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Evaluation of damage on silicon wafers using the angle lapping method and a biaxial fracture strength test

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The damage of sawn, lapped, etched and polished wafers was evaluated by the angle lapping method and a biaxial fracture strength test. The Si wafers for analysis were fabricated by the commercial wafering process. As the wafering process proceeded, the depth of damage (DOD) measured by the angle lapping method decreased but the fracture strength measured by the ring-on-ring test increased. As a result, a correlation between DOD and fracture strength was verified using an equation for the fracture toughness, K_{IC}. The fracture strength obtained from the ring-on-ring test was found to be one of the representative values for the mechanical properties of a wafer as it passed through the wafering process.

Key words: depth of damage, angle lapping method, silicon wafer, fracture strength, ring-on-ring test.

Introduction

A semiconductor silicon wafer is manufactured by the wafering process, which is composed of sawing, lapping, etching and polishing processes. The wafer inevitably experiences creation and propagation of damages during the wafering process. This damage to the wafer acts as a defect in the backend processes, and degrades the quality and reliability of the product. Therefore, in the wafering process, the control of the damage is very important and so it is necessary to evaluate the damage. The angle lapping method, which was standardized by ASTM [1], has been used to observe the depth of damage (DOD) produced during the wafering process. However, the DOD measured by the angle lapping method may not be the representative value for the whole wafer because specimens are selected from limited small portions of the whole wafer body. Therefore, a more representative test is required for evaluation of DOD.

The fracture strength of ceramics, including silicon, is related to surface defects [2]. Therefore, a fracture strength test can be adopted to evaluate the process of induced damage. Actually, fracture strength tests of silicon have been carried out for the evaluation of silicon in a number of studies [3-5]. The correlation between the thickness of the silicon chip and the quality of the backend process was studied by 3 point bending strength tests on wafers cut into the rectangular specimens [3]. McGuire *et al.* studied the influence of grinding geometry and DOD on 100 mm diameter (111) silicon wafers to analyze the influence of backgrinding on the fracture strength, using a piston on 3 ball test [4]. Vedde and Gravesen studied the influence of the concentration of nitrogen and oxygen on the fracture strength of cut, lapped and polished silicon wafers using a ring-on-ring test [5]. In 3 and 4 point bending tests, the wafers should be cut into small pieces and the maximum load is concentrated on the cut edge, so that it is very difficult to obtain a representative strength of the overall wafer surface owing to the edge effect. However, for biaxial fracture strength tests, including the piston-on-3-ball test and the ring-on-ring test, a larger specimen area and volume are used [6]. Therefore, the biaxial fracture strength can give a representative value for the mechanical properties of materials and can be adopted for the reliable evaluation of silicon wafers. Therefore, in the present study, the DOD was measured by the angle lapping method and the fracture strength by using the ring-on-ring test, and the results applied to a study of damage reduction in the wafering process.

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Experiments

200 mm (8 inch) diameter, p-type (100) oriented Czochralski silicon wafers were fabricated by the wafering process adopted at MEMC Korea. The wafering process was composed of sawing, lapping, etching and two-step polishing (polishing 1 and polishing 2) processes, which have been adopted to produce commercial wafers for mass production.

The sawn, lapped, etched and polished wafers were analyzed to observe the damage produced at each step of the wafering process. The samples were taken from four positions on the wafer; one was taken from the center and the others were taken from three of the edges of the wafer. Thermal oxidation generates the oxidation-induced stacking faults (OISFs), which enable the damage to be revealed more easily [7, 8]. The wafers were cut into 2 pieces; one for dry oxidation and the other for wet oxidation. Dry and wet oxidation were carried out at 800°C for 4 hours and 1100°C for 80 minutes, respectively. After thermal oxidation, the DOD was measured by the angle lapping method using selective etching and Nomarski interference microscopy (Nikon, Japan).

The fracture strengths of 200 mm (8 inch) diameter wafers were measured by a ring-on-ring test using a universal testing machine (H10K-C, Hounsfield Test Equipment, U.K.). For each condition, 10 wafers were tested to obtain a statistical value of the fracture strength. For the ring-on-ring fixture, the diameters of the supporting ring and the loading ring were 170 mm and 140 mm, respectively. The biaxial strength of the wafers measured by the ring-on-ring test was determined from eq. (1) [8]:

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

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

Results and Discussion

The OISFs were created by dry and wet oxidation to measure the DOD in the wafer. The length of OISF is dependent on the oxidation temperature, time and atmosphere [7]. Unfortunately, in this study, the dry and wet oxidations were fixed at 800°C for 4 hours and 1100°C for 80 minutes, respectively. Therefore, the analysis for the atmospheric effect on the OISF is not currently available. However, the OISF method is very useful in order to compare the DODs for each process and the results are presented in Fig. 1. The DOD decreased according to the order of the processes; sawing, lapping, etching, polishing 1 and polishing 2, which is the generally adopted order of the wafering processes in mass production. Even if the measured DOD is obtained from one wafer for each wafering process, a very large variation of the data appeared. From these results, it is assumed that the DOD measured by the angle lapping method is dependent on the location of the sample tested. The successive wafering processes could not gradually reduce the damage in the wafer, but selectively removed the damage. In addition, the damage was more severe at the edges than at the center of the wafer. This result is explained by the following two reasons. Firstly, the edge was more heavily damaged compared with the central area of the wafer. Secondly, more specimens were taken from the edge than the center for these tests. Therefore, the probability of finding more severe damage is assumed to be higher at the edge of the sample.

