AMD5-2
Invited

Interface-Modulated Solid-Phase Crystallization of Sn-Doped Ge Ultrathin-Films for Advanced TFT

Taizoh Sadoh[1], Takaya Nagano[1], Taishiro Koga[1], Kenta Moto[2,3], Keisuke Yamamoto[2]

sadoh@ed.kyushu-u.ac.jp
[1]Departement of Electronics, Kyushu University, 744 Motooka, Fukuoka 819-0395, Japan
[2]Interdisciplinary Graduate School of Engineering Sciences, Kyushu University,
6-1 Kasuga-koen, Kasuga, Fukuoka 816-8580, Japan
[3]JSPS Research Fellow, 5-3-1 Kojimachi, Chiyoda-ku, Tokyo 102-0083, Japan
Keywords: Ge, Thin-Film, Solid-Phase Crystallization, TFT

ABSTRACT

High-speed fully-depleted thin-film transistors (TFTs) are required for next-generation electronics, such as three-dimensional large-scale integrated circuits and advanced system-in-displays. For this purpose, a novel growth technique, i.e., interface-modulated solid-phase crystallization, of Sn-doped Ge has been developed. This achieves high carrier mobility (~100 cm^2/Vs) of ultrathin films (20 nm) on insulators.

1 Introduction

Germanium (Ge), is a promising material for realization of next-generation large-scale integrated circuits (LSIs) and displays, because they have high carrier mobility and superior optical properties compared with Si. To integrate Ge-based high-speed transistors and high-efficiency optical devices on LSIs and displays for realization of three-dimensional LSIs and system-in-displays, development of formation techniques of Ge films on insulators at low-temperatures (≤500°C) is essential. Moreover, the films should be ultrathin (≤20 nm) to fabricate fully-depleted devices for high-speed operation with low-power consumption. Thus, various techniques, such as solid-phase crystallization (SPC), metal-induced lateral crystallization, metal-induced layer-exchange crystallization, and laser annealing, have been developed.[1]

Among them, SPC has advantage of the simple process. In the presentation, we review recent studies of SPC of Ge on insulator, in focusing on Sn-doping and interface-modulation.[2−5]

2 Effects of Sn-doping and thickness on SPC of Ge films

Amorphous GeSn films with wide ranges of Sn concentration (0−20%) and film thickness (15−500 nm) were deposited on quartz substrates. The sample structure is schematically shown in (i) of Fig. 1. The samples were annealed (450ºC) to induce crystallization.

Figure 2 shows Sn-concentration dependence of carrier mobility for grown samples.[2] With increasing Sn concentration from 0% to 2%, mobility increases; however, it decreases for Sn concentration exceeding 2%. It is noted that the optimum Sn concentration (2%) for the maximum mobility is almost equal to the solid-solubility of Sn in Ge. Weakening of average atomic bonding energies by Sn-doping (2%) without Sn precipitation is a key to realize high carrier mobility of Ge films on insulator.

Film thickness dependence of the carrier mobility of the grown samples (Sn concentration: 2%) is shown by blue symbols (i) in Fig. 3. The mobility significantly decreases with decreasing thickness, and cannot be measured for a sample with thickness of 20 nm, due to the high resistivity. Such a decrease in the carrier mobility is a serious problem in achieving fully-depleted devices.

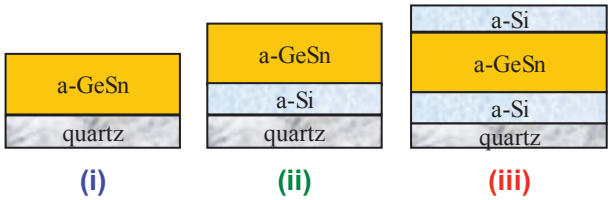

Fig. 1 Schematic sample structures (i), (ii), and (iii).

