Simultaneous measurement of refractive index and thickness of transparent films by white-light interferometry

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We propose a new method for simultaneous measurement of refractive index and geometric thickness of transparent films by use of an interferometric surface profiler. It is based on a combination of two techniques, which we have proposed recently. Firstly, the target film is inserted into the measuring optical path, and the surface height change of a back-mirror surface is measured. Then the optical thickness is measured from the two peak positions in the interferogram. From these two measurements, we can obtain the refractive index and thickness of the film separately. The experimental results verify the feasibility of this method.

1. Introduction

The surface profile measuring device [1,2] using optical interference is widely used in the industry because it can measure the surface profiles in the field of view of the camera collectively at high accuracy and at high speed. Consider the application of this device to the thickness measurement of plastic films. We have already proposed and put into practical use a method for simultaneous measurement of the front and back surface profiles and film thickness distribution of transparent films by signal processing of interferograms [3-5]. These mainly target a film having a substrate (i.e. covering film) such as a film on semiconductor wafers or LCD glass substrates.

In the case of a film without a substrate (i.e. independent film) such as a plastic film, it is difficult to hold the sample horizontally, and we proposed a method to measure the film thickness distribution of the transparent film by a simpler operation [6].

However, with these measuring methods, the film thickness and the refractive index cannot be obtained separately, and the film thickness is usually obtained with the refractive index known.

On the other hand, in the industrial world, the refractive index may be unknown, and there is a need for simultaneous measurement of the film thickness and the refractive index. So far, methods using a combination of a confocal optical system and an interference optical system [7,8], ellipsometry, multiple incidence angle method, etc. have been proposed, but they require a special optical system, and many methods is point measurement. Therefore, mechanical scanning is required to measure the distribution.

We propose a film thickness/refractive index simultaneous measurement method for an independent transparent film using a commercially available optical interferometric surface profiler.

2. Measuring method

The proposed method utilizes the two methods we have already reported. The two methods used will be briefly described below.

2.1 KF method

In a method called white-light interferometry or vertical scanning interferometry, an interferometer as shown in Fig. 1 is used to continuously capture interference images while vertically scanning the Z axis. When a transparent sample such as a film or glass is measured, an interferogram as shown in Fig. 2 is obtained. The two peaks correspond to the front and back of the transparent object body. In the KF method [3-5], two peaks are separated by a discriminant analysis method, individual peak positions are detected, and the surface profile, back surface profile, and film thickness distribution are simultaneously measured. Here, what is obtained is the "optical thickness" which is the product of the film thickness t and the refractive index n, and the separation measurement is impossible.

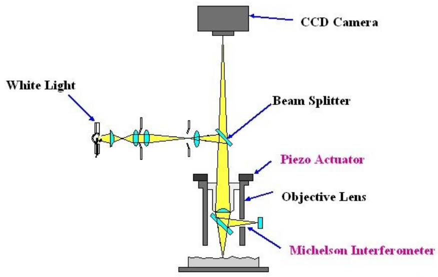

Fig.1 White-light interferometry

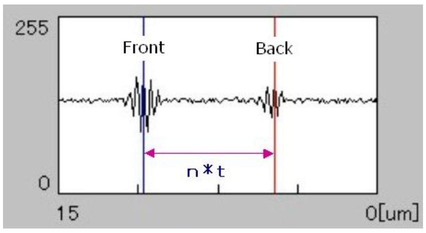

Fig.2 Interferogram of a transparent object

2.2 TF method

The film thickness measurement method by the transmission interferometry using a surface profiler (TF method) [6] inserts a transparent film to be measured on one side of the interference optical path, and detects the change in optical path difference due to the film thickness distribution. That is, a separately prepared flat surface is used as a measurement reference surface, a transparent film to be measured is inserted in the measurement optical path of the interference system, and the film thickness is obtained from the change in the measurement result of the measurement reference surface.

For example, as shown in Fig. 3, when a transparent film is inserted into a part of the measurement visual field of the surface profiler and a flat measurement reference surface is measured, a step D [= $(n-1)t$] occurs. If the refractive index n is known, the film thickness t can be obtained. Stable measurement can be performed without being affected by the position of the film and its waviness.

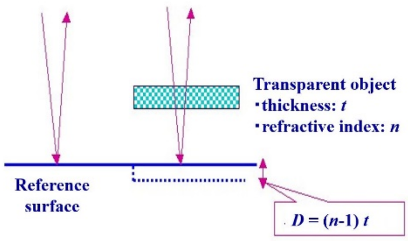

Fig.3 Principle of TF method

What is obtained here is the optical path difference, namely $(n-1)t$, and it is also impossible to separately measure the film thickness and the refractive index.

