15.4: Reflective LCD Cell Gap Measurement by QHQ Compensation Method

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Abstract

A phase compensation method is presented for measuring the cell gap of reflective LCD. We use the so-called QHQ compensator that is made up of two quarter-wave plates (Q) and one half-wave plate (H). This method is different from other compensation methods in that we can change both the orientation angle and retardation value of the compensator by rotating the quarterwave and halfwave retarders. As a result, the QHQ compensation method has a higher accuracy and a simpler procedure.

1. Introduction

In reflective LCD design, the retardation value $\delta = \frac{d\Delta n}{\lambda}$ is most important. It makes a critical influence to the performance of the LCD. But its value is quite often not known exactly in a finished LCD since the final cell gap can deviate from the designed value due to processing inaccuracies. So it is desirable to determine the final cell gap (final retardation value δ) of a filled LC cell. Previous transmissive methods are unsuitable for the measurement of reflective LCD.

In recent years, a few methods using laser or spectrometer to characterize reflective LCD cell gap have been reported [1-4]. They can be classified into two approaches. The first one is a rotation method (rotating LC cell or Polarizer/Analyzer) [1-4]. Tang and Kwok [1] called these methods as LP1/LP2/CP methods. These methods have simple set-ups and procedures, and use either the laser source [1-3] or a broadband light source [4]. However, the accuracy is not very good.

The other class of method makes use of phase compensation. The phase value of the compensator corresponding to minimum transmission of the whole system is used to determine the cell gap [2,3]. However, the change of the transmission isn't very sensitive to the change of the phase value of the general compensator around the minimum transmission. Therefore, the general compensator method [2] cannot give an accurate cell gap either. Method [3] is accurate but needs more calculations; what's more, to normalize transmission they must know the maximum & minimum transmissions, which depend on the laser source. So method [3] is not too reliable either.

In this paper, we will report a new cell gap measurement technique using QHQ compensation. This method has a simpler procedure and a higher accuracy than those reported.

2. Theory

The experimental set-up is shown in Figure.1.

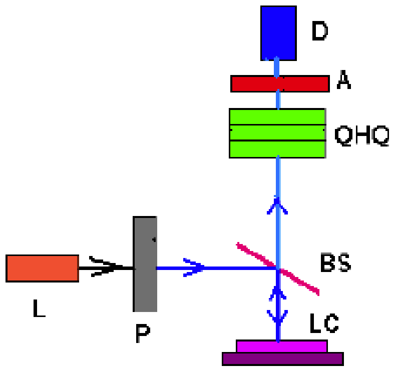

Figure 1. The set-up for reflective LCD cell gap measure. L-laser source, P- polarizer, A-analyzer, D-detector. The QHQ is the sequence of quarter waveplate - half waveplate - quarter waveplate.

It has been shown that a nematic LCD system is equivalent to the combination of a retardation plate and a polarization rotator [5]

$$Mlc = R(\chi)WP(\Gamma,\psi) \qquad (1)$$

where

$$\tan 2\psi = (\phi/\beta)\tan\beta \qquad (2)$$

$$\sin^2(\Gamma/2) = (\delta^2/\beta^2)\sin^2\beta \qquad (3)$$

and

$$\chi = \phi - 2\psi \qquad (4)$$

$$\beta = \sqrt{\phi^2 + \delta^2} \qquad (5)$$

$$\delta = \frac{\pi d\Delta n}{\lambda} \qquad (6)$$

R and WP are the polarization rotation and waveplate Jones matrices. χ is the rotation angle of the rotator, Γ and ψ are the phase retardation and orientation of the c-axis of the equivalent waveplate relative to the x-axis respectively. ϕ, Δn and d being the twist angle, birefringence and thickness of the LC cell respectively.

It has been proved that in the same reference coordinate, the Jones matrix of a reflective unitary system is given by [6]

$$M_R = M^T M \qquad (7)$$

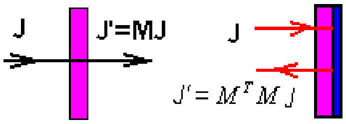

Figure 2. The Jones matrix for a transmissive and reflective unitary system. M^T is the transpose of M.

