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3D tomography of multilayer film structure

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Abstract
We describe a new scheme of a Linnik interferometric configuration based on spectrally-resolved white-light interferometry for simultaneous measurement of top surface and its underlying film surfaces in multilayer film structure. Our proposed technique enables accurate measurments of the phase and reflectance over a large range of wavelengths using the iterative least-squares phase-shifting algorithm by supplessing critical phase shift errors, and it provides a better measeurement result than conventional methods. To vearify our method a complex multilayer film was prepared and we measured it, and compared with well-known conventional technqieus. Comparison results show our new method successfully works well with high precision as same as existing methods.

Spectrally-resolved white-light interferometry, multilayer film structure

1. Introduction

Industrial demands to inspect multilayer circuits consisted of a stack of transparent conductive thin-film layers have been rapidly increasing throught entire industries including semiconductor, flat panel display, and LED industries. It is because field inspection is essential to improve productivity and lower costs. So the thin-film metrology is critical to control the manufacturing process. The most reliable and intuitive thin-film analysis is the cross section observation with a scanning electron microscope (SEM). But this technique is time consuming for specimen preparation and damages the specimen itself. Non-destructive methods using ellipsometry [1] and reflectometry [2] are widely used for thin film characterization in industrial field. However, they are basically a point by point thickness measurement and not suitable for 3D inspection of the internal structure of complex multilayer films.

Recently, in response to industrial needs, much research has been done on 3D inspection of complex thin-film structures using white-light interferometry [3,4]. These approaches allow simultaneous measurements of top surface and its underlying film surfaces with high precision, but their applications are only limited to measurement of a single layer film structure. To further effort to expand into multilayer films, other research attempt [5] has been performed by utilizing both the phase and reflectance spectra of sample to measure individual film thickness of each layer in a stack with more improved precision. However, this technique selects only several phase and reflectance spectra with corresponding filters available with narrow bandpass regions and wave plates also inherently introduce the wavelength-dependent errors in the phase shift.

As a summary of the authors' previous paper [6], we describe a Linnik interferometric configuration based on spectrally-resolved white-light interferometry. This proposed technique enables accurate measurements of the phase and reflectance over a large range of wavelengths and these spectral signals are used to achieve volumetric inspection of complex multilayer film structure

2. Multilayer thin film measurement using spectrally-resolved white-light phase-shifted interferometry

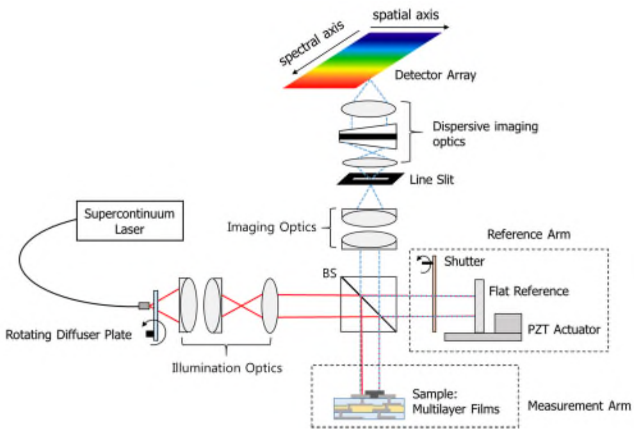

Figure 1. A schematic diagram of spectrally-resoloved white-light phase-shifted interferometry

A schematic diagram of our proposed method is shown in Figure 1. A supercontinuum laser with high output power and broad spectrum was used as the light source to obtain the spectral signals as wide as possible. The high-spatial-coherence broadband fiber source generates the speckle noisy pattern and this random granular pattern is eliminated using a rotating diffuser plate. Kohler illumination is used to provide uniform distribution of intensity in the measurement and reference arms. In the reference arm, we use a shutter to block or pass an incident beam in the reference arm to obtain only the reflected beam from the sample or the interference beam between the sample and the reference. The resulting reflected or interfered light beam is passed through a line slit and dispersive elements and it allows the 2D detector array to obtain the spectral information of the pixels on a single spatial line of a sample, of which one axis corresponds to the spatial axis of the selected line and the other corresponds to the spectral axis. In the measurement arm, we use a PZT actuator to acquire sequential phase-shifted spectral images and iterative least-squares phase-shifting algorithm is used to measure accurately the broadband phase spectra by suppressing serious phase-shift errors. Through these procedures described above, the absolute reflectance and phase over a wide range wavelenths of source used are precisely obtained, and it leads to a better solution for simultaneous measurments of thin-film surface and thickness.

For verification of our proposed technique, we manufactured a three-layer film strucuture by series of sequential photolithography process. In our system, the whole measurement process can be divided into two steps. The first is to calculate the absolute reflectance of our sample. By blocking the incoming beam on the reference arm by activating the shutter, we can obtain the measurement beam from the specimen. Second by deactivating the shutter, the interference beam between the measurement and the reference is obtained. To determine the phase of the measurement wave over a broad wavelength range, we used the iterative least-squares phase-shifting algorithm. Figure 2 shows 3D thickness profile of the complex three-layer film structure.

