MEASUREMENTS OF THE THERMALLY INDUCED PHASE-RETARDATION CHANGES IN AN OPTICAL POLARIZATION-SENSITIVE INSTRUMENT

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ABSTRACT: *The thermally induced phase-retardation changes between two orthogonal polarizations of a propagating light while passing through some optical components have been investigated in an optical polarization-sensitive instrument. The measurements were performed in a dual-channel common-path polarization interferometer based on optical homodyne method. We study temperature dependent phase-retardation variations when the lights pass through a heated quarter-wave plate at different azimuth angles. By the way, we also successfully measure the path dependent phase-retardation changes when the lights pass through the different kinds of beam splitters under the same thermal impacts. These results show that the variations of ambient temperature will easily cause the systematical measurement errors in the optical polarization-sensitive instrument.* Microwave Opt Technol Lett 53:771–773, 2011; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.25838

Key words: *optical homodyne; polarization interferometer; polarization-sensitive instrument*

1. INTRODUCTION

The thermal birefringence effects have been studied extensively in a variety of fields, including solid-state laser cavity designs, optical projectors, optical-data storage substrates, and optical polarization-sensitivity instruments [1–4]. Measurements of the thermally induced optical phase variations are important for characterizing the optical system performance, which is deeply dependent on the stabilities of refractive index of the used optical components. The optical components are heated easily by the incident high-power lights at specific wavelengths due to material absorption [3]. In a polarization-sensitive instrument, a quarter-wave plate (QWP) and a beam splitter (BS) are essential components for modulating the polarization states and dividing the incident light beams, respectively. Recently, beam-splitting cubes with embedded metal or dielectric layers have been studied widely for controlling not only the intensity ratios but also the phase retardations between the orthogonal polarizations in the transmitted and reflected lights [5, 6].

In this study, we adopt a dual-channel phase measurement arrangement to evaluate the thermally induced phase variations when the incident lights pass through some optical components in the polarization-sensitivity instrument. This measurement setup and metrology principle is the same as proposed in [7, 8]. When two orthogonal polarizations were launched into the heated QWP, the phase-retardation variations were caused by the thermal birefringence in the uniaxial crystals. Unlike the thermally induced birefringence changes in the QWP, a cubic beam splitter (CBS) and a plate beam splitter (PBS) are mainly made by the isotropic glasses. The thermally induced refractive index changes near the boundary are the main reasons to cause the phase-retardation variations for the different transmitted and reflected paths. We also found that the path dependent phase variations are different in the CBS and PBS.

2. MEASUREMENT SETUP AND PRINCIPLE

Figure 1 presents the setup for measuring the thermally induced phase-retardation variations when the lights passing through the optical components such as the zero-order QWP and the BS. The zero-order QWP (Model S33A-633-4, Suruga Seiki/Japan) is constructed by two quartz plates with their optical axes (*c*-axis) crossed, as shown in the inset Figure 1(a). The difference in thickness between the two plates determines the phase retardation. There are two different kinds of BSs used for this measurement. The CBS (Model S322-20-550, Suruga Seiki/Japan) is made from two triangular glass prisms which are glued together at their base using the resin layer, as shown in the inset Figure 1(b). The PBS (Model S11-20-550N, Suruga Seki/Japan) is made by a plate of glass with a thin coating of chromium (Cr) layer, as shown in the inset Figure 1(c). Traditionally, the dual-path arrangement is adopted to improve the measurement precisions by suppressing the common phase noise from the light source and environment [8]. Therein, one optical path is for a sensing signal, and the other one is for a reference signal. In such measurement setup, the BS is typically used to separate the incident light into the transmitted (sensing) and the reflected (reference) paths. A linearly polarized incident light of 632.8 nm from a He-Ne laser is obtained after passing through a polarizer (PL). The polarized light +45° with respect to the x-axis of laboratory coordinate system was launched into the homemade lithium niobate Zn-indiffused phase modulator (ZIPM) [7] by using an objective lens (L1). Then, the sinusoidal phase delay between the transverse-electric and transverse-magnetic polarizations was modulated via a driving peak-to-peak voltage of 10 V at a frequency of 100 Hz. The output focused light from another objective lens (L2) was divided into the transmitted and reflected lights after the BS. The interferometric intensities through the analyzers at −45° (AL1 and AL2) are received by the corresponding amplified photodetectors (PD1 and PD2). According to the optical homodyne method, the phase retardation ϕ is decided by considering the relations between different harmonic intensities (I_f and I_{2f}) and Bessel functions (J_1 and J_2). It is expressed by $\phi = \tan^{-1}\left(\frac{I_f \cdot J_2(\beta)}{I_{2f} \cdot J_1(\beta)}\right)$, where the different harmonic intensities were obtained from the spectra analysis. β is a modulation depth for the optical phase applied by the ZIPM. In this experiment, the zero-order QWP was placed in the sensing path. Then, the phase retardations of the transmitted lights can be adjusted by changing the azimuth angles of the QWP. The

