Effects of TCA Incorporation During Annealing Process on the Properties of Oxygen Ion Implanted Silicon Wafers

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ABSTRACT

The effects of TCA incorporation during annealing process on the SIMOX quality is studied. Silicon wafers are implanted with heavy dose of oxygen ions, and are annealed at 1300℃ for 4 hours. The annealing process is splitted into three conditions due to some differences of low temperature preliminary annealing step which are without pre-annealing step, with pre-annealing step, and TCA incorporated pre-annealing step. The specimens are analyzed by several methods, such as AES, XTEM, and TRXFA. TCA incorporation during pre-annealing step is effective in dislocation density reduction and heavy metal content reduction.

1. INTRODUCTION

SIMOX(separation by implanted oxygen) is one of the leading silicon-on-insulator(SOI) fabrication technology due to high crystal quality, uniform and reliable thin film SOI availability, and compatibilty to conventional silicon process1]. SIMOX fabrication process consists of deep oxygen ion implantation and post implantation annealing. During oxygen implantation, extraordinarily high dose of oxygen is needed to make complete buried oxide layer(BOX). And then many crystal defects are induced in surface silicon layer. They should be removed by appropriate annealing process. Although, there have been many research results of reducing the crystal defects and improving the SIMOX quality by improvement of implantation process and/or annealing process2-4], it leaves much to be improved to make use of SIMOX wafer as a

ULSI substrate. In this study, the effects of TCA(trichloroethane) incorporation during annealing step on the SIMOX quality is studied especially focusing on the reduction of dislocation density and heavy metal concentration which are the most typical defects of SIMOX.

2. EXPERIMENTS

The substrate used in this work is p-type, (100) crystal direction, FZ-grown Si wafer which has resistivity of 1000 ohm-cm. Oxygen implantation is carried out at a dose of $2\times10^{18}/cm^2$, energy of 180 keV. The substrate temperature is maintained at 550℃ during implantation. Post-implantation annealing is done at 1300℃ for 4 hours, but it is splitted into three conditions due to some differences in pre-annealing step. The first is high temperature annealing(HTA) only sample as 1300℃, 4 hours annealing in Ar plus 0.5% oxygen. The second condition has 1000℃, 1 hour pre-annealing step before main HTA in the same atmosphere of the first. In the third condition, temperature sequence is the same as the second one but 1000℃ pre-annealing step is done in TCA oxidation atmosphere. The oxygen depth profile is analyzed by Auger depth profile. The microstructures of the samples are investigated by XTEM(cross sectional transmission electron microscopy). And the heavy metal content is investigated by TRXFA(total reflectance x-ray fluorescent analysis).

3. RESULTS AND DISCUSSIONS

Fig. 1(a) shows the oxygen depth profile of the as implanted specimen. In the surface silicon layer, the oxygen concentration is much more than the value of solid solubility limit of oxygen in silicon. Therefore the excess oxygen will be precipitated. In the BOX region, oxygen concentration is saturated at the value of 67%, which is stoichiometric value of oxygen concentrations in the SiO_2, and then resulting oxygen concentration profile is flat topped gaussian profile. Excess oxygen atoms at the gaussian peak are diffused to silicon layer/BOX and BOX/substrate interfaces at the temperature of 550℃ during oxygen implantation. During the annealing process, the phenomenon of growth of large precipitates at the expense of smaller ones is happened, which is known as Ostwald ripening5]. At a given temperature, there exists the critical radius of precipitates which would be grown or dissolved. The size of critical radius is related with annealing temperature and oxygen concentration. And then, the annealing temperature and sequence is very important to fabricate the high quality SIMOX SOI. After high temperature annealing, there is no oxygen in the surface silicon layer within the sensitivity of AES system as shown in figure 1(b). The interfaces of surface silicon layer/BOX and BOX/substrate is sharpened. This shows that the annealing condition is sufficient to resolve all precipitates in the surface silicon layer.

