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Evolution of Extended Defects in High Temperature (T>1150°C) Oxidized SIMOX

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The evolution of extended defects during high temperature oxidation was investigated by means of transmission electron microscopy and defect etching. It has been observed that the main extended defects are oxidation induced stacking faults (OISFs). In the first stages of the oxidation process the OISFs grow continuously but after a critical time, which depends upon oxidation temperature, they start shrinking until they completely vanish. This process is probably attributed to the fast point defect recombination rate at the Si/SiO_2 interface.

1. Introduction

SIMOX (Separation by IMplanted OXygen) is one of the leading SOI technologies for fully depleted CMOS devices[1]. Standard SIMOX substrates having a silicon film thickness of about 2000-3000 Å and a buried oxide (BOX) layer thickness of 1000-4000 Å are produced by implanting a dose of 0.4-1.8x10^{18} O^+cm^{-2} at energies of 180-200 keV followed by an annealling at 1320-1350°C for 4-6 h in an argon rich ambient. Thinner silicon overlayers can be achieved by sacrificial oxidation of the top silicon overlayer. Although this method is very attractive due to its simplicity there have been several reports[2,3] which did show that oxidation induced stacking faults (OISFs) are formed during dry oxidation treatments in the temperature range of 900°C to 1150°C. The presence of OISFs in the active layer of SIMOX substrates has proven to be detrimental for device reliability[4] and therefore it is of the outmost importance to eliminate them. The aim of this paper is to investigate the formation and evolution of extended defects during dry oxidation of SIMOX substrates at temperatures higher than 1150°C.

2. Experimental Details

Two batches of 4 inch (001) silicon wafers were implanted using the NV-200 implanter at NTT laboratories. The first batch was implanted with a low oxygen dose (ϕ=4x$10^{17}O^+cm^{-2}$) at 180 keV while the second one was implanted with a high oxygen dose (ϕ=1.8x$10^{18}O^+cm^{-2}$) also at 180 keV. The samples were then annealed at 1350°C for 4 h in an Ar + 0.5% O_2 ambient. One SIMOX wafer of each batch was kept as reference to control the crystallographic defect density before oxidation. The thermal oxidation experiments were carried out at temperatures varying from 850°C to 1350°C for times ranging from 1.6 min to 40 h in a 100% oxygen ambient. Plan view transmission electron microscopy (PVTEM) and chemical defect etching[5] were used to determine the crystallographic defect density both before and after the thermal oxidation experiments. The length and density of the OISF were obtained by analysing a minimum of 10 optical micrographs from the surface of the defect etched samples. The PVTEM observations were carried out using the JEOL 100 CX microscope at NTT LSI labs. operated at 100 keV and using the 2 beam diffraction condition. The preparation of the PVTEM samples was carried out by dipping the SIMOX samples in a HF (50%) solution for several hours in order to 'peel off' the silicon overlayer. This preparation method was used to enable areas as large as 28 mm^2 to be analysed.

3. Results

Figure 1 a) and b) are PVTEM micrographs from low dose SIMOX samples oxidized for 15 and 25 min. at 1200°C. The PVTEM micrographs were taken using the g=[220] diffraction vector. Well delineated OISFs are clearly observed in both micrographs. The OISF length is respectively 6 µm and 12.5 µm for Fig. 1 a and b. Furthermore, the extrinsic nature of the OISFs, shown in Fig. 1, was characterized using the method proposed by Art et al[6]. In Fig. 1 the topography of the Si/SiO_2 interface is also apparent. It is observed that the Si/SiO_2 interface micro-roughness consist of a square-like 'mosaic' structure in close agreement with previous Atomic Force Microscopy (AFM) observations[7].

Figure 2 shows the dependence of the OISF length upon oxidation time for the low dose SIMOX samples oxidized at temperatures of 1175-1275°C. The OISF lengths were estimated by defect etching studies according to the procedure mentioned above. From Figure 2 we can clearly see that, for all temperatures except 1275°C, the OISFs grow continuously until a critical time is reached after which they start shrinking. At 1200°C the OISFs first grow and then rapidly shrink to values below our observation limit (L< 0.5 µm) for oxidation times of 1h20min. Retrogrowth of OISF was also observed at temperatures of 1190-1195°C although the OISF length did not decrease below our observation limit value. Similar results were also obtained for the high dose SIMOX samples.

Figure 3 shows the critical oxidation time (t_c) for OISF retrogrowth as function of the oxidation temperature.

It is observed that as the temperature increases t_c decreases. At 1275°C, retrogrowth of the OISF was not observed because the length of the OISF was already shorter than our observation limit even for oxidation times as short as 100 sec. This result suggests that the growth-retrogrowth process of OISF at T ≥ 1275°C may occur on the first minute of oxidation and therefore it would be very difficult to experimentally observe it.

