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Investigation of Relaxed SiGe on Insulator and Strained Si

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Abstract

Strained silicon on insulator combines the advantages of strained silicon and SOI and becomes one of important materials in future circuit. In this paper, strained silicon was grown on fully relaxed SGOI substrate fabricated by Ge condensation technology. Raman and TEM results indicate that good quality strained silicon with the ε about 1.8% has formed on the relaxed SGOI substrate.

1. Introduction

With the scaling of ultra-large integrated circuits, materials and process on bulk silicon are approaching their physical limit. Strained silicon is considered to be the solutions for electronic devices with nano feature size because of its high mobility.[1] Now it has been used in 90nm process node for greater digital circuit performance. Circuits fabricated on SOI substrates benefit from decreased operating voltage, low power consumption, higher radiation and temperature tolerance, and device scaling.[2] Tensile-strained silicon on insulator combines the performance of SOI and the mobility enhancement in strained silicon. [3-5] For partially depleted SOI device architectures, relaxed SiGe on insulator, with a tensile-strained silicon layer on top, [6-8] can boost circuit performance by up to 30%. To obtain tensile strained Si, SiGe on insulator (SGOI) is a key substrate.

Several approaches have been reported for the fabrication of SGOI including Separation by Implantation of Oxygen (SIMOX), [9] and Smart-cut [10]. For the growth of strained silicon, SGOI with high Ge content is needed. Although two step annealing can reduce the diffusion of Ge, it is still difficult to get SGOI with the Ge content larger than 10%. [11] As for Smart-cut technology, thick SiGe buffer layers should be needed. Recently, a new SGOI fabrication technique based on Ge condensation by oxidation of the SiGe layer was studied. [12,13] In this method, a SOI substrate with an epitaxial SiGe is thermally oxidized at a high temperature. During oxidation, Si atoms are more reactive than Ge atoms due to the lower free energy of formation of SiO_2 than that of GeO_2. Therefore, Ge atoms are rejected from the SiGe-oxide layer and then the interface disappears between the SiGe and SOI layers. Since diffusion is blocked by the buried oxide (BOX), Ge atoms are confined in the SiGe layer sandwiched between the two oxide layers. As oxidation proceeds, the average Ge fraction in the SiGe layer increases with decreasing SiGe layer thickness.

In this paper, SGOI was fabricated by Ge condensation technology, and then strained silicon was grown on it. Material structures and strain were characterized by Raman and TEM.

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2. Experiment

Ultra-thin SOI with a 45-nm-thick top Si layer were loaded into an ultra-high vacuum chemical vapor deposition (UHVCVD) system. A 100nm layer with a uniform Ge composition of 15% was grown on the ultra-thin SOI substrate using SiH_4 and GeH_4 precursors at 550°C. In order to avoid the formation of GeO_2, mixed $(Si,Ge)O_2$, or SiO_2–GeO_2 during the subsequent processes, GeH_4 was shut off and an additional Si cap about 8-nm thick was deposited on top of the SiGe layer as a modify of the Ge condensation technique. The samples were oxidized for 1-2 h at 1150°C in oxygen ambient. After the removal of top silicon oxide, strained silicon layer with the thickness about 18nm were grown on SGOI.

The degree of strain relaxation in the oxidized samples and the strain in top silicon was assessed by Raman spectroscopy. The structures and crystalline quality were also studied using transmission electron microscopy (TEM).

3. Results and discussion

Figure 1 shows the microstructure of SiGe film

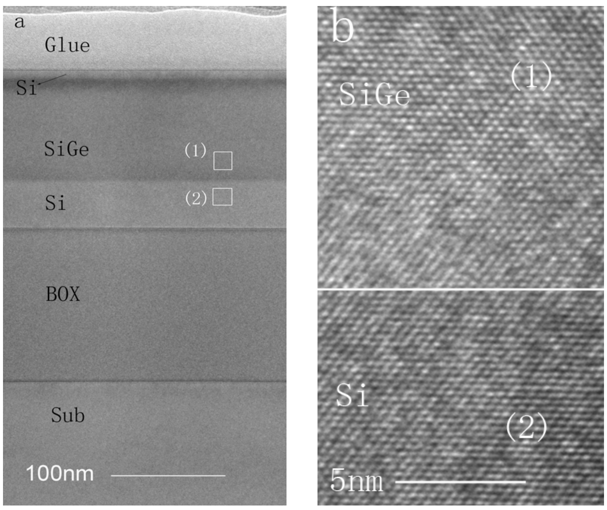

Fig.1 High resolution TEM image of SiGe grown on SOI substrate

grown on SOI. From the high resolution image it can be seen that the quality of SiGe is really good.

