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High-speed interferometric thickness measurement of transparent plate and film using a current modulation technique

Jae Wan Kim[1,2], Jong-Ahn Kim[1], Chu-Shik Kang[1,2], Jonghan Jin[1,2] and Tae Bong Eom[1]

[1]*Center for Length, Korea Research Institute of Standards and Science, 267 Gajeong-ro, Yuseong-gu, Daejeon, Republic of Korea, 305-340*
[2]*Department of Science of Measurement, Korea University of Science and Technology, 217 Gajeong-ro, Yuseong-gu, Republic of Korea, 305-350*

jaewan@kriss.re.kr

Abstract
A high-speed thickness measurement method is presented which is applicable to in-line inspection of thickness variations of transparent plates and films. The thickness values are obtained by analysing the interference signals generated by multi-reflected beams on the surfaces of transparent plates or films. To calculate the phase angle accurately, which is proportional to the thickness variation, we obtain quadrature interference signals by applying a high-speed current modulation technique to two laser sources whose centre wavelengths are different slightly. Using a transmissive-type experimental setup, we proved the proposed method and measured thickness profiles of a polyethylene (PE) film. In repeated measurements, the repeatability was evaluated as less than 5 nm when the film was translated with speed of 300 mm/s. Since the proposed method measures a thickness profile with high speed and nanometric resolution, it can be used effectively for the in-line inspection of thickness variation of various flat transparent plates and films.

Keywords: Thickness measurement, Transparent plate, Transparent film, Current modulation, Quadrature interference signal

1. Introduction

In flat panel display industries, various transparent plates and films are used as a base plate or a coating film. Since their thickness uniformity is one of critical factors affecting overall performance of display panels, it is important to ensure an accurate measurement method applicable to an in-line thickness inspection. For this purpose, various optical measurement methods have been proposed [1-5].

We propose an interferometric method for thickness measurement of transparent plates and films. A high-speed current modulation technique enables us to obtain quadrature interference signals essential to accurate phase calculation. In the following sections, the measurement principle will be explained shortly, and several experimental results will be presented to prove and evaluate the proposed method.

2. Measurement principle

When a monochromatic light is incident on a transparent plate or film, multiple reflections on both surfaces generate a transmissive interference signal as shown in figure 1. If the reflectance of each surface is small, the interference signal can be approximated as

$$I_T \approx \frac{2I_0T^2}{(2+F)(1-R)^2}\left(1+\frac{F}{2+F}\cos\frac{4\pi nd}{\lambda}\right), \qquad (1)$$

where I_0 is the intensity of the primary ray, T is the transmittance, R is the reflectance of one surface, F is the coefficient of finesse described as $4R/(1-R)^2$, n is the refractive index of plate or film, d is the thickness, and λ is the vacuum wavelength of light source [6]. Therefore, we can measure thickness variation by extracting the phase change from the interference signal.

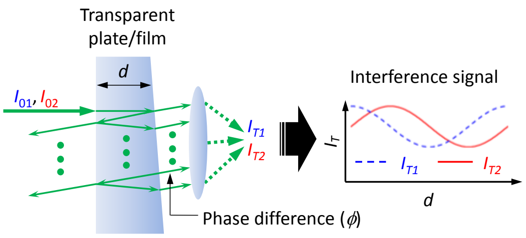

Figure 1. Sinusoidal interference signals generated by multiple reflections on both surface of a transparent plate or film

In general, for accurate phase calculation, we need quadrature interference signals which can be applied to the arctangent function. If two wavelengths of light sources, λ_1 and λ_2, satisfy Eq. (2), the interference signals generated by each source can compose the quadrature interference signals as expressed in Eqs. (3) and (4).

$$\frac{4\pi n_2 d}{\lambda_2} = \frac{4\pi n_1 d}{\lambda_1} - \frac{\pi}{2}. \qquad (2)$$

$$I_{T1} = \frac{2I_{01}T^2}{(2+F)(1-R)^2}\left(1+\frac{F}{2+F}\cos\frac{4\pi n_1 d}{\lambda_1}\right), \qquad (3)$$

$$I_{T2} = \frac{2I_{02}T^2}{(2+F)(1-R)^2}\left(1+\frac{F}{2+F}\sin\frac{4\pi n_1 d}{\lambda_1}\right). \qquad (4)$$

When the thickness of plate is less than 300 μm, the required wavelength difference of λ_1 and λ_2 exceeds the tuning range of a DFB laser [5]. Thus two separated lasers are needed to fulfil the requirement shown in Eq. (2). By alternating on/off states of these lasers with high-speed driving current modulation, we can obtain I_{T1} and I_{T2} at different time t_1 and t_2.

