Evaluation of the Surface Anchoring Strength by Means of Renormalized Transmission Spectroscopic Ellipsometry

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Abstract

Evaluating methods of the polar and/or azimuthal anchoring strength coefficients by means of the renormalized transmission spectroscopic ellipsometry are demonstrated. The Anchoring strength coefficients can be evaluated from the measurement of ellipsometric parameters measured by the oblique incident transmission ellipsometry, where the effect of multiple-beam interference is eliminated. The device parameters such as the pretilt angle and cell gap can be determined simultaneously even in the case of the twisted nematic liquid crystal sample cells.

1. Introduction

Liquid Crystal Display (LCD) is exactly the device which makes use of the ability of optical polarization. Similar to the other dielectric media, evaluation of the state of polarization, so called ellipsometry, can be quite effective for analyzing the characteristics of LCD. The measurement of the surface anchoring strength coefficients is not outside of the coverage. Needless to say, the coefficients of the anchoring strength (polar anchoring strength A_θ and azimuthal anchoring strength A_ϕ) at the LC-wall interface are the basic parameters for LCD. Up to today, a number of the reports in regard to the measurement of the anchoring strength coefficient have been published, and the measurement technique has progressed year by year. 1980's, several types of evaluation technique of A_θ which is based on the measurement of optical retardation (R) of the LC cell have been proposed [1,2]. Fundamentally, when the subject A_θ is relatively strong, R should be measured accurately. Generally say, however, R measured by the experiment was not genuine R. Because, LCD is composed of glass substrates, transparent electrodes, alignment films and an LC layer, the experimentally measured value contains the optical effect of the multiple-beam interference (MBI). Akahane reported [3] that MBI may induce a serious error in the determination of A_θ. It was also pointed out that; to determine the anchoring strength accurately, it is necessary to preliminarily measure the physical parameters such as the thickness and refractive indices of transparent electrodes, alignment films, and then these parameters have to be taken into consideration in the numerical analysis of multilayer. The technique has been successfully realized and was reported as the total reflection ellipsometry for LCD [4]. However, the measurements of the optical constants of transparent electrodes and alignment films may cause practical complexity as well as experimental errors. Therefore, another technique of eliminating the effect of MBI is an interest in experiments.

Recently, an optical technique for eliminating the effect of MBI is developed by the detailed analysis of obliquely incident transmission ellipsometry [5]. The accurate measurement of the director distortion of a Nematic LC (NLC) without information on the refractive indices of transparent electrodes, alignment films and glass substrates results in the realization of A_θ with a high accuracy. Experimental results are demonstrated in this paper.

Up to today, many measurement methods of A_ϕ have also been proposed. Nowadays, torque balance method and the Néel wall method [6, 7] are very popular because of their simple principles. From some preliminary experiments, however, it was found that the azimuthal anchoring energy estimated by the torque balance method and/or the Néel wall method is sometimes one order of magnitude smaller than that obtained in the electro optical experiment. The fundamental problem is the deviation of the original easy axis from the direction of alignment treatment, after filling the NLC into the cell. To solve this problem, we proposed the improved torque balance method [8,9]. Furthermore, to use the torque balance method even for the high pretilt surface alignment film, plural incidence angle spectroscopic fitting (PISF) method with renormalized transmission ellipsometry was demonstrated [10]. Here we demonstrate the experimental results.

2. Offset of multiple-beam interference

When the refractive index of a thin film is different from that of the exterior refractive index, multiple-beam reflection and multiple-beam interference occur. Now let us consider the obliquely incident light toward an LCD, as shown in fig.1.

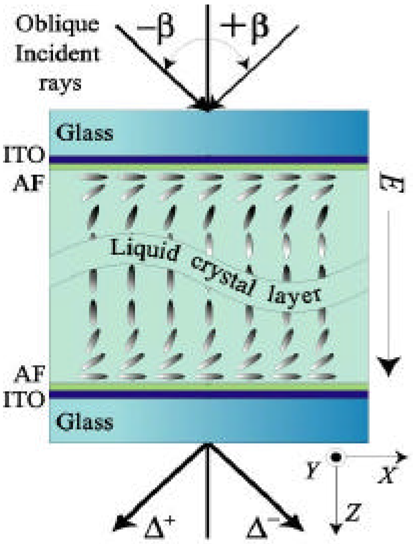

Figure 1 Schematics of LCD and incident and outgoing rays.

