Application of Rotating Polarizer Method to Low LC Cell Gap Measurement

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Abstract

Measurement of low cell gap and retardation by using a rotating polarizer method was proposed. For more precise calculation and measurement, we applied a retardation film that has large retardation value of 1 μm to measurement system. From experiments, we proved that cell gap and retardation could be measured even though the values of those are so small.

I. Introduction

A cell gap is an important parameter in optical properties of a LC cell and it strongly influences on the optical performance of liquid crystal devices. Therefore, the measurement technology for cell gap and twist angle is very important both in manufacturing techniques and in basic studies on LCDs. Fast and accurate measurement of cell thickness of LC layers is fundamental for realizing good performance of displays in the manufacturing process. Many methods have been introduced in the past. In measuring empty cell gap, the spectral interferometric method so called peak-to-peak method has been used. However, after the liquid crystal is filled, the cell gap and its variation across the entire cell may not be the same as they were before the filling. Therefore, a method to measure the cell gap of the filled LC cell is strongly desirable. Recently, the interferometric method[1] has been extended to measure the cell gap for a filled LC cell. However, since the cell gap obtained by this method is determined from other interference pattern, the thickness measured would be the effective thickness of the LC layer plus two alignment layers. It would not be easy to apply this method to measure the cell gap of a color TN cell due to too many reflection surfaces for a color LCD. Other methods to measure the cell gap of the filled LC cell are the rotating polarizer method[2] and the phase compensation method[3]. Both methods have a high accuracy. However, the phase compensation method is rather complicate and takes a long time to measure the cell gap. So, this method is not recommended for automated measurement system. The rotating polarizer method needs a short time to measure the cell gap. This method is suitable for the automated measurement system. However, the rotating polarizer method has serious problems in measuring a low cell gap. In this paper, we present a retardation film used rotating polarizer method, which is application of rotating polarizer method to low cell gap measurement.

II. Rotating Polarizer method

The rotating polarizer method, established by Otsuka (Japan), has been widely used for cell gap measurement because of its own simplicity and high accuracy. This method doesn't need an iteration process in experiment. So it takes a short time for measuring a cell gap. The necessary measuring equipment for the rotating polarizer method is achieved by using a polarizing microscope as shown in Fig. 1(a). Where θ, ϕ_P and ϕ_A are the exit LC director and the entrance and exit polarizer angles, with respect to the entrance LC director. The optical components and a filled LC cell were arranged in the following sequence: the white light source, the entrance polarizer, the filled LC cell, the exit polarizer and the fiber bundle, which could be connected to a spectrometer. The transmission axis of the entrance polarizer makes a 45° angle with respect to the entrance LC director. The transmission axis of the exit polarizer is perpendicular to that of the entrance polarizer. By solving the Jones matrix representation, the transmittance of the system shown in Fig 1(a) is given as

$$T = [\cos(\theta x)\cos(\theta+\phi_P-\phi_A)+\frac{\sin(\theta x)}{u}\sin(\theta+\phi_P-\phi_A)]^2 + (\frac{u}{x})^2\sin^2(\theta x)\cos^2(\theta-\phi_P-\phi_A) \quad (1)$$

where

$$x=\sqrt{u^2+1}, \quad (2)$$

$$u=\frac{\pi d}{\lambda\theta}(n_e^{'}-n_o)=\frac{\pi d}{\lambda\theta}(\frac{n_e}{\sqrt{1+w\sin^2\theta_s}}-n_o) \quad (3)$$

$$w=(\frac{n_e}{n_o})^2-1 \quad (4)$$

And where n_e and n_o are the ordinary and extraordinary indices of refraction of LC, respectively, d is the cell gap thickness, θ_s is the pretilt angle, and λ is the wavelength of the light source.

When the entrance polarizer angle (ϕ_P) makes 45° angle and the exit polarizer angle (ϕ_A) makes θ+45° with respect to the entrance LC director, the optical transmittance is represent as follows

$$T=\cos^2(\theta x) \quad (5)$$

In this measurement system, the low cell gap cannot be measured because the transmission peak or valley does not appear on the visible spectrum range. Therefore, the new measurement system is required.

III. Application of Rotating Polarizer method

Adding the optical retardation film to the LC cell can solve the problem in low cell gap measurement. This film can add retardation (Δnd) to the LC cell that has low optical retardation. After adding the retardation film, the transmission peaks or valleys can be appear at the visible spectrum range. Then, we can use those points for measuring a low cell gap.