Figure 2 depict the cross-sectional TEM images of the samples oxidized for 2 h. The images exhibit nice and sharp SiO_2/SiGe/SiO_2 sandwiched structures.

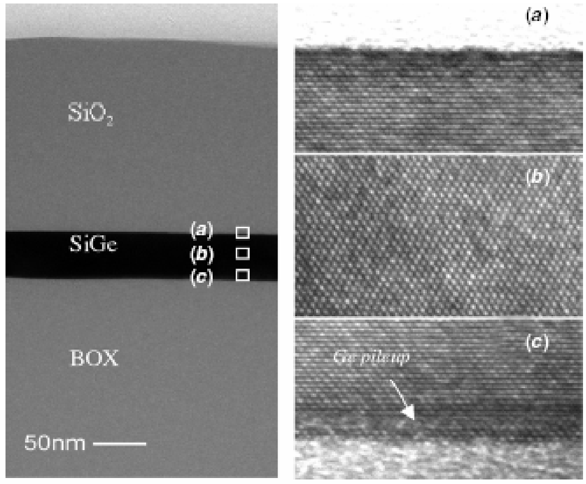

Fig.2 High resolution TEM image of SGOI

Relaxation of the strain in the SiGe layers during oxidation is investigated in details by Raman spectroscopy. Fig. 3 shows the differences in the Raman spectra for different oxidation times at 1150°C. The peaks associated with the Si–Si vibrational mode in the SiGe layer are clearly observed, in addition to the standard Si–Si phonon peak emerging at ~520 cm^{-1} from the Si substrate. The continuous Raman shift of the Si–Si vibrational mode in the SiGe layer suggests that the Ge fraction increases because of an increase in the oxidation time and relaxation of the strained SiGe layer. Fig. 4 shows the calculated Raman shift of Si–Si vibrational mode in both the fully-relaxed and fully-strained SiGe according to the Ge fraction. The plots are obtained from the as-deposited and oxidized samples. For $x \leq 0.2$, the Si–Si phonon mode in the SiGe layer exhibits a linear dependence on the Ge fraction in both the fully-relaxed incommensurate pseudo-alloy [14] and fully-strained commensurate superlattice [15]. In the calculation, we use the proportionality relationship summarized by Perry et al.: [16]

$$\begin{cases} \Delta_{p.a.} = 69.0x(cm^{-1}), (fully - relaxed) \\ \Delta_{s.l.} = 36.0x(cm^{-1}), (fully - strained) \end{cases} \quad (1)$$

Here, $\Delta_{p.a}$ is the phonon shift of the fully-relaxed pseudo-alloy and $\Delta_{s.l.}$ is that of the fully-strained superlattice SiGe alloy. The Raman shift of the as deposited sample is similar to that of the fully strained SiGe alloy, indicating that the SiGe layer deposited directly on the SOI substrate is not relaxed. The Raman shifts obtained from the oxidized samples are in agreement with the calculated values from fully-relaxed SiGe, suggesting that the SiGe layer releases the strain effectively during oxidation. Because the Ge fraction of the sample after oxidation for 2 h is higher than 20%, which is beyond the region allowed by Eq. (1), the true value is expected to deviate slightly from that of the fully relaxed SiGe layer.

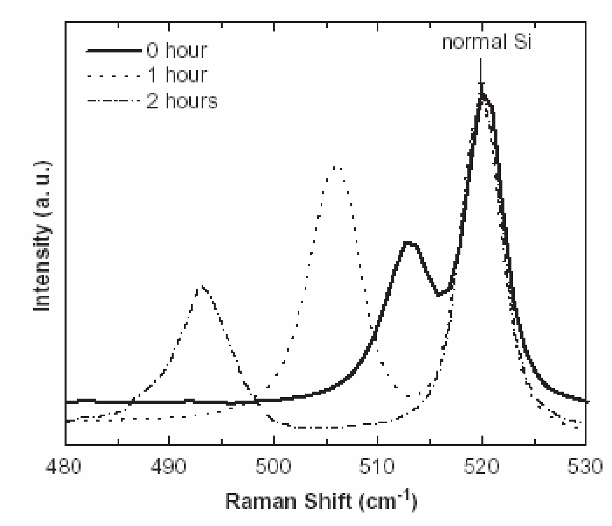

Fig.3 Raman spectra acquired from samples oxidized at 1150°C for different times.

