Japanese Journal of Applied Physics
Vol. 43, No. 1A/B, 2004, pp. L 30–L 32

Simple Cell Gap Measurement Method for Twisted-Nematic Liquid Crystal Cells

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(Received September 1, 2003; accepted October 20, 2003; published December 19, 2003)

We propose a method for measuring the cell gap of twisted-nematic liquid crystal (TNLC) cells using a single wavelength. We measure the total transmitted intensity ratio with the polarizer angles rotated in two arbitrary ranges. The proposed total intensity ratio method is resistant to measurement errors because it is an integral method. It can applied to the determination of cell thickness in small cell gaps as well as large ones. [DOI: 10.1143/JJAP.43.L30]

KEYWORDS: liquid crystal display, LCD parameters, cell gap measurement

Liquid crystal displays (LCDs) have been widely used in various fields. One of the basic requirements in manufacturng LCDs that can display high-quality images is the precise cell gap control, since the optical performance of LCDs is significantly affected by the cell gap. For realizing high-performance displays through the manufacturing process, simple, precise, and fast measurement of the cell gap and the twist angle is required. Several cell gap measurement methods have been proposed in previous works,[1–7] and two of them have been widely used: One is the single-wavelength method[2] and the other is the spectral method.[3] For filled LC cells, the rotating polarizer method,[4] which is based on the spectral method, has been mainly used. The rotating polarizer method can be applied with a simple measurement setup. However, it cannot be applied to a small cell gap. A suitable measurement method for a small cell gap is the phase compensation method,[5] which is based on the single-wavelength method. However, it is not suitable for automation because it requires repeated measurements and must use sources of two wavelengths in order to solve the problem caused by multiple solutions. We have already proposed the rotational wave-plate method[6] and the spectral total intensity ratio method (TIRM).[7] However, a quarter-wave plate is required for the former, and the latter requires a spectroscope. We can determine the cell thickness by measuring the integrated intensity ratio of the transmitted light in two arbitrary polarizer angle regions. Compared with the spectral TIRM, this single-wavelength TIRM is easy to use and can provide precise results for small cell gaps as well as large ones.

The optical transmittance of a twisted-nematic liquid crystal (TNLC) cell can be expressed by the Jones matrix using parameters such as the twist angle ϕ, the cell thickness d, the wavelength-dependent birefringence Δn of the LC material, and the angles of the polarizer α and the analyzer γ with the direction of the input director as the reference. For the alignment shown in Fig. 1, the transmittance T is given as

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

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

$$M = R(-\phi)\begin{pmatrix} \cos\beta - \mathrm{i}\delta\dfrac{\sin\beta}{\beta} & \phi\dfrac{\sin\beta}{\beta} \\ -\phi\dfrac{\sin\beta}{\beta} & \cos\beta + \mathrm{i}\delta\dfrac{\sin\beta}{\beta} \end{pmatrix} \tag{2}$$

with

$$\delta = \pi d\Delta n/\lambda, \quad \beta^2 = \delta^2 + \phi^2 \tag{3}$$

$$\Delta n = \frac{n_e}{\sqrt{1 + w\sin\theta^2}} - n_o \quad w = \left(\frac{n_e}{n_o}\right)^2 - 1, \tag{4}$$

where θ is the pretilt angle and n_e and n_o are the extraordinary and ordinary refractive indices of the LC material, respectively. $R(\phi)$ is the rotation matrix given by

$$R(\phi) = \begin{pmatrix} \cos\phi & \sin\phi \\ -\sin\phi & \cos\phi \end{pmatrix} \tag{5}$$

Then, eq. (1) can be rewritten as

$$T = \left[\cos\beta\cos(\phi - \gamma + \alpha) + \frac{\phi}{\beta}\sin\beta\sin(\phi - \gamma + \alpha)\right]^2 + \frac{\delta^2}{\beta^2}\sin^2\beta\cos^2(\phi - \gamma - \alpha). \tag{6}$$

