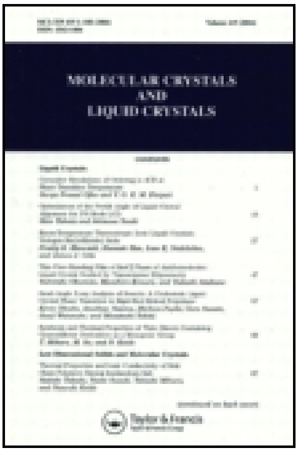

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Measurements of the Azimuthal Anchoring Energy of a Nematic Liquid Crystal (5CB) Aligned on As-Stacked Polyimide Langmuir-Blodgett Films

A. Ishizaki [a b] , H. Abe [a] , N. Ando [a] , Y. Iimura [a] & S. Kobayashi [a]
[a] Division of Electronic and Information Engineering, Faculty of Technology, Tokyo University of Agriculture and Technology, 2-24-16 Naka-machi, Koganei-shi, Tokyo, 184, Japan
[b] Control and Power System Works, Mitsubishi Electric corporation, 1-1-2 Wadasaki, Hyougo-ku, Kohbe-shi, Hyougo, 652, Japan
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Measurements of the Azimuthal Anchoring Energy of a Nematic Liquid Crystal (5CB) Aligned on As-Stacked Polyimide Langmuir–Blodgett Films

A. ISHIZAKI*, H. ABE, N. ANDO, Y. IIMURA and S. KOBAYASHI

Division of Electronic and Information Engineering, Faculty of Technology, Tokyo University of Agriculture and Technology, 2-24-16 Naka-machi, Koganei-shi, Tokyo 184, Japan

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We have proposed a new optical method for measuring the twist angle of twisted nematic cells. The method is applied to estimate the azimuthal anchoring energy of a nematic liquid crystal 5CB aligned on the as-stacked polyimide Langmuir–Blodgett (PI-LB) films. The measured values of the anchoring energies are shown to range from 2×10^{-6} J/m^2 to 1×10^{-5} J/m^2, which depend on the LB deposition conditions and show the optimum condition for the deposition. The values of the azimuthal anchoring energy are known to be one or two orders of magnitude lower than the corresponding polar anchoring energy.

Keywords: Liquid crystal, azimuthal anchoring, polyimide, Langumuir–Blodgett film, one side rubbing cell.

1. INTRODUCTION

The alignment of liquid crystals (LCs) on polymer substrates has become an attractive subject due to its practical importance and physical interest. There are two senses in considering the anchoring of LCs on the polymer substrates; one is the polar anchoring or out-of-polar anchoring, and the other is the azimuthal (torsional) or in-plane anchoring. The polar anchoring defines the out-of-plane motion of LC molecules from the substrate and is important for considering an adhesion and a pretilt angle formation. On the other hand, the azimuthal anchoring restricts the in-plane motion of LC molecules on the substrate and becomes significant in the presence of in-plane anisotropies (optically or topographically) in the substrate.

Until now, much effort has been made to study the polar anchoring properties but few studies on the azimuthal anchoring properties were presented in spite of their importance from the practical and physical points of view.[1] Regarding the measuring methods for the azimuthal anchoring energy several methods have been proposed and

* Present address: Control and Power System Works, Mitsubishi Electric corporation, 1-1-2 Wadasaki, Hyougo-ku, Kohbe-shi, Hyougo 652, Japan.

demonstrated by several researchers: Faetti et al. used a mechanical torsional balance;[2] Ohide et al. applied magnetic fields to sandwich LC cells to give a twist deformation of nematic liquid crystal (NLC) media and measured the optical transmission.[3] This method was applied to investigate the effect of the alkyl branches attached to rubbed polyimide by Sugiyama et al.;[4] Uchida et al. used the cano's wedge method and measured the twist angle at the point near the first disclination line.[5]

In this paper, we describe a new method to measure the twist angle of TN-LC cells with fairly good accuracy and its application to estimate the azimuthal anchoring energy E^{φ} at LC/polymer interfaces. Polymer films used in this research were polyimide LB films. Through this research the optimum condition of the LB film deposition is clarified.

