SUPER OBLIQUE INCIDENCE INTERFEROMETER USING SWS PRISM

Yukitoshi OTANI [1,2], Yasuhiro MIZUTANI[2], Norihiro UMEDA[2]

1) Optical Sciences Center, University of Arizona, Arizona 85721

2) Dept, of Mech. Sys. Engg., Tokyo University of Agriculture and Technology, Koganei, Tokyo, 184-8588 JAPAN

Abstract

A super oblique incidence interferometer is proposed by using an anti-reflection prism with sub-wavelength structure (SWS). Its sensitivity is lower than an ordinary interferometer with high contrast. A fringe interval of its interferometer depends on the incident angle. The SWS prism has a feature of increasing transmittance even if near the critical angle. The rigorous coupled wave analysis (RCWA) is used to analyze the anti-reflection effects of SWS. An experimental result of transmittance of SWS prism agrees well with the calculated result. High contrast fringe is achieved at 86° of the incident angle. A flatness measurement of a silicon wafer with circuit patterns is succeeded by this interferometer.

Keywords oblique incidence interferometer, flatness measurement, SWS(sub-wavelength structure), anti-reflection prism

1 Introduction

A surface profile measurement of silicon wafer is still important in the field of the semiconductor industry. A size of wafer is larger than 300 mm of the diameter and its thickness is thinner and thinner. Moreover, a fabrication process is more complicate for multilayer interconnection of the circuit patterns. Therefore, the flatness and/or waviness in this large area become bigger and bigger. Meanwhile, the requirement of the flatness in the micro area is more accurate using a process of the chemical mechanical polishing. There are many reports to overcome contrariety requirements[1]. The fringe interval of a common interferometer with vertical incidence is half of wavelength. If the flatness is much waviness, we can not detect the surface profile because of 2π uncertainty and/or overlapped fringes. In general, an interferometer, especially a white light interferometer, is powerful tool for this purpose. An oblique interferometer is also possible to reduce the sensitivity of the fringe[2,3]. Abramson proposed an oblique incidence interferometer by using a right-angled prism[2] but there is a limitation of incident angle to increase the fringe interval because of a critical angle. To overcome this problem, we propose a super oblique incidence interferometer using a sub-wavelength structure (SWS) prism with the anti-reflection effect. Recently, many papers related a SWS for anti-reflection effect have been proposed[4-7]. The period of width and height of SWS is almost equal to the wavelength of the incident light. An anti-reflection effect of moth eye structure was first discovered by Bernhard [4]. A vector model for

SWS was first proposed by Moharam called the rigorous coupled wave analysis (RCWA) [5]. It is powerful tool for accurate analysis of the diffraction of electromagnetic waves by periodic structure. We have proposed a model error resulted at the numerical model divided SWS into several sections of model by the RCWA [7]. Most of the anti-reflection studies have been for vertical angle of the incident light. We study optical behaviors at SWS for oblique incidence. Experimental results are compared accurately with simulation results of simulation model by using AFM.

2. Super oblique incidence interferometer by SWS prism

2.1 Experimental setup

Figure 1 is an optical configuration for a super oblique incidence interferometer using SWS prism. This interferometer is based on Mach-Zehnder type with two pair of SWS prism. A beam expander (L1, L2) and two half mirror (HM1, HM2) are used for collimate and tilt of the light. The incident beam is divided into a reference and a object beam by HM1 and HM2. One of the prisms is faced to the sample as an object beam and the other is used as a reference to the M2 mirror. A light source is possible to use both a white light and a monochromatic light. Its sensitivity can be adjusted by changing the incident angle θ to the sample. The height of a sample *h(x,y)* is shown

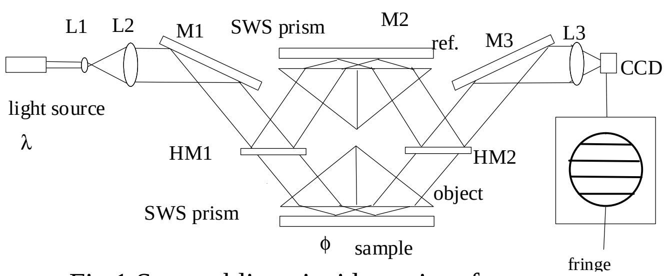


Fig.1 Super oblique incidence interferometer

$$h_{(x,y)} = \frac{\lambda}{4\pi\cos\theta}\cdot\phi_{(x,y)}, \qquad (1)$$

where λ is the wavelength and $\phi(x,y)$ is the phase difference between the reference and the object beam. The intensity $I(x,y)$ of the interference fringe captured by the CCD camera is expressed as,

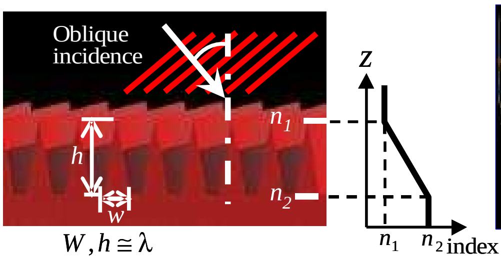
$$I_{(x,y)} = a^2 + b^2 + 2ab\cos\left(\phi_{(x,y)} + \delta\right). \qquad (2)$$

Here, a and b are the bias of the reference and the object beam. δ is the phase shift. Four step phase-shifting technique is employed to analyze this fringe.

