Journal of Ceramic Processing Research. Vol. 12, No. 5, pp. 509~514 (2011)

J O U R N A L O F
Ceramic Processing Research

Analysis of the effect of surface roughness on the bending strength of silicon wafers

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For a single crystal wafer, due to its inherent brittleness, the surface roughness is regarded as the most critical factor in determining the strength of the chip. After a grinding process is applied to the back side, grinding traces can be left on the wafer, depending on the grinding mode. This paper is intended to evaluate the effects of grinding marks on the bending strength of chips quantitatively when the grinding marks are generated by back grinding during the course of the silicon wafer thinning process. To that end, chips were taken from wafers under different grinding conditions and the bending strength of each was then measured, depending on the direction of the bending axis and on the grinding marks. Using the AFM, surface roughness was measured in each grinding condition. In addition, after the bending strength test, the fracture behavior depending on each bending condition was analyzed. In conclusion, when polishing using grit that was less fine than number-2000 grit, the bending strengths of thinned chips were strikingly different depending on the location on the wafer. However, the chips precisely polished had a greater strength than the chips that were ground.

Key words: Roughness, Bending Strength, Silicon wafer.

Introduction

The semiconductor production process has developed remarkably to the extent that very large-scale integrated chips as well as micro-semiconductor chips can be successfully produced. Electronics based on this process include mobile phones, laptop computers, and portable memory devices, as IC cards are becoming more compact and lightweight and now include more improved functions. Wafers with increasingly large diameters are being produced to increase the efficiency of semiconductor production. In addition, for a higher production yield, many studies have investigated the devices and working conditions suitable for precision polishing [1, 2]. As the size of the semiconductor chips gradually decreases, the wafer cutting process must be able to distinguish between the continually diminishing circuits. In the wafer cutting process, precise cutting and machining technologies are regarded as important elements so as to prevent chipping [3, 4].

Because electronic devices are becoming thinner and thinner, it is necessary to fabricate much thinner semiconductor chips. According to general wafer film thinning processes, after a photolithography process is applied onto the front side of a wafer, the wafer is covered by a protective film to prevent damage to the pattern. The back side of the wafer is then polished via a diamond process at a high grinding rate, thus giving it the desired thickness. Due to the introduction of more compact-sized goods, the IC packaging field is increasingly demanding much thinner semiconductor chips, with recent polished chips as thin as tens of micrometer. As thin chips are vulnerable to the bending load placed on them, they are frequently damaged during the IC packaging process, especially during actions that entail chip movement or molding. For a single crystal wafer, due to its inherent brittleness, the surface roughness is regarded as the most critical factor in determining the strength of the chip. After a grinding process is applied to the back side, grinding traces can be left on the wafer, depending on the grinding mode. After dicing, these types of traces are created on the back of a chip in the direction of 0 to 90 degrees, thus affecting the bending strength. As discussed above, when an external load is applied to a chip, how the strength reflects the grinding trace left on the back of the chip has not been evaluated thus far.

Therefore, in this study, chips diced from a wafer under different back grinding conditions were assessed in terms of the bending strength. This study was designed to increase the production yield of thin semiconductor chips and their reliability for use in products by evaluating the impact on the bending strength according to the grinding trace direction and surface roughness.

Experimental

As shown in Table 1, a grinding process under different conditions was applied to an 8-inch (200 mm) silicon wafer

Table 1. Grinding parameters used in back grinding

Grinding parameters	Coarse grinding	Fine grinding
Grit size	#400	#2000
Spindle speed (rpm)	4800	3500

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grown in the <110> direction so that each had a different thickness and a different surface roughness. In addition, some wafers were precision-polished with the conditions described in Table 2 to eliminate the grinding traces. The wafers were then polished to thicknesses of 80, 100, 150, 200, and 300 μm to measure the bending strength given each thickness and polishing condition. After the back grinding of the wafer, it was cut into chips according to the sizes and conditions shown in Table 3. Depending on the thickness of the wafer these chips were cut into lengths of 2 to 6.5 mm and widths of 2.5 to 6.5 mm.