In eq. (6), when the polarizer is rotated, the transmittance varies periodically as a function of the rotation angle for a given cell thickness. If the polarizer is rotated from 0° to 180°, the total intensity of the transmitted light can be expressed by

$$I_{\text{total}} = \int_0^{180^\circ} T\, d\alpha \tag{7}$$

The total intensity I_{total} is a function of the cell gap. Therefore, if it is obtained experimentally, the cell gap can be determined. However, the absolute values of the measured total intensity may be different from the calculated values because of the absorption by the LC layer, glass, indium tin oxide (ITO), the polarizer, and the analyzer. Thus,

$$\int_{\alpha_1}^{\alpha_2} T_{\text{exp}} d\alpha \neq \int_{\alpha_1}^{\alpha_2} T_{\text{cal}} \mathrm{d}\alpha, \tag{8}$$

where T_{exp} [T_{cal}] is the measured [calculated] transmitted light intensity. In comparison, we found that the measured value of the total intensity ratio is in good agreement with the calculated value, since the absorption rate is a constant, namely,

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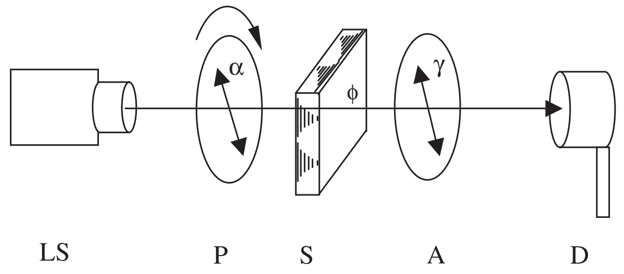

Fig. 1. Setup for LC cell gap measurement. LS: the light source (halogen source for the spectral wavelength method, laser source for the single-wavelength method), P: the polarizer, S: LC cell sample, A: the analyzer, D: the detector (spectrometer for spectral wavelength methods, photodetector for single-wavelength methods).

$$\frac{\int_{\alpha_3}^{\alpha_4} T_{\mathrm{exp}} \mathrm{d}\alpha}{\int_{\alpha_1}^{\alpha_2} T_{\mathrm{exp}} \mathrm{d}\alpha} = \frac{\int_{\alpha_3}^{\alpha_4} T_{\mathrm{cal}} \mathrm{d}\alpha}{\int_{\alpha_1}^{\alpha_2} T_{\mathrm{cal}} \mathrm{d}\alpha}. \quad (9)$$

Our measurements were performed for LC cells [ZLI-1557, spacer: 2.4 μm (no twist), 4.2 μm (90° twist), 7.9 μm (60° twist)] with the experimental setup shown in Fig. 1. For the alignment of the LC, SE-3140 was used as the polyimide coated on a substrate. The pretilt angle was approximately 5°. A He–Ne laser operating at a wavelength of 632.8 nm was used as the light source. The stepping motor that had steps of 0.5° was used to rotate the polarizer. Information about the dispersion of the LC material (ZLI-1557) is available from the manufacturer (Merck).

Figure 2 shows the measured transmittance as a function of rotation angle, when the analyzer angle (γ), the twist angle (ϕ), and the wavelength (λ) are 45°, 90°, and 632.8 nm, respectively, for the spacer size of 4.2 μm. The total intensity ratio of the transmitted light for two rotation angle regions of the polarizer (0°–90° and 30°–60°), also shown in Fig. 2, was found to be 13.33%.

$$\frac{\int_{30^\circ}^{60^\circ} T \mathrm{d}\alpha}{\int_{0^\circ}^{90^\circ} T \mathrm{d}\alpha} = 0.1333$$

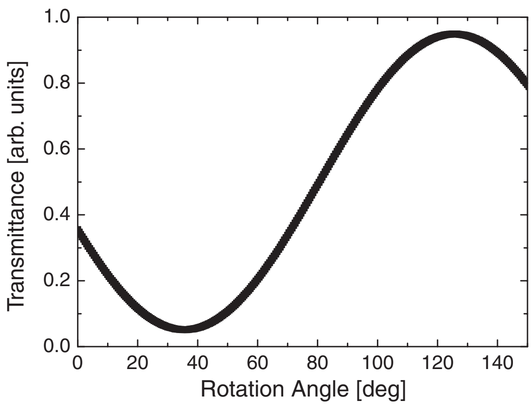

Fig. 2. Transmittance measured as a function of rotation angle: analyzer angle γ, twist angle ϕ and wavelength λ are 45°, 90° and 632.8 nm, respectively.