The phase difference between p-polarized and s-polarized light for +β and -β incidences are expressed as Δ^+ and Δ^-, respectively. Algebraically, Δ^+ and Δ^- can be expressed by the summation of the genuine retardation and the components of multiple-beam reflection, which is expressed as

$$\Delta^+ = R^+ + d^+, \qquad \Delta^- = R^- + d^-, \qquad (1)$$

where d^+ and d^- represent algebraically the phase difference caused by multiple-beam reflection. Here, it is theoretically proved that $d^+ = d^-$ [5]. This means that, from the continuum theory, A_θ can be estimated by

$$\Delta^- - \Delta^+ = R^- - R^+ = \frac{16p}{l}\frac{K_{11}\sin b}{A_q \sin 2(dq_0)}\sqrt{\frac{(1+k\sin^2 q_0)(\sin^2 q_m - \sin^2 q_0)}{1+g\sin^2 q_0}}$$
$$\times\int_{q_0}^{q_m}\frac{n\sin q\cos q}{1+n\sin^2 q}\sqrt{\frac{(1+k\sin^2 q)(1+g\sin^2 q)}{\sin^2 q_m - \sin^2 q}}dq \text{ , } (2)$$

where $k = (K_{33} - K_{11}) / K_{11}$, K_{11} and K_{33} are the spray and bend elastic constant, $\gamma = e_a / e_?$, $e_a = e_{\|} - e_?$, λ is the wavelength of the incident ray, d is the cell gap. θ_0 and θ_m are the angle between the director and xy plane at the surface and middle of the cell under the applied electric field, $\delta\theta_0 = \theta_0 - \theta_p$, θ_p is pretilt angle.

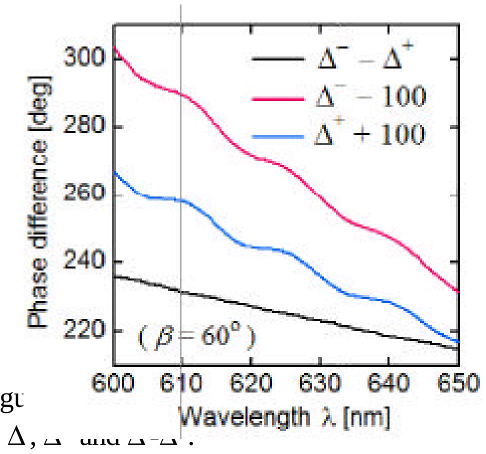

Fig nce of Δ, and Δ-Δ^+.

Figure 2 represent the experimental results of the dependence of Δ^-, Δ^+ and Δ^--Δ^+ on the wavelength for the antiparallel homogeneous NLC cell. The fringes appearing in the curves of Δ^- and Δ^+ show the effects of MBI due to transparent electrode (Indium Tin Oxide films), alignment films and NLC layer itself. The disappearance of the fringes in the Δ^--Δ^+ curve implies that the effects of MBI were eliminated.

Experimentally, A_θ can be estimated by

$$A_q = \frac{4K_{11}}{d\sin 2(dq_0)}\sqrt{\frac{(1+k\sin^2 q_0)(\sin^2 q_m - \sin^2 q_0)}{1+g\sin^2 q_0}}\int_{q_0}^{q_m}\sqrt{\frac{(1+k\sin^2 q)(1+g\sin^2 q)}{\sin^2 q_m - \sin^2 q}}dq$$

and (3)

$$V = 2\sqrt{\frac{K_{11}}{e_0 e_a}}\sqrt{1+g\sin^2 q_m}\int_{q_0}^{q_m}\sqrt{\frac{1+k\sin^2 q}{(1+g\sin^2 q)(\sin^2 q_m - \sin^2 q)}}dq \qquad (4)$$

Where V is applied voltage to the NLC cell. From the numerical procedure with polytope method, when the wavelength dispersion of the refractive indices of NLC are already known, A_θ, d and θ_p can be obtained.

3. Improved torque balance method

A_ϕ was measured by the conventional torque balance method [6] and the improved torque balance method [8]. In the case of the conventional torque balance method, A_ϕ can be calculated from the director' s twist angle of the TN cell;

$$A_f = \frac{2K_{22}\Phi_t}{d\sin 2\Delta\Phi}, \qquad (5)$$

where Φ_t is the actual twist angle of the director throughout the cell, $\Delta\Phi = (\Phi^0_t - \Phi_t)/2$, Φ^0_t is the angle between the rubbing direction of the substrates. For measurement by the improved torque balance method, the initial sample setup should be a homogeneous cell other than a TN cell. A spatially uniform planar cell was cooled below the Isotropic-Nematic transition temperature, allowing the molecules at the surface to align along the genuine easy axes. After three days, one substrate was rotated by 90° and the rotation angle of the liquid crystal was measured.

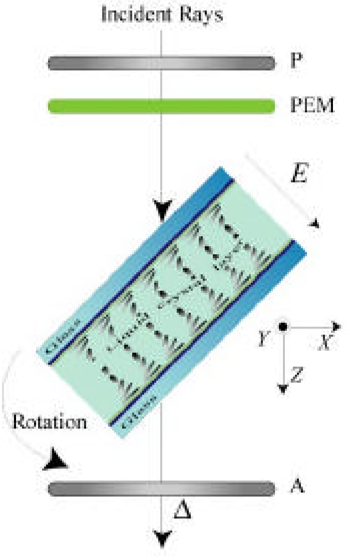

Figure 3 Optical path of the measurement system. P and A represent polarizer and analyzer. PEM is photo elastic modulator.

