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EFFECT OF LUBRICANT ENVIRONMENT ON SAW DAMAGE IN SILICON WAFERS

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The chemomechanical effect of lubricant environments on the I.D. sawing induced surface damage in Si wafers was tested for four different lubricants: water, dielectric oil, and two commercial cutting solutions. The effects of applying different potentials on Si crystal during the sawing were also tested. The results indicated that the number and depth of surface damage are sensitive to the chemical nature of the saw lubricant. By combining the damage depth profile and the surface structure observations, it was determined that the lubricants that are good catalysts for breaking Si bonds can dampen the out-of-plane blade vibration more effectively and produce less surface damage. Correlations between the applied potential and the depth of damage in the dielectric oil and one of the commercial cutting solutions were observed and possible mechanisms involved were discussed.

INTRODUCTION

The depth of surface damage induced in Si wafers during the I.D. sawing process is known to be sensitive to several operational variables, such as blade size, feed rate, blade tension, wafer size, direction of sawing, etc. (1-5). So far most of the studies of the I.D. sawing process have concentrated on determining the depth of damage and its correlation to the mechanical conditions of the operating system. Little attention was paid to the effect of the nature of the lubricant environment on the sawing process. The physical as well as the chemical nature of the environment is known to influence significantly the efficiency of comminution operations such as grinding and drilling in the cement, ball milling, oil drilling and other industries (6,7). Recently, we have examined the relation between the chemical nature of the I.D. saw lubricant and the surface damage structures (8). The results indicated that saw lubricant is an important operational variable, and the depth and number of surface damage can be reduced by improving the lubricant environment.

The sawing of brittle materials, such as Si, is believed to be largely a cleavage process, but prior to our studies the detailed structure of the sawing induced surface damage and the role of plastic flow in the sawing process have not yet been determined in the literature. The damage structures due to mechanical abrading consist of cracking at the surface and strained dislocation networks underneath the surface. Meek and Huffstutler argued from their etching and stress measurements that the sawing induced defects are predominantly microcracks rather than dislocations (4). Schwuttke, using TEM, characterized the very deep saw damage as microcracks (5). We have observed the saw damage from both the top and the crosssectional view angles by TEM and have characterized the damage structure as mainly cracks extending roughly along both (110) and (111) planes from the chipped surface. Dislocations were found only at the top ~1 μm layer, and their occurrence was attributed to the abrasive motion of the saw blade (8). The major events that create the kerf are therefore the initiation and propagation of cracks. Those lubricants that facilitate the nucleation and propagation of cracks can reduce the energy expended in the sawing operation and the amplitude of the saw blade vibration which in turn affects the damage structure.

We have tested four different lubricant environments: (i) that of the standard production process-water, which is a strong catalyst for the breaking of Si covalent bonds; (ii) dielectric oil, which is chemically inert; (iii) a commercial cutting solution (Kleenzol-B); and (iv) a commercial coolant (Kleen-Kool[1]) in 80 parts water, which is also an active catalyst for breaking Si and other covalent bonds. The testing results are reviewed in the following sections.

EXPERIMENTAL PROCEDURES

Test wafers were sawn from vertically mounted, Czochralski (100) oriented, p-type, 100 ohm-cm, Si single crystals on a commercial HAMCO ID-diamond saw using a new blade with feed speed of 2.54 cm/min and rotation speed of 2100 rpm. Crystals with diameters of 5.7 cm and 8.3 cm were used. The sequence and operational parameters for the test performed on the 5.7 cm diameter crystal are listed in Table 1. Except for the lubricant and the applied potential, all the other operational variables were kept as constants. The wear of the diamond saw blade was considered to be insignificant since only 30 wafers were sawn in each environment.

Thickness and warpage of the as-sawn wafers were measured by an ADE 6043 microsense capacitance gauge. The surface morphologies of the as sawn wafers were observed by optical microscopy. The density profile of the saw damage was measured by an improved metallographic taper-sectioning method (9). Using this method, samples from six experiments were mounted on a beveling fixture and mechanically polished to obtain a 5 degree angle-lapped surface on each sample. The mechanical polishing is known to generate surface damage. In order not to obscure the pre-existing saw damage, this damaged layer newly introduced from polishing was removed by a chem-mech polish (using Syton HT-40[2]), which does not generate additional surface damage. The polished surfaces were then etched for 25 sec in dilute Sirtl etch solution to reveal the saw damage. The distribution of saw damage was read directly from optical micrographs taken from each etched surface. Figures 1(a) and (b) show the micrographs of samples sawn in dielectric oil and Kleen Kool solution, respectively. The number of damage pits and their distances from the wafer surface were recorded, and damage distribution profiles were plotted for each sample.