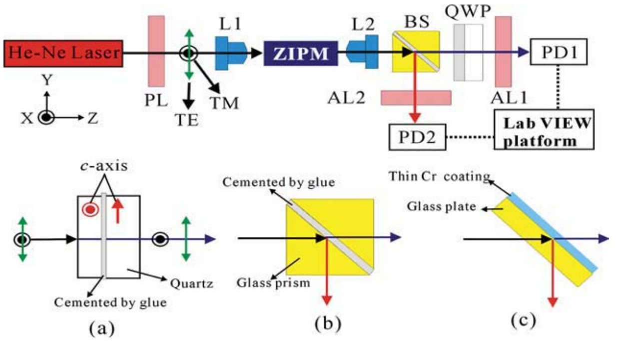

Figure 1 Measurement set up and device structures of the tested optical components: (a) QWP, (b) CBS, and (c) PBS. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

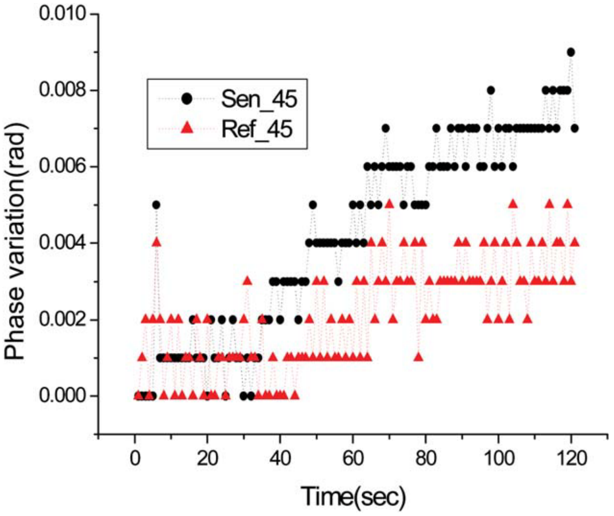

Figure 2 Phase variation versus time for both paths at QWP azimuth angle 45°. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

BS and QWP were individually heated by using hot wind from a hair dryer. The temperatures were measured by a thermal meter via a *k*-type thermal coupler attached onto the holders of optical devices. The dual-channel phase measurements were performed by using the proposed method in the previous work [7]. The temperatures and the dual-path phase variations are simultaneously measured by using the LabVIEW platform (National Instruments).

3. RESULTS AND DISCUSSION

Figure 2 shows the phase variations of both sensing and reference signals under the thermal impacts for the QWP in a measurement period of 2 min, when the *c*-axis of the QWP is set at +45° with respect to the *x*-axis of the laboratory coordinate system. In this case, the incident linear polarization at 45° is parallel to the *c*-axis of the QWP. Therefore, the phase variations are below 0.009 and 0.005 rad for the sensing and reference paths, respectively. To reduce the slight phase drifts caused by the photorefractive effects in the ZIPM, we take the subtracted values between both channels for the net phase variation due to the thermally induced birefringence changes in the heated QWP. The measured results show that the net phase variations of the heated QWP at 45° are below 0.004 rad. These results imply that the ZIPM exhibits enough phase stability for optical homodyne metrology. Moreover, the simultaneous phase measurements for both channels can enhance the resolutions. Figure 3 gives the phase variations when the QWP is set at 0°. The phase values of the reference path are still stable. However, the phases are increased dramatically up to 0.97 rad in the sensing path. The net phase variations for different azimuth angles of the QWP are shown in Figure 4. Similar to the QWP at 0°, the net phase changes of the QWP at 90° are also obvious. The net phase changes are less than 0.006 rad for other azimuth angles of 30°, 45°, and 60°. In this experiment, the QWP with different azimuth angles are heated with the same thermal impact conditions. The measured temperatures are increased from room temperature 25 to 52°C and represented by the trace of the empty-circular symbols as shown in Figure 4.

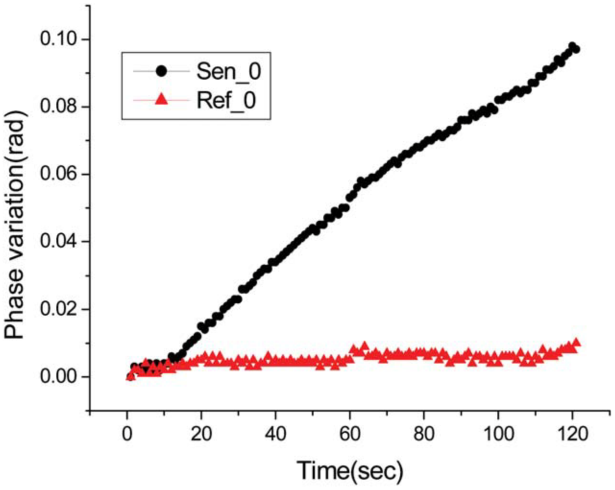

Figure 3 Phase variation versus time for both paths at QWP azimuth angle 0°.[Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

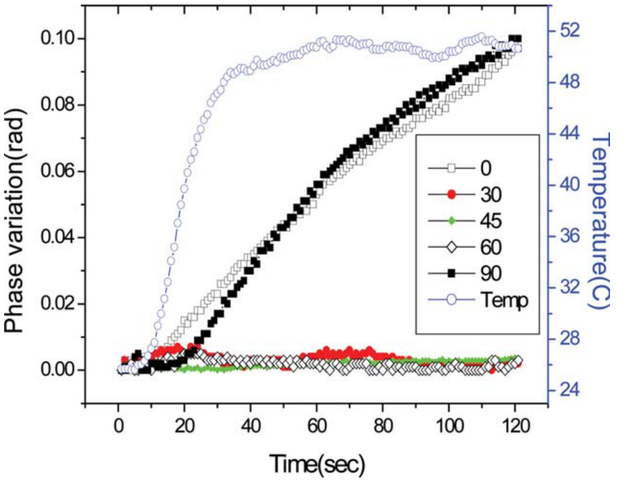

Figure 4 Net phase variation versus time for different azimuth angles of the heated QWP. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

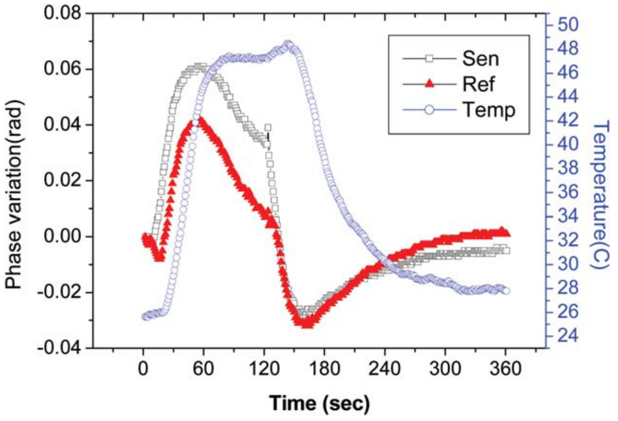

Figure 5 Phase variation versus time for both paths after the heated CBS. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