The measuring equipment for the retardation film used rotating polarizer method is achieved as shown as Fig. 1(b). By using the Jones matrix representation, one can show that the optical transmittance of the system shown in Fig 1(b) is given as

$$T=\left|\begin{bmatrix}\cos\phi_A & \sin\phi_A\end{bmatrix}\begin{bmatrix}\cos\psi & -\sin\psi\\ \sin\psi & \cos\psi\end{bmatrix}\begin{bmatrix}e^{-i(\Gamma/2)} & 0\\ 0 & e^{+i(\Gamma/2)}\end{bmatrix}\times\begin{bmatrix}\cos\psi & \sin\psi\\ -\sin\psi & \cos\psi\end{bmatrix}\begin{bmatrix}J_m\end{bmatrix}\begin{bmatrix}\cos\phi_P\\ \sin\phi_P\end{bmatrix}\right|^2 \quad (6)$$

where Γ is the retardation of the film, and Ψ is the retardation film angle(slow axis) with respect to the entrance LC director. And matrix J_m represents the LC cell as follows.

$$J_m = e^{i(\pi d/\lambda (n_e' - n_o))}\begin{bmatrix} a & b\\ -b^* & a^*\end{bmatrix} \quad (7)$$

where

$$a=\frac{1}{x}\sin\theta\sin(x\theta)+\cos\theta\cos(x\theta)+i\frac{u}{x}\cos\theta\sin(x\theta) \quad (8)$$

$$b=\frac{1}{x}\cos\theta\sin(x\theta)-\sin\theta\cos(x\theta)+i\frac{u}{x}\sin\theta\sin(x\theta) \quad (9)$$

This matrix can be achieved by using the Chebyshev's identity.

In this system, the retardation value (Δnd) of the film should be measured at first. From the simulation result, we found a favorable retardation value is over 430 nm below 1500 nm. Considering the effect of the twist angle and cell gap, the most favorable retardation value of the film is over 430 nm. If this value is too large, Retardation of LC cell can be ignored. So large error can be produced. The retardation of the film is achieved by the spectrum analysis. When the entrance polarizer angle (ϕ_P) makes -45° angle and the exit polarizer angle (ϕ_A) make 45° with respect to the retardation film angle, the optical transmission is attained as shown in Fig 2. We used the peak (501.0 nm) and the valley (629.0 nm) for measurement of film retardation and used a minimum transmission condition and Caushy formula. Then the film retardation can be achieved as follows

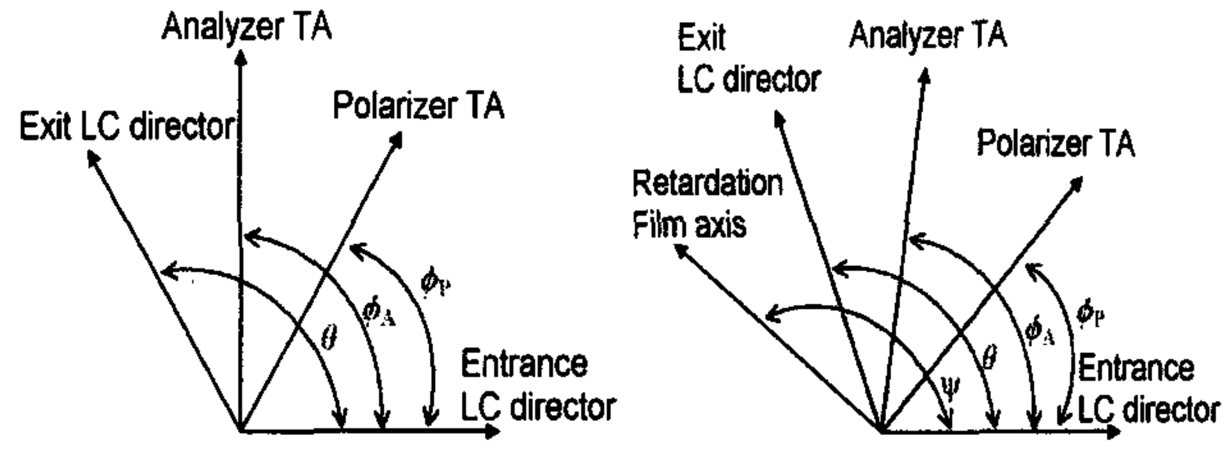
$$\Delta nd_{film} = 8.42\times10^{-7} + 4.02\times10^{-20}/\lambda^2\ \mathrm{K} \quad (10)$$

