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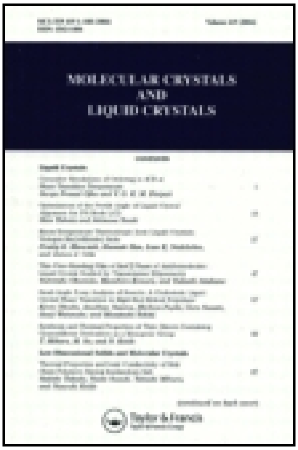

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Pretilt Angle Measurement Method for Twisted Nematic Cells with Low Cell-Gap

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PRETILT ANGLE MEASUREMENT METHOD FOR TWISTED NEMATIC CELLS WITH LOW CELL-GAP

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We propose a method to measure the pretilt angle as well as the cell gap in TN cells with low cell-gap with a single wavelength source. We use simple optical configurations with a TN cell between an analyzer and a polarizer. As we rotate the analyzer by 180°, we can find analyzer angles at which the transmittance is minimum or maximum under normal or oblique incidence. By using the measured analyzer angle, we can determine the pretilt angle.

Keywords: pretilt angle measurement; twisted-nematic cell

1. INTRODUCTION

In a liquid crystal display, important parameters that need to be measured are the cell gap, the twist angle, and the pretilt angle. Measurement method of the pretilt angle has not been widely studied until now unlike the cell gap and the twist angle. Suitable control of LC directors' pretilt angle is important for the improvement of optical performances of LCDs. For example, appropriate pretilt angle prevents disclination due to unwanted domain while an LC cell is driven and shifts electro-distortional curve to lower voltages with slight increase in steepness.

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A measurement method of the pretilt angle known as crystal rotation method has advantages, such as simplicity and short measurement time. However, since this method requires that the cell gap of an LC cell be thick enough to show apparently the symmetric point in the transmission curve, it is applicable only to anti-parallelly rubbed cells. Therefore, in case of a TN cell and a low cell-gap LC cell, this method may not be suitable [1].

In this work, we propose a simple method to measure the pretilt angel as well as the cell gap in a TN cell with low cell gap with a single wavelength source. In the measurement of the pretilt angle, we need to separate the equation for the cell gap and that of the pretilt angle from each other. While it is relatively easy in anti-parallelly rubbed cells, it is not true with TN cells. We can separate the two equations by making use of two measurement steps: 1) the light is normally incident to a TN cells. 2) the light is obliquely incident. From the separated equations, we can determine the pretilt angle and the cell gap.

2. THEORY

Optical setup for the measurement of the pretilt angle in a TN cell is shown in Figure 1. A He-Ne laser operating at the wavelength 632.8 nm is used as

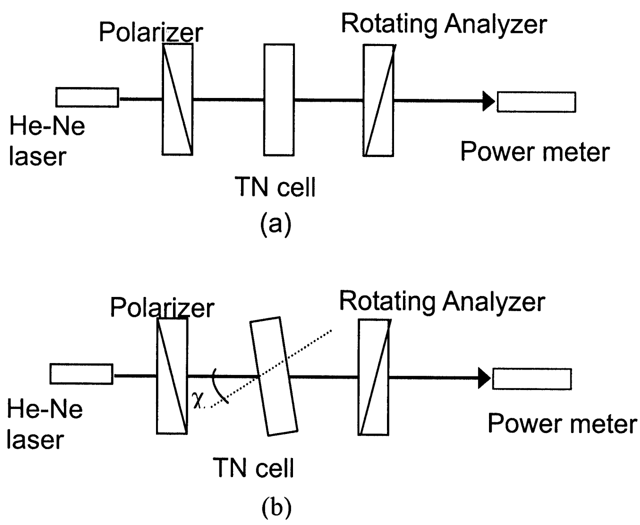

FIGURE 1 Optical setup for the pretilt angle measurement of a TN cell: (a) Normal incidence, and (b) oblique incidence.

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a light source. Optical transmittance in a TN cell between a polarizer and an analyzer is varied by the rotation of the polarizer or the analyzer angle in a certain range, in order to find the minimum or the maximum point in the transmittance curve. The analyzer attached to a stepper motor is rotated by 180°. While we rotate the analyzer by 180°, we can divide the rotation by 0.5°. At each angle, transmittance values can be obtained with a power meter.

