Study on Support Method in Sori Measurement of 300mm Silicon Wafer

Wataru NATSU[1], Yukihiro ITO[1], Masanori KUNIEDA[1], and Kaoru NAOI[2]

[1] Tokyo University of Agriculture & Technology
2-24-16 Nakacho, Koganei, Tokyo 184-8588, Japan
[2] Kuroda Precision Industries Ltd.
239 Simohirama, Saiwai-ku, Kawasaki 212-5560, Japan

1 Introduction

The “sori” of a semiconductor wafer is defined as the difference between the maximum and minimum distances to the front surface of a free, unclamped wafer from the least squares reference plane of the front surface. The sori measurement of a large diameter silicon wafer, for example 300mm wafer, at nanometer order is required in order to achieve the maximum yield of semiconductor device processing. Also, sori measurement is used to monitor residual stress in wafers caused by thermal and mechanical effects during device processing. It is well-known that precise sori measurement for silicon wafers of 300mm in diameter and 0.775mm in thickness is difficult due to gravity-induced deflection and other disturbances. Up to now, the American Society for Testing and Materials (ASTM) has proposed a sori measuring method [1], called one-point-support method in this study because the wafer is supported by a small-area chuck at the wafer center during the measurement. The shape of the front surface including gravity-induced deflection is measured with the front surface upward, and then it is measured again after turning the front surface downward. Sori is thus obtained from the two measurements using the principle of the gravity cancel method by wafer inversion [2]. However, the use of only one support at the wafer center makes the measuring process unstable, resulting in decreased repeatability. Especially, when the wafer is vacuum chucked, the shape in the absorption area cannot be measured and the sori itself may vary depending on degree of vacuum. On the other hand, a method for measuring the bow of a silicon wafer under 100mm diameter has been specified by the Japanese Industrial Standard (JIS) [3]. With this method, the bow, which is how concave or convex the deformation of the median surface of the wafer is at its center point, is obtained by taking the difference between heights of the wafer at its center point measured with the wafer front surface upward and downward, when the wafer is horizontally supported by three balls. Because the bow is obtained only from the measured data at the wafer center, the measured value is different from sori. Besides, the wafer shape over the whole surface cannot be obtained. Finally, there is a method [4] with which the wafer is set vertically in order to decrease the effects of gravity-induced deflection. The wafer is supported at three positions on the periphery and rotated during the measurement. It is obvious that the force working on each support changes with the rotation of both wafer and support so that the wafer position may move slightly during measurement. In addition, buckling and distortion of wafer are thought to be caused by clamp force, making accurate sori measurement impossible.

In this study, a new sori measurement method called three-point-support method was proposed. With this method, the gravity cancel method mentioned above is applied to a 300mm silicon wafer supported horizontally by three steel balls on the vertexes of a regular triangle at the wafer edge. A comparison between the one-point-support and three-point-support methods was carried out experimentally, considering the repeatability influenced by wafer loading operation, the change in the degree of vacuum, and disturbance vibration. Finally, the influence of the crystal orientation on the sori measurement was investigated.

2 Measurement principle and experimental equipment

The 300mm wafers used in this research were single crystal silicon wafers, whose front and back surfaces were polished to mirror-surface finish. The thickness deviation of the wafers was about 1μm, which is relatively small compared to the sori itself.

2.1 Principle of sori measurement

In this study, sori was measured with the gravity cancel method by wafer inversion [2]. The principle of this method can be explained using the one-point-support model shown in **Fig.1**. The principle was also similarly applied to a three-point-support model. Here, the condition in which the front surface is faced upward is called the normal direction, while that in which the front surface is faced downward is called inverted direction. After the shape of the wafer front surface $y_f(x,y)$ including gravity-induced deflection $g_f(x,y)$ and true shape $s_f(x,y)$ in normal direction, as expressed by equation (1), is measured, the wafer is turned in the inverted direction and the shape of the back

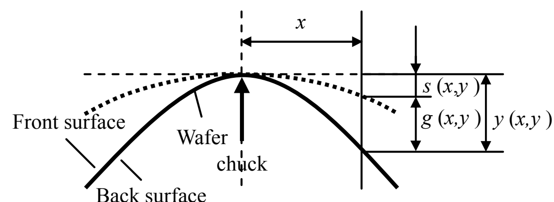

Fig.1 Principle of sori measurement

surface, $y_b(x,y)$ expressed by equation (2), is measured again. In case the thickness deviation is considerably smaller than the sori value, the shape of the front surface $s_f(x,y)$ is considered the same as the measured back surface shape $s_b(x,y)$, as shown in equation (3). Under the assumption that the gravity-induced deflections in both normal and inverted directions are the same as expressed by equation (4), subtracting the two measurements at corresponding points can cancel the gravity effect and sori is obtained from the maximum value of s(x,y) shown in equation (5). Besides, the gravity-induced deflection g(x,y) is derived by dividing the addition of $y_f(x,y)$ and $y_b(x,y)$ with two as shown in equation (6).

