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Enhanced Metal-Induced Lateral Crystallization in Amorphous Ge/Si Layered Structure by Precursor Modulation

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1. Introduction

Low temperature (<550^{o}C) formation of polycrystalline Si (poly-Si) films on insulator has been expected to realize advanced system-in-display and three-dimensional ULSI. To achieve this, recrystallization processes of amorphous Si (a-Si) on SiO_2 have been widely investigated. However, only poly-Si with small grains (<0.1μm) was obtained by solid-phase recrystallization. Melt-grown process such as laser annealing achieved poly-Si with large grains (~5μm), however surface ripples with ~15nm height were observed. Recently, low temperature solid-phase crystallization of a-Si was realized by using the catalytic effect of some metals [1]. This metal-induced lateral crystallization (MILC) achieved poly-Si with large grains (~10μm). However, growth velocity is not so fast that long annealing time of 20h is necessary. To solve this problem, we examined effects of crystallinity-modulation of precursor on MILC, which successfully enhanced growth velocity by three times.

2. Experimental Procedures

In the experiment, a-Si layers (50-80nm thickness) and a-Ge layers (30nm thickness) were deposited on SiO_2/Si substrates with or without Ni pattern (5nm thickness) by using a MBE system (base pressure: 5×10^{-11}Torr). Subsequently, the samples were pre-annealed at 300^{o}C in the MBE chamber. Finally, they were annealed at 550^{o}C in a nitrogen ambient. The grown layers were evaluated with Nomarski optical microscopy, secondary ion mass spectroscopy (SIMS), and μ–probe Raman spectroscopy.

3. Results and Discussion

First, effects of pre-annealing of precursor (a-Si) were investigated. Amorphous-Si films deposited in the MBE chamber were *in-situ* annealed (250-600^{o}C). Nomarski optical micrographs of the samples after MILC processing, i.e., Ni deposition followed by 550^{o}C annealing, and the lateral growth characteristics were shown in Fig. 1. Results indicate that pre-annealing at higher temperatures enhances MILC. This suggests that modulation of crystallinity of the precursor plays an important role to enhance MILC.

Figure 2(a) shows the nucleation temperature of a-$Si_{1-x}Ge_x$ (x: 0-1) deposited on SiO_2 without Ni-patterns, which was measured by using spectroscopic ellipsometry. This indicates that crystal nucleation of a-Ge occurs at a low temperature of 500^{o}C, which is 200^{o}C lower than that of a-Si. Both results shown in Figs. 1 and 2(a) trigger off the following idea as shown in Fig. 2(b): If we use a-Ge/a-Si layered structures for MILC processing, crystal nucleation initiated in a-Ge will modulate crystallinity of the precursor (a-Si). Such modulation will enhance MILC during subsequent annealing.

To realize this idea, we examined MILC process in the a-Ge (30nm)/a-Si (50nm)/Ni-pattern/SiO_2 layered structure. Figures 3(a) and 3(b) show schematic cross sectional views of the structures and Nomarski optical micrographs after MILC processing. The crystallized region is observed around the Ni pattern. Lateral growth characteristics at 550^{o}C are summarized in Fig. 3(c). That result indicates that growth velocity of the a-Ge/a-Si layered structure is three times higher than that of the conventional a-Si single layer. As a result, poly-Si with large area (10μm) was obtained in a short annealing (<5h).

Redistribution of Ni, Si, and Ge atoms during MILC processing was examined for the a-Si/a-Ge/a-Si/Ni/SiO_2 structures. Results obtained before and after MILC processing are shown in Figs. 4(a) and 4(b), respectively, which indicates that Ni diffused to the sample surface through all layers. However, an inter-diffusion of Si and Ge is hardly observed. This shows that growth velocity enhancement shown in Fig. 3 cannot be attributed to the mixing effect of Si and Ge [2].