2. EXPERIMENTAL

2.1. Sample Preparation

Sample cells were the sandwich type, which consisted of two ITO-coated glass plates where the inner sides were covered with polyimide (PI) alignment films, where the both PI films were Langmuir–Blodgett (LB) films and one of the films was strongly rubbed. The cells were assembled to form a TN configuration where the two easy axes were chosen to make 85°. The sample is referred to as a one-side rubbing (OSR) cell. The NLC of 5CB was injected into a cell about 10 μm thick. The method and conditions of the deposition of the PI-LB films were similar to those described in a previous paper;[6] that is, the deposition was performed at the surface-pressures of 5 ~ 35 mN/m at 15°C, where the insertion and withdrawal rates for a glass substrate were kept at a constant rate of 13.6 mm/min. The azimuthal anchoring energy of 5CB on the PI-LB film was measured with the instrument described in the next subsection. The measurements were carried out on the samples which were kept at a temperature of 5°C below the clearing point (~35°C).

2.2. A Measurement System for a Twist Angle

Figure 1 shows the measurement system developed by the authors for obtaining the twist angle of an LC cell.[7] A He-Ne laser beam passing through a polarizer incidents upon a photoelastic modulator (PEM) with a modulation frequency of 50 kHz. The optical retardation of the PEM is expressed as $\Delta m \cdot \cos(2\pi f t)$. The laser beam passing through the PEM then normally incidents upon an LC cell. The intensity of the transmitted laser beam is detected by a photodiode after passing through a rotatable analyzer. In addition to the fundamental component (f), the detected signal $V(\theta)$ contains DC and higher harmonic components of the PEM modulation frequency f and is represented as

$$V(\theta) = V_{DC}(\theta) + V_{1f}(\theta)\cos(2\pi f t) - V_{2f}(\theta)\cos(4\pi f t) + \dots \quad (1)$$

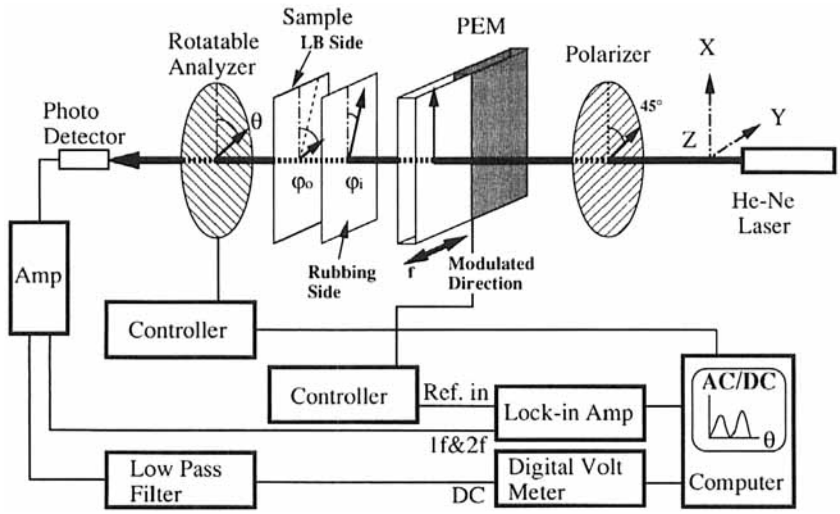

FIGURE 1 An experimental setup for measuring the twist angle of LC cells.

Therefore, by using a digital voltmeter and a lock-in amplifier, the voltage components of V_{DC}, V_{1f} and V_{2f} are separately obtained. These components are then fed into a computer, and the values of V_{1f}/V_{DC} and V_{2f}/V_{DC} are plotted as a function of the polarization director (θ) of the rotatable analyzer with respect to the X-axis.