$$y_f(x,y) = g_f(x,y) + s_f(x,y) \quad (1)$$

$$y_b(x,y) = g_b(x,y) - s_b(x,y) \quad (2)$$

$$s_f(x,y) = s_b(x,y) = s(x,y) \quad (3)$$

$$g_f(x,y) = g_b(x,y) = g(x,y) \quad (4)$$

$$s(x,y) = \frac{y_f(x,y) - y_b(x,y)}{2} \quad (5)$$

$$g(x,y) = \frac{y_f(x,y) + y_b(x,y)}{2} \quad (6)$$

To improve the measuring efficiency, a representative wafer in nominal diameter, thickness, composition and crystal orientation can be measured to obtain the gravity-induced deflection $g_{rep}(x,y)$ in advance. Sori of the sample wafer is then obtained by subtracting $g_{rep}(x,y)$ from $y_f(x,y)$ of the sample wafer measured in the normal direction.

2.2 Experimental equipment

An ultra-precision surface measuring system (NANOMETRO 750F, made by Kuroda Precision Industries,Ltd.), with a non-contact optical sensor (KL1301B, made by Anritu Corp.), was used in shape and sori measurements. A 300mm silicon wafer was supported at the center by a vacuum chuck 30mm in diameter, in case of the one-point-support method. While in case of three-point-support method, the wafer was supported by three steel balls 10mm in diameter on the vertexes of a regular triangle at the wafer edge.

3 Comparison of one-point-support and three-point-support

From the viewpoint of mechanics, it is clear that the wafer supported by three supports at the peripheral edges is much more stable than that supported at one point at the center. A chuck with a certain area is therefore needed to support the wafer at the center for stabilization. In this case, it is not clear where and how the wafer and chuck contact each other, also the same contact cannot be guaranteed for the normal and inverted directions. The three-point-support was therefore proposed in this study.

This section describes the effects of the degree of vacuum on wafer distortion and comparison of repeatability due to wafer loading and disturbance vibration between the one-point-support and three-point-support.

3.1 Effects of degree of vacuum on wafer distortion

Error results in sori measurement if the wafer is distorted due to vacuum chucking. The change in the displacement Y_{fmax} of a point on the peripheral edge, where the maximum deflection appeared in the measurement of one-point-support, was measured while changing the degree of vacuum from 760 to 160mmHg, in order to examine the effects of the degree of vacuum on the wafer shape. The change in displacement Y_{fmax} with degree of vacuum is shown in **Fig.2**. It was found that the displacement changes greatly with the degree of vacuum. This result indicates that the measurement repeatability will decrease if the degree of vacuum fluctuates due to the invasion of fine particles into the clearance of the chuck and wafer or other reasons. Moreover, if the wafer does not fit completely with the chuck surface on the chucking area because of poor wafer sori or chuck flatness, the wafer will be distorted by vacuum chucking, meaning that vacuum chucking is not suitable in sori measurement. All the following experiments with one-point-support were therefore conducted without vacuum chucking.

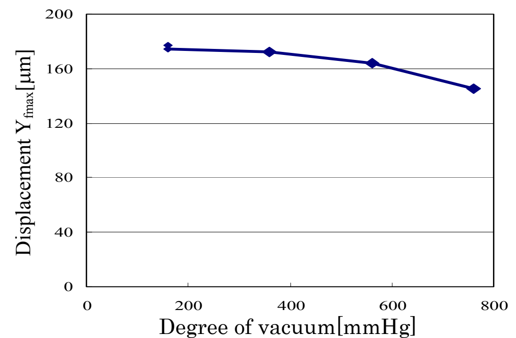

Fig.2 Influence of degree of vacuum on wafer distortion

3.2 Measuring repeatability for wafer loading operation

In order to evaluate the repeatability of both support methods, the change in the displacement Y_{fmax} where the maximum deflection occurred was measured for repeated unloading-and-loading operations. After the completion of one measurement, the wafer was unloaded from the support, and loaded again to the original place, after which the next measurement was conducted. Maximum deflection occurs on the wafer edge for one-point-support, and at the wafer center for three-point-support. Measurements were repeated five times for each condition, and the maximum and minimum results were used to show the measuring dispersion.