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1. DoAll trade name. The active agent in Kleen Kool, previously thought to be methyl silane (8), was later identified as an aqueous solution of a glycol ether.
2. Monsanto trade name.

EXPERIMENTAL RESULTS

The results of thickness and warpage measurements on 5.7 cm diameter as-sawn wafers are listed in Table 2. For the 5.7 cm diameter crystal, sawing in water consumed about 7 μm less material per wafer than sawing in other lubricants. Sawing in dielectric oil environment would, on the average, consume 8 μm more material per wafer if a positive potential is applied to the crystal and 4 μm less material for a negative potential, as compared to sawing without any applied potential. The sawing of 8.3 cm crystal was found to consume about 6 μm less material per wafer in water and about 10 μm less material per wafer in Kleen Kool solution than the sawing of 5.7 cm crystal in water under the same condition . This is probably due to the smaller amplitude of the saw blade vibration in the sawing of larger crystals. As indicated in Table 2, Kleenzol B gives the largest warpage value. The applied potential, whether positive or negative, also increases the warpage value.

When the saw blade cuts through the crystal, cracks are generated at the blade edge, and as they propagate and meet in the crystal, small pieces of Si are knocked off and removed by the rotating blade. The diamonds plated on the edge and sides of the blade also abrade the newly cleaved surface. These two processes give rise to two kinds of surface structures revealed in the micrographs taken from the as-sawn wafers: the original chipped off (or cleaved) regions and the flat (or abrasive) regions with scratches lying in the direction of blade motion. The surface of the chipped off region is about 1 μm below that of the abrasive region. The continuous diamond scratches in the abrasive region have a long range ordering with periodicity of about twice the feed distance per rotation. Since the periodicity distance was found to be the same for the two wafer surfaces that are on opposite sides of the saw blade but different for different lubricant environments, this periodic structure on sawn surface (saw mark) must be predominantly from the out-of-plane blade membrane vibration.

The out-of-plane blade vibration which can be modified in different lubricant environments is believed to be the major damage mechanism during the I.D. sawing of Si wafers (4). The surface percentage of the abrasive region and the depth of the scratches are sensitive to the amplitude of the blade vibration. For instance , as compared to sawing in water, sawing in dielectric oil lubricant (with zero potential) increases while sawing in Kleenzol B and in Kleen Kool solution decreases the size of the abrasive area. It was found that an applied negative potential also markedly decreases the size of this area.

The depth profiles of the number of defects obtained by the taper-sectioning method for 5.7 cm diameter wafers indicated that the number of defects drops markedly in the first 20 μm and remains at a constant low value to about 60 μm. In some cases the saw damage distribution can extend to 90 μm or more under the surface. It was found that sawing the 5.7 cm crystal in Kleenzol B and Kleen Kool solution decreases the number of cracks in the top 10 μm layer by about 20 % and 50 %, respectively, as compared to sawing in water. The dielectric oil increases the number of cracks by a factor of about 3 as compared to water in the first 10 μm,but the rest of the profile follows closely that of water. The applied positive potential noticeably increases the number of defects in the 15-30 μm range by a factor of about 2 and also maintains a higher amount of defect from 30 μm to the depth of 70 μm. On the other hand, the applied negative potential decreases the number by a factor of about 2 in the first 15 μm as compared to the zero potential case. In Table 2 the total numbers of defects counted between 2 and 100 μm from 10 optical micrographs, such as those shown in Figure 1, are listed for different environments. The numbers represent the total amount of defect underneath one line with length of 8.95 mm on the sawn wafer.

The sawing of a 8.3 cm crystal shows much less surface damage than that in a 5.7 cm crystal. The crack distribution profile usually extends to about 12 μm under the surface. Sawing large crystal in the Kleen Kool solution also results in less surface defects than sawing in water. The application of +6 V increases while -18 V decreases the number of defects by about 30 % in the Kleen Kool environment. The application of +18 V or -6 V has a negligible effect on the number of defects.

