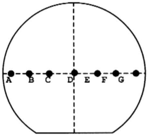
CHAPTER SIX : OISF DENSITY

6.1 Objective and Experimental

In this chapter, OISF densities on (111) and (100) wafers were compared. OISFs were formed under similar sand blasting, heat treatment and preferential etching conditions. Polished (100) and (111) wafers were sand blasted under moderate blasting condition, oxidized (1100°, 60 minutes, O_2), and followed by repeated referential etching. The OISF density was determined after every etching process by counting the number of OISF on wafer surface under an optical microscope (at 1000 times magnification), on pre-determined regions with a known surface area ($0.12cm^2$).

During etching, it was assumed that the surface removal rate was the same for both surfaces of silicon wafer. Thus the amount of material removed from a surface, which is the depth, is given by half of the difference in wafer thickness before and after etching. Seven regions on wafer ware chosen for OISF counting. These positions are indicated in Figure 6.1. The average OISF density for (100) and (111) wafers at different depths below the surface was recorded.



LABEL	POSITION / LOCATION
A	8mm from left edge
B	31.25mm from left edge
C	50mm from left edge
D	62.5mm from left edge
E	75mm from left edge
F	93.75mm from left edge
G	117mm from left edge

Figure 6.1 : Positions on 5" wafer for OISF counting after every preferential etching process.

Measurements were also carried out to determine the effect of different levels of sand blasting to OISF density for (100) and (111) wafers. In this case these wafers were subjected to similar oxidation and etching conditions before OISF counting. Positions at which the number of OISF was counted are same as those shown in Figure 6.1.

6.2 Results

6.2.1 OISF Density as a Function of Depth

The average of OISF density as a function of depth calculated was plotted in Figure 6.2. OISF density of both (100) and (111) wafers does not change with depth. OISF density for (100) and (111) wafers remained at 1200kpcs/cm^2 and 800kpcs/cm^2 respectively. For depth ranged from 1μm to 5μm, OISF density is much higher on (100) wafer compared to (111) wafer.

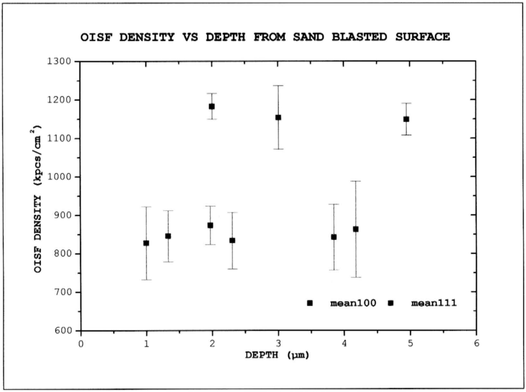


Figure 6.2 : OISF density Vs depth for (100) and (111) wafers (*Repeated Etching Technique, plotted are the average and ± standard deviation of OISF density*)

6.2.2 OISF Density as a Function of Blasting Pressure

The average of (100) and (111) wafers OISF density was plotted against blasting pressure (in arbitrary value) in Figure 6.3 below. For lower blasting pressure, OISF density for (100) wafer is greater than (111) wafer. Under these conditions, OISF density on (100) wafer is approximately double of OISF density on (111) wafer.

At higher pressure, OISF density on (100) wafer tends to saturate at about 1800kpcs/cm^2, however this was not shown by (111) wafer. No saturation trend was observed in Figure 6.3. for (111) wafer. Its OISF density continues to rise as pressure is increased until it overtakes (100) wafer OISF density at very high blasting pressure.

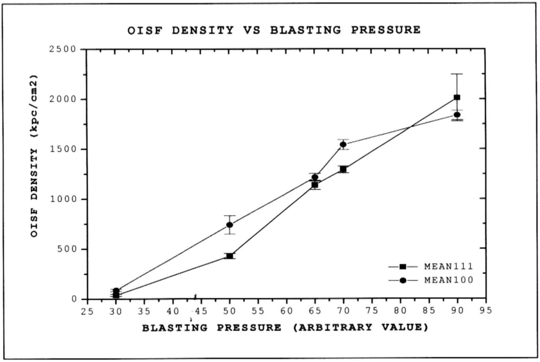


Figure 6.3 : OISF density as a function of sand blasting level.