To examine other effects originating from stacked layers, the SiO_2/a-Si structure (Fig. 5(a)), the thick a-Si structure (Fig. 5(b)), and the inversion structure of a-Si/a-Ge (Fig. 5(c)) were prepared as the precursors. Growth characteristics shown in Fig. 5(d) indicate that both effects of SiO_2 capping and thickening are not enough to explain the growth enhancement. On the other hand, the inversion structure of a-Si/a-Ge shows enhanced MILC velocity almost identical to that for the a-Ge/a-Si structure. This clearly demonstrates that existence of the Ge layer is essential to the MILC velocity enhancement.

Crystallinity of the a-Si/a-Ge/Ni-pattern/SiO_2 structure after MILC processing (550^{o}C, 20h) was evaluated by using μ–probe Raman spectroscopy. The results are shown in Fig. 6. Crystalline Ge-Ge peaks are observed in all regions, even where MILC did not progress (region C), which supports our idea that crystal nucleation initiated in a-Ge modulates crystallinity of the precursor (a-Si).

4. Conclusion

Effects of precursor modulation on MILC of a-Si have been investigated. Enhanced growth velocity was observed by using the a-Ge/a-Si layered structure, which achieved poly-Si with large area (~30μm). This will be a powerful tool to realize poly-Si on insulating films at low temperatures.

References

[1] C. Hayzelden, et al., J. Appl. Phys. 73 (1993) 8279
[2] H. Kanno et al., Appl. Phys. Lett. 82 (2003) 2148

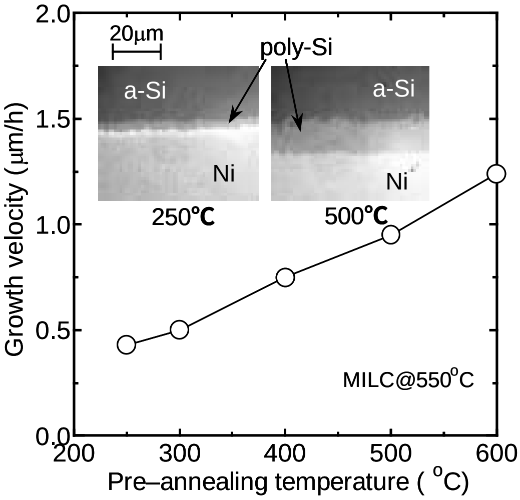

Fig. 1 MILC velocity at 550^{o}C as a function of pre-annealing temperature. Insertions were Nomarski optical micrographs after MILC processing (pre-annealing: 250 and 500^{o}C).

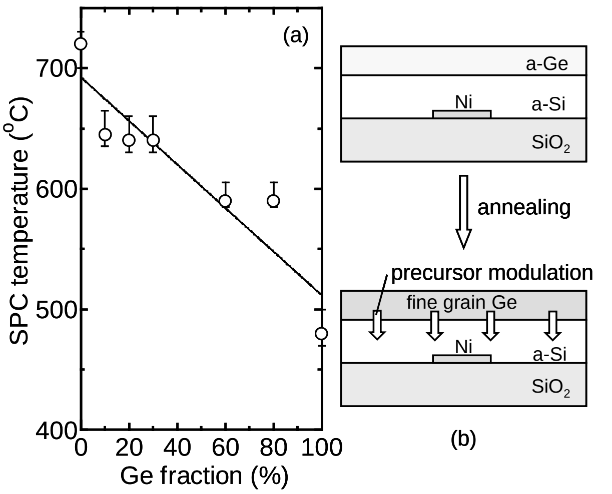

Fig. 2 Crystal nucleation temperature of a-$Si_{1-x}Ge_x$ (a) and schematic diagram of precursor modulated MILC by using a-Ge/a-Si layered structure (b).

