Study on orientation distribution of discotic liquid crystal in compensating film for viewing angle improvement of liquid crystal displays

J. W. Ryu*, Y. S. Shin, Y. K. Kim[1], and S. Y. Kim
Dept. of Molecular Science & Technology, Ajou University, Suwon, Kyunggi, Republic of Korea
Samsung Advanced Technology Training Institute, Suwon, Kyunggi, Republic of Korea[1]

Phone: +82-31-219-2585, E-mail: jangwisi@ajou.ac.kr

Abstract
The discotic liquid crystal in compensating film used for the viewing angle improvement of the twist nematic liquid crystal display panel is analyzed. For the optical characterization of the compensating film, we measured the polarization state of the light passing through the film as the tilt angle and the azimuth angle of the film were varied, and then we compared the measured polarization state with the calculated one. Finally we suggested the best fit configuration of the discotic liquid crystal.

1. Objectives and Background
It is well known that the contrast ratio of the twisted nematic(TN) liquid crystal display (LCD) panel is not maintained high throughout the whole viewing angle, due to increased phase differences at wider viewing angles. To improve the viewing angle characteristics of TN LCD panels, the phase compensation method is used by using uniaxially compensating films or biaxially compensation films.[1] Since biaxial films compensate much more effectively than uniaxial films at wider viewing angles, biaxial films are preferred to uniaxial films. But biaxial films have problems of high manufacturing cost and limited capacity in mass production. In order to replace biaxial films, the technique of distributing discotic liquid crystals on a uniaxial substrate has been proposed. However the method to directly observe the orientation distribution of the discotic liquid crystal on a uniaxial substrate has not been reported yet. In the present report, we suggest a method to determine the orientation distribution of the discotic liquid crystal by analyzing the polarization state of the light passing through the compensating film.

2. Ellipsometry and ellipsometer

Ellipsometry is an optical technique to study optical properties of layered structures based on the control and measurement of the polarization state variation upon reflection from or transmission through a sample.[2] Ellipsometric constants are defined as the ratio of reflection coefficients or transmission coefficients for the perpendicular (s-wave) and the parallel (p-wave) components of the incident light($\tan\Psi e^{i\Delta} = r_p / r_s$ or $\tan\Psi e^{i\Delta} = t_p / t_s$), where Ψ refers the amplitude ratio of the reflection or transmission coefficients, and Δ refers the difference in phase change. A typical wide view film is made of layered discotic liquid crystals such that its optic axis is gradually varied from in-plane to out-of-plane. In order to figure out the nonuniform distribution of anisotropic liquid crystals in the wide view film, we used the transmission type ellipsometer and measured the polarization state variation at various incident angles and various azimuth angles of the wide view film. Figure 1 shows optical schematic of the ellipsometer(Ellipso Technology, Elli-Ret-V) operating at 550 nm. A detailed explanation of this ellipsometer can be found elsewhere.[2]

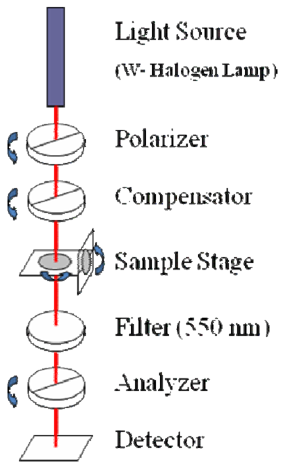


Figure 1. Transmission type rotating analyzer ellipsometer. All optical components can be rotated, and sample stage can be rotated and tilted.

In rotating analyzer ellipsometer, the measured Fourier coefficients (α, β), are related to the ellipsometric constants Ψ and Δ, as $\alpha = \frac{\tan^2\Psi - \tan^2 P}{\tan^2\Psi + \tan^2 P}$, $\beta = \frac{2\tan\Psi\cos\Delta\tan P}{\tan^2\Psi + \tan^2 P}$, where P is the azimuth angle of the polarizer.

3. Experiments and Results

In order to calculate the polarization state variation of the light passing through the compensating film, we choose the model that the liquid crystal has a multilayer structure where each layer is anisotropic but uniform and the optic axis varies its direction smoothly over adjacent layer. For the calculation of transmission coefficients at interfaces and propagation matrix of each layer, we used the extended Jones matrix method.[3]

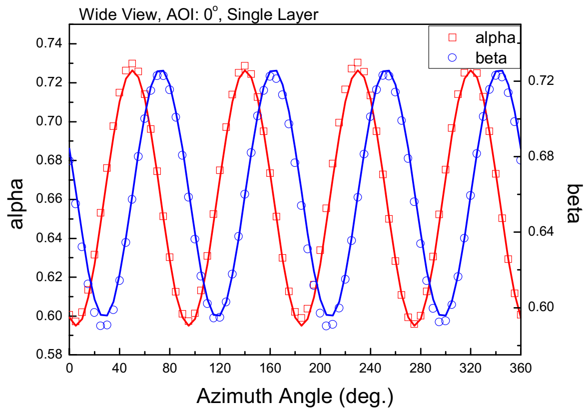


Figure 2. The measured and calculated α, β curves of wide view film vs azimuth angle.

