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# High-hole mobility GeSn on glass formed by solid-phase crystallization using an atomic density controlled precursor

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**Abstract**

**The solid-phase crystallized $Ge_{0.97}Sn_{0.03}$ thin film on a glass substrate exhibited a hole mobility exceeding 380 $cm^2$/Vs, the highest value among semiconductor thin films on insulators formed at low temperatures (< 900 °C). The key technology was the formation of an amorphous GeSn precursor with its atomic density close to that of crystalline GeSn.**

## 1. Introduction

To realize high-performance thin-film transistors, solid-phase crystallization (SPC) of Ge and GeSn films on insulators has been widely investigated [1,2]. Very recently, we found that the control of the atomic density of an amorphous Ge precursor for SPC dramatically enlarged the grain size and reduced the potential barrier height of the grain boundary in the resulting polycrystalline Ge (poly-Ge). The poly-Ge thin film exhibited a hole mobility of 340 $cm^2$/Vs. In the present study, we applied this method to GeSn and updates the highest hole mobility.

## 2. Experimental Procedures

Figure 1 shows the schematic of sample preparation. Amorphous $Ge_{1-x}Sn_x$ ($0 \leq x < 0.05$) precursors (thickness: 80-100 nm, deposition temperature $T_d$: 50-200 °C) were deposited on quartz glass substrates by a molecular beam deposition technique. We note that $T_d$ spontaneously rises from room temperature to 50 °C for Ge and 60 °C for GeSn without heating the substrate because of the radiation heat from the Knudsen cell. The Sn concentrations of the samples were quantified by Rutherford backscattering spectroscopy (RBS). The prepared samples, precursors for SPC, were then analyzed by X-ray reflectivity (XRR) measurement. Finally, the samples were annealed in $N_2$ ambient (growth temperature $T_g$: 450-475 °C) to induce SPC. The grown layers were analyzed by the electron backscattering diffraction (EBSD) measurement and Hall effect measurement (van der Pauw method).

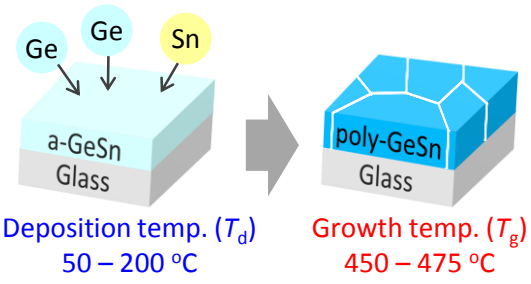


Fig. 1 Schematic of sample preparation.

## 3. Results and Discussion

Figure 2 shows that the densities of both precursors increase and asymptotically approach to that of crystals with increasing $T_d$. The Sn doping allows the density of a precursor to be close to that of the crystal where $T_d$ is low (< 100 °C).

After annealing the precursors at 450 °C for 5 h, the grain sizes were evaluated. Figure 3 shows that the grain size of the Ge sample is significantly enlarged by heating the substrate during the precursor deposition. This suggests that the lateral growth of nuclei is facilitated owing to the precursor whose density is close to that of crystalline Ge. On the other hand, the grain sizes of the $Ge_{0.97}Sn_{0.03}$ samples are large and decrease by heating the substrate during the precursor deposition. This behavior is likely related to the fact that the crystallization temperature of GeSn is lower than that of Ge: nucleation at $T_d$ = 125 °C.

The electrical properties were evaluated and shown in Fig. 4. All the samples showed p-type conductivity originating from the acceptor levels of vacancy-related defects [3,4]. The hole mobilities of both the Ge and $Ge_{0.97}Sn_{0.03}$ samples are the highest at $T_d$ = 125 °C. For the whole range of $T_d$, $Ge_{0.97}Sn_{0.03}$ exhibits the higher hole mobility and lower hole concentration than Ge.

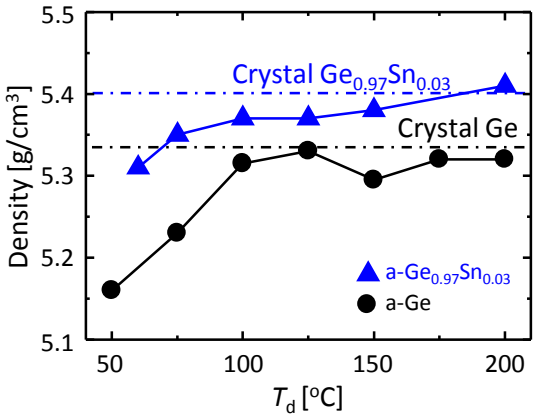


Fig. 2 Density of as-deposited Ge and $Ge_{0.97}Sn_{0.03}$ thin films determined by XRR patterns.

