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Citation for published version:
Lei, J, Liu, W, Tuo, Y, Hanson, SG, Takeda, M & Wang, W 2024, Measurement of the orientation of the fast/slow axis and surface roughness for birefringent material. in W Liu, W Wang & Y Zhu (eds), *Speckle 2023: VIII International Conference on Speckle Metrology.*, 130700Z, Proceedings of SPIE - The International Society for Optical Engineering, vol. 13070, SPIE, 8th International Conference on Speckle Metrology 2023, Xi'an, China, 18/10/23. https://doi.org/10.1117/12.3021239

Digital Object Identifier (DOI):
10.1117/12.3021239

Link:
Link to publication record in Heriot-Watt Research Portal

Document Version:
Publisher's PDF, also known as Version of record

Published In:
Speckle 2023

Measurement of the orientation of the fast/slow axis and surface roughness for birefringent Material

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ABSTRACT

When light propagates in a heterogeneous object, its propagation speed and refractive index value usually change with different vibration directions. However, when light passes through a heterogeneous optical crystal from a particular direction, no birefringence occurs, and this special direction is the optical axis of the birefringent material. Presently, the traditional measurement method for determining the optical axis relies on scalar imaging, which can only characterize scalars and cannot characterize polarization. Given the anisotropy of birefringent materials, it becomes difficult to determine the optical axis and measure the surface roughness. Speckle method, as an important non-contact measurement method, has gradually become the main method for measuring surface roughness due to its advantages such as small error and easy operation. The purpose of this article is to provide a device and method, to solve the problems of measuring the optical axis and roughness of birefringent materials, simultaneously.

Key Words: Optical axis measurement, laser speckle, scattering imaging, surface roughness, autocorrelation function, birefringence

1. INTRODUCTION

At present, for the determination of optical axis [1], the traditional measurement method is based on scalar imaging and cannot characterize polarization. Surface roughness [2] is one of the parameters that describe the micro-unevenness of an object's surface. The usual measurement method is contact measurement, but it is easy to cause damage to the surface of the part and produce measurement errors. Therefore, people gradually came to measure the target surface roughness by non-contact techniques, such as speckle method [3]. When a highly coherent beam of light shines on a rough surface, bright and dark spots of varying sizes can be observed through the receiving screen, which is called speckle phenomenon [4].

2. OPTICAL AXIS DETERMINATION

The device used in this paper for the determination of the optical axis of birefringent materials is shown in Figure 1. The birefringent material to be measured is placed between the half wave plate and the circular polarizer. The coherent beam emitted by the laser is transformed into linearly polarized light through the linear polarizer, and then vertically incident onto the half wave plate to adjust its polarization plane. The light is incident onto the birefringent material represented by a depolarizing diffuser to form scattered light, whereafter it is vertically incident onto the circular polarizer system and enters the camera.

Speckle 2023: VIII International Conference on Speckle Metrology, edited by
Weiguo Liu, Wei Wang, Yechuan Zhu, Proc. of SPIE Vol. 13070, 130700Z
· doi: 10.1117/12.3021239

