Surface and thickness measurement of a transparent film using three-wavelength interferometry

K. Kitagawa
Toray Engineering Co., Ltd., Japan
mailto:katsuichi.kitagawa@nifty.com

Keywords: surface profiling, film thickness, interferometry, three-wavelength

Abstract

We have developed a novel areal film thickness and topography measurement method by three-wavelength interferometry. It estimates both the profiles of front and back surfaces and the thickness distribution of a transparent film simultaneously by model-based separation of two overlapped signals in the interferograms. The validity of the proposed method is proved by computer simulations and actual experiments.

1. Introduction

The conventional interferometric surface profiling methods can't be used for measuring objects covered with a transparent film, because it is required to separate the interference signal of the front surface from that of the back surface. To resolve these drawbacks, we've been working on a new approach called SOSS (Separation of Overlapped Sinusoidal Signals) algorithm that estimates both the profiles of front and back surfaces and the thickness distribution of a transparent film.

2. Principle

2.1 Basic concept

In our technique, a three-wavelength interferometric imaging system [1,2] is used, which consists of a three-wavelength (B, G, R) illumination system and a colour camera (Fig. 1). With this system we can obtain three interferograms with different wavelengths simultaneously (Fig. 2(a)). Since the bandwidth of each illumination light is narrow enough, the interferograms can be expressed as the sum of two sinusoidal signals, one corresponding to the front surface and one to the back surface:

$$g(i,j) = a(j) + b_1(j)\cos\left[4\pi\{z(i) - z_1\}/\lambda(j)\right] + b_2(j)\cos\left[4\pi\{z(i) - z_2\}/\lambda(j)\right]$$

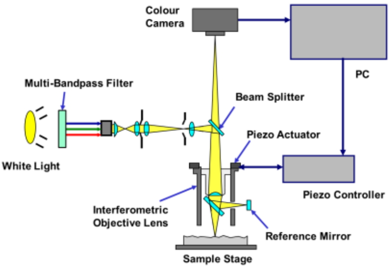


Figure 1. System configuration.

where $g(i, j)$ is the intensity at frame i ($i = 1, 2, \ldots, N$) and wavelength j (j = B, G, R), $a(j)$ is the average value, $b_1(j)$ and $b_2(j)$ are the modulation of the waveform of the front surface and the back surface, respectively, $z(i)$ is the height, z_1 and z_2 are the height of the front surface and the back surface, respectively, and $\lambda(j)$ is the wavelength of the wavelength j. The unknown parameters $a(j)$, $b(j)$, z_1 and z_2 are estimated using the following least-square fitting equation:

$$F = \sum_{j=1}^{3}\sum_{i=1}^{N}\left[g(i,j) - g_{i,j}\right]^2$$

where $g(i, j)$ is the model intensity and g_{ij} is the observed intensity.

2.2 Parameter reduction

Let us consider the necessary conditions to obtain the unknown parameters. The total number of the parameters is eleven. On the other hand, the number of the valid observed data of three interferograms is only nine, because one sinusoidal wave has three parameters of the bias, amplitude and phase. Therefore this least-square fitting problem cannot be solved.

To reduce the number of the unknowns, we assume that the ratio of the modulation parameters is independent of the wavelength; i.e. $\alpha \equiv b_1(j)/b_2(j)$ = constant. Then the model is expressed as

$$g(i,j) = a(j) + \alpha b_2(j)\cos\left[4\pi\{z(i) - z_1\}/\lambda(j)\right] + b_2(j)\cos\left[4\pi\{z(i) - z_2\}/\lambda(j)\right]$$

The number of unknown parameters is reduced to nine, i.e. $a(j)$, $b_2(j)$, z_1, z_2, and α. Therefore this least-square fitting problem becomes solvable.

3. Computer Simulations

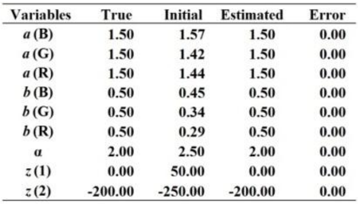
3.1 Test method

A set of theoretical three-wavelength interferograms was calculated with the parameters shown in the True column of table 1. The wavelengths are 470 nm (B), 560 nm (G), and 600 nm (R). The synthesized signals are shown in Fig. 2(a). All the computations were done in MS Excel with a Windows PC. The initial guess values were set as shown in the Initial column of table 1.

