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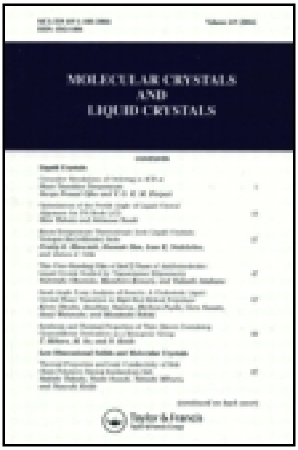

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Evaluation of Cell Parameters of TN Liquid Crystal Cells by using a Stokes Parameter Method

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Evaluation of Cell Parameters of TN Liquid Crystal Cells by using a Stokes Parameter Method

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Evaluation of cell thickness and a twist angle of a liquid crystal layer is very important in the liquid crystal study and manufacturing. We have developed an analysis system of the cell thickness and the twist angle of the liquid crystal layer, named 'LCD Analyzer', which is based on the Stokes Parameter Method. We have examined the effects of the performance of the optics on the measurement and a measuring condition, and achieved good precision of evaluating the cell parameters.

Keywords: TNLCD; cell thickness; twist angle; Stokes Parameter Method

INTRODUCTION

Cell thickness and twist angle of a liquid crystal (LC) layer are the most important parameters in a twisted nematic (TN) liquid crystal display (LCD). Recently, the Stokes Parameter Method (SPM) has been proposed by Zhou *et al.* [1] for evaluating the cell thickness and the twisted angle of the LC layer. The SPM is very simple technique because only 4 transmitted monochromatic light intensities with different optics setup are needed. But precision of evaluating the cell

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parameters is not good in some cases.

In this paper, we examined the effects of the performance of the optics used on the SPM measurement, and determined practical specifications of the optics. According to this result, we have developed the analysis system of the cell thickness and the twist angle of the LC layer, named 'LCD Analyzer', which is based on the SPM. The cell thickness and the twist angle can be measured simultaneously. Moreover, 2 dimensional distribution of these parameters can be measured by using a CCD camera. It is also possible to calculate the anchoring energy from the measured parameters. In this paper, we also demonstrate a specification of the LCD Analyzer and an example of the measurement (the dependence of the twist angle on the cell thickness was measured).

THEORY

In this section, we summarize the outline of the SPM measurement [1,2]. The Stokes parameters of the polarization through the TN cell normalized by the incident light intensity are written as a function of the cell thickness d and the twist angle ϕ.

$$S_0 = a_1^2 + a_2^2 + b_1^2 + b_2^2 = 1 \quad (1)$$

$$S_1 = b_1^2 - a_1^2 - a_2^2 \cos 4\alpha + b_2^2 \cos 4\alpha + 2a_2 b_2 \sin 4\alpha \quad (2)$$

$$S_2 = 2a_1 b_1 + (b_2^2 - a_2^2)\sin 4\alpha - 2a_2 b_2 \cos 4\alpha \quad (3)$$

$$S_3 = 2b_1(b_2 \sin 2\alpha - a_2 \cos 2\alpha) - 2a_1(a_2 \sin 2\alpha + b_2 \cos 2\alpha) \quad (4)$$

$$a_1 = \frac{1}{\sqrt{1+u^2}} \sin\phi \sin(\sqrt{1+u^2}\phi) + \cos\phi \cos(\sqrt{1+u^2}\phi) \quad (5)$$

$$a_2 = \frac{u}{\sqrt{1+u^2}} \cos\phi \sin(\sqrt{1+u^2}\phi)) \quad (6)$$

$$b_1 = \frac{1}{\sqrt{1+u^2}} \cos\phi \sin(\sqrt{1+u^2}\phi) - \sin\phi \cos(\sqrt{1+u^2}\phi)) \quad (7)$$

$$b_2 = \frac{u}{\sqrt{1+u^2}} \sin\phi \sin(\sqrt{1+u^2}\phi) \quad (8)$$

$$w = \left(\frac{n_e}{n_o}\right)^2 - 1 \quad (9) \qquad u = \frac{\pi d}{\lambda\phi}\left(\frac{n_e}{\sqrt{1+w\sin^2\theta_s}} - n_o\right), \quad (10)$$

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where n_o and n_e are indices of the ordinary and extraordinary light of LC material, respectively, λ is the wavelength of the incident light, θ_s is the pretilt angle, d is the cell thickness, ϕ is the twist angle, and α is the azimuthal angle of the incident director of the LC layer.

