A Measurement System for Linear Birefringence and Optical Rotation

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NSC Project No.: NSC-97-2221-E-269-010

Abstract

An optical technique is proposed for measuring the principal axis angle, retardance, and rotation angle of optical samples in this study. A rotating-wave-plate Stokes polarimeter is used to extract the 2x2 central elements of the Mueller matrix of the sample via two probe lights linearly polarized at angles of 0 and 45 degrees, respectively. The validity of the method is demonstrated using a half-wave plate positioned in series with a quarter-wave plate, the measured values of the principal axis angle and retardance of the quarter-wave plate are found to have average normalized errors of 0.56 % and 1.16 % respectively, while the measured rotation angle of the half-wave plate has an error of just 0.39 %. When analyzing glucose solutions with concentrations ranging from 0 to 1.2 g/dl positioned in front of a half-wave plate, the average normalized errors in the principal axis angle and retardance measurements of the half-wave plate are 0.69 % and 2.65 % respectively, while the error in the rotation angle measurement of the glucose solutions is 2.13 %. Overall, the uncertainty analysis for the rotation angle measurement is simulated and experimental results demonstrate the ability of the proposed system to accurately measure the linear and circular birefringence.

Keywords: Circular birefringence; Linear birefringence; Optical rotation

1. Introduction

Birefringence (double refraction) is an important property of optically anisotropic media. It can be classified as either linear or circular. In the former case, the birefringence effects are determined by changes in the principal axis angle and phase retardance of the optical medium as the result of variations in the externally-applied stress. In the latter case, the birefringence effects are the result of a particular property of some optical media known as “optical activity”, which causes right-circularly polarized light to be transmitted at a different velocity through the medium than left-circularly polarized light. Birefringence has many practical applications, including strain-sensing systems, wave plates, glucose concentration sensing systems, and so forth.

As a result, the literature contains many proposals for measuring either the linear [1-2] or circular [3-4] birefringence properties of optical media. However, in many applications (e.g. liquid crystal displays), both linear and circular birefringence effects are present at the same time. Therefore, in designing, manufacturing and characterizing the optical performance of such applications, a requirement exists for methods capable of obtaining simultaneous measurements of both the linear and the circular birefringence properties.

Kobayashi and Uesu [5] developed a high-accuracy universal polarimeter for the simultaneous measurement of the optical activity and birefringence properties of crystal media. The authors showed that by applying a suitable compensation for the systematic errors associated with the parasitic ellipticities of the polarizer and analyzer, respectively, the optical activity and birefringence properties of crystal samples could be obtained with an accuracy as high as 4.2 x 10⁻³ and 2.2 x 10⁻³, respectively. Ebisawa et al. [6] presented a microscopic system for measuring the birefringence and optical rotation distribution in biological tissues. The authors showed that by adjusting the rotation angles of the half-wave plate, quarter-wave plate and analyzer, respectively, four different phase changes could be introduced, allowing the retardation, azimuthal angle of birefringence and optical rotation angle to be extracted.

The current study proposes a novel technique for the concurrent measurement of the principal axis angle, phase retardance and rotation angle of optical samples. In the proposed approach, a rotating-wave-plate Stokes polarimeter is used to extract the 2x2 central elements of the Mueller matrix of the sample of interest by means of two probe lights linearly polarized at angles of 0° and 45°, respectively. The validity of the proposed approach is demonstrated experimentally using two composite samples, namely a half-wave plate positioned in series with a quarter-wave plate and a glucose solution positioned in front of a half-wave plate.

2. Method

2.1 Principle

Figure 1 presents a schematic illustration of the optical configuration used in the present study to measure the linear and circular birefringence properties of the sample of interest, including the principal axis angle (α), phase retardance (β) and optical rotation angle (γ). As shown, the system comprises a He-Ne laser, a polarizer and a Stokes polarimeter (Thorlabs
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摘要

本研究中提出一項新技術以測量光學樣本的主軸角度、相位延遲和旋轉角度。旋轉波片史托克偏光儀是經由兩個偏振角度為0°和45°的探測光束擷取樣本Mueller矩陣2x2的中心元素。方法之確認是採用二分之一波片與四分之一波片為樣本來展示的，四分之一波片主軸角度和相位延遲的測量發現平均相對誤差是0.56 %和1.16 %，而二分之一波片的光學旋轉角度誤差僅為0.39 %。在分析濃度在0到1.2克/分升葡萄糖緊接二分之一波片的測試知，二分之一波片平均主軸角度和相位延遲測量誤差是0.69 %和2.65 %，而葡萄糖的旋轉角度測量誤差是2.13 %。總之，旋轉角度不確定性分析的模擬和實驗結果表明，所提出的系統具有準確測量線雙折射和圓雙折射的能力。

關鍵字： 圓雙折射、線雙折射、光學旋轉

Fig.6 Variation of rotation angle with glucose concentration in composite sample composed of glucose sample positioned in front of half-wave plate.