The measured dispersion of the maximum and minimum displacement Y_{fmax} by different loading is shown in **Fig.3**. It proves that the dispersion for one-point-support is larger than that for three-point-support. This difference may be caused by the intervention of fine particles between the wafer surface and chuck. That is, the possibility of fine particles intervening is small for three-point-support method, since the contact area between the wafer surface and support is much smaller than that with the one-point-support method.

3.3 Anti-disturbance ability

During measurement, inevitable disturbances such as forced vibration due to air shower or neighboring machines are met. The difference in ability to resist the disturbance vibration of different support methods was investigated by measuring the forced vibration. A small air compressor was intentionally run near the measuring instrument, thus the instrument suffered forced vibration via the ground. Because the vibration amplitude at the point where the maximum deflection was seen varied every moment, the maximum and minimum amplitudes over five minutes were measured. They are shown in **Fig.4**. It can be seen that the variation of the maximum amplitude for one-point-support is considerably larger than that for three-point-support, which means that the three-point-support has a higher anti-disturbance ability under the given experimental conditions.

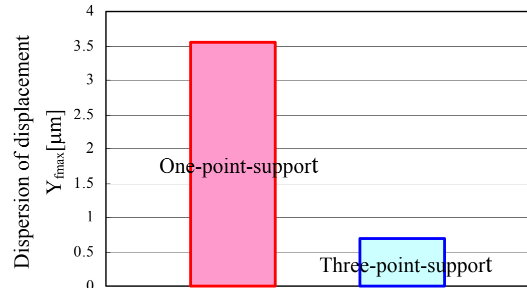

Fig.3 Measuring repeatability for unloading-and-loading operation

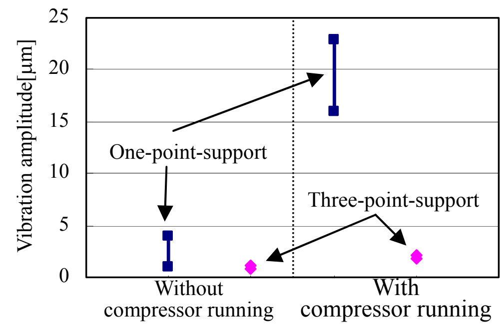

Fig.4 Difference of anti-disturbance ability for two support methods

4 Sori measurement

The experimental results and discussion above demonstrate that the three-point-support is superior to the one-point-support, from the viewpoint of repeatability and anti-disturbance ability.

The sori measurement results obtained with the one-point-support and three-point-support are compared here. To avoid distorting the sample wafer, it was not vacuum chucked in measurements for the one-point-support. The wafer was just put on top of the chuck 30mm in diameter.

Figure 5 is one example of the measured front surface of a free, unclamped wafer, s(x,y), after the gravity cancel processing explained in section 2. The maximum value in the figure represents the sori of the wafer. The sori measurement results of a silicon wafer with the two methods are shown in **Fig.6**. The sori obtained with three-point-support was found to be almost the same as that obtained with the one-point-support.

However, the positioning accuracy of the supports is expected to influence the accuracy of sori measurement because the process of canceling gravity-induced deflection needs good symmetry. The effects of the positioning accuracy of the supports on the measured results were therefore experimentally examined. First, the sori was measured when the three supports were accurately positioned on the vertexes of a regular triangle at the wafer edge. Then the sori was measured again after the position of two supports were moved as shown in **Fig.7**.

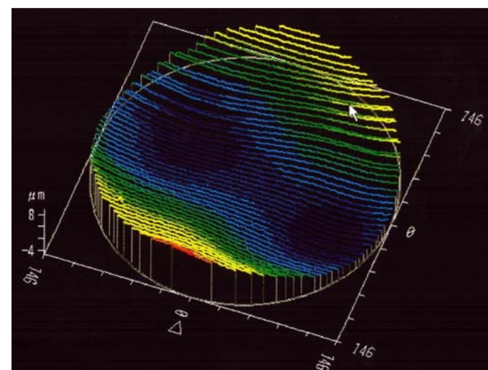

Fig.5 Example of measured front surface without gravity-induced deflection

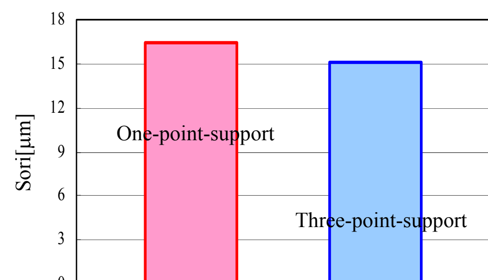

Fig.6 Results of sori measurement with one-point-support and three-point-support

The sori measured value changed greatly from 15μm to 25 μm after the support positions were moved (see **Fig.8**). This difference proves that the positioning accuracy of the supports plays an important role in the three-point-support method.

