Extended Abstracts of the 2016 International Conference on Solid State Devices and Materials, Tsukuba, 2016, pp215-216

D-5-04

Thickness-Controlled Low-Temperature (~380°C) Solid-Phase Crystallization of Sn-Doped Poly-Ge/Insulator for High Carrier Mobility (~320 cm^2/Vs)

Kenta Moto, Taizoh Sadoh, Yuki Kai, Ryo Matsumura, and Masanobu Miyao
Department of Electronics, Kyushu University, 744 Motooka, Fukuoka 819-0395, Japan
Phone: +81-92-802-3737, E-mail: sadoh@ed.kyushu-u.ac.jp

Abstract

To achieve poly-Ge with high carrier mobility, thickness-controlled solid-phase crystallization of a-GeSn has been developed. Tuning of film-thickness (200 nm) and Sn-concentration (2%), combined with low-temperature annealing (380°C), enables formation of Sn-doped poly-Ge having high carrier mobility (~320 cm^2/Vs). This is the highest mobility of semiconductor films grown on insulator at low-temperatures (≤500°C).

1. Introduction

Low-temperature (≤500°C) formation of semiconductor-on-insulator with high carrier mobility is desired to realize high-performance thin-film transistors for 3-dimensional LSI and advanced system-in-display. Recently, Sn-doped poly-Ge with mobility of ~130 cm^2/Vs was reported by solid-phase crystallization (SPC) of a-GeSn (Sn concentration: 2%, thickness: 300 nm) at 450°C.[1] However, the mobility is as low as that of previously-reported poly-Ge grown by SPC at 500°C.[2] Therefore, further improvement of mobility is necessary.

In the present study, we investigate effects of Sn concentration, film thickness, and annealing conditions in wide ranges on SPC of a-GeSn. Important roles of these parameters are clarified. As a result, very high mobility (~320 cm^2/Vs) is achieved at a low temperature (~380°C).

2. Experiments and Results

Amorphous GeSn films with wide ranges of Sn concentration (0−20%) and film thickness (30−500 nm) were deposited on quartz substrates. The samples were annealed (380−500°C) to induce crystallization.

Hall effect measurements indicated p-type conduction for all grown layers. Figs. 1(a) and 1(b) show isothermal annealing characteristics (450°C) of carrier concentration and mobility, respectively, for samples (Sn concentration: 0%, 2%, 20%, thickness: 100 nm). With increasing annealing time, carrier concentration and mobility decrease and increase, respectively. They reach saturated values after annealing over 15 h, indicating whole crystallization of a-GeSn layers. Fig. 1(c) shows Sn-concentration dependence of mobility for samples after long-time annealing (450°C, 19 h), together with electron backscattering diffraction (EBSD) images. With increasing Sn concentration from 0% to 2%, mobility increases; however, it decreases for Sn concentration exceeding 2%. The EBSD images indicate that grain size becomes the maximum for Sn concentration of 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.

In-depth profiles of acceptor concentration and mobility in samples (Sn concentration: 2%), analyzed by successive Hall effect measurements combined with layer-by-layer wet etching, are shown in Fig. 2. Here, results obtained from samples with different thickness (200, 300 nm) are compared. The electrical properties can be distinguished into two regions, i.e., interface region (distance: ≤120 nm) and surface region (≥120 nm). Acceptor concentration and mobility are ~5×10^{17} cm^{-3} and ~150 cm^2/Vs, respectively, in the interface region. These values are almost the same as those for poly-Ge obtained by SPC (500°C), where mobility is degraded by scattering due to vacancy-related defects.[2] On the other hand, in the surface regions, acceptor concentration and mobility become low (~5×10^{16} cm^{-3}) and high (~300 cm^2/Vs), respectively. These values are comparable to single-crystal Ge-on-insulator (GOI) obtained by high-temperature oxidation-induced Ge condensation (900−1200°C).[3]

In Fig. 3, effects of film thickness on mobility and grain size are summarized for samples (Sn concentration: 2%). Here, thickness of the interface region (~120 nm), evaluated in Fig. 2, is indicated by hatching. For thickness ≤120 nm, grain size is almost constant (5−6 μm). In addition, mobility increases with increasing thickness, which reflects in-depth profiles of mobility (Fig. 2). On the other hand, for thickness ≥120 nm, mobility shows the highest value for 200-nm thickness, and then mobility and grain size decrease with increasing thickness. These results indicate that mobility is degraded by grain-boundary scattering due to decreased grain size for thickness ≥120 nm.

To improve mobility of samples (Sn concentration: 2%, thickness: 200 nm), we investigate effects of annealing temperature. Mobility and EBSD images are summarized as a function of the annealing temperature in Fig. 4. The EBSD images reveal that with decreasing annealing temperature, grain sizes increase from ~1 (500°C) and ~2 (450°C) to ~4 μm (380°C). As a result, very high mobility of 320 cm^2/Vs is achieved at 380°C. In the inset of Fig. 4, mobility obtained in the present study is compared to reported data for SPC-GeSn,[1] SPC-Ge,[2] and single-crystal GOI.[3] It is found that the mobility (320 cm^2/Vs) of the present study is comparable to single-crystal GOI obtained by high-temperature process (~1200°C).[3] This will facilitate realization of high-performance thin-film transistors for 3-dimensional LSI and advanced system-in-display.

3. Conclusion

Thickness-controlled low-temperature SPC of a-GeSn has been developed. By controlling film-thickness (200 nm) and Sn-concentration (2%), Sn-doped poly-Ge with high mobility (~320 cm^2/Vs) is obtained at low temperature (380°C). This high value of mobility is the top data of semiconductor films grown at low temperatures (≤500°). This SPC technique will be useful to realize high-performance thin-film transistors for next-generation electronics.

