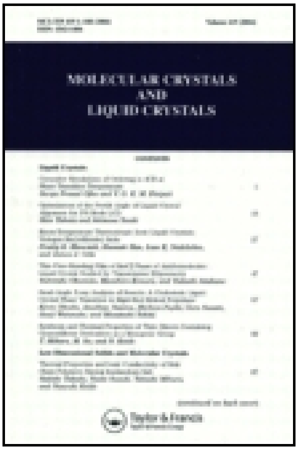

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Analysis of Electrical Response of Nematic Liquid Crystal by Ellipsometry

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The electrical responses of the LC directors at the bulk and near the surface were investigated by the transmission and the total reflection ellipsometries, respectively. The dynamic response of the Δ on the electric field was measured by the transmission ellipsometry. The optical bounce of Δ was observed as soon as the high voltage was removed from the LC cell. This bounce is caused by the flow effect in the LC. Since the static response of Δ on the electric field measured by the total reflection ellipsometry depended on the interfacial LC director reorientation, the polar anchoring strength of the LC cell was evaluated quantitatively.

Keywords: ellipsometry; interface; total reflection; flow effect; anchoring strength

Introduction

The ellipsometry can be generally defined as the measurement of the polarization state of a polarized vector wave and is conducted in order to obtain the information about the optical system that modifies the polarization state. The liquid crystal (LC) has a birefringence so that the polarization states of the waves transmitted and reflected from an LC are also modified. The ellipsometry is one of the most suitable methods for the investigation of an LC[1]–[7]. In this paper, the transmission and total reflection ellipsometries are utilized to understand the LC director reorientation. The former, analyzing the polarization state of the wave transmitted the LC layer, is applied to investigate the LC director reorientation at the bulk of an LC layer. The later is one of the reflection ellipsometries, which is proposed to investigate the LC director reorientation at the interface between the alignment film and an LC layer[5],[6].

Principle of Ellipsometry

When the two modes (one is the p-polarized light whose electric field vector is parallel to the plane of incidence, the other is s-polarized light whose electric field vector is perpendicular to it) are incident on the LC cell, their emergent modes are modified mainly due to the birefrigence of an LC. Then, the polarization state, the phase and the amplitude of p-polarized emergent waves are usually different from those of s-polarized emergent waves. The ellipsometry allows us to evaluate the changes between the polarization states of two emergent waves as the phase difference Δ and the angle of amplitude ratio Ψ. The analysis of Δ and Ψ give us the information about the LC director reorientation. The electrical response of the director reorientation at the bulk of an LC layer and near the interface between the alignment film and an LC layer is measured by transmission and total reflection ellipsometries, respectively. The cell configurations for these ellipsometries and the schematic diagram of the traveling waves are shown in Fig. 1.

In the transmission ellipsometry, the polarized light is incident normally on the LC cell. Then, the polarization states of the transmitted light is dominantly changed by the director reorientation at the bulk of an LC. In this case, the information about the interfacial director reorientation which is restrained by the substrate is almost hidden

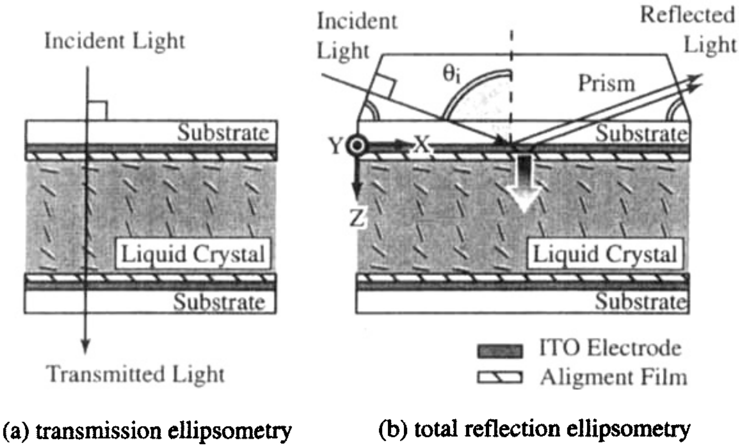

Figure 1: Cell configurations for ellipsometry and schematic diagram of traveling wave. The prism consists of the same glass as the substrate whose refractive index is higher than that of an LC.

under that about the director reorientation at the bulk. It is difficult to analyze the interfacial director reorientation by the transmission ellipsometry.

