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Investigation of cross-polarized heterodyne technique for measuring refractive index and thickness of glass panels

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ABSTRACT

A new mathematical model of cross-polarized heterodyning is proposed for measuring glass panels. An optical system is presented for obtaining relative thickness variation and difference distribution of refractive indices simultaneously, and the dual-balanced coherent demodulation technique is used. The experiment results show that the transmittance of light beam can be less than 0.5% when the vibration amplitude of the glass panels is equal to 5 mm. It takes about 200 s to scan the whole glass sample with size of 1430×1360 mm^2. The resolution of the thickness variation is 0.3 μm, and the lateral sampling resolution is 1 mm.

1. Introduction

Glass substrate is an extremely important component of the liquid crystal display (LCD) where quality significantly depends on it. In recent years, the tenth generation of the glass substrate with the size of 2880×3130 mm^2, whose thickness is between 0.3 mm and 0.7 mm, is developed in western countries; whereas the fifth generation of the glass substrate with the size of 1430×1360 mm^2, whose thickness is between 0.5 mm and 0.7 mm, is developing in China. As the glass substrate of the thin film transistor (TFT) LCD, there are three requirements to be met for the glass substrate: first, it should not contain arsenic, antimony, barium or halides; second, the thinner the thickness of the glass substrate, the less variation of the thickness; last, the glass substrate should have good heat-resistant quality. Therefore, the qualified product can be chosen by measuring the thickness variation and the difference distribution of refractive indices. Obviously, it is most important to measure these two parameters simultaneously in manufacturing the glass panels. Traditionally thickness and difference distribution of refractive indices were measured separately, using different techniques; while thickness can be measured by a variety of well-elaborated methods such as heterodyne ellipsometry [1,2], optical triangulation and interferometry [3], ultrasound [4], etc. Measurement of difference distribution of refractive indices remained a challenging task through the past decades. To the best of our knowledge, the first attempt to design a reliable technique for the measurement of difference distribution of refractive indices was done by Chen [5]. Further development of modulation of the polarization state of the light beam was then extended by Serreze and Goldner [6,7]. These methods cost much time to measure difference distribution of refractive indices. Another method based on heterodyning technique was first proposed by Tsukiji [8]. In recent years, this technique has been developed [9–12] and commercialized in the market from CORING Inc and IRICO group. There is also the cross-polarized technique, which has many advantages, such as easy operation, high stability, good resolution and accuracy. SunghoonCho uses the cross-polarized heterodyne technique to scan the sample with horizontal and vertical lights side by side [13], but in this reference, firstly, there is no discussion about the difference distribution of refractive indices problem, secondly, the horizontal and vertical lights are scanned side by side on the surface of the sample, so the lateral sampling resolution is not high. The goal of our research is to develop a new optical system for measuring both thickness variation and difference distribution of refractive indices of the glass panel simultaneously based on cross-polarized heterodyne technique. In the present article we introduce the mathematical model of cross-polarized heterodyning for measuring glass panels firstly and present the optical system for measuring relative thickness variation and refractive indices distribution simultaneously. A heterodyne I/Q-interferometer scheme which can map the phase and the amplitude change simultaneously is also given. I/Q-demodulation is a well known technology in rf-communications and we apply this technique for demodulating the heterodyne beat signal [14–15]. Finally, the experimental results and discussions are presented.

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2. Experiment

The schematic of optical arrangement is shown in Fig. 1. A dual-frequency, dual-polarization, stabilized, Zeeman laser is used as a light source of the scanning interferometer. The operational wavelength is 632.8 nm. Frequency difference between the two linearly cross-polarized waves is 2.34 MHz. Output light from the laser enters into a quarter-wave plate, and the purpose of this element is to compensate for residual ellipticity of one of the two linearly polarized laser components. The transmitted beam from the quarter-wave plate is split by a beam splitter (BS) into two paths. Two polarization modes in the reflected beam from BS are mixed by the use of an analyzing polarizer oriented at 45° to the polarization modes and a high speed photodiode, PD1. AC component of the beat signal from PD1 is used as the local oscillator signal (LO) in the RF mixing. As shown in Fig. 1, the transmitted beam from BS is used as the probe beam signal (PB) of the scanning heterodyne interferometry. The PB probe is focused on the sample by using a lens system, which decreases the diameter of incident beam into 1 mm. The diameter of transmitted beam from sample is increased to 6 mm by using the same lens system. When the two polarization modes are transmitting in the sample, these two polarization modes are orthogonal all the time, but their phases are also changed by the sample. Finally, these two polarization modes are mixed by the use of an analyzer oriented at 45° to the polarization mode and a high speed photodiode, PD2. Therefore, the information about thickness variation and difference distribution of refractive indices is contained in the photocurrent.

Let us consider now the case of the physical procedure between the two polarization mode beam and the sample as shown in Fig. 2. The field expressions of the two polarization modes are $E_1 e^{i(\omega_1 t + \varphi_{01})}$ and $E_2 e^{i(\omega_2 t + \varphi_{02})}$, where E_1 and E_2, ω_1 and ω_2, φ_{01} and φ_{02}, stand for amplitude, angular frequency, and initial phase of the two beams, respectively. As we know, glass is an isotropic media and, therefore, principal axes of stress tensor and ellipsoid of wave directions coincide. Also, directions of linearly polarized wave vectors which can propagate in the media without changes in polarization are always orthogonal. Therefore, independent of orientation of stress ellipsoid in the given point of glass sample we can consider two orthogonal directions along which refractive indices are n_1 and n_2.