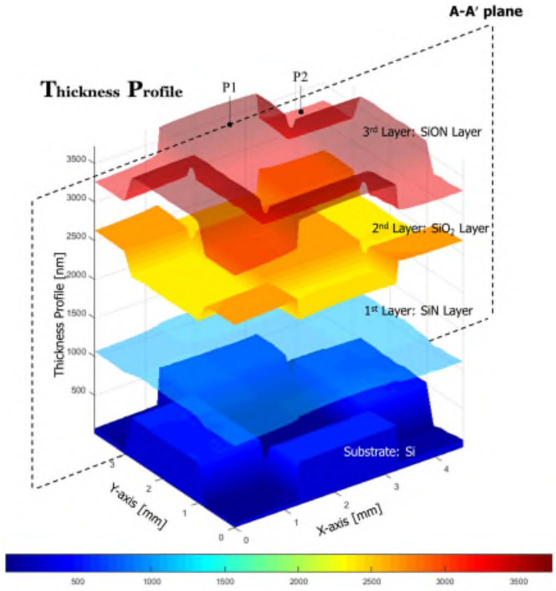

Figure 2. Three-dimensional measurement result of complex three-layer film structure using our proposed technique.

Table 1 Comparison results with a commercial instrument of ellipsometer

Sampling Position		Ellipsometer	Our method (mean $\pm\sigma$)
SiN Layer (1^{st} Layer)	P1	581.7 nm	594.3 ± 0.25 nm
	P2	1004.3 nm	1011.5 ± 1.55 nm
SiO_2 Layer (2^{nd} Layer)	P1	1246.9 nm	1255.2 ± 0.75 nm
	P2	1563.9 nm	1568.0 ± 2.52 nm
SiON Layer (3^{rd} Layer)	P1	1312.1 nm	1294.1 ± 2.06 nm
	P2	641.5 nm	642.6 ± 0.27 nm

We verified the measurement accuracy of our proposed method through comparisons with two well-known measurement techniques, ellipsometer and stylus profilometer. Table I shows the comparison results of the film thickness of each layer with a commercial ellipsometer at P1 and P2 positions of the sample. The discrepancy between the results of the two measurement methods is less than ~18 nm. Figure 3 shows another comparisons of our measurement results with a Veeco Dektak 8 stylus profilometer when measuring an A-A′ line surface profile of each layer of the sample. For ease of comparison, the minimum values of each line profile measured by two different methods were adjusted close to zero, and these two measured surface profiles are well matched to each other.

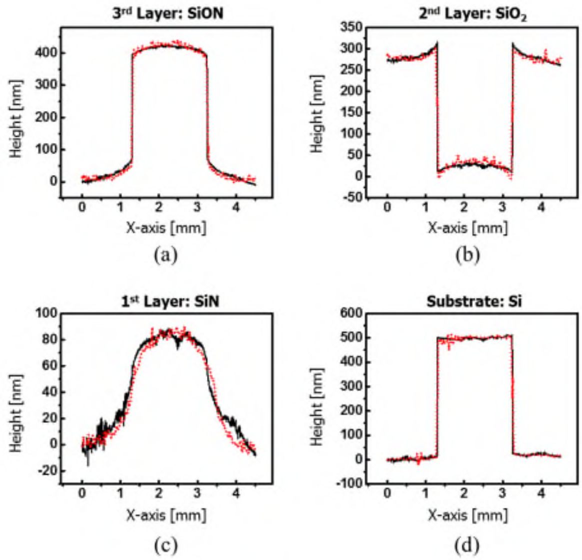

Figure 3. Comparisons of our measurement result (black-solid line) with a Dektak 8 (Veeco) stylus profilometer (red dots) when measuring an A-A′ line profile of the multilayer film sample. : (a) surface profile of a 3^{rd} SiON layer, (b) surface profile of a 2^{nd} SiO2 layer, (c) surface profile of a 1^{st} SiN layer, and (d) surface profile of a silicon substrate.

3. Conclusion

To summerize, we proposed a new approach that goes one step further than conventional methods for simultaneous measurement of film surface and thickness without any damages to the sample. We used the iterative least-squares phase-shifting algorithm for precise measurement of the broadband phase spectra by suppressing critical phase shift errors and also measured the reflectance spectra over a wide range of wavelengths at the same time. Obtaining these additional information at every wavelength is essential to improve measurement accuracy, stability, and precision for multilayer thin-film metrology. To verify our proposed technique, a three-layer complex multilayer film was made and the surface profile and film thickness were measured by two different commercial instruments of a stylus profilometer and an ellipsometer, respectively. Comparison results confirmed that our method enables us effectively to inspect the internal structure of multilayer film while maintaining good precision same to existing methods.

Acknowledgment

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