FRACTURE STRENGTH EVALUATION OF SEMICONDUCTOR SILICON WAFERING PROCESS INDUCED DAMAGE

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Introduction

Recently, fracture strength test has been introduced to evaluate the damage of silicon wafer. There have been several works to observe and analyze mechanical damage in silicon wafers and to demonstrate optimum process condition. So far, 3 point bending strength was measured after cutting wafers into the rectangular type specimens and also the biaxial strength was measured by piston-on-3-ball test for 4in wafers[1-2]. In case of strength measurement after cutting wafers into small parts, the maximum load is concentrated on the cut edge, so that it is very difficult to represent the strength of the overall wafer surface owing to the edge effect. In case of measurement by piston-on-3-ball test, the maximum load is concentrated on the face area of the piston(diameter=5mm), therefore, it is unable to detect the damage which is only slightly deviated from the center of the wafer.

Therefore, in this study, a new testing method, "ring-on-ring biaxial strength test", was adapted to get the more reliable data for 8in wafers. Therefore, in this study, a new testing method, "ring-on-ring biaxial strength test", was adapted to get the more reliable data for 8in wafers. To analyze stress and displacement distribution of wafer under ring-on-ring test, stress analysis was performed using finite element method. Angle lapping method was also used to measure the damage of Sawn, Lapped, Etched and Polished wafers, respectively. The fracture strength test was used to evaluate the damage of Sawn, Lapped, Etched and Polished wafers. The results of angle lapping method were compared with those of fracture strength test.

Experiment

1 Equipments and finite element analysis

UTM(Universal Test Machine, H10K-C, Hounsfield Test Equipment, U.K.) was used in this study together with the ring-on-ring fixture. In the ring-on-ring fixture, the diameter of the upper ring was designed as 140mm and that of the lower ring was designed as 170mm, to fit the diameter(200mm) of the wafer [3]. Since the upper ring and lower ring must be put into a coaxial circle, 3 fixing pins were set to fix the wafer into its center. The load cell(maximum load:10000N) of UTM was set together with the ring-on-ring fixture.

The biaxial strength of the wafers measured by the ring-on-ring test can be determined by the expression (1) [4].

$$\sigma = \frac{3P}{4\pi t^2}[2(1+\nu)\ln\frac{a}{b} + \frac{(1-\nu)(a^2-b^2)}{R^2}] \qquad (1)$$

where P is the load, t is the thickness of wafer, ν is the Poisson's ratio, a is the radius of the supporting ring, b is the radius of the ring and R is the radius of the wafer.

In the real system, the load cell is set on the ring-on-ring fixture, however, the load distribution is not known on the wafer. Therefore, the load stress on the wafer was calculated by Finite Elemente Analysis. ANSYS package was used for finite element analysis [5].

2. Depth of damage evaluation by angle lapping method

The angle lapping, so called section polishing, is a technique to observe the defects of the wafers. By this method, the section surface is observed after lapping the tilted surface. To observe the damage better, dry oxidation at 800℃ for 4 hours and wet oxidation at 1100℃ for 80 minutes are performed before the selective etching and observation. [6]. Nomarski microscope(Nikon, Japan) was used for observation. Fig. 1 shows the locations of the four samples taken from the wafer; one sample was taken from the center and other three were taken from three edges of the wafer as shown in Fig. 1. After cutting a wafer into 2 pieces, one was applied to the dry oxidation process and the other was applied to the wet oxidation process. One sample at center and 3 samples at edges were to be observed.

3. Fracture strength evaluation of wafer using ring-on-ring test

The fracture strength evaluation was performed by the ring-on-ring test. The wafering process is commonly composed of sawing, lapping, etching and polishing processes, so that the sawn, lapped, etched and polished wafers,

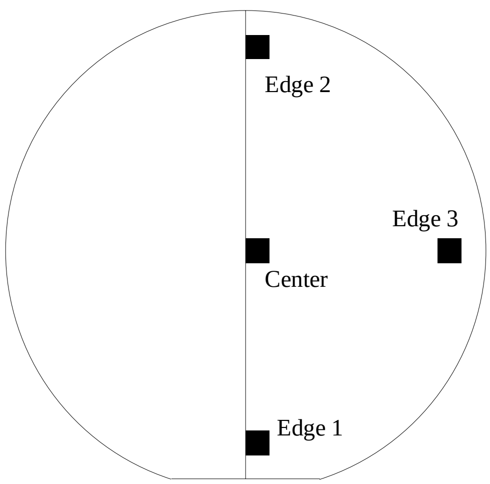

Fig. 1. Schematic diagram showing the locations of the samples (Center, Edge 1, Edge 2 and Edge 3) to measure DOD.