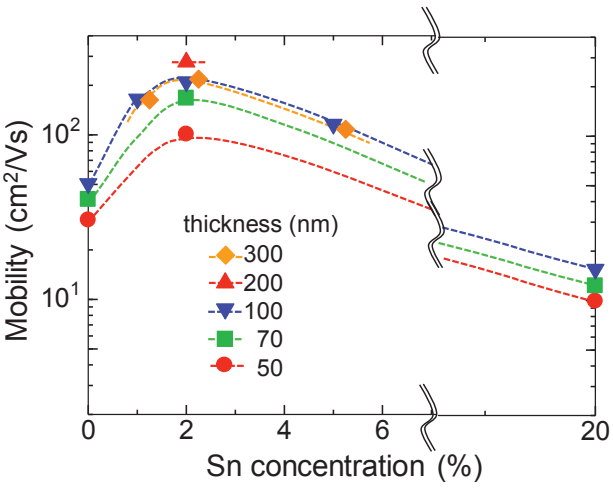

Fig. 2 Sn concentration dependence of mobility for sample structure (i).[2]

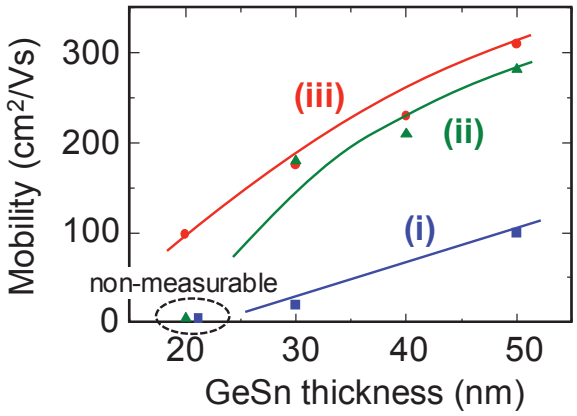

Fig. 3 Thickness dependence of carrier mobility for sample structures (i), (ii), and (iii). Sn concentration is 2%.

To reveal the phenomena, in-depth profile of the mobility in a sample (Sn concentration: 2%, thickness: 300 nm) is shown in Fig. 4.[2] The electrical properties can be distinguished into two regions, i.e., interface region (distance from the interface: ≤70 nm) and bulk region (≥70 nm). In the bulk region, the carrier mobility is high (~300 cm^2/Vs). On the other hand, the mobility significantly decreases in the interface region.

An electron backscattering diffraction (EBSD) image of the sample (thickness: 50 nm) with Sn concentration of 2% is shown in (i) of Fig. 5, where large grains preferentially oriented to (100) are observed. The (100)-oriented growth is attributed to the interface nucleation. This result suggests that the decrease in the carrier mobility in the interface region shown in Fig. 4 is attributed to defects in crystal grains initiated from the interface nucleation.

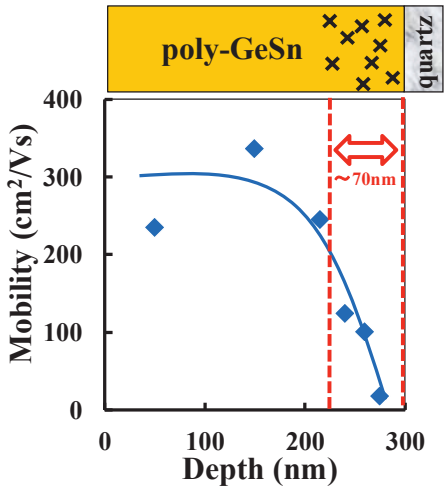

Fig. 4 In-depth profile of carrier mobility for sample structure (i) with Sn concentration of 2%.[2]

