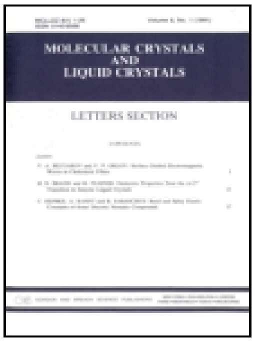

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Control of Pre-tilt Angle and Evaluation of Azimuthal Anchoring Strength Considering the Pre-tilt Angle on the Alignment Film Formed by the ESD Method

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The electrospray deposition (ESD) method is an established film-forming technique. The pre-tilt angle was controlled by using the improved ESD method has been proposed by our previous report. In this paper, a novel torque balance method for measuring an improved azimuthal anchoring strength for the high pre-tilt angle was proposed. The pre-tilt angle was controlled and the azimuthal anchoring energy depended on the pre-tilt angle was evaluated. The azimuthal anchoring energy was obtained in the range from 10^{-4} to 10^{-5} J/m^2 depending on the pre-tilt angle.

Keywords LC alignment; ESD method; Anchoring strength; Pre-tilt angle

1. Introduction

The pre-tilt angle is one of the important factors for the LC orientation. Some methods for controlling of the pre-tilt angle have been proposed up to now, for example; as an alignment material, the horizontal and vertical alignment materials were blended with the optional ratio, and that blended material was coated by the spin-coating method [1]. However, maybe the inducing pre-tilt angle does not show the good repeatability because the liquid separation occurs due to the difference of the specific gravity for each solution. The Electro-Spray Deposition (ESD) is one of the film forming methods by using the electric field and electric charges has been proposed by V. N. Morozov et al. [2–9] And, a hybrid method which is a combination of the spin-coat and the ESD has been proposed by our group [10] for the control of pre-tilt angle in the LC cell. The special alignment film consisted of innumerable tiny multi-domains with the horizontal and vertical alignment materials can be formed by this method. After that, the improved method of that has been proposed, i. e., two solutions of alignment materials were alternately sprayed to form tinier domains of alignment materials [11]. The purpose of this study is to control the pre-tilt angle by using this technique, and the azimuthal anchoring depending on the pre-tilt angle is evaluated. For

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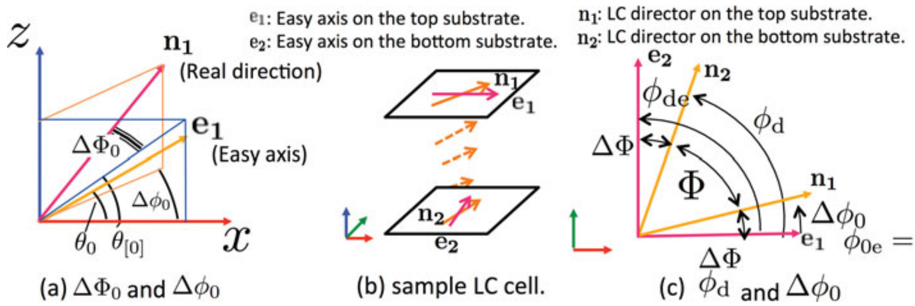

Figure 1. Coordinate systems.

the evaluation, we propose an improved measurement method of the azimuthal anchoring strength considering the pre-tilt angle.

2. Definition of the Improved Azimuthal Anchoring

Generally, the azimuthal anchoring energy $W_\phi$was defined as $(1/2)\sin^2\Delta\phi_0$[12]. [See Fig. 1 (a)] However, this expression is defined under the zero pre-tilt condition. Thus, this definition shows irrationality if the azimuthal anchoring with a large pre-tilt angle LC cell is discussed. Therefore, an improved azimuthal anchoring energy W'_ϕ was proposed [13]; that has been defined as $(1/2)\sin^2\Delta\Phi_0$. [See Fig. 1(a)] Then, the torque balance method [14, 15] for LC cells with a large pre-tilt angle is redefined. The anchoring strength A'_Φ can be obtained as follows when the LC director and easy axis are defined as shown in Fig. 1 (c);