Generally, a grinding mark is made depending on the rotation speed of the grinding wheel and the chuck. Mathematical modeling was applied according to the method of Chidambaram *et al*. [5], with the grinding conditions shown in Fig. 1. A modeled grinding mark based on nearly identical grinding conditions to those in this test was similar to the actual mark. Grinding marks at different locations were observed through a microscope, and the changes were characterized, as shown in Fig. 2. The photomicrographs in Fig. 2 show the grinding marks that formed on the back

Table 2. Polishing parameters used in back grinding

Polishing parameters	
SiO_2 content (%)	40
Average particle size (nm)	60~85

Table 3. Dicing process parameters

Dicing conditions	
Spindle speed (rpm)	45,000
Max. feed speed (mm/s)	30 ± 5
Blade height (mm)	0.155 mm ± 0.01
Blade thickness (mm)	0.062 ± 5

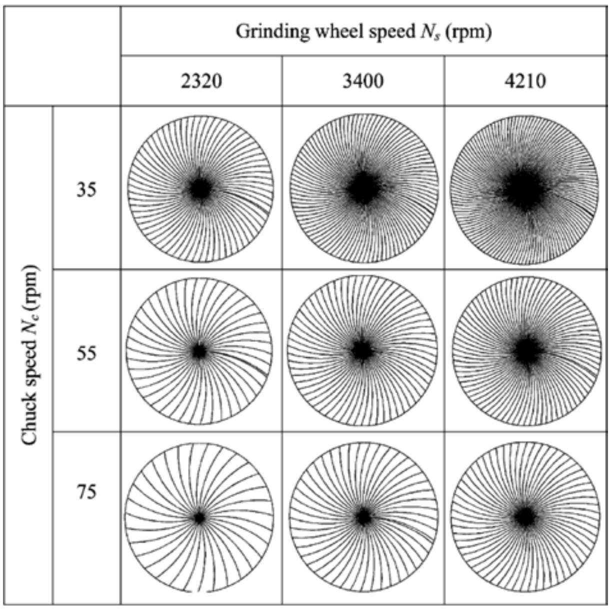


Fig. 1. Effects of wheel speed and chuck speed on grinding marks [5].

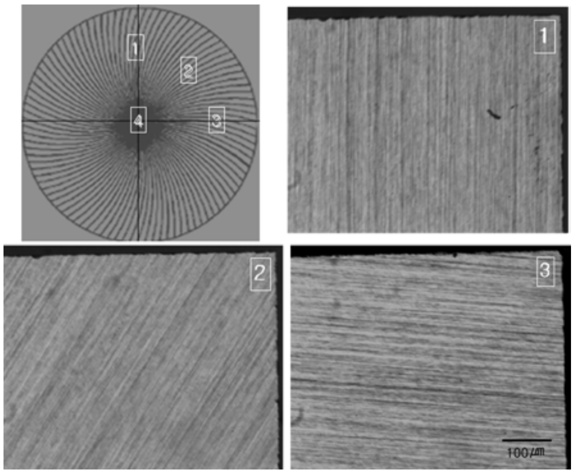


Fig. 2. Correlation of grinding marks with chip site in wafer.

of a chip which had moved from location 1 to location 3. These are defined as site-1, site-2, site-3 and site-4. Assuming that site-1 is in the direction of the y-axis, the grinding mark on site-1 runs parallel (0°). Progressing to site-3, the angle continuously grows larger. Consequently, the grinding amark on site-3 is at a right angle (90°). The wafer was cut so that the major axis could go towards the direction of site-1 rectangular to a die. Additionally, the grinding mark is symmetric along the center of the wafer. Therefore, the site1, site-2, and site-3 specimens represent the bending strength of other locations whose specimens were not assessed.

Atomic force microscope (AFM, D-3100, Veeco) was used to measure the surface roughness for each grinding condition. Due to its light weight, a silicon nitride tip was used for the silicon wafer. According to the surface roughness, it was observed under the two modes of 60 × 60 μm and 10 × 10 μm. The average surface roughness (Ra) was calculated, covering all areas observed.

A ball-break test was conducted to measure the chip breaking strength [6-9], while a three-point bending test was conducted with the aim of minimizing any impact resulting from the interaction between the pads and the chips during the ball-break test and adjusting the grinding mark direction and stress direction. A load cell (Instron, 5848) with a high capacity of 500N was used to measure the bending strength. Depending on the size of each chip, support span distances of 1.6, 3 and 4 mm were used. The bending speed was fixed at 0.1 mm min^{-1} through displacement control. Regarding the bending direction of the specimens, they were bent toward the direction of the lower support so that the maximum tensile load could be placed on the back side that was polished. The crosshead travel distance represents the level of the bending strain of the chip; thus, this distance was measured initially when the weight was used and again when a rupture occurred. Fig. 3 shows images during the bending test and the location of the back side of the die. Table 4 displays the scratch direction of the bending axis depending on each location of the wafers from which the chips were supplied.