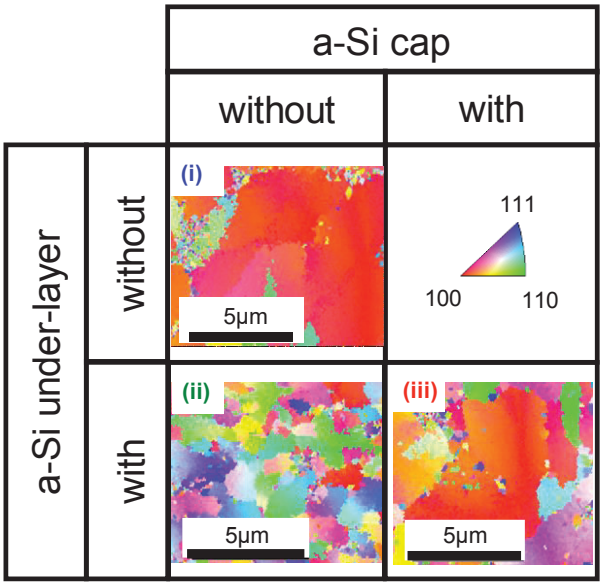

Fig. 5 EBSD images of sample structures (i), (ii), and (iii) with GeSn thickness of 50 nm and Sn concentration of 2%.

3 Effects of interface-modulation on SPC of Sn-doped Ge

To suppress interface nucleation, a-Si under-layers (thickness: 10 nm) are introduced into a-GeSn/substrate interfaces.[3] The sample structure is shown in (ii) of Fig. 1.

The EBSD image of the sample (GeSn thickness: 50 nm) is shown in (ii) of Fig. 5. This indicates that the crystal orientation of the grains becomes random, which is attributed to suppression of the interface nucleation and domination of the bulk nucleation. In this sample structure (ii), the grain sizes become smaller compared with the sample structure (i).

The thickness dependence of the carrier mobility in grown films for the sample structure (ii) is shown by the green symbols (ii) in Fig. 3. Interestingly, the carrier mobility becomes large by adding the a-Si under-layers for all film thickness, though the grain sizes become small. Analysis of the electrical properties of the grain boundaries reveals that the barrier height at the grain boundaries becomes low by adding the a-Si under-layers, which results in the higher carrier mobility compared with the sample structure (i). However, the mobility of the samples with thickness of 20 nm cannot be measured, as shown in Fig. 3.

It is speculated that this decrease in the mobility is also cased by retardation of SPC due to introduction of air in the surface regions of the a-Ge films. To solve this problem, addition of capping layers on the a-Ge films is examined.[4] Here, the sample structure shown in (iii) of

Fig. 1 is employed, where the Sn-doped Ge layer is covered with the a-Si capping layer (thickness: 5 nm).

The carrier mobility of the grown samples is shown as a function of the GeSn layer thickness by the red symbols (iii) in Fig. 3. Although the carrier mobility decreases with decreasing thickness for this sample structure, the carrier mobility becomes higher than that without a-Si cap, i.e., the sample structure (ii). It is noted that it becomes possible to measure the carrier mobility of the GeSn ultrathin film with 20 nm thickness, where the carrier mobility shows a high value of about 100 cm^2/Vs.

The EBSD image of the sample (GeSn thickness: 50 nm) with a-Si capping is shown in (iii) of Fig. 5. It is found that the grain sizes of the sample with a-Si capping become larger compared with the sample without capping shown in (ii). This results in the higher carrier mobility.

4 Summary

Recent studies of SPC of Ge thin films on insulator have been reviewed, in focusing on Sn-doping and interface-modulation. Selection of optimum Sn concentration (2%) is a key for achieving high carrier mobility. Moreover, interface-modulation using a-Si under-layers together with a-Si capping layers effectively improves the carrier mobility of ultrathin Sn-doped Ge films. This technique will be useful to realize advanced Ge-based fully-depleted devices for the next-generation electronics, such as three-dimensional LSIs and system-in-displays.

References

[1] M. Miyao and T. Sadoh, Jpn. J. Appl. Phys. **56**, 05DA06 (2017).

[2] T. Sadoh, Y. Kai, R. Matsumura, K. Moto, and M. Miyao, Appl. Phys. Lett. **109**, 232106 (2016).

[3] C. Xu, X. Gong, M. Miyao, and T. Sadoh, Appl. Phys. Lett. **115**, 042101 (2019).

[4] R. Hara, M. Chiyozono, and T. Sadoh, Ext. Abs.2021 International Conference on Solid State Materials and Devices, K-6-06 (2021).

[5] T. Nagano, R. Hara, K. Moto, K. Yamamoto, and T. Sadoh, Ext. Abs.2022 International Conference on Solid State Materials and Devices, B-8-04 (2022).