$$A'_\phi = \frac{(K_{22}\cos^2\theta_{[0]} + K_{33}\sin^2\theta_{[0]})(\phi_d - \Delta\phi_0)}{2d\left(1 - 2\cos^2\theta_{[0]}\sin^2\frac{\Delta\phi_0}{2}\right)\cos\theta_{[0]}\sin\Delta\phi_0}, \tag{1}$$

where K_{22} and K_{33} are the twist and bend elastic constants. d is the cell thickness. When the pre-tilt angle $\theta_{[0]}$ is zero, the anchoring strength A'_Φ which is defined by us is equal to the conventional A_Φ.

3. Experimental Procedure

Two types of alignment material solutions were sprayed by using the improved ESD implement, as shown in Fig. 2. One of the materials was a horizontal alignment material PI-A, the other one was a vertical alignment material SE-1211, these materials had been diluted by 4 wt% with thinner. (Materials were offered by Nissan Chemi. Ind.) Then, for spraying the ESD method, each solution was diluted with the special mixture solvent, mentioned below. The weight ratio of the solution to the special solvent was 1:9. This solvent was mixed with the tetrahydrofuran (THF) and acetonitrile (ACN), the weight ratio of the THF to ACN was 6:4. The distance between the capillary top and the substrate was 8 cm, and the applied voltage was 4.2 kV. The timing diagram for switching capillaries was shown in Fig. 3. In the experiment, one cycle for the spraying solutions was 10 sec. The total spraying time was varied from 5 to 15 min. And, the spraying time rate of the vertical alignment solution was varied from 20 to 80%. The pressure air was applied to each syringe via each solenoid valve,

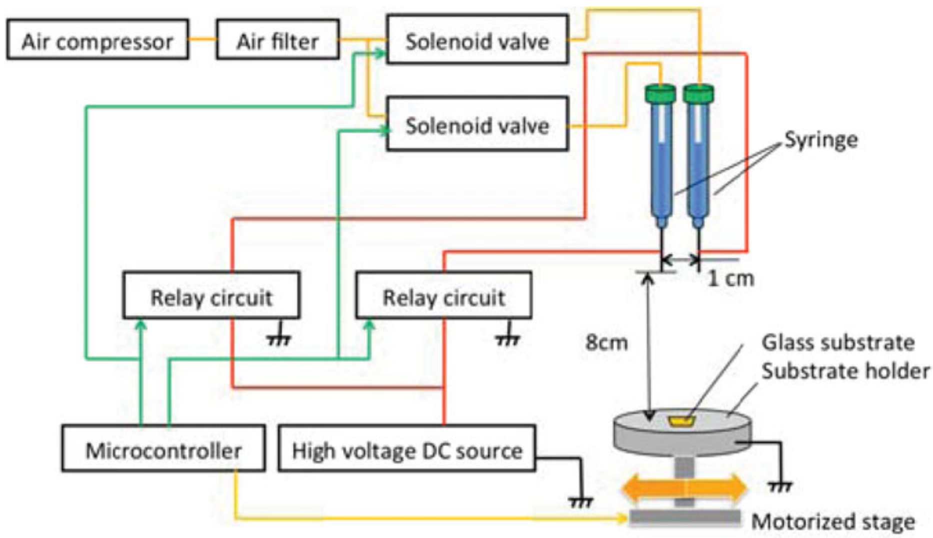

Figure 2. Schematic model of our ESD implement.