3. THEORETICAL CONSIDERATION

3.1. Optical transmission of a TN cell

The transmitted laser beam intensity in the system shown in Figure 1 can be calculated using the Jones matrix representation. Assuming a negligible pretilt angle of the TN cell, the transmitted laser intensities for the $1f$- and $2f$-components are given as

$$\frac{V_{1f}}{V_{DC}} = \frac{2J_1(\Delta m)k_a}{\alpha}\sin(2\alpha)\left[\sin\{2(\varphi_0-\theta)\} - \frac{\Delta\varphi}{\alpha}\tan(\alpha)\cdot\cos\{2(\varphi_o-\theta)\}\right], \tag{2}$$

$$\frac{V_{2f}}{V_{DC}} = \frac{2J_2(\Delta m)}{\alpha^2}\Big[\alpha^2\cos(2\alpha)\sin\{2(\Delta\varphi-\theta)\}$$

$$-\alpha\cdot\Delta\varphi\cdot\sin(2\alpha)\cdot\cos\{2(\Delta\varphi-\theta)\} - 2\cdot k_a^2\cdot\sin(2\varphi_i)\sin^2(\alpha)\cdot\cos\{2(\varphi_0-\theta)\Big], \tag{3}$$

where $J_1(\Delta m)$ and $J_2(\Delta m)$ are 1st- and 2nd-order Bessel functions, respectively. φ_i is the angle of the LC director at the entrance surface of the LC cell with respect to the X-axis. $\Delta\varphi$ is the actual twist angle, and φ_0 is $\varphi_i + \Delta\varphi$. α is defined as $\alpha = \sqrt{(k_a^2 + \Delta\varphi^2)}$, where

$k_a = \pi(n_e - n_o)d/\lambda$ with the cell thickness d and the optical birefringence $\Delta n = n_e - n_o$. Normalizing the V_{1f} and V_{2f} signals with V_{DC}, any influences of the incident laser intensity fluctuation on the measured signals can be eliminated. It is clear from Eqs. (2) and (3) that the unknown parameters are φ_i, $\Delta\varphi$ and Δnd. Therefore, using the least-squares fitting procedure (θ is a variable) for the $1f$- and $2f$-components, and the best solution of (φ_i, $\Delta\varphi$, Δnd) is determined.

3.2. A Relation of the Twist Angle and the Azimuthal Anchoring Energy

The azimuthal anchoring energy of a TN cell is deduced by measuring the actual twist angle of the cell. Figure 2 shows the spatial variation of the azimuthal angle of the director in a one-side rubbing cell, in which we assume strong anchoring at the LC/rubbed PI interface and weak anchoring at the LC/PI-LB interface. It is considered that the actual twist angle $\Delta\varphi$ of the TN cell deviates from the intended twist angle Φ (in our case: 85°), because of the weak anchorage at the LC/PI-LB interface. Taking the linear variation of the azimuthal angle of the director (the solid line) into account, the extrapolation length at the LC/PI-LB interface d_e is calculated with an assumption of the negligible extrapolation length at the LC/rubbed PI interface as

$$d_e = \frac{(\Phi - \Delta\varphi)d}{\Delta\varphi} \tag{4}$$

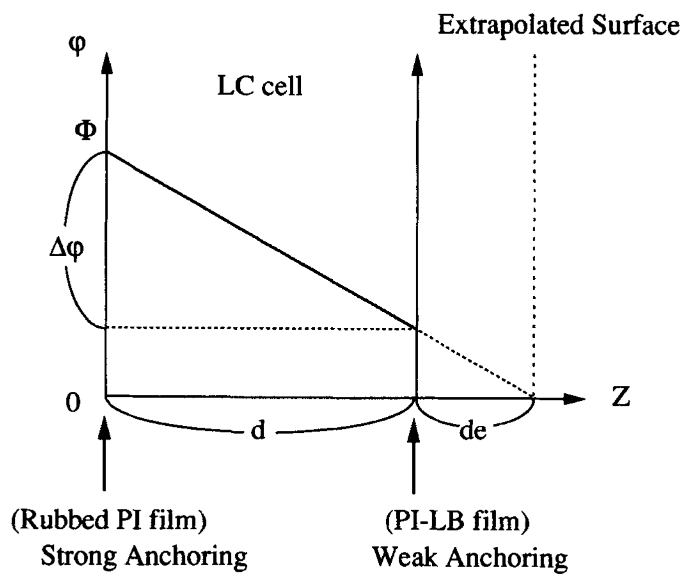

FIGURE 2 A spatial variation of the azimuthal angle of the director in a one-side rubbing cell.