When OISF density of (100) wafer was plotted against OISF density of (111) wafer blasted at the same condition *(Refer Figure 6.4)*, it is clearly showed that OISF density on (100) wafer is higher than on (111) wafer. At lower blasting pressure, data points were positioned above the x = y. This indicated that OISF density for (100) wafer was higher than (111)'s. Once pressure was increased to 90 (arbitrary value), the data point shifted below the y = x.

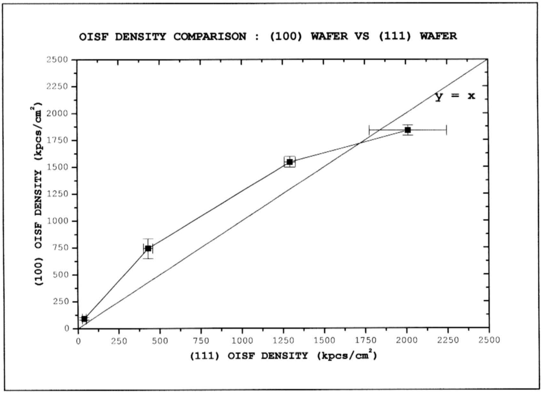


Figure 6.4 : OISF Density of (100) Wafer Vs OISF Density of (111) Wafer

6.3 Discussion

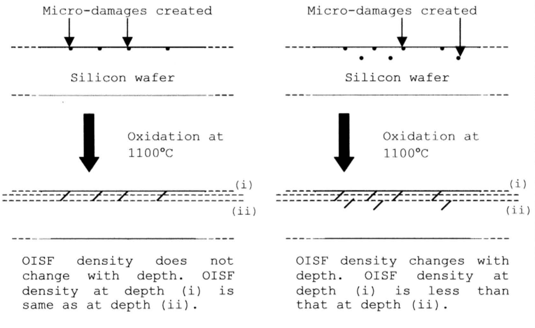
OISF density as a function of depth and blasting pressure was studied in this chapter. OISF density was found independent of depth but it was dependent of pressure used during sand blasting. During sand blasting process, surface atoms are exposed to sand blasting impact. If impact given by blasting pressure was too little, no surface micro-damage will be created.

OISF formed on mechanically damaged surface through heterogeneous nucleation process, hence surface micro-damages served as nucleation sites during oxidation. Due to its heterogeneous nucleation behavior, OISF will not present on wafer surface that does not contain surface micro-damage. The number of OISF formed depends on the amount of nucleation sites created during sand blasting process.

OISF density for both (100) and (111) wafers was found independent of depth. With this it was concluded that OISFs revealed by preferential etching are those nucleated at surface damaged sites. At the range of blasting pressures tested, no sub-surface region nucleation sites were created during sand blasting process because silicon atoms on wafer surface consist of dangling bonds. Compared to surface silicon atoms, sub-surface silicon atoms are fully bonded therefore energy required to displace surface atom is much lower for surface silicon atoms.

If surface and sub-surface micro-damages are created during sand blasting process, OISF will be formed started from both surface and subsurface region. When this wafer is etched after oxidation, at shallower depth, OISF density reflects the density of OISF formed at surface nucleation sites. When depth is increased through further etching, OISF density would increase due to OISFs formed at sub-surface nucleation sites were delineated as well. This scenario is clearly showed in Figure 6.5 (b).

If OISFs formed were predominantly at surface nucleation sites due to only very small quantity of sub-surface OISFs were formed then OISF density would remain constant when depth is increased (*Refer Figure 6.5(a)*). This explained the independence of OISF density to depth that was demonstrated by both (100) and (111) sand blasted wafers.