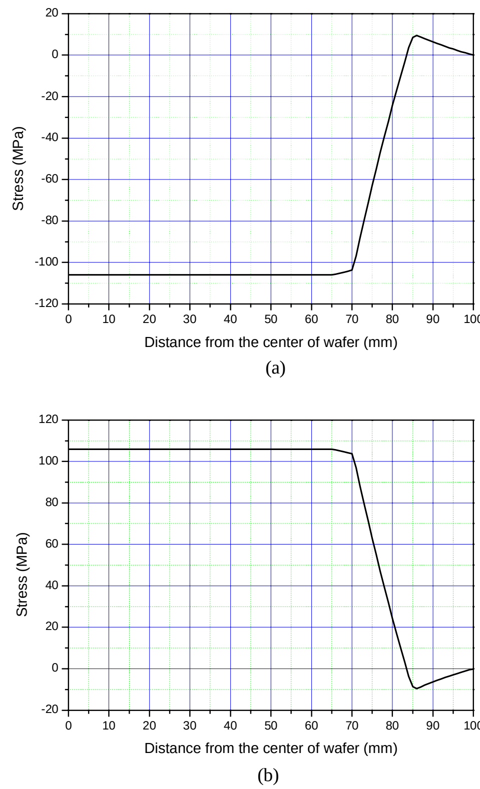

Fig. 2. Surface stress distribution of the wafer in the ring-on-ring test, calculated for a 725mm thick 8 inch wafer loaded under 5000N. (a) upper face (b) lower face

respectively, were analyzed to observe the residual damage produced in each wafering processes. Especially, when polishing1 was compared with polishing2, polishing2 process was better than polishing1 process.

Results and discussion

1. Stress distribution in ring-on-ring test

Fig. 2 shows the stress distribution on the upper and the lower faces of the wafer as a function of the distance from the center of the wafer when 5000N was loaded on the wafer of 725㎛ thickness and 8in diameter. As can be seen in Fig. 2, the compressive stress of 106MPa is uniformly loaded on the upper face of the wafer and the tensile stress of 106MPa is loaded on the lower face of the wafer. The stress is rapidly decreased from the supporting ring to the loading ring so that the stress is nearly 0 at the edge of the wafer. Therefore, the damage located in the central area inside loading ring of the wafer can be precisely calculated without reflecting the edge effect on strength because of the uniform load in the central area of 70mm radius. This area corresponds to 49% of the entire wafer surface area, which means that this ring-on-ring method can detect the surface damage on wafer better than any other existing damage evaluating method.

2. Depth of damage measurement by angle lapping method

For comparison with fracture strength evaluation method, the depth of damage was measure by angle lapping method. The damage length was multiplied by the value of sine(grinding angle) to obtain DOD(depth of damage). The obtained DOD values are represented in Fig. 3. The values of DOD decrease according to the order of the processes, sawing->lapping->etching->polishing, which is generally adapted wafering process as shown in Fig. 3. This means that the damage of Sawn wafer is highest and the damage of wafer is removed by progress of lapping, etching, polishing processes. The damage was more remarkably observed for the samples processed through dry oxidation rather than those processed through wet oxidation. This means that damage can be observed more clearly by dry oxidation process than by wet oxidation process. It was observed that the damage at the edge was more severe than that at the center of the wafer. This means that the edge is more heavily damaged compared with the center of the wafer. Because the sample quantity selected from edge site is more than that from center site, the probability of finding severe damage in edge is assumed to be higher. It is also probable that the larger damages cannot be found in the selected parts rather than can be found at some other places because DOD was measured for the ultimately small part of the wafer. Therefore, it is reasonable to compare the maximum values of DOD for all processes regardless of the positions(center or edge).

