

Improvement of Oxidation-Induced Ge Condensation Method by H^+ Implantation and Two-Step Annealing for Highly Stress-Relaxed SGOI

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1. Introduction

Formation of highly stress-relaxed $c\text{-Si}_{1-x}\text{Ge}_x$ buffer layers on insulator (SGOI) is a key process to establish the strained Si technology for the advanced CMOS [1,2]. The oxidation-induced Ge condensation process of $c\text{-Si}_{1-x}\text{Ge}_x/\text{Si}$ on insulator (SOI) structures is one of the most promising techniques to form ultrathin SGOI for realization of fully depleted devices [3]. However, completely relaxed SGOI is hard to be obtained because of stiff bonding at $c\text{-Si}_{1-x}\text{Ge}_x/\text{buried SiO}_2$ (BOX) interfaces. Implantation of H atoms to Si/BOX interfaces will break the interface bonding between Si-O [4], which is expected to enhance the stress-relaxation during oxidation. In the present study, effects of H^+ implantation and post-annealing on the stress relaxation of SGOI during the oxidation process have been investigated.

2. Experimental Procedure

The $c\text{-Si}_{0.85}\text{Ge}_{0.15}$ layers (thickness: 55nm) were grown by CVD on SOI wafers (top Si thickness: 55nm). These samples were implanted with H^+ ions (energy: 8.1keV, dose: $0\text{-}5 \times 10^{16}\text{cm}^{-2}$) and subsequently oxidized at 1100°C . The ion energy was selected so that the projected range of H^+ ions matched to the top Si/BOX interfaces. The formed SGOI were evaluated by Raman spectroscopy, scanning electron microscopy (SEM), and transmission electron microscopy (TEM). The concentration profiles of Si, Ge, and H atoms were obtained by Auger electron spectroscopy (AES) and secondary-ion mass spectroscopy (SIMS).

3. Results and Discussion

Raman spectra for samples oxidized for 120min are shown in Fig.1(a). For the samples without and with low-dose ($5 \times 10^{14}\text{cm}^{-2}$) implantation, two weak peaks due to Si-Ge and Si-Si bonds in $c\text{-Si}_{1-x}\text{Ge}_x$ were observed at 410 and 500cm^{-1} , respectively. The strong peak at 520cm^{-1} is due to the c-Si substrate, which is neglected in the following discussions. When high-dose ($5 \times 10^{16}\text{cm}^{-2}$) implantation was performed, the position of the peak due to Si-Si bonds shifted to lower frequency. In addition, the peaks due to Si-Ge bonds became large, and the peak due to Ge-Ge bonds appeared at 300cm^{-1} . These results suggest that both the stress relaxation rate and Ge fraction in the formed $c\text{-Si}_{1-x}\text{Ge}_x$ layers increase with increasing dose. In order to examine such phenomena, the Ge fraction and thickness of the $c\text{-Si}_{1-x}\text{Ge}_x$ layers was evaluated by AES and cross sectional SEM, respectively. The results are summarized in

Fig.1(b). The thickness decreases, and Ge fraction increases with dose, which clearly demonstrates that oxidation was enhanced by H^+ implantation.

The enhanced oxidation should be suppressed to clarify the effect of H^+ implantation on stress-relaxation. Radiation-induced damage, which is the main cause of the enhanced oxidation, can be removed by high-temperature ($>800^\circ\text{C}$) annealing. However, the H atoms necessary to break interface bonding (Si-O) can also be removed by high-temperature annealing. Bruel et al. reported that wafer splitting can be accomplished by medium-temperature ($400\text{-}600^\circ\text{C}$) annealing after H^+ implantation [4]. By referring these data, we investigate the windows between these two processes. Change of H concentration profiles after medium and high temperature annealing (500°C for 30min and 850°C for 60min) were evaluated by SIMS, and shown in Fig.2, together with the profile before annealing obtained by the TRIM simulation. The H concentration at the Si/BOX interface after annealing at 500°C was almost identical to that before annealing. After annealing at 850°C , the H concentration significantly decreased and became under the detection limit in the Si/ $c\text{-Si}_{1-x}\text{Ge}_x$ /Si layers.