Considering a torque balance equation at the LC/PI-LB interface, the following relation is obtained

$$E_\varphi = \frac{2K_2\cdot(\Phi - \Delta\varphi)}{d_e\cdot\sin\{2(\Phi - \Delta\varphi)\}}, \tag{5}$$

where K_2 is a twist elastic constant of a LC material, and E_φ is the azimuthal anchoring energy. Therefore, by measuring the twist angle of the one-side rubbing cell, the azimuthal anchoring energy at the LC/PI-LB interface can be estimated using Eq. (5).

4. RESULTS AND DISCUSSION

In Figure 3, a typical example of measured results of transmitted laser intensities for normalized $1f$- and $2f$-components is shown as a function of the rotation angle θ of the analyzer. The open circles indicate the experimental results for $1f$- and $2f$-components, and the solid lines are the theoretically best fitted curves using the normalized equations of (2) and (3). The measurement is carried out using a one-side rubbing cell with a PI-LB film, the cell is constructed so that the intended twist angle becomes 85°. As expected, the fitting is pretty good and the obtained twist angle is 80°, corresponding to the extrapolation length of ~600 nm.

The results of the measurement on the one-side rubbing cells provide us with the LC alignment capability of the PI-LB films and the optimum condition of the LB deposition. The results are shown in Figure 4 as a function of the surface-pressure during the insertion period of the LB deposition. As can be seen in the figure, the

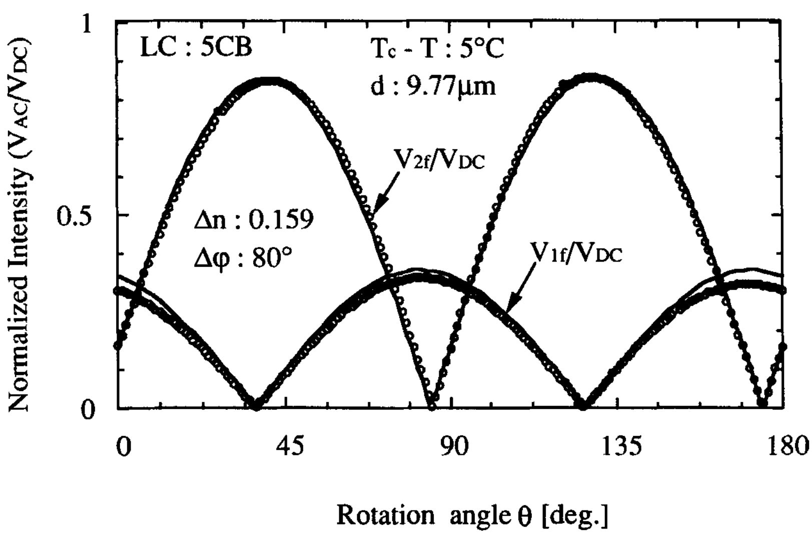

FIGURE 3 Experimental results of normalized transmitted intensities for $1f$- and $2f$-components. Solid lines are theoretically fitted curves.