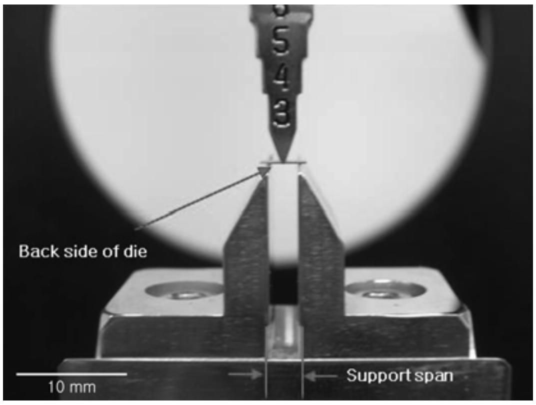


Fig. 3. A photograph of the 3-point bend test.

Table 4. Correlation of sampling position with scratch angle

Sampling position	Site-1	Site-2	Site-3	Site-4
Angle*	90°	45°	0°	random

Results and Discussion

The backside of the wafer was polished in accordance with the aforementioned conditions and the surface roughness was then measured using AFM, consequently generating the results shown in Table 5. In addition, changes in the surface roughness could be identified depending on the grit size. Fig. 4 shows the results of the AFM analysis regarding the grinding marks left after contact between an abrasive grinding wheel and the wafer's surface. The grinding mark occurring in a fixed direction may be considered a surface defect, accordingly causing a yield drop due to concentration of the stress. Fig. 5 and 6 show the results of the AFM analysis on an 80 μm-thick wafer after using a number-2000 abrasive grinding wheel and after precision polishing, respectively. With the number-2000 abrasive grinding wheel, grooves are generated continuously in a fixed direction. On the other hand, under precision

Table 5. Comparison of measured roughness data for wafers

Wafer thickness (μm)	100	200	300	400
Grit size	#2000	#2000	#2000	#400
Roughness (nm)	15.01	14.21	16.86	280.7
Thickness (μm)	90	80	80	80
Grit size	#2000	Polishing	Polishing	#2000
Roughness (nm)	14.55	1.18	0.75	19.03

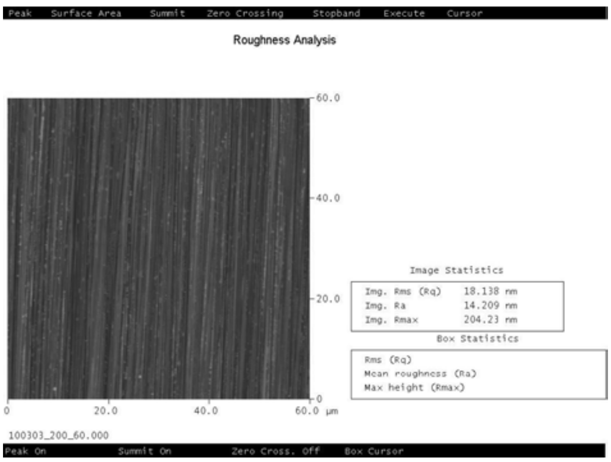


Fig. 4. AFM section analysis for a 200 μm wafer ground by a wheel with 2000 grit size.

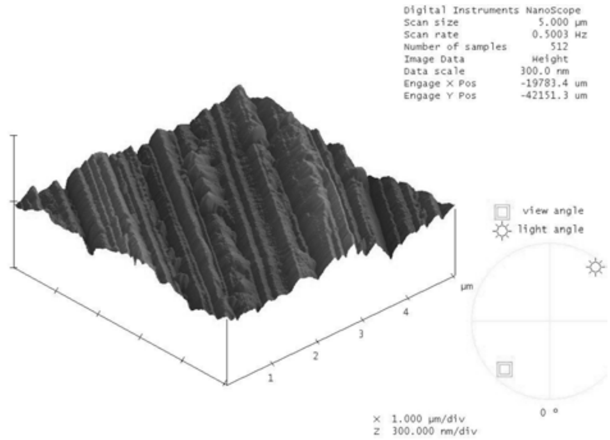


Fig. 5. AFM section analysis for 80 μm wafer ground by a wheel with 2000 grit size.

