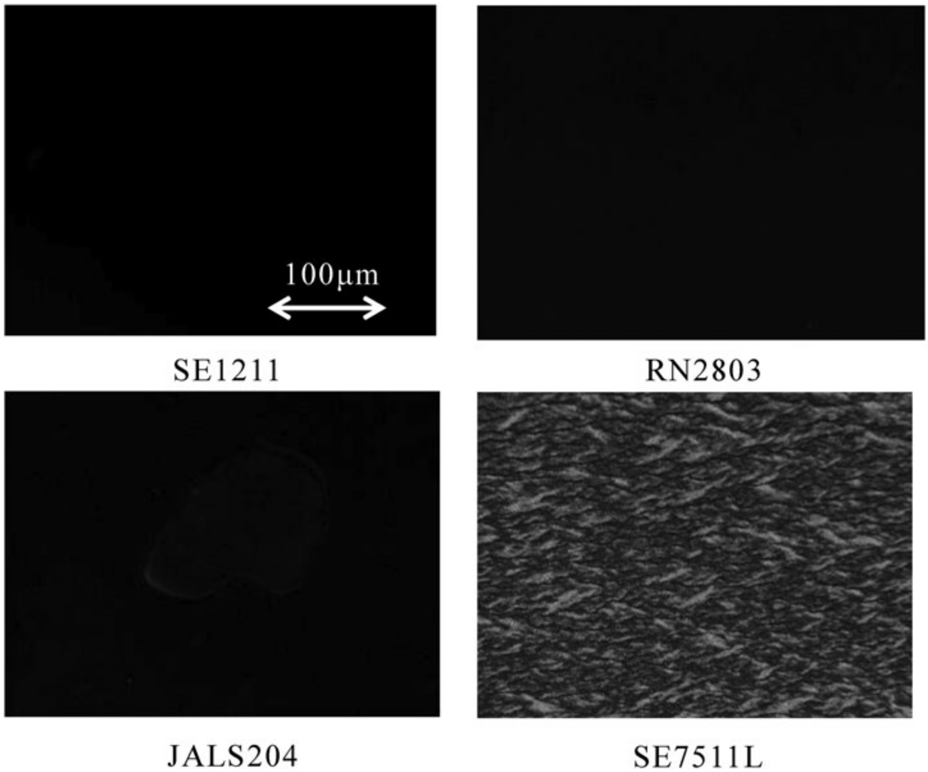

Figure 3. Microscopic textures in cells fabricated using FH8002N.

However, in the case using SE7511L, Schlieren texture is observed, and thus, a uniformly vertical alignment cannot be obtained. Although the dark texture and the uniform vertical alignment can be obtained in the SmA phase, Schlieren texture appears at the transition to the SmC* phase. Next, Fig. 4 shows the microscopic textures in the cells fabricated using FH8006N. Schlieren texture is observed in SE7511L similarly to the case of FH8002N. Furthermore, in the case using JALS204, the bright texture is obtained. It is guessed that an anisotropy of FLC medium is caused by the inclination of the helical axis of FLC molecular alignment originated in the tilt of FLC molecules at the phase transition, as same as the case using SE7511L. An obvious Schlieren texture appears as the increase of the inclination of the helical axis. Since the FLC molecular tilt shrinks the smectic layer spacing, the increase of the number of layer or the inclination of the layer must occur. In the latter situation, since the layer normal and the helical axis incline to the substrate surface of the cell, the anisotropy of FLC medium and the Schlieren texture appear. Table 3 shows the transmitted light intensity of the cells fabricated in this research. It is found that the transmittance in FH8002N is lower than that in FH8006N. Therefore, it is guessed that FLCs which have smaller tilt angle tend to form better vertical alignment, because the structural change of the smectic layer strongly depends on the tilt angle of FLC as mentioned above. Furthermore, it is found that the transmitted light intensity in the cells fabricated using SE1211 alignment films is the lowest of the cells fabricated in this research. The vertical alignment ability would depend on the anchoring strength of alignment film.

