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Low-Temperature Formation of Poly-$Si_{1-x}Ge_x$ (x: 0-1) on SiO_2 by Au-Mediated Lateral Crystallization

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1. Introduction

Low temperature (<500°C) formation of polycrystalline silicon-germanium (poly-SiGe) films on insulator has been expected to realize advanced system-in-display and three-dimensional ULSI. To achieve this, recrystallization processes of amorphous SiGe (a-SiGe) on SiO_2 have been widely investigated. However, only poly-SiGe with small grains (<0.1μm) was obtained by solid-phase recrystallization. Melt-grown process such as laser annealing achieved poly-SiGe with large grains (~5μm), however Ge atoms were not distributed uniformly in the films, and surface ripples with ~15 nm height were observed [1].

Recently, low temperature solid-phase crystallization of a-SiGe was realized by using the catalytic effect of Ni [2]. This metal-mediated lateral crystallization achieved poly-SiGe with large grains (~10μm). However, growth velocity (1μm/h@550°C) is not so fast. In addition, uniform crystallization was obtained for only samples with low Ge fractions (<30%). To solve these problems, we examined the possibility of utilizing other types of catalysis. Present paper reports our findings of important role of gold (Au) on metal-mediated lateral crystallization, which successfully realizes high growth velocity as well as uniform crystallization for SiGe samples with all Ge fractions (0~100%).

2. Experimental Procedures

In the experiment, a-$Si_{1-x}Ge_x$ layers (50 nm thickness, x: 0-1) were deposited on SiO_2 films by using an MBE system (base pressure: $5x10^{-11}$ Torr). Subsequently, Au films (15 nm thickness) or Ni films (5 nm thickness) were evaporated on top of the a-$Si_{1-x}Ge_x$ and then patterned by using the lift-off process with photolithography. Finally, these samples were annealed at 400 or 550°C in a nitrogen ambient. Such experimental procedures are schematically shown in Fig.1. The crystal structure and quality of grown layers were evaluated with Nomarski optical microscopy and μ-probe Raman spectroscopy (spot diameter: ~1 μm).

3. Results and discussion

Figures 2(a)-2(d) show Nomarski optical micrographs of $Si_{1-x}Ge_x$ (x: 0-1) samples obtained by Au-mediated lateral crystallization at 400°C. The annealing times are shown in the figures. It is clear that crystal growth propagated laterally from Au-pattern and crystallized areas with plane morphology were formed for all samples. For reference, the micrographs of the samples obtained by Ni-mediated lateral crystallization at 550°C are shown in Figs. 2(e)-2(h).

In the case of pure Si, uniform crystallization perpendicular to the metal-pattern, i.e., seeding region, was obtained for both Au- and Ni-mediated samples. Au-mediated lateral growth length after annealing (400°C, 2h) was estimated to be 120μm. Consequently, high growth velocity (60μm/h) was obtained at a low temperature of 400°C. This value is 15 times larger than that in Ni-mediated lateral crystallization at 550°C.

When the Ge fraction exceeded 40%, crystalline morphology obtained by Ni-mediated lateral crystallization was drastically changed, i.e., dendrite growth for sample with intermediate Ge fraction (Fig. 2(f)), and no-crystallization for high Ge fraction (Figs. 2(g) and 2(h)). This is because formation probability of $NiSi_2$ acting as seeds for lateral growth decreases with increasing Ge fraction [2]. On the other hand, Au-mediated lateral crystallization enabled uniform growth for the samples with all Ge fractions as shown in Figs. 2(b)-2(d). These phenomena are attributed to the formation of eutectics between Au and $Si_{1-x}Ge_x$ (x: 0-1) below 400°C.

The lengths of Au-mediated lateral growth at 400 °C are summarized as a function of annealing time and Ge fraction in Figs. 3(a) and 3(b). Results obtained by Ni-mediated growth at 550°C are also shown for comparison. Au-mediated growth progresses rapidly and saturates in a very short time (<2 h). In addition, growth length decreased with increasing Ge fraction as shown in Fig. 3(b). The mechanism for such phenomena has not been clarified yet. However, long growth length (>20μm) sufficient for device fabrication was obtained for all $Si_{1-x}Ge_x$ (x: 0-1) samples by utilizing Au instead of Ni. This is a great advantage for the fabrication of SiGe devices.

In order to evaluate crystal quality in the lateral growth regions, μ-probe Raman spectra were measured. The typical spectra of the samples annealed at 400°C are shown in Fig. 4. Three sharp peaks, originating from the vibration modes of Ge-Ge, Si-Ge, and Si-Si bonds, are clearly observed. Analysis of Raman shift showed that the grown layers were completely strain free. In this way, uniform growth of $Si_{1-x}Ge_x$ (x: 0-1) by low temperature MILC method has been achieved for the first time. Electrical characterization of these crystallized regions is now underway.

4. Conclusions

Au-mediated low-temperature (~400°C) crystallization of a-$Si_{1-x}Ge_x$ (x: 0-1) on SiO_2 has been investigated. Growth velocity exceeding 20μm/h was obtained for samples with all Ge fractions. As a result, a large growth area (>20μm), which is sufficient for device fabrication, has been obtained at a low temperature (~400°C). These new polycrystalline SiGe films on insulator should be used for advanced system in display and three-dimensional ULSI.