2.3 Simultaneous measurement of film thickness and refractive index

When measuring a transparent film sample, the optical film thickness is obtained by the KF method, the step is obtained by the TF method, and by combining the information obtained by both methods, it is possible to measure both the film thickness and the refractive index separately. That is, if the optical film thickness is T and the step is D,

$$T = nt \quad (1)$$

$$D = (n-1)t \quad (2)$$

Therefore, the film thickness and the refractive index can be independently obtained by the following equations.

$$T = T\text{-}D \quad (3)$$

$$N = T/(T\text{-}D) \quad (4)$$

By the way, this method was originally devised by us while we examined the measurement results of the KF method and TF method. Later, when the literature was searched, we found the principle was briefly described in the specification of the old patent [9]. However, there is no experimental data, and it seems to be little known.

3. Measurement results

3.1 Thin glass sample

Two types of thin glass plates (nominal thickness 30 µm, 50 µm; nominal refractive index 1.523) were measured using a surface profiler SP-500 [2]. An HDD substrate (metal mirror surface) was used as the reference surface for the TF method. Figure 4 shows the optical film thickness and step difference of the sample with a nominal thickness of 30 µm, and Fig. 5 shows the profiles of the refractive index and film thickness obtained from these data. Both are obtained as three-dimensional data, but the figures show profile data on one line. Table 1 shows nominal values and measured values (in-plane average value and standard deviation σ).

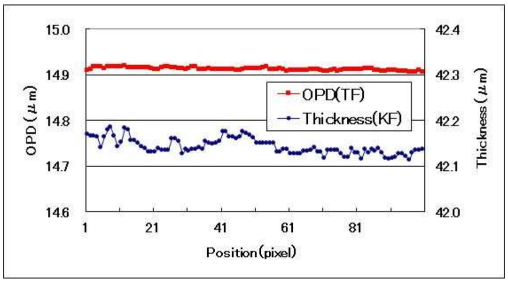

Fig.4 Profile data of thin glass by KF and TF method

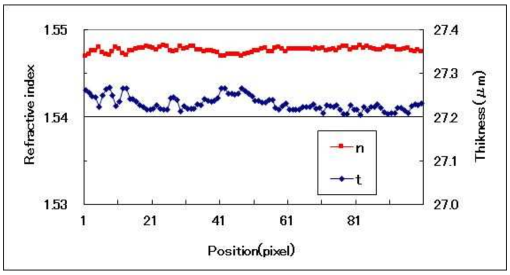

Fig.5 Measured profiles of thin glass thickness and refractive index

Table 1 Measurement results of thin glass plates

Sample	Nominal thickness	Measured thickness Ave ± σ	Nominal RI	Measured RI Ave ± σ
#1	33µm	27.23µm ±0.02	1.523	1.547 ±0.000
#2	51µm	50.66µm ±0.03	1.523	1.545 ±0.000

Note) The nominal values are from the supplier and averaged; The nominal RI (refractive index) is n_d(588nm).

3.2 Plastic film sample

A polyester (PET) film having a nominal film thickness of 1.5 µm and a nominal refractive index of 1.65 and a polyethylene (PE) film having an unknown film thickness and a nominal refractive index of 1.53 were attached to the left and right sides of a slide mounter with a gap therebetween for measurement. Figure 6 shows the optical film thickness by the KF method and the step difference by the TF method. The PET film is on the left, the PE film is on the right, and the center is the part without the film. The refractive index and film thickness profiles obtained from these data are shown in Fig. 7. Table 2 shows the nominal values and the measured values (in-plane average value). They are in good agreement.

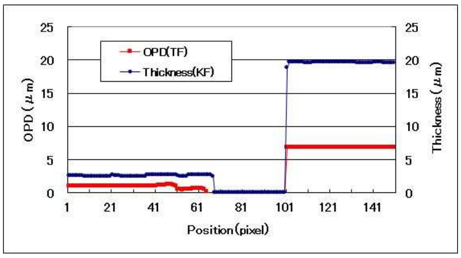

Fig.6 Profile data of plastic films by KF and TF method

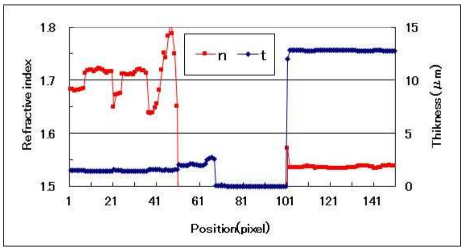

Fig.7 Measured profiles of plastic film thickness and refractive index

Table 2 Measurement results of plastic films

Sample	Nominal thickness	Thickness by contact	Measured thickness	Nominal RI	Measured RI
PET	1.5µm	1.6µm	1.51µm	1.65	1.69
PE	-	12µm	12.8µm	1.53	1.53

Note) Thickness by a contact device is 5 points average.

4. Summary

(1) We proposed a method of simultaneously measuring the film thickness and the refractive index of a transparent film or a transparent plate using white light interferometry.

(2) Using a commercially available surface profiler, thin glass and plastic film were measured to confirm the effectiveness of the method.

(3) It features that it is possible to collectively obtain four types of three-dimensional data of the surface profile, the back-surface profile, the film thickness distribution, and the refractive index distribution of the transparent film in a non-destructive and non-contact manner.

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