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Tsunoda, Isao
Department of Electronics, Graduate School of Information Science and Electrical Engineering, Kyushu University : Graduate Student

Nagatomo, Kei
Department of Electronics, Graduate School of Information Science and Electrical Engineering, Kyushu University : Graduate Student

Kenjo, Atsushi
Department of Electronics, Faculty of Information Science and Electrical Engineering, Kyushu University

Sadoh, Taizoh
Department of Electronics, Faculty of Information Science and Electrical Engineering, Kyushu University

他

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Solid Phase Crystallization of a-Si in Si/Ge Multi-layer

Isao TSUNODA*, Kei NAGATOMO*, Atsushi KENJO**
Taizoh SADOH** and Masanobu MIYAO**

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Abstract: We have investigated the effects of local Ge-insertion in a-Si films on solid-phase crystallization (SPC). Experiments were performed by using three types of stacked structures, i.e., (a) a-Si/a-Ge/a-Si/SiO_2, (b) a-Si/a-Ge/SiO_2, and (c) SiO_2/a-Ge/a-Si/SiO_2. These samples were annealed at 600°C. The results for the structure (a) with Ge films of 5 nm, Ge atoms were completely diffused into a-Si regions, and no-enhanced SPC was detected. However, if Ge thickness was increased to 15 nm, Ge atoms were localized. Such phenomena became significant by (b) and (c) structures even for samples with Ge films of 5 nm. In addition, significant enhancement of SPC of a-Si was found. These results indicated that crystal nucleation was initiated at Ge layers, and then propagated into a-Si layer. Therefore, interface nucleation driven SPC becomes possible by using the structures (b) and (c). It is expected that this process can be used to grow oriented Si crystals on SiO_2.

Keywords: Solid-phase crystallization, Nucleation, Poly-Si, Poly-SiGe, Thin film transistor

1. Introduction

In recent years, low-temperature formation of high-quality poly-Si on SiO_2 has been widely investigated for the fabrication of high-performance thin film transistors (TFTs) for advanced active-matrix liquid-crystal displays (AMLCDs) and Si-based optoelectronic integrated circuits (OEICs)[1),2),3)]. A melt-grown process such as laser annealing is widely used for this purpose. However, this method does not ensure sufficient reliability, due to the energy fluctuation of laser. Consequently, a low-temperature growth method such as solid-phase crystallization (SPC) is strongly required.

The SPC of amorphous Si (a-Si) on SiO_2 consists of two processes, i.e., crystal nucleation and subsequent nuclei growth. Activation energies necessary for these processes are 3.7 and 2.7 eV, respectively[4),5)]. Due to the large activation energy of nucleation (3.7 eV), a practical technique for SPC at a low temperature has not been established so far. In addition, it is known that the nucleation occurred randomly in the whole region of a-Si films and at the a-Si/SiO_2 interface. Such a situation makes oriented crystal growth impossible. Therefore, the position control of nucleation becomes essential to realize oriented crystal growth[6)].

Our main idea in this paper to solve this problem is the local doping of Ge atoms into a-Si films in order to stimulate crystal nucleation. The present paper describes the annealing characteristics of a-Si/SiO_2 structure, in which a thin Ge film is inserted in the various positions.

2. Experimental Procedures

In the present study, CZ-Si(100) substrates were covered with thermally grown SiO_2 films (thickness: 160 nm). Subsequently, amorphous Ge and Si films (Ge thickness: 5–15 nm, total thickness: 50 nm) were deposited on the SiO_2 films by using a solid-source molecular beam epitaxy (MBE) system (base pressure: 5×10^{-11} Torr) at room temperature.

Figure 1 shows the cross-sectional views of three types of stacked structures, i.e., (a) a-Si/a-Ge/a-Si/SiO_2, (b) a-Si/a-Ge/SiO_2, and (c) SiO_2/a-Ge/a-Si/SiO_2. The top SiO_2 layer shown in (c) was deposited by using a TEOS-CVD system at 300°C. In addition, a-$Si_{1-x}Ge_x$ single alloy layer ($0 \leq x \leq 1$, thickness: 90 nm) were also deposited on SiO_2 for the reference sample. The Ge fraction (x) was defined by using Auger Electron Spectroscopy (AES). These samples shown in Fig. 1 were annealed at 600°C in a dry nitrogen ambient. The growth characteristics were evaluated by using the spectroscopic ellipsometry, AES, and X-ray diffraction (XRD) method. All measurements were carried out at room temperature.

