Measurement of Phase Retardation in a Liquid Crystal Variable Wave Retarder Using a Polarizing Triangular Interferometer

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ABSTRACT

The purpose of this study aims to investigate a new method for measuring the phase retardation caused by the induced birefringence from a liquid crystal sample. The method uses a polarizing triangular interferometer whose arrangement requires just a few optical devices .The liquid crystal phase retarder under investigation is inserted into an optical path of the triangular interferometer. The modified interference beam, therefore, is used to characterize the sample property. The method is proved to be effective and suitable for the measurements of polarization related parameters of the optical devices.

Keywords: *polarizing triangular interferometer; phase retardation; liquid crystal*

1. INTRODUCTION

Precise and effective methods for the phase retardation measurement due to the induced birefringence via the electro-optic effect are important for the characterization of several optical materials [1]. The interferometric method is often used in this kind of work due to their high sensitivity [2,3]. In this study, the phase shift in a liquid crystal wave retarder introduced to the transmitted light beam is induced by an applied electric field across the liquid crystal. The phase retardations related to the change of liquid crystal birefringence and of path length are measured using a proposed polarizing triangular cyclic interferometer (pCTi). The pTCi phase modulation technique [4,5] provides precise and reliable measurements. In this paper, the report is organized as follows. The setup and its operation are described in the next section, followed by the formulas from which the signal processing is elaborated. The findings from the measured retardation are presented in the experimental results. Finally a brief summary is given in the last section of the paper.

2. THEORY

A. Experimental Setup and Principle of Operation

The apparatus used in this study is the polarizing triangular cyclic interferometer shown in Fig. 1. Two orthogonally linearly polarized beams are injected into the cyclic path. Their polarization directions, perpendicular and parallel to a reference plane, are created by a polarization beam splitter (PBS) and cyclically propagating in the opposite directions within the arrangement. Both beams are recombined and guided to the output by the PBS. An additional piezo electric transducer (PZT), driven by a sinusoidal signal from a function generator, is placed at one corner of the triangular cyclic interferometer to introduce the phase modulation. The rotating linearly polarized light is obtained by inserting a quarter wave plate (QWP) and a linear polarizer (P) at the output of the interferometer.

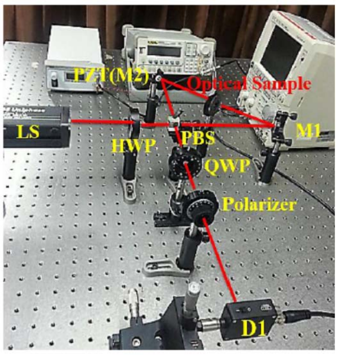

Fig. 1. Schematic diagram of the experimental setup of the polarizing triangular cyclic interferometer.

This recombination of the orthogonally linearly polarized beams at the QWP forms a rotating linearly polarized light. In this arrangement, the azimuth of the linear polarized light can be controlled by modulating the frequency Ω introduced by the PZT. The electric field (E_{out}) of the recombined light beams can be written in terms of Jones notation as [6]

$$E_{out} = (1+i)\frac{E_o}{2}\begin{bmatrix}1\\1\end{bmatrix}e^{i[(\Delta)-(\omega_0+\Omega)t]} \quad (1)$$

where E_o is an amplitude of electric field, Δ is a phase, ω_o is angular frequency and t is time.

The output light intensity I without a sample is found to be

$$I_{out} = E_{out} \bullet E^{*}_{out} = \frac{1}{2}\left[1+sin(\Omega t+2\theta)\right] \quad (2)$$

Eq.(2) shows the intensity of the rotating linearly polarized light as a function of an angle θ set by the polarizer at the output and frequency Ω from the modulation with PZT. The angle θ is the key parameter to characterize the samples from the signal processing.