To analyze the interfacial director reorientation, the total reflection ellipsometry is utilized[5],[6]. The light reflected from the sandwiched LC cell usually contains the reflection component from the front interface (interface between an LC layer and the substrate of incidence) and that from the rear interface (interface between an LC layer and the substrate of emergence). The former component only depends on the LC director reorientation near the front interface. The latter one depends not only on the director reorientation near the rear interface but also the director reorientation at the bulk of an LC. Because of this, the latter component had gone through the LC layer two times and been modified by the bulk of an LC. To get the information about the interfacial director reorientation with a high sensitivity, the latter component should be removed from all of reflection components. The LC cell configuration and the schematic diagram of the traveling wave is shown in Fig. 1 (b). In Fig. 1 (b), a trapezoid prism and the glass substrate have same refractive index which is higher than that of an LC. The light is incident normally on the prism so that the incident angle θ_i is the same as the base angle of the trapezoid prism. When the incident light is totally reflected at interface between an LC layer and the front substrate, the light penetrated into the LC layer attenuates and dose not reach to the rear interface. The light reflected from the cell is, then, dominantly modified by the LC director reorientation near the front interface. The analysis of this light by the ellipsometry gives us the information about the interfacial LC director reorientation. We call this method the total reflection ellipsometry.

Experiments

The glass substrate and the trapezoid prism used were SFL6-FD60 (HOYA Co.), whose refractive indices are 1.80 at 632.8 nm. The trapezoid prism had a 75° base angle. The surface of a glass substrate had been coated with the indium tin oxide (ITO) film. The surfaces of the substrates were coated with polyimid films (PSIA-2001 : Chisso Co.), and then unidirectionally rubbed. The anti parallel cell, ECB cell, was fabricated with two treated substrates and filled with 4-cyano-4'-pentyl biphenyl (5CB). The thickness of the LC layer was 5 μm. For the total reflection ellipsometry, the prism was attached to the substrate of incidence by a matching oil which had also the same refractive index as a high index glass. The measurements were performed by a polarization modulated ellipsometor ,PMSE M-150 (JASCO Co.), which has the high resolution of time as 20 μsec. The light source was a He-Ne laser (632.8 nm).

The ellipsometric angles of the LC cell are theoretically simulated as follows. The change of the LC director distribution to electric field is calculated, which is based on the continuum theory. Then, the complex transmission coefficients or complex reflection coefficients of the LC cell ρs are calculated with the LC director distribution by the Berreman's 4 × 4 matrix method, which is also taken the influence of the multiple reflection and the multiple interference in the ITO film and the alignment film into account[7]. Δ and Ψ are calculated by

$$\begin{cases} \Delta = \arg(\rho_p) - \arg(\rho_s) \\ \Psi = \tan^{-1}\left(\dfrac{|\rho_p|}{|\rho_s|}\right) \end{cases} . \tag{1}$$

where the subscripts indicate the p-polarized or s-polarized waves. The thickness and the refractive indices of their films had been measured by the reflection ellipsometry. The thickness of the ITO and alignment films were 130 nm and 65 nm, respectively. The refractive indices of the ITO and alignment films were 2.00 and 1.64 at 632.8 nm, respectively.

The material parameters of 5CB are shown Tab. 1, which are used in simulation.

Results and Discussion

Transmission and Total Reflection Ellipsometries

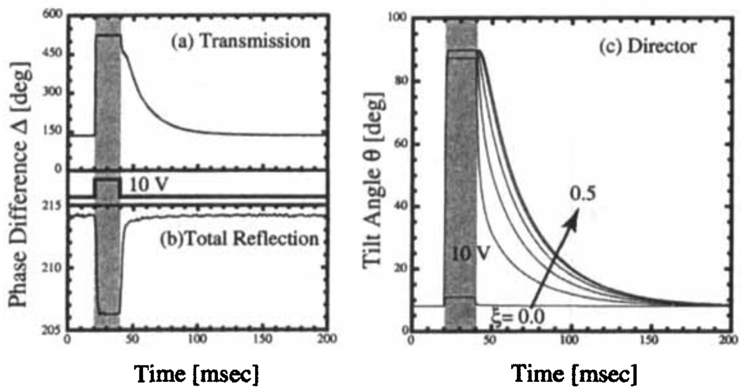

Figure 2: Electrical responses of the phase difference measured by (a) transmission and (b) total reflection ellipsometries and (c) electrical response of the directors at normalized positions.