References

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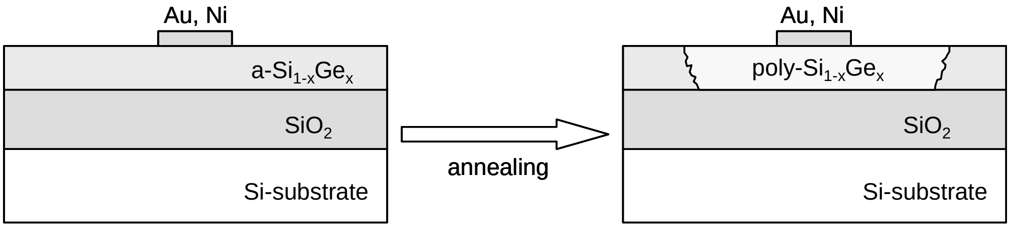


Fig. 1 Schematic experimental procedures for metal-mediated lateral crystallization of a-$Si_{1-x}Ge_x$ on SiO_2.

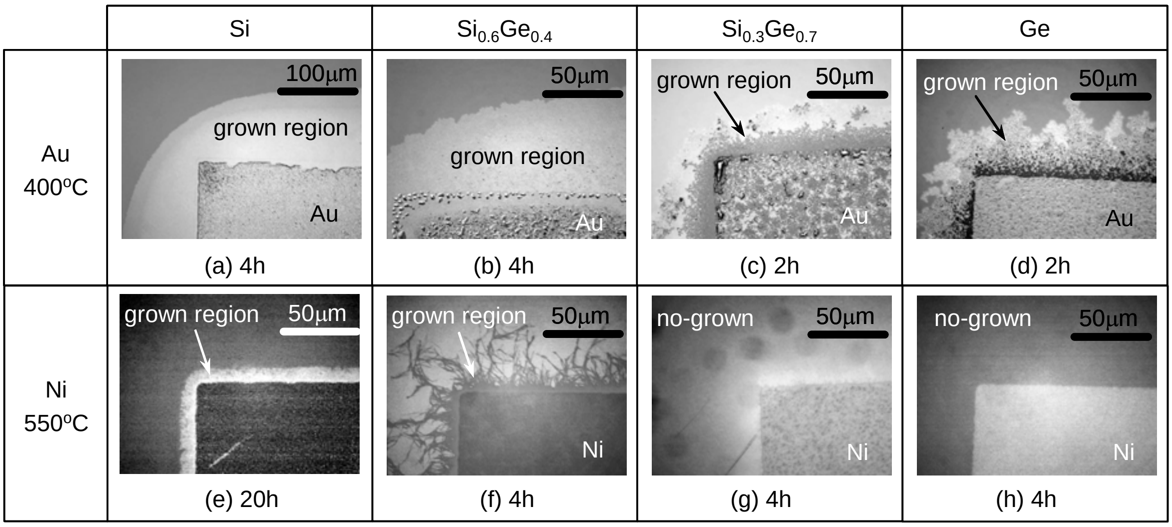
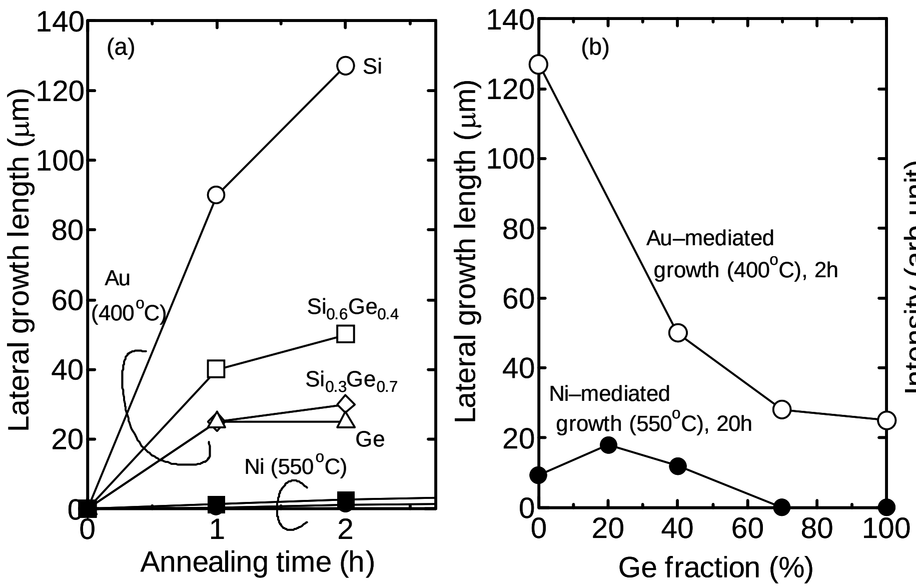


Fig. 2 Nomarski optical micrographs of samples with different Ge fraction. (a)-(d): Au-mediated lateral crystallization at 400°C, (e)-(h): Ni-mediated lateral crystallization at 550°C.



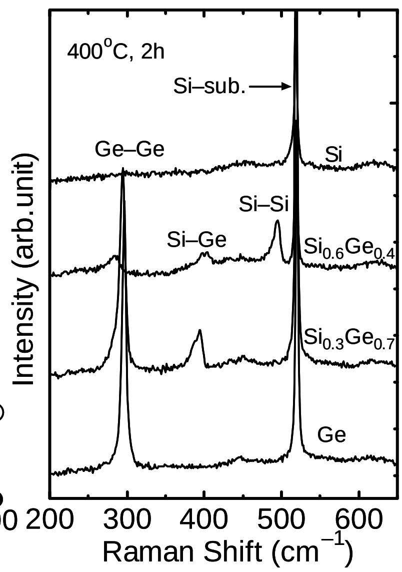


Fig. 3 Au-mediated lateral growth length for samples with different Ge fractions as a functions of annealing time (a), and as a function of Ge fraction (b). Results obtained by Ni-mediated growth are also shown.

Fig. 4 Raman spectra for samples after Au-mediated lateral crystallization at 400°C for 2h with different Ge fractions.