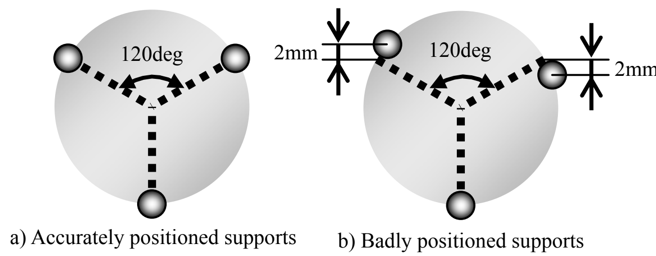

Fig.7 Arrangement of supports in experiments investigating effects of positioning accuracy

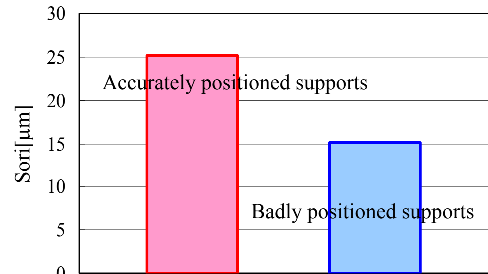

Fig.8 Results of effects of support positioning accuracy on sori measurment

5 Effect of crystal orientation on sori measurement

As mentioned in section 2.1, in order to improve the measuring efficiency, subtracting the gravity-induced deflection of a representative wafer from the measured results of a sample wafer in normal direction is sometimes used in sori measurement. However, even if the sample wafer has the same diameter and thickness as the representative wafer, a large error will occur if the crystal orientations of these two wafers are different. This is because elastic stiffness constant depends on the crystal orientation. Here, the effects of crystal orientation on the gravity-induce deflection are discussed. The wafer was supported by a chuck 30mm in diameter on the center, then the gravity-induced deflection distribution was obtained with the gravity cancel method using equation (6). The contour map of the gravity-induced deflection in showed distorted curves especially towards the circumference, and they are symmetric to the axes with 45 degree interval. The maximum deflections of the wafer on the cross section every 45 degrees are shown in **Fig.9**. It was found that the maximum deflection changes about 7μm every 45 degrees, which means that the deflection of silicon wafer changes with orientation. This result shows that sori measurement result will bear a error about several μm, if the orientation of the sample wafer differs from that of the representative wafer, not only in one-point-support but also in three-point-support when sori is measured using the representative wafer.

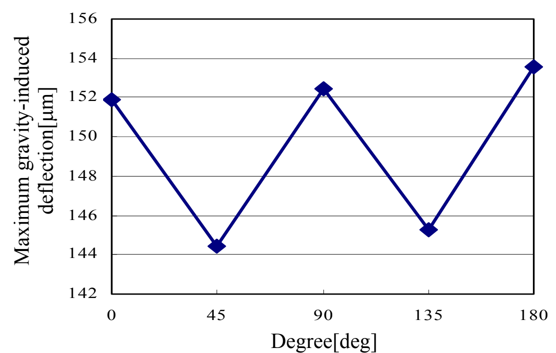

Fig.9 Change in maximum gravity-induced deflection with crystal orientation

6 Conclusions

In this research, a three-point-support method for the sori measurement of a 300mm silicon wafer was proposed. From the comparison of the repeatability and anti-disturbance ability between the proposed method and the conventional one-point-support method, it is found the three-point-support method is superior to the conventional one in repeatability and anti-disturbance ability. Moreover, precise positioning of the supports is crucial in sori measurement with the three-point-support method. Finally, a measuring error about several μm will appear if the crystal orientation of the sample wafer is different from that of the representative wafer when sori is measured using the representative wafer.

References

[1] ASTM, Standard Test Method for Measuring Sori on Silicon Wafers by Automated Noncontact Scanning, F1451-92.
[2] Poduje, N., Eliminating Gravitational Effect in Wafer Shape Measurements, NIST/ASTM/SEMI/SEMATECH Technology Conference, Dallas, TX Technology for Advanced Materials/Process Characterization, 1990.
[3] JIS, Methods of Measurement of Thickness, Thickness Variation and Bow for Silicon Wafer, H0611-1994.
[4] Nanometro 300TT, Kuroda Precision Industries Ltd., Kanagawa, Japan.