The following measurement example on a 45°, 90°, 180° TN cell filled with ZLI-1557(E. Merck) having a pretilt angle of 4° illustrates how this cell gap measurement system is worked. We used a halogen lamp for the white light source, which have visible range wavelength (from 400 nm to 800 nm). the entrance polarizer angle makes -45° angle and the exit polarizer angle make 45° and the retardation film angle make 45° with respect to the entrance LC director, the optical transmission is attained as shown in Fig 3.

All of the 45°, 90°, 180° TN cells didn't show the optical transmission peak or valley without retardation film. After using film, the optical transmission peak or valley appeared at 591.0 nm, 595.5 nm, and 536.0 nm. We used iteration method to find a cell gap, which made the coincident peak or valley between experiments and simulation as shown in Fig 4. Finally we could find that the each low cell gap were 2.2 ㎛, 2.2 ㎛, and 3.0 ㎛.

IV. Conclusion

In this paper we showed that a low cell gap could be measured using the film used rotating polarizer method. To improve the accuracy, the exact dispersion information of the retardation film is needed and high-resolution spectrometer must be used.



(a) (b)

Fig 1. System configuration (a) Rotating polarizer method (b) Film used rotating polarizer method

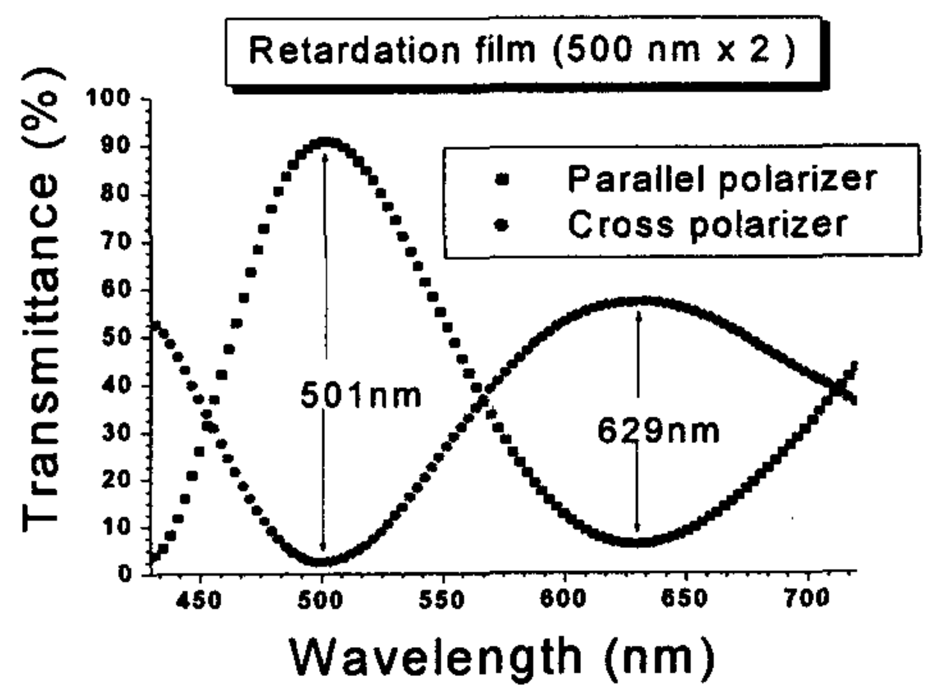


Fig 2. Spectral analysis of the retardation film for calculation of dispersion of retardation film

