### Thickness Profile Measurement of a Transparent Film using Transmission Interferometry

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#### 1. Introduction

For measuring the thickness of plastic film or its coating film, various methods have been used, such as (1) infrared method, (2) radiation method ( $\beta$ -ray,  $\gamma$ -ray, X-ray, fluorescent X-ray, etc.), (3) spectroscopic method, (4) optical interference method, (5) electrostatic capacity method, (6) microwave method, etc. However, most of them are point measurement and mechanical scanning of the sample or the instrument is necessary to obtain the thickness distribution.

On the other hand, the surface profiler that uses optical interference is widely used in the industry because it can measure surface profiles in the field of view of a camera collectively at high accuracy and at high speed [1]. Consider the application of this device to the thickness measurement of plastic films.

The author has already proposed and put into practical use a method for simultaneously measuring the front and back surface profiles and film thickness distribution of a transparent film by interferogram signal processing [2] [3]. These mainly target a film with a substrate (coated film) such as a semiconductor wafer or a liquid crystal substrate, and in the case of a film without a substrate (independent film) such as a plastic film, it is difficult to hold it horizontally, and easier operation is required.

Therefore, in this paper, we propose a new method [4] for measuring the film thickness distribution of a transparent film using a surface profiler.

#### 2. Principle of measurement

Figure 1 shows the basic optical system of the surface profiler used. As a typical method for obtaining height from multiple interference images obtained by moving the reference plane, phase-shifting interferometry (PSI) and white-light interferometry (also called vertical scanning interferometry; VSI) can be used [5].

The proposed method (hereinafter referred to as the TF method) measures the film thickness distribution using

this surface profiler by inserting an "independent transparent film" to be measured on one side of the interference optical path and detecting the change in optical path difference (OPD) due to the film. That is, the separately prepared flat surface is used as the measurement reference surface, and the film thickness is obtained from the change in the height measurement value due to the insertion of the transparent film.

For example, as shown in Fig. 2, when a flat reference surface is measured with a transparent film inserted in a part of the measurement field of view of the surface profiler, an OPD occurs due to the film, and the step D [ = (n-1)\*t] appears. Therefore, if the refractive index n is known, the film thickness t can be obtained by D/(n-1). The transparent film is sufficiently separated from the reference plane and placed outside the coherence range. This method can be applied to a thin film or a multilayer film. In addition, stable measurement can be performed without being affected by the position of the film and the waviness.



Fig.1 Optics of interferometric profiler



Fig.2 Principle of TF method

#### **3. Experiment (#1): Wide-field interferometer 3.1 Experimental conditions**

- (1) Sample: Polyester film (attached to slide mounter)
- (2) Thickness: Nominal value 0.9-6.0 µm
- (3) Refractive index: Nominal value 1.65
- (4) Measuring device: Our wide-field type surface profiler SP-530 [5]
- (5) Reference flat surface: HDD disk media mirror surface
- (6) Measurement method: White light interferometry (VSI)
- (7) Vertical scanning speed: 2.4 µm/sec

#### 3.2 Experimental result

Figure 3 shows the measurement results for a polyester film with a nominal thickness of 0.9  $\mu$ m. A film thickness value of 0.89  $\mu$ m was obtained from the step average value of 0.58  $\mu$ m and the refractive index of 1.65.

Figure 4 shows the measurement results when two films having a thickness of 0.9  $\mu$ m and 1.5  $\mu$ m are cross-stacked. The measured step values were 0.55  $\mu$ m, 1.03  $\mu$ m, and 1.60  $\mu$ m with reference to the filmless area, and when converted into film thickness, they were 0.84  $\mu$ m, 1.58  $\mu$ m, and 2.46  $\mu$ m.

Furthermore, Fig. 5 shows the correlation between the nominal film thickness and the measured values.



Fig.3 Measurement result by TF method (right half is film-covered area)



Fig.4 Measurement result by TF method (two cross-stacked sample)



Fig.5 Correlation of nominal film thickness and measured one

#### **3.3 Discussion**

Good correlation with the nominal values was obtained for the samples with the nominal thickness of 0.9  $\mu$ m to 6.0  $\mu$ m and their stacked samples. The validity of the proposed method was confirmed.

# 4. Experiment (#2): Interference microscope with low magnification

#### 4.1 Experimental conditions

As a measuring device, a microscope type surface profiler SP-500 [5] was used. When the objective lens has a low magnification, since the distance (WD) between the lens and the sample is large, a transparent film can be inserted between them. However, it will disturb the microscope imaging system. Here, using a 5X lens, the height position of the sample was changed by the method as shown in Fig. 6, and the influence on the measured value was examined. The thickness of the slide glass used as a spacer is about 1.3 mm, and other conditions are the same as in Section 4.1 above.

#### 4.2 Experimental result

Figure 7 shows the height profile measurement results when a sample with a nominal film thickness of 0.9  $\mu$ m was inserted in the right half of the microscope field and the number of spacers was changed. The height change



Fig.6 Test method of sample height effect



Fig.7 Effect of sample position

profiles are displayed with reference to the height of the left end of the filmless area.

