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Krishna

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Phase shift reflectometry for wafer inspection

Kuang Peng^{a,b}, Yiping Cao^{*a}, Hongru Li^{b,c}, Jianfei Sun^{b,d}, Thomas Bourgade^b,

Anand Krishna Asundi^b

^aOpto-Electronics Department, Sichuan University, Chengdu, 610064, China

^bCentre for Optical and Laser Engineering, School of Mechanical and Aerospace Engineering,
Nanyang Technological University, Singapore 639798, Singapore

^cCollege of Electronics and Information Engineering, Sichuan University, Chengdu, Sichuan
Province 610064, China

^dHefei University of Technology, School of Instrument Science and Opto-electronic
Engineering, No.193 of Tunxi Road, Hefei, 230009, China

(Corresponding author Email: ypcao@scu.edu.cn)

ABSTRACT

In 3D measurement, specular surfaces can be reconstructed by phase shift reflectometry and the system configuration is simple. In this paper, a wafer is measured for industrial inspection to make sure the quality of the wafer by calibrating, phase unwrapping, slope calculation and integration. The profile result of the whole wafer can be reconstructed and it is a curve. As the height of the structures on the wafer is the target we are interested in, by fitting and subtracting the curve surface, the structures on the wafer can be observed on the flat surface. To confirm the quality farther, a part of the wafer is captured and zoomed in to be detected so that the difference between two structures can be observed better.

Keywords: specular surface; phase shift reflectometry; wafer inspection;

1. INTRODUCTION

It is of great importance to get three dimension (3D) shape information in investigating an object [1]. The technology of 3D profile measurement is catered in medical research, computer science, national defense security, quality inspection and many other fields. Among these, there are numerous applications in research and industry for 3D surface of specular object [2-8]. Phase measuring reflectometry with computer aided fringes is a good approach to measure specular reflective surfaces [9-10]. A stereoscopic phase measuring deflectometry way with a gradient-based stereovision principle is proposed by Knauer et al. [11]. M. Petz et al. [9] suggest a deflectometric system with the grating reflection technique. T. Bothe et al. [10] proposed a monoscopic fringe reflectometric method without mechanical movement, which is suitable for almost flat specular surfaces with the height known a priori roughly.

Phase measurement profilometry [12-15] is a technique with high accuracy in fringe projection profilometry method. By shifting the fringes, the phase containing the information of object's height can be calculated. Temporal phase unwrapping method can transfer the truncated phase to the absolute phase maps. As the pixel-independent unwrapping

processing, we can avoid the errors happening in the targets with large discontinuities, which affect the accuracy greatly. Then by the principle of fringe reflectometry and the parameters through previous calibration, the pixel coordinate can be transferred to be real distance along each axis.

In this paper, a suitable and practical setup for wafer inspection is built. A whole wafer on which there are some structures is measured. By calibration procession, phase unwrapping, slope calculation and integration, the surface of the whole wafer can be reconstructed. Compared with the curve, the height of the structures on the surface is really little. To observe the structures better, it is better to fit and subtract the curve. After these experiments, some small parts on the wafer we are interested in can be zoomed in for a farther detection according to the same steps.

This work focuses on the full-field and non-contact specular surface measurement and the industrial demands for wafer inspection. The rest of the article is arranged as follows. Section 2 presents the principle of phase shift reflectometry briefly. Section 3 shows the details and the experiment steps for wafer inspection and section 4 concludes the work.

2. PRINCIPLE

The phase shift reflectometry system model is shown as figure 1. There is a camera with imaging lens capturing patterns, an LCD screen showing some structured fringes, a beam splitter reflecting and transmitting the light and a computer controlling and processing the necessary data in the system. Some coded sinusoidal patterns are shown on the LCD screen and the camera captured the deformed patterns containing the phase information after the reflected light goes through the beam splitter. $\Delta\alpha$ is affected by the specular surface.

Fig.1 Phase Shift Reflectometry System

In the phase shift reflectometry system, the system can be calibrated by three steps [16-17]. The first step is to calibrate the camera by the printed calibration pattern and standard flat mirror so that the pixel can be corresponding to the real distance. Then the relation between the geometric size in the screen coordinate system and phase values should be built. Last but not least, it is essential to connect world system, camera system and screen system.