By using the Jones matrix representation, in case of normal incidence, the transmittance T_{normal} in the system in Figure 1 (a) is given as

$$T = \left|(\cos\gamma \;\; \sin\gamma) M \begin{pmatrix} \cos\alpha \\ \sin\alpha \end{pmatrix}\right|^2, \tag{1}$$

where M is the Jones matrix of a twisted nematic LC layer;

$$M = R(-\phi)\begin{pmatrix} \cos\beta - i\delta\dfrac{\sin\beta}{\beta} & \phi\dfrac{\sin\beta}{\beta} \\ -\phi\dfrac{\sin\beta}{\beta} & \cos\beta + i\delta\dfrac{\sin\beta}{\beta} \end{pmatrix}$$

with $\delta = (\pi \cdot d \cdot \Delta n/\lambda), \beta^2 = \delta^2 + \phi^2, \Delta n = \frac{n_e}{\sqrt{1+W\sin\theta_{av}^2}} - n_0, W = (\frac{n_e}{n_0})^2 - 1$ α is the angle of the polarizer transmission axis, γ is the angle of the analyzer transmission axis, ϕ is the twist angle, and n_o and n_e are the ordinary and extraordinary indices of refraction of the LC layer, respectively. d is the cell gap, θ_{av} is the averaged tilt angle, and λ is the wavelength of the incident light.

In the case of oblique incidence, transmittance T_{oblique} can be written in a form the same as the transmittance in the normal incidence under a particular condition between input director angle and twist angle [2]

$$T = \left|(\cos\gamma \;\; \sin\gamma) R(-\alpha_{in}) M' R(\alpha_{in}) \begin{pmatrix} \cos\alpha \\ \sin\alpha \end{pmatrix}\right|^2, \tag{2}$$

and $\delta' = (\pi \cdot d \cdot \Delta n'/\lambda), \beta'^2 = \delta'^2 + \phi^2, \alpha_{in} = a\tan\left(\dfrac{-\phi + \sin\phi}{1 - \cos\phi}\right)$.
$R(\alpha_{\mathrm{in}})$ is the rotation matrix;

$$(\alpha_{in}) = \begin{pmatrix} \cos\alpha_{in} & \sin\alpha_{in} \\ -\sin\alpha_{in} & \cos\alpha_{\mathrm{in}} \end{pmatrix}$$

in which α_{in} is the angle between the entrance LC (liquid crystal) director and the rubbing direction. Difference between Eq. (1) and Eq. (2) is only in Δn and Δn′. We could extract Δn′ by using extended Jones matrix representation:

$$\Delta n' = n'_e - n'_0$$

where, $n'_e = -\frac{\varepsilon_{xz}}{\varepsilon_{zz}}X + \sqrt{\frac{n_e^2 n_0^2}{\varepsilon_{zz}} - \frac{\varepsilon_{xx}\varepsilon_{zz} - \varepsilon_{xz}^2}{\varepsilon_{zz}^2}X^2}, \quad n'_0 = \sqrt{n_0^2 - X^2}$

with $\varepsilon_{zz} = n_0^2 + (n_e^2 - n_0^2)\ \sin^2\theta_{av},\ \varepsilon_{xx} = n_0^2 + (n_e^2 - n_0^2)\cos^2\theta_{av}\sin^2\theta_{av},$

$$\varepsilon_{xz} = (n_e^2 - n_0^2)\sin\theta_{av}\cos\theta_{av}\cos\alpha_{in}, \quad \text{and} \quad X = \sin\chi.$$

χ is the incident angle in the system shown in Figure 1(b). Therefore, while we rotate the analyzer by 180°, we can obtain transmittance data in both, normal and oblique incidence. With the calculated transmittance curve, we can always find the analyzer angle at which the transmittance is minimum or maximum. Figure 2 shows the calculated minimum points as the cell gap is increased in a TN cell with twist angle $\phi = 90°$ and the pretilt angle of 6°. In this calculation, we assumed that the polarizer angle is 45°, and the input director angle is 0° in the normal incidence and 29.7° in the oblique incidence with 5°. Using Figure 2, we can select two minimum points for any cell gap in the normal and oblique incidence, respectively.