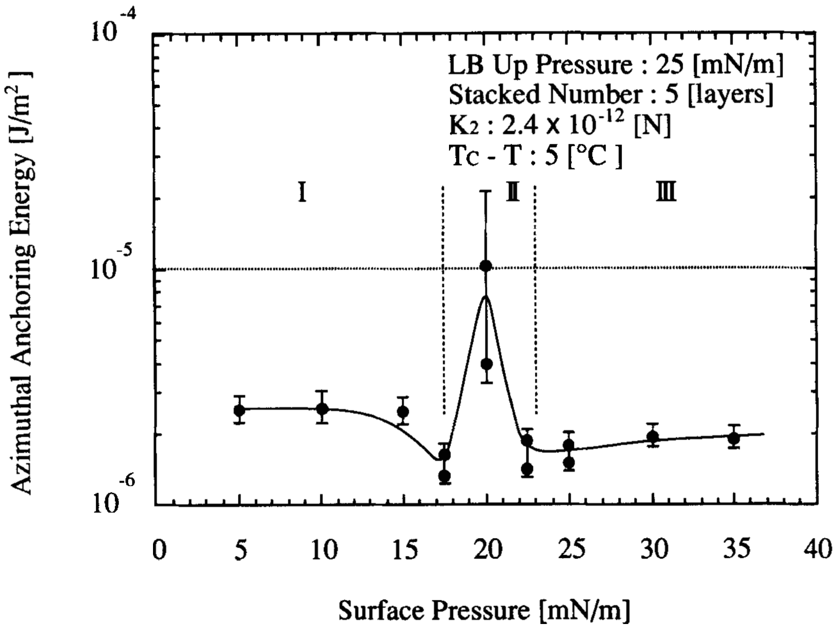

FIGURE 4 The azimuthal anchoring energy of 5CB aligned on PI-LB alignment films. The data are plotted as a function of the surface pressure during the insertion period in the LB deposition.

azimuthal anchoring energies are almost constant at about 2×10^{-6} J/m^2 except for the surface pressure region around 20 mN/m. This rather abrupt increase in the azimuthal anchoring energy suggests that the surface morphology of the monomolecular layer of PI on the water undergoes a considerable change in this region. One possible explanation for this phenomenon is as follows; we divide the surface pressure range into three regions as indicated by I, II and III in Figure 5. In region I, many monomolecular domains may be formed on the water as depicted in Figure 5 (a). As the surface pressure increases upto about 20 mN/m (region II), these domains join each other and a dense monomolecular LB layer may be formed (Figure 5(b)). A further increase in the surface pressure (region III) induces the layer stress resulting in the

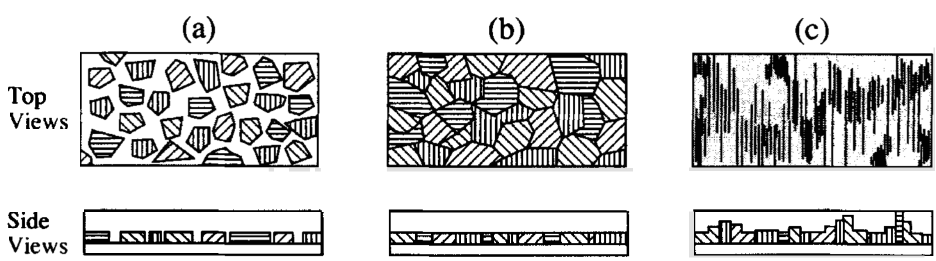

FIGURE 5 The top and side views of surface states of the PI-LB layer spread on the water at various surface pressures.

degradation of the layer flatness as shown in Figure 5 (c). Therefore, the quality (uniformity) of the deposited LB film on a glass substrate may be better in region II than in other regions, leading to the larger azimuthal anchoring energy in the region II. This model for the surface morphology is partially supported by the texture observation of the aligned phase of NLC. To confirm the validity of this understanding a direct observation of the surface state of the LB film on the water is now underway, and the result will be published elsewhere.

5. CONCLUSION

We presented a new optical method to measure the twist angle of TN cells, and the method was applied to deduce the azimuthal anchoring energy for 5CB aligned on the PI-LB alignment film that provides a weak anchoring. The result indicated that the surface state of the PI monomolecular layer spread on the water showed a critical change at around the surface pressure of 20 mN/m. The obtained anchoring energies ranged from 2×10^{-6} to 1×10^{-5} J/m^2, which were about one or two orders of magnitude lower than the corresponding polar anchoring energy.[8]

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