

## C-3-2

# Novel SOI Fabrication Process by Light Ion Implantation and Annealing in Oxygen Including Atmosphere

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## 1. Introduction

A Si-on-insulator (SOI) substrate enables CMOS devices to be miniaturized beyond the bulk-device limitation. Separation by implanted oxygen (SIMOX) is one of the promising techniques for SOI fabrication. However, the  $O^+$  implantation introduces extremely high damage in Si substrates, therefore causing high-density defect generation in the SOI substrate even after high-temperature annealing [1-3]. On the other hand, we have found that the atmospheric oxygen can contribute to BOX formation, and we predicted the possibility of the eliminating  $O^+$  implantation from the SIMOX process by enhancing atmospheric oxygen precipitation at the controlled depth [4-6].

In this paper, we present a novel SOI fabrication process consisting of light ion implantation and annealing in an oxygen including atmosphere.

## 2. Experiment

The concept of the novel SOI fabrication process is illustrated in Fig. 1. In the process, crystalline defects are introduced at the controlled depth in the Si

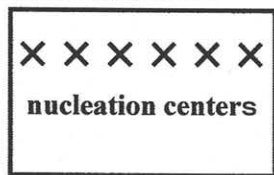
substrate in order to create the nucleation centers for oxygen precipitation [Fig. 1(a)]. The sample is then annealed in the  $Ar/O_2$  atmosphere to enhance the oxygen precipitation. The precipitates also grew and coalesced during the annealing [Fig. 1(b)]. Complete SOI structure with a continuous buried oxide (BOX) layer may appear after the annealing [Fig. 1(c)].

In the present study, we implanted  $H^+$  and  $He^+$  ions for the defect formation process. Nakashima *et al.*, demonstrated that the damage induced by the light ion implantation acts as an efficient nucleation centers for the oxygen precipitation [7]. The implantation conditions were 45 KeV acceleration voltage for both ions, and  $5 \times 10^{16}/cm^2$  and  $1-5 \times 10^{17}/cm^2$  doses for  $H^+$  and  $He^+$ , respectively. Then the samples were annealed at  $1340^\circ C$  for four hours in  $Ar/O_2$  atmosphere at a ramping rate of  $0.02$  to  $0.1^\circ C/min$  from  $1200$  to  $1340^\circ C$ , and at an  $Ar/O_2$  ratio of  $100/6-20$ . The fabricated structures were evaluated by cross-sectional TEM.

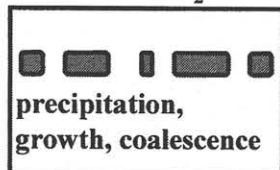
## 3. Results and discussion

The annealed surface of the  $H^+$  implanted sample was partially exfoliated probably because of the internal hydrogen pressure. However, the TEM observation revealed that the oxygen precipitation also occurred in several places at the depth of  $H^+$  implantation damage [Fig. 2(a)]. Moreover, the complete SOI structure with a BOX layer was also fabricated in some places [Fig. 2(b)]. Although the fabricated structure was not uniform, we verified that the implantation damage could act as nucleation centers for the oxygen precipitation, and a SOI

(a) Defect formation



(b) Anneal ( $Ar/O_2$ )



(c) SOI formation?

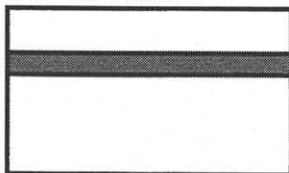


Fig. 1 Concept of novel SOI fabrication process.

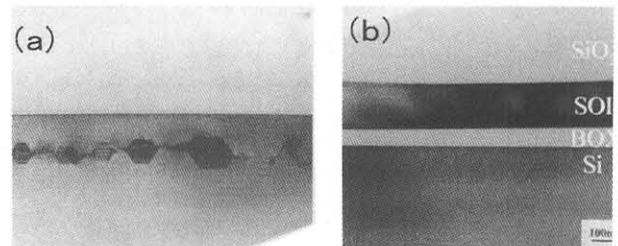


Fig. 2 Structures obtained by  $H^+$  implantation and annealing.

structure could be partially fabricated with this process. It is well known that H atoms easily react with Si dangling bonds. So the chemical reaction of H with damaged Si might enhance the inhomogeneous precipitation and caused the non-uniform structure. The rapid diffusion of H in Si might also enhance the nonuniformity of the structure.