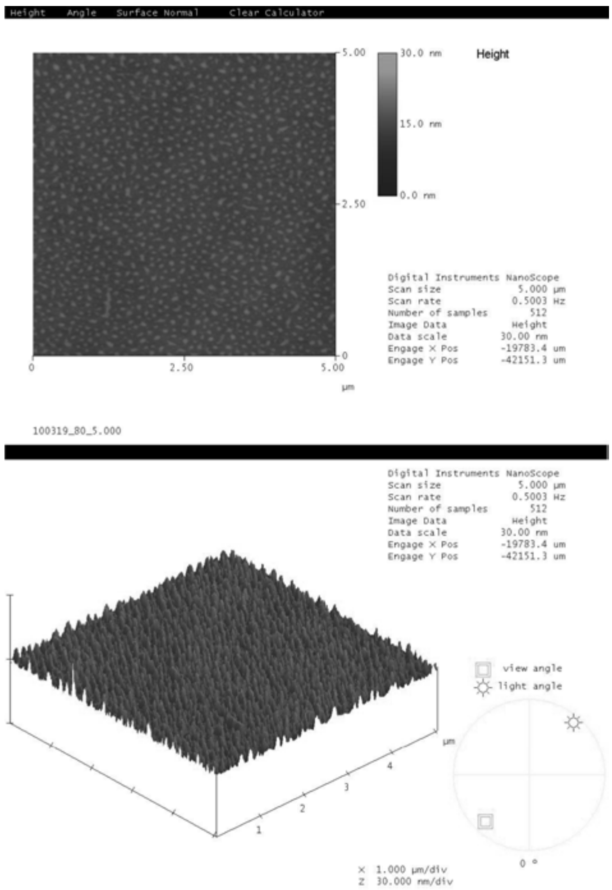


Fig. 6. AFM section analysis for 80 μm wafer ground by a wheel with 4000 grit size.

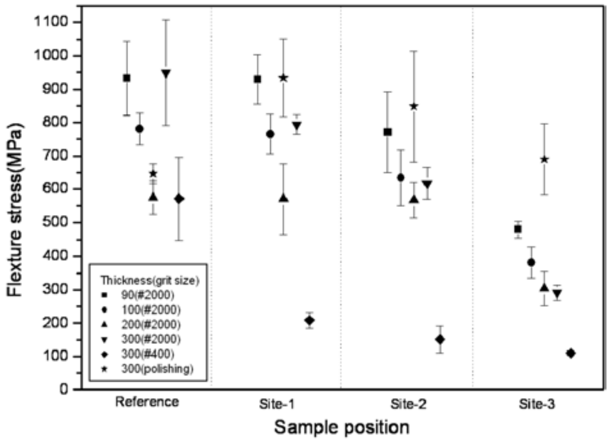


Fig. 7. Variation of the flexure stress within sampling position of 80 μm wafer.

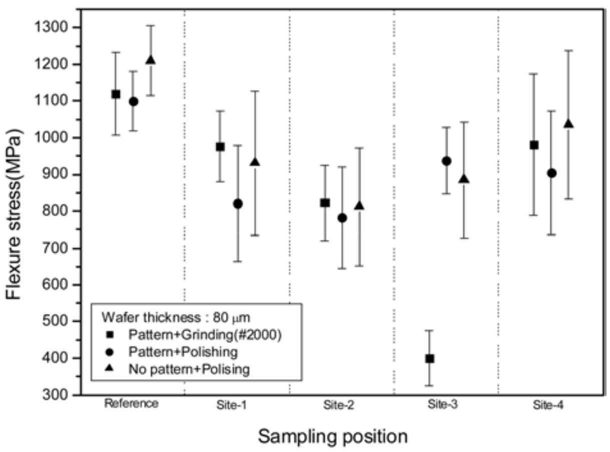


Fig. 8. Variation of the flexure stress within sampling position and roughness of wafer back side.

polishing, grinding marks were not generated in a fixed direction; instead, discontinuous unevenness was noted.