The principle of phase shift reflectometry can be seen in reference 4. According to the reflection law, the angle of incidence light and reflection light is equivalent. Then by the geometric relationship and calculating normal vector, we can get the gradient data which is proportional to $\Delta\alpha$. The result can be shown in equation 1.

$$\nabla z(x, y) = -\frac{1}{N_z} \begin{bmatrix} N_x \\ N_y \end{bmatrix} = \begin{bmatrix} p(x, y, z) \\ q(x, y, z) \end{bmatrix} \quad (1)$$

Where $p(x,y,z)$ and $q(x,y,z)$ represent slope values at a point along x and y direction, and N_x , N_y , N_z are the surface normal along x , y , z direction respectively. Then by calculating the integration of gradient data [18-19], we can reconstruct the height of the specular surface $z(x,y)$.

In addition, by differential calculation of $p(x,y,z)$ and $q(x,y,z)$, the curvature along x and y axis k_x , k_y can be gotten shown as equation 2.

$$\begin{cases} k_x = \frac{dp(x,y,z)}{dx} \\ k_y = \frac{dq(x,y,z)}{dy} \end{cases} \quad (2)$$

3. WAFER INSPECTION

For industrial demand, a series of experiments have been done for wafer inspection. The setup is shown in figure 2(a). It is basically composed of a camera (Imaging source DMK 41BU02, with a resolution of 1280×960 pixels), an LCD screen (Dell E193FPc, with a resolution of 1280×1024 pixels), plate beam splitter (Reflection/Transmission Ratio: 50/50) and some metallic frames.

Fig.2 Setup and deformed patterns

Figure 2(b) and 2(c) shows the horizontal and vertical deformed pattern respectively and both the fringe period of the patterns along x and y axis is 16 pixels. And the calibration processing described above has been done by the sinusoidal patterns with the same fringe periods. The diameter of the wafer for inspection is 6 inches.

The experimental study is shown in figure 3. In figure 3(a), the area in the red rectangle is the region of interest, on where there are some small structures. Figure 3(b) and 3(c) are the horizontal and vertical unwrapped phase respectively.

Then according to the principle of phase shift reflectometry mentioned above, by slope calculation, the gradient along x and y axis can be seen in figure 3(d) and 3(e). After integration of the gradient data, we can reconstruct the result of the region of interest as figure 3(f). As the result is a curve and it is not easy to observe the small structures, a fitting has been done and the fitting curve surface can be seen as figure 3(g). Finally, by subtracting the fitting surface, the small structures can be observed on a flat surface as figure 3(h). The size of the region of interest is around $80\text{mm} \times 80\text{mm}$.

(a) Region of interest

(f) Reconstructed wafer

(g) Fitting curve

(b) Horizontal unwrapped phase

(c) Vertical unwrapped phase

(d) Gradient along x

(e) Gradient along y

(h) The small structures on the flat surface

Fig.3 Experimental study

As the range of reconstruction is very large, more details on the structures should be observed to confirm whether the structures are the same to meet the demand of wafer inspection. To confirm the quality farther, a part of the wafer shown as figure 4(a) is zoomed in to be detected so that the details between two structures can be observed better. The reconstructed result of the part and the fitting curve are shown in figure 4(b) and 4(c) respectively. Figure 4(d) is the small structures on the flat surface. More details can be seen and we can get these two structures are different. And the precision can meet the demand of industrial wafer inspection. The size of the result is about $35\text{mm} \times 18\text{mm}$. These experiments show the feasibility of the proposed method in this paper.

Fig.4 Experiments of the part of the wafer

4. CONCLUSION

In this work, phase shift reflectometry, a non-contact method, is applied to inspect the quality of the wafer. After reconstructing the wafer of the region of interest, by fitting and subtracting the curve surface, the small structures on the wafer can be detected. As the details on the small structures are the keys for wafer inspection, a part of the wafer is zoomed in to be observed to differentiate them. The accuracy and precision can meet the demand of industrial wafer inspection. A series of experiments show the validity of phase shift reflectometry for wafer inspection.

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