Under a laboratory coordinate shown in FIGURE 1, the normalized Stokes parameters are determined experimentally as follows.

$$S_0 = (I_x + I_y)/(I_x + I_y) = 1 \quad (11)$$

$$S_1 = (I_x - I_y)/(I_x + I_y) \quad (12)$$

$$S_2 = [2 I_{xy} - (I_x + I_y)]/(I_x + I_y) \quad (13)$$

$$S_3 = -[2 I_{qxy} - (I_x + I_y)]/(I_x + I_y) , \quad (14)$$

where I_x is the transmitted light intensity when the fast axis of the wave plate and the transmission axis of the analyzer are along the x axis, I_y is when the both axes along the y axis, I_{xy} is when the both axes along a bisector of the x and the y axis, and I_{qxy} is when the wave plate axis is along the x axis and the analyzer axis is along the bisector of the x and the y axis.

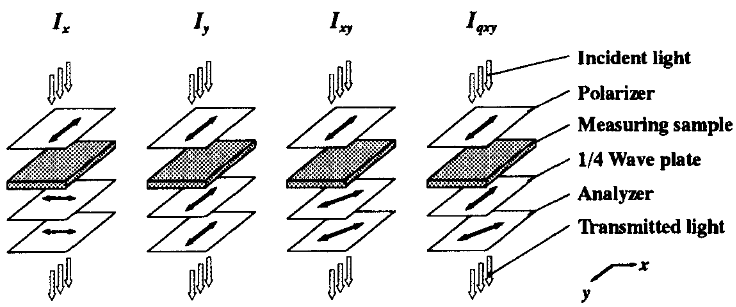

FIGURE 1 Schematic figures of the optics setup for measuring the Stokes Parameters

After measuring I_x, I_y, I_{xy} and I_{qxy}, we can calculate the normalized Stokes parameters by using Equations (11~14) and evaluate d and ϕ by fitting the measured Stokes parameters to Equations (1~4).

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SPECIFICATIONS

The photograph of measurement system is shown in FIGURE 2, and system diagram is shown in FIGURE 3.

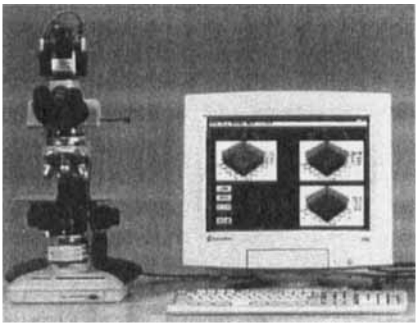

FIGURE 2 Photograph of the LCD Analyzer

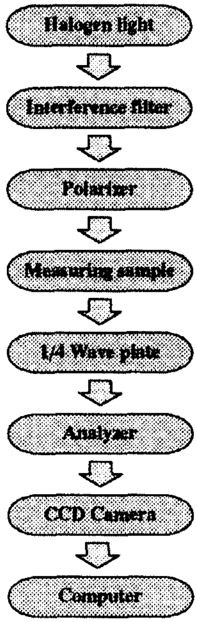

FIGURE 3 System diagram

Since the flicker of the light source causes the experimental error, the high-stable type light source is used in the LCD Analyzer. The deviation of the light intensity is less than 1 %. We simulated the influence of the 1 % flicker on the evaluation of d and ϕ as shown in FIGURE 4. d is evaluated within the range of $\pm 0.05\,\mu$ m and ϕ is evaluated within the range of ± 0.5 degree at the worst.