(a) (b)

Figure 6.5 : OISF density is independent of depth when OISF is nucleated only at surface nucleation sites.

OISF density is independent of depth but the dependence of OISF density on surface orientation [1, 2] is repeatedly observed in the results. OISF density when wafers were blasted at moderate blasting pressure is ~1200kpcs/cm^2 on (100) wafer and ~850kpcs/cm^2 on (111) wafer.

Crystal planes are distinguished from one another by their atom packing. Crystal planes with different atomic packing density are represented by different miller indices. Atomic packing density for (100) silicon wafer is lower than atomic packing density for (111) wafer. Silicon atom is bonded to four neighbouring atoms therefore bond length for all atoms are the same.

For {100} planes that are lower in atomic packing density, the distance between atoms on the same plane is further compared to {111} planes. This difference caused (100) wafer surface to be more vulnerable to mechanical impacts and chemical attacks compared to silicon atoms on the surface of (111) wafer [2]. Hence when (100) and (111) wafers were blasted under moderate conditions, OISF for (100) wafer is observed to be higher than (111) wafer's OISF density experimentally.

Hu [4] in one of his published paper commented the same phenomenon from the aspect of OISF formation mechanism in silicon wafer. According to him OISF density increases when interstitial silicon increases. The amount of interstitial silicon available for OISF formation is affected by the amount of surface kinks on wafer surface. Amount of surface kinks is crystal orientation dependent. It decreases with the order of (111), (110), and (100).

Surface kinks tend to capture the interstitial silicon produced during sand blasting, at SiO_2-Si interface during oxidation to form OISF. This phenomenon reduces the amount of interstitial silicon atoms available for OISF formation. Since surface kinks are more on (111) wafer compared to (100) wafer, less self-interstitial silicon atoms are available for OISF formation on (111) plane compared to (100) plane when blasting condition is moderate.

In the investigation of the impact of sand blasting pressure to OISF density, it was found that OISF density increases when blasting pressure increases. In the event of sand blasting process, impact given by blasting pressure to surface silicon atoms may displace silicon atom from their lattice sites to lattice interstice.

It is known that the amount of silicon atom displaced depends on the pressure used. When lower pressure is used, only small amount of silicon atoms can be displaced, as a result only small quantity of interstitial silicon is produced for OISF formation. Similarly higher pressure will displace more silicon atoms and OISF of higher density is produced after oxidation. When OISF density for (100) and (111) wafer is compared at different blasting pressures, lower blasting pressure gives higher OISF density for (100) wafer compared to (111) wafer however at higher blasting level, the reverse trend was observed.

A minimum energy is required to displace surface silicon atoms from wafer surface and this minimum energy required by (100) wafer is lower compared to (111) wafer. Lets represent the minimum energy required for atomic displacement for (100) and (111) wafer is E_{100} and E_{111} respectively and the blasting energy is E_{blast}.

The effective silicon atomic displacement energy for (100) is therefore proportional to (E_{blast}-E_{100}) while (E_{blast}-E_{111}) for (111) wafer. For the same E_{blast}, (E_{blast}-E_{100}) is always higher than (E_{blast}-E_{111}) due to E_{100} is smaller than E_{111}. This implies that for the same E_{blast} applied, where E_{blast} is more than E_{111}, effective energy available for atom displacement for (100) wafer is higher compared to (111) wafers.

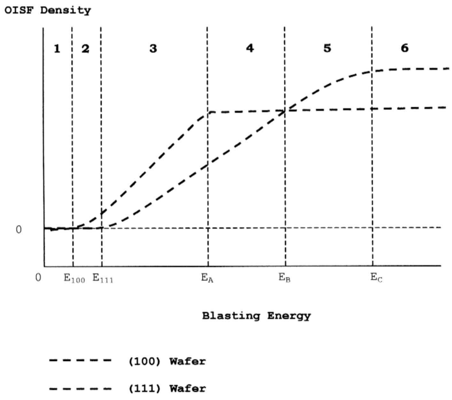


Figure 6.6 : Illustration of OISF density comparison between (100) and (111) wafers under different sand blasting energy.

