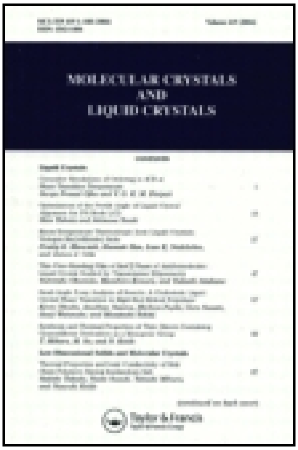

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Jin Gwag [a] , Seo Lee [a] , Kyoung Ho-Park [a] , Won Park [a] , Kwan-Young Han [a] , Tae-Hoon Yoon [a] , Jae Kim [a] , Kwan-Young Han [b] , Tae-Hoon Yoon [b] & Jae Kim [b]

[a] Department of Electronics Engineering, Pusan National University, Pusan, Korea

[b] Research Institute of Computer, Information and Communication, Pusan National University, Pusan, Korea

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HIGH PRETILT ANGLE MEASUREMENT BY EXTENDED CRYSTAL ROTATION METHOD

Jin Seog Gwag, Seo Hern Lee, Kyoung Ho-Park, Won Sang Park, Kwan-Young Han, Tae-Hoon Yoon, and Jae Chang Kim
Department of Electronics Engineering, Pusan National University, Pusan 609-735, Korea

Kwan-Young Han, Tae-Hoon Yoon, and Jae Chang Kim
Research Institute of Computer, Information and Communication, Pusan National University, Pusan 609-735, Korea

Measurement ranges of pretilt angle using the conventional crystal rotation method is limited in $0 \sim 10^\circ$ and $80^\circ \sim 90^\circ$. So the determination of a pretilt angle for a cell which has a high pretilt angle of $10^\circ \sim 80^\circ$ is not easy by this method. We propose a new method which can find a pretilt angle for cells which have high pretilt as well as cells which have low pretilt angle. In this method, the determination of a pretilt angle is achieved by finding the rotation angles which become a maximum and a null transmittance in the crystal rotation method.

Keywords: high pretilt angle; LCD parameter; pretilt angle; tilt bias angle

1. INTRODUCTION

Pretilt angle is one of the most important parameters because it strongly influences the performance of liquid crystal display devices. In order to optimize display performance, it is very important to have an accurate technique to measure pretilt angle. Several methods to measure the pretilt angle of nematic liquid crystal molecules were proposed [1,2]. To determine the pretilt angle of a nematic liquid crystal, the crystal rotation method is generally used because of its simple, precise and rapid measurement. However, when pretilt angle is higher than 10°, the conventional crystal rotation

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Address correspondence to Jin Seog Gwag, Department of Electronics Engineering, Pusan National University, Pusan 609-735, Korea.

method cannot be used because it is difficult to determine the optical symmetry point. Thus it has a restricted range of application. The commonly studied pretilt angles are either well below 20° or higher than 80°. But pretilt angle in the range of 20°–80° is important in both developing new LCD technologies and improving existing LCDs such as π-cell display. At a pretilt angle higher than 20°, the magnetic null method is commonly used but it is more complicated because of measurement system with a large magnet. In this paper, we propose the extended crystal rotation method applicable to high pretilt angle (10°–80°). The proposed method can be applied to all range of pretilt angle in a nematic liquid crystal cell. In the proposed method, we determine a pretilt angle by finding the rotation angles β which becomes a maximum and a null transmittan in the crystal rotation method.

As in the crystal rotation method, the liquid crystal cell is rotated between crossed polarizers, the polarizer angle of 45° and the analyzer angle of $-45°$ or between the polarizer angle of 15° and the analyzer angle of 45° with respect to the rubbing direction.

2. CRYSTAL ROTATION METHOD

We assume that a nematic liquid crystal confined between two antiparallel rubbed substrates forms a part of a uniaxial single crystal having its optic axis at some angle α with respect to the plane of the layer, as shown in Figure 1, the optic axis is uniformly oriented within the layer and the orientation of the optic axis is determined only by the pretilt angle, independent of the cell gap and the strength of the boundary coupling. In this method, because the pretilt angle is measured for a nematic liquid crystal cell, when the cell is rotated around the midpoint of the cell as shown in Figure 2, the retardation $\Theta(\beta)$ of light passing through the cell is expressed by the

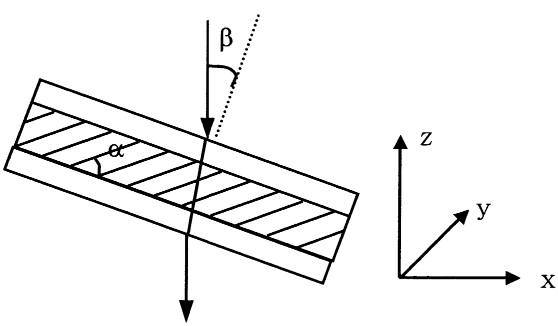

FIGURE 1 A liquid crystal cell showing pretilt angle α and angle of light incidence β.