We apply this useful result to the reflective LCD. The Jones matrix of the reflective LC cell is

$$M_R = M^T M = WP\ (2\Gamma,\ \psi) \qquad (8)$$

This result tells us the LC for reflective system can be equivalent to one simple waveplate. And we also know that any waveplate can be synthesized by the sequence Q-H-Q [7]:

$$\mathrm{QWP3}(\alpha+\pi/4)\mathrm{HWP2}(\alpha+\pi/4+\Gamma)\mathrm{QWP1}(\alpha+\pi/4) = \mathrm{WP}(\alpha, 4\Gamma). \qquad (9)$$

By using the Jones matrix, if the polarizer and analyzer are crossed in the system in Figure.1, the transmittance T is given as:

$$T = \left| (0,1) \bullet WP(\alpha, \Gamma_{QHQ}) WP(\psi, 2\Gamma_{LC}) \bullet \begin{pmatrix} 1 \\ 0 \end{pmatrix} \right|^2 \qquad (10)$$

where

$$WP = \begin{pmatrix} \cos\Gamma/2 - i\sin\Gamma/2\cos2\alpha & -i\sin\Gamma/2\sin2\alpha \\ -i\sin\Gamma/2\sin2\alpha\cos\Gamma/2 & i\sin\Gamma/2\cos2\alpha \end{pmatrix} \qquad (11)$$

In the experiment we set the orientation of two quarter-waveplates to be the same (α); and the orientation (β) of half waveplate is different from α. Then we change α and β, that's, we change both the orientation (α-π/4) and retardation value ($4\beta - 4\alpha$) of the equivalence waveplate to compensate the LC cell. This provides us with a flexible cell gap measurement method.

Also we should observe that the retardation value of the equivalence waveplate is equal to $4(\beta-\alpha)$. If we fix the angle α and just rotate the half-waveplate (change the angle β), the retardation value of the equivalence waveplate will change 4 time as much. This will result in a more precise measurement. The reason is that the change of transmission is much sensitive to the change of the angle β around the minimum transmission. So we can get the precise orientation angle β corresponding to the minimum transmission, then we can get accurate LC cell gap. Figure.3 show one example of this measurement.

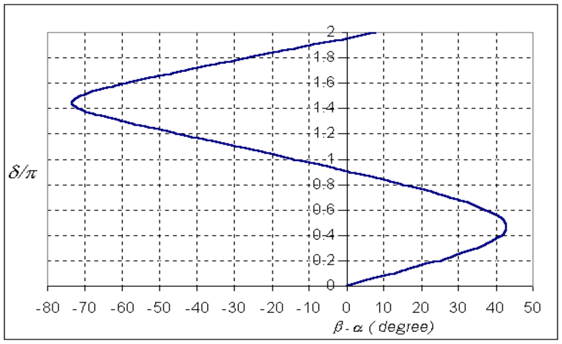

Figure 3. The solution curve for a 52-degree twist angle reflective cell with the orientation of two quarter-waveplates is equal to ψ that is the orientation of the c-axis of the LC equivalent waveplate relative to the x-axis.

In the case of Figure.3, we can get a null transmission. So we can compare this method with the LP2 method [1,4], which gives orientation of the input polarizer corresponding to the null transmission to determine cell gap. This solution curve has a wider angular range and a smaller slope than those of LP2. So we can obtain more accurate cell gap than the LP2 method.

3. Experimental results

In the experiment we made the polarizer and analyzer crossed, and beam splitter (BS) was used in the measurement system as shown in Figure.1. The following simple procedure can be carried out to obtain the cell gap.

(1) Put the reflective LC cell on the stage, and fix the orientation angle of two quarter-waveplates to be one arbitrary angle;

(2) Rotate the half-waveplate until minimum detector reading is obtained;

(3) Record the orientation angles of quarter-waveplate (α_o) and half-waveplate (β_o).

(4) Substitute the known twist angle value ϕ and orientation angle (α_o) of quarter-waveplates into eq.(9)

and solve the equation $\frac{\partial T}{\partial \beta}|_{\beta=\beta 0}=0$. (Calculate $\frac{\partial^2 T}{\partial \beta^2}|_{\beta=\beta 0}>0$, to confirm that's the minimum transmission) for the cell gap.

To vertify our compensation method, a cell with twist angle $\phi = 76^{o}$ is used. The cell gap is about 3.97um, which was obtained by LP1 method [1]. Figs. 4 & 5 show the measured detector readings as a function of the rotation angle of the half-waveplate with the quarterwave plate fixed at 55° and 60° respectively.

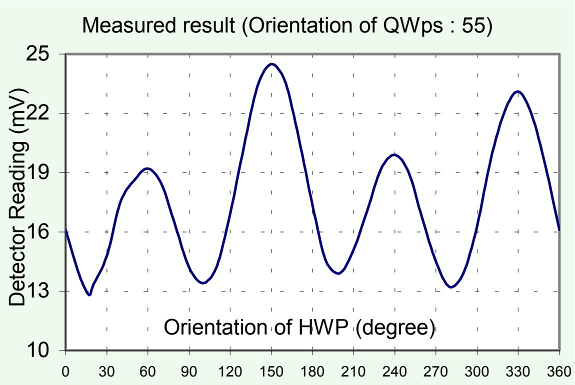

Figure 4. The measured detector readings as a function of the rotation angle of the HWP.

