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Simultaneous measurement of retardance and fast axis azimuth based on liquid crystal wave plate group

Guiyun Li[a,b], Liyuan Gu[a,b], Shuaiyan Gu[a,b], Aijun Zeng[a,b,*], Huijie Huang[a,b]

[a] Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

The simultaneous measurement of retardance and fast axis azimuth based on liquid crystal wave plate group (LCWPG) is presented. The laser beam propagates through an aperture and then splits into two beams by a non-polarizing beam splitter (NPBS). The intensity of the reflected beam is detected by a photomultiplier tube (PMT) as the reference light intensity. The transmitted beam, which passes through a polarizer, a quarter-wave plate, a retarder sample to be measured and the LCWPG successively, is finally detected by another PMT. The LCWPG is composed of four liquid crystal wave plates (LCWPs). In addition, the LCWPG works in six different polarized modulation modes dependent on the voltages applied on each LCWP. The six corresponding sets of light intensity are then measured by the two PMTs. By calculating and deriving from the six sets of light intensity, the retardance and fast axis azimuth of the measured sample can be obtained, respectively. In the experiment, the retardance of a quarter wave plate as the sample is measured when its fast axis is at different angles. The standard deviations of the retardance and the fast axis azimuth of the measured sample are 0.67° and 0.85°, respectively. The effectiveness of the proposed method is verified.

1. Introduction

Wave plate, commonly made by birefringent crystal, is an important optical element in the field of optical polarization. The wave plates have been widely used in displacement measurement [1–3], vortex light generation [4,5], nonlinear optical system [6,7], optical coherence tomography [8,9], etc. The phase and polarization state of the light via the wave plate will change obviously when the wave plate changes slightly. The changed phase and polarization state of the light depend on the wave plate's key parameters, known as the retardance and fast axis azimuth [10–12]. Therefore the retardance and fast axis azimuth are necessary to be measured precisely before a wave plate is used. There are kinds of methods for the accurate measurement. Among them, the rotating polarization device method, the beam splitting method and the photoelastic modulation method are usually utilized. For the rotating polarization device method [13,14], it has the advantages of simple structure and low cost. However, the method can only measure the retardance for the sample whose fast axis azimuth is known beforehand. For the beam splitting method [15], it can measure the sample's retardance and fast axis azimuth in real time. But its system is very complicated and its measurement result is largely influenced by the splitting ratio of Wollaston prism. The photoelastic modulation method [16] is based on the photoelastic modulator (PEM), a component which can modulate the polarization state of the light at a high frequency. The method has high accuracy but requires a precise calibration of the PEM before measurement and the data processing is also complicated. And furthermore, the

* Corresponding author at: Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China.
E-mail address: aijunzeng@siom.ac.cn (A. Zeng).

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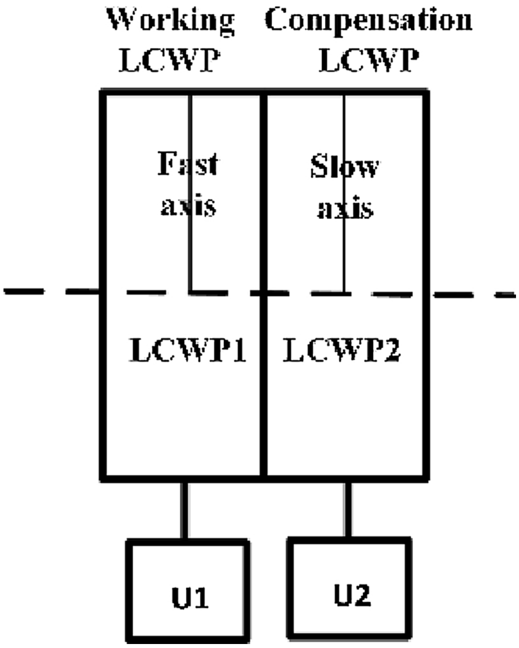

Fig. 1. Schematic diagram of the CLCWP.

commercial PEM is a bit expensive. In this paper, a measurement method based on LCWPG is proposed. In the proposed method, the system is low cost and the measurement speed is fast.

2. Principle

2.1. Composite liquid crystal wave plate

As is well known, there is a residual retardance in nematic LCWP and thus it can't realize true zero retardance [17]. To solve the problem, the composite liquid crystal wave plate (CLCWP), including a working LCWP and a LCWP compensator together, is constructed as illustrated in Fig. 1. The working voltages U1 and U2 are applied on the two LCWPs, respectively. The fast axis of the working LCWP1 is parallel to the slow axis of the compensation LCWP2 and thus the two LCWPs can be adjusted properly to generate an arbitrary overall phase shift, including zero retardance.

The muller matrix of the working LCWP can be expressed as follows:

$$M_{LCWP1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos^2(2\theta) + cos\delta sin^2(2\theta) & (1-\cos\delta)\cos(2\theta)sin(2\theta) & -\sin\delta\sin(2\theta) \\ 0 & (1-\cos\delta)\cos(2\theta)sin(2\theta) & \sin^2(2\theta)+\cos\delta\cos^2(2\theta) & \sin\delta\cos(2\theta) \\ 0 & \sin\delta\sin(2\theta) & -\sin\delta\cos(2\theta) & \cos(\delta) \end{bmatrix}, \tag{1}$$

where θ and the δ are the fast axis azimuth and the retardance of the working LCWP, respectively. In addition, the two composite LCWPs have the same retardance δ. For the compensation LCWP, the fast azimuth angle and the retardance are $(\theta + 90^{\circ})$ and δ, respectively. Therefore, its muller matrix is written as:

$$M_{LCWP2} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos^2(2\theta) + cos\delta sin^2(2\theta) & (1-\cos\delta)\cos(2\theta)sin(2\theta) & \sin\delta\sin(2\theta) \\ 0 & (1-\cos\delta)\cos(2\theta)sin(2\theta) & \sin^2(2\theta)+\cos\delta\cos^2(2\theta) & -\sin\delta\cos(2\theta) \\ 0 & -\sin\delta\sin(2\theta) & sin\delta\cos(2\theta) & \cos(\delta) \end{bmatrix}. \tag{2}$$

With the Eqs. (1) and (2), the muller matrix of the CLCWP can be presented as:

$$M_{CLCPW} = M_{LCWP2}M_{LCWP1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \tag{3}$$

From Eq. (3), it can be verified theoretically that the overall retardance of the CLCWP is zero when the two LCWPs' fast axes are orthogonal to each other. Therefore, the CLCWP realizes zero retardance for the nematic LCWP.