4. Measurement procedure

Figure 3 illustrates the optical path of the measurement system based on the transmission ellipsometry. When the wavelength dispersion of refractive indices of NLC is unknown, refractive indices are determined by renormalized transmission ellipsometry with homogeneously aligned NLC sample cell [11]. θ_p of the homogeneous NLC cell can be determined by the incident angle dependence of the ellipsometric parameters (the phase difference Δ and the angle of the amplitude ratio Ψ), where θ_p is calculated by numerical fitting procedure with polytope method. In order to estimate A_θ, Δ and Ψ under the applied voltage V are measured at a certain incident angle β and $-\beta$, then A_θ is calculated by polytope method.

A_ϕ is determined by a method based on the torque balance method combined with the renormalized transmission ellipsometry. A_ϕ, d and θ_p of TN cell can be determined by 4 x 4 matrix method combined with polytope method [10].

5. Results and discussion

Figure 4 shows the dependence of Δ^+ and Δ^- on applying electric field V, where incident angle β=45 degree and λ=480nm. The LC material used in this experiment was ZLI-2293 (Merck). The nominal d is 10 µm.

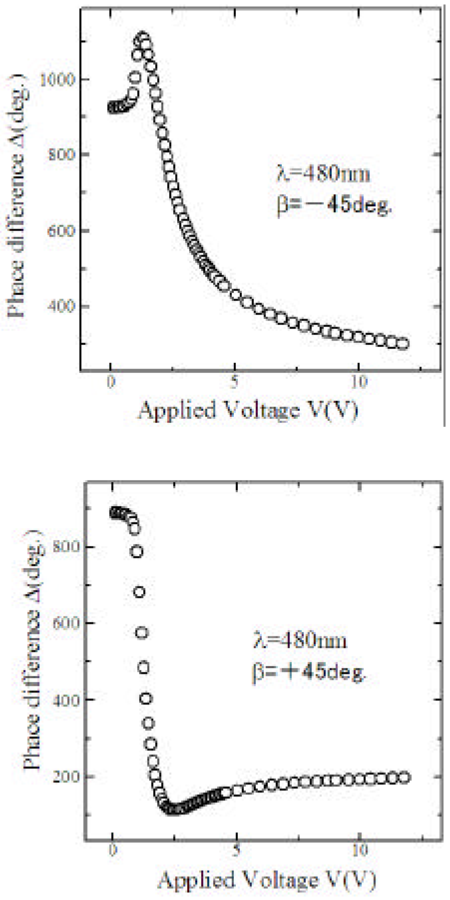

Figure 4 Experimental result of the dependence of Δ^+ and Δ^- on applying electric field V.

From fig.4, the dependence of Δ^{-}-Δ^{+} on applying electric field V is replotted in fig. 5, where the solid line is the numerical fitting. Minimizing the square errors between the calculated and the experimentally measured values of Δ^{-}-Δ^{+}, subject cell parameters d, θ_p and A_θ as well as the physical values κ and γ are obtained simultaneously. This method is, of course, applicable to the A_θ measurement of homeotropic alignment.

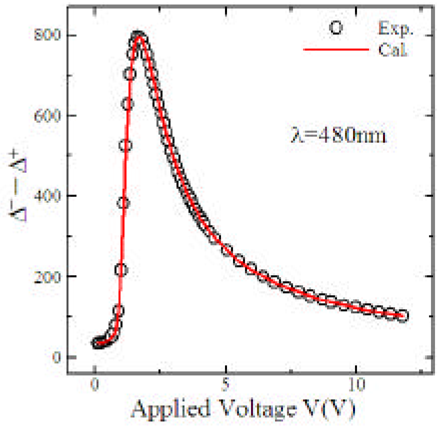

Figure 5 Experimental result of the dependence of Δ^{-}-Δ^{+} on applying electric field V.

6. Conclusion

From the numerical and experimental studies, it was found that cell parameters d, θ_p and A_θ as well as the physical values κ and γ of NLC can be determined simultaneously by the renormalized transmission ellipsometry.

Latest results in regard to the determination of A_ϕ by renormalized transmission ellipsometry will be presented by Mr. Norihiko Tanaka in poster session.

It is quite beneficial that, not only the surface anchoring coefficient but also the physical values of NLC can be determined with one general-purpose measuring instrument, ellipsometry.

7. Acknowledgement

The author appreciates Mr. H. Ichinose (Merck Ltd.) for providing us LCs, and Dr. Y. Hirano (Chisso petrochem.) for providing us polyimide materials. This work is partly supported by Grant-in-Aid (No.15760020) for Young Scientists (B) of Japan Society for the Promotion of Science and 21st century COE program "Creation of Hybridized Materials with Super-Functions and Formation of International Research and Education Center" from Ministry of Education, Culture, Sports and Technology, Japan.

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