References

[1] W. Takeuchi, et al., APL **107**, 022103 (2015).
[2] K. Toko, et al., SSE **53**, 1159 (2009).
[3] N. Hirashita et al., APEX **1**, 101401 (2008).

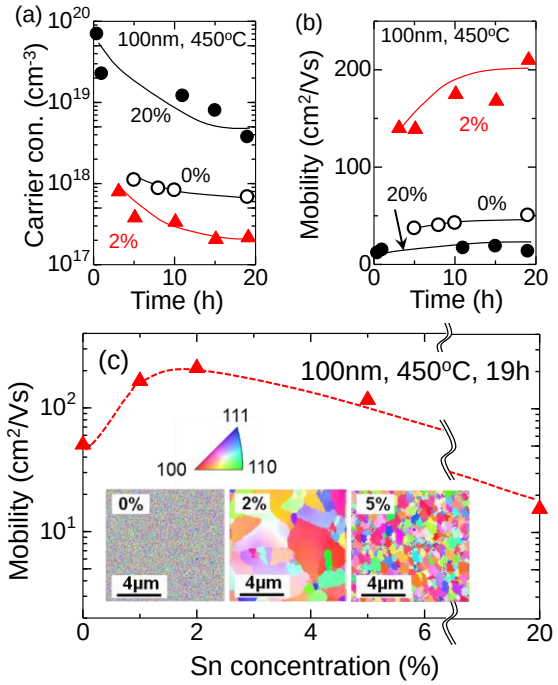

Fig. 1. Isothermal annealing characteristics (450°C) of carrier concentration (a) and mobility (b) for samples (thickness: 100 nm) with various initial Sn concentrations, and Sn concentration dependence of mobility (c) after annealing (450°C, 19 h). EBSD images of samples (Sn concentration: 0%, 2%, 5%) are also shown in (c).

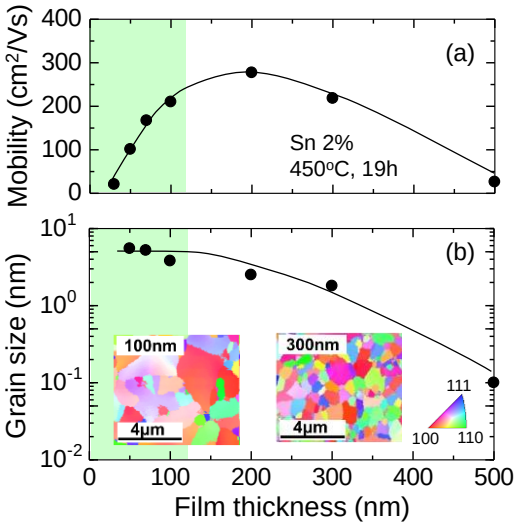

Fig. 3. Film thickness dependence of mobility (a) and grain size (b) for samples (Sn concentration: 2%) after annealing (450°C, 19 h). EBSD images of samples (thickness: 100, 300 nm) are also shown in (b).

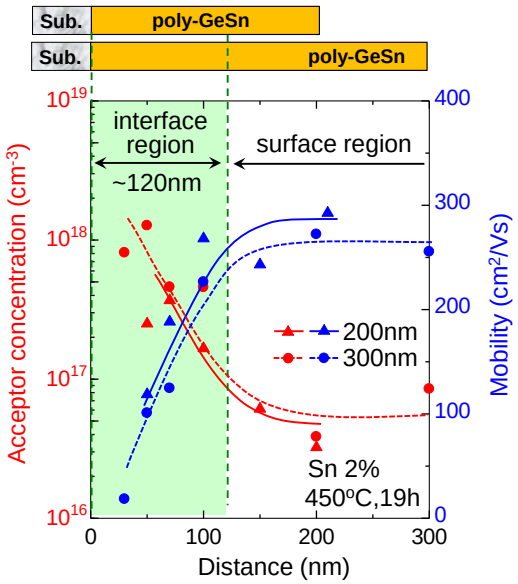

Fig. 2. In-depth profiles of acceptor concentration (a) and mobility (b) for samples (Sn concentration: 2%, thickness: 200, 300 nm) after annealing (450°C, 19 h). Schematic structures of grown samples are also shown.

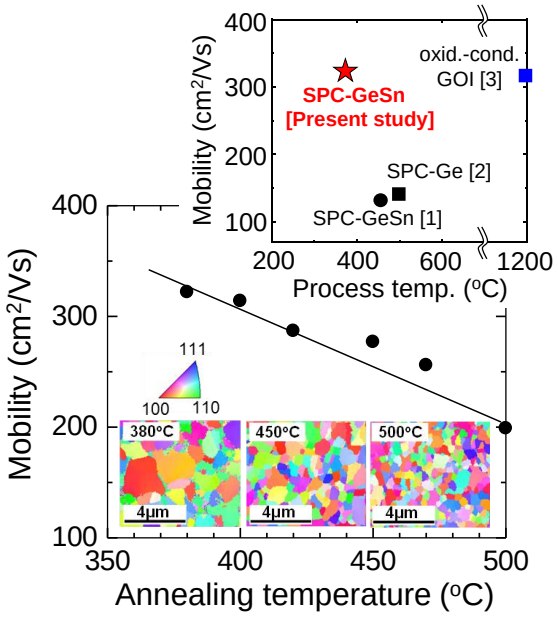

Fig. 4. Annealing-temperature dependent mobility and EBSD images of samples (Sn concentration: 2%, thickness: 200 nm). Inset shows comparison among the present study and reported SPC-GeSn,[1] SPC-Ge,[2] and oxidation-induced Ge condensation GOI.[3]