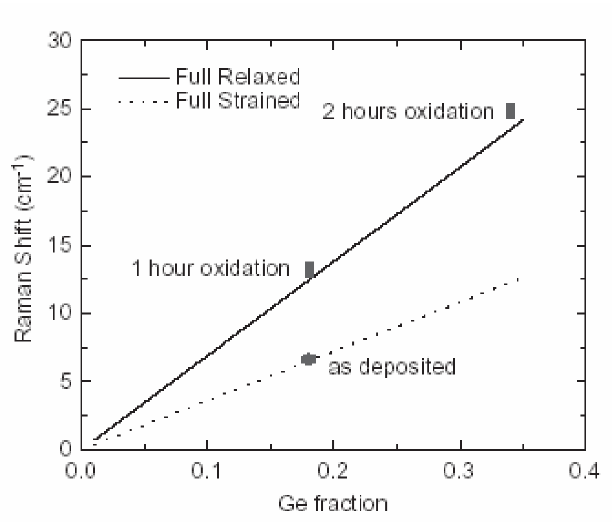

Fig.4 Calculated Si-Si vibrational Raman shifts in both the fully-relaxed and fully-strained SiGe layers according to the Ge fraction. The plots are acquired from the oxidation and as-deposited samples.

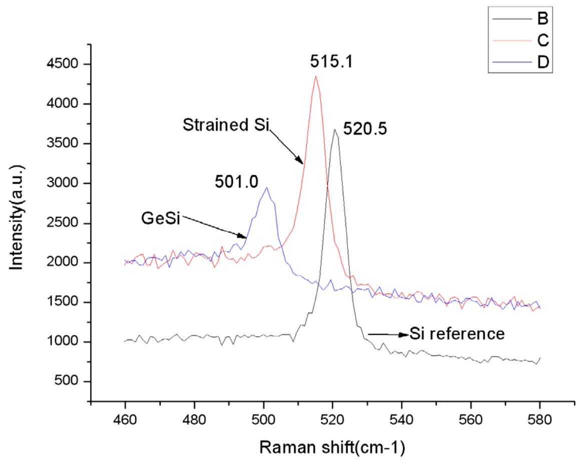

Fig.5 Raman spectra from strained silicon and SGOI

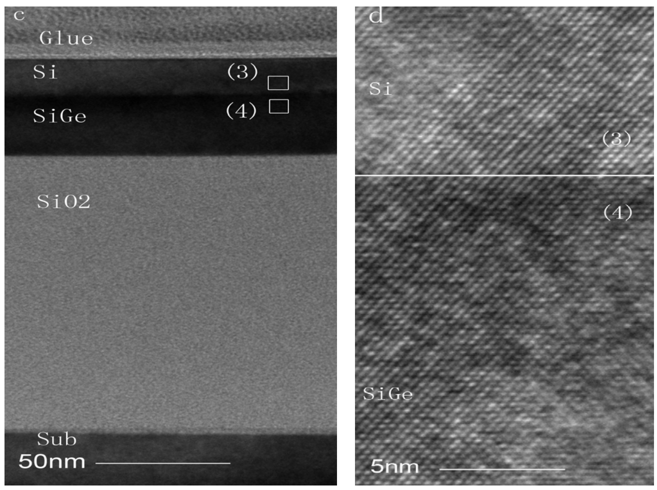

Fig.6 High resolution TEM images of strained Si on SGOI substrate

Strained in the thin strained silicon layer can be proved by the measurement of UV-micro-Raman spectra (shown in Figure 5). According to the literature, the absorption data for Si is known, and the penetration depth of the 368nm line of the Ar^+ laser can be calculated to 10-20nm. So in our Raman measurement, we probed the strained layer only. Our strained silicon on the SGOI has a distinct Raman shift of 515.1cm^{-1}. It can be calculated that the strain of silicon (ε) is about 1.8%.

Figure 6 shows the lattices of strained silicon and the interface between strained silicon and SGOI. It can be seen that no obvious defects can be found in the TEM images. The interface between strained and SGOI is sharp.

4. Conclusions

We have studied the structure of strained silicon/ SiGe/SiO_2/Si. Results show that oxidation process used in our experiment lead to the formation of SGOI with the Ge content larger than 30% and make the SiGe layer fully relaxed. Good quality strained silicon with the ε about 1.8% can be formed on the relaxed SGOI substrate.

Acknowledgments

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