行政院國家科學委員會補助專題研究計畫成果報告

光彈調變式橢圓偏光儀(一) 反射面之校正

計畫類別：☑個別型計畫　　□整合型計畫

計畫編號：NSC89-2112-M-009-032

執行期間：88年8月1日至89年7月31日

計畫主持人：趙于飛

計畫參與人員：王夢偉 交大光電所 博士

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一、中文摘要

本計畫利用三個亮度量測技術以校正偏光片, 析光片及光彈調變制器等之偏光角的位置。先用穿透式將偏光片, 析光片及光彈調變制器等之偏光角的相對位置，再將此元件放在返射面上利運用三個亮度量測技術量測偏光角，本計畫並證明利用同樣的三個亮度量也可量出其橢圓參數 ψ。

關鍵詞：橢圓偏光儀，彈調變制器，校正技術

Abstract Instead of nulling method, a three-intensity-measurement technique is proposed to determine the azimuth deviation of the polarizer (P), photoelastic modulator (PEM) and analyzer (A) with respect to the specimen surface for ellipsometric measurements. After the initial alignment in a straight- through set-up, we adjusted the azimuth of P at 45^o to the strain axis of the PEM. Arranging a PPEMSA ellipsometry by subjecting a specimen at the required incident angle, we measured a set of three DC radiances at zero point of the zero-order Bessel function. In addition to the azimuth deviation, the ellipsometric parameter ψ can also be determined from the same measurements.

Keywords: Ellipsometry, photoelastic modulator, alignment

二、Introduction

Recently, the photoelastic modulator (PEM) has been used to replace the wave plate in an ellipsometric system [1-3]. The PEM is a device that utilizes the photoelastic effect to modulate the phase retardation in a harmonic form [3]. This ability allows not only the use of PEM for a wide range of wavelengths, but also the chopping of the light beam at reasonable frequencies for synchronous detection. Moreover, in the PEM ellipsometric system the orientations of the polarizer and analyzer are fixed with respect to the plane of incidence while the ellipsometric parameters are obtained by modulating its phase retardation. This is in contrast to a conventional ellipsometric system, in which the ellipsometric parameters are obtained by rotating one of the optical components, such as the polarizer, analyzer or compensator. It is known that this rotating setup may cause beam deviation [4] and thus produce parasitic error, which can be avoided in the PEM ellipsometric.

The azimuth alignment of the optical components in the ellipsometer is essential to the accuracy of measurements because any improper azimuth setting in the system can cause significant errors [5,6]. The nulling method [7,8] has been the most frequently used technique in polarization-related measurements. McCrackin et al. [9,10] suggested some systematic alignment techniques for aligning the azimuth angles of the optical components in ellipsometer. Because the minimum intensity must be precisely located, a highly sensitive detecting system and high- extinction-ratio polarizers are required in those techniques. In a previous study [11], we improved Steel’s intensity ratio technique [12] for aligning the azimuths of the polarizer and analyzer to the specimen surface in a Polarizer-Sample-Analyzer ellipsometric system, but only determined [13] the relative azimuth position of the strain axis of a PEM to the transmission axes of the polarizer and the analyzer in a straight-through (polarizer-PEM-analyzer, PPEMA) setup. In this paper, we continue our efforts by applying a similar technique to align all of the optical components (namely P, PEM and A) to the reflective surface of a specimen in a PEM ellipsometer. Initially, the relative positions of P, PEM and A can be directly determined [13] in a straight-through arrangement with the specimen removed. The specimen is then positioned and arranged at the required angle of incidence in a PPEMSA type ellipsometer. The small azimuth deviation from the incident plane is determined by applying a three-intensity-measurement technique [14] to its DC component at the zero point of the zero-order Bessel function, under the condition that the azimuth of the PEM and polarizer are set at 0 and 45^o, respectively. This direct determination technique can be operated at any incident angle with the specimen *in situ*. Without any additional measurement, this technique can also determine one of the ellipsometric parameters, ψ.