The dynamic response of the phase difference to the electric field with 10 V was measured by transmission and total reflection ellipsometries, which are shown in Fig. 2 (a) and (b), respectively. The electrical response of the director was simulated, which is shown in Fig. 2 (c). In Fig. 2 (c), θ is the angle between the director and the plane of the substrate and ξ denotes the normalized position along the direction of the cell thickness (for example, the director at $\xi = 0$ corresponds to one at the interface between the alignment film and the LC layer). Δ measured by the transmission ellipsometry was slowly relaxed to the initial state (Δ at t=0) when the electric field was removed, whereas Δ measured by the total reflection ellipsometry is quickly recovered to the initial state. From Fig. 2 (c), the former is mainly modified by the director reorientation at the bulk of an LC and the later is dominantly modified by the interfacial director reorientation.

Evaluation of Polar Anchoring Strength

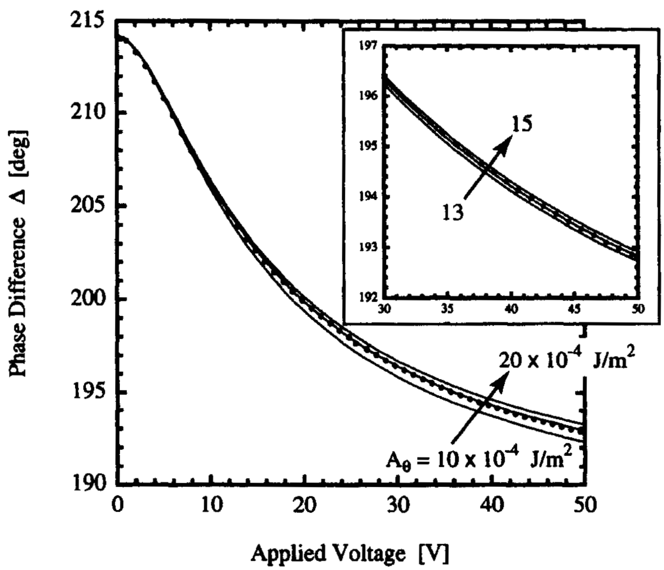

Figure 3: Estimation of the polar anchoring strength.

As the electrical response of Δ measured by the total reflection ellipsometry depends on the interfacial director reorientation, the analysis of Δ allows us to estimate the polar anchoring strength. The static response of Δ to the electric field was measured, which is shown in Fig. 3. The closed circles denote experimental results and lines are theoretical results for several polar anchoring strength. By fitting the theoretical curve to the experimental result, the polar anchoring strength of the LC cell was evaluated quantitatively. From experimental and theoretical results, the polar anchoring of the cell was 1.4×10^{-3} J/m^2. It was confirmed that the total reflection ellipsometry is sensitive enough to estimate the polar anchoring strength of the LC cell even if the polar anchoring strength is rather strong.

Dynamic response of Director to Electric Field

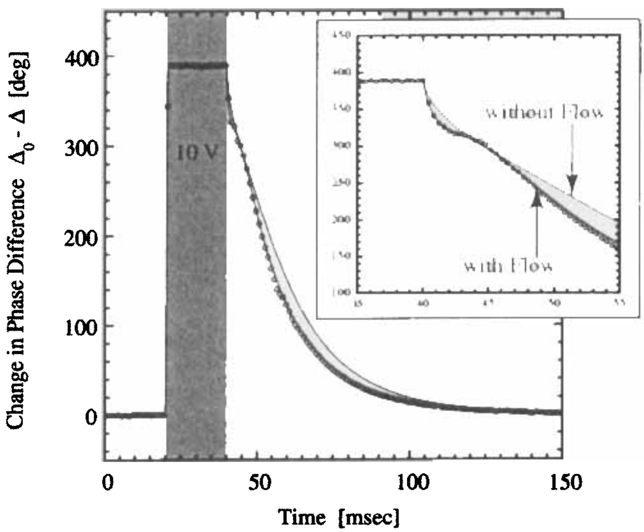

Figure 4: Dynamic response of Δ to electric field measured by the transmission ellipsometry.

