Basic Principle for Determining Azimuthal Anchoring Strength by using HAN/TN Two Domain Liquid Crystal Cell

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Abstract

We propose a novel technique for evaluating the azimuthal anchoring strength of the alignment film on the nematic liquid crystal (LC). In our evaluation, a unique cell, which has two domain in one cell, was used; one is hybrid aligned nematic (HAN) region, the other is twsited nematic (TN) region (viz. HAN/TN two domain cell). From the comparison of director angles on the front substrate with each region, we are able to determine the angle between easy axis and real director axis on the front substrate. From this evaluation, the azimuthal anchoring strength was obtained accurately.

1 Introduction

The determination of the surface anchoring strength is an important subject for liquid crystal displays (LCDs). Torque balance method[1] is well known as an evaluation of the azimuthal anchoring strength. This method has such a benefit that applying electric or magnetic field, is not required, while precise twist angle between lower and upper director and precise angle between upper and lower rubbing axes(≈easy axis) should be known.

Saitoh and Lien proposed an improved method using liquid crystals with different chiralities[2]. There are such benefits such an avoiding the cell assemble errors. On the other hand, we should know the exact pith of the LC. Therefore, in order to overcome this weak point, we propose the novel method by using HAN/TN two domain cell method. We also apply a novel technique which has a potential to determine the director profile by using a plural incidence angle spectroscopic fitting (PISF) method with renormalized transmission ellipsometry[3]. Based on this technique, we evaluated the surface azimuthal anchoring strength precisely.

2 Evaluation of the Azimuthal Anchoring Strength

Figure 1 shows the schematic model of the LC cell and the optical path for the transmission ellipsometry, and its Cartesian local coordinate system. The angle between the projection of $\vec{n}_{\mathrm{upper}}$ and $\vec{n}_{\mathrm{lower}}$ onto the $x-y$ plane is called 'twist angle,' and here we denote as $\phi_{[0]}$. The angle between $\vec{n}_{\mathrm{upper}}$ and the axis of the polarizer is defined by ϕ_{i}. The anchoring energy shows how much energy one has to spend to deviate the director from the easy direction. Conventionally, the azimuthal anchoring energy W_ϕ is expressed:

$$W_\phi = 1/2 A_\phi \sin^2(\Delta\phi_0), \quad (1)$$
$$2\Delta\phi_0 = \phi_0 - \phi_{[0]},$$

where A_ϕ means an anchoring strength coefficient, $\phi_{[0]}$ means the azimuthal angle of the director, ϕ_0 means the rubbing angle between lower and upper substrates.

Equation (2) denotes the calculation formula of azimuthal anchoring strength,

$$A_\phi = \frac{2\pi K_{22}\phi_{[0]}}{d\sin(2\Delta\phi_0)}. \quad (2)$$

In this method, we should know the precise angle between upper and lower rubbing (≈easy) axes. However, because cell fabrication error exists, it is difficult to know the precise easy axis angle between two surfaces. Therefore, HAN/TN two domain cell was used. In the HAN region, the director at the planar surface align along the easy axis because there are no torsional torque, while the director in the TN region depends on the surface azimuthal anchoring strength. In comparison with director angle at the planar surface of each HAN and TN region, we can obtain deviation angle $\Delta\phi_{0(\mathsf{TN})} = \phi_{\mathsf{i(TN)}} - \phi_{\mathsf{i(HAN)}}$.

3 Optical Calculation

From optical viewpoints, constituents such as glass substrates are not negligible. That is, J_{SM} of the LCD cell represents the laminate of glass substrates and LC substance layer, which can be expressed as follows,

$$\mathsf{J}_{\mathsf{SM}} = \mathsf{J}^{glass-air}_{\mathsf{glass}} \cdot \mathsf{J}_{\mathsf{LC}} \cdot \mathsf{J}^{air-glass}_{\mathsf{glass}}, \quad (3)$$

where J_{LC} is the Jones matrix of the LC substance layer, $\mathsf{J}_{\mathsf{glass}}$ is the Jones matrix of the glass substrate.