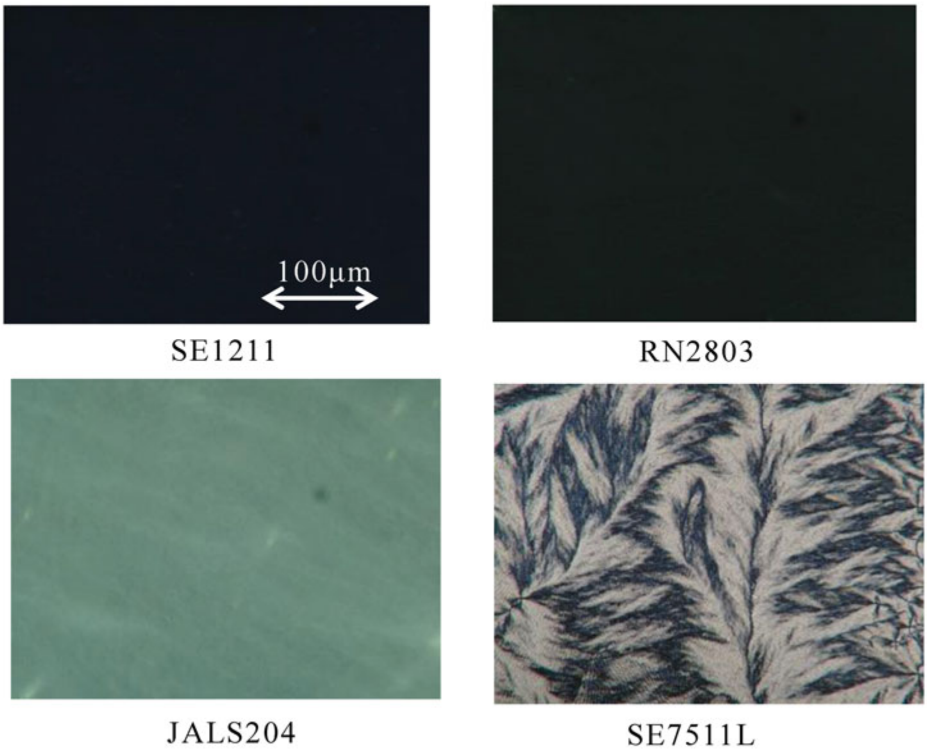

Figure 4. Microscopic textures in a cells fabricated using FH8006N.

Table 3. Transmitted light intensity of FLC cells fabricated using vertical alignment films: the intensity shown is the ratio to the transmittance in the isotropic liquid phase

	Transmitted light intensity	
Alignment films	FH8002N	FH8006N
SE1211	7.67	24.5
RN2803	11.0	77.3
JALS204	9.62	212
SE7511L	150	410

Table 4. Threshold voltage in ZLI2806 and MLC2039 cells

	Threshold voltage (V)	
Alignment films	ZLI2806	MLC2039
SE1211	4.9	4.6
RN2803	4.2	4.2
JALS204	3.3	4.1
SE7511L	3.4	3.9

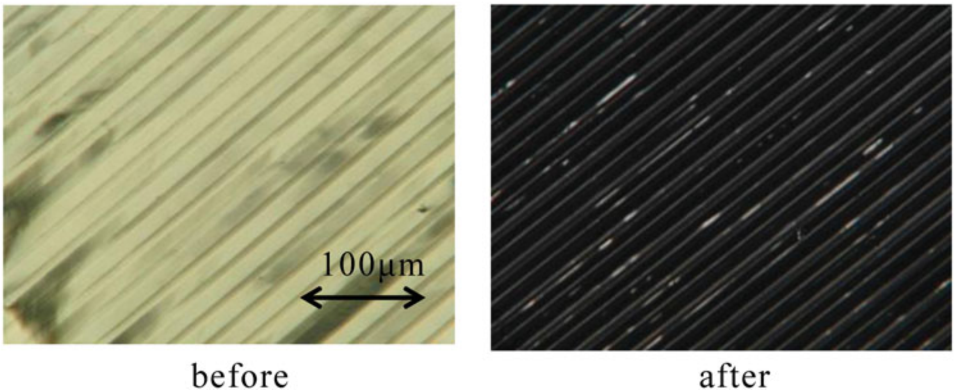

Figure 5. Microscopic textures in a cell, which is fabricated using FH8002N, SE1211, and a substrate with comb-shaped electrodes (line width: 20 μm and gap: 10 μm), before and after the application of 6 V/μm.

Table 4 shows the measuremental results of the threshold voltage in ZLI2806 and MLC2038 cells. In the case using SE1211, the threshold voltage is highest for both LCs. Therefore, it is found qualitatively that SE1211 has relatively strong anchoring strength. It is concluded that although the FLC molecules tilt to the substrate surface by the tilt angle of FLC, the good vertical alignment shown in Fig. 1 can be obtained by utilizing the alignment films which have the strong anchoring strength.

Finally, Fig. 5 shows the microscopic textures of a cell fabricated using FH8002N, SE1211, and a substrate with comb-shaped electrodes to apply the in-plane electric field. The dark textures and then the vertical alignment of FLC cannot be obtained before the application of the electric field. It is thought that the uneven topography of the substrate surface due to the electrode may prevent the formation of the uniform vertical alignment. On the other hand, the dark texture can be obtained in the quiescent condition after applying the electric field. It is guessed that the in-plane electric field can modify the FLC molecular alignment into the uniformly vertical alignment shown in Fig. 1, because the permanent dipole moment of FLC directs parallel to the electric field.

4. Conclusions

We researched the conditions for the fabrication of uniformly vertical alignment FLC cells. As a result, it was found that the vertical alignment ability strongly depends on the tilt angle of FLC and the anchoring strength of alignment film. The FLCs which have smaller tilt angle can form better vertical alignment, because the structural change of smectic layer is larger as the tilt angle is higher. Furthermore, it is concluded that the vertical alignment can be realized by utilizing the alignment film which has the strong anchoring strength, though the FLC molecules tilt to the substrate surface by the tilt angle of FLC. Moreover, we fabricated a cell with a substrate having comb-shaped electrodes to apply the in-plane electric field. Although the vertical alignment of FLC cannot be obtained before the application of the electric field, it can be obtained after applying the electric field because the permanent dipole moment of FLC directs parallel to the electric field.

Acknowledgments

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