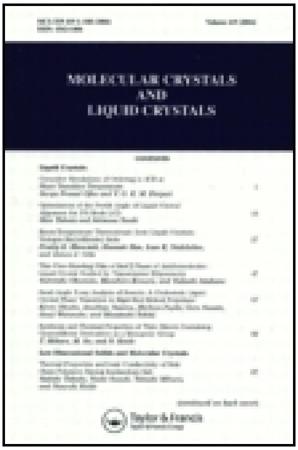

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Measurements of Cell Parameters in Reflective Liquid Crystal Cells by using a Stokes Parameter Method

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We propose an application of Stokes Parameter Method (SPM) for determining cell parameters of reflective twisted nematic (TN) liquid crystal (LC) cells by measuring Stokes parameters of the LC cells. The relationship between the Stokes parameters of the reflection light of the reflective TN LC cells and cell properties such as the thickness and twist angle are given on Jones matrix representation. The cell properties of the reflective LC cell are discussed and compared with those of the transmissive LC cell. The cell thickness of the reflective TN LC cell can be measured, but the twist angle cannot be determined by this method.

Keywords: Reflective liquid crystal cell; Stokes Parameter Method; cell thickness measurement; twist angle measurement

INTRODUCTION

Reflective liquid crystal displays (LCDs) have favorable properties compared with transmissive LCDs. Since direct-view reflective LCDs do not need a backlight, low power consumption enables portable applications [1-3]. In conventional LCDs, the thickness of the LC layer and twist angle of LC molecules are two very important parameters. The cell thickness and twist angle of the LC layer are directly related to the contrast ratio properties of the LC displays, and then high contrast ratios are realized with an appropriate these properties. Therefore, the accurate and fast measurement of the cell thickness and twist angle of

TN LC cells is desirable both in practical manufacturing processes and fundamental physical studies of LCs. Recently, we have developed a Stokes Parameter Method (SPM) for determining simultaneously the cell thickness and twist angle by measuring Stokes parameters of the light transmitted through twisted nematic (TN) LC cells [4-6]. The cell thickness and twist angle can be calculated by the solution of some deduced Stokes parameters equations. Fast determination of the cell thickness and twist angle is possible by this method.

In this study, we propose an application of SPM to determining the cell parameters of the reflective TN LC cells, and these properties are discussed and compared with those of transmissive type LC cells.

THEORY

Figure 1 shows a coordinate system of the reflective TN LC cell and incident light in this study. The transmission axis of the entrance polarizer is set to the x-axis. The entrance liquid crystal director forms an angle α with the x-axis. The director of liquid crystal in the LC cell is twisted for an angle ϕ, so that the exit liquid crystal director forms the

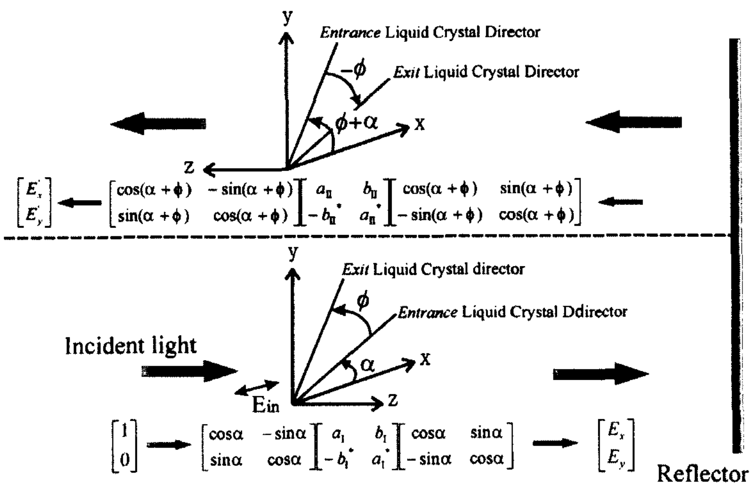


FIGURE 1 Coordinate system referring to a reflective liquid crystal cell and incident light in this study.