#### 4.3 Discussion

As the number of spacers increases, the edge of the step becomes dull, and the correct step cannot be measured with two spacers. This corresponds to image blurring of the edge due to the disturbance of the microscope imaging system.

# 5. Experiment (#3): Interference microscope with high magnification

#### 5.1 Experimental conditions

When the objective lens has a high magnification, the distance (WD) between the lens and the sample is small, so it is difficult to partially insert the transparent film within the fields of view. Therefore, it was tried to insert a transparent film over the entire field of view and determine the film thickness from the measured height change before and after the insertion. A sample with a nominal thickness of 0.9  $\mu$ m was measured using a 20X lens. Other conditions are the same as in Section 4.1 above. **5.2 Experimental result** 

The measurement result before the sample insertion is shown in Fig. 8, the result after the sample insertion is shown in Fig. 9, and the film thickness obtained from the difference is shown in Fig. 10. The average value of measured film thickness was 0.85  $\mu$ m for the nominal thickness of 0.9  $\mu$ m.

#### 5.3 Discussion

The problem with this method is the height change of the reference plane between the two measurements. In this experiment, the sample was taken out after the second measurement, the third measurement was performed, and the average height of the first and third measurements was adopted as the reference surface height. The amount of change was 23 nm.



Fig.8 Height profile before sample insertion



Fig.9 Height profile after sample insertion



Fig.10 Thickness profile calculated from OPD change

## 6. Experiment (#4): Comparison with other methods

The author has developed and commercialized the KF method [2] for thick films, which is capable of simultaneously measuring the surface profiles and film thickness distribution, mainly for films with substrates (coating films). Here, the comparison results between this method and the proposed method are shown.

#### **6.1 Experimental conditions**

With a 5X lens, the sample with a nominal film thickness of 1.5  $\mu$ m occupies the right half of the field of view, and was placed close to the reference plane. The vertical scanning speed is 1.2  $\mu$ m/sec, and other conditions are the same as in Section 4.1 above.

#### 6.2 Experimental result

The same sample was measured by two methods. The result of film thickness measurement by the TF method is shown in Fig. 11, and the result by the KF method is shown in Fig. 12. Figure 13 shows the average film thickness profile of the central 50 lines obtained by the two methods.



Fig.11 Thickness profile by TF method (upper right is a marker)



Fig.12 Thickness profile by KF method



Fig.13 Comparison of thickness profiles by two methods

#### 6.3 Discussion

It can be seen that the TF method compares favorably with the KF method and gives stable results, except for the disturbance at the edge. The partial difference in film thickness between the two methods is presumed to be either (1) unevenness on the reference surface or (2) error in refractive index.

The TF method has the following features as compared with the KF method.

(1) In principle, there is no limit on the measurement range.

- (2) Only film thickness can be measured (i.e. the surface profiles cannot be measured).
- (3) Strong against disturbance such as sample vibration.



Fig.14 Mach-Zehnder interferometer

#### 7. Discussion : Effect of dispersion

In general, the refractive index of a transparent film is not constant, and has wavelength dependence (i.e. spectral dispersion). When the phase shifting method is used for measurement, since the illumination is monochromatic, there is no influence of dispersion. As in this experiment, when using white light interferometry for measurement, it is necessary to consider the influence of dispersion.

When the refractive index of the sample having the film thickness t changes from n to  $n + \Delta n$ , the OPD change is  $t \Delta n$ . In the wavelength band used for white light interferometry, the wavelength dispersion  $\Delta n$  of common substances is on the order of 1/1000, so the peak position change due to the OPD by the dispersion is on the order of 1 nm per 1 µm of film thickness. This is sufficiently smaller than the period of the interference waveform of 300 nm, and is not a problem for height measurement.

## 8. Discussion: Comparison with other interferometric methods

The Mach-Zehnder interferometer shown in Fig. 14 is known as an optical interferometer capable of measuring the thickness of a transparent film. This method is a transmission interference, which is the same as the TF method in principle and does not require a reference plane. However, it is not marketed as a commercial product. Also, realization of the microscope type will not be easy.

#### 9. Discussion: Other possible applications

(1) Multilayer film: The total optical film thickness of each film layer is measured.

(2) Coated film: Applicable when the substrate is transparent, and the total thickness of the substrate and the transparent film is measured. Furthermore, if the film can be partially peeled off, the film thickness of the coating film can be obtained from the step between the peeled area and the non-peeled area.

#### **10. Summary**

We proposed a method of inserting the transparent film to be measured into the measurement optical path of the interference system and determining the film thickness from the change in the measurement result of the reference plane. First, we confirmed the basic principle with a widefield interferometer. Furthermore, in the microscope type interferometer, the effect of the height of the sample was investigated, and the practicality of the two-step measurement method was confirmed.

According to this method, the thickness distribution of the transparent film can be measured easily and stably by using a commercially available reflection type surface profiler without being affected by the position of the sample or the waviness. In addition, this method can be applied to ultra-thin films and multilayer films.

#### References

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