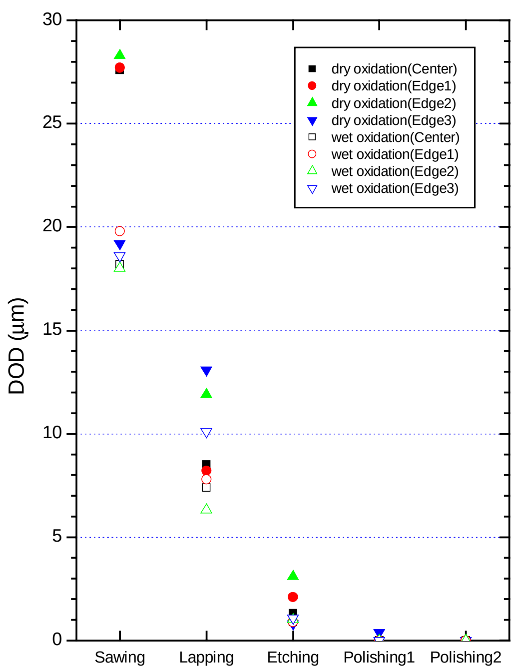

Fig. 3. DOD measured by angle lapping after heat treating wafer for various processes.

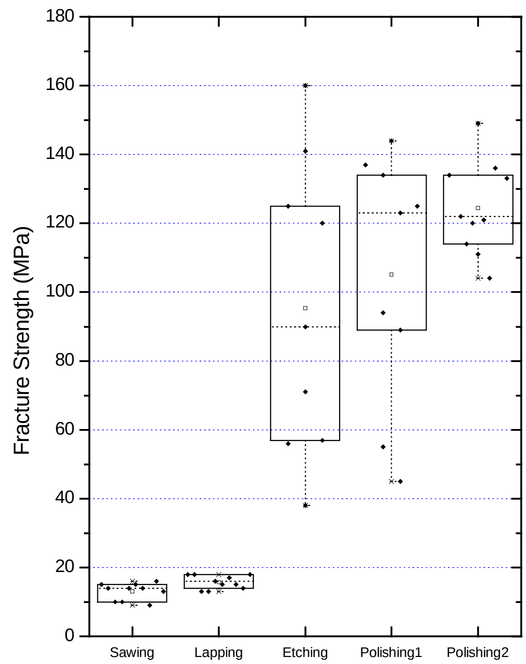

Fig. 4. Fracture strength of wafers for various processes in ring-on-ring test.

3. Fracture strength analysis for wafer with ring-on-ring test

The fracture strength analysis for sawn, lapped, etched and polished wafers, respectively, was performed by ring-on-ring test. Fig. 4 shows the fracture strength by ring-on-ring test. The maximum damage existing inside the circle with radius of 70mm is considered to determine the strength of the wafer. The wafer of the lower strength showed the smaller variation of strength and the wafer of the higher strength showed the larger variation of the strength as shown in Fig. 4. This is because the strength is inversely proportional to depth of damage. The strength increases gradually to the order of sawing->lapping->etching->polishing process because the damage decreases gradually in this order. Therefore, it could be confirmed that the damage of Sawn wafer was highest and the damage of wafer was gradually removed according to the progress of lapping, up to etching and up to polishing processes.

4. Comparison with fracture strength and depth of damage

The fracture strength value obtained by ring-on-ring test was compared with the depth of damage obtained by angle lapping method. Generally, the strength is inversely proportional to the root of the depth of damage. In other words, the larger the damage of wafer is, the lower the strength value is. In fracture mechanics, strength and damage have the relation as the following expression (2).

$$K_{IC} = \sigma_f Y \sqrt{a_f} \qquad (2)$$

where K_{IC} is the fracture toughness, σ_f the fracture strength, Y the geometric factor and a_f the damage. Since K_{IC} is the material constant and Y is the constant value related to the loading system, the size and shape of the specimen and the damage, it can be understood that the damage is inversely proportional to the square of the strength of the specimen.