twist angle ϕ with the entrance liquid crystal director. When the light is incident along z-axis, based on the Jones matrix representation, the electric field components (E_x and E_y) for the x- and y- axes behind the TN LC cell before the light is reflected by a reflector can be represented in matrix form as

$$\begin{bmatrix} E_x \\ E_y \end{bmatrix} = \begin{bmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{bmatrix} \begin{bmatrix} a_I & b_I \\ -b_I^* & a_I^* \end{bmatrix} \begin{bmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix}. \quad (1)$$

If we define a_I and b_I as

$$a_I = a_{I1} + ja_{I2}$$
$$b_I = b_{I1} + jb_{I2}\ , \quad (2)$$

then a_{I1}, a_{I2}, b_{I1} and b_{I2} are

$$\begin{aligned} a_{I1} &= \frac{1}{\sqrt{1+u^2}}\sin\phi\sin(\sqrt{1+u^2}\phi) + \cos\phi\cos(\sqrt{1+u^2}\phi) \\ a_{I2} &= \frac{u}{\sqrt{1+u^2}}\cos\phi\sin(\sqrt{1+u^2}\phi) \\ b_{I1} &= \frac{1}{\sqrt{1+u^2}}\cos\phi\sin(\sqrt{1+u^2}\phi) - \sin\phi\cos(\sqrt{1+u^2}\phi) \\ b_{I2} &= \frac{u}{\sqrt{1+u^2}}\sin\phi\sin(\sqrt{1+u^2}\phi) \end{aligned} \quad (3)$$

,

in which

$$u = \frac{\pi d}{\lambda\phi}\left(\frac{n_e}{\sqrt{1+w\sin^2\theta}} - n_o\right)$$
$$w = \left(\frac{n_e}{n_o}\right)^2 - 1\,. \quad (4)$$

Here, n_o and n_e are ordinary and extraordinary indices of the refraction of liquid crystal materials, λ is the wavelength of incident light, θ is the pretilt angle and d is the thickness of the TN LC cell.

Since the transmission light passing through the LC cell is reflected by the reflector, the twist direction is reversed ($-\phi$) and a second angle α of the coordinate system is defined as $\phi+\alpha$. Therefore, the electric field components ($E_x^{'}$ and $E_y^{'}$) of the LC cell reflected by the reflector can be represented as in matrix form as

$$\begin{bmatrix} E_x^{'} \\ E_y^{'} \end{bmatrix} = \begin{bmatrix} \cos(\alpha+\phi) & -\sin(\alpha+\phi) \\ \sin(\alpha+\phi) & \cos(\alpha+\phi) \end{bmatrix} \begin{bmatrix} a_{\text{II}} & b_{\text{II}} \\ -b_{\text{II}}^{*} & a_{\text{II}}^{*} \end{bmatrix} \times \begin{bmatrix} \cos(\alpha+\phi) & \sin(\alpha+\phi) \\ -\sin(\alpha+\phi) & \cos(\alpha+\phi) \end{bmatrix} \begin{bmatrix} E_x \\ E_y \end{bmatrix}, \tag{5}$$

where a_{II} and b_{II} are

$$\begin{aligned} a_{\text{II}} &= a_{\text{II}1} + ja_{\text{II}2} = a_{11} + ja_{12} \\ b_{\text{II}} &= b_{\text{II}1} + jb_{\text{II}2} = -b_{11} - jb_{12}. \end{aligned} \tag{6}$$

The Stokes parameters of reflection light from the reflective TN LC cell can be deduced as follows:

$$\begin{aligned} S_1 &= E_x^{'}E_x^{'*} - E_y^{'}E_y^{'*} \\ S_2 &= E_x^{'}E_y^{'*} + E_x^{'*}E_y^{'} \\ S_3 &= j\left[E_x^{'}E_y^{'*} - E_x^{'*}E_y^{'}\right]. \end{aligned} \tag{7}$$

The Stokes parameters of the reflected light are functions of α, ϕ and d. If the angle α and the pretilt angle θ are known, and the Stokes parameters S_1, S_2 and S_3 are measured experimentally, the cell properties can be determined simultaneously by the solution of the Stokes parameter equations such as eq. (7).