Fig. 7 and 8 show the results of the bending test of the chips. The chips were collected from each location after they went through the thinning and cutting processes. As the front polishing process is based on the same conditions for each test, this paper considers the front bending strength as the reference. According to Fig. 7, the chips ground by the number-2000 grit had a strength that exceeded 500 MPa as measured as the base value for site-1 and site-2 regardless of the thickness. However, the strength of the chips grinded by number-400 grit was lower than the reference at all locations. In particular, they showed remarkably low strength compared to the chips grinded by number-2000 grit at site-1 and site-2. Compared to the other locations, site-3 demonstrated lower bending strength under all grinding conditions. The wafer (number-400 grit) whose Ra value was at the highest level had low strength. Hence, the surface roughness has a significant influence on the bending strength of the chips, particularly those chips whose grinding marks and bending axes are in parallel are highly vulnerable. Fig. 8 displays the impact of the pattern on the bending strength with all wafers having the same thickness. Chips with patterns precisely polished and chips without patterns appear to have a similar bending strength. In this sense, the wafer's front pattern was found not to affect the bending strength. When comparing the wafer ground using number-2000 grit and a polished precisely wafer, they showed a similar level of bending strength at all locations except site-3. When there was a ten-fold gap in the Ra value, the bending strength was decreased by approximately 50%.

As chips become increasingly thinner, the importance of the flexure strain is being emphasized. For chips used in credit cards or smart cards, the flexure strain, not the bending strength, can serve as a more important variable. Fig. 9 shows changes in the flexure strain depending on each measurement location on the wafers. Under the condition of grinding with number-2000 grit only at site-3, the flexure strain was much lower than that in the condition of precision

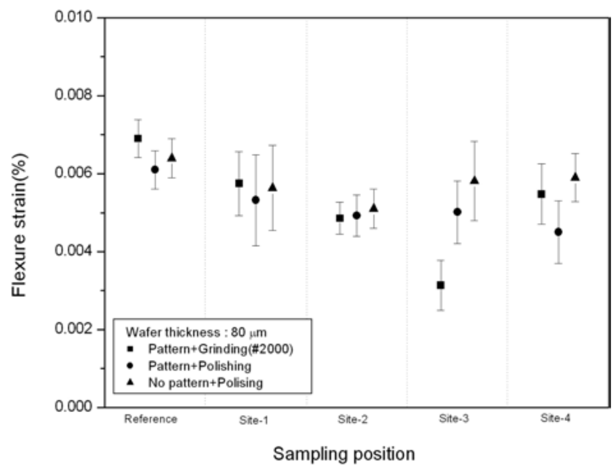


Fig. 9. Variation of the flexure strain within sampling position and roughness of wafer back side.

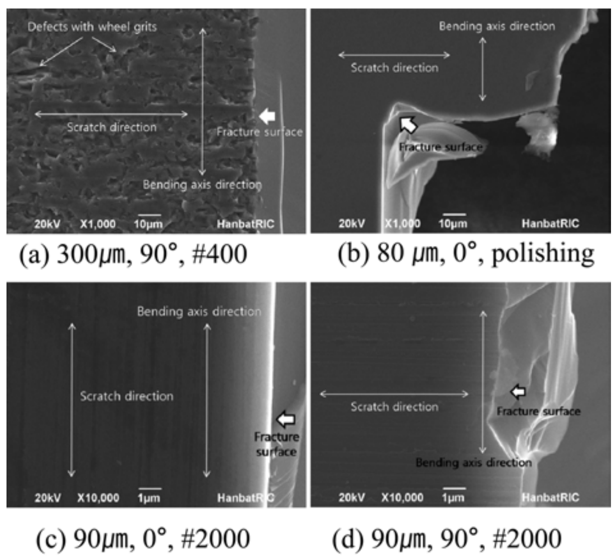
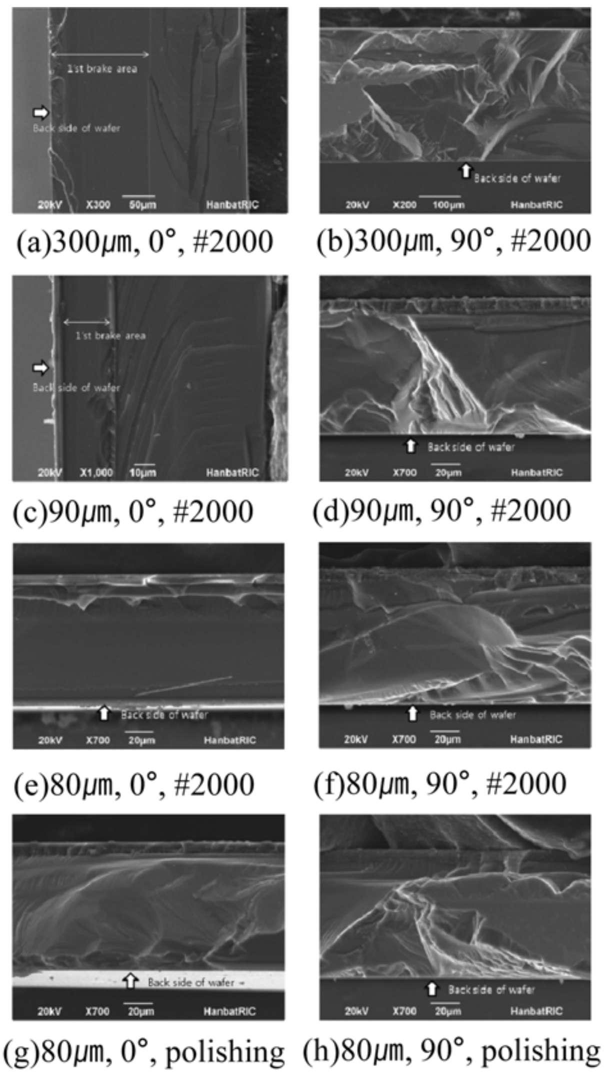