DISCUSSION

The depth of I.D. saw damage reported in the literature varies from 7 μm to more than 50 μm. The discrepancy is largely due to the differences in crystals, operational parameters, measurement methods, and the definitions of damage used in previous investigations. In this study the optical microscopy observation on etched taper-sectioned surfaces showed that the saw damage distribution can extend to 90 μm or more under the surface in 5.7 cm diameter wafers. Schwuttke has previously reported that some of the saw damage structures are so deeply ingrained in the crystal that they can affect the reliability of the finished MOS device even after 90 μm of material has been etched off from the wafer (5). The depth of damage fo·:d in 8.3 cm wafers is, however, only of the order of 10 μm, which is probably due to the smaller blade vibration in the sawing of larger wafers.

The depth of saw damage is determined by the length and direction (with respect to the cutting surface) of cracks propagating into the bulk from the blade edge. Those cracks propagating along directions nearly normal to the surface are mostly affected by the out-of-plane saw blade vibration which imparts on the Si wafer a force component normal to the sawing direction. This is evident from the correlation between the depth of saw mark and the thickness of the damaged layer observed in different environments.

Since the blade tension, feed rate, rotation speed and other mechanical conditions are the same in all the experiments, the change in saw blade vibration must be due to the effect of lubricant environment. However, the mechanisms involved in the modification of saw blade vibration is not clear at present. We can speculate that the blade deflection is different in different environments because the environments alter the hardness of the Si surface and/or the friction condition between the saw blade and the Si surface.

The Kleen Kool solution, Kleenzol B, and water are strong catalysts for breaking Si bonds and therefore could enhance crack nucleation at the blade edge and lower the Si hardness. Westwood and co-workers had shown that for covalent or ionic crystals in an electrolyte, the electrical influence of ionic species adsorbed at the surface can alter the dislocation mobility and near-surface fracture behavior (6). They found that the surface hardness is the greatest and the dislocation mobility is the least when the zeta potential is zero. It was suggested that the adsorbates induce redistribution of the carrier in the near surface regions which in turn affects the velocities of dislocation motion and crack propagation. The Kleen Kool solution and Kleenzol B are electrolytes. The dielectric oil molecule may decompose during the sawing and become an electrolyte. The applied -6 V would then enhance the adsorption of the cations and reduce the near-surface hardness. The applied +6 V may be sufficient to cause the desorption of the cations but not sufficient for the adsorption of the anions, which therefore increases the hardness.

Another possible mechanism is that the adsorbates can act as a lubricant layer between the blade and the Si surface and reduce the drag imparted to the saw blade. The applied positive or negative electrical potential then alters the amount or polarity of the adsorbed ions which in turn affects the frictional property of the Si surface.

CONCLUSION

Chemically active environments can influence the fracture process during the I.D. sawing of Si crystal. Our test results indicated that certain lubricant environments can reduce the sawing induced surface damage. The use of a lubricant which is also a strong catalyst for breaking Si bonds can effectively dampen the out-of-plane blade vibration and produce less surface damage. Applying an electrical potential of proper magnitude and polarity on the Si crystal during the sawing can also enhance the benificial chemomechanical effect of the environment. Our experimental data shows that at least a 50 % decrease in surface damage and a 30 % decrease in the depth of damage can be achieved by using a proper lubricant environment.

REFERENCES

(1) J.K. Howard, J. Regh, and G.H. Schwuttke, IBM TR 22.714 (1968).

(2) M.L. Joshi and J.K. Howard in "Silicon Device Processing", C.P. Marsden, Editor, p. 313-364, NBS Spec. Publ. No. 337, Gaithersburg, Maryland (1970).

(3) W.R. Runyan, "Silicon Semiconductor Technology", p.231, Mc-Graw Hill, New York (1965).

(4) R.L. Meek and M.C. Huffstutler, Jr., J. Electrochem. Soc., 116,893 (1969).

(5) G.H. Schwuttke, IBM TR 22.1588 (1973), TR 22.1692 (1973).

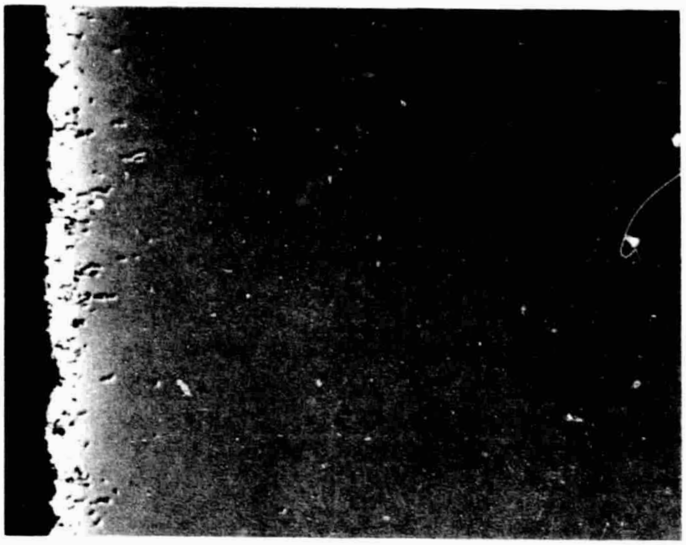
(6) A.R.C. Westwood, J. Mater. Sci., 9, 1871 (1974).

