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# Low-Temperature Solid-Phase Crystallization of SiSn on Insulator - Effects of Sn Concentration and Film Thickness -

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**Abstract**

**Formation of SiSn films with various Sn concentrations (5-10%) and thicknesses (40-200 nm) on insulator by solid-phase crystallization at low temperatures has been investigated. It is found that growth velocities significantly increase with increasing Sn concentration. For low Sn concentration (5%), the growth velocities decease with decreasing film thickness. On the other hand, for high Sn concentration (10%), the growth velocities do not depend on the thickness. These phenomena suggest that the growth process for low Sn concentrations are easily affected by the interface. The grown films have substitutional Sn concentrations (4-9%) exceeding the solid-solubility of Sn in Si (~1%), which demonstrates that the low-temperature solid-phase crystallization technique enables non-thermal equilibrium processing of SiSn.**

## 1. Introduction

The approach for improvement of Si-based LSI performance by scaling is facing physical limits. For further improvement of LSI performance, a new approach is required. The candidate is integration of high-speed transistors and high-efficient optical devices, consisting of novel functional materials, onto Si-based LSIs.

Sn-doped materials, such as GeSn and SiSn, are attractive owing to band structure tuning by Sn incorporation, which enables enhancement of optical and electrical properties. To merge devices consisting of these materials onto Si-based LSI, low-temperature growth techniques of these materials on insulators should be developed. Among these materials, low-temperature growth of GeSn has been intensively investigated [1]. On the other hand, reports of SiSn are very limited [2], and growth characteristics of SiSn have not been clarified yet.

In the present study, we investigate solid-phase crystallization (SPC) of SiSn films with various Sn concentrations and thicknesses on insulator. Effects of Sn concentrations and film thicknesses on SPC characteristics and substitutional Sn content in grown layers are discussed.

## 2. Experiments and results

Amorphous SiSn films (Sn concentration: 5-10%, thickness: 40-200nm) were deposited on fused-quartz substrates by a molecular-beam deposition system (base pressure: ~$5\times10^{-10}$ Torr). The samples were annealed (220°C-600°C) in $N_2$ to induce SPC. The sample structure is schematically shown in Fig. 1.

Growth features of the samples were analyzed by Nomarski microscopy. Figure 2(a) shows a micrograph of a sample (Sn concentration: 5%, thickness: 200 nm) annealed at 300°C for 60 min, where we can observe bright contrast domains. Here, some domains have black spots at the centers, as indicated by a white arrow in the figure. With increasing the annealing time to 120 min, the bright domains become large, as shown in Fig. 2(b). Micro-probe Raman measurements revealed that the bright domains are crystallized SiSn and the black points consist of crystal Sn (α-Sn).

To investigate growth characteristics, the radii of the bright domains are evaluated using the optical micrographs. Figure 3 shows the radii of bright domains with and without black points for samples (Sn concentration: 5%, thickness: 200 nm) as a function of the annealing time at 300°C. At respective annealing time, the domain radii of bright domains having black points are larger than those without black points. From the slopes of the fitted lines, growth velocities are evaluated, which indicate that the growth velocities for domains having black points ($4.3\times10^{-2}$ μm/min) are almost the same as those without black points ($4.1\times10^{-2}$ μm/min).

Arrhenius plots of the growth velocities of bright domains with and without black points for samples (Sn concentration: 5% and 10%, thickness: 200 nm) are shown in Fig. 4. It is found that the growth velocities significantly increase with increasing Sn concentration with keeping almost the same slopes for film thickness of 200 nm, where almost the same values of the growth velocities are obtained for samples with and without black points for respective Sn concentrations.

We investigated growth velocities of samples with various film thicknesses. The growth velocities did not depend on the thickness for the Sn concentration of 10%, while they are significantly decreased with decreasing thickness for the Sn concentration of 5%. The activation energies of the growth velocities are evaluated from the slopes of the Arrhenius plots for samples (Sn concentration: 5% and 10%) with various film thicknesses (40-200 nm). The values are summarized as a function of the thickness in Fig. 5. For Sn concentration of 5%, the activation energies increase from ~3 to ~8 eV with decreasing film thickness from 200 to 40 nm. On the other hand, for Sn concentration of 10%, the activation energies are almost constant in the thickness range of 40-200 nm. This thickness dependence of the activation energy suggests that growth process of SiSn with Sn concentration of 5% is more affected by the interface compared with 10%. However, further investigation is needed to clarify the detail.