Fig. 10. Comparison of fracture aspects according to grinding condition and bending axis direction to scratches.

polishing. Therefore, precision polishing is necessary to improve the bending strength of chips regardless of the location. This will also reduce incidences of a faulty packaging process and enhance the production efficiency of chips.

Fig. 10 shows the results upon a rupture in the flank via a scanning electron microscope (SEM) after the bending test. In the case of (a), which was ground using number 400 grit and accordingly has considerable surface roughness, a linear fracture was found, although the bending axis and the scratch are at a right angle (90°). For (b), which was polished precisely, an irregular fracture formed at site-3(0°). Samples (c) and (d) display the fractures of chips collected from the wafer ground using number-2000 grit at site-3 and site-1, respectively. In the case of (c) where the bending axis and the grinding marks are in parallel, the crack starts along the scratch and goes deep inside. Like (b), (d) shows an uneven fracture where the crack occurs that does not progress in a fixed direction. According to the bending strength test, with the number-400 grit, much lower strength is shown at all locations. Upon precision polishing, higher strength was noted. Significantly lower strength was noted at site-3 in the case of number-2000 grit. Based on the test results, it can be assumed that the aforementioned results are related to the surface roughness, the direction of the scratch and the bending axis.

Fig. 11 shows the fracture result after the bending test was completed. When the scratch and the bending axis are at 0° and 90°, fracturing occurs under the condition of number-2000 grinding. In other words, there is a clear gap between (a), (c), and (e) and (b), (d), and (f) in terms of the fracture patterns. A cleavage fracture occurs, covering some parts or many parts in the 0° direction. According to (g), (h) of Fig. 11, the precisely polished chips display similar fractures regardless of their location on the wafers.



(a)300μm, 0°, #2000 (b)300μm, 90°, #2000

(c)90μm, 0°, #2000 (d)90μm, 90°, #2000

(e)80μm, 0°, #2000 (f)80μm, 90°, #2000

(g)80μm, 0°, polishing (h)80μm, 90°, polishing

Fig. 11. Comparison of fracture aspects according to grinding condition and bending axis direction to scratches.

Conclusions

This paper is intended to evaluate the effects of grinding marks on the bending strength of chips quantitatively when the grinding marks are generated by back grinding during the course of the silicon wafer thinning process. To that end, chips were taken from wafers under different grinding conditions and the bending strength of each was then measured, depending on the direction of the bending axis and on the grinding mark. In addition, after the bending strength test, the fracture behavior depending on each bending condition was analyzed to draw the following conclusions: Upon grinding with number-400 grit, due to the defects that formed on the surface, the strength in all locations of the wafer dropped to one third of the strength under precision polishing using number-2000 grit. When polishing using grit that was less fine than number-2000 grit, scratches were created that showed a distinct direction. Under precision polishing, a discontinuous uneven surface was observed. The bending strengths of thinning chips under grinding with number-2000 grit were strikingly different depending on the location on the wafer. However, the chips precisely polished had greater strength than the chips that were ground. In conclusion, we derived the conditions necessary to improve the production yield and reliability of thin chips by measuring the effects of the grinding trace direction and surface roughness on the bending strength.

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