The dynamic response of Δ to electric field measured by the transmission ellipsometry is shown in Fig 4. The small bounce of Δ is observed at t$\sim$ 44 msec after the electric field is removed. To understand the presence of the bounce, the theoretical simulation was performed by taking the flow property of an LC into account. The flow effect has been known in twisted nematic LC cell as 'back flow' but is conventionally neglected. The reason is that the bounce of the transmittance is too small to observe the flow effect for the ECB cell. From experimental and theoretical results, it was found that the bounce of Δ is caused by the flow effect of an LC. The presence of the flow effect in the ECB cell is experimentally confirmed by using the ellipsometor with high resolution of time as 20 μsec.

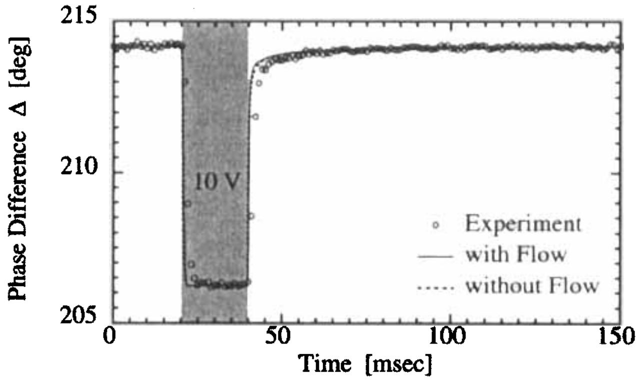

Figure 5: Dynamic response of Δ to electric field measured by the total reflection ellipsometry.

The dynamic response of Δ to electric field measured by the total reflection ellipsometry is shown in Fig 5. The bounce of Δ is not observed for the total reflection ellipsometry, which indicates that the flow effect is mainly occurred at the bulk of an LC. From theoretical simulations, the electrical response of Δ with flow effect is almost equal to that without flow effect for the total reflection Ellipsometry.

The director distributions for decay process is shown in Fig. 6, which were used in the theoretical simulations for Fig. 4 and 5. The simulation of the director distribution is performed under the polar anchoring strength is 1.4×10^{-3} J/m^2 and the pretilt angle is 8°. The directors for both of (a) and (b) at the mid-plane are normal to the substrate plane at t=0 (just before electric field is removed). In Fig. 6 (a), however, the director tilts more than 90° as soon the electric field is removed. This phenomenon is caused by the flow effect so that the bounce of Δ is appeared in Fig. 4.

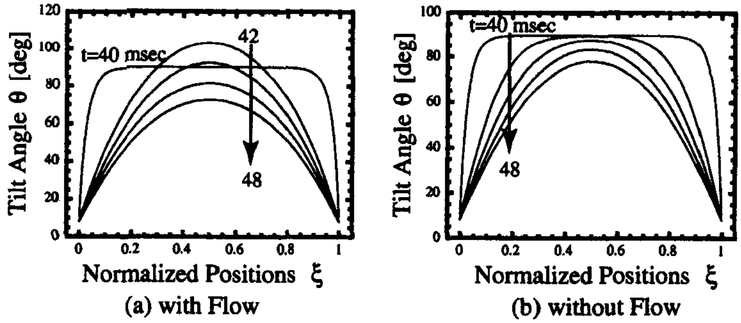

Figure 6: Director distribution for decay process.

Table 1: Material parameter of 5CB

K_{11}	6.37×10^{-12} N	n_e	1.7092	α_3	-3×10^{-3} Pa·s
K_{33}	8.60×10^{-12} N	n_o	1.5299	α_4	84×10^{-3} Pa·s
ε_1	17.9	α_1	-19×10^{-3} Pa·s	α_5	58×10^{-3} Pa·s
ε_1	6.9	α_2	-79×10^{-3} Pa·s	α_6	-36×10^{-3} Pa·s

*αs are Leslie's coefficients.

Conclusion

The electrical response of the LC director reorientation studied by transmission and total reflection ellipsometries.

As the total reflection ellipsometry allows us to observe the interfacial director reorientation, the polar anchoring strength of the ECB cell is evaluatedquantitativelyy. The analysis of the dynamic response of Δ to the electric field give us the information about the LC director reorientation. The presence of the flow effect in the ECB cell is experimentally confirmed by using the ellipsometor with high resolution of time as 20 μsec.

As a result, it was confirmed that these ellipsometries are one of the most useful methods to understand the LC director reorientation.

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