First, J_{LC} is calculated by Berreman's 4 × 4 matrix method or the Jones matrix method properly. Second, J_{SM} is obtained using eq. (3). Then substituting the transmission coefficients of J_{SM} into following equation;

$$\begin{cases} \rho_{\mathsf{p}} \equiv \rho_{\mathsf{pp}} + \rho_{\mathsf{sp}} \\ \rho_{\mathsf{s}} \equiv \rho_{\mathsf{ps}} + \rho_{\mathsf{ss}} \end{cases}, \quad (4)$$

where, ρ_{p} (or ρ_{s}) means the amplitude of total emergent electromagnetic plane waves by the p-polarized (or s-polarized) incident light proceeding into the subject. Simulated Δ and Ψ are calculated using,

$$\begin{cases} \Delta = \Delta_{\mathsf{p}} - \Delta_{\mathsf{s}} = \arg(\frac{\rho_{\mathsf{p}}}{\rho_{\mathsf{s}}}), \\ \Psi = \tan^{-1}(\frac{|\rho_{\mathsf{p}}|}{|\rho_{\mathsf{s}}|}). \end{cases} \quad (5)$$

4 Experimental

A sandwich-typed cell was filled with the nematic LC substance. The glass substrate was an indium tin oxide (ITO) coated glass. Both substrates were treated with the polyimide film PI-1(Chisso Petrochemical Co.), which was baked at 220°C for 1 hour.

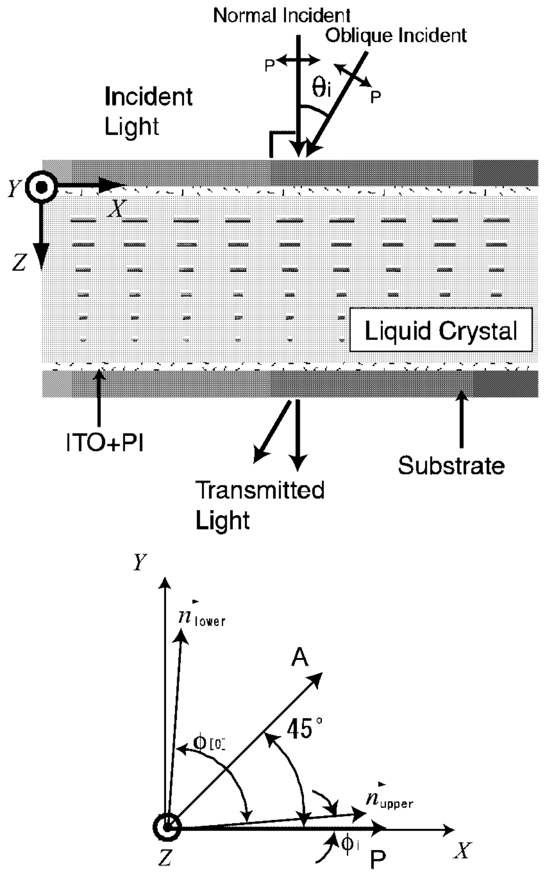


Figure 1: Schematic model of the LCD cell and its Cartesian local coordinate system.

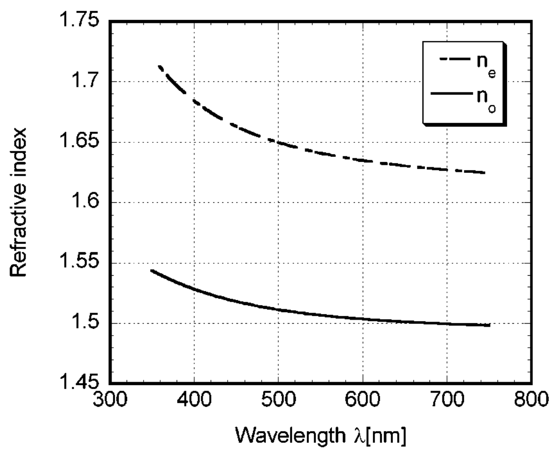


Figure 2: Refractive indices of nematic liquid crystal ZLI-2293(Meck).

The nematic liquid crystal substance used in this experiment was ZLI-2293 (Merck) where clearing temperature is 85.0°C. $n_e(\lambda)$ and $n_o(\lambda)$ of ZLI-2293 shown in Fig. 2 were evaluated by using RTE[3]. The elastic constants of ZLI-2293, $K_{11} = 12.5 \times 10^{-12}$ [N], $K_{22} = 7.3 \times 10^{-12}$ [N], $K_{33} = 17.9 \times 10^{-12}$ [N], were used. In our experiments $\Delta(\lambda)$ and $\Psi(\lambda)$ were measured by the polarization modulated spectroscopic ellipsometer (PMSE) (M-150, JASCO., Co.) equipped with a photoelastic modulator.

In order to apply RTE to the HAN and TN cell, two stages measurement is effective for determining these LCD parameters: stage one is RTE with normal incidence, stage two is RTE with oblique incidence. From the experimentally measured ellipsometric parameters with normal and obliquely incidence $\Delta^{\text{normal}}_{\text{exp}}(\lambda)$, $\Delta^{\text{oblique}}_{\text{exp}}(\lambda)$, $\Psi^{\text{normal}}_{\text{exp}}(\lambda)$ and $\Psi^{\text{oblique}}_{\text{exp}}(\lambda)$, d, θ_p, ϕ_t and ϕ_i can be determined by the numerical fitting procedure.

