Low-Temperature Metal-Induced Crystallization of Orientation-Controlled SiGe on Insulator for Flexible Electronics

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INTRODUCTION

Development of low-temperature (≤250°C) formation technique of orientation-controlled large-grain (>10 μm) poly-SiGe on amorphous insulator is essential to realize flexible electronics, where various advanced devices, such as high-speed thin-film transistors, high-efficiency optical devices, and nonvolatile spintronic memories, are integrated on flexible plastic substrates (softening temperature: ~300°C). In line with this, we have been developing metal-induced crystallization of SiGe [1-4]. This achieves selectively (100)- or (111)-oriented large-grain (≥20 μm) SiGe at low temperatures (~250°C). Present paper reviews our recent progress in this novel growth technique.

LOW-TEMPERATURE CRYSTALLIZATION BY SELECTING Au AS NEW CATALYST

By conventional solid-phase crystallization, high-temperature annealing at above 500°C is necessary to induce crystallization of SiGe [5]. To obtain poly-SiGe films on insulator at low temperatures, metal-induced crystallization techniques, such as Ni-induced lateral crystallization [6,7], Ni-imprint-induced crystallization [8,9], and Al-induced crystallization (AIC) [1,4,10,11,12] were developed. In these processes, the crystal nucleation and subsequent nucleus growth are enhanced by the catalytic effects of metals.

Recently, the AIC processes of Si, SiGe, and Ge are intensively investigated, where a-Si/Al, a-SiGe/Al, and a-Ge/Al stacked structures are employed [1,4,10,11,12]. In these AIC processes, layer-exchange of the stacked structures results in formation of poly-crystal films on insulator. Owing to bond-modulation by catalysis, AIC of Ge proceeds at ~325°C [12]. However, the crystallization temperatures should be further decreased in order to employ flexible plastic substrates.

Such layer-exchange growth was also reported for the a-Si/Ag structures, though high temperature annealing (530°C) was necessary [13]. It is noted that these metals (Al and Ag) form eutectics with Si and Ge. Moreover, it is suggested that the layer-exchange growth temperatures are slightly lower than the eutectic temperatures [420°C (Al-Ge), 577°C (Al-Si), 845°C (Ag-Si)] and decrease with decreasing eutectic temperature. Based on this suggestion, we have selected Au as a new catalyst. Au forms a eutectic system with Si and Ge, and the eutectic temperatures [363°C (Au-Si), 361°C (Au-Ge)] are very low. We have examined this ides. As a result, low temperature (~250°C) crystallization of SiGe with the whole Ge fractions has been achieved [2,3] as shown in Fig. 1, where the layer-exchange growth temperature is plotted as a function of the eutectic temperatures together with reported data [1,12,13]. At the presentation, our recent results using Sn (eutectic temperature: 231°C) will be also discussed.

ORIENTATION CONTROL BY ANISOTROPIC FREE ENERGY OF Ge NUCLEI

To obtain orientation-controlled large-grains, randomly-oriented bulk nucleation should be suppressed and instead, preferentially-oriented nucleation at Au/substrate interfaces should be dominated. This domination of interface nucleation can be achieved through retarding Ge atomic supply by introducing diffusion barrier between a-Ge and Au layers, because interface nucleation is energetically favorable compared to bulk nucleation. In addition, use of anisotropy of free energy of Ge nuclei is a key for orientation control.

Based on these ideas, we have examined control of nucleation site by modulating atomic diffusion in the layer-exchange process, as shown in Fig. 2. Here, we introduced Al_2O_3 or SiO_2 nucleation-control layers between Au layer and insulating substrates to generate (100)- or (111)-oriented interface nucleation, respectively, due to interface energy minimization [14,15]. As a result, (100)- or (111)-oriented large-grain (≥20 μm) SiGe crystals are realized on amorphous insulator at a low temperature (~250°C).

This technique opens up the possibility of high-performance thin-film devices for flexible electronics.

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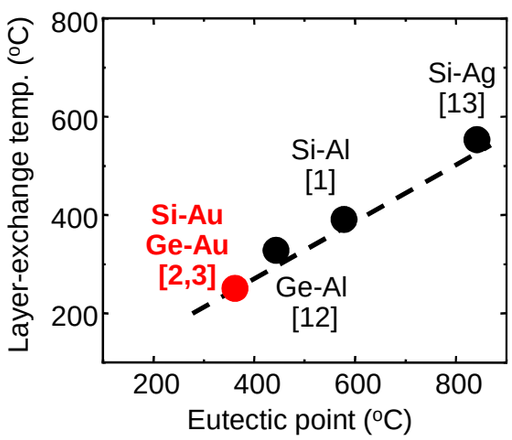

Fig.1 Summary of layer-exchange-growth temperature as a function of eutectic temperature. The data of Si/Au [2], Ge/Au [3], Ge/Al [12], Si/Al [1], and Si/Ag stacked structures[13] are plotted.

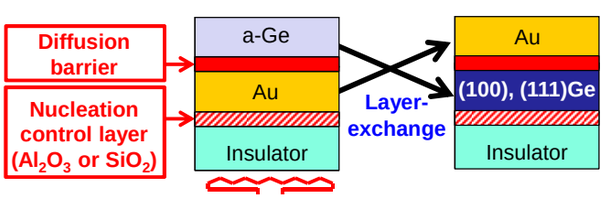

Fig.2 Schematic of nucleation-controlled gold-induced layer-exchange crystallization.