euspen's 18th International Conference & Exhibition, Venice, IT, June 2018
www.euspen.eu

Film measurement through transparent medium using Linnik type white-light spectral interferometer

Tong Guo[1*], Minghui Li[1], Zhuo Chen[1], Xing Fu[1], Xiaotang Hu[1]

[1]State key laboratory of precision measurement technology and instruments, Tianjin University, Tianjin 30072, China

guotong@tju.edu.cn

Abstract

According to the requirement for high precision measurement of the film growth in the vacuum condition, a Linnik type measuring system with long working distance was built up based on white-light microscopic spectral interferometry. The influence of the transparent medium on the interferogram was minimized by the optical path compensation in the reference beam of the interferometer. The phase difference between two interference beams can be obtained by a phase-shifting method from the spectral interferogram. The influence of nonlinear phase error caused by the beam splitter can be removed by introducing a wavelength correction to convert the effective thickness into a constant value and the nonlinear phase error caused by the two microscopic objectives can be extracted, which made thickness measurement more accurate. Some experiments on the film standard with calibrated film thickness showed that introducing a wavelength correction made the film thickness measurement more accurate through a transparent medium.

Linnik type; white-light spectral interferometer; transparent medium; nonlinear phase correction

1. Introduction

Many emerging applications of micro and nano devices require the samples to be measured through a transparent medium, such as digital micro-mirror device (DMD) and coating in the vacuum. It needs to detect the static or dynamic behaviors through the transparent medium[1]. However, the introduction of the transparent medium affects the measurement. We built up a Linnik type measuring system with long working distance based on white-light microscopic spectral interferometry, which is compensated at the reference beam to measure film thickness through a transparent medium.

2. Theory

According to double beam interference theory, the general form of the interference signal is given by Eq. (1). Here, I_r and I_m represents the light intensity of the reference and measurement beam, respectively. $\delta = 2\mathrm{hk}$ represents the phase difference between the two beams; h represents the optical path difference between the reference beam and the measurement beam; $\mathrm{k} = 2\pi/\lambda$ represents the wavenumber.

$$\mathrm{I} = I_r + I_m + 2\sqrt{I_r I_m}\cos\delta \tag{1}$$

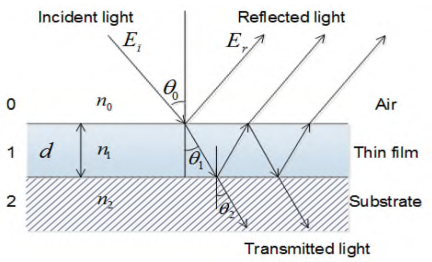

Figure 1. Reflection of a single layer film on a substrate

There is a single layer of film thickness d and refractive index n_1 on a substrate with refractive index n_2. A parallel beam of incident light reaches the top surface with refractive index n_0 under an angle θ_0 with respect to the normal to the surface. This is illustrated in Figure 1. By the coherent superposition theory of the reflected light, the reflectance can be expressed as Eq. (2). Here r_{01} , r_{12} represents Fresnel reflection coefficient of the upper and lower surface of the film, respectively. β represents the phase difference of light propagating twice within the film.

$$\mathrm{R} = \frac{r_{01}+r_{12}\exp(-j2\beta)}{1+r_{01}r_{12}\exp(-j2\beta)} \tag{2}$$

According to Eq.(1) and Eq.(2), the phase of the interference signals of the film structure is given by Eq.(3) and Eq.(4). $\varphi(\mathrm{k},\mathrm{d})$ represents the phase caused by the film structure, including the linear portion caused by the thickness and the nonlinear portion caused by the multiple reflections.

$$\delta = 2\mathrm{hk} + \varphi(\mathrm{k},\mathrm{d}) = 2\mathrm{hk} + \angle\mathrm{R} \tag{3}$$

$$\varphi(\mathrm{k},\mathrm{d}) = 2nkd + \phi(k,d) \tag{4}$$

The nonlinear phase $\phi(k,d)$ caused by the multiple reflections of the film is obvious. By extracting the phase of the interference signals and then obtaining the nonlinear phase, the film thickness parameter can be obtained by means of L-M algorithm[2]. The evaluation function used is given by Eq.(5). Here A^T, A^M represents the theoretical and measured values, respectively.

$$\chi(\mathrm{d}) = \sum_{i=1}^{N} |A^T(\lambda,d,n) - A^M(\lambda,d,n)|^2 \tag{5}$$

3. System set-up

The experimental set-up used is a Linnik type measuring system with long working distance based on white-light microscopic spectral interferometry, which is shown in Figure 2. We used 5x and 10x objective in the experiments.