FIGURE 5 shows the simulated dependence of the transmitted light intensity on the wavelength of the light. Only $I_{\phi xy}$ shows small dependence, but the effect of this dependence can be neglected by using the interference filter with narrow width. In the LCD Analyzer, the full width at half maximum (FWHM) of the interference filter is less than 10 nm.

The extinction ratio of the polarizer and the analyzer also affects the reliability of the measurement. In the LCD Analyzer, the polarizer

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and the analyzer with high extinctionfactor less than 10^{-4} are used.

According to the above discussion, the specifications of the optical components used in the LCD Analyzer were determined as shown in TABLE 1 .

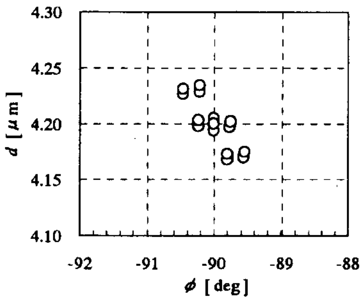

FIGURE 4 The scatter chart by the light intensity deviation 1 %

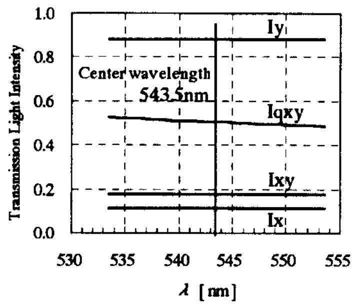

FIGURE 5 Dependency of the light wavelength

TABLE 1 Optical component specifications

Item	Specifications
1. Light source	Halogen light source 12V 100W Color temperature 3100K with intensity adjustment mechanism
2. Interference filter	λ=546nm FWHM 10nm or less
3. Polarizer	Extinction factor 10^{-4} or less
4. Wave plate	1/4 Wave plate (λ=546 nm)
5. Analyzer	Extinction factor 10^{-4} or less
6. Detector	Full frame type Cooling-High-step- CCD-Camera (16bit-output (65,535 steps))

FIGURE 6 and 7 show the calculated logarithmic value of variance between the Stokes parameters of a designed TN cell (d = 4 μm, ϕ = -90 degree) and of a hypothetical cell having arbitrary d and ϕ

(coordinates of figures) in given α's. In the case of α = 60 degree (FIGURE 6), some local minimums are observed. This is the reason that the precision of evaluating the cell parameters by the SPM is not good in some special cases. To avoid this problem, the LCD Analyzer has a sample rotation stage. Therefore the LCD Analyzer achieves good precision of evaluating the cell parameters by the SPM.

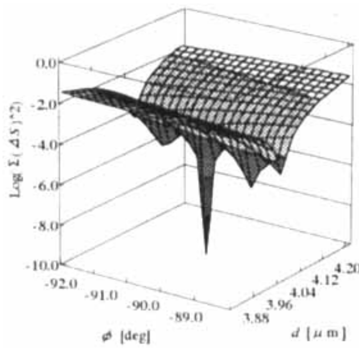

FIGURE 6 Potential curve (α = 60 degree)

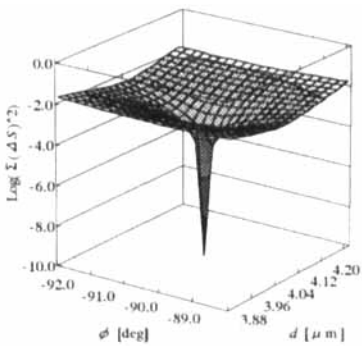

FIGURE 7 Potential curve (α = 10 degree)

The LCD Analyzer can measure the cell thickness, twist angle and the anchoring energy of TNLCD, (TFTLCD), STNLCD, and so on. Moreover the LCD Analyzer can measure and display the 2 dimensional distribution of these parameters by using the CCD camera.