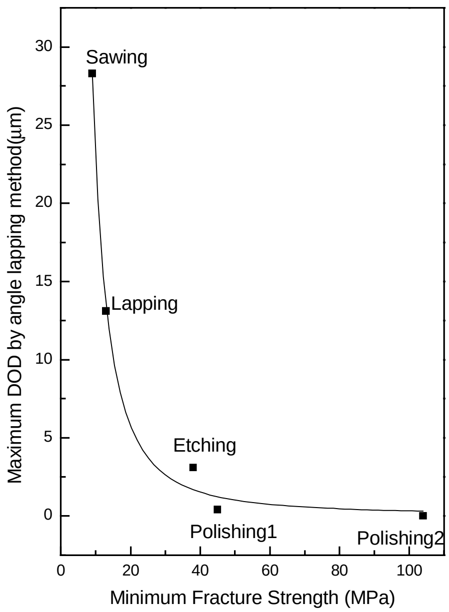

Fig. 5. Curve fitting of maximum depth of damage measured by angle lapping method as a function of the measured maximum fracture strength.

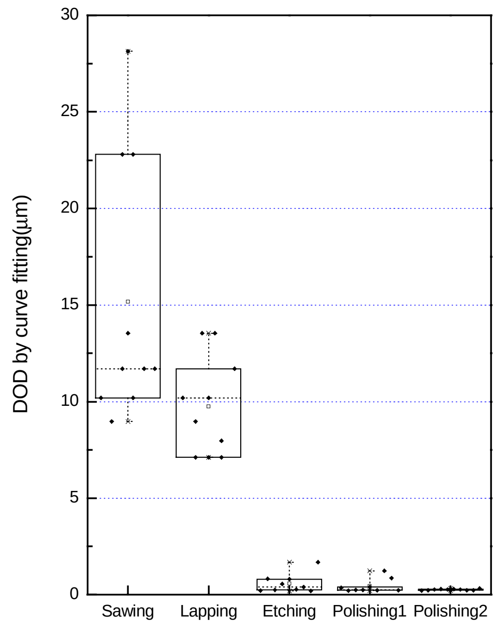

Fig. 6. Depth of damage obtained from the fitting of fracture strength of wafers for various processes in ring-on-ring test.

The values of the maximum depth of damage for various processes measured by angle lapping method are plotted in Fig. 5 together with the minimum fracture strength measured by ring-on-ring test for curve fitting. In real system, the maximum value of damage is more meaningful to control the condition of wafering processes and the fracture strength will have smallest value for the largest damage. Therefore Fig. 5 shows the plots of maximum value of damage obtained by the angle lapping method against the minimum value of fracture strength of the sawn, lapped, etched and polished samples to fit the two parameter power fitting function which is expressed as Equation (3) [7].

$$y = y_0 + \frac{A_1}{x^2} \tag{3}$$

where y_0 is Y offset, A_1 the amplitude, y DOD calculated by the angle lapping method, and x the strength measured by the ring-on-ring test. y_0 and A_1 are the constants 0.108 and 2270.0, respectively, obtained by the curve fitting from Fig. 5.

Fig. 6 shows depth of damage values obtained by curve fitting from the ring-on-ring strength data shown in Fig. 5 using the two parameter power fitting function. In general, the samples with the smaller damage(polishing, etching) showed smaller variation, on the other hand, the samples with the larger damage(sawing, lapping) showed larger variation, which is considered to be related to the variation in strength data. Though the variation of DOD was smaller when DOD was larger, the variation of strength becomes larger, due to the inverse proportion of the strength to DOD value. Although the variation of damage was larger when damage was smaller, the variation of the strength was not so large as can be seen in Fig. 5.

In contrast to the strength data given in Fig. 4, depth of damage value becomes smaller in the order of sawing->lapping->etching->polishing processes as shown in Fig. 6. Comparing depth of damage values in the processes etching and polishing, about half of the wafers passed through etching process had zero depth of damage value, however, more than half of the wafers passed through polishing process had zero DOD, that is, the damage decreased gradually to zero as the wafering proceeds.

Conclusions

A new damage analyzing technique, ring-on-ring test, was suggested to the wafering process of 200mm Si wafer and analyzed the damage of Sawn, Lapped, Etched and Polished wafers, respectively. The depth of damage obtained by angle lapping method, the existing damage measuring technique, decreased in the order of sawing->lapping->etching->polishing process. The values of fracture strength obtained by ring-on-ring test increased according to the order of sawing->lapping->etching->polishing process.

Acknowledgment

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