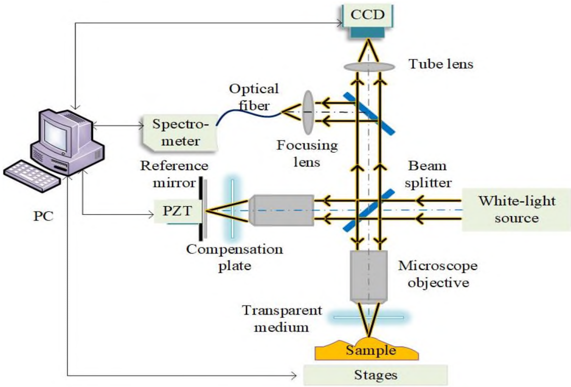

Figure 2. Experimental setup with a Linnik interferometer

4. Experimental results and discussion

4.1. The nonlinear phase errors of effective thickness[3] and microscopic objectives

The Linnik structure has a great impact on the measurement of the thin film because of its special structure, including the mismatch of the beam splitter prism and the mismatch of the double objective lens. We define these as nonlinear phase errors. In order to eliminate the impact, the influence of nonlinear phase error caused by the beam splitter can be removed by introducing a wavelength correction to convert the effective thickness into a constant value and the nonlinear phase error caused by the two microscopic objectives can be extracted. The above method is described in detail in another paper we published[4]. Finally, the nonlinear phase errors of the effective thickness after wavelength correction and the nonlinear phase of the microscopic objectives are shown in Figure 3.

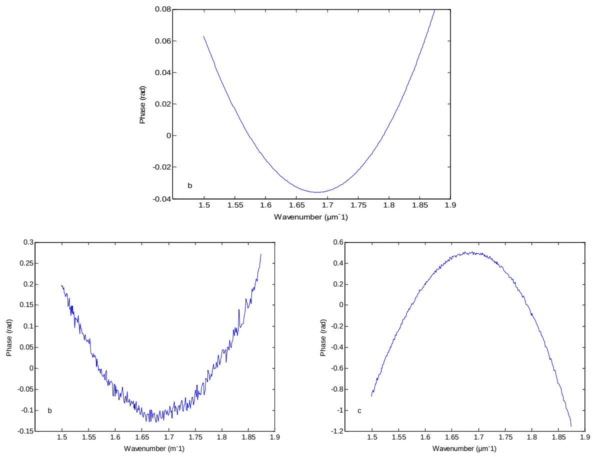

Figure 3. The nonlinear phase of (a) effective thickness (b) microscopic objective - 5X (c) microscopic objective -10X

4.2. The results of standard film through transparent medium

The tested film is VLSI standard film with the calibrated film thickness (1052.2 ± 0.9 nm). In the experiments, different pieces of cover glasses were used at the measurement beam and compensated at the reference beam. The phase of the interference signal was extracted and then obtained the nonlinear phase. Furthermore, we subtract the nonlinear phase errors of the effective thickness and the microscopic objectives and then get the nonlinear phase of the film which is shown in Figure 4. The film thickness parameter can be obtained by means of L-M algorithm using the nonlinear phase of the film. Through the testing system, we finally achieved the measurement of the film thickness through different numbers of cover glasses. The results obtained are summarized in Table 1. It can be seen from the measurement results that there is a high correlation between the measured nonlinear phase and the theoretical non-linear phase. Figure 4 demonstrates a very good agreement between the theoretical and the experimental results with the correlation coefficient as high as 0.9982 in some cases. The experimental results show that the system can measure through a transparent medium and has the nano-level precision.

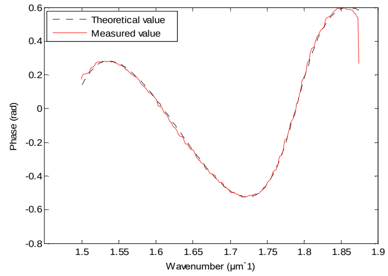

Figure 4. Nonlinear phase curves of the measured value (solid) and the theoretical value (dash) of the film

Table 1. Results under different numbers of cover glasses

Cover glasses (pieces)	5×		10x	
	Results (μm)	Correlation coefficient	Results (μm)	Correlation coefficient
1	1.0524	0.9980	1.0526	0.9982
2	1.0519	0.9959	1.0527	0.9982
3	1.0527	0.9974	1.0526	0.9979
4	1.0523	0.9978	1.0526	0.9979
5	1.0521	0.9972	1.0527	0.9975
6	1.0500	0.9973	1.0525	0.9966
7	1.0521	0.9973	1.0530	0.9881
8	1.0508	0.9967	1.0539	0.9931
9	1.0503	0.9922	1.0527	0.9953
10	1.0506	0.9959	1.0540	0.9922
11	1.0517	0.9947	1.0539	0.9868
12	1.0510	0.9843	1.0534	0.9855

5. Conclusion

We used a Linnik white-light microscopic spectral interferometer to measure the film thickness through a transparent medium. The influence of the transparent medium on the interferogram was minimized by the optical path compensation in the reference beam of the interferometer. A technique for eliminating the influence of the nonlinear phase error is described. We showed that the optical path compensation in the reference beam of the interferometer is an important means for an accurate measurement of the nonlinear phase information of a film.

References

[1] Koev S T, Ghodssi R. Advanced interferometric profile measurements through refractive media[J]. *Review of Scientific Instruments*, 2008, 79(9): 093702

[2] Fachinotti V D, Anca A A, Cardona A. A method for the solution of certain problems in least squares[J]. *Int J Numer Method Biomed Eng*, 2011, 27(4): 595-607

[3] Hlubina P, Lunácek J, Ciprian D, et al. Variable effective thickness of beamsplitter cube and dispersion error in white-light spectral interferometry[C]. *Proc. of SPIE Vol*, 2008, 7141:71410X-1

[4] Guo T, Li M H, Zhou Y, et al. Wavelength correction for thin film measurement in a microscopic white light spectral interferometer[J]. *Optik-International Journal for Light and Electron Optics*, 2017, 145: 188-201