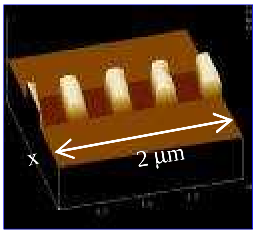
In case of a white light interferometer, we use the reference SWS prism to compensate wavelength dispersion. However, we can remove it when a monochromatic light source is utilized.

2.2 Fabrication of SWS prism

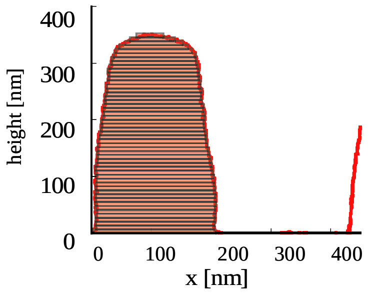
A SWS prism with anti-reflection effect is illustrated in Fig.2. Figure 2 (a) is a detailed structure of SWS. The requirement of this structure is to fabricate a cycle of width and height equal to the wavelength. An oblique



(a) Structure of SWS and effective refractive index



(b) 3D view by AFM



(C) Cross section and simulation model for RCWA

Fig.2 Sub-wavelength structure of anti reflection effect for oblique-incidence

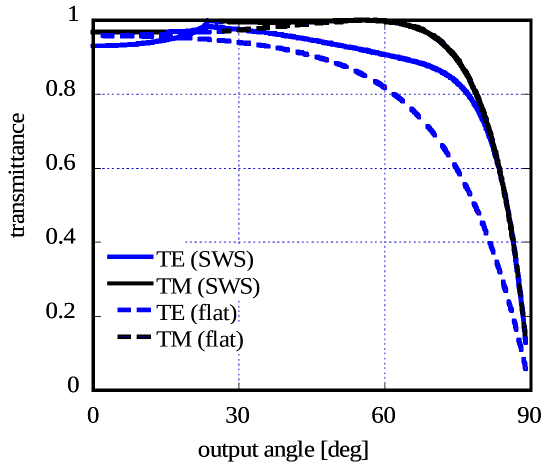
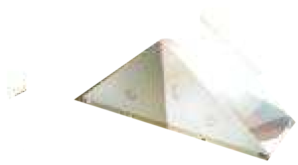
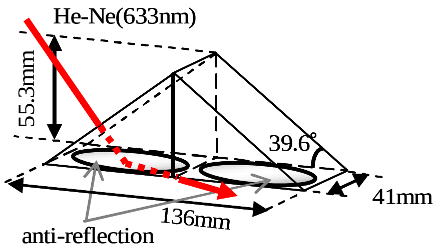


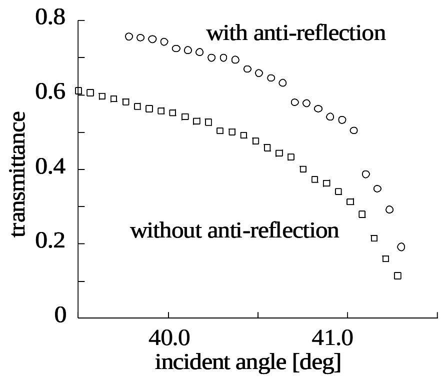
Fig.3 RCWA simulated results of transmittance



(a) Picture of SWS prism (BK7 n=1.52)



(b) Detail of SWS prism



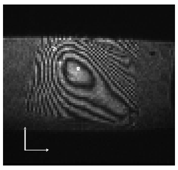
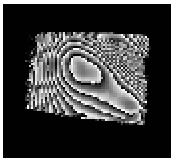
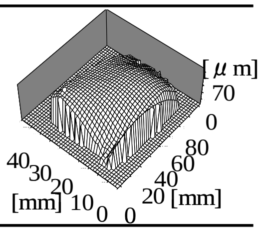
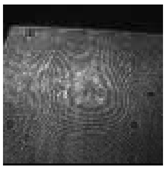
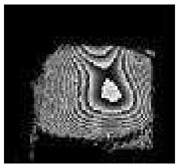
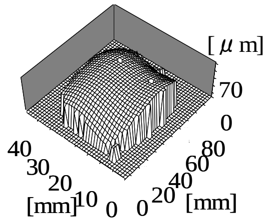
(c) External result of the transmittance