Minimizing the square errors between the calculated and the experimentally measured values of parameters , the appropriate values of d, θ_p, ϕ_t and ϕ_i are obtained simultaneously.

Wavelengths λ were ranging from 350 nm to 750 nm. Incident angle θ_i is 0° for normal incidence and 10°(HAN) or 30°(TN) for oblique incidence. Measurements were carried out at 25°C.

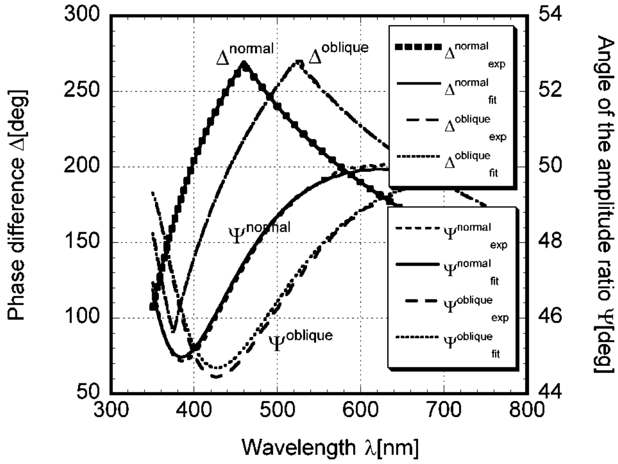
5 Results and Discussion

Figure 3(a) and (b) show the experimental results of $\Delta(\lambda)$ and $\Psi(\lambda)$ for the HAN and TN region, measured by normal and oblique incidence. Obtained fitting results were listed in Table 1.

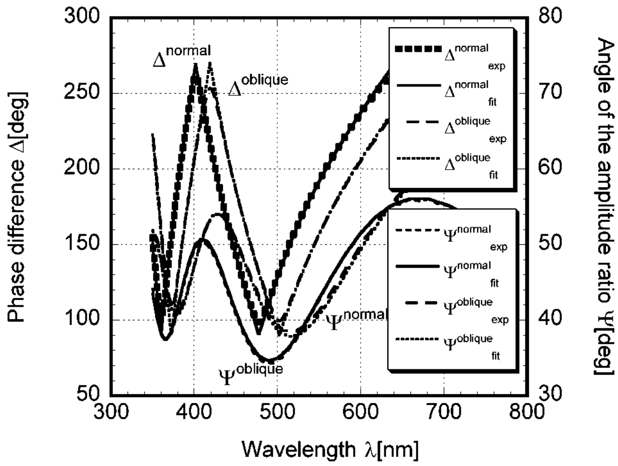
Table 1: Fitting results by using our method.

gap $d[\mu\text{m}]$	pretilt $\theta_{[0]}$ [deg.]	twist $\phi_{[0]}$ [deg.]	rotation ϕ_i [deg.]
(HAN)5.88	8.88	0.00	2.48
(TN)5.85	9.58	88.59	2.84

The outline of $\Delta(\lambda)$ mainly depends on d, $\theta_{[0]}$ and $\phi_{[0]}$. The outline of $\Psi(\lambda)$ curve consists of long periodic surges and short periodic ripples. Long periodic surges were generated by the interference be-



(a) HAN region.



(b) TN region.

Figure 3: Fitting of the theoretically calculated results with the experimental results of $\Delta(\lambda)$ and $\Psi(\lambda)$ of a HAN and TN cell of normal and oblique incidence.

tween the ordinary and extraordinary rays, therefore the outline of the surges depends on $\phi_{[0]}$ and ϕ_{i}. Short periodic ripples were generated by multiple interference in the LC cell which resulted from the difference in refractive index between the LC substance and the ITO, the alignment film and the glass substrate.

The numerical fitting are also depicted. A good agreement between the experimental and numerical results was also obtained. From the results, deviation angle $\Delta\phi_0$ was equal to 0.36[deg.]. By using this results, A_ϕ was determined by eq. (2). Obtained A_ϕ was 3.07×10^{-4}[J/m^2].

6 Conclusions

The azimuthal anchoring strength of the alignment film of the LC was evaluated by using the HAN/TN two domain LC cell. In the case of torque balance method with conventional cell, rubbing axis was assumed to be 90[deg.]. However, this assumed factor causes evaluation error. Therefore, applying the PISF-RTE with two domain cell, we proposed one solution of this problem. Our results suggest that this is a powerful tool to improve new LCDs.

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