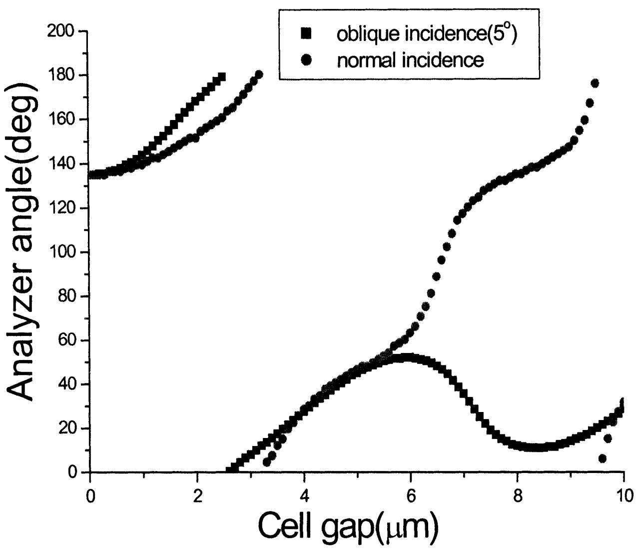

FIGURE 2 Dependence of the analyzer angle at the minimum point in transmittance curves upon the cell gap.

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Once we can obtain the min/max point in case of the normal and oblique incidence with experiment, we can find two parameters having the information of the pretilt angle and the cell gap in the normal and oblique incidence, respectively, by differentiating the transmittance T_{normal} and T_{oblique} of the normal and oblique incidence with respect to analyzer angle. At the min/max points, derivative of T_{normal} and T_{oblique} with respect to analyzer angle is zero.

$$D(\beta) = \left|\frac{\partial T_{\text{normal}}}{\partial \gamma}\right|_{\gamma\,\text{max/min}} = 0, \tag{3}$$

$$D'(\beta') = \left|\frac{\partial T_{\text{oblique}}}{\partial \gamma}\right|_{\gamma\,\text{max/min}} = 0, \tag{4}$$

Figure 3 shows the calculated data, which can be used to determine β and β' with the pretilt angle of 5° and the cell gap of 6 um. From Figure 3, we find that β is 3.63 and β' is 3.665. Once we obtain values of β and β', we use following two equations which relate the pretilt angle with cell gap;

$$\frac{\pi \Delta n d}{\lambda} = \sqrt{\beta^2 - \phi^2}, \tag{5}$$

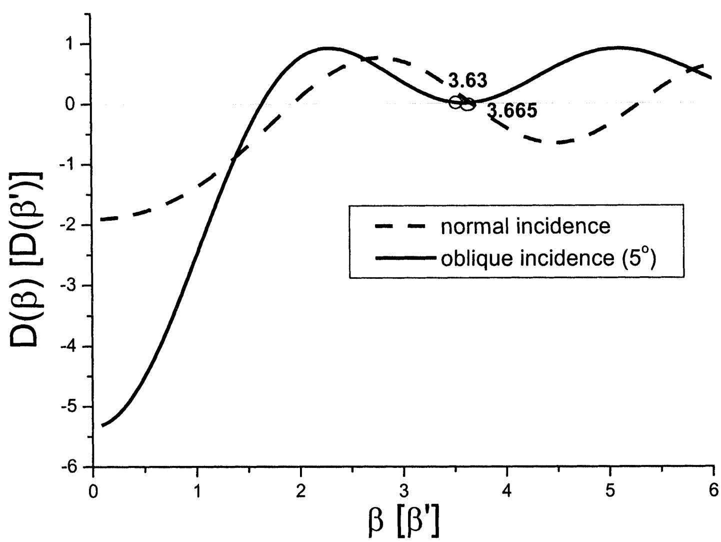

FIGURE 3 Determination of β and β' under the pretilt angle of 5°, the polarizer angle of 0°, and the cell gap of 6 μm.

