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Au-induced lateral crystallization of a-$Si_{1-x}Ge_x$ (x: 0–1) at low temperature

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Abstract

Au-induced lateral crystallization of amorphous $Si_{1-x}Ge_x$ (x: 0–1) on SiO_2 at a low temperature (400 °C) has been investigated. Although the growth velocity decreased with increasing Ge fraction, growth velocity exceeding 20 μm/h was obtained for all Ge fractions. As a result, poly-$Si_{1-x}Ge_x$ with large areas (>20 μm) was obtained at a low temperature (400 °C). This is a great advantage of Au-induced lateral crystallization compared with Ni. However, the concentrations in the surface regions (depth: 0–20 nm) of the lateral growth regions were high (10–30%), though those in the deeper regions (depth: 20–50 nm) were as small as 1–2%. Removing of the surface regions with the high Au concentrations and gettering of Au atoms in the deeper regions are necessary to apply the grown layers to the device fabrication.

Keywords: Crystallization; Poly-SiGe; Metal-induced lateral crystallization; Eutectic reaction

1. Introduction

Low temperature formation of polycrystalline silicon-germanium (poly-SiGe) films on insulating substrates has been expected to realize the advanced system-in-displays and three-dimensional ultralarge-scale integrated circuits (ULSI). To prevent the diffusion of dopant atoms and the softening of glass substrates, the formation temperature should be lower than 500 °C. In line with this, the recrystallization processes of amorphous SiGe (a-SiGe) on SiO_2 have been extensively investigated. Melt-growth processes such as laser annealing enabled the formation of poly-SiGe with large grains (~5 μm); however, Ge atoms were not distributed uniformly in the films, and surface ripples (~15 nm in height) were observed [1]. The solid-phase crystallization (SPC) of SiGe realized uniform distribution of Ge atoms and the flat surface; however, high temperature annealing (>550 °C) was required [2,3].

Recently, the low-temperature solid-phase crystallization of a-Si was realized using the catalytic effect of the silicidation species such as Ni [4–6], where $NiSi_2$ formed at a low temperature acted as a seed for lateral solid-phase crystallization. We have applied this technique to crystallize a-$Si_{1-x}Ge_x$ (x: 0–1) at a low temperature (500 °C), and obtained poly-SiGe with large grains (~10 μm) [7–9]. However, the lateral growth velocity (1 μm/h at 550 °C) was not sufficiently high, and uniform crystallization was obtained only for samples with low Ge fractions (<30%) [7,8].

One possible solution for these problems is utilization of other types of reactants such as Ag, Al, In, and Au. This is because these metals cause eutectic reactions with Si and Ge [10–13], which are expected to induce liquid-phase growth of SiGe with all Ge fractions at a low temperature. Among them, we selected Au, because the eutectic temperatures for Au–Si (363 °C) and Au–Ge systems (361 °C) are very close [14,15]. In the present paper, we report our new findings concerning the important role of Au on the metal-induced lateral crystallization of a-$Si_{1-x}Ge_x$ (x: 0–1).

2. Experimental procedure

In the experiment, p-type Si substrates with the (100) orientation were used. They were covered with SiO_2 films (160 nm thick) by dry oxidation, and then a-$Si_{1-x}Ge_x$ (x: 0–1) layers (50 nm thick) were deposited on the SiO_2 films by using a molecular beam epitaxy system (base pressure: 5×10^{-11} Torr), where Si and Ge were evaporated (rate: ~0.1 nm/s) using the electron-beam gun and the Knudsen cell, respectively, with keeping the substrates at room temperature. The composition ratio (x) in a-$Si_{1-x}Ge_x$ was controlled by monitoring Si and Ge fluxes, and calibrated by Auger electron spectroscopy (AES). Subsequently, Au films (~30 nm thick)

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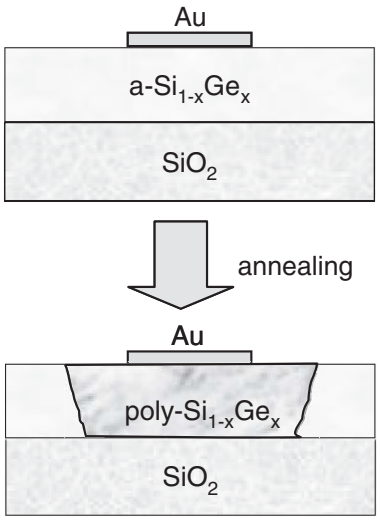

Fig. 1. Schematic experimental procedure for Au-induced lateral crystallization of a-$Si_{1-x}Ge_x$ on SiO_2.

were evaporated on the a-$Si_{1-x}Ge_x$ films and then patterned by lift-off process with photolithography. Finally, these samples were annealed at 400–550 °C in a dry nitrogen ambient. The cross sectional views during crystallization are schematically shown in Fig. 1.

