Al-induced Crystallization of Amorphous-Ge Thin Films on Conducting Layer Coated Glass Substrates

K. Nakazawa¹, K. Toko¹, N. Usami², and T. Suemasu¹

¹ Institute of Applied Physics, University of Tsukuba, Tsukuba, Ibaraki 305-8573, Japan

²Materials, Phys. and Energy Eng., Nagoya Univ., Nagoya 464-8603, Japan

Phone: +81-29-853-5472, Fax: +81-29-853-5205, E-mail: toko@bk.tsukuba.ac.jp

1. Introduction

Germanium is applicable to the bottom cell of high-efficiency tandem solar cells because of its desirable characteristics, such as its narrow band gap (0.66 eV), large absorption coefficient ($\sim 10^4$ cm⁻¹ at 0.8 eV), and good lattice matching to group III-V compound semi-conductors (0.1% lattice mismatch with GaAs). However, a bulk Ge substrate is expensive, which has limited its application to special uses, such as in tandem solar cells for space satellites. One promising approach to reduce the fabrication cost is substituting the bulk Ge substrate with a high-quality polycrystalline Ge (poly-Ge) thin film on an inexpensive glass substrate. A low-temperature process (550 °C) is required to avoid softening the glass substrate. Many growth techniques have been developed: solid-phase crystallization (SPC) [1], metal-induced SPC [2], laser annealing [3], and chemical vapor deposition (CVD) [4]. However, the resulting Ge layers consist of small, submicron grains, with nearly random orientations.

Aluminum-induced crystallization (AIC) is a metal-induced SPC technique developed for amorphous-Si films on insulators [5-6]. Recently, we have obtained an AIC-Ge thin film on a glass substrate: the area fraction of the (111)-orientation reached as high as 99% and the average grain size more than 100-µm diameters [7]. For practical solar-cell application, conducting layer should be formed on the glass substrate. In this paper, we investigated the AIC of amorphous Ge (a-Ge) thin films on conducting layer coated glass substrates.

2. Experimental Procedures

The sample preparation procedure is shown in Fig. 1. 100-nm-thick various conducting layers, such as Al-doped ZnO (AZO), ITO, and TiN, were prepared on quartz glass (SiO₂) substrate. For comparison, 100-nm-thick SiO₂ layer was also prepared. Subsequently, Al films were prepared (45-nm thickness) on these samples, followed by 5-min air exposure to form native AlO_x layers as diffusion control layers. After that, a-Ge films (40-nm thickness) were prepared. Here, these thickness values have a margin of error of \pm 5%. All the depositions were carried out at room temperature using a radio-frequency magnetron sputtering method. Finally, those samples were annealed at 325°C for 100 h in a N₂ ambient to induce the AIC. The crystal orientations were evaluated using electron backscattered diffraction (EBSD) measurements after removing the aluminum and oxide layers on the Ge layers by diluted HF solutions (HF: 1.5%). The surface roughness was evaluated using atomic force microscopy (AFM).

3. Results and Discussion

The completion of the layer exchange was confirmed using Nomarski optical microscopy for all the samples. Figure 2 displays the EBSD mappings of samples along the normal direction (ND) and transverse direction (TD) with respect to the substrates. These EBSD images show that the orientation and grains size of AIC-Ge strongly depend on the underlayer materials. For the sample with SiO₂ and TiN, the poly-Ge layer is dominantly oriented to (111) and has large grains (>100 µm diameters). This result is almost the same as the AIC-Ge formed directly on a SiO₂ substrate [7]. In contrast, the sample with AZO has dominantly (100)-oriented small grains (10-µm diameters). For the sample with ITO, the orientation is random, and the grain size is smaller than other samples (5-µm diameters). We infer two possibilities which may cause this underlayer dependent crystal orientation: surface roughness of underlayers and interfacial energy at the interface of Ge and underlayers. The AFM images of the underlayer surfaces are exhibited in Fig. 3. By comparing Figs. 2 and 3, we found that there is no consistent correlation between the surface roughness and the crystal orientation of AIC Ge layers. This result suggests that the underlayer dependent crystal orientation shown in Fig. 2 originates from the difference of the interfacial energy between Ge underlayers. Some papers on AIC state that Si (Ge) nuclei heterogeneously occur on the substrates, and thus the Si (Ge) is preferentially oriented to a plane with the lowest interfacial energy [5-8]. This growth model supports our experimental results: the orientation of AIC-Ge depends on the underlayer.

4. Conclusions

We investigated the AIC of a-Ge films on conducting layer coated glass substrates. The layer exchange successfully occurred on the AZO, ITO, TiN conducting layers. We found that the crystal orientation of the AIC-Ge depended on conductive materials: (111) strongly orientation for TiN, (100) orientation for AZO, and random orientation for ITO. The maximum grain size (>100-µm diameters) was obtained for sample with TiN. Therefore, we accomplished large-grained (111)-oriented poly-Ge thin films on conducting layer coated glass substrates, which is be epitaxial expected to useful as templates for high-efficiency tandem solar cells.

References

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Fig. 1. Schematic structure of the sample preparation procedure.



Fig. 2. EBSD images along ND and TD for the samples with SiO_2 , AZO, ITO, and TiN. A color key corresponding to the crystal orientations is inserted.



Fig. 3. AFM images of the surfaces of (a) SiO_2 , (b) AZO, (c) ITO, and (d) TiN layers on SiO_2 substrates.