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Segregation-Free Giant Single-Crystalline SiGe-on-Insulator by Super-Cooling-Controlled Rapid-Melting Growth

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Abstract

Seedless rapid-melting growth of SiGe-on-insulator (SGOI) is investigated. By controlling the cooling rate, segregation-free giant SGOI (~400 μm) is achieved. TEM observations reveal that the crystallinity of SGOI is very high. This technique is useful for integration of advanced multi-functional devices on Si platform.

1. Introduction

To break through the scaling limit of LSIs, multi-functional devices should be integrated on Si platform. SiGe-on-insulator (SGOI) structures are essential for this purpose. They provides advanced channels for high-speed transistors. In addition, SGOI is ideal epitaxial template for various optical- and spintronic-materials with different lattice constants.

We have been developing the rapid-melting Ge growth seeded from Si substrates which has achieved giant Ge-on-insulator structures with high carrier mobility [1-3]. To expand the application fields of this technique to thin-film-transistors and/or 3-dimensional LSIs, the Si substrate-free, i.e., seed-free, processing should be developed. Recently, we investigated seedless rapid-melting growth of a-SiGe, and realized SGOI crystals by optimizing initial Si concentrations and RTA conditions [4]. However, initial SiGe profiles turned into laterally-graded profiles by SiGe segregation during the melt-back process.

In the present study, we propose the idea of "mild super-cooling" to achieve SGOI with uniform Si concentrations. This achieves giant SGOI (~400 μm) with various uniform Si profiles identical to initial Si concentrations.

2. Experiments

Si(100) wafers covered with Si_3N_4 films were employed. After a-Si_xGe_{1-x} ($0.07 \leq x \leq 0.2$) films (thickness: 100 nm) were deposited, the SiGe films were patterned into strips (width: 5 μm, length: 400 μm). After deposition of SiO_2 capping layers (thickness: 800 nm), the samples were heat-treated by RTA (950-1150ºC, 1 sec) [Fig.1(a)]. The cooling rate after RTA was controlled in a wide range of 2-17ºC/sec.

Let us consider cooling-rate-dependent growth features, as shown in Fig.1(b). For the slow cooling rate (i), Si-rich nuclei will be generated in the molten region, when the temperature approaches the solidus curve. Growth initiated at the nuclei follows the solidus curve, which results in SiGe segregation. For the fast cooling rate (ii), nucleation occurs at temperatures far below the solidus curve, i.e., under excess super-cooling. This is because incubation time for nucleation cannot be secured above the solidus curve. Such excess super-cooling will generate many nuclei, which results in small-grain poly-crystals without segregation. These consideration triggers the following idea. For the medium cooling rate (iii), the nucleation is considered to occur at temperatures in the vicinity of the solidus curve. Such "mild" super-cooling will generate a limited number of nuclei and thus, a large single-crystal SiGe without segregation is expected.

3. Results and Discussions

Growth features of samples with various initial Si concentrations were investigated under various cooling rates. The results are summarized in Fig.2. Typical EBSD images and Si concentration profiles for $Si_{0.1}Ge_{0.9}$ samples are also shown in Fig.2. It is found that, for the slow cooling (i) (squares), the EBSD image indicates formation of a giant crystal grain (~400 μm), where the Si concentration shows a laterally graded profile indicating segregation during melt-back process [4-5]. For the fast cooling (ii) (triangles), the EBSD image indicates poly-crystallization (grain size: 5-10 μm). Interestingly, as we expected, a large SiGe crystal with uniform Si concentration is achieved under medium cooling rate (iii) (circles). Here, the Si concentrations identical to the initial values are maintained.

These results evidence our idea that the control of super-cooling enables the formation of segregation-free SiGe crystals. It is worth noting that process-window of cooling-rate for this purpose is large enough for device application, as shown in Fig.2.

TEM images of the segregation-free giant SGOI (Si conc.: 10%, cooling rate: 10ºC/sec) are shown in Fig.3. These clearly indicate that the top- and bottom- interfaces of the SiGe layer are very flat, and no defects exist in the grown SiGe layer. Moreover, EDX measurements revealed that there was no in-depth Si segregation in grown SGOI. These results show that segregation free SGOI with high crystallinity is realized by seedless rapid-melting growth under "mild" super-cooling. It is noted that the grain-size (~400 μm) in the present study is limited by the strip-pattern size. Thus, the grain-size can be further increased.

4. Summary

Super-cooling-controlled rapid-melting growth of SiGe has been investigated to obtain segregation-free SGOI. By alleviating super-cooling of molten SGOI, segregation-free giant SGOI is achieved for a wide range of the Si concentrations. Moreover, TEM observations have revealed that the crystallinity of SGOI is very high. This technique opens up the possibility of integration of advanced multi-functional devices on Si platform.