B. Working principles of intensity sensitive polarization to determine the phase retardation

A liquid crystal retarder is inserted into an optical path of the triangular interferometer. This introduces an output modification in terms of intensity and phase, which, in turn, can be used to characterize the sample itself. The intensity output from the sample, i.e. liquid crystal wave retarder, can simply be analyzed by following Jones matrix treatment. The vector of electric field through the sample can be expressed as [1].

$$E_{out} = P(45^o)\bullet QWP(45^o)\left[E_{aT^{'}sample} + E_{aR^{'}sample}\right] \quad (3)$$

The Jones matrix of the liquid crystal sample is given in Eq.(4) [4,7]. Generally, an applied voltage V across the liquid crystal sample induces an additional retardation γ via the electric field effect. For a proper operation, the characteristics of the liquid crystal cell has to be specified in terms of its azimuth angle (α) and ellipticity angle (ε).

$$Sample = \begin{bmatrix} \cos\frac{\gamma}{2} + i\sin\frac{\gamma}{2}\cos 2\varepsilon\cos 2\alpha & \sin\frac{\gamma}{2}\sin 2\varepsilon + i\sin\frac{\gamma}{2}\cos 2\varepsilon\sin 2\alpha \\ -\sin\frac{\gamma}{2}\sin 2\varepsilon + i\sin\frac{\gamma}{2}\cos 2\varepsilon\sin 2\alpha & \cos\frac{\gamma}{2} + i\sin\frac{\gamma}{2}\cos 2\varepsilon\cos 2\alpha \end{bmatrix} \quad (4)$$

The analysis is taken to be the transmission mode to measure the unknown phase retardation from a sample. The liquid crystal sample is placed in an optical path between PZT(M2) and M1. By choosing the orientation of the sample to be at 0°, 45° and 90° with respect to a reference axis, the intensities of beam outputs captured by the photodetector (D) are written as

$$I_{out}^{0^o} = E_{out}^{0^o}\bullet E_{out}^{0^{o*}} = V^2\cos^2(\Omega t) \quad (5)$$

$$I_{out}^{45^o} = E_{out}^{45^o}\bullet E_{out}^{45^{o*}} = 4V^2\cos^2(\frac{\gamma}{2}+\Omega t) \quad (6)$$

$$I_{out}^{90^o} = E_{out}^{90^o}\bullet E_{out}^{90^{o*}} = V^2\cos^2(\Omega t) \quad (7)$$

The phase difference can be resolved from

$$\gamma = 2\cos\left[\frac{1}{2}\sqrt{\frac{I^{45^o}_{out,polarizer}}{I^{0^o}_{out,polarizer}}}\right] \quad (8)$$

As $I^{45^o}_{out,polarizer}$, $I^{0^o}_{out,polarizer}$, and $I^{90^o}_{out,polarizer}$ can be determined, the phase retardation γ of the optical sample can be worked out consequently.

3. EXPERIMENTAL RESULTS

In this section, the phase retardation measurement performed by pTCi is presented in terms of the relationship between the induced retardation and the applied voltages to the liquid crystal. In order to verify the method and assess the performance of the proposed system, the following experiment was carried out. The sample used in the experiment was a liquid crystal variable wave retarder from Meadowlark Optics. The liquid crystal was induced by varying the applied voltage between 0 V to 20V to create the phase retardation. The phase retardation γ was calculated using Eq. (8). The measured phase retardation was then compared with the calibrated data provided by a commercial polarimeter, the PolarView 3000. The experimental results are illustrated in Fig. 2.

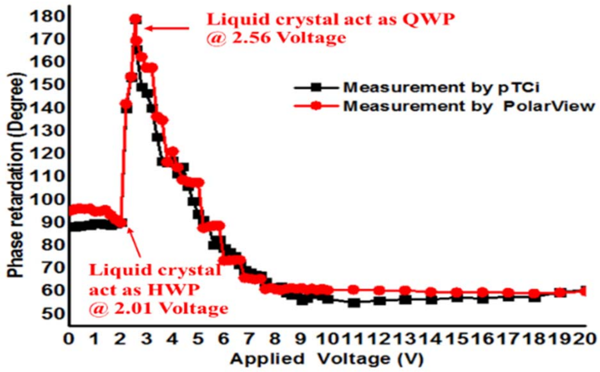

Fig. 2. The comparison of the applied voltage induced birefringence of a liquid crystal variable wave retarder used as a sample, measured @ 633nm with the triangular cyclic interferometer (square data point), with the calibrated retardation versus applied voltage (solid line). The two crucial points are shown @ 2.56 and 2.01 V corresponding to HWP and QWP operations, respectively.

