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High-Quality Hybrid-GeSn/Ge Stacked-Structures by Low-Temperature Sn-Induced-Melting Growth

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INTRODUCTION

To break through the scaling limit of Si-LSIs, development of functional materials becomes essential. GeSn is a big candidate for this purpose, because GeSn provides direct energy-band gap and very light carrier effective-mass [1,2]. In line with this, development of a formation technique of high-quality GeSn is desired.

Our approach for formation of high-quality GeSn is utilization of liquid-phase reaction. To induce liquid-phase crystallization at low temperatures, we propose to employ a-Ge/Sn stacked structures deposited on c-Ge as a starting material. To examine this idea, in the present study, we investigate growth characteristics of a-Ge/Sn/c-Ge stacked structures.

EXPERIMENTS

The experimental procedure is schematically shown in Fig. 1. Sn (20 nm thickness) and a-Ge (100 nm) layers were deposited on Ge(100) substrates by using a molecular beam technique. After capping with SiO_2 layers (800 nm), the samples were heat-treated (450-600^{o}C, 1 sec- 1 min) to induce crystallization. The grown layers were analyzed by using electron backscattering diffraction (EBSD), Rutherford backscattering spectroscopy (RBS) and cross-sectional transmission electrical microscopy (TEM).

RESULTS AND DISCUSSION

The EBSD images of the samples after annealing are shown Fig. 2. For samples annealed at 450-600^{o}C for 1 sec, crystallization is not detected. On the other hand, after annealing at 600^{o}C for 1 min, single crystallization with (100)-orientation, identical to the substrate, is clearly observed. In order to investigate crystallinity and Sn-distribution in grown layers, RBS measurements were performed. The RBS spectra, obtained under channeling and random configurations, are shown in Fig. 3(a). From change in the channeling-signals due to Ge atoms, it is clear that epitaxial growth starts to progress at 600^{o}C, and completes after annealing for 1 min. On the other hand, analysis of signals due to Sn indicated that the peak positions of Sn profiles moved toward the surface with increasing annealing temperature and time. Such peak-shift cannot be explained by a simple diffusion model of Sn in Ge. To reveal the phenomena, the positions of the Sn peaks and growth fronts, i.e., amorphous/crystal interfaces, are comparatively summarized as a function of the annealing temperature in Fig. 3(b). Interestingly, shift of the Sn peaks shows a good agreement with that of growth fronts. RBS analysis showed that Sn concentration in epitaxially-grown GeSn was about 2%.

Based on these findings, we propose a growth model of a-Ge/Sn/c-Ge structures. The Sn layer melts at the early stage of annealing. This results in formation of liquid-GeSn by Ge incorporation from the a-Ge layer. With increasing annealing time, a GeSn layer epitaxially grown on the c-Ge substrate, and Ge atoms in the a-Ge layer are introduced into liquid-GeSn, because crystal state is energetically favorable compared with amorphous. Such a growth process progresses until the liquid-GeSn layer reaches the surface. Finally, during the cooling process, the GeSn layer epitaxially solidifies with Sn segregation at the surface [3].

In order to examine effects of c-Ge substrate attaching to the liquid-GeSn, annealing of a-Ge/Sn/a-Ge stacked structures was investigated. Even though under the same annealing conditions (450-600^{o}C, 1 sec), Sn peak positions did not move after annealing. These results support our growth model that epitaxial growth of GeSn accompanies movement of liquid-GeSn regions.

To clarify the crystallinity of grown layers, TEM analysis was performed. No dislocations or faults are found in the grown GeSn region. Detailed investigation of the crystal structures revealed complete lattice-matching at the GeSn/Ge interface without any defects. These result indicate very high-quality of grown layers.

In summary, high-quality GeSn/Ge stacked structures are achieved by low-temperatures annealing (600^{o}C) of a-Ge/Sn/c-Ge structures. These phenomena are explained on the basis of Sn-induced melting growth. This technique facilitates the next-generation multi-functional LSIs.

REFERENCES

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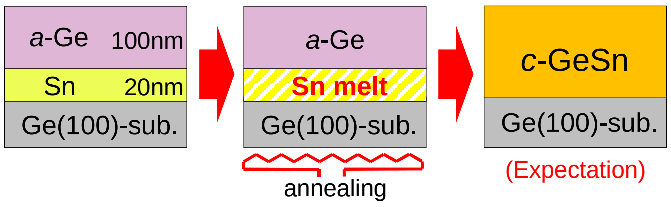

Fig. 1 Schematic sample structures before and after annealing.

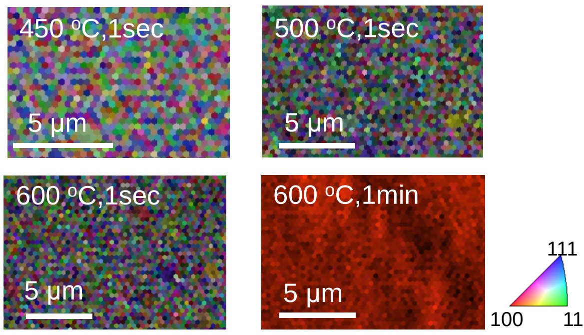

Fig. 2 The EBSD images of sample after annealing.

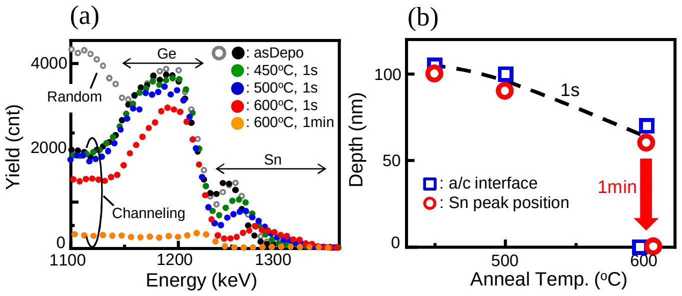

Fig. 3 RBS channeling and random spectra (a) and annealing temperature dependence of Sn-peak-position and growth-front (b).