These results triggered an idea of two-step annealing: medium-temperature (500°C) annealing to break the interface bonding between Si and BOX and high-temperature (850°C) annealing to remove radiation damage. New processing steps of H^+ implantation, two-step annealing, and oxidation-induced Ge condensation are schematically shown in Fig. 3. The stress relaxation rate and Ge fraction obtained by this new processing (oxidation at 1100°C for 110 and 120min) were summarized in Figs.4(a) and 4(b), respectively. The relaxation rate abruptly increases for doses above $1 \times 10^{15}\text{cm}^{-2}$. On the other hand, the Ge fraction is almost a constant value of 45% (110min) or 52% (120min). These results demonstrate that combination of H^+ implantation and two-step annealing enhanced stress-relaxation in the SGOI layers during oxidation-induced Ge condensation process.

The crystallinity of SGOI was investigated by cross-sectional TEM. The results for samples without and with H^+ implantation ($5 \times 10^{16}\text{cm}^{-2}$) are shown in Figs.5(a) and 5(b), respectively. For the implanted samples, no additional defects by implantation were detected. In addition, a very smooth $c\text{-Si}_{1-x}\text{Ge}_x/\text{BOX}$ interface was observed, though the no-implanted sample showed a zigzag interface. These results will support that H^+ implantation realizes uniform gliding of $c\text{-Si}_{1-x}\text{Ge}_x$ layers on BOX during the oxidation process.

4. Summary

The effects of H^+ implantation on the stress relaxation of SGOI were investigated. The stress-relaxation during oxidation-induced Ge condensation process was remarkably enhanced by combination of high dose ($>10^{15} \text{cm}^{-2}$) H^+ implantation and two-step annealing. This newly developed technique will be a powerful tool to fabricate highly stress-relaxed SGOI for advanced strained Si-MOSFET.

References

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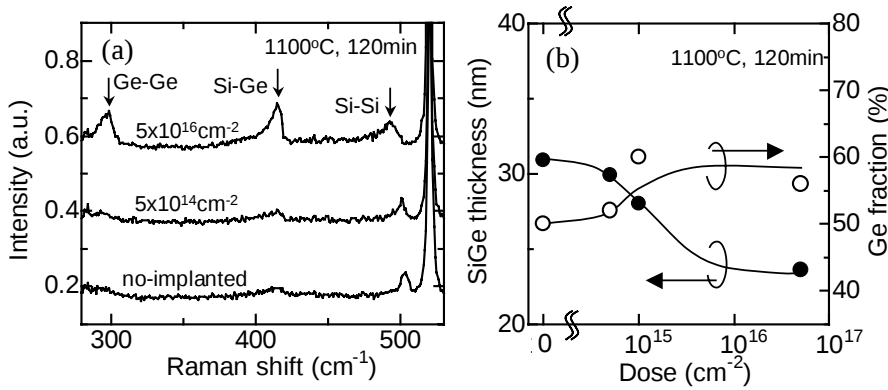


Fig.1 Raman spectra (a) and thickness and Ge fraction of SGOI (b) as a function of H^+ dose for samples oxidized at 1100°C for 120 min.

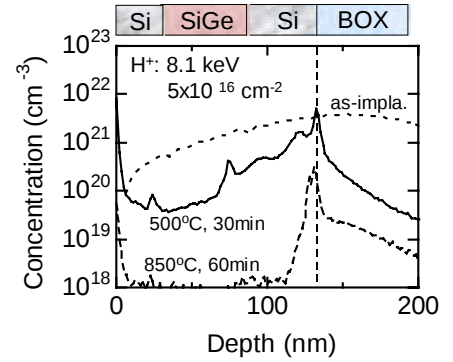


Fig.2 Concentration profiles of H atoms before and after annealing (500°C for 30min, 850°C for 60min).