* Department of Electronics, Graduate Student
** Department of Electronics

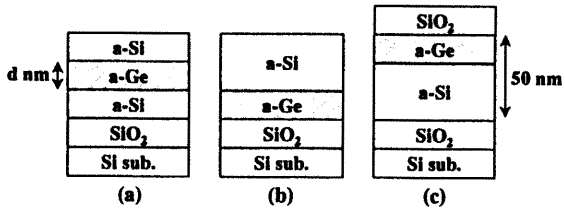

Fig.1 The cross-sectional views of sample structures: (a) a-Si/a-Ge/a-Si/SiO_2, (b) a-Si/a-Ge/SiO_2, and (c) SiO_2/a-Ge/a-Si/SiO_2.

3. Results and Discussion

First, effects of Ge fraction on the SPC of a-$Si_{1-x}Ge_x$ ($0 \leq x \leq 1$) on SiO_2 were examined. Isochronal annealing (20 min) characteristics of the crystallinity for a-$Si_{1-x}Ge_x$ alloy are shown in Fig. 2(a). The crystallinity (normalized to 100% for crystal Si and 0% for a-Si) was evaluated on the basis of the imaginary part of refractive index (k) value corresponding to E_2 peak (4.3 eV) from the spectroscopic ellipsometry measurement[7),8),9)]. It is clearly observed the SPC of a-$Si_{1-x}Ge_x$ on SiO_2 was significantly enhanced with increasing Ge fraction. The nucleation temperature was estimated as the temperature where SPC initiated, and they are summarized in Fig. 2(b). This clearly indicates that the nucleation temperature was significantly decreased with increasing Ge fraction. As a result, nucleation at 500°C becomes possible by using a-Ge films. Crystal orientations of grown layer evaluated by using XRD method are shown in Fig. 2(c). The diffraction peaks corresponding to $Si_{0.7}Ge_{0.3}$ (111), (220), and (311) are observed at around $2\theta = 28°$, 47°, and 56°, respectively. The other diffraction peaks originates from the SiO_2 substrate. Such multi peaks due to $Si_{0.7}Ge_{0.3}$ are attributed to the random nucleation in the whole region of a-Si films and at a-Si/SiO_2 interface. Therefore, control of nucleation position is necessary to obtain oriented growth.

The result shown in Fig. 2(b) triggers the following idea of the nucleation-positioning: When we insert thin Ge layers into a-Si on SiO_2 structures, crystal nucleation should be initiated in the Ge region due to the low activation energy of nucleation in Ge compared with that in Si. This will enable the position control of the nucleation.

To examine this idea, experiments were performed by using the stacked structures (a), (b) and

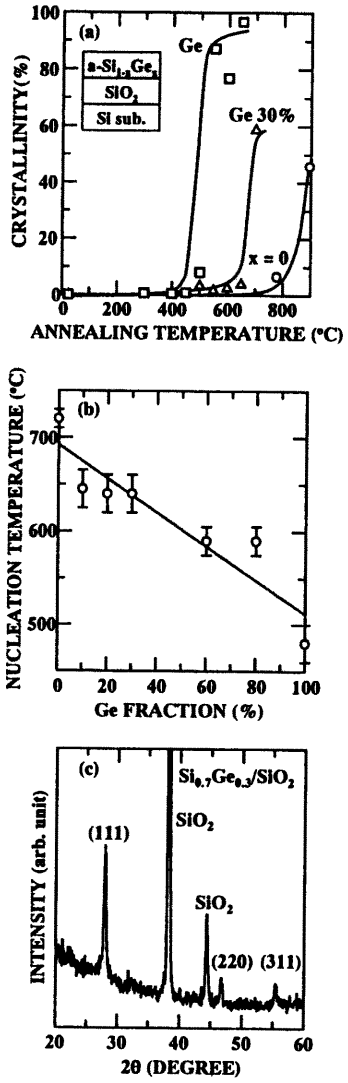

Fig.2 Isochronal annealing (20 min) characteristics of crystallinity of a-$Si_{1-x}Ge_x$ ($0 \leq x \leq 1$) on SiO_2 (a), nucleation temperature as a function of Ge fraction (b), and XRD spectra of poly-$Si_{0.7}Ge_{0.3}$ on SiO_2 after annealing at 600°C for 20 min (c).

(c) shown in Fig. 1. Figure 3 shows the atomic concentration profiles of Si and Ge (thickness: 5, 10 and 15 nm) before and after annealing, which were measured by using AES. For the sample (a) with thin-Ge films (5 nm), Ge distribution is remarkable, which indicates that Ge atoms were completely diffused into both sides of a-Si regions because of the high diffusion coefficient of Ge in a-Si (6.3×10^{-20} m^2/s at 600°C)[10)].

