Simultaneous Measurement of Warp and Thickness of Large-Diameter Silicon Wafer Using Three-Point-Support Inverting Method

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Abstract

This paper proposes a method to simultaneously measure the thickness and warp of large-diameter silicon wafers. The warp was measured using the three-point-support inverting method. The thickness was obtained from the measured shapes of both front and back surfaces and the wafer deflection due to gravity which was calculated by the finite element method (FEM). Since the calculated wafer deflection depended on the thickness distribution, the thickness was iteratively calculated by means of the self-consistent method. It was found that the warp and thickness of 300mm silicon wafers could be accurately measured with the proposed method.

1 Introduction

The accurate warp and thickness measurements of thin-large panels such as silicon wafers and glass substrates used for the flat panel display (FPD) are desired due to the miniaturization of design rules of semiconductor manufacturing and the improvement of the performance of the FPD. In order to measure the warp, the authors proposed the three-point-support inverting method[1]. The principle of this shape measurement is basically the same as the reversal method[2] which is a self-calibration method for the geometric error of the measurement equipment. Meanwhile, the measurement of wafer thickness seems more important in semiconductor industry. In this research, we proposed a method to simultaneously measure both warp and thickness with the same measuring device.

2 Three-point-support inverting method

2.1 Measurement principle

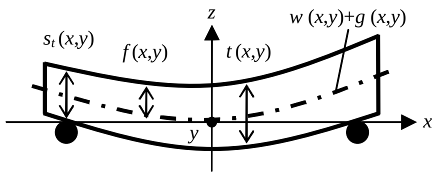

Fig.1 Principle of inverting method

Fig.1 shows the schematic of the principle of the three-point-support inverting method. With this method, the back surface of the measured object is supported horizontally with three balls which are positioned every 120deg on a circle concentric with the center of the wafer. The front surface shape $f(x,y)$ superposed with the deformation due to gravity is measured when the front surface is faced up. The shape $f(x,y)$ is expressed by Eq.(1) with the warp $w(x,y)$, deformation due to gravity $g(x,y)$, thickness distribution $t(x,y)$ and inclination correction $s_t(x,y)$. Here, $s_t(x,y)$ indicates the plane which linearly interpolates the points on the front surface at the three support points. After measuring the front surface, the measured object is inverted around the *y*-axis and the back surface is measured in a similar way. When the measured object is inverted, the deflection due to gravity occurs consistently in the direction of gravity, whereas the warp shape is inverted. Considering that the sign of *x*-coordinates is reversed, the back surface shape $b(x,y)$ of the measured object is expressed by Eq.(2).Then, from Eq.(1) and (2), the warp shape and thickness distribution can be obtained by Eq.(3) and Eq.(4), respectively .Eq.(3) shows that $w(x,y)$ can be obtained by cancelling the influences of $g(x,y)$, $t(x,y)$ and $s_t(x,y)$. Meanwhile, Eq.(4) indicates that $t(x,y)$ cannot be obtained without knowing $g(x,y)$ and $s_t(x,y)$. Since $g(x,y)$ and $s_t(x,y)$ are functions of $t(x,y)$, which is expressed implicitly by Eq.(4), $t(x,y)$ can be obtained by an iterative calculation of Eq.(4) using measured $f(x,y)$ and $b(-x,y)$, and calculated $g(x,y)$ and $s_t(x,y)$. Initially, the inclination correction $s_{t0}(x,y)$ is calculated from $t_0(x,y)$ which is assumed appropriately. Since the initial deflection due to gravity $g_0(x,y)$ can be calculated from $t_0(x,y)$, the corrected thickness distribution $t_1(x,y)$ will be obtained from Eq.(4). To assure the convergence, $t_1(x,y)$ is then modified using a relaxation coefficient 0.5 (see Eq.(5)). The above operations are repeated until the criterion shown in Eq.(6) is satisfied. Thus consistent solutions of $t(x,y)$ and $g(x,y)$ are obtained.

$$f(x,y) = w(x,y) + g(x,y) + \frac{t(x,y)}{2} + \frac{s_t(x,y)}{2} \tag{1}$$

$$b(x,y) = -w(-x,y) + g(-x,y) + \frac{t(-x,y)}{2} + \frac{s_t(-x,y)}{2} \tag{2}$$

$$w(x,y) = \frac{f(x,y) - b(-x,y)}{2} \tag{3}$$

$$t(x,y) = \{f(x,y) + b(-x,y)\} - 2g(x,y) - s_t(x,y) \tag{4}$$

$$t_n(x,y) = t_{n-1}(x,y) + 0.5\{t_n(x,y) - t_{n-1}(x,y)\} \tag{5}$$

$$\left| t_{n-1}(x,y) - t_n(x,y) \right| < \varepsilon \tag{6}$$

2.2 Measurement method

Three steel balls of 10mm in diameter were used as the supports to minimize the contact area between the measured object and support. The measurement repeatability is high because no external force is acting on the measured object except for gravity and negligibly small friction forces between the measured object and supports. An ultra-precision surface shape measurement system (Fig.2) was used for the measurement. Both the data sampling intervals in the x and y direction were 5mm. A triangulation type optical displacement sensor was used because of its high response and non-contact measuring ability.

