GeSn Alloy for Nanoelectronic and Optoelectronic Devices

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The development of new materials for ULSI technology is necessary to overcome various kinds of limits in realizing nano-scale CMOS devices. We are paying the attention to high-mobility channel technology using alternative channel materials such as $Si_{1-x}Ge_x$, Ge and III-V compound semiconductors for enhancing the current drivability of MOSFETs. Ge is an attractive candidate for the next generation CMOS applications, since its higher carrier mobilities than bulk-Si not only for holes but also electrons. Moreover, theoretical calculation has predicted that a biaxial tensile-strained Ge has higher mobilities than bulk-Ge both holes and electrons. We need to apply a biaxial tensile strain over 1.0% into Ge layers to obtain higher effective electron mobilities than conventional strained Si. Here, we are interested in strain-relaxed $Ge_{1-x}Sn_x$ buffer layers as a stressor for realizing tensile-strained Ge layers, because $Ge_{1-x}Sn_x$ has a larger lattice constant than Ge [1]. In addition, $Ge_{1-x}Sn_x$ alloy is also considered for embedded source/drain (S/D) stressors for realizing uniaxial compressive-strained Ge channel [2].

On the other hand, we can expect other applications of $Ge_{1-x}Sn_x$ alloy for optoelectronic devices. The energy band gap of $Ge_{1-x}Sn_x$ can be decreased with increasing Sn content. Also, we can control the energy band structure of $Ge_{1-x}Sn_x$ alloy with modifying Sn content. The conduction band minimum at the Γ point decreases more rapidly than that at the L point with the increase of the Sn content, and $Ge_{1-x}Sn_x$ with a high Sn content over 11% has been predicted to be a direct-transition semiconductor from indirect-transition [3]. Therefore, extending the detectable wavelength and improving on the adsorption of light in optoelectronic devices are expected by using high Sn content $Ge_{1-x}Sn_x$.

Therefore, high Sn content $Ge_{1-x}Sn_x$ promises applications for not only light receiving devices but also light emitting devices. Moreover, high Sn content $Ge_{1-x}Sn_x$ is also attractive for the application to high speed electronic devices. Because the electron mobility is expected to increase significantly with becoming the direct-transition from the indirect-transition due to preferential occupation of free electrons with much smaller effective mass in the Γ valley than the L valley [4].

We have investigated the formation and crystalline properties of heteroepitaxial $Ge_{1-x}Sn_x$ on various substrates. Recently, we have achieved the epitaxial growth of strained or strain-relaxed $Ge_{1-x}Sn_x$ layers with a Sn content of 5~12% on Si and Ge substrates and also the heteroepitaxial growth of $Ge_{1-x}Sn_x$ layers with a very high Sn content of 27% on InP substrates (Fig. 1) [5]. We clarified the Sn content dependence of the energy bandgap of $Ge_{1-x}Sn_x$ layers with the Fourier transform infrared spectroscopy (FTIR) measurement (Fig. 2).

We have also investigated the electrical properties of epitaxial $Ge_{1-x}Sn_x$ layers for the electronic applications. We found that the Sn incorporation effectively improves the redistribution and electrical activation of dopant atoms in Ge (Figs. 3 and 4) [6]. In addition, we also found that the interaction of Sn and vacancy in Ge matrix is an important factor to suppress the unintentional hole generation due to vacancy defects. We will discuss the effect of the Sn incorporation on the carrier behavior in the Ge epitaxial layers [7].

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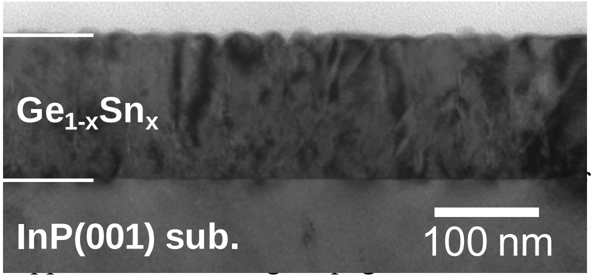

Fig. 1 Cross-sectional TEM image of the $Ge_{0.77}Sn_{0.23}$ heteroepitaxial layer on InP(001) substrate.

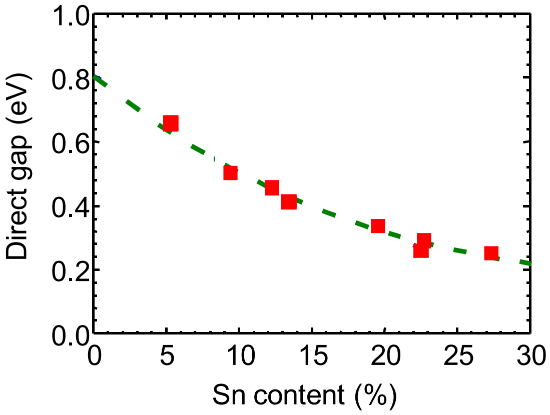

Fig. 2 The direct energy bandgap estimated with FTIR spectra for $Ge_{1-x}Sn_x$ epitaxial layers as a function of the Sn content.

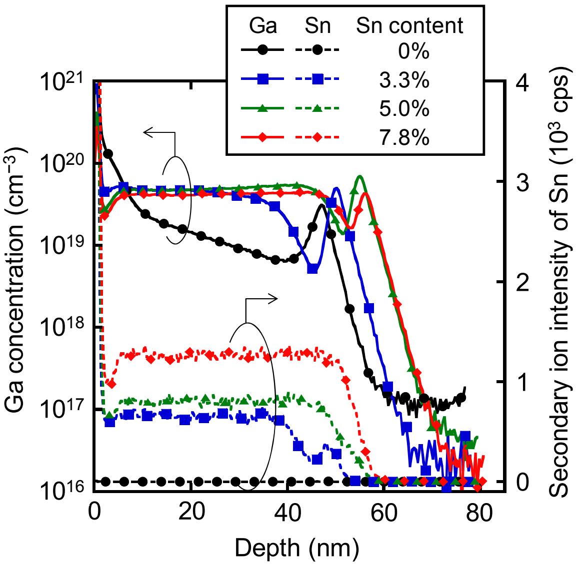

Fig. 3 SIMS depth profiles of Ga and Sn atoms in as-grown Ga-doped $Ge_{1-x}Sn_x$/Ge samples with various Sn contents.

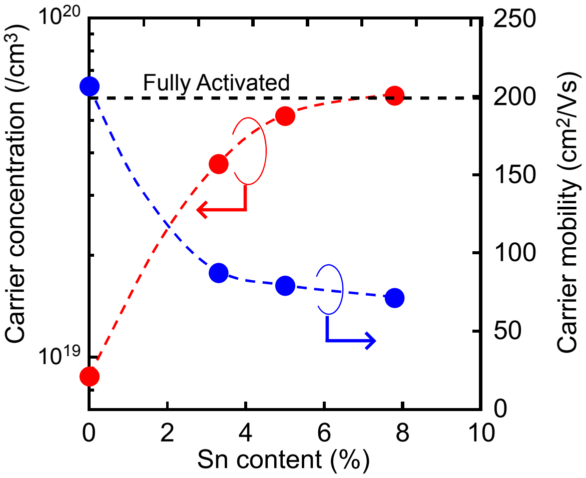

Fig. 4 The carrier concentration and mobility estimated using µ4pp-Hall measurement for as-grown Ga-doped $Ge_{1-x}Sn_x$ layers on Ge(001) substrates.