EXPERIMENTAL

Figure 2 shows an experimental setup for measuring the Stokes parameters of the reflected light of the reflective LC cells by using the

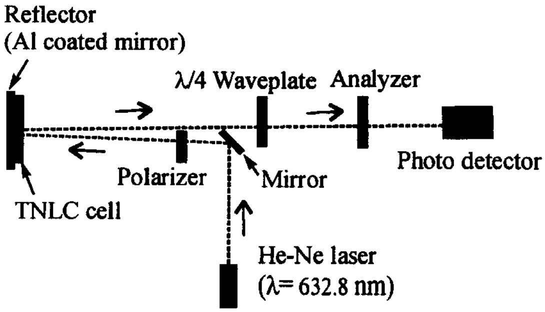


FIGURE 2 Experimental setup.

SPM. A He-Ne laser (λ=632.8 nm) is used as a light source, and its light is reflected by a mirror, where the angle between the incident light and reflected light of the LC cell is less than 1°. Using a polarizer, we obtain a linearly polarized light parallel to the x-axis, which is incident on the TN LC cell with about 0.5°. An analyzer and a quarter wave plate are inserted between the TN LC cell and a photo detector. The incident light to the TN LC cell is reflected by a reflector (Al coated mirror) behind the LC cell with matching gels, and then the reflected light passes through the same LC cell. With respect to the x-axis, the reflected light intensities are measured for parallel (I_x), perpendicular (I_y), +45°direction (I_{xy}) and rotating the quarter-wave plate (I_{qxy}) whose slow axis is parallel to the x-axis. With the four light intensities, we can calculate the normalized Stokes parameters of the reflected light.

By using the Stokes parameter representations of the TN LC cell, we can understand that the factors affecting the experimental accuracy are the refractive indices of liquid crystal materials, the pretilt angle of the LC cell, and the angle of the entrance liquid crystal director with the x-axis (the angle α). The experimental accuracy for determining the cell thickness and the twist angle is directly decided by the accuracy of the measurement of the Stokes parameters. Therefore, the Stokes parameters, S_1, S_2 and S_3 are measured by changing α, while the sample reflective TN LC cell is fixed and polarizer, analyzer and λ/4 plate are set to each α.

In our experiments, polyvinyl-alcohol (PVA) films were used as alignment layers, coated on cleaned glass substrates and then unidirectionally rubbed by a rubbing machine. The easy axis of the rubbed PVA substrate has been proved in the rubbing direction. Two substrates were overlapped to let the rubbing directions form a designed angle. The cell thickness was controlled by use of polymer ball spacers. However, it is difficult to obtain the designed values exactly, especially in the case of the twist angle under the conditions of the fabricated LC cells. The experiments were carried out at room temperature about 24°C

RESULTS AND DISCUSSION

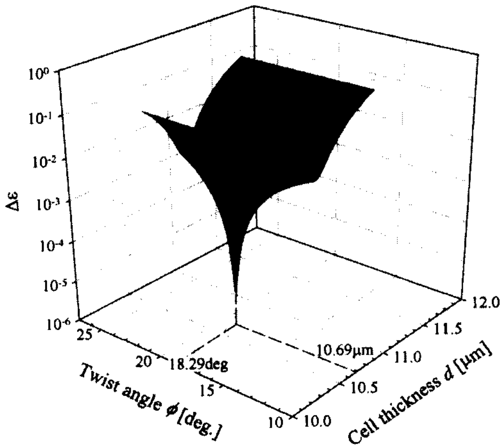
Nematic LC (K15) was filled into two (Sample 1 and Sample 2) LC cells, of which cell thicknesses were designed to 7μm and 11μm, and the twist angles were set to about 30° and 20°, respectively. The pretilt angle θ was 0.25° in all sample cells. Table 1 shows the experimental results of the thicknesses and twist angles measured by the transmission mode and reflection mode. The Stokes parameters are calculated with four light intensities, and then the cell thickness and twist angle are solved using Stokes parameter equations [4]. The measured cell thickness and twist angle of the Sample 1 and Sample 2 are close to the designed values for transmission mode, as expected. The same LC cell is overlapped with the reflector (Al coated mirror) with matching gels, and then the Stokes parameters are measured by using the reflection mode as shown in Fig. 2. The cell thicknesses of the reflective TN LC cell can also be measured by this reflection mode, and the cell thicknesses are in good agreement with all of the designed values. On the other hand, it is difficult to determine the twist angle of the reflective TN LC cell because a right-handed coordinate system is

TABLE 1 Experimental results.