三 Theoretical Background

The basic setup of the ellipsometric system is shown in Fig. 1.

$$I = I_o \left| \langle A | R(-\theta) M_S R(\theta) M_{PEM} | P \rangle \right|^2$$

$$\Delta = \Delta_o \cos \omega t .$$

As the zero-order Bessel function (J_o) equals zero, i.e., Δ_o=2.405, the appendix provides the calibration technique of the zero point of the zero-order Bessel function in a PEM system, and intensity can be further simplified as

A three-intensity-measurement technique [13] can be easily applied to determine the azmuth position of θ. Measuring three radiances through three analyzers evenly spaced 60^o apart in half a cycle, one can use the following relation

$$\tan 2(A-\theta) = \frac{-\sqrt{3}[I_{DC}(A+60) - I_{DC}(A+120)]}{[2I_{DC}(A) - I_{DC}(A+60) - I_{DC}(A+120)]}$$

One can also obtain one of the ellipsometric parameters, ψ, by the relation of

$$\tan^2 \psi = \frac{1-\kappa}{1+\kappa} ,$$

where

$$\kappa = \frac{\sqrt{3}[I(A+60) - I(A+120)]}{\sin 2(A-\theta)[I(A) + I(A+60) + I(A+120)]} ,$$

through the same measurements.

$$I_{DC}(A) = \frac{I_i}{2}\{\sin^2(A-\theta) + \tan^2\psi \cos^2(A-\theta)\}.$$

四 Experimental Results

The azimuth deviation of P, PEM and A with respect to the specimen surface was deduced from the reflected intensity measurements; the deviations were evaluated before and after the adjustment, and were -0.60±0.02^o and 0.008±0.02^o, respectively, as shown in Fig 2. The azimuth angle of the system can be arranged within 0.01^o of the specimen surface in our system. The ellipsometric parameter ψ was also obtained from the same measurements, and our results are comparable with those measured by using a conventional null ellipsometer. The ellipsometric parameter ψ of a thick platinum film and a standard SiO_2/Si thin film are tabled in Table 1 at an incident angle of 70^0 by this PEM ellipsometer. The ellipsometric parameter ψ of thick Pt film measured using a Rodulph AutoEL III is 34.15 ± 0.01^o. However, the ellipsometric parameter ψ of the standard SiO_2/Si thin film is 50.58^o, which is calculated by considering its thickness as 1133 Å and refractive index as 1.462.

Concluding Remark

The three-intensity-measurement technique [14] can directly determine the azimuth deviation of the PPEMA system to the specimen surface by high-level intensity measurements instead of the time-consuming measurements in which the angular positions of the analyzer as well as the polarizer corresponding to the intensity minimum are required to be determined. Since the azimuth position is determined by an intensity ratio technique, it cannot only reduce the error caused by the imperfection of the analyzer, but also determine the parameter ψ simultaneously. Because this method can determine the azimuth position at the working angle of incident with the specimen *in situ*, a prior testing sample for alignment is not required in the system. The major problem in this system is the intensity fluctuation. Because the multiple reflection effect [17] can be avoided in the reflective arrangement, the standard deviation of the reflected system ($\Delta\theta=0.02^o$) is less than the straight-through measurements [13] ($\Delta\theta=0.05^o$). Further study will be devoted to measure the tilting angle of the reflective surface.

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References

1. S. N. Jasperson and S. E. Schnatterly: Rev. Sci. Instrum. **40** (1969) 761.
2. E. Huber, N. Baltzer and M. von Allmen: Rev. Sci. Instrum. **56** (1985) 2222.
3. J. C. Kemp: J. Opt. Soc. Am. **8** (1969) 950.
4. R. J. Zeidler, R. B. Kohles, and N. M. Bashara: Appl. Opt. **13** (1974) 1938.
5. R. M. A. Azzam and N. M. Bashara: *Ellipsometry and Polarized Light* (North-Holland, Amsterdam, 1980) p 387
6. D. E. Aspnes and A. A. Studna: Appl. Opt. **10** (1971) 1024.
7. G. E. Jellison and F. A. Modine: SPIE Proc. **1166** (1989) 231.
8. O. Acher, E. Bigan and B. Dr**é**villion: Rev. Sci. Instrum. **60** (1989) 65.
9. F. L. McCrackin, E. Passaglia, R. R. Stromberg and H. L. Steinberg: J. Res. Natl. Bur. Stand. **A67** (1963) 363.
10. J. Monin, H. Sahsah, A. Siblini and O. Brevet-Philibert: Appl. Opt. **33 (**1994) 1213.
11. Y. F. Chao, C. S. Wei, W. C. Lee, S. C. Lin and T. S. Chao: Jpn. J. Appl. Phys. **34** (1995) 5016.
12. M. R. Steel: Appl. Opt. **10** (1971) 2370.
13. Y. F. Chao and C. K. Wang: Jpn. J. Appl. Phys. **37** (1998) 3558.
14. Y. F. Chao, W. C. Lee, C. S. Hung and J. J. Lin: J. Phys. D **31** (1998) 1968.
15. A. P. French and E. F. Taylor: *An introduction to Quantum Physics* (W. W. Norton & company Inc. New York, 1978) P. 299.
16. R. M. A. Azzam and N. M. Bashara: *Ellipsometry and Polarized Light* (North-Holland,Amsterdam, 1980) P. 274.
17. N. G. Theofanous and A. T. Arapoyianni: J. Opt. Soc. Am. A **8** (1991) 1746.

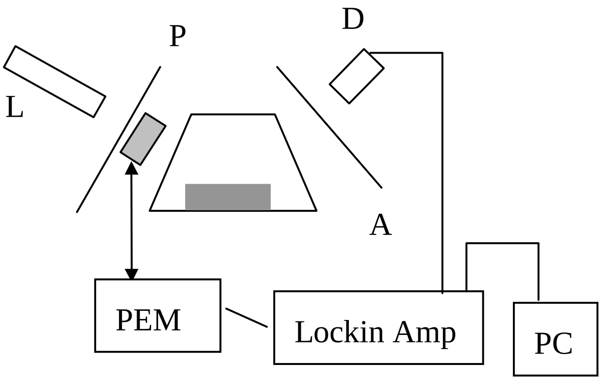

Fig. 1 Schematic view of the experimental setup: L:light source, P:polarizer, A:analyzer, D: detector.

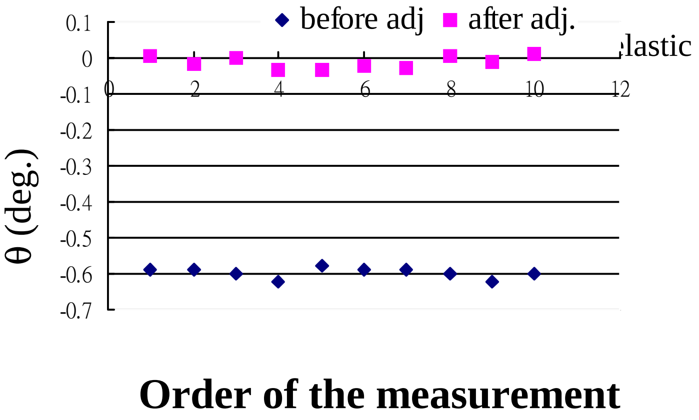

Fig. 2 θ, the azimuth deviation (◆: before adjustment, ■ after adjustment) of P, PEM and A with respect to the surface of reflection.

Table 1

Pt thick film	ψ (deg)	θ (deg)
1	34.15	0.007
2	34.17	-0.014
3	34.09	0.002
4	34.18	-0.036
5	34.16	-0.035
Mean (std)	34.16(0.02)	0.01 (0.02)
SiO_2/Si std thin film	ψ (deg)	θ (deg)
1	50.58	-0.01
2	50.63	0.03
3	50.60	-0.01
4	50.61	-0.04
5	50.58	0.04
Mean (std)	50.60(0.02)	0.002(0.03)