The wavelengths are adjusted to satisfy Eq. (2) by monitoring a Lissajous figure consisting of I_{T1} and I_{T2}, while translating a sample. After acquiring the interference signals, several procedures are applied to estimate their amplitudes and offsets. Using these parameter values, the phase can be obtained without nonlinearity error. Since the calculated phase is wrapped in $\pm\pi$ range, it should be unwrapped through a simple unwrapping process. Finally, the thickness variation can be obtained considering the refractive index and the vacuum wavelength [5].

3. Experiments

Figure 2 shows the experimental setup for measuring thickness variation of a transparent film. Two distributed feedback (DFB) lasers (λ = 780 nm) are used as light sources, and light from these lasers are combined using an optical fibre combiner. A relay-optic system delivers the interference fringe generated at the film to the detector. To suppress a high frequency noise in the interference signal, the fringe was averaged over a full detector aperture (ϕ = 1 mm). A scaling amplifier extracts the dc offsets and equalizes amplitudes of the quadrature signals to increases signal-to-noise ratio of the signals. A motorized stage translates the film up to 300 mm/s and its encoder signal is used as a trigger signal for data acquisition. A field-programmable gate array (FPGA) board controls the overall experimental setup. It modulates current of the laser diodes, and acquires the photodiode output through the scaling amplifier triggered by the modulation signal.

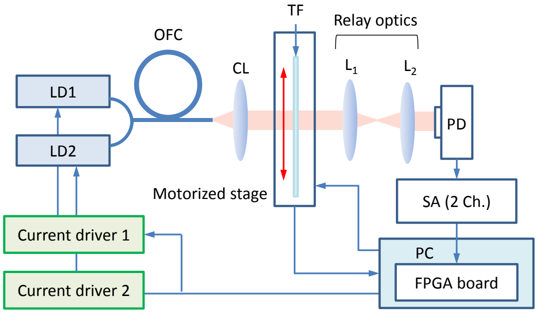

Figure 2. Schematic diagram of the experimental setup (LD: laser diode, OFC: optical fibre combiner, CL: collimation lens, TF: transparent film, SA: scaling amplifier)

An exemplary quadrature interference signals are presented in figure 3, which were obtained when a polyethylene (PE) film of 100 μm thickness was translated.

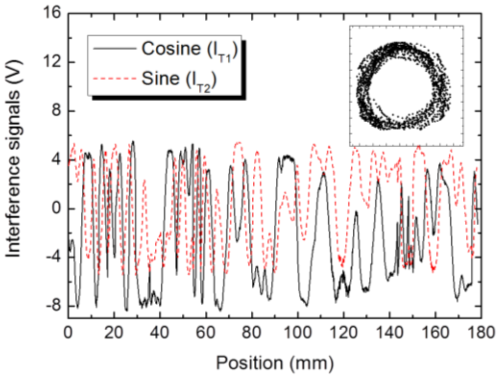

Figure 3. Quadrature interference signals obtained in the thickness measurement of a transparent film (the inlet shows a Lissajous figure of these signals.)

The Lissajous figure shows a circular shape, but contrast of the interference signal varies along the measurement positions. This is mainly caused by the large-sized aperture and flatness of the film surface, but it will not cause serious measurement error since its variation is usually cancelled out in the arctangent function.

We evaluated repeatability in the film thickness measurement. The 100 μm PE film was translated with speed of 300 mm/s, and its thickness was measured 10 times. The thickness of PE film varied within ±0.5 μm, and its standard deviations were less than 5 nm (see figure 4).

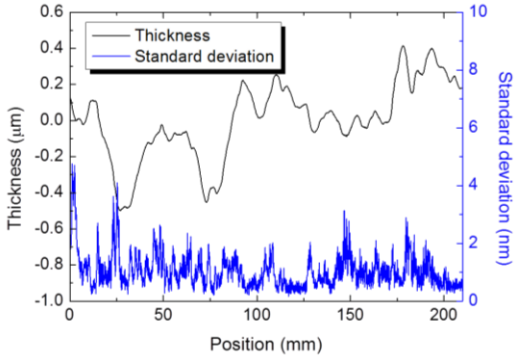

Figure 4. Measurement results of thickness variation when a transparent film was translated with speed of 300 mm/s

4. Conclusion

A quadrature laser interferometer measuring thickness profile of transparent plates and films was proposed. Using a simple and fast current modulation of two laser sources, quadrature interference signals can be obtained and the phase angle, which is proportional to the thickness variation, was calculated with high accuracy and stability. Using a transmissive-type experimental setup, we checked the feasibility of the measurement method and evaluated its repeatability. When a PE film was translated with speed of 300 mm/s, the repeatability of thickness measurement was less than 5 nm. From these results, we conclude that the proposed method can be used effectively for the in-line inspection of thickness variation of various flat transparent plates and films.

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