In Fig. 2, the photocurrent is proportional to

$$i = |A_1 + A_2|^2, \tag{1}$$

where A_1 and A_2 denote projections of the complex amplitude components along the directions of the waves E_1 and E_2 on the direction of the analyzer:

$$A_1 = E_1 \exp[i(\omega_1 t + \varphi_{01})] \cdot [\cos\alpha \cdot \cos\theta \cdot \exp(ikn_1 l) - \sin\alpha \cdot \sin\theta \cdot \exp(ikn_2 l)] \tag{2}$$

$$A_2 = E_2 \exp[i(\omega_2 t + \varphi_{02})] \cdot [\cos\alpha \cdot \sin\theta \cdot \exp(ikn_1 l) + \sin\alpha \cdot \cos\theta \cdot \exp(ikn_2 l)] \tag{3}$$

where, $k = 2\pi/\lambda$ is the wave number, and l is the thickness of a glass panel. α is the angular between analyzer axis and direction of n_1, θ is the angular between E_1 and direction of n_1. For making good use of the heterodyne detection principle, expressions of A_1 and A_2 are transformed by the mathematical transformation operation, respectively:

$$A_1 = E_1 r_1 \exp[i(\omega_1 t + \theta_1)] \tag{4}$$

$$A_2 = E_2 r_2 \exp[i(\omega_2 t + \theta_2)] \tag{5}$$

where

$$r_1^2 = \cos^2\alpha \cos^2\theta + \sin^2\alpha \sin^2 \sin^2\theta - 2\cos\alpha \sin\alpha \cos\theta \sin\theta \cos(\Delta\varphi) \tag{6}$$

$$\theta_1 = \tan^{-1}\left(\frac{\cos\alpha \cos\theta \sin(\Delta\varphi) - \sin\alpha \sin\theta \sin(\Delta\varphi)}{\cos\alpha \cos\theta \cos(\Delta\varphi) - \sin\alpha \sin\theta \cos(\Delta\varphi)}\right) \tag{7}$$

$$\Delta\varphi = k(n_1 - n_2)l. \tag{8}$$

In a similar way, we can get the expressions of r_2 and θ_2, and substituting Eqs. (4) and (5) into Eq. (1), we then obtain the photocurrent:

$$i = \eta \cdot \left[E_1^2 r_1^2 + E_2^2 r_2^2 + 2E_1 E_2 r_1 r_2 \cos(\Delta\omega t + \theta_1 - \theta_2 + \varphi_{01} - \varphi_{02})\right] \tag{9}$$

$$tg(\theta_1 - \theta_2) \approx \frac{\Delta\varphi \cdot \sin 2\alpha}{\sin(2\alpha + 2\theta)} \tag{10}$$

where η and $\Delta\omega = \omega_1 - \omega_2$ are the responsivity of the photodetector and frequency difference between A_1 and A_2, respectively. As can be seen from Eq. (7), the first and the second items stand for the direct photocurrent. The direct photocurrent variations of the heterodyne scheme provide information about thickness variations. Due to interference the intensity of a laser beam transmitted through a

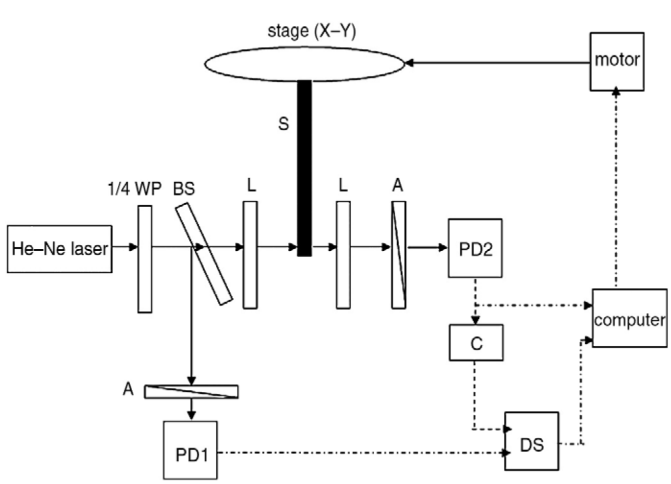

Fig. 1. Schematic of experimental arrangement (BS: beam splitter, L: lens, A: analyzer, PD: detector, C: capacitance, DS: demodulation system, WP: wave plate).

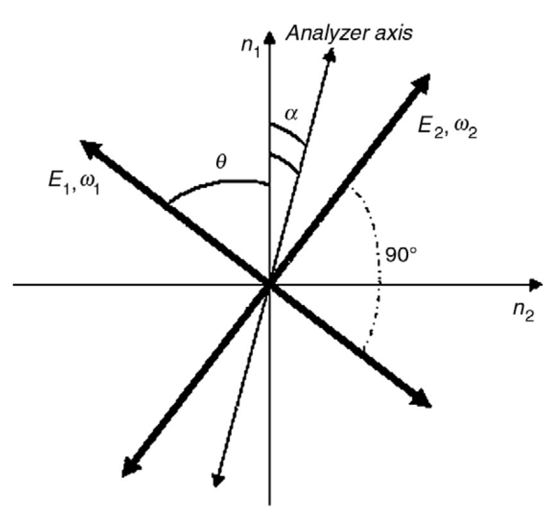

Fig. 2. Schematic of heterodyne detection.