and each applied pressure was switched with synchronizing with each applied voltage to the capillary. The air pressure was 0.2 kgf/cm^2. Furthermore, the position of the substrate holder was mechanically controlled, the glass substrate was positioned just under the capillary which was sprayed. Then, the rubbing treatment was done to these substrates after the baking treatment. Two different types of the cells with 20 μm thickness were fabricated. One was an anti-parallel configuration for the measurement of the pre-tilt angle, the other one was a 90 deg. TN configuration for the measurement of the azimuth anchoring strength. The nematic LC, 5CB [Merck], was injected into those cells with the I-phase and cooled down. Then, the pre-tilt angle $\theta_{[0]}$ was measured by the magnetic-null method[16]. And, the real twisted angle Φ in the LC cell was measured by the novel measurement method, the measurement system was shown Fig. 4. The azimuth anchoring strength A'_{Φ} was calculated using the equation (1) by substituting the measurement values $\theta_{[0]}$, $\Delta\phi_0 = (90^{\circ} - \Phi)/2$, and $\phi_d = \Delta\phi_0 + \Phi$. In addition, the conventional azimuthal anchoring strength A_{Φ}

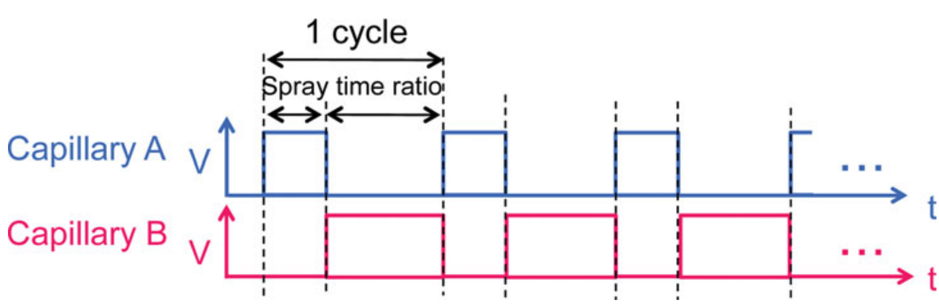

Figure 3. Timing diagram.

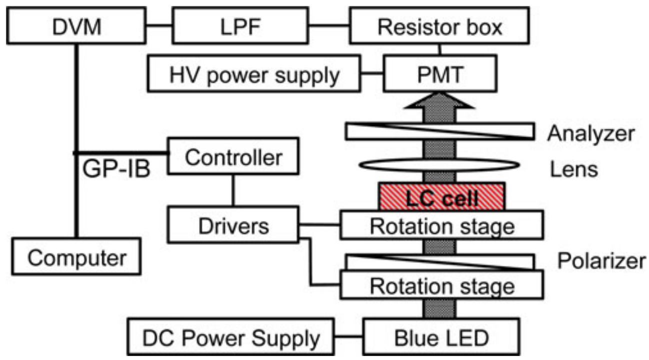

Figure 4. Schematic diagram of a measurement system for the torque balance method.

was calculated by follows, [14,15]

$$A_\Phi = \frac{K_{22}(\phi_d - \Delta\phi_0)}{d\,\sin(2\Delta\Phi)}. \tag{2}$$

4. Results and Discussion

Figure 5 shows the measurement results of the pre-tilt angles. The pre-tilt angle was able to be widely controlled 5 to 40 deg. In this result, the pre-tilt angle rose in proportion to the total spraying time. This result showed a tendency that lower pre-tilt angle was induced when the spraying time was shorter.