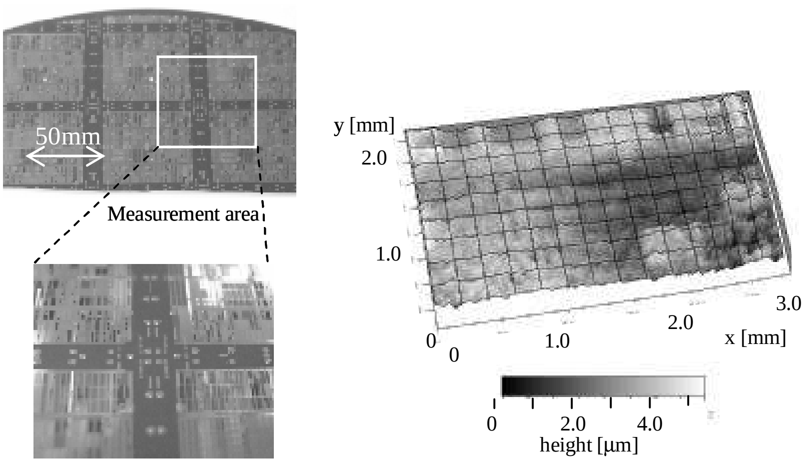
Fig.4 SWS prism

incidence wave transmitted from region I (refractive index: n_1) to region II (refractive index: n_2). The refractive indices between two mediums along optical axis are changing slowly. Effective refractive index is obtained on the average of refractive indices of z axis in Figure 2(a). This means the Fresnel reflection at a boundary is also reduced. Figure 2(b) shows a surface profile of the manufactured SWS measured by a critical dimension (CD)-AFM. Its cross-section is shown in Fig.2(c). As this result, a height of SWS is 350 nm, a width is l97 nm and a period is 433 nm.

A transmittance of SWS for the oblique incidence has been simulated by using RCWA. The surface profile for this simulation is measured by CD-AFM. The equality horizontal lines in Fig.2(c) mean the simulation

Table 1 Experimental result of surface profile measurement

Incident angle[°]	interferogram	phase map	surface profile
75 ($\Delta h = 1.2\mu m$)			
86 ($\Delta h = 4.5\mu m$)			



(b) surface profile

Fig.5 Surface profile of silicon wafer with circuit pattern

model for the SWS and the number of layers is 50 [7]. Figure 3 shows the transmittance along output angle compared the SWS prism with the flat surface by RCWA. A wavelength of incident wave is 632.8 nm and polarizations of the incident wave are p and s-polarization. The reflectance of TE mode is lower than flat surface at all incident angles.

Figure 4 slows an experimental result of the anti-reflection effect for the oblique incidence of SWS prism. The SWS prism is made of BK7 glass and polymer film of the sub-wavelength structure shown in Fig.4(a). The size of the prism is illustrated in Fig.4(b). The two parts of SWS, as shown circled area, glued on the bottom of a prism SWS. Figure 4(c) is the experimental result. The transmittance by SWS prism is much higher than by without SWS. The transmittance of 41º is succeeded to increase more than 50%.

3. Experimental results of surface profile measurement

We measured a piece of silicon wafer by the super oblique incidence interferometer shown in Fig.1. In this experiment, we utilized a He-Ne laser at 632.8nm as a light source. A reference minor (M2) is moved for phase-shifting by a piezoelectric actuator (PZT, NEC-TOKIN).

Table 1 shows two difference interferogram, phase map and surface profile given by different incident angles. The silicon wafer is taped down on the glass substrate. An oblique incident angles are 75 and 86º. A fringe space of 86º is wider than that of 75º. We can measure a smooth surface profile such as a silicon wafer by this method. The waviness of this silicon is 47μm.

Figure 5 shows the measured result of a silicon wafer with multilayer interconnection of circuit patterns as Low-k + Cu -DD (Duel Damascene) with CMP (Chemical Mechanical Polishing). Its measurement area is 3x2 mm. We can succeed to measure wafer surface even if the large steps and waviness .

4. Conclusion

We have proposed a super oblique incidence interferometer by SWS prism. We succeeded to increase an efficient transmittance at the oblique incidence by the SWS prism under the condition of the vicinity or critical angle. A shape of the structure is a trapezoid with height and width of sub-wavelength order periodically. The experimental results of transmittance agree well with the calculated results by RCWA. The incident angle of the oblique interferometer could be achieved 86º. The measurement of a silicon wafer with multilayer interconnection of circuit patterns was succeeded to measure by this interferometer.

The authors thank to Japan Veeco for helping the AFM measurement.

References

1. D.Malacara : Optical shop testing (Wiley, 1992).
2. N.Abramson: Optik, 30, 56 (1967).
3. Y.Otani, N.Okuhara, T. Yoshizawa : Opt. Eng. 37. 261 (1998).
4. C.G.Bermhard : Endeavour, 26,79 (1967.)
5. M.G..Moharam, T.K.Gaylord : Applied Optics, 20, 240 (1981).
6. Y.Kanaori, M.Sasaki, K.Hane: Opt.Lett., 24, 20, 1422 (1999).
7. Y.Mizutani, K.Minato, Y.Otani, N.Umeda: ICO '04, 54l, (2004).