EXAMPLE OF MEASUREMENT

The flow diagram of the SPM measurement by using the LCD Analyzer is shown in FIGURE 8. We measured 3 TN cells, which had different cell thickness with each other and were made by the same rubbing process. The designed parameters are listed in TABLE 2. The measurements were carried out at 3 points in each cell (here calling A-1, A-2, A-3, and so on).

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TABLE 2 Designed data of the samples

Sample	d[μ m]	ϕ [deg]	θ_s[deg]
A	3.9	-90	5
B	4.9	-90	5
C	6.3	-90	5

The obtained results are listed in TABLE 3 and shown in FIGURE 9. The measurements are performed at the angle α of -72 degree (Sample A), -54 degree (B), 88 degree (C).

Solid and dotted curves in FIGURE 9 represent the theoretical curves of dependence of the twist angle ϕ on the cell thickness d with different anchoring energies.

The tendency that ϕ becomes smaller with decreasing d is clearly observed, as predicted theoretically. The anchoring energy was evaluated by 2.0×10^{-4} N/m, which is consistent with the strong rubbing case. These results show good measurement precision of the LCD Analyzer.

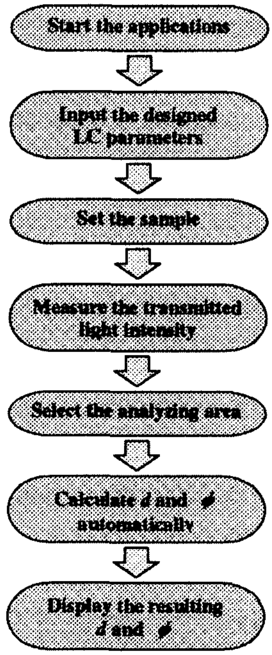

FIGURE 8 Measurement flow diagram

TABLE 3 Sample measurement results

Sample	d [μ m]	ϕ [deg]
A-1	3.94	-88.1
A-2	3.95	-88.8
A-3	3.96	-88.0
B-1	4.82	-89.0
B-2	4.92	-89.4
B-3	4.85	-88.9
C-1	6.34	-89.9
C-2	6.32	-89.9
C-3	6.30	-89.5

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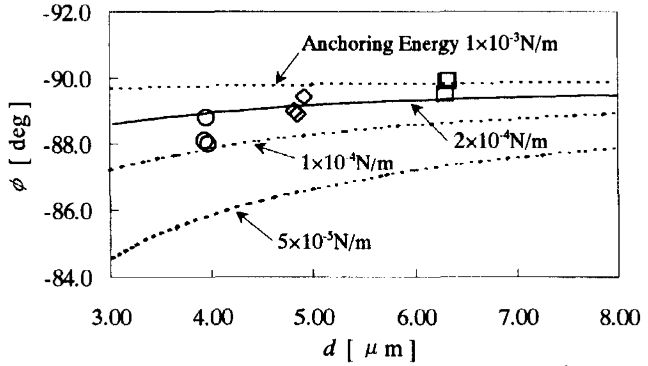

FIGURE 9 **Relationships between *d* and ϕ**

CONCLUSION

We have developed the analysis system of the cell thickness and the twist angle of the liquid crystal layer, named 'LCD Analyzer', which is based on the Stokes parameter method. The Stokes parameter method is very simple technique because the only 4 transmitted monochromatic light intensities with different optics setup are needed.

By examining the effects of the performance of the optics on the measurement and a measuring condition, the LCD Analyzer can measure the cell thickness and the twisted angle with good precision. We demonstrated the simultaneous measurement of the cell thickness and the twist angle by using the LCD Analyzer, and the dependence of the twist angle on the cell thickness, *i.e.*, the twist angle becomes smaller with decreasing the cell thickness, was clearly observed. The obtained anchoring energy of 2.0×10^{-4} N/m is consistent with the strong rubbing case.

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