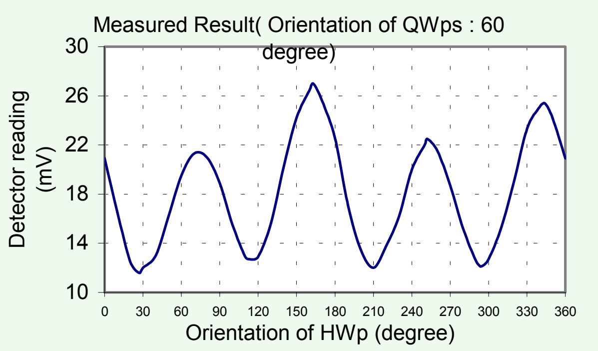

Figure 5. The measured detector readings as a function of the rotation angle of the HWP.

Table.1 shows the orientation angles of HWP corresponding to minimum transmission in the experiment.

Table.1 The orientation angles of HWp corresponding to minimum transmission.

QWP: 55 degree; Rotate HWP to get Min Trans		QWP: 60 degree; Rotate HWP to get Min Trans	
Orientation of HWP	Min. Trans	Orientation of HWP	Min. Trans
13	32%	27	28%
100	34.5%	113	31%
194	35%	208	29%
282	34%	294	30%

So we solve the eq. $\frac{\partial T}{\partial \beta}|_{\beta=\beta 0}=0$ for the cell gap. Fig. 6 shows $\frac{\partial T}{\partial \beta}$ as a function of the cell gap. Then we can get that cell gap is nearly 4um.

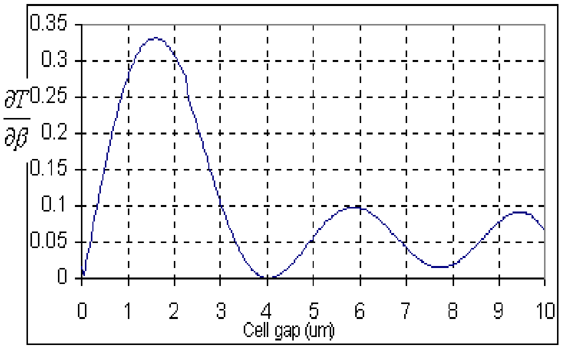

Figure.6 . $\frac{\partial T}{\partial \beta}$ as a function of the cell gap with the QWP at 55° and the HWP at 13°.

Sometimes we are confronted with multiple solutions using this method. We can change the orientation angle of QWPs to solve this problem.

Also we can use another calculation method to obtain the cell gap. We record the minimum detector readings. Then we calculate the corresponding transmittances. The results have been shown in Table.1. And we can obtain the cell gap according to the corresponding transmittances we have calculated.

Figure. 7 shows the transmittance as a function of cell gap with the different orientation angles of QWps and HWp.

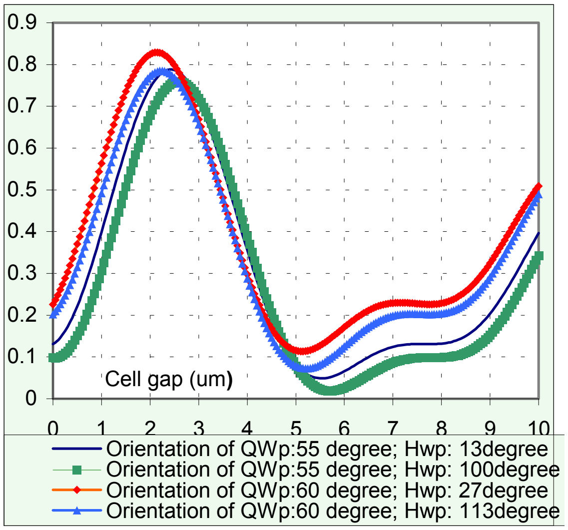

Figure 7 The transmittance as a function of cell gap with the different orientation angles for the QWPs and HWP.

So we measured the cell gap to be 3.95-4. μm using this method. The advantage of the second method is that we are able to obtain one average cell gap, for we can get one value of cell gap for each minimum transmittance.

4. Conclusion

We have proposed and demonstrated the QHQ compensation method to measure the cell gap of reflective LCDs. This method has a better accuracy and a simpler procedure than those proposed earlier.

Acknowledgment

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