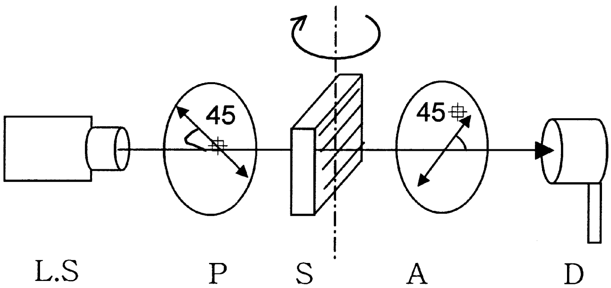

FIGURE 2 Configuration of polarizers, sample, light source and detector: the polarizer angle of 45° and the analyzer angle of − 45° with respect to the rubbing direction.

following equation.

$$\Theta(\beta) = \frac{\pi}{\lambda} d f(\alpha, \beta) \tag{1}$$

Where d is the cell gap of the liquid crystal cell, λ is the wavelenght of the incident radiation and $f(\alpha,\beta)$ is a function of the pretilt angle α and the rotation angle β which is defined as the angle between the incident light beam and the direction normal to the cell. $f(\alpha,\beta)$ is expressed as follow

$$\begin{aligned} f(\alpha,\beta) &= \frac{1}{c^2}(a^2 - b^2)\sin\alpha\cos\alpha\sin\beta + \frac{1}{c}\left(1 - \frac{a^2b^2}{c^2}\sin^2\beta\right)^{1/2} \\ &\quad - \frac{1}{b}(1 - b^2\sin^2\beta)^{1/2} \\ a &= \frac{1}{n_e}, \quad b = \frac{1}{n_o}, \quad c^2 = a^2\cos^2\alpha + b^2\sin^2\alpha, \end{aligned} \tag{2}$$

where n_o and n_e are the ordinary and extraordinary refractive indices of the nematic liquid crystal. The transmission of light through this uniaxial section placed between the cross polarizers and oriented with its principal plane at 45° to the plane of polarized light is given by

$$T(\beta) = \frac{1}{2}\sin^2(\Theta(\beta)). \tag{3}$$

where ideal polarizers have been assumed and surface reflection as well as absorption in the liquid crystal have been neglected.

Figure 4 shows the calculated result of the transmittance and the retardation as a function of the incident angle by using Eqs. (1) and (2) for the case $\alpha = 3°$, $n_o = 1.4978$, $n_e = 1.6101$, $d = 30\,\mu m$, and $\lambda = 632.8$ nm. The curve is almost symmetrical around a certain angle β_x. For this angle β_x, the retardation $\Theta(\beta)$ becomes a maximum.

An implicit relationship between α and β_x is obtained by differentiating Eq. (2) with respect to β and equating the result to zero.

$$\frac{1}{c^2}(a^2 - b^2)\sin\alpha\cos\alpha - \frac{a^2b^2}{c^3}\left(1 - \frac{a^2b^2}{c^2}\sin^2\beta_x\right)^{-1/2}\sin\beta_x + b(1 - b^2\sin^2\beta_x)^{-1/2}\sin\beta_x = 0. \tag{4}$$

This equation includes neither the wavelength of the light nor the cell gap of a nematic cell. If we find by experiment the rotation angle β_x which become the symmetrical point of transmittance, from Eq. (4), the pretilt angle can be determined as a function of β_x.

3. EXTENDED CRYSTAL ROTATION METHOD

For a liquid crystal cell which has high pretilt angle more than 20°, we cannot find the pretilt angle of the cell by using the conventional crystal rotation method. Therefore a method which chooses accurately high pretilt angle is required. As in the crystal rotation method, optical configuration of the our proposed method for determining a pretilt angle is that the polarizer angle is 45° and the analyzer angle is 45° with respect to the rubbing direction as shown in Figure 2. Then transmittance is given by

$$T(\beta) = \frac{1}{2}\cos^2(\Theta(\beta)). \tag{5}$$

Then if the retardation Θ is $\pm n\pi$, transmittance should be maximum where n = 1, 2, 3, $\propto$, and if the retardation Θ is $\pi/2 \pm m\pi$, transmittance should be null where m = 0, 1, 2, $\propto$, as the following equations

$$\Theta(\beta_1) = \frac{\pi}{\lambda}df(\alpha, \beta_1) = \pm n\pi \ (n = 1, 2, 3 \ldots.) : \textit{maximum transmittance} \tag{6}$$

$$\Theta(\beta_2) = \frac{\pi}{\lambda}df(\alpha, \beta_2) = \pi/2 \pm m\pi \ (m = 0, 1, 2 \ldots.) : \textit{null transmittance}. \tag{7}$$