The liquid crystal was chosen as a reliable sample of birefringence wave retarder. The sample is normally used for a continuous and convenient control of the phase shift by way of voltage application. A suitable applied voltage can turn the liquid crystal to act like a specific wave retarder such as a quarter wave plate (QWP) or a half wave plate (HWP). Generally, the pCTi can measure the whole range of the induced phase retardation from the sample. Results depicted in Fig. 2 show the relationship between the applied voltage and phase retardation. To confirm the measured values from the pTCi, specific applied voltages are chosen for the liquid crystal. The experimental results from the pTCi reveal that the liquid crystal cell acts as the HWP and QWP at 2.56 and 2.01 V, respectively. As seen in Fig. 3, this is evident that at an applied voltage of 2.56 V, the linearly polarized state in the cyclic path remains linear, but its orientation is changed to the opposite direction with respect to the input. Under this circumstance, the output is almost zero, the phase retardation introduced by the liquid crystal coupled with the property of the PBS just divert the initial two linearly polarized beam from the output of the interferometer. Such a characteristic of the liquid crystal is equivalent to the HWP.In addition, at the applied voltage of 2.01 V, the liquid crystal transforms the linear polarized light in the cyclic path to a circular polarized light. This suggests that the recombination of the circular

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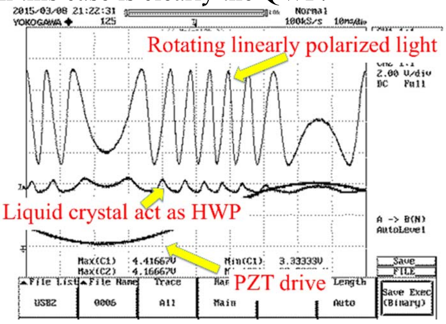
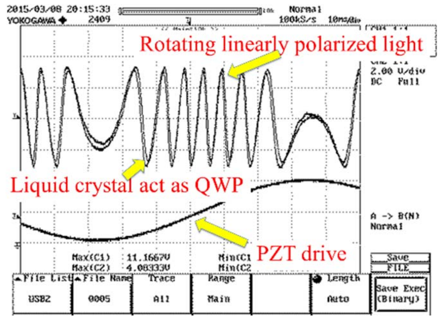
polarized light beams after PBS still gives a rotating linear polarized light beam. The result is exactly the same as the reference. Therefore, the performance of the liquid crystal in this case is clearly the QWP.

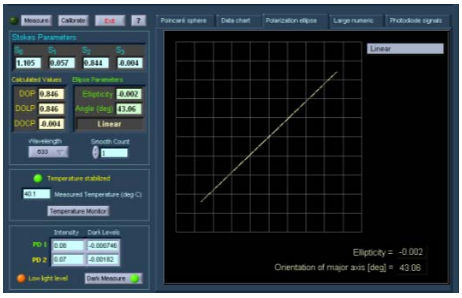


(a)



(b)

Fig. 3. The output signals from pCTi are displayed on the oscilloscope. The results are composed of three sinusoidal curves. Two curves represent the modulation signal and rotating linearly polarized light output. The curves seen in (a) and (b) due to the inserted liquid crystal acting as HWP and QWP in the setup, respectively, can be clearly seen.



(a)

(b)

Fig. 4. The state of polarized light output from the liquid crystal with the appropriate applied voltage detected by a polarimeter; (a) liquid crystal performs as the HWP (b) liquid crystal performs as the QWP. The displays correctly confirm the proposed setup performances.

To confirm the phase retardation introduced by the liquid crystal wave retarder, the PolarView 3000 was used to determine the state of polarization generated by the liquid crystal wave retarder. A separate and simple arrangement was setup by sending linearly polarized beam through the liquid crystal wave retarder when 2.56 or 2.01 V was applied. The measured polarization states obtained from the PolarView 3000 show linear and circular polarized light as seen in Fig. 4. This, therefore, verifies the precision of phase retardation measurement obtained from the proposed pTCi.

4. CONCLUSIONS

This paper has described a pTCi method for measuring the induced phase retardation in a liquid crystal sample. The experimental setup for the phase retardation measurement was found to be easy to implement, stable, and robust against external perturbations. The performance of the pCTi was verified against the measured results made by a commercial polarimeter. Both results were in a good agreement. This method may be useful for a routine characterization of the liquid crystal samples, optical samples, and transparent film samples. This also suggests that the proposed setup is well suited for identifying the optical samples with birefringent properties.

5. ACKNOWLEDEMENTS

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