Fig. 2 is cross sectional TEM micrograph. Fig. 2(a) shows the cross section of as implanted specimen. The surface silicon layer and the substrate adjacent to BOX is greatly damaged by oxygen implantation. And BOX layer is continuously formed. Fig. 2(b) shows the cross section of specimen which is annealed at 1300℃ for 4hrs. As can be seen, the thickness of surface silicon is reduced, but thickness of BOX is increased. The crystallinity of surface silicon is recovered and there is no oxide precipitates. This confirms the AES results that annealing condition of this experiment is sufficient to produce SIMOX SOI which has no oxide precipitates. But high density of threading dislocation is observed in surface silicon layer, These threading dislocation can be cause of gate oxide failure in MOS devices and leakage problem.

Although it is not revealed compeletely, some behaviors of the threading dislocations are known2-4]. The first, the agglomeration of the excess interstitial silicon atoms which is emmitted from oxide precipitation in surface silicon layer and from internal oxidation process at silicon layer/BOX interface during oxygen implantation and annealing. The second, the heavy metal atom can be cause of dislocation nucleus. Therefore we can believe that dislocation density can be reduced by reducing the interstitial silicon atoms and heavy metal content at initial state of annealing. On the basis of this hypothesis, we disigned the annealing sequences. The first, 1300℃, 4hrs HTA only standard annealing method. The second, we put the low temperature 1000℃, 1hr pre-annealing step as prior to HTA step to give the excess silicon atoms time to diffuse to the surface. The third, temperature sequence is the same as the second one, but 1000℃, 1hr pre-annealing step is done in TCA added oxidation atmosphere to reduce the heavy metal concentration by gettering process.

Fig. 3 shows the cross sections of the three samples for comparison of dislocation density. As can be seen, threading dislocation density is highest in the HTA only sample 3(a), medium in the pre-annealing plus HTA sample 3(b), lowest in the TCA oxidation pre-annealed sample 3(c). It is believed that pre-annealing step gives the exess interstitial si atoms time to diffuse to the surface which are believed to be the origin of dislocation. And TCA contained pre-annealing step is effective in reducing the threading dislocation density.

Fig. 4 shows the TRXFA results to analyze the heavy metal content. As can be seen, there is lower metal density in the TCA oxidation pre-annealed sample than no TCA pre-annealed specimen. This confirms that TCA contained pre-annealing step is effective to reduce the metal content and consequently effective to reduce the dislocation density.

4. CONCLUSIONS

We investigated the effects of TCA incorporation during annealing process on the properties of SIMOX wafers. Silicon wafer is implanted with high dose of oxygen and annealed under several conditions. The annealing condition dependence of SIMOX properties are investigated. Incorporation of TCA during pre-annealing step is effective in heavy metal content reduction by gettering process, and consequently effective to reduce the dislocation density.

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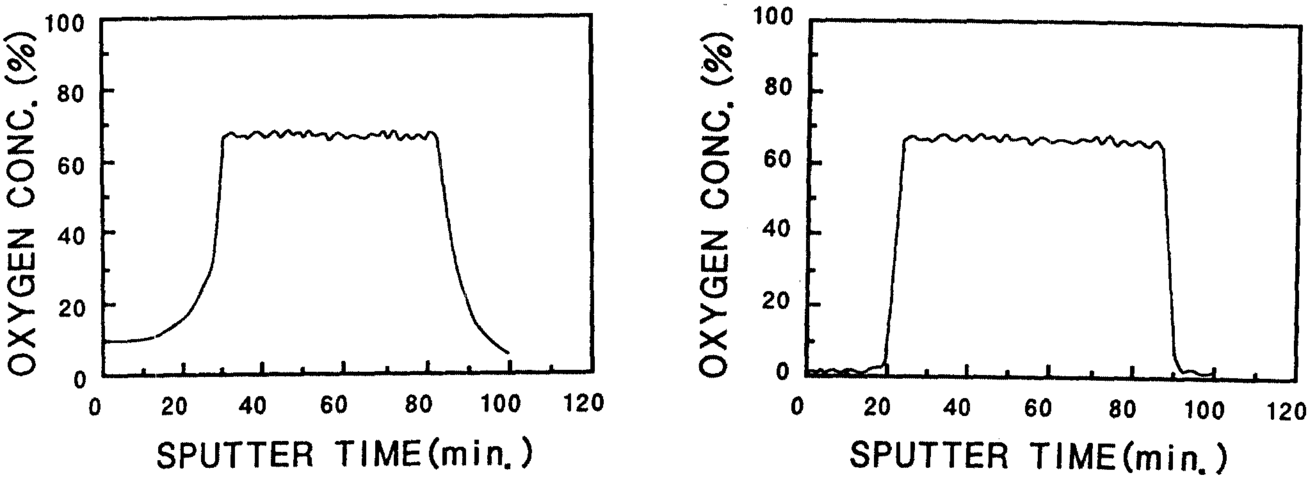
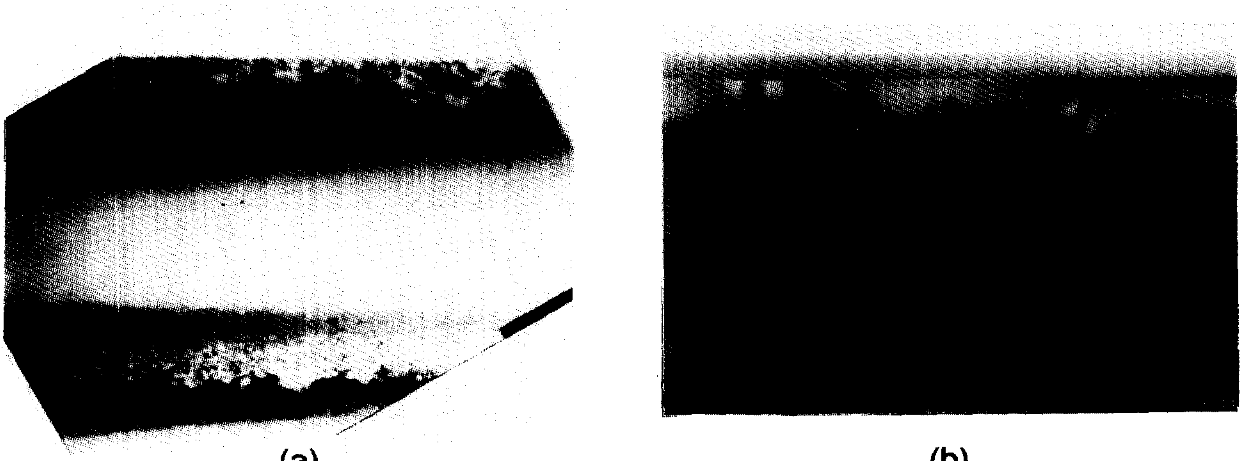


(a) (b)

Fig. 1. AES depth profile of oxygen concentration.
(a) as implanted specimen (b) 1300℃, 4hrs annealed specimen



(a) (b)

Fig. 2. Cross sectional TEM micrographs
(a) as implanted specimen (b) 1300℃, 4hrs annealed specimen

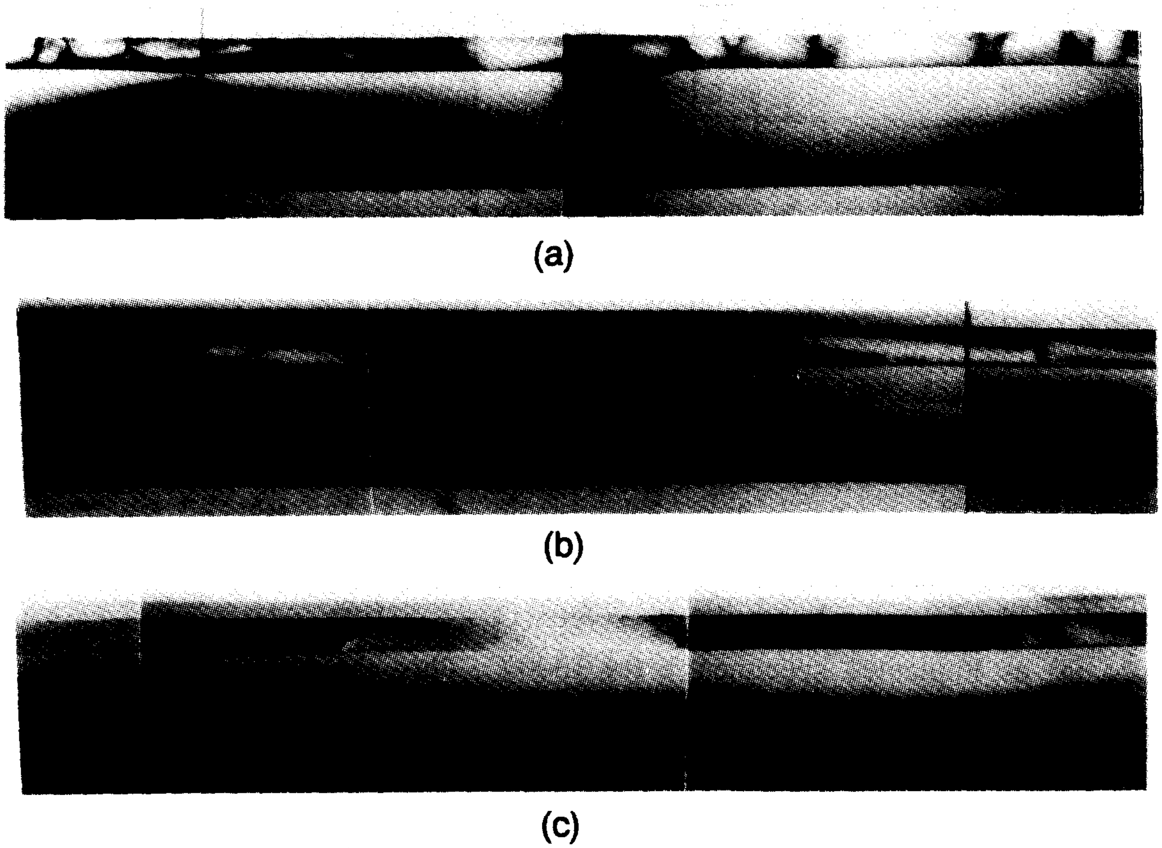


Fig. 3. Cross sectional TEM micrographs.
(a) HTA only. (1300℃, 4 hrs in Ar/O₂)
(b) 1000℃, 1 hr pre-annealing + HTA.
(c) 1000℃, 1 hr pre-annealing in O₂/TCA + HTA.

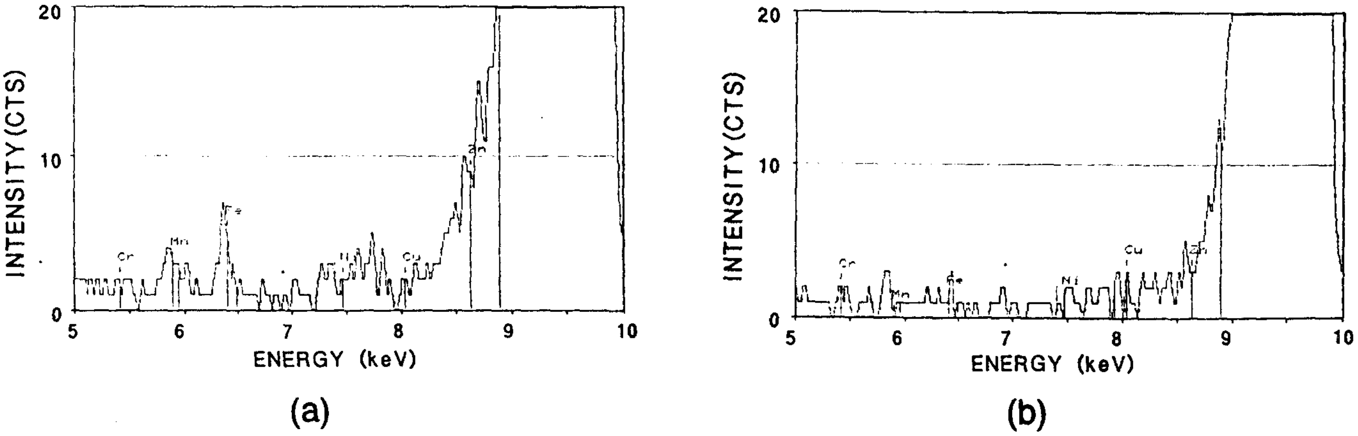


Fig. 4. TRXFA analysis
(a) No TCA pre-annealing + HTA.
(b) TCA pre-annealing + HTA.