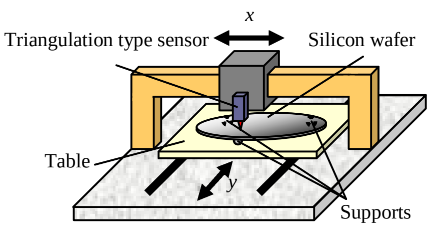

Fig.2 Schematic of surface shape measuring system

2.3 Numerical analysis of deflection due to gravity of silicon wafer

The finite element software ABAQUS was used to calculate the deflection due to gravity $g(x,y)$. A 300mm wafer was modeled using triangular shell elements of 5mm in edge length with a variable thickness defined at each node. The

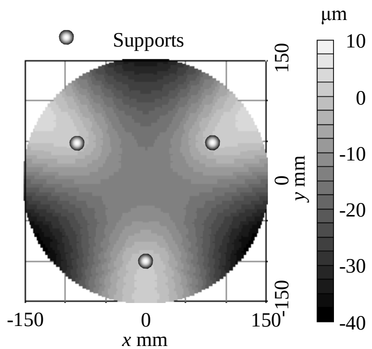

Fig.3 Shape of deflection due to gravity calculated by FEM

displacements in the z-direction at the support points and the horizontal displacement at the center of the wafer were constrained as the boundary conditions. The weight of the wafer was loaded at each node as a distribution load. The orthotropy of monocrystalline silicon was taken into consideration. When the coordinate axes were set parallel to the crystal orientation [100], the stiffness constants were C_{11}=1.66×10^{5}GPa, C_{12}=0.639×10^{5}GPa and C_{44}=0.796×10^{5}GPa[3]. Fig.3 shows an example of the numerically analyzed result of $g(x,y)$, when the wafer has a uniform thickness of 775μm and the distance between the supports and the center is 100mm.

3 Measurement results of warp and thickness distribution

In order to verify the effectiveness of the proposed method, a wafer whose thickness distribution is already known (Fig.4) was used in the experiment. The value of the thickness distribution was 3.2μm. Fig.5 shows the warp obtained from the Eq.(3)

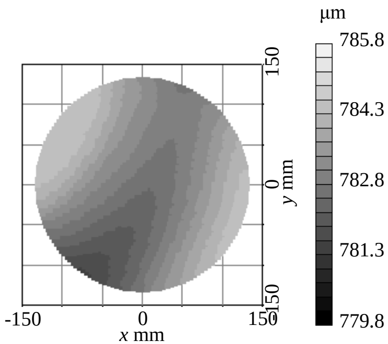

Fig.4 Real thickness distribution of wafer

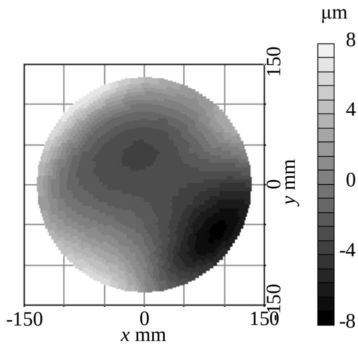

Fig.5 Warp of wafer

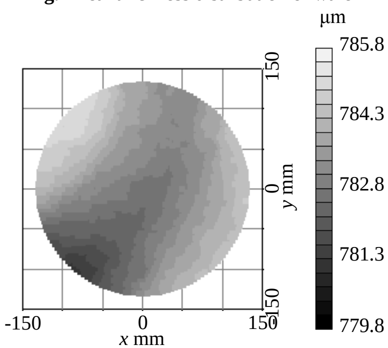

Fig.6 Thickness distribution obtained by Three-point-support inverting method

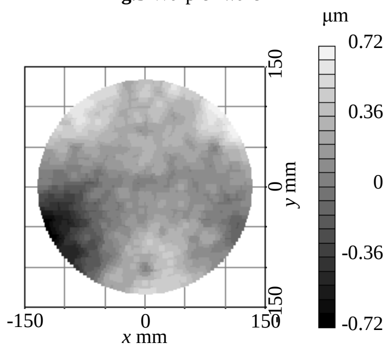

Fig.7 Difference between the measured thickness distribution and real one

using the shape measurement results of the front and back surfaces. The P-V value of the warp was 14.4μm. Moreover, the thickness distribution of that wafer was calculated by the method described in section 2.2. In the iterative calculation, the initial thickness $t_0(x,y)$ was set to 775μm which was the typical thickness of a commercial 300mm wafer and the criterion ε for the convergence determination was 0.1 μ m, which was one digit smaller than the desired accuracy of the thickness distribution. Fig.6 shows the calculated result of the thickness distribution using the three-point-support inverting method. The iterative number of calculation was 30. From the comparison between Fig.4 and Fig.6, it was found that the thickness distribution obtained by the three-point-support inverting method was similar to the real one. Fig.7 shows the difference between the measured thickness distribution and the real one. It was found that the difference was smaller than ±0.72μm. This result shows that the thickness distribution of a silicon wafer can be obtained by our proposed method.

4 Conclusions

This paper proposed a method to simultaneously measure the warp and thickness of a large-diameter silicon wafer. It was found that the error of the thickness measurement using the proposed three-point-support inverting method was less than ±0.72μm, which means the measuring accuracy for the wafer thickness is very high.

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