The structures obtained by  $\text{He}^+$  implantation and annealing were quite uniform unlike the case of  $\text{H}^+$  implantation, and showed strong dependence on the annealing conditions such as ramping rate and oxygen concentration in the atmosphere. Figure 3 shows the TEM images for  $\text{He}^+$  dose of  $1 \times 10^{17}/\text{cm}^2$  samples after annealing at a ramping rate of  $0.1^\circ\text{C}/\text{min}$  [Fig. 3(a)] and  $0.02^\circ\text{C}/\text{min}$  [Fig. 3(b)], respectively. The  $\text{Ar}/\text{O}_2$  ratios were also varied as 100/20 for Fig. 3(a) and 100/6 for Fig. 3(b) so that the surface oxide had almost the same thickness. The oxygen precipitation apparently occurred at the damage induced by the  $\text{He}^+$  implantation, and the precipitates became larger with decreasing ramping rate. The precipitates probably grew and coalesced during the slow-ramping-rate annealing. It is well known that the minimum size of the oxygen precipitates in Si depends on the temperature, and is larger at higher temperature. Therefore, it can be thought that the slow ramping rate helped small precipitates to grow larger than the minimum size as the temperature rose [4].

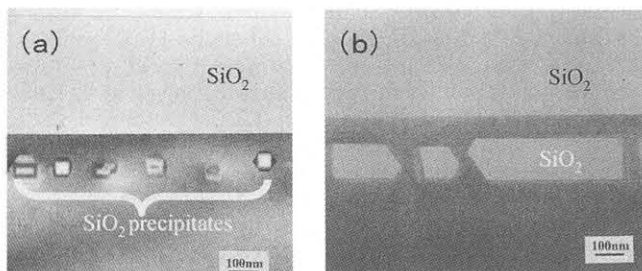


Fig. 3 Structures obtained by  $\text{He}^+$  implantation and annealing.

Further decrease of the ramping rate for the  $1 \times 10^{17}/\text{cm}^2$  dose sample did not produce a continuous BOX. Therefore, we increased the  $\text{He}^+$  implantation dose with anticipating the increment of the nucleation center density introduced by the implantation damage. As a result, a complete SOI structure with a continuous BOX layer was obtained with  $\text{He}^+$  dose of  $4 \times 10^{17}/\text{cm}^2$  as shown in Fig. 4.

We eventually succeeded to demonstrate a novel SOI fabrication process formed simply by light ion implantation and annealing. Comparing to the conventional SIMOX, this technique replaces the  $\text{O}^+$  implantation by light ion implantation. The implantation damage therefore is much smaller. The Si surface after the implantation remained as a single

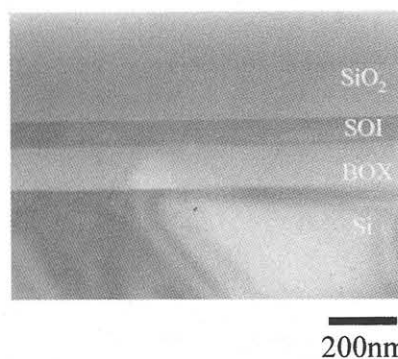


Fig. 4 SOI structure obtained by  $\text{He}^+$  implantation and annealing.

crystal even though the implantation was carried out at room temperature, while the substrate is usually kept around  $600^\circ\text{C}$  during  $\text{O}^+$  implantation in the conventional SIMOX to keep the surface as a single crystal. This small damage process definitely provides a good effect on a crystal quality, i.e. low defect density. The room temperature implantation may give an advantage of low cost process. Light ions may be easier to control the implantation profile by changing implantation energy, therefore provides a flexible control of the SOI structures.

#### 4. Summary

We have developed a novel SOI fabrication technique in which light ions such as  $\text{H}^+$  and  $\text{He}^+$  are implanted into a Si substrate (in place of  $\text{O}^+$  implantation in the SIMOX process). A continuous BOX layer was formed by oxygen precipitation at the implantation damage during annealing in an oxygen including atmosphere. This process potentially provides a less damaged SOI structure compared to the conventional SIMOX.

#### Acknowledgement

The authors thank Dr. Y. Mochiduki and Dr. M. Fukuma for their continuous encouragement.

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