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Impact of ultra-high Sn content Sn_xGe_{1-x} interlayer on reducing Schottky barrier height at metal/n-Ge interface

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Abstract

We have investigated the impact of an ultra-high Sn content-Sn_xGe_{1-x} interlayer on the electrical conduction property of metal/Ge interface. Atomically flat epitaxial Sn_xGe_{1-x} layers with Sn contents of 14–60% were successfully obtained by considering the strain magnitude of epitaxial layer. We found that the SBH of Al/Sn_xGe_{1-x}/n-Ge decreases by 0.13 eV with increasing the Sn content to 60%.

1. Introduction

One of the serious issues for realizing high performance Ge-complementary metal-oxide-semiconductor (CMOS) transistors is a high contact resistance of metal/n-Ge interface due to its high Schottky barrier height (SBH). This is because of Fermi level pinning (FLP) phenomenon, in which the Fermi level of metal electrode is pinned at the valence band edge of Ge and SBH at metal/n-Ge interface generally shows a high value of 0.55–0.66 eV independently on the metal work function [1, 2]. SBH-reduction methods by dielectric interlayer [3, 4], epitaxial metal [5–7], and TiN [8] were previously reported. From these reports, both perfect Fermi level depinning and the shift of pinning position have to be investigated in detail for the reduction of SBH at metal/n-Ge interface.

α-Sn has a potential to alleviate FLP and shift the pinning position. The reduction of SBH by an α-Sn interlayer is expected in terms of low-defect structure with an epitaxial α-Sn/Ge interface, suppression of the penetration of the electron wave function from zero-bandgap semiconductor, α-Sn, and the shift of pinning position to the conduction band edge considering a large valence band offset of 0.69 eV at the α-Sn/Ge interface [9]. Recently, the SBH reduction at β-Sn/n-Ge interface by an α-Sn interlayer is expected from the theoretical calculation [10]. However, the epitaxial growth of atomically-flat α-Sn layer on Ge is a difficult challenge because of a large lattice mismatch of 14% between α-Sn and Ge.

In this study, we try to form a Sn_xGe_{1-x} interlayer because, by alloying α-Sn with Ge, the formation of dislocations at the interface for the strain relaxation can be suppressed. The impact of an ultra-high Sn content Sn_xGe_{1-x} interlayer on the SBH at the metal/n-Ge interface is discussed. It is found that the pinning position can be controlled by the Sn content of Sn_xGe_{1-x} layer.

2. Sample preparation

N-Ge(001) wafers were prepared. After chemical and thermal cleaning, 3 nm-thick Sn_xGe_{1-x} layers were deposited on the Ge substrate by using Knudsen cells of Sn and Ge source with a growth temperature of 50°C. Using X-ray photoelectron spectroscopy, Sn contents of prepared Sn_xGe_{1-x} layers were estimated to be 14%, 48%, and 60%. In the reflection high energy electron diffraction (RHEED) observation, the epitaxial growth of Sn_xGe_{1-x} layers were confirmed in all samples (**Fig. 1**). Uniform and flat surfaces without Sn precipitation were observed in all samples by using atomic force microscopy (AFM) (**Fig. 2**). As a result of suppressing the strain relaxation of Sn_xGe_{1-x} layers by decreasing the thickness as thin as possible, we can see no three dimensional growth, dislocation generation, nor Sn precipitation in all Sn_xGe_{1-x}/Ge(001) samples. After taking out the samples to atmosphere, native oxide on the Sn_xGe_{1-x} surface was chemically removed by dipping into diluted hydrofluoric acid. Then, Al electrodes were immediately deposited on the surface and backside with vacuum evaporation method to prepare Al/Sn_xGe_{1-x}/n-Ge(001) Schottky diodes.

3. Results and discussion

Current density-voltage (*J*-*V*) characteristics of Al/Sn_xGe_{1-x}/n-Ge(001) Schottky diodes for various Sn contents at 300K are shown in **Fig. 3**. The forward current density increases with the Sn content. This suggests that the SBH decreases with increasing in the Sn content of the Sn_xGe_{1-x} interlayer.

Figure 4 shows the Arrhenius plots of the saturation current density obtained from the forward *J*-*V* characteristics of all samples at 200–300K. The ideality factors, n are near to unity at all measurement temperatures for all diodes, which means thermionic emission current is dominant and any leakage current component can be negligible in the total current at the metal/n-Ge interface.

The Sn content dependence of SBHs obtained from the Al/Sn_xGe_{1-x}/n-Ge(001) Schottky diodes are shown with circle plots in **Fig. 5**. The SBH of the Al/2 nm-thick Sn/n-Ge Schottky diode is also shown. The deposition temperature of a 2 nm-thick Sn layer was room temperature.

SBH decreases with increasing in the Sn contents of the Sn_xGe_{1-x} layers.

To deduce the reason why the SBH reduces by the increasing the Sn content of the Sn_xGe_{1-x} interlayer, we considered the energy band structure of Sn_xGe_{1-x} as shown in the inset of **Fig. 5**. The energy bandgap of Sn_xGe_{1-x} decreases with increasing in the Sn content [11, 12], and the value is expected to be zero when the Sn content is over 40%. Additionally, considering that the valence band edge of α-Sn is higher than that of bulk Ge by 0.69 eV [9], we can expect that the valence band edge of the Sn_xGe_{1-x} becomes higher than that of Ge with increasing in the Sn content, although the conduction band edge is approximately constant independently on the Sn content. This band structure would lead that the Fermi level position of the Al electrode at the interface shifts toward the conduction band edge of Ge, leading the SBH reduction for n-Ge.

4. Conclusions

We investigated the impact of a Sn_xGe_{1-x} interlayer on the electrical property of the metal/Ge interface. The epitaxial growth of a thin Sn_xGe_{1-x} layer with a very high Sn content of 60% is achieved by controlling the strain of the grown layer. The SBH can be reduced with increasing in the Sn content of Sn_xGe_{1-x} interlayer. Considering the energy band structure of high-Sn content Sn_xGe_{1-x}, we deduce that the SBH reduction would be due to the shift of the pinning level at the Al/n-Ge interface toward the conduction band edge of Ge.

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References

[1] A. Dimoulas *et al.*, Appl. Phys. Lett. **89**, 252110 (2006).
[2] T. Nishimura *et al.*, Appl. Phys. Lett. **91**, 123123 (2007).
[3] T. Nishimura *et al.*, Appl. Phys. Exp. **1**, 051406 (2008).
[4] M. Kobayashi *et al.*, J. Appl. Phys. **105**, 023702 (2009).
[5] K. Yamane *et al.*, Appl. Phys. Lett. **96**, 162104 (2010).
[6] T. Nishimura *et al.*, Microelectron. Eng. **88**, 605 (2011).
[7] Y. Deng *et al.*, Thin Solid Films **557**, pp. 84-89 (2014).
[8] K. Yamamoto *et al.*, Appl. Phