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Novel cell parameter determination of a twisted-nematic liquid crystal display*

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In this paper a novel method is proposed to determine the cell parameters including the twist angle, optic retardation and rubbing direction of twisted-nematic liquid crystal displays (TNLCD) by rotating the TNLCD. It is a single-wavelength method. Because using subtraction equation of transmittance as curve fitting equation, the influence of the light from environment and the absorption by polarizer, the sample of TNLCD and analyser on the transmittance is eliminated. Accurate results can also be obtained in imperfect darkness. By large numbers of experiments, we found that not only the experimental setup is quite simple and can be easily adopted to be carried out, but also the results are accurate.

Keywords: liquid crystal display, twist angle, optical retardation, rubbing direction
PACC: 4200, 4270D

1. Introduction

Now twisted-nematic liquid crystal displays (TNLCD) are the most extended devices due to their relative ease of availability and low cost, but the widespread use of TNLCD in optics is based on their inherent ability to spatially modulate an optical beam in a programmable manner. In this situation no precise information about physical parameters of liquid crystal (LC) cell is available due to the problems in the manufactory. To control the optical modulation response, it is essential to determine the cell parameters, which are the molecular twist angle ϕ, the optical retardation Δnd and the rubbing direction.

Several methods have been proposed to evaluate the TNLCD parameters.[1−7] They are usually devoted to measure the cell gap, the twist angle, and sometimes the pretilt angle of the LC cells. In some methods[1−3] the rubbing direction must be known in advance to determine other parameters, in some spectrum methods[4−7] broadband light source and spectrometer are needed. In this article, we propose a simple method to determine the cell parameters, including the molecular twist angle ϕ, the optical retardation Δnd and the rubbing direction. It is a standard PSA configuration, P is a polarizer, S is a sample of TNLCD, A is an analyser. The experimental setup is quite simple and is easily adopted to be carried out.

2. Fundamental theory and system of measurement of twist angle and optical retardation

2.1. System of measurement of twist angle and optical retardation

The system of the measurement is shown in Fig.1. L is a laser as monochromatic light source, P is the polarizer, S is a sample of TNLCD, A is an analyser, D is a detector. It is the standard PSA configuration. The directions of the polarizer and analyser are parallel to each other.

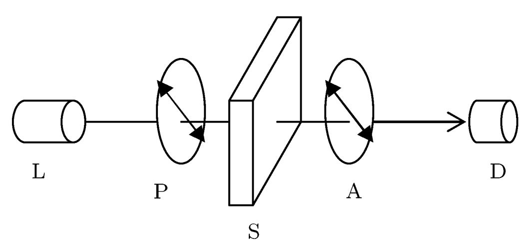

Fig.1. Setup for transmissive LC cell measurement.

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2.2. Fundamental theory

The coordinate system referring to the sample of TNLC cell and incident light is shown in Fig.2.

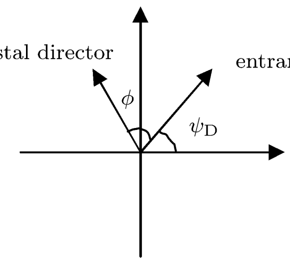

Fig.2. Coordinate system referring to the sample of TNLC cell and incident light.

The normalized intensity T transmitted by the system is given by:

$$T = \left|(1,0)\, R(\Psi_D) M_{LC} R(-\Psi_D) \begin{pmatrix} 1 \\ 0 \end{pmatrix}\right|^2, \quad (1)$$

where R is the rotation matrix:

$$R(\theta) = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}, \quad (2)$$

M_{LC} is the Jones matrix of a twisted nematic LC layer:

$$M_{LC} = R(-\phi) \begin{pmatrix} \cos\beta - i\delta\dfrac{\sin\beta}{\beta} & \phi\dfrac{\sin\beta}{\beta} \\ -\phi\dfrac{\sin\beta}{\beta} & \cos\beta + i\delta\dfrac{\sin\beta}{\beta} \end{pmatrix} \quad (3)$$

with

$$\begin{aligned} \beta^2 &= \phi^2 + \delta^2, \\ \delta &= \pi \Delta nd/\lambda, \\ \Delta n &= \frac{n_e}{\sqrt{1 + w\sin\theta^2}} - n_o, \\ w &= \left(\frac{n_e}{n_o}\right)^2 - 1. \end{aligned} \quad (4)$$

Where ϕ is the twist angle, d is the thickness of a TNLC cell, λ is the wavelength, θ is the pretilt angle and n_e and n_o are the extraordinary and ordinary refractive indices of the LC material respectively and Δnd is optical retardation. Then, Eq.(1) can be rewritten as

$$\begin{aligned} T =& \left(\cos\beta\cos\phi + \frac{\phi}{\beta}\sin\beta\sin\phi\right)^2 \\ &+ \left(\frac{\delta}{\beta}\sin\beta\cos(\phi + 2\Psi_D)\right)^2. \end{aligned} \quad (5)$$

Usually the parameters are measured not in darkness and T' is the intensity from environment supposed to be steady in short time. Then, equation (5) can be rewritten as

$$\begin{aligned} T_2 =& \left(\cos\beta\cos\phi + \frac{\phi}{\beta}\sin\beta\sin\phi\right)^2 \\ &+ \left(\frac{\delta}{\beta}\sin\beta\cos(\phi + 2\Psi_D)\right)^2 + T'. \end{aligned} \quad (6)$$