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$$\frac{\pi \Delta n' d}{\lambda} = \sqrt{\beta'^2 - \phi^2}, \tag{6}$$

From Eqs. (5) and (6), we can obtain an equation for the pretilt angle independent of cell gap.

$$\frac{\Delta n}{\Delta n'} = \frac{\sqrt{\beta^2 - \phi^2}}{\sqrt{\beta'^2 - \phi^2}} = \eta, \tag{7}$$

Because Eq. (7) is an equation for the average tilt angle θ_{av}, we use the following equation relating the average tilt angle with the pretilt angle (θ_{S}) [2]:

$$\theta_s = \frac{\theta_{av}}{1 - \frac{2}{\pi} Q}, \tag{8}$$

with $Q = \dfrac{\phi}{2\pi} \dfrac{2(2\pi d/p - \phi)K_2 + \phi K_3}{\pi K_1/2 + (2\phi d/p - \phi^2/\pi)K_2 + \phi^2 K_3/2\pi}$

where K_1, K_2, and K_3 are the elastic constants of the splay, twist, and bend energys, respectively, and p is the chiral pitch. Finally, we can determine the pretilt angle from Eq. (8) and then the cell gap by using Eq. (6) or (7) and the pretilt angle.

3. EXPERIMENT

To verify the usefulness of the proposed method, TN cells filled with liquid crystal ZLI-1557 (the twist angle $\phi = 90^\circ$) are fabricated with spacer thickness of 4.2 μm and 6 μm, and by using SE-3140(Nissan) as an alignment layer. The pretilt angle of SE-3140 has been known as $4^\circ \sim 6^\circ$.

Figure 4 shows measured transmission data under the normal and the oblique (5°) incidence. From the data, we can determine the min/max points. In this case, we choose maximum point of 78.5° in the normal incidence and that of 78° in the oblique incidence. With these analyzer angles, we could calculate β of 2.7525 and β' of 2.7651 by using Eqs. (3) and (4). At last, from Eq. (7), we could obtain the value of 0.9933 as η.

Figure 5 shows η curve versus average tilt angle. We find the average tilt angle of 4° from the obtained η value. Finally, we determine the pretilt angle of 4.1° by using Eq. (8) and the cell gap of 4.1 μm using Eq. (6) or Eq. (7) Table 1 shows the measured results with SE-3140 as the alignment layer.

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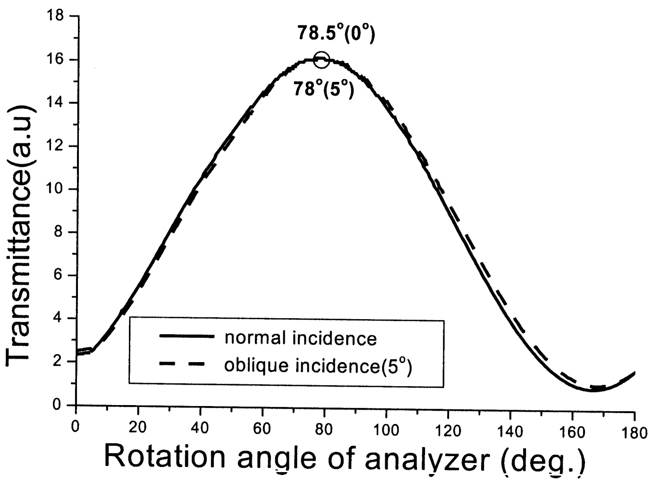

FIGURE 4 Measured transmittance under normal and oblique incidence of a 90° TN cell with the spacer thickness of 4.2 μm and the polarizer angle of 0°.

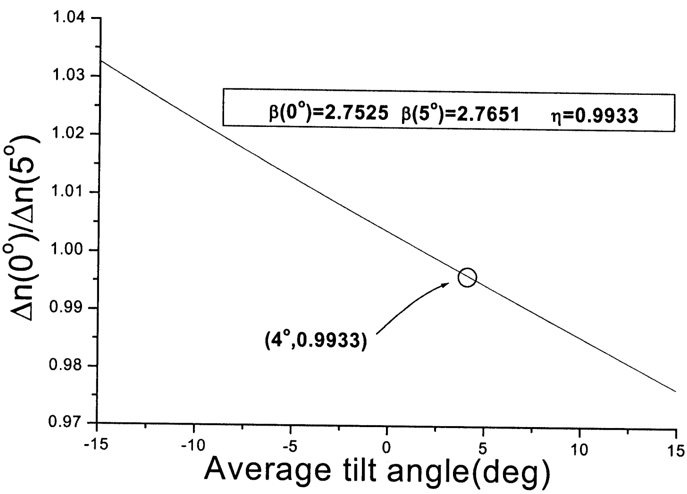

FIGURE 5 $\eta[\Delta n(0°)/\Delta n(5°)]$ vs. versus average tilt angle.