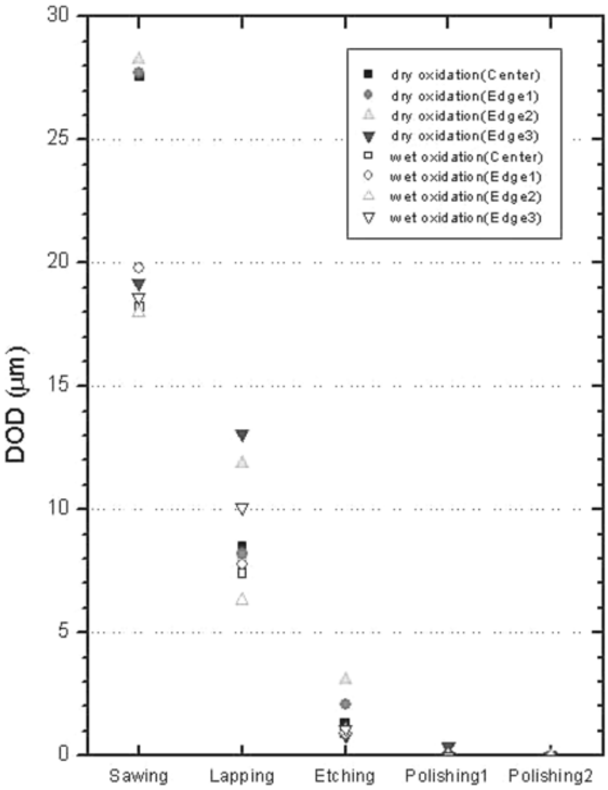

Fig. 1. Physical properties change as a function of wafering processes. (a) DOD measured by angle lapping method after thermal oxidation for each wafering process. (b) Fracture strength of wafers for each wafering process measured by ring-on-ring test.

The fracture strength of the wafer is shown in the form of a box chart, which is a method expressing the statistical distribution of data in Fig. 2. In the box chart, the scattered points represent the individual data point, while the squares are determined by the distribution of data from 25 to 75%. As shown in Fig. 2, the fracture strength of the wafer increased gradually according to the order of the processes; sawing, lapping, etching, polishing 1 and polishing 2. It is assumed that the damage remaining is dependent on the wafer as well as on the location on the surface of the wafer as can seen from the large variation of the fracture strength.

From Figures 1 and 2, it can be appreciated that the DOD decreases as the fracture strength increases according to the order of the wafering processes. Therefore, in order to analyze the relationship between DOD and the fracture strength, the maximum DOD as a function of the minimum fracture strength is plotted in Fig. 3, in which the wafer with the larger DOD shows the lower fracture strength. The experimental power fitting function is derived for the correlation between DOD and fracture strength, which is expressed as:

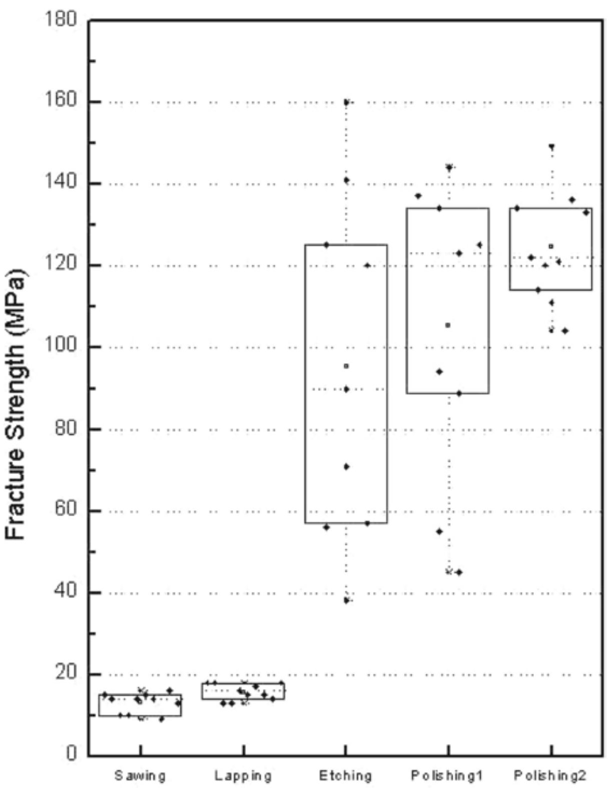

Fig. 2. The relationship between maximum DOD and minimum fracture strength.