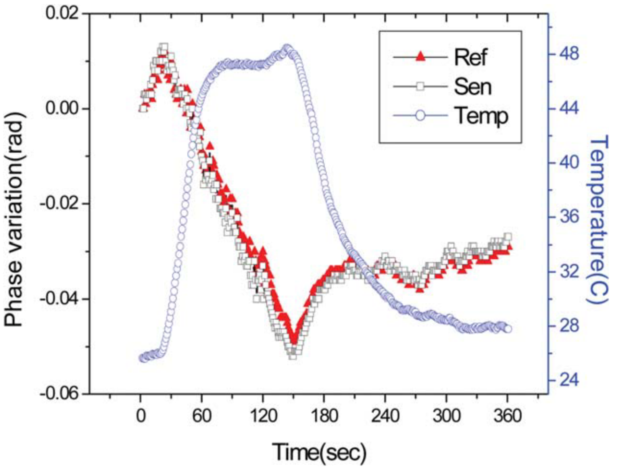

Figure 6 Phase variation versus time for both paths after the heated PBS. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

To measure the path dependent phase variations under the same thermal impacts for the different BSs, the QWP was removed from the setup of Figure 1. The phase variations for both transmitted and reflected lights after the CBS are shown in Figure 5. The trace of the empty-circular symbols represents the temperature variations. The different thermal expansion coefficients between the glass prism and the resin layer will easily cause the stress induced refractive index changes in the thin resin layer. The refractive index ratios between the glass prism and the resin layer are also dependent on the ambient temperatures. Therefore, the phase retardations of the reflected light are also changed due to the different total internal reflection conditions [9]. Moreover, the additionally different phase variations of the transmitted light are due to the thermally induced birefringence in the thin resin layer. Therefore, the different trends of phase variations between them are obvious during the heating period. The differences are gradually decreased in the natural cooling period. Figure 6 shows the phase variations for both transmitted and reflected lights after the PBS. In this case, their phase variation trends are almost the same. Because the thickness of the coating metallic Cr layer is much thinner than that of the resin layer in the CBS, it is expected that the phase retardations of the transmitted light are not affected by the Cr layer. Therefore, they will have the similar phase variations during the heating and cooling periods. Figure 7 gives the net phase variations between two paths for the CBS and PBS under the same thermal impacts. According to previous analysis, the net phase variations are smaller than 0.0065 rad for the PBS. However, the maximum net phase variation of the CBS is around 0.027 rad that is sensitive to the temperature changes under the same testing conditions.

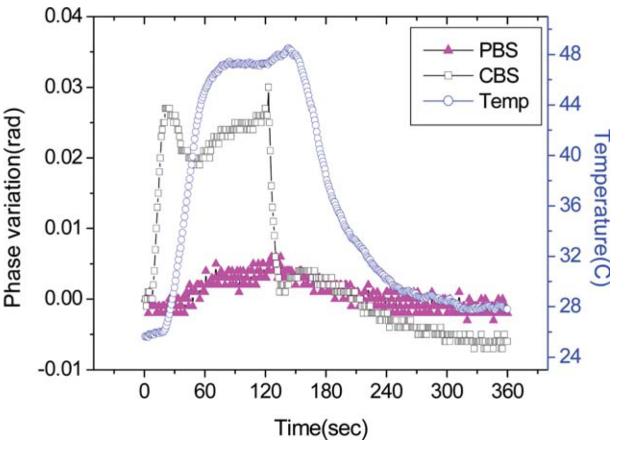

Figure 7 Net phase variation between two paths for the CBS and PBS. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

4. CONCLUSIONS

In this study, measurements of the thermally induced phase-retardation changes of a propagating light while passing through some optical components have been successfully demonstrated by using a dual-channel common-path polarization interferometer. The phase retardations of the heated QWP are sensitive to temperature changes due to the thermally induced birefringence effects. We also measure the path dependent phase retardations when the incident lights passing through two different kinds of BSs. The temperature dependent phase differences between two paths in the cubic BS are obvious. However, the phase differences are small in the plate BS. Lastly, the experimental results show that the developed instrument provides the capability of characterizing the thermal properties of the wave plats and BSs very precisely.

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