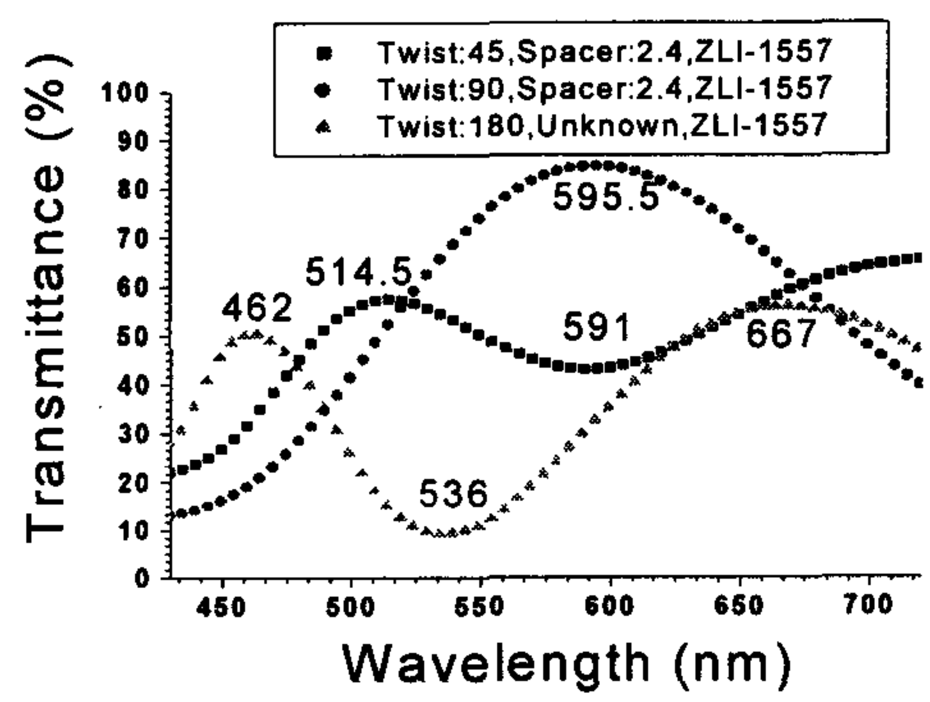


Fig 3. Measured result from the film used rotating polarizer method

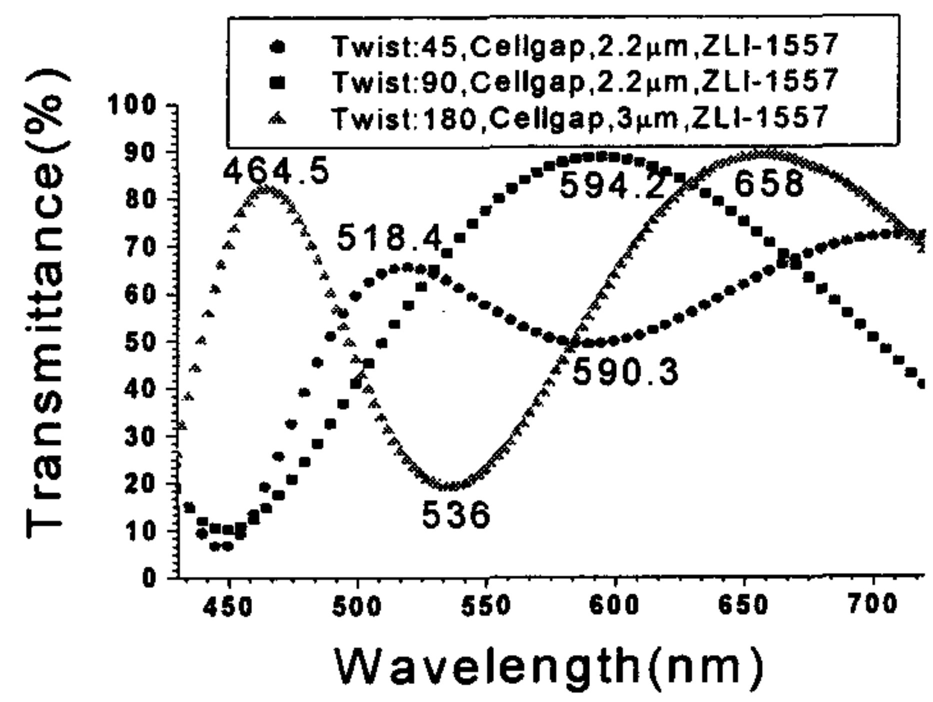


Fig 4. Simulated result from the film used rotating polarizer method

Acknowledgement

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References and notes

[1] K. H. Yang and H. Takano, J. Appl. Phys., 67, p. 5, 1990.
[2] Otsuka publication, "Multi channel Retardation Measuring System Rets-2000".
[3] A. Lien and H. Takano, J. Appl. phys., vol. 69, no. 3, 1991.