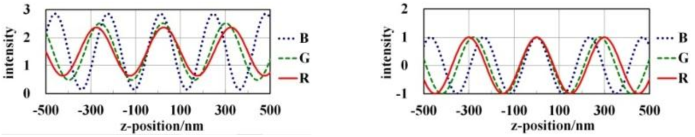
3.2 Test results

The results are shown in table 1. The parameters and heights were correctly estimated. The separated waveforms and the fitted model waveform are shown in Fig. 2(b)(c)(d).

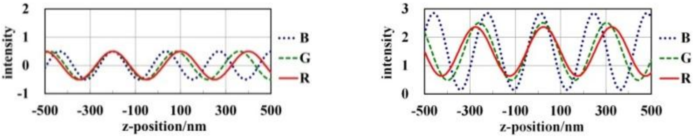
Table 1. Estimated variable values.



Variables	True	Initial	Estimated	Error
a (B)	1.50	1.57	1.50	0.00
a (G)	1.50	1.42	1.50	0.00
a (R)	1.50	1.44	1.50	0.00
b (B)	0.50	0.45	0.50	0.00
b (G)	0.50	0.34	0.50	0.00
b (R)	0.50	0.29	0.50	0.00
α	2.00	2.50	2.00	0.00
z (1)	0.00	50.00	0.00	0.00
z (2)	-200.00	-250.00	-200.00	0.00



(a) Synthesized data (b) Separated surface signals



(c) Separated back-surface signals (d) Fitted signals

Figure 2. Waveforms in the computer simulation.

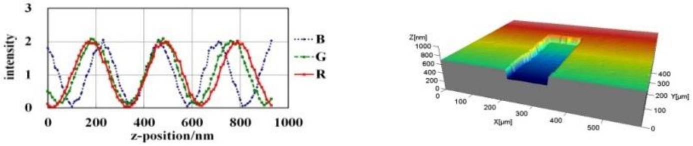
4. Actual Experiments

4.1 Test method

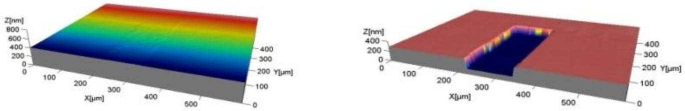
We wrote a program in the C language to implement the algorithm on the Windows PC. The nonlinear least-squares equation was solved using the Davidon-Fletcher-Powell method. In our experiments, a thickness step of 100 nm and 300nm was used, which consists of a silicon dioxide (*n* = 1.46) steps on Si-wafer. The vertical scanning speed was 150 nm/second, and the sampling interval was 10 nm.

4.2 Test results

The observed data are shown in Fig. 3(a). The obtained surface, back-surface and thickness profiles are shown in Fig. 3(b)(c)(d). The areal average thicknesses were 294 nm and 102 nm. These are in good agreement with the nominal values.



(a) Observed data of the center pixel (b) Estimated surface profile



(c) Estimated back-surface profile (d) Estimated thickness profile

Figure 3. Results of the actual experiment.

5. Conclusion

We have proposed a new interferometric profiling technique, named SOSS algorithm, which enables us to estimate both the profiles of front and back surfaces and the thickness distribution of a transparent film by separating two overlapped signals in the interferogram. In our technique, a three-wavelength interferometric imaging system is used, which consists of a three-wavelength (B, G, R) illumination system and a colour camera. With this optics three interferograms with different wavelengths can be obtained simultaneously. From the observed interferogram data, we can estimate the unknown parameters including the front and back surface heights by the least-squares fitting method under some assumptions to reduce the number of the unknown parameters. The proposed method has been validated by computer simulations and experiments.

References:

[1] Kitagawa K 2012 *J. Electron. Imaging* **21** 021107

[2] Kitagawa K 2013 *Appl. Opt.* **52** pp 1998-2007