Epitaxial Growth and Characterization of $Ge_{1-x}Sn_x$ Layers on Ge(110) and Si(110) Substrates

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1. Introduction
(110)-oriented Ge channel is one of promising candidates for future MOSFET devices in considering surface orientation because of its lager hole mobility than that of Ge(001) [1]. We have to develop the epitaxial growth technique of Ge on Si(110) to realize Ge(110) channel MOSFET. On the other hand, channel strain engineering is also important to enhance the carrier mobility. $Ge_{1-x}Sn_x$ alloy, which has a lager lattice constant than Ge, is expected to be source/drain (S/D) stressor for realizing uniaxial compressive strained Ge channel [2]. However, the epitaxial growth of Ge and $Ge_{1-x}Sn_x$ layers on (110) substrates has many difficulties compared to that on (001) substrates [3]. In this study, we demonstrated the incorporation of Sn atoms effectively improves on the crystalline quality of Ge layers grown on Si(110) and Ge(110) substrates.

2. Experimental procedure
A Ge or $Ge_{1-x}Sn_x$ layer was grown on a Si(110) or Ge(110) substrate using a molecular beam epitaxy (MBE) system with a base pressure less than 1×10^{-8} Pa. The growth temperatures were 200°C and 150°C on Si and Ge substrates, respectively.

3. Results and discussion
Figures 1(a) and 1(b) show cross-sectional TEM images of Ge layers grown on Ge(110) and Si(110) substrates. In Fig. 1(a), we confirmed the formation of twin defects in the upper regions of the Ge layers with the selected area diffraction. The Ge layer grown on Si(110) has a lot of defects including misfit dislocations, stacking faults, and heavily twinned structures.

On the other hand, cross-sectional TEM images of $Ge_{1-x}Sn_x$ layers grown on Ge(110) and Si(110) substrates were shown in Figs. 2(a) and 2(b), respectively. In contrast to the Ge growth, the $Ge_{1-x}Sn_x$ layer with a Sn content of 2.4% grown on Si(110) has the superior crystalline quality; no twin defect growth. Furthermore, in the case of the $Ge_{1-x}Sn_x$ growth on a Ge(110), we can find no Sn precipitation and no defects such as stacking faults and twin defect in the $Ge_{1-x}Sn_x$ layer. This behavior is considered to be the reduction of the anisotropy in the surface reconstruction of Si(110) and Ge(110) due to the Sn adsorption.

We also investigated the strain relaxation behavior of the $Ge_{1-x}Sn_x$ layer during the post deposition annealing (PDA) at 600°C for 10 min in N_2 ambient. As shown in Figs. 3(a) and 3(b), XRD-2DRSM results reveal the pseudomorphic growth of the as-grown $Ge_{1-x}Sn_x$ layer on a Ge(110) substrate. The strain in the $Ge_{1-x}Sn_x$ layer is relaxed along the [001] direction after the PDA as shown in Fig. 3(c). On the other hand, we confirmed the strain in the $[\bar{1}10]$ direction is hardly relaxed (*not shown*). These results indicate that the anisotropic strain relaxation along the [001] direction preferentially occurs with PDA.

4. Conclusions
We examined the epitaxial growth of Ge and $Ge_{1-x}Sn_x$ layers on Si(110) and Ge(110) substrates. The incorporation of Sn effectively improves on the crystallinity of the epitaxial Ge layer on both Si(110) and Ge(110) substrates. We also found the anisotropic strain relaxation behavior of a $Ge_{1-x}Sn_x$ layer grown on Ge(110).

Acknowledgements

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References

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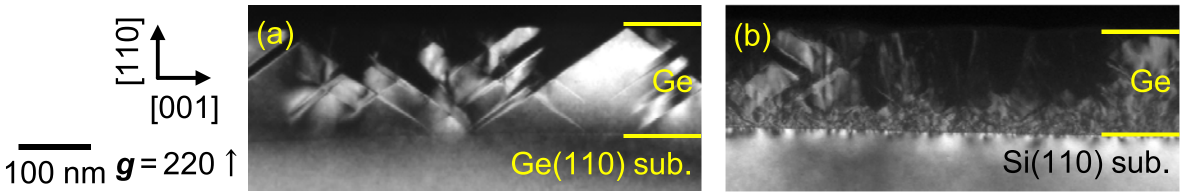

Fig. 1: Cross-sectional TEM images of Ge layers grown on (a) Ge(110) and (b) Si(110) substrates.

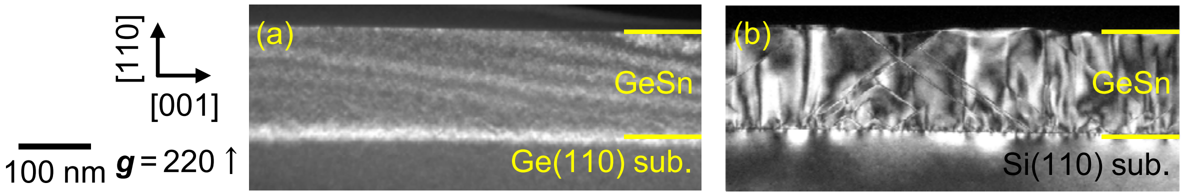

Fig. 2: Cross-sectional TEM images of (a) the $Ge_{0.954}Sn_{0.046}$ layer grown on a Ge(110) substrate and (b) the $Ge_{0.976}Sn_{0.024}$ layer on a Si(110) substrate.

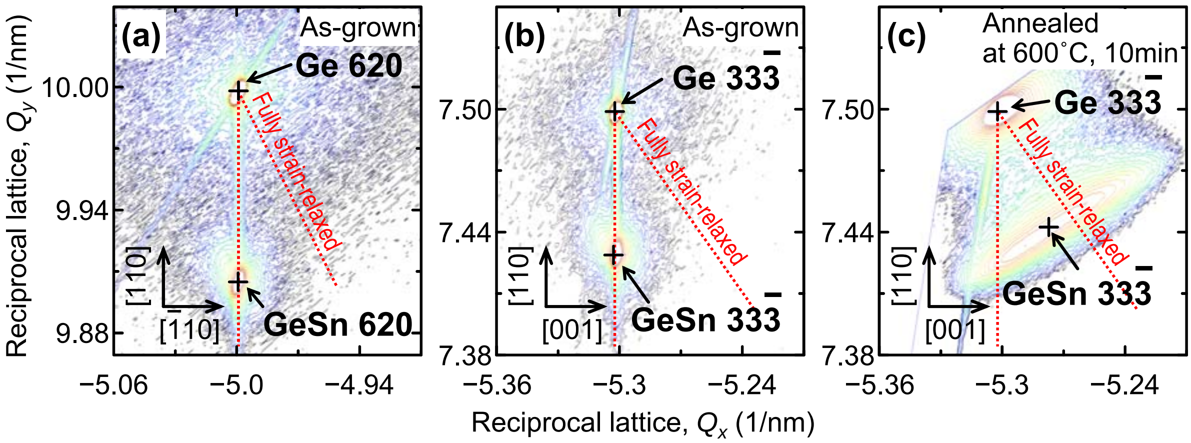

Fig. 3: XRD-2DRSM results for the $Ge_{0.954}Sn_{0.046}$ layers; (a), (b) as-grown and (c) after PDA at 600°C for 10 min.