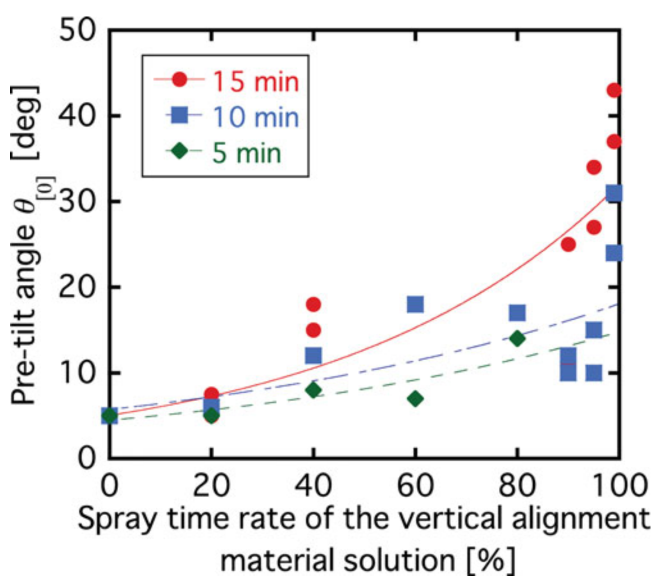

Figure 5. Measurement results of the pre-tilt angle.

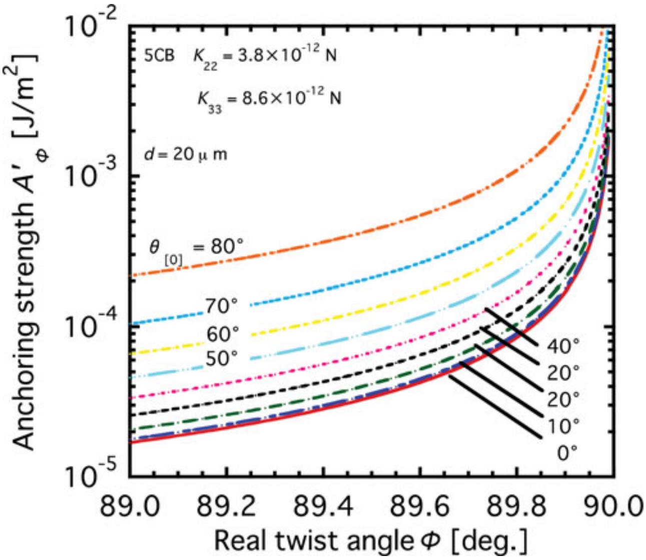

Figure 6. Calculation results of A'_Φ based on the real twist angle and pre-tilt angle.

Calculated results of the anchoring strength A'_Φ based on the real twisted angle Φ and the pre-tilt angle $\theta_{[0]}$ were shown in Fig. 6. In the case of the large pre-tilt angle close to the vertical alignment, the value of A'_Φ was different more than an order of magnitude from the value of A_Φ which was obtained by the conventional method (assuming $\theta_{[0]} = 0$). In particular, the difference was noticeable when the anchoring strength was weak. In other words, our approach was useful in the evaluation of the alignment film that had a weak anchoring strength with a large pre-tilt angle.

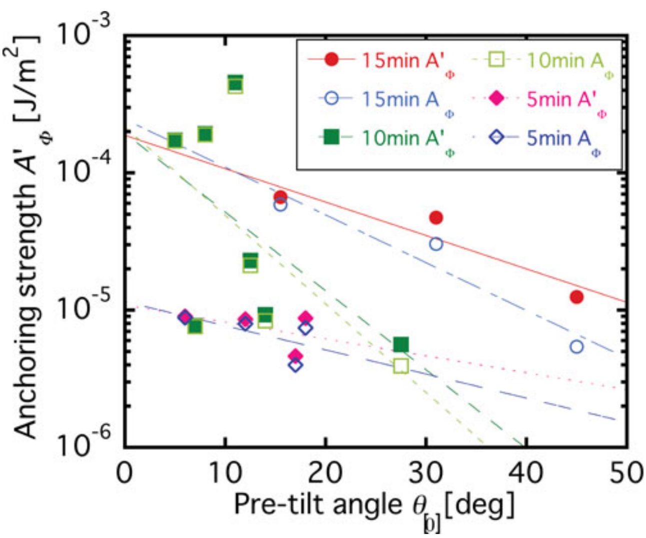

Figure 7. Pre-tilt angle vs. A_Φ and A'_Φ.