Figure 2. shows the measured(symbols) and calculated(lines) Fourier constants, that is, (α, β) curves of wide view film as the azimuth angle is varied at normal incidence. The calculated curves are those of a single uniform anisotropic film whose optic axis is in the sample plane. From the excellent agreement between the measured data and the calculated ones, it can be said that the wide view film behaviors like an a-plate at normal incidence. However this optical model of a single a-plate does not reproduce the measured (α, β) curves at oblique angle of

incidence. A better fit to those (α, β) curves at oblique angle of incidence can be obtained by adopting a more elaborate optical model.

Table 1 shows the summarized results of the analysis of the data taken at the incident angle of 50º. In Table 1, MSE(Mean-Squared Error) represents the mean-square difference between the measured (α, β) pairs and the calculated (α, β) pairs, defined as $MSE = \left\{ \sum_{i=1}^{N} \left[\left(\alpha_i^{\text{model}} - \alpha_i^{\text{exp.}} \right)^2 + \left(\beta_i^{\text{model}} - \beta_i^{\text{exp.}} \right)^2 \right] \right\} / N$, where N (=72) is the number of (α, β) pairs. Tilt angle is measured from out-of-plane, and azimuth angle is measured in the sample plane from the mechanical line. The measured (α, β) curves are converted into the corresponding trajectory on the Poincaré sphere to visualize the polarization state of transmitted light. Model 1 is the model used to fit data at normal incidence as shown in Fig. 2. Although Model 1 is good enough to explain the in-plane retardation characteristics of the wide view film at normal incidence, it is not sufficient to explain out-of-plane retardation characteristics at oblique incidence. The deviation of the simulated trajectory(solid line) from the measured one(open circles) on the Poincaré sphere is quite large. An improved model appears as Model 2, which is consisted with a substrate (a-plate) and a single o-plate. By adopting Model 2, we achieved a remarkable improvement in Poincaré trajectory simulation and MSE. This improvement was made possible by accepting the fact that two anisotropic layers have with different tilt angles and different azimuth angles. Based on the analysis using Model 2, one can verify that the o-plate layer has greater retardation than the substrate and the optic axis of the o-plate is closer to plane normal(12 degrees from out-of-plane). Model 3 is a refined version of Model 2, where three o-plates with gradually decreasing tilt angles are placed on a substrate (a-plate).

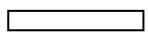
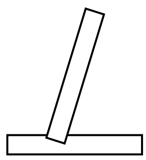
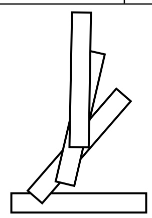
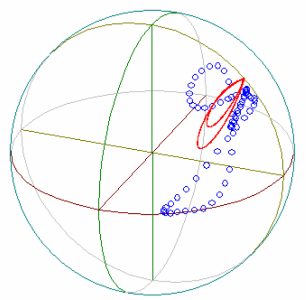
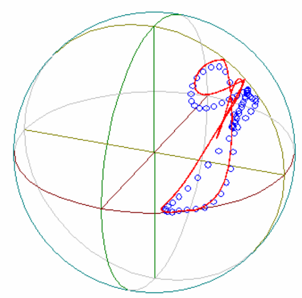
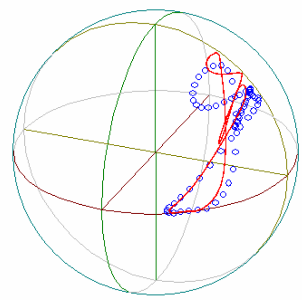
	Model 1			Model 2			Model 3		
	Tilt(º)	Azimuth(º)	d (nm)	Tilt(º)	Azimuth(º)	d (nm)	Tilt(º)	Azimuth(º)	d (nm)
Layer 1	90	39	530	90	38	425	90	38	300
Layer 2				12	31	2110	41	35	310
Layer 3							13	35	1025
Layer 4							1	35	1100
Layer structure for optical model									
Poincaré sphere representation of polarization state									
MSE	0.0922			0.0052			0.0035		

Table 1. Optical models and Poincaré sphere representation of the transmitted light of wide view film

3. Summary

In this study, the distribution of the discotic liquid crystals in compensating film for improvement of the viewing angle characteristics of twisted nematic liquid crystal display is analyzed. The polarization state variation of transmitted wave is measured in terms of the ellipsometric constants while the tilt angle and the azimuth angle of the sample are independently varied, and the measured ellipsometric constants are analyzed to find the distribution of the discotic liquid crystals. The optic axes of the discotic liquid crystals are gradually tilted from in-plane direction to out-of-plane direction. The substrate has relatively small in-plane retardation. The azimuth angle of the discotic liquid crystal does not coincide with that of the substrate or a-plate.

4. Acknowledgements

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5. References

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