B-3-4 STACKING FAULTS FROM OXIDE PRECIPITATES IN CZ SILICON

Hidetoshi Takaoka, Jiro Oosaka and Naohisa Inoue
Musashino Electrical Communication Laboratory,NTT,
Musashino -shi, Tokyo, 180 Japan

Many workers had paid special attention on behavior of oxygen in CZ silicon with respect to stacking fault(SF) formation during thermal oxidation process. We have controlled the concentration of oxide precipitates(OP's) and SF's by two step anneal in argon atmosphere and have investigated the role of oxygen on the generation and growth of bulk SF's in well defined specimens.

Figure 1 shows an example of the densities of OP's and SF's in two step annealed specimens versus first annealing temperature T_1. Oxygen content was 11×10^{17} atoms/cm^3 and the second annealing temperature T_2 was 1050°C in this case. The oxide precipitate density(OPD) was found to be definitely determined by the oxygen content and T_1 and to be generally highest when T_1 was 200 to300°C lower than T_2. This result suggests that there exist the critical nuclei[1)] for the onset of the growth of OP's on the second anneal and that the nuclei larger than the critical radius are introduced at the highest concentration when annealed at such T_1. The stacking fault density(SFD) shows the same temperature dependence as OPD, but the former is always two order of magnitude lower than the latter. Figure 2 shows a transmission electron micrograph of typical OP's and SF, the latter is always nucleated at a precipitate.

Stacking fault in bulk silicon is Frank interstitial type and the interstitial Si atoms had been surmised to be emitted from Si-O clusters.[2)] Oxide with the cristoballite structure is most likely to form in the silicon lattice because the arrangement of Si atoms in the structure is the same as that in the silicon crystal. Cristoballite contains 2.1×10^{22} of Si atoms and 4.2×10^{22} of O atoms in unit volume and silicon with the diamond structure contains 5.0×10^{22} of Si atoms per cm^3. If excess Si atoms are completely emitted from OP's without any residual strain, the ratio of interstitial Si atoms to precipitated O atoms becomes 0.67. The precipitated oxygen content O_p was obtained by IR measurement. Total number of the interstitial Si atoms gathered on SF's in unit volume, Si_i, was calculated as SFD x $(SFL)^2$ x N, where SFL is the diameter of circular stacking fault and N= 1.23×10^7 is the number of Si atoms introduced in an SF of 1μm in diameter. Experimental result is shown in TABLE I.

TABLE I Observed content of precipitated oxygen and interstitial silicon

No	1st anneal	O_p(at/cm^{-3})	2nd anneal	SFD(cm^{-3})	SFL(μm)	Si_i(at/cm^{-3})	Si_i/O_p
1	850°C 3hr	11×10^{17}	1050°C 2hr	7×10^9	2.2	4×10^{17}	0.4
2	750°C 210hr	9×10^{17}	1050°C 2hr	5×10^{10}	0.8	4×10^{17}	0.4

Well agreement was obtained between the observed Si_i/O_p values and the calculated one, 0.67.

The growth of SF's even in an inert ambient undergoes the complex process of the oxygen precipitation and the emission, diffusion and rearrangement of interstitial Si atoms. In a case where supersaturated O atoms are completely precipitated and the interstitial Si atoms are expected to be emitted already, the growth of SF's can be regarded as the simple process of the growth of two dimensional crystals in the supersatulated solution of the interstitial Si atoms. The number n of Si atoms supplied to the SF center by three dimensional diffusion is expected to follow a power law of $n \propto t^{3/2}$, where t is the annealing time. SFL is proportional to $n^{1/2}$, then must be proportional to $t^{3/4}$. The observed SFL follows the expected power law as shown in Fig.3. The agreement confirms that the diffusion of the interstitial Si atoms is the rate-determing step of the growth of bulk SF's. The diffusion coefficient of interstitial Si atoms was roughly estimated to be $10^{-11\sim-12}cm^2/sec.$, a few order of magnitude larger than that of self diffusion in silicon.

The growth termination at a certain diameter was found and considered to be due to the complete consumption of supersaturated interstitial Si atoms supplied from OP's.

Our results described above undoubtedly reveal that the oxygen precipitation plays an important role on both the nucleation and growth of bulk stacking faults in CZ silicon.

Reference

1) P.E.Freeland et al: Appl.Phys.Lett., 30 (1977) 31.

2) S.Mahajan, G.A.Rozgonyi and D.Brasen: ibid, 30 (1977) 73.

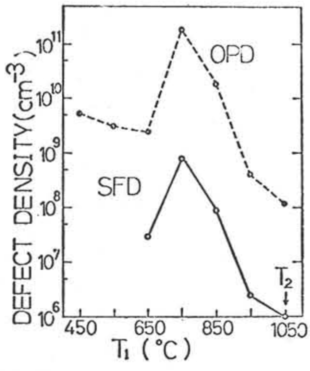

Fig.1. Oxide precipitate and bulk stacking fault density in two step annealed specimens. T_2 = 1050°C.

Fig.2. Oxide precipitates and a stacking fault from precipitate.

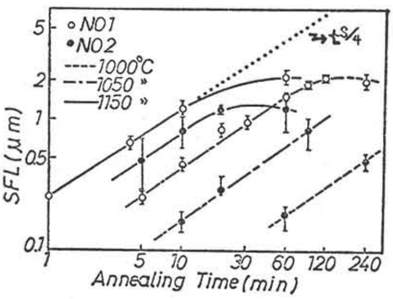

Fig.3. Time dependence of stacking fault diameter in specimens annealed at various T_2 in an inert ambient.