The crystal structure and quality of grown $Si_{1-x}Ge_x$ layers were characterized by Nomarski optical microscopy and microprobe Raman spectroscopy (spot diameter: ~1 μm). The composition of the grown layers was evaluated by energy-dispersive X-ray spectroscopy (EDX) and AES. All measurements were carried out at room temperature.

3. Results and discussion

Fig. 2(a)–(d) show Nomarski optical micrographs of $Si_{1-x}Ge_x$ (x: 0–1) samples obtained by the Au-induced lateral crystallization at 400 °C. The annealing time for each sample is shown in the figure. The Au patterns, which act as the seeding

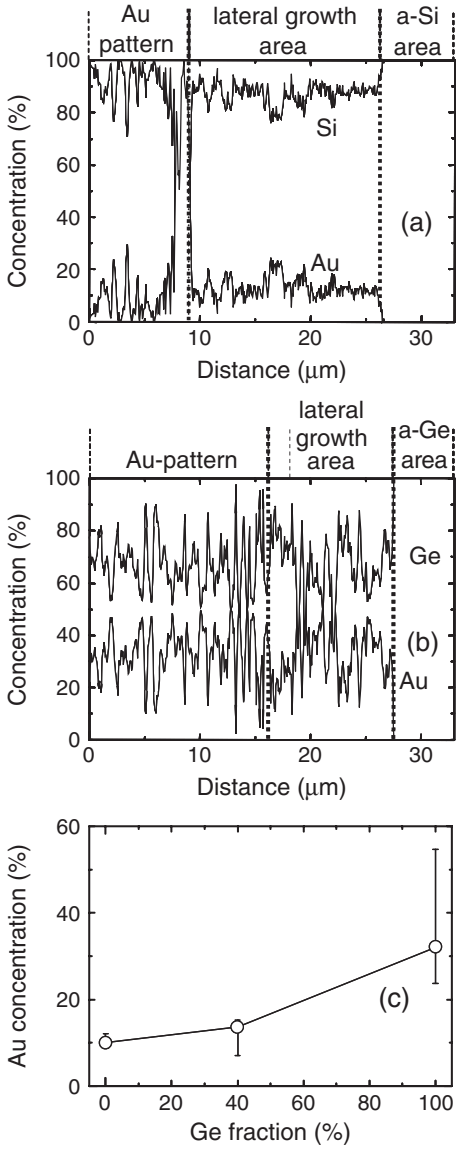

Fig. 3. Line scan profiles (Au, Si, and Ge) in Au-induced lateral growth area (400 °C, 2 h) obtained by EDX for a-Si/SiO_2 (a) and a-Ge/SiO_2 (b), and Au concentration in the lateral growth area as a function of Ge fraction (c).

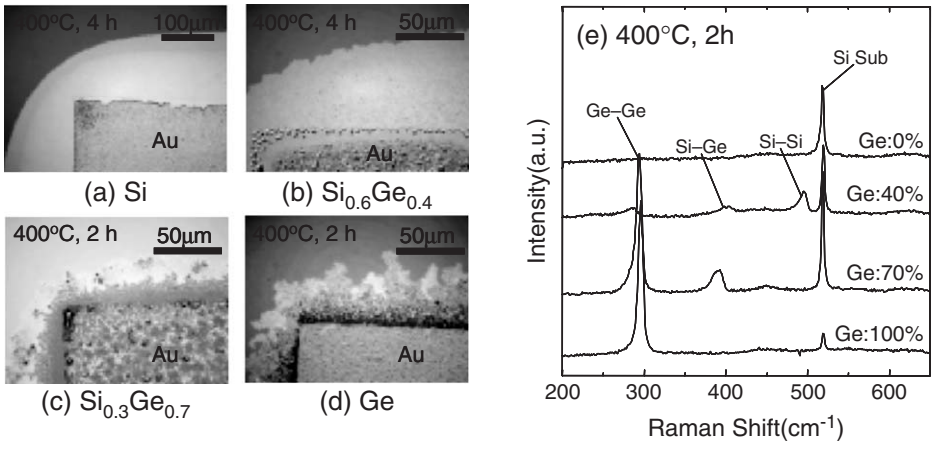

Fig. 2. Nomarski optical micrographs (a)–(d) and Raman spectra (e) for samples with different Ge fractions obtained by Au-induced lateral crystallization. The annealing times for samples are shown in the figures.