Then Eq. (6) divided by Eq. (7) is given as the following equation

$$\frac{f(\alpha, \beta_1)}{f(\alpha, \beta_2)} = \frac{\pm n}{1/2 \pm m}. \tag{8}$$

Therefore, since we can find two rotation angles at which become a maximum and a null transmittance by experiment, a pretilt angle can be determined by using Eq. (8). Another optical configuration for determining a pretilt angle is that the polarizer angle is 45° and the analyzer angle is 15°

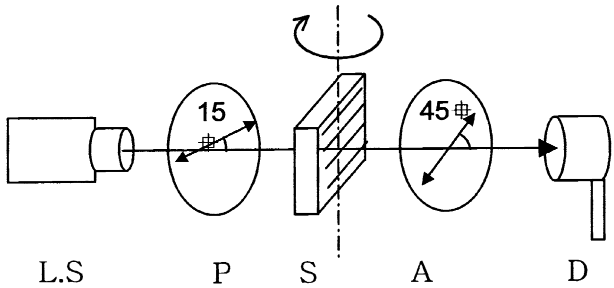

FIGURE 3 Configuration of polarizers, sample, light source and detector: the polarizer angle of 15° and the analyzer angle of 45° with respect to the rubbing direction.

with respect to the rubbing direction as shown in Figure 3. Then transmittance is given by

$$T(\beta) = \frac{3}{8}\cos^2(\Theta(\beta)) + \frac{1}{8}\sin^2(\Theta(\beta)). \tag{9}$$

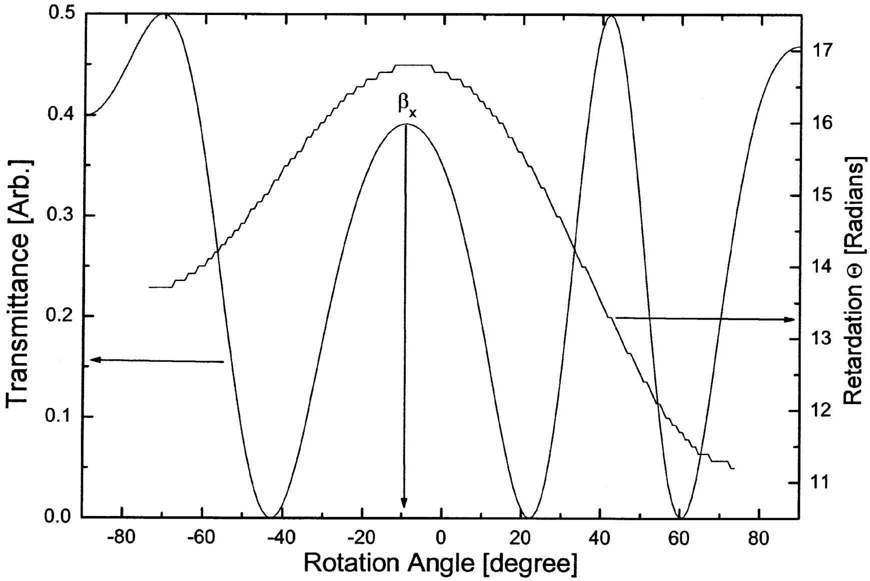

FIGURE 4 Dependence of transmittance T and retardation Θ on rotation angle β for the case $\alpha = 3°$, $n_o = 1.4978$, $n_e = 1.6101$, $d = 30\,\mu m$, $\lambda = 632.8\,nm$, the polarizer angle of 45° and the analyzer angle of $-45°$ with respect to the rubbing direction.

In above equation, the maximum of transmittance is determined by the first term and the null is by the second term. Therefore this equation as in Eq. (5) becomes if the retardation Θ is $\pm n\pi$, maximum transmittance and if the retardation Θ is $\pi/2 \pm m\pi$, null transmittance where $m = 0, 1, 2, \propto$. So then we also can obtain Eq. (8). In the result, if there are two rotation angles at which become maximum and a null transmittance in between $-90^\circ \sim 90^\circ$, a pretilt angle is determined. Figure 5 shows the calculated result of the transmittance and the retardation as a function of the incident angle by using Eqs. (1) and (9) for the case $\alpha = 20^\circ$, $n_o = 1.4978$, $n_e = 1.6101$, $d = 10\,\mu m$, and $\lambda = 632.8\,nm$.