Substitutional Sn concentrations in grown regions are analyzed from the positions of Raman peaks [3]. The results for samples (Sn concentration: 5% and 10%, thickness: 200 nm) are summarized in Fig. 6. In the figure, the value (~1%) of thermal equilibrium solid-solubility of Sn in Si is also shown. It is found that although the substitutional Sn concentrations (4% and 9%) in grown layers are slightly below the initial Sn concentrations (5% and 10%, respectively), they exceed the thermal equilibrium solid-solubility of Sn in Si. This demonstrates that non-thermal equilibrium processing becomes possible by this technique.

## 3. Conclusion

Low-temperature solid-phase crystallization of SiSn films on insulator has been investigated. The growth velocities significantly increase with increasing Sn concentration. The activation energies of the growth velocities depend on the thick ness for a low Sn concentration (5%), while they are independent of the thickness for a high Sn concentration (10%). These results suggest that growth process for the low Sn concentration (5%) is more easily affected by the interface compared with the high Sn concentration (10%). The grown films have high substitutional Sn concentrations, exceeding the thermal equilibrium solid-solubility of Sn in Si. This demonstrates that non-thermal equilibrium processing of SiSn is possible by low temperature SPC.

## References


[1] M. Miyao et al., JJAP **56**, 05DA06 (2017)
[2] M. Kurosawa et al., APL **106**, 171908 (2015)
[3] V. R. D'Costa et al., PRB **76**, 035211 (2007)


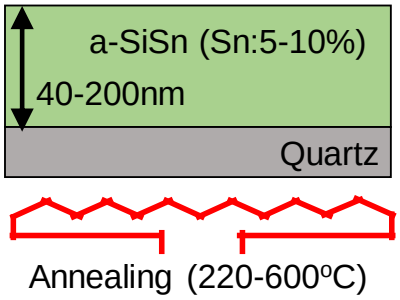


Fig.1 Schematic sample structure.

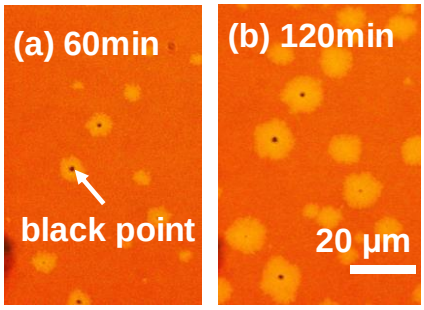


Fig.2 Nomarski micrographs of samples annealed for 60 (a) and 120min (b) at 300ºC.

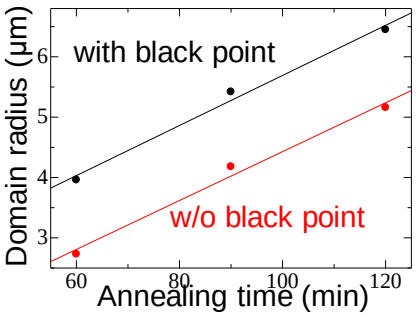


Fig.3 Annealing time dependence of domain radius.

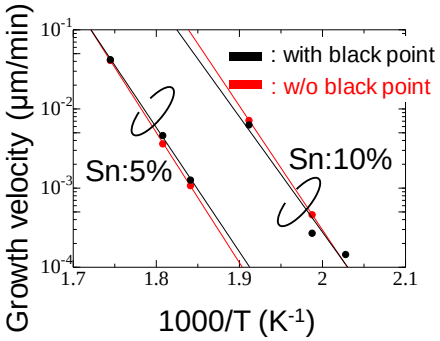


Fig.4 Arrhenius plot of growth velocity for samples with 200-nm-thickness.

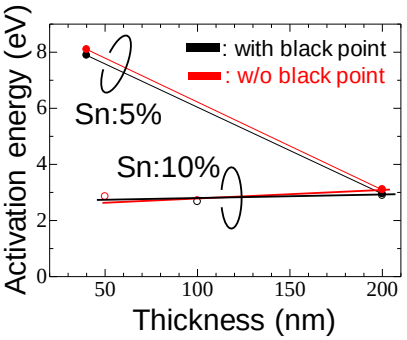


Fig.5 Activation energy of growth process as a function of thickness.

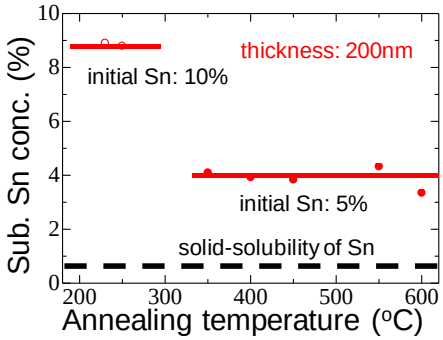


Fig.6 Sub Sn concentration as a function of annealing temperature for samples with 200-nm-thickness.