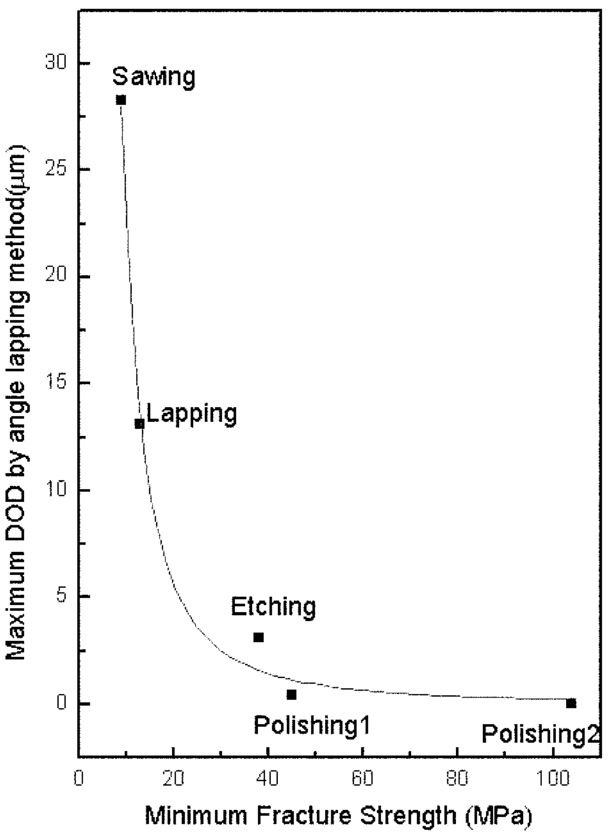

Fig 3. Depth of damage obtained from the fitting of fracture strength of wafers for various processes in the ring-on-ring test.

$$y = y_0 + \frac{A_1}{x^2} \quad (2)$$

where y_0 is the Y offset, A_1 the amplitude, y the DOD calculated by the angle lapping method, and x the strength measured by the ring-on-ring test. In this study, y_0 and A_1 were 0.108 and 2270.0, respectively.

Generally, the fracture strength is inversely proportional to the square root of DOD [2]. Therefore, the relationship between the strength and the damage can also be expressed according to the relationship between the fracture strength and the damage as in the well known equation for the fracture toughness, K_{IC} [2]:

$$K_{IC} = \sigma_f Y \sqrt{a_f} \quad (3)$$

where σ_f is the fracture strength, Y a geometric factor and a_f the crack length or the damage.

Equation (2) can be explained as another form of eq. (3), by considering the experimental calibration, y_0. Thus, the fracture strength can be converted to DOD to analyze the wafering process in mass production using eq. (2), as represented in Fig. 4. The DOD calculated from the fracture strength may be substituted for the DOD measured by the angle lapping method. While the use of the angle lapping method is limited to selected locations to measure the DOD and the measured value may not be the one representative for the whole wafer body, the biaxial fracture strength is considered

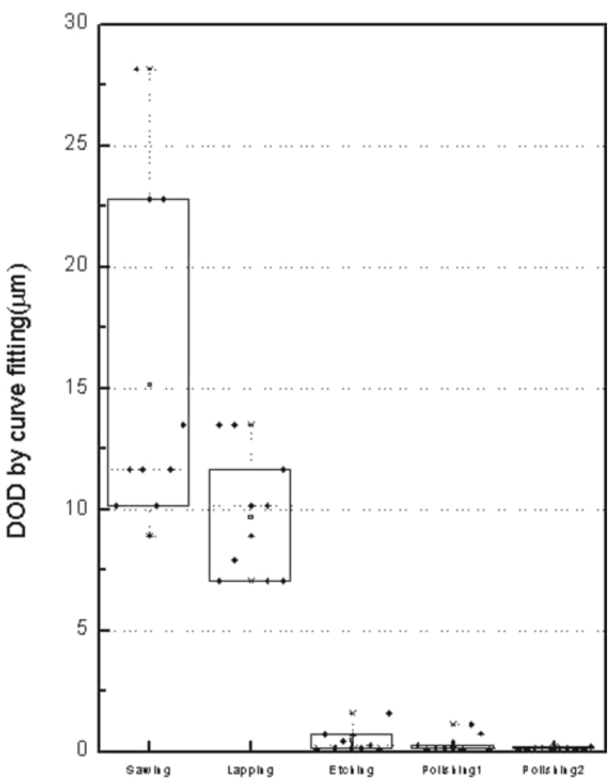

Fig 4. Depth of damage obtained from the fitting of fracture strength of wafers for various processes in the ring-on-ring test.

to be a result of the damage of the whole area of the wafer inside loading ring. Therefore, even if the fracture strength test is rather expensive, it can be adopted for the evaluation of the DOD of the wafer in the wafering process.

Conclusions

The DOD and the fracture strength, which were obtained by the angle lapping method and the ring on ring test, were correlated according to an equation of the relationship between the crack length and the fracture strength. The fracture strength showed inversely proportionality to the root of DOD. Since the fracture strength gives a representative value for the whole wafer body, the DOD was calculated from the fracture strength of the wafers using an experimental fitting function.

Acknowledgements

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