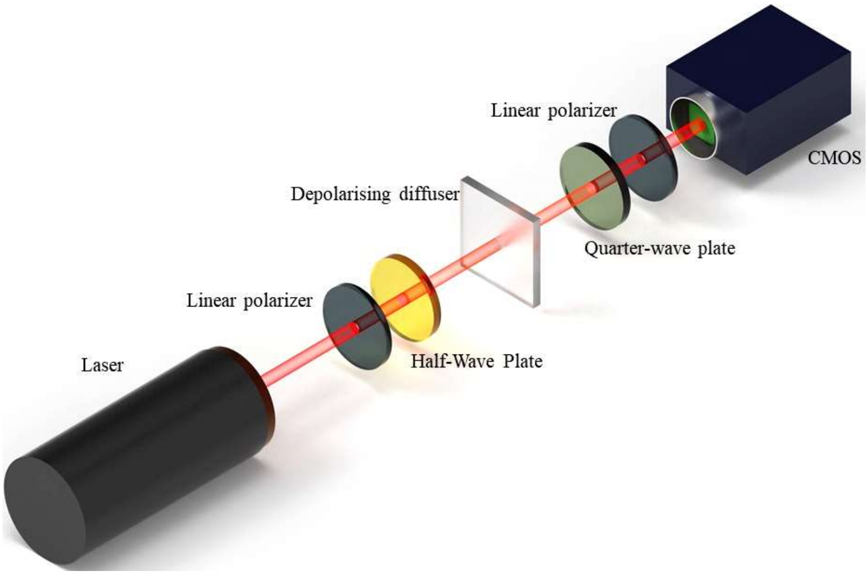

Figure 1. Experimental device for measuring the orientation of the fast axis of birefringent material.

After passing the zoom system of the entire optical path, image processing technology is used to process and record the gray speckle image acquired by the CMOS camera. Figure 2 shows the speckle images acquired in the experiment.

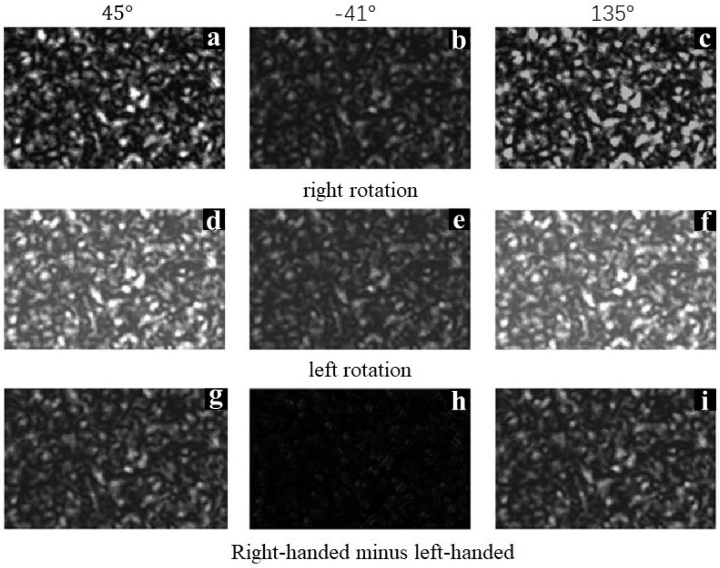

Figure 2. The recorded speckle images

After obtaining the speckle image, we calculate the Stokes parameter $\overline{|S_3|}$ by equation (1). By changing the angle of the half-wave plates θ, we obtained $\overline{|S_3|}$. Based on the mathematical relationship between the two, we determined the optical axis of the birefringent material at the lowest point of the fitted curve, ideally at which $\overline{|S_3|} = 0$. Figure 3 shows the fitting curve of the optical axis.

$$S_3(x, y) = I_{(45°,\frac{\pi}{2})}(x, y) - I_{(135°,\frac{\pi}{2})}(x, y) \tag{1}$$