4. EXPERIMENT AND DISCUSSION

Our measurement for the determination of the pretilt angle was performed for a LC cell [LC: ZLI-3449, spacer : 50 μm]. The chalcone contained polyimide (DDCn(ρ)) shown in Figure 4 was used for the creation of high pretilt angle in this cell. Then pretilt angle could be controlled by the length of chalcone. A He-Ne laser was used as the light source. The optical configuration without analyzer was used as a reference. Figure 6 shows the

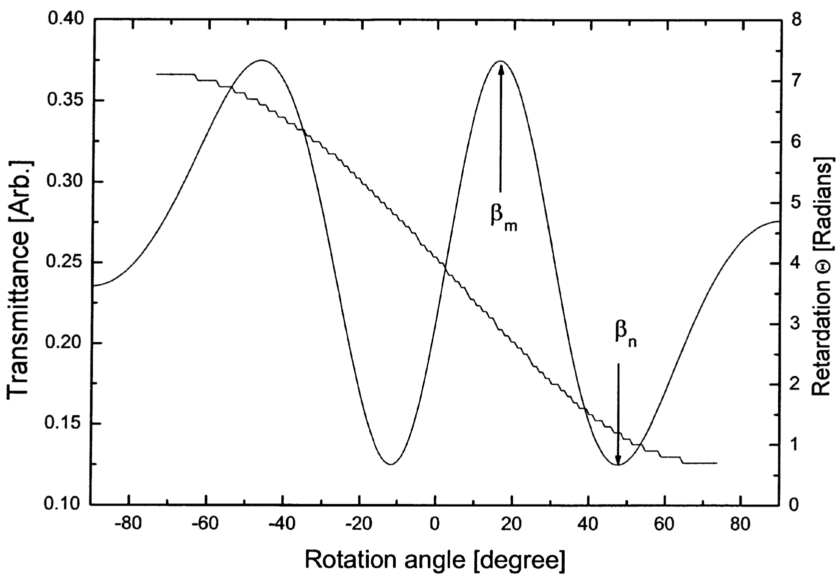

FIGURE 5 Dependence of transmittance T and retardation Θ on rotation angle β for the case $\alpha = 20^\circ$, $n_o = 1.4978$, $n_e = 1.6101$, $d = 10\,\mu m$, $\lambda = 632.8\,nm$, the polarizer angle of 15° and the analyzer angle of 45° with respect to the rubbing direction.

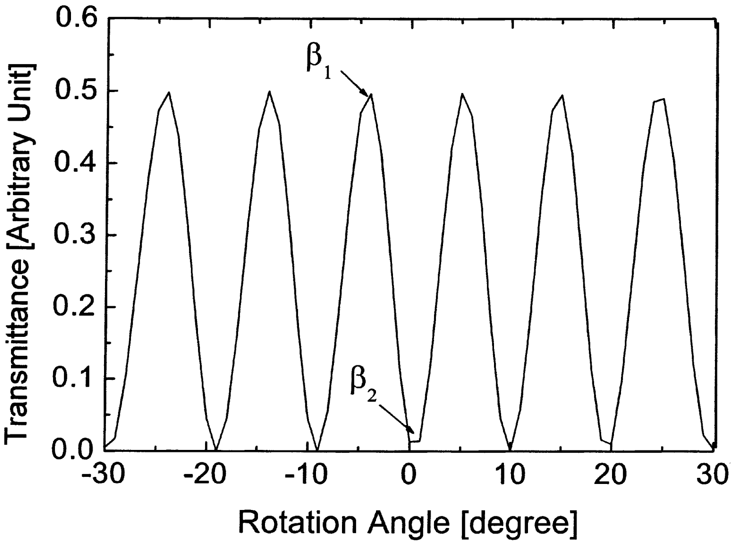

FIGURE 6 Measurement of transmittance T on rotation angle β for the case LC: ZLI-3449, $d = 50\,\mu m$, $\lambda = 632.8\,nm$, the polarizer angle of 45° and the analyzer angle of $-45°$ with respect to the rubbing direction. Then β_1 is $-5°$ and β_2 is 1°.

measured results of the transmittance corresponding to each rotation angle. Then the two rotation angles, β_1, and β_2 where the transmittances are maximum are $-4°$ and 1° respectively. And as most cases, if the size of spacer used is known, we can find the order numbers of n and m. Putting these values into Eq. (8), then the pretilt angle is obtained to be 33.4°. Here we chose the rotation angles near 0° where the error by fresnel reflection is not so much.

5. CONCLUSION

The extended crystal rotation method which can measure low pretilt angle as well as high pretilt angle is proposed. The pretilt angle can be found by measuring the rotation angles where transmittances become maximum and minimum in the periodic transmittance characteristics obtained with the variation of rotation angle.

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