Figure 4, shows the OISF density upon temperature for thermal oxidized SIMOX samples having a thermal oxide thickness equal or thicker than 2000 Å. It is observed that in the temperature range of 850°C-1125°C, the OISF density is almost independent of temperature for both the high and low dose SIMOX. However, for higher temperatures (i.e 1175°C-1275°C) the OISF density rapidly decreases with temperature until it reaches our observation limit ($\rho < 10\ cm^2$) for T ≥ 1200°C. This decrease in the OISF density is attributed to an uniform retrogrowth of the OISFs.

4. Discussion

Several models have already been reported to explain the retrogrowth of OISF in bulk silicon [8-10]. Although there are some differences in the approach taken by different authors the most accepted one is that retrogrowth of OISFs occurs at high temperatures (or long oxidation times) because the supersaturation of Si interstitials (or undersaturation of vacancies) is suppressed by point defect recombination[9]. A significant difference between bulk silicon and SIMOX is the presence of the buried oxide (BOX) layer which may act as a barrier for the migration of point defects[11] and it presumably leads to a large supersaturation of interstitials. However, our results have shown that despite the presence of the BOX layer the OISFs undergo a retrogrowth process at T≥ 1190°C.

This finding suggests that in SIMOX, point defects may rapidly reach their thermal equilibrium concentration. One explanation for this presumably low supersaturation of interstitials, is that the micro-roughness at the Si/BOX interface (see Fig. 1) may act as an effective sink for interstitials (or source for vacancies) and therefore enhances the recombination rate of point defects. This assumption is backed by a recent report on the oxidation enhanced diffusion (OED) of dopants in SIMOX[12], which showed that the effective recombination velocity at the Si/BOX interface is higher than the value for a thermal oxide interface. Another possible explanation is that for high oxidation temperatures vacancies are injected into the silicon substrate from the oxidizing interface. This hypothesis was first proposed by Francis and Dobson[13] for bulk silicon. If this process is active in SIMOX a large supersaturation of vacancies in the top Si layer would be established due to the presence of the BOX layer, leading to the shrinkage of extrinsic OISFs (see Fig. 5). In the near future, further work will be carried out to determine if this process is active in SIMOX.

5. Conclusions

In this paper we have reported on the retrogrowth process of OISF in SIMOX. We have shown that in SIMOX the retrogrowth process starts at temperatures as low as 1190°C for oxidation times of t = 2 h. Furthermore, we have also shown that for T ≥ 1200°C the OISF length decreases to values below our observation limit (i.e L < 0.5 μm) for t ≤ 1h20min. This retrogrowth process has been explained by the assumption that the point defect equilibrium concentration is rapidly reached due to the fast recombination rate at the Si/BOX interface and also by a possible vacancy injection during the high temperature oxidation temperature.

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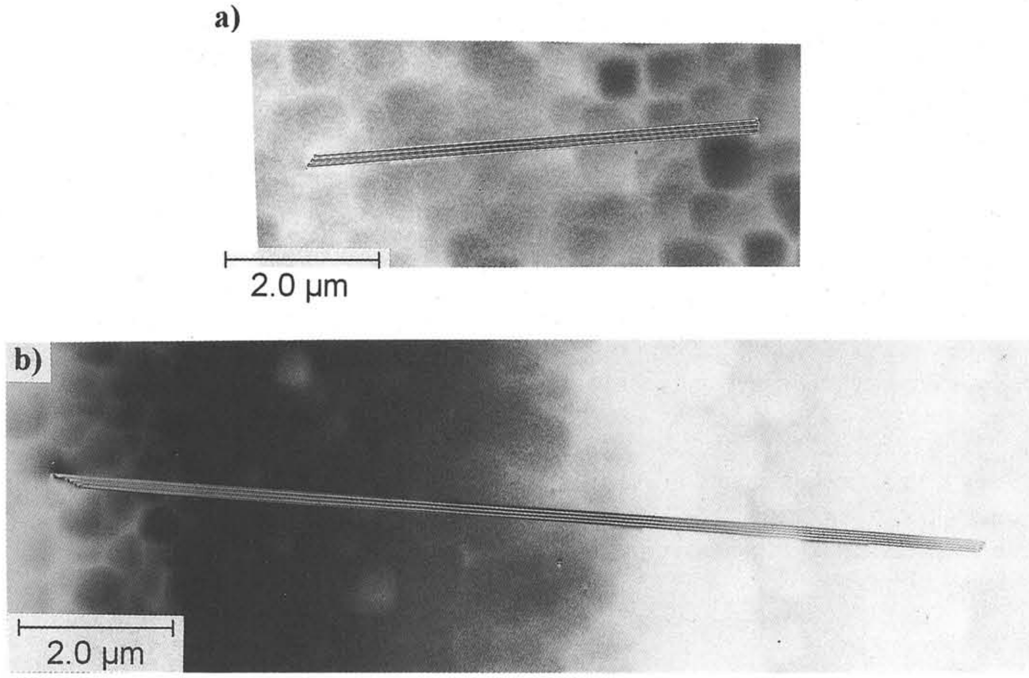

Fig. 1- PVTEM micrographs of samples oxidized for a) 15 min. and b) 25 min. at T =1200°C.

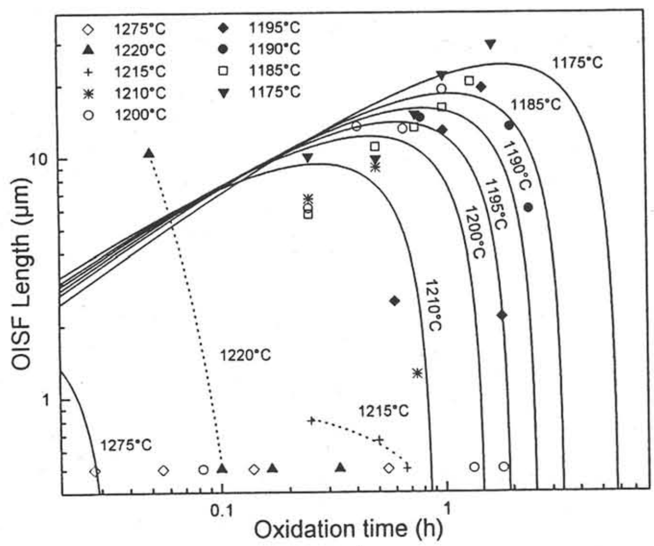

Fig. 2 - OISF length upon oxidation time.

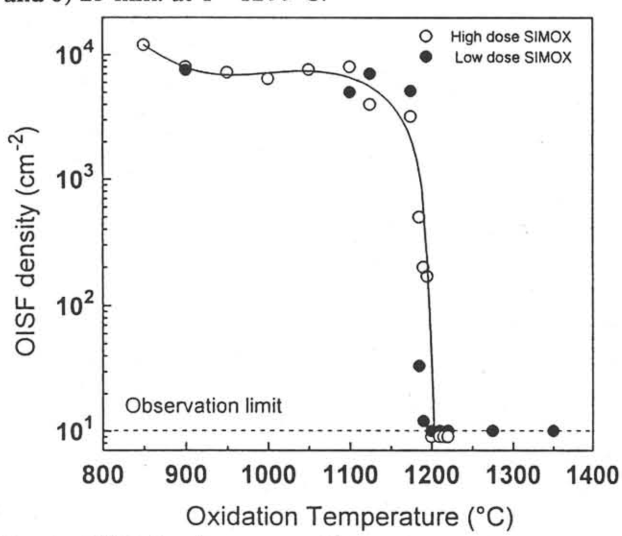

Fig. 4- OISF density upon oxidation temperature.

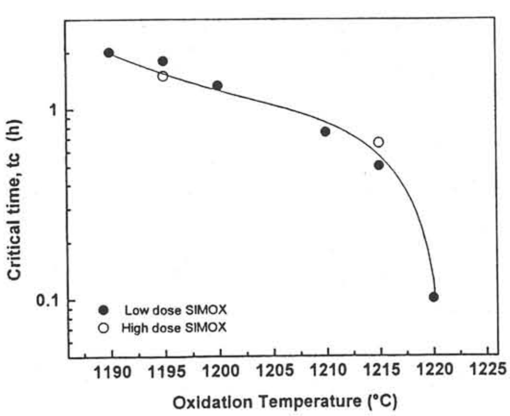

Fig. 3 - t_c dependence with oxidation temperature.

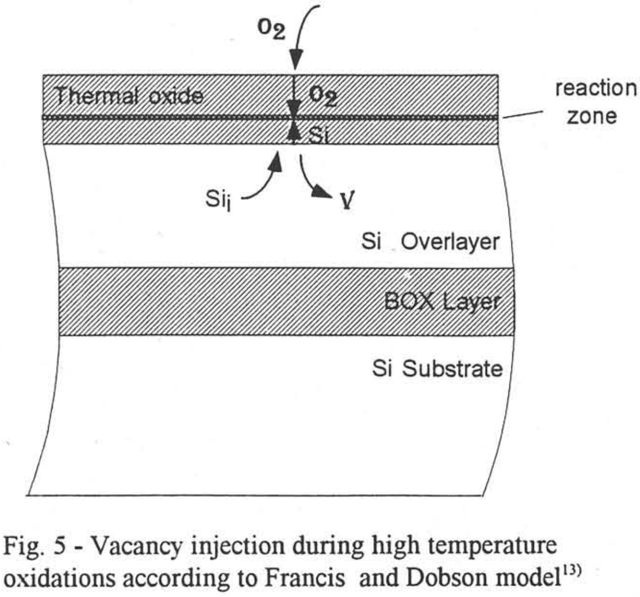

Fig. 5 - Vacancy injection during high temperature oxidations according to Francis and Dobson model[13)]