B-3-4 STACKING FAULUTS FROM OXIDE PRECIPITATES IN CZ SILICON
Hidetoshi Takaoka, Jiro Osaka and Nachisa 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 $1.1 \times 10^{17}$ atoms/cm$^3$ and the second annealing temperature $T_2$ was $1050^\circ$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 $200$ to $300^\circ$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 $2.1 \times 10^{22}$ of Si atoms and $4.2 \times 10^{22}$ of O atoms in unit volume and silicon with the diamond structure contains $5.0 \times 10^{22}$ 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 $SFD \times (SPL)^2 \times N$, where SPL is the diameter of circular stacking fault and $N=1.23 \times 10^7$ is the number of Si atoms introduced in an SF of 1 μm in diameter. Experimental result is shown in TABLE I.

<table>
<thead>
<tr>
<th>No</th>
<th>1st anneal</th>
<th>OP(at/cm$^3$)</th>
<th>2nd anneal</th>
<th>SFD(cm$^{-2}$)</th>
<th>SPL(μm)</th>
<th>Si$_i$(at/cm$^3$)</th>
<th>Si$_i$/O$_p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>850°C 3hr</td>
<td>$1.1 \times 10^{17}$</td>
<td>1050°C 2hr</td>
<td>$7 \times 10^9$</td>
<td>2.2</td>
<td>$4 \times 10^{17}$</td>
<td>0.4</td>
</tr>
<tr>
<td>2</td>
<td>750°C 210hr</td>
<td>$9 \times 10^{17}$</td>
<td>1050°C 2hr</td>
<td>$5 \times 10^{10}$</td>
<td>0.8</td>
<td>$4 \times 10^{17}$</td>
<td>0.4</td>
</tr>
</tbody>
</table>
Well agreement was obtained between the observed $\frac{Si_{i}}{O_{p}}$ 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 supersaturated 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 SF follows the expected power law as shown in Fig.3. The agreement confirms that the diffusion of the interstitial Si atoms is the rate-determining step of the growth of bulk SF's.

The diffusion coefficient of interstitial Si atoms was roughly estimated to be $10^{-11}$-$12$ 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