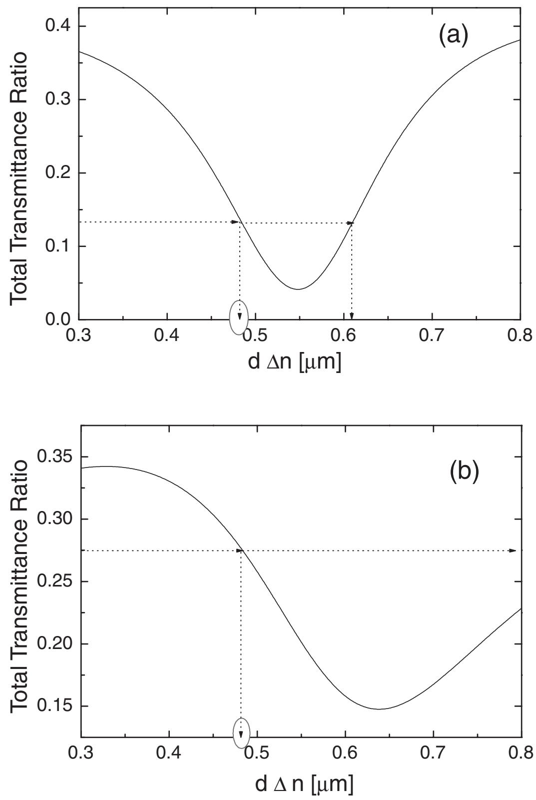

Fig. 3. Total transmittance ratio between two polarizer angle regions for a 90° TN cell. (a) 0°–90 and 30°–60°, (b) 0°–120° and 60°–90°.

This value corresponds to the retardation values of 0.484 μm and 0.610 μm, as shown in Fig. 3(a). The total intensity ratio of the transmitted light for two rotation angle regions of the polarizer (0°–120° and 60°–90°) was found to be 27.5%.

$$\frac{\int_{60^\circ}^{90^\circ} T \mathrm{d}\alpha}{\int_{0^\circ}^{120^\circ} T \mathrm{d}\alpha} = 0.275$$

This value corresponds to the retardation values of 0.483 μm and 0.900 μm, as shown in Fig. 3(b). We can conclude that 0.484 μm is the real retardation value. As shown by the measured results, this proposed method is more accurate than others because it is an integral method. It is more resistant to measurement errors because it is based on the ratio that can cancel out measurement errors.

Cell gaps were measured for cells with spacer sizes of 2.4 μm and 7.9 μm, using the same method, and the results are compared with the cell gap values measured by the rotational polarizer method and the spectral TIRM, as summarized in Table I.

In this method, an important cause of the measurement

Table I. Comparision of measured cell gap data obtained by the rotational polarizer method, spectral TIRM and the proposed method.

spacer size	twist angle	rotational polarizer method	TIRM (spectral method)	Proposed method
2.4 μm	0°	-	2.52 μm	2.51 μm
4.2 μm	90°	4.33 μm	4.35 μm	4.31 μm
7.9 μm	60°	7.96 μm	7.94 μm	7.94 μm

error is the inaccuracy of the pretilt angle for small cell gaps of less than 3 μm and the twist angle. By numerical calculation we found that, if the inaccuracies of the twist angle and the pretilt angle were $\pm 0.5^\circ$ and $\pm 1^\circ$, respectively, the total error in the measurement of cell gaps using this method would be within a maximum of ± 0.03 μm.

In summary, we proposed a novel TIRM method using a single wavelength for determining cell gaps. We measure the total intensity ratio of the transmitted light for two arbitrary rotation angle regions of the polarizer. We found that the measurement error for our method is within 0.03 μm. Because it is simple and precise, this method could be used widely during the manufacturing process of LCDs.

This work was supported from Information Display R&D Center, one of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology of Korea.

1) K. H. Yang: J. Appl. Phys. **64** (1988) 4780.
2) Y. Zhou, Z. He and S. Sato: Jpn. J. Appl. Phys. **36** (1997) 2760.
3) S. T. Tang and H. S. Kwok: SID Symp. Dig. **29** (1998) 552.
4) S. T. Tang and H. S. Kwok: J. Appl. Phys. **89** (2001) 80.
5) A. Lien and H. Takano: J. Appl. Phys. **69** (1991) 1304.
6) S. H. Lee, W. S. Park, T. H. Yoon, G. D. Lee and J. C. Kim: Jpn. J. Appl. Phys. **41** (2002) 379.
7) J. S. Gwag, S. H. Lee, K. Y. Han, J. C. Kim and T. H. Yoon: Jpn. J. Appl. Phys. **41** (2002) L79.