At lower blasting pressure where E_{blast} is lower than both E_{100}, no silicon atom will be displaced for both (100) and (111) wafers therefore no OISF is observed. This blasting pressure region is shown as Zone 1 in Figure 6.6. At higher blasting pressure, indicated as Zone 2, E_{blast} is just between E_{100} and E_{111} therefore OISF only observed in (100) wafer.

At blasting energy higher than E_{111}, indicated by Zone 3 in Figure 6.6, OISF is observed in both types of wafers. Under this condition, OISF density increases with blasting pressure and OISF density for (100) wafer is always higher than (111) wafer's. This is due to the effective atomic displacement energy for both (100) and (111) wafers are only affected by silicon inter-atomic distance on their planes because blasting pressure is still low.

When blasting pressure is E_A, (100) wafer OISF density reached its saturation point. At this point, all displaceable surface atoms from (100) wafer surface were displaced due to the high blasting energy applied. However not all displaceable surface atoms on (111) wafers were displaced at blasting pressure E_A because the amount of displaceable atom for (111) wafer is more than those available on (100) wafer surface.

As blasting pressure increased to higher than E_A, surface atoms continue to be displaced from (111) wafer surface. Therefore saturation of (100) wafer OISF density was observed but (111) wafer OISF density is still increases with blasting pressure (*Zone 4 in Figure 6.6*). Further increase of blasting pressure increases OISF density for (111) wafer (*as in Zone 5*) until Zone 6 is reached where OISF density for (111) wafer is saturated. Range of blasting pressure studied lied within Zone 3 to Zone 5. This same trend was clearly seen in Figure 6.3.

To further prove the difference in OISF density and the difference in OISF depth between these two types of wafers, OISF depth and density were studied by wafer polishing technique. Sand blasted and oxidized wafers were cleaved and polished to different depths from sand blasted surface. OISF depth and density at different depth were studied. Depth studied ranged from 1μm to 9μm. OISFs on etched surface were counted under 1000x magnification by optical microscope.

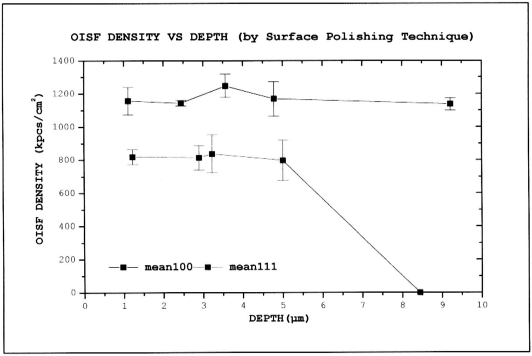


Figure 6.7 : OISF density as a function of depth (by surface polishing technique).

Consistent with results obtained in the study of the impact of depth to OISF density, by repeated etching technique (*Refer Figure 6.2*), OISF density at different depth (surface polishing method) was concluded to be independent of depth. In Figure 6.7, OISF density for (111) wafer dropped to zero at depth of 9μm (removal by polishing) while OISF density for (100) wafer remains constant at the same depth.

This technique is different from repeated etching technique. In repeated etching technique, OISF will not disappear because all delineated OISF will continue to be enlarged not removed. In contrary, surface-polishing technique removed silicon atom layer by layer. Since we had concluded that OISF formed on sand blasted wafer is at surface nucleation sites, if the removal of OISF is incomplete, OISF will be visible after preferential etching.

At certain depth where OISF layer was fully polished, no OISF will be left for delineation. At the depth of ~9μm, no OISF was observed on (111) wafer after etching but OISF density for (100) remains at ~1200kpc/cm^2. This indicates that the OISFs depth for (111) is deeper than OISF depth of (100) wafer.