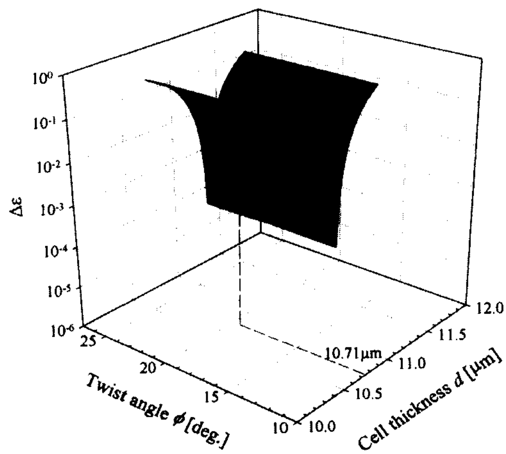
		Sample 1	Sample 2
Designed value	Cell thickness	7μm	11μm
	Twist angle	30°	20°
Measured value (Transmission mode)	Cell thickness	7.04μm	10.69μm
	Twist angle	27.48°	18.29°
Measured value (Reflection mode)	Cell thickness	7.16μm	10.71μm
	Twist angle		

converted into a left-handed one reversed by the reflector behind the LC cell and then the twisted direction of the LC cell is reversed.

Figure 3 (a) and (b) show the relationship between the error (Δε) and



(a) Transmission mode



(b) Reflection mode

FIGURE 3 Relationship between the error and cell parameters.

two cell parameters such as the cell thickness and twist angle measured by the transmission mode and reflection mode in Sample 2, where the measurements are performed at the angle α of -40° and -20°, respectively. The error is defined as the mean deviation between the experimentally measured Stokes parameters and calculated Stokes parameters. It is shown in Fig.3 (a) that the cell thickness and twist angle can be determined at minimum error values and the measured cell properties are close to the designed values for the transmission mode. On the other hand, as shown in Fig.3 (b), the error for the cell thickness becomes a minimum value but that for the twist angle is uncertain and cannot be determined. Therefore, only the cell thickness can be measured by the reflection mode.

CONCLUSION

We have proposed an application of SPM for determining cell parameters such as a cell thickness and twist angle of reflective TN LC cells by measuring the Stokes parameters of reflected light from the LC cell. Although the cell thickness and twist angle can be measured by the transmission mode, only the cell thickness can be determined by the reflection mode. That is, the twist angle of the reflective LC cell can hardly be determined by this method because the coordinate system is converted by the reflector behind the LC cell.

Using this SPM method for measuring cell parameters of the reflective TN LC devices, two-dimensional (2D) distributions of the cell thickness can also be determined by measuring 2D Stokes parameters which are obtained with four reflective light intensity distributions.

References

[1] T. Uchida, Takayama, T. Miyashita, M. Suzuki and T. Ishinabe: Digest of AM-LCD 95 (1995) 27.

[2] S. Fujita, H. Mizuno, M. Nishinaka, H. Yamaguchi, T. Ohtani, T. Hatanaka and T. Ogawa: Proc. IDW'98 (1998) 213.

[3] H. Kobayashi, Y. Takahashi and Y. Iimura: Proc. IDW'99 (1999) 57.

[4] Y. Zhou, Z. He and S. Sato: Jpn. J. Appl. Phys. 36 (1997) 2760.

[5] Y. Zhou, Z. He and S. Sato: Jpn. J. Appl. Phys. 37 (1998) 1982.

[6] Y. Zhou, Z. He and S. Sato: Jpn. J. Appl. Phys. 37 (1998) 2567.