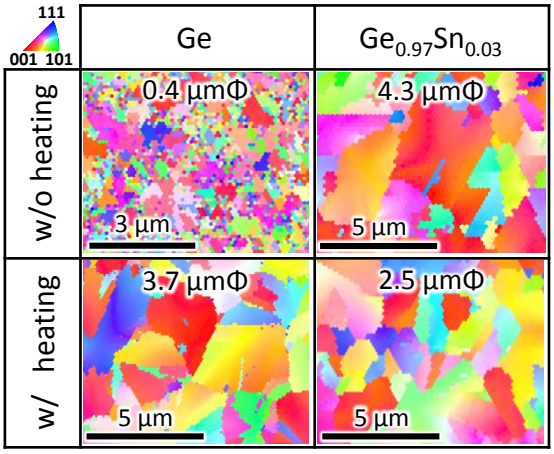


Fig. 3 EBSD images of the Ge and $Ge_{0.97}Sn_{0.03}$ samples after annealing ($T_g$ = 450 °C), where these precursors are prepared with and without heating the substrates ($T_d$ = 125 °C).

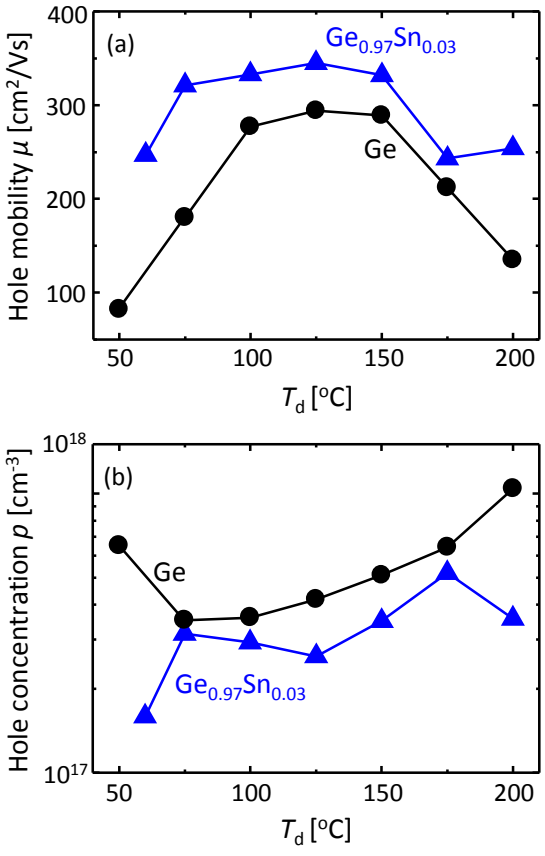


Fig. 4 $T_d$ dependence of the (a) hole mobility and (b) hole concentration for the Ge and $Ge_{0.97}Sn_{0.03}$samples with $T_g$ = 450 °C.

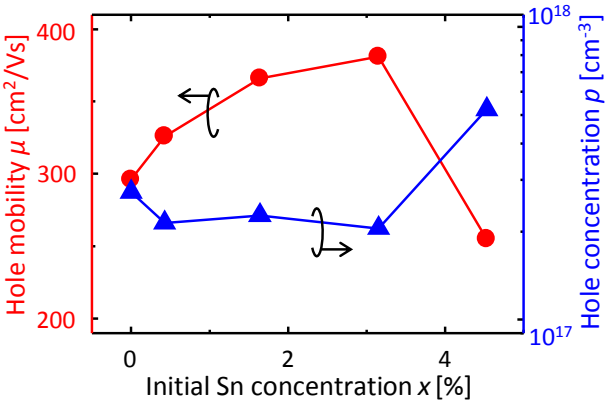


Fig. 5 Initial Sn concentration dependence of the electrical properties for the samples with $T_d$ = 125 °C, $T_g$ = 475 °C.

We investigated the effect of the Sn concentration on the electrical properties of GeSn. Figure 5 shows that the samples with a Sn concentration of 3.2 % provide the highest hole mobility (381 $cm^2$/Vs) and the lowest hole concentration ($2\times10^{17}$ $cm^{-3}$). The Sn concentration is slightly higher than the solubility limit of Sn in Ge. From the temperature dependence of the hole mobility, we determined that the enhancement of the hole mobility is owing to the low energy barrier height of the grain boundary (3.6 meV) in the $Ge_{0.97}Sn_{0.03}$. This suggests the passivation effect of Sn in poly-Ge. In the presentation, we discuss the relationship between the atomic density of precursor, substitutional Sn concentration, and electrical properties.

## 4. Conclusion

We focused on the atomic density of precursor for SPC of $Ge_{1-x}Sn_x$ ($0 \le x < 0.05$) on glass. By controlling the deposition temperature ($T_d$ = 125 °C) and the initial Sn concentration (3.2 %), we achieved the poly-GeSn with a high hole mobility (381 $cm^2$/Vs) and a low hole concentration ($2\times10^{17}$ $cm^{-3}$). The hole mobility is the highest among semiconductor thin films on insulators formed at low temperatures (< 900 °C).

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## References

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