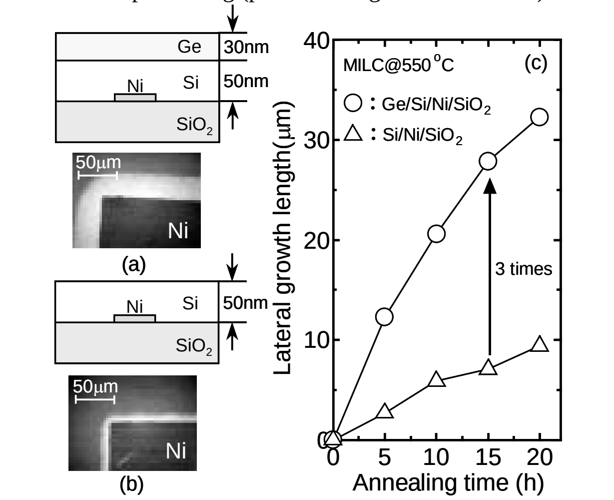

Fig. 3 Schematic cross sectional views of sample structures and Nomarski optical micrographs after MILC proceeding for a-Ge/a-Si layered structure (a) and conventional a-Si single layer (b). Lateral growth length at 550^{o}C as a function of annealing time (c).

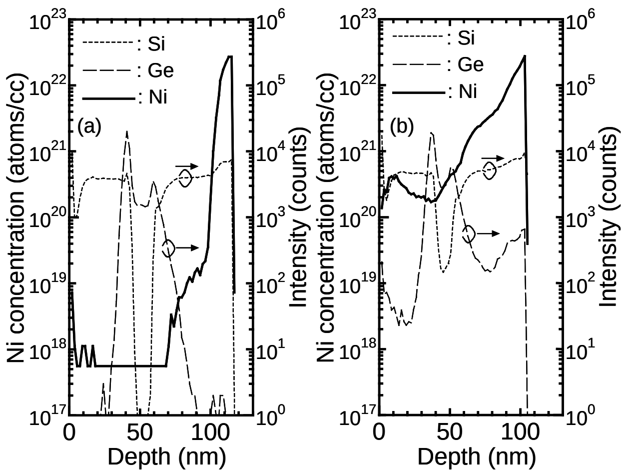

Fig. 4 SIMS depth profiles of Ni, Si, and Ge for samples before (a) and after annealing at 550^{o}C for 2h (b). Sample structure was a-Si/a-Ge/a-Si/Ni/SiO_2.

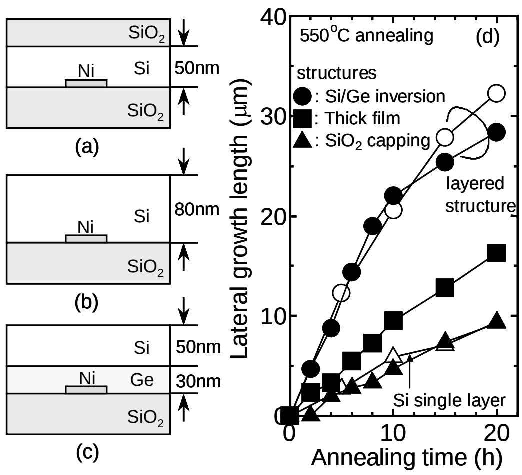

Fig. 5 Schematic cross sectional views of samples: SiO_2/a-Si structure (a), thick a-Si structure (b), and inversion structure of a-Si/a-Ge (c). Lateral growth length for samples annealed at 550^{o}C as a function of annealing time (d).

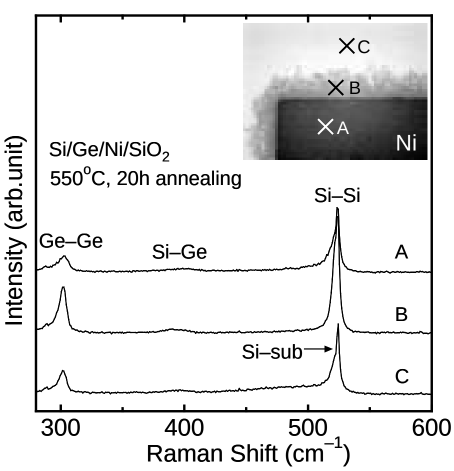

Fig. 6 Raman spectra obtained in Ni pattern region (A), MILC region (B), and a-Si region (C) in Si/Ge/Ni/SiO_2 structure after annealing at 550^{o}C for 20h.