This fact suggests that it is difficult to realize our idea by using the structure (a). However, when Ge thickness is increased to 15 nm, abnormal localization of Ge atoms is obtained. Such phenomena become significant by using the samples (b) and (c),

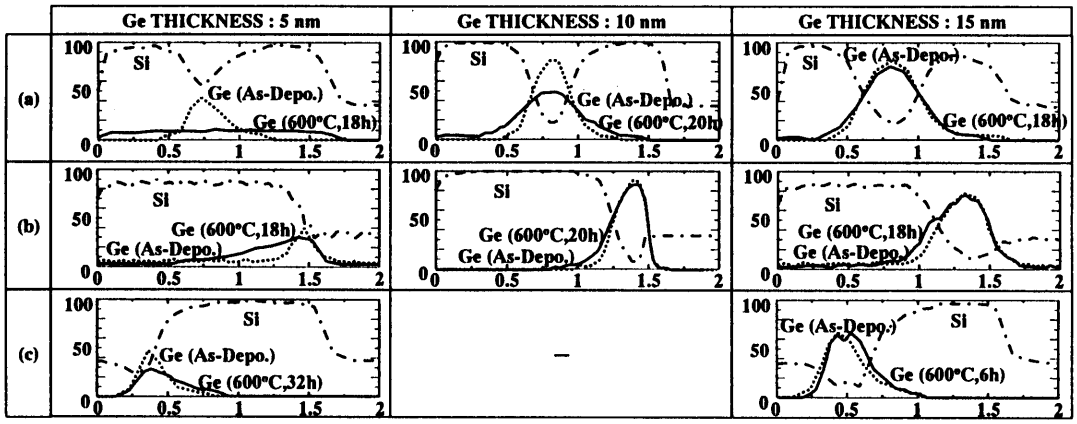

Fig.3 Concentration profiles of Si and Ge before and after annealing at 600°C measured by AES for the samples (a), (b), and (c) with different Ge layer thickness. The sample structures are shown in Fig. 1. X-axis is sputtering time (min), corresponding to the depth from the sample surface, and Y-axis is atomic concentration (%).

where Ge localized even for samples with thin Ge films (5, 10 nm).

To understand such phenomena, isothermal annealing characteristics of the crystallinity for the samples (a) and (b) was examined. These results were summarized in Fig. 4. Annealing characteristics of a-Si/SiO_2 and a-$Si_{0.9}Ge_{0.1}/SiO_2$ were also shown for comparison. For the sample (a) with thin Ge thickness (5 nm), crystallization occurred after long time annealing (~1000 min). Such characteristics are very close to those for the a-$Si_{0.9}Ge_{0.1}/SiO_2$ structure. This indicates that SPC of the sample (a) with thin Ge thickness is caused after diffusion of Ge atoms. On the other hand, for all samples which showed abnormal Ge localization, SPC was significantly enhanced compared with that for a-Si/SiO_2. This resulted in the short incubation time for crystallization, i.e., about 50 min. Consequently, the inserted Ge layers successfully acted as preferential nucleation sites.

These results suggest that two-dimensional nucleation at a-Si/SiO_2 interface can be possible by using the sample structures (b) and (c) with thin Ge films (5 nm). Preliminary experiments using XRD method indicated the preferential nuclei growth along the [111] direction. Such a SPC driven by interface nucleation will be a useful tool to achieve high quality poly-Si on SiO_2.

4. Conclusion

Local insertion effects of thin Ge layers into a-Si/SiO_2 structures were examined from the view point of SPC control. Abnormal retardation of Ge diffusion during SPC was found for all samples where Ge layers were inserted between a-Si and SiO_2. This enabled the positioning of nucleation by preferential nucleation in the Ge regions. In addition, possibility of oriented crystal growth driven by the interface nucleation was presented.

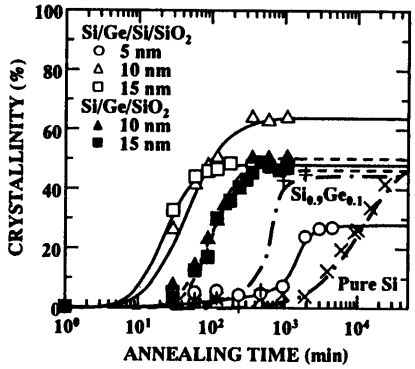

Fig.4 Isothermal annealing (600°) characteristics of crystallinity for the samples (a) and (b). The results obtained for a-Si/SiO_2 (×) and a-$Si_{0.9}Ge_{0.1}/SiO_2$ (+) are also shown for reference.

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