References

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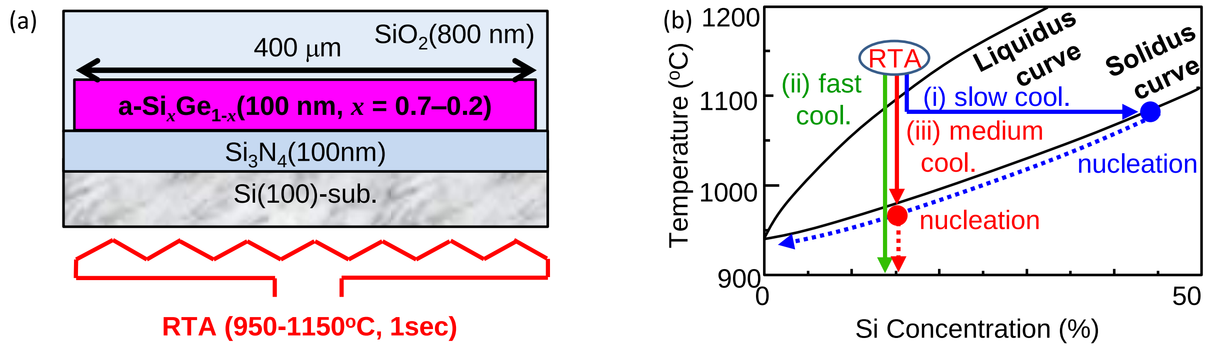

Fig. 1 (a) A schematic sample structure. (b) Si-Ge phase diagram and expected behavior of nucleation with various cooling rates. Liquid-phase and crystallization-phase are indicated by the solid and dotted arrows, respectively, in (b).

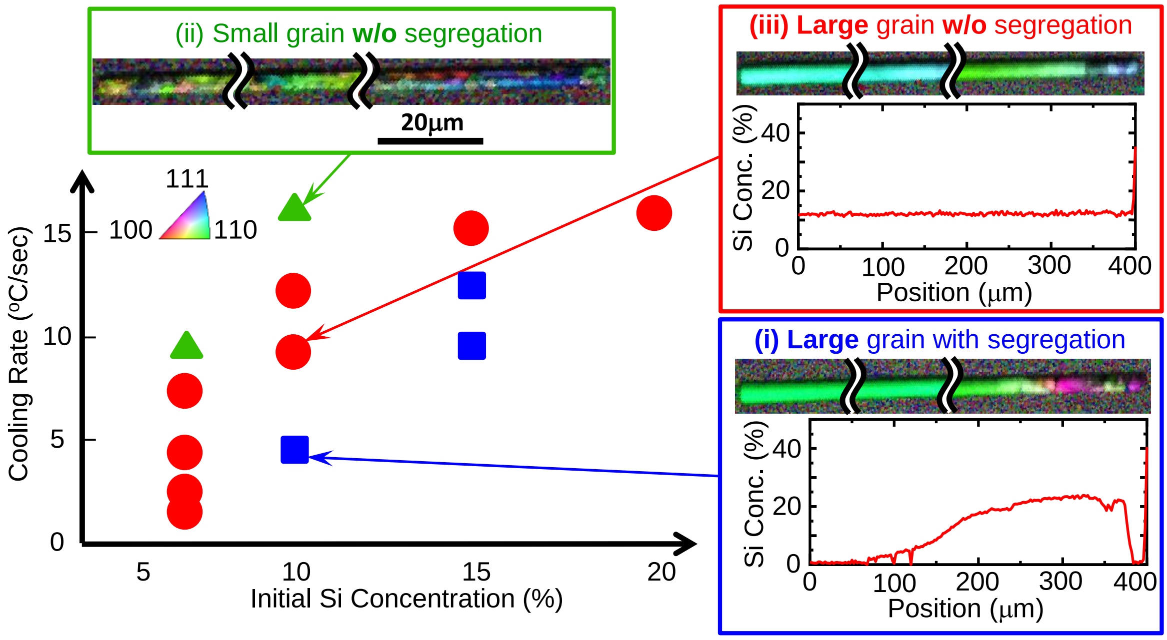

Fig. 2 Summary of SiGe growth features as a function of initial Si concentration and cooling rate.

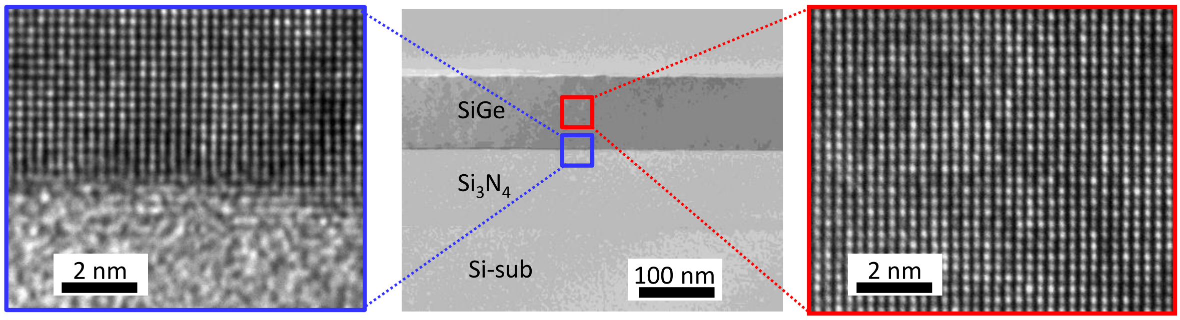

Fig. 3 TEM images of segregation-free giant SGOI (Si concentration: 10%, cooling-rate: 10°C/sec).