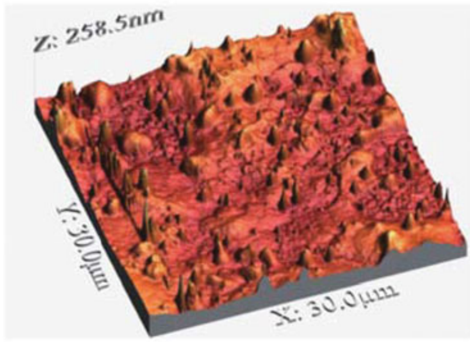

Figure 8. AFM image on the alignment film surface fabricated by the ESD method.[11]

Figure 7 shows the graph of azimuthal anchoring strength against pre-tilt angle for the measurement results. The azimuthal anchoring energies in the order of 10^{-4} to 10^{-5} J/m^2 were obtained. In general, the azimuthal anchoring strength of the polyimide alignment film formed by the spin coating method is approximately 10^{-3} to 10^{-4} J/m^2. In our experiment, almost same values were obtained by 15 min of the spraying time. In the case of other conditions, obtained values were lower or less than those of the spin-coated films. There were some reasons, the measurement error was induced by the optical scattering in the LC cell due to lots of domains of alignment materials. A typical AFM image for the surface of film formed by the ESD was shown in Fig. 8. Furthermore, if the film thickness was not enough, lots of pinholes might be easy to appear on the film. And, maybe the side-chain of polyimide materials didn't function well as an LC alignment. Then, it was considered that the weak anchoring strength was measured for those films.

Incidentally, the anchoring strength on the horizontal film without containing any vertical alignment materials forming the ESD process was measured with varying the film thickness [17]. The measurement results were shown in Fig. 9. As a result, it seemed that the enough azimuthal anchoring strength (close to 10^3 J/m^2) was obtained when the film

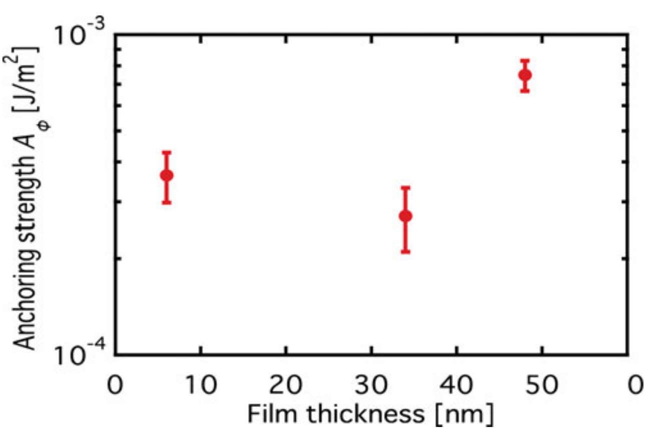

Figure 9. Anchoring energy vs. Film thickness.[17]

thickness was 50 nm. That is, the normal order of anchoring strength was obtained when the film had an enough thickness.

Sometimes, a reproducibility of the formed film was poor and a low quality film was formed when the thick film was formed by the ESD for a long time continuous operation to deposit thicker. Some troubles occurred such a clogging of capillary tube, during a long time operation. Therefore, it may be necessary to reconsider the ESD conditions.

A weak anchoring strength was obtained when the pre-tilt angle was increased. And, both A'_{Φ} and A_{Φ} decreased with increasing the pre-tilt angle.

5. Conclusion

There are almost no research groups to study about the LC alignment by the ESD technique except for us. The pre-tilt angle was able to be widely controlled in the region of 5 to 40 deg. by using our ESD method. The novel torque balance method for measuring an improved azimuthal anchoring strength was proposed. The measurement method was corresponded to the LC alignment with high pre-tilt angle. And, the measurement was carried out. The azimuthal anchoring strength dependency on the pre-tilt angle was evaluated. The azimuthal anchoring energy was obtained in the range from 10^{-4} to 10^{-5} J/m^2 depending on the pre-tilt angle.

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