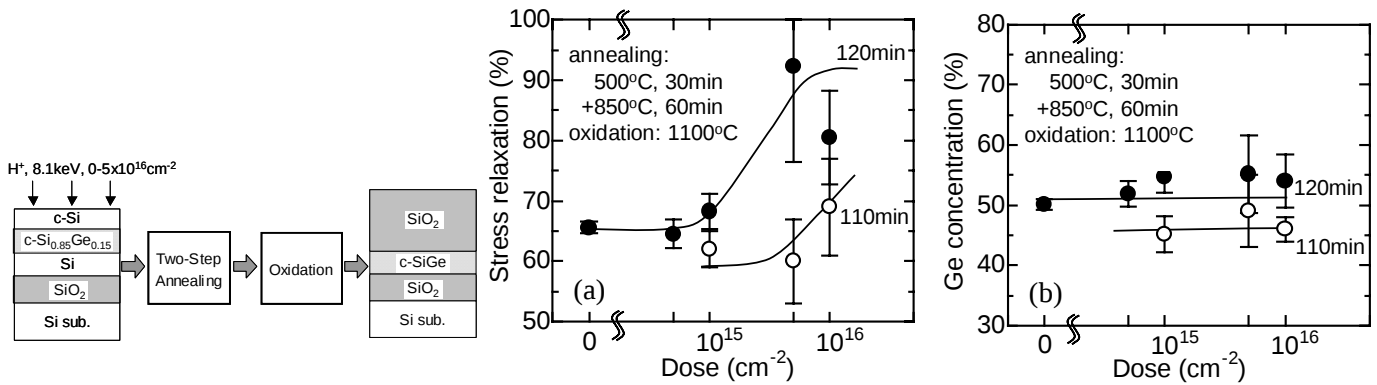


Fig.3 Schematics of H^+ implantation, two-step annealing, and oxidation-induced Ge condensation process.

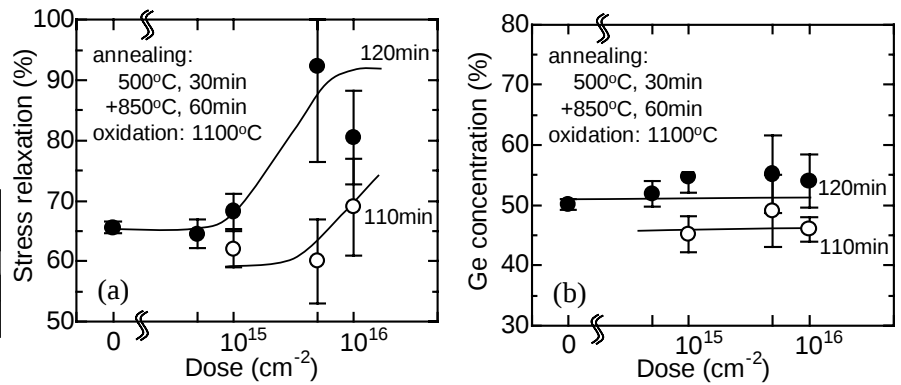


Fig.4 Stress relaxation rate (a) and Ge fraction (b) for samples after two-step annealing (1st: 500°C for 30min, 2nd: 850°C for 60min) and subsequent oxidation (1100°C for 110 and 120min).

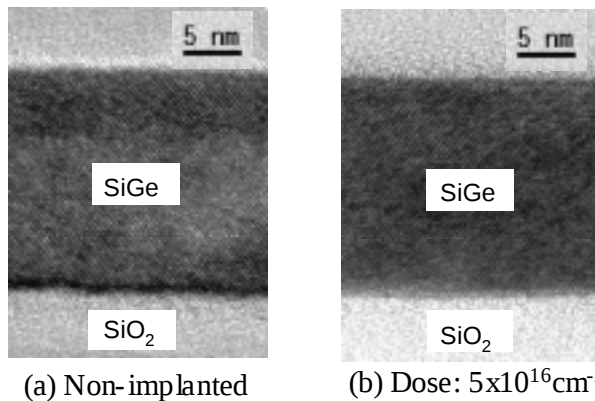


Fig.5 Cross sectional TEM images for oxidized samples (1100°C , 120 min) without (a) and with H^+ implantation (8.1 keV , $5 \times 10^{16} \text{cm}^{-2}$) (b).