(7) P. Somasundaran and I.J. Lin, Ind. Eng. Chem. Process Res. Dev., 11, 321 (1972).

(8) T.S. Kuan, K.K. Shih, J.A. Van Vechten and W.A. Westdorp, J. Electrochem. Soc., 127, 1387 (1980).

(9) T.H. Irish, IBM TR 22.1933 (1975).

(a)



(b)

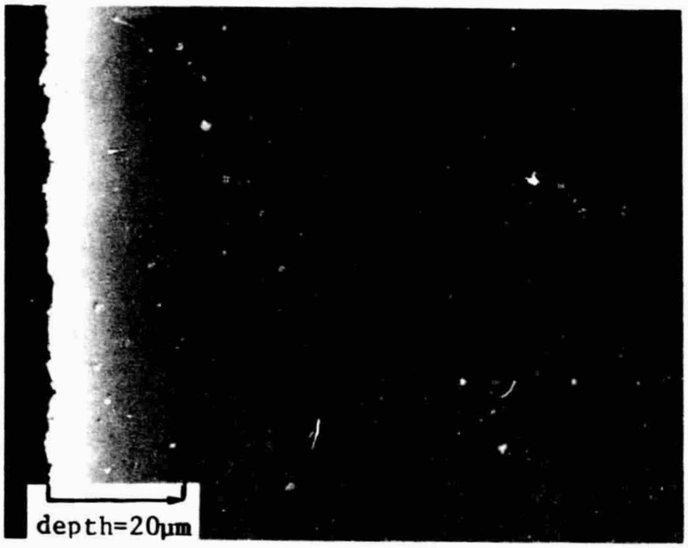


Figure 1 The beveled and etched sample section from wafer sawn in dielectric oil (a), and in Kleen Kool solution (b). The etch pits indicate the number and distribution of defects.

Table 1. Lubricant environments tested in the sawing of a 5.7 cm diameter crystal.

Experiment	Environments
1	Water
2	Solution of Kleen Kool in 80 parts water
3	Kleenzol B
4	Dielectric oil with no potential
5	Dielectric oil with +6 V on crystal
6	Dielectric oil with -6 V on crystal

Table 2. Thickness, warpage, and surface damage measurements on 5.7 cm diameter wafers sawn in the lubricant environments listed in Table 1.

Experiment	Average thickness	Average centerline warpage	Thickness of damaged layer	Total # of defects between 2 and 100 μm
1	602 μm	17 μm	60 μm	6.1×10^2
2	593	19	55	3.3×10^2
3	596	30	55	4.4×10^2
4	593	11	60	12.0×10^2
5	585	16	70	10.8×10^2
6	597	20	65	7.9×10^2

DISCUSSION:

LIU: You mentioned that the out-of-plane vibrations do have major affects on the depth of damage. Do you see any distribution changes of damage depth from the point of entrance, where you start cutting the wafer, to where you finish cutting the wafer? I would imagine that the out-of-plane vibrations would be different.

KUAN: Yes, that is a good point. All the data I show you is data obtained from the center of the wafer. Besides, we got a very good correlation between the surface observation which indicated the vibration amplitude and the depth of damage.

FRIZELL: The oil that you were using flashes at approximately 150^{o}F. Therefore, in the temperatures that you are working at, your oil loses its lubricating ability rather quickly. What you are getting with your results was the fact that nitrates are a very good cooling agent, that's true.

I want to know how you connect with the charge and what you think this accomplishes for you, I still don't see how it accomplishes anything.

KUAN: We apply the positive or negative potential on the crystal during the sawing, and what I tried to say is that the potential either changes the frictional property between the saw blade and the crystal surface or it changes the polarity of the ion so that it effects the chemomechanical effect.

FRIZELL: What ratio of these products did you use to water?

KUAN: In the Kleenzol B we just use it as an ideal solution. The KleenKool is a concentrated fluid and we dilute it with 80 parts water.

LANE: This dielectric oil, is it a commercial cutting fluid?

KUAN: Yes.