If the sample of TNLCD is rotated, ψ_D will be correspondingly changed and T_2 will be also varied. But if ψ_D is satisfied with the condition $\phi + 2\psi_D = \pm n\pi$, at the same time ψ_D is written as $\psi_D(\max)$, T_2 will be maximum $T_{\max}$. When TNLCD is rotated by α from $\psi_D(\max)$, $T(\alpha)$ can be written as:

$$\begin{aligned} T(\alpha) =& \left(\cos\beta\cos\phi + \frac{\phi}{\beta}\sin\beta\sin\phi\right)^2 \\ &+ \left(\frac{\delta}{\beta}\sin\beta\cos(\phi + 2(\Psi_D(\max) + \alpha))\right)^2 + T' \\ =& \left(\cos\beta\cos\phi + \frac{\phi}{\beta}\sin\beta\sin\phi\right)^2 \\ &+ \left(\frac{\delta}{\beta}\sin\beta\cos(\pm n\pi + 2\alpha)\right)^2 + T'. \end{aligned} \quad (7)$$

We define $f(\alpha)$ as the following equation

$$\begin{aligned} f(\alpha) =& T_{\max} - T(\alpha) \\ =& \left(\frac{\delta}{\beta}\sin\beta\right)^2 (1 - \cos^2 2\alpha). \end{aligned} \quad (8)$$

Once the dependence of $f(\alpha)$ on α is known, ϕ and Δnd as fitting parameters can be determined by a curve fitting using Eq.(8) and software Matlab 7.0.

3. Result and discussion

3.1. Twist angle and retardation

Our measurement were performed for the sample of TNLC (material of LC: SLC-7609A, space: 10μm, the designed angle between the rubbing directions of a pair of glass substrates: 0°) by this proposed method. Figure 3 shows the relationship between $f(\alpha)$ and α.

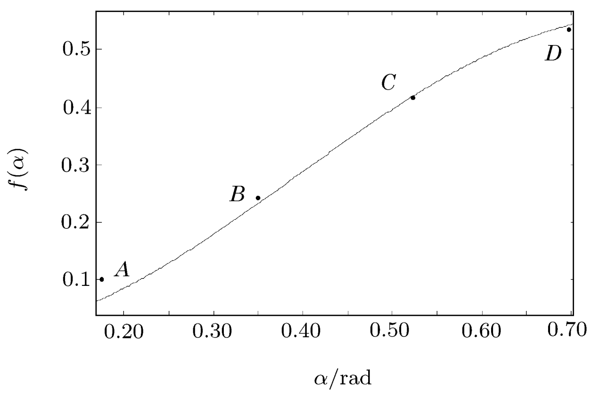

Fig.3. Relationship between $f(\alpha)$ and α (A, B, C and D are experimental data points).

The twist angle ϕ and optical retardation Δnd as fitting parameters are 0° and 1.434μm respectively.

3.2. Rubbing direction

The rubbing direction on the LC cell can be obtained for an unknown cell if we assume strong surface anchoring. In other words, the rubbing direction on glass surface is equal to the liquid crystal surface director orientation, which is usually the case for all commercial LC cells where the alignment is carried out by rubbing a polyimide film. When the transmittance T becomes maximum by rotating the sample of TNLCD then

$$\phi + 2\psi_{\rm D} = \pm n\pi. \tag{9}$$

Because ϕ has been known by the curve fitting, $\psi_{\rm D}$ can be also determined and the rubbing direction is known too.

3.3. Influence from environment and absorption

Because we use Eq.(8) as a curve fitting equation which is a subtraction equation of transmittance, the influence from the absorption by polarizer, the sample of LCD, the analyser and the light from environment is eliminated. It can be proved by the following experiments. The experiments were performed for the two samples of LC cell full of the same material of 5CB in the different environment. The results are shown in Table 1.

Table 1. The measurement results in the different environment.

sample	space	the angle between the rubbing directions	$T_{\rm out}/T_{\rm laser}$	ϕ	Δnd
A	10μm	90°	19.6%	90.47°	1.79μm
B	15μm	67°	0.24%	67.61°	2.72μm

$T_{\rm out}$ is intensity of the disturbing light from environment and $T_{\rm laser}$ is intensity of laser. From the results in the Table 1, we can see that although the intensity of the disturbing light from environment is large to sample A, the results are also accurate.

3.4. Discussion

From the Fig.3 we see that the curve did not properly pass the experimental data A, it is because that there is error during measurement of data A . There are two important factors that influence the exactness of experimental results. One is the error of the place of $\psi_{\rm D}$(max), the other is the visual reading error of rotated angle α, but the following method can help us to determine the place of $\psi_{\rm D}$(max) exactly. When the sample of TNLCD is rotated anticlockwise from $\psi_{\rm D}$(max) by α, the intensity T is written as $T(\alpha)$; when the sample of TNLCD is rotated clockwise from $\psi_{\rm D}$(max) by α, the intensity T is written as $T(-\alpha)$. $T(\alpha)$ should be equal to $T(-\alpha)$ if the place of $\psi_{\rm D}$(max) that we find is right. In this way the second error can also be found, meanwhile in the experiment the step between α is 0.1745 radian, we can use the stepping motor with 0.05 radian per step to diminish the second error.

4. Conclusions

We proposed a novel method to determine the cell parameters of TNLCD, including the twist angle, optical retardation and the rubbing direction. This method is a single-wavelength method and the influence from the absorption by polarizer, the sample of LCD and analyser and the light from environment can be eliminated. The experimental setup is quite simple and can be easily adopted to be carried out. By numerical experiments we found that the total error in the experiment of determining ϕ and Δnd would be within a maximum of $\pm 1^\circ$ and $\pm 0.02\mu$m. Because it is simple and precise, this method could be used widely during the manufacturing process of LCD.

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