TABLE 1 Measured Pretilt Angles of SE-3140

Spacer thickness (μm)	Pretilt angle (deg.)	cell gap(μm)
4.2	4.1	4.1
6.0	4.9	5.9

4. DISCUSSION

Now we discuss the accuracy of the proposed method. For this method, we can classify the causes of the measurement inaccuracy into two. First, there is an inaccuracy coming from the deviation of the polarizer angle in the optical setup. Second, there is an inaccuracy due to the non-uniformity of the cell gap in fabricating LC cells.

By numerical simulation, we studied the effect of the deviation angle of the polarizer angle. Figure 6 shows the calculated results in a LC cell with pretilt angle 5° and cell gap 7.6 μm when the angle is deviated up to 4° from the set angle. As shown in Figure 6, we found that analyzer angle at min-/max point shifts with the increase of deviation of the polarizer angle. As a result, we may obtain inaccurate values of β and β'. In case of normal incidence, we found that the analyzer angle at maximum is 93.1° for deviation of 2° and 90.7° for deviation of 4°. For oblique incidence, the analyzer angle at minimum is 57° for deviation of 2° and 55.8° for deviation of 4°. From these wrong data, we obtain β of 4.589 and 4.684, and β' of 4.399 and 4.353, respectively. The calculated pretilt angle by using these β and β' show severe inaccuracy. So, in this measurement, the precise setting of the polarizer in the optical setup is very important. However, in an actual measurement, since we control the polarizer angle automatically, we do not need to worry about the effect of inaccuracy of the polarizer.

In fact, the non-uniformity of the cell gap may be much more influential to the measurement error than the inaccuracy in the optical setup. If the cell gap is not uniform, the path of the normal incident light is different

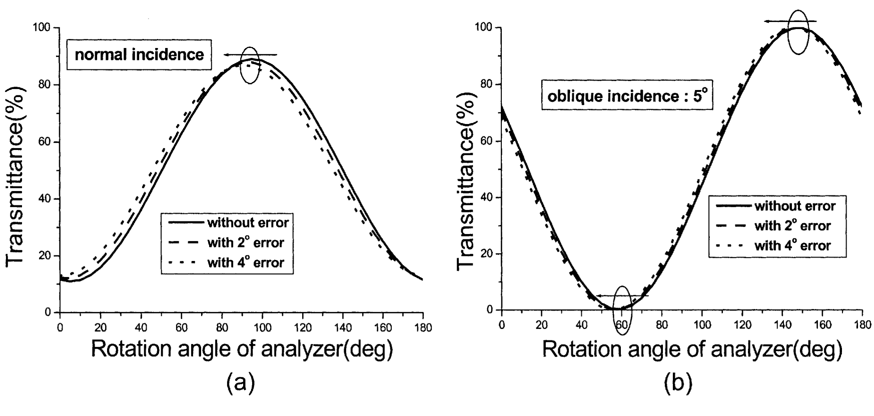

FIGURE 6 Dependence of transmittance curve upon the inaccuracy of the polarizer angle for a 90° TN cell with the cell gap 6.4 μm, the polarizer angle of 0°, and the pretilt angle of 5°.

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from that of the oblique incident light. As a result, their paths go through the different cell gap and so the error occurs. So, in the system shown in Figure 1(b), we used the incident angles of $3^\circ \sim 5^\circ$ in order to reduce the error which is generated by passing through the different cell gap. The smaller incident angle is, the lower error rate is. Effect of the uniformity of cell gap was investigated in ref. 3 [3].

5. CONCLUSION

In conclusion, we propose a method to measure the pretilt angle in a TN cell with low cell gap. With a single wavelength source that is incident normally or obliquely incident on a TN cell, we can measure the pretilt angle.

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