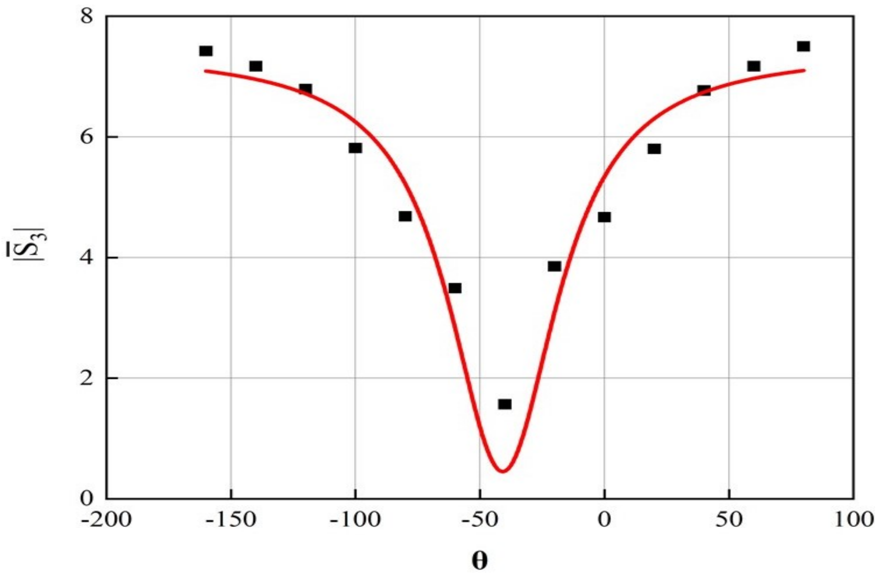

Figure 3. Curve for fitting the orientation of the fast axis of the birefringent material.

3. ROUGHNESS MEASUREMENT

The device used to characterize the surface roughness of birefringent materials is shown in Figure 4. For roughness measurement, the birefringent material to be measured represented by the depolarizing diffuser is placed between the half wave plate and the pupil of the imaging lens. After determining the optical axis of the birefringent material, the plane direction of vibration of the electric field of the incident light is adjusted to the direction of the optical axis of the birefringent material. At this time, the scattered field remains to be linear polarized light, which is incident to the camera through the lens and a variable diaphragm.

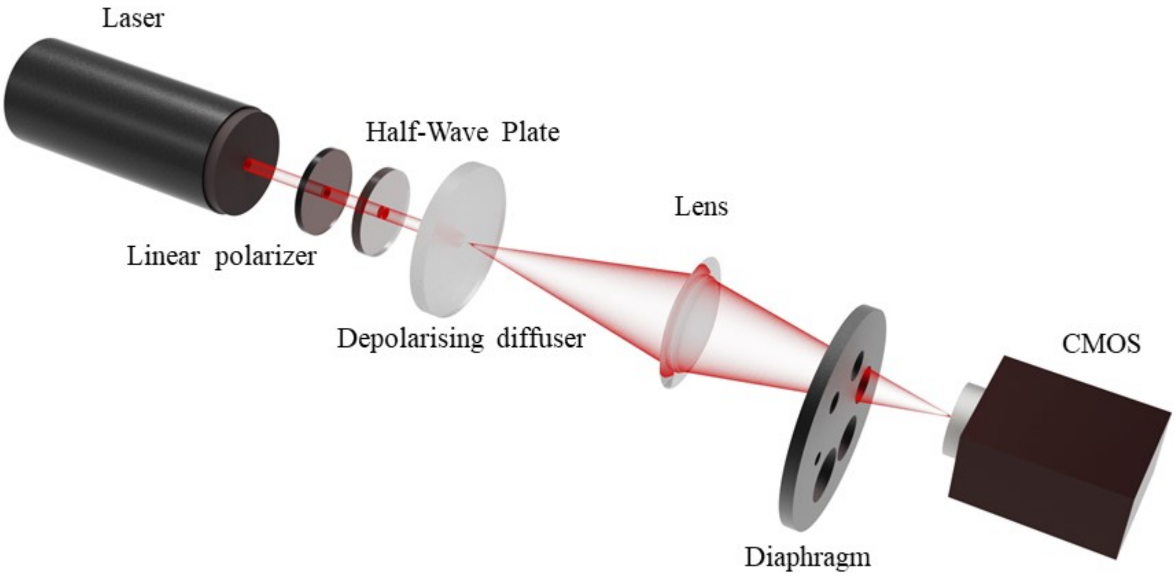

Figure 4. Experimental device for measuring surface roughness.

Figure 5 shows the speckle images collected in the experiment. Figures (a) - (f) represent the speckle images of the ground glass with different pupil sizes and grinding mesh numbers. We notice that as the aperture size increases, the number of speckles gradually increases due to the reduced speckle size, and as the ground glass mesh size increases, the modulation depth decreases.

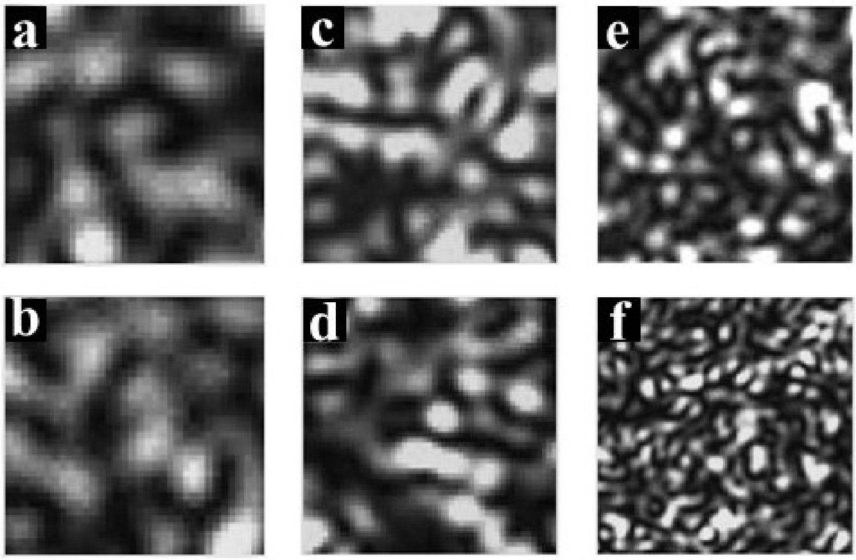

Figure 5. The speckle images.

In speckle image processing, the principle of autocorrelation function is used to self-correlate [5] the intercepted speckle image, resulting in a speckle autocorrelation map. The average number of speckles N is obtained by the ratio of the area X_k of the intercepted speckle image to the area $-41°$ of the autocorrelation center peak profile of the speckle. The speckle contrast C is the ratio of the standard deviation of the speckle intensity σ_I to the average intensity of the speckle $\overline{I}$. By drawing and fitting the scatter plots of N and C, the estimated roughness value can be obtained, as shown in Figure 6.

$$N = \frac{X_k}{X_a} \tag{2}$$

$$C = \frac{\sigma_I}{I} \tag{3}$$

$$\sigma_I = \sqrt{\overline{I^2} - \overline{I}^2} \tag{4}$$

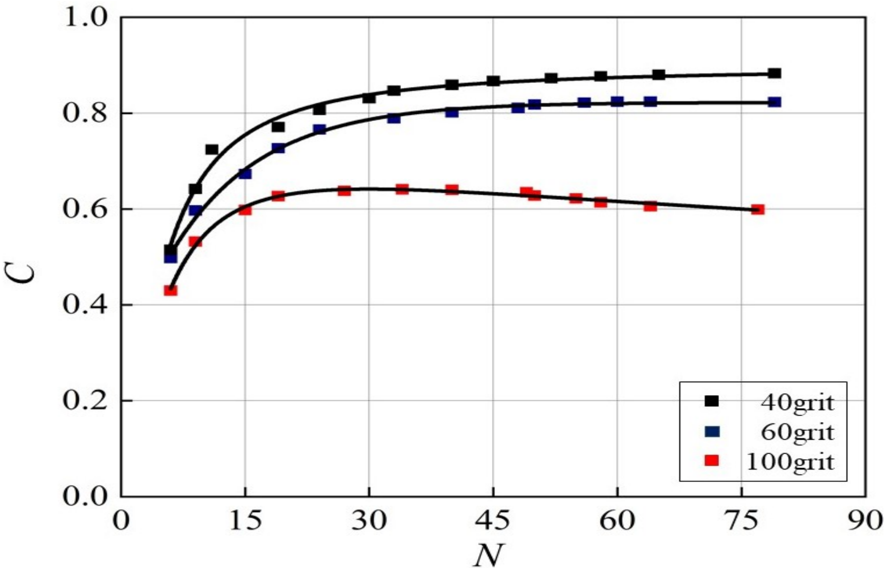

Figure 6. Diagram for fitting surface roughness.

4. CONCLUSION

Through experiments and data calculations, we here measured the optical axis direction of the birefringent material to be $-41°$. Figure 6 shows that as the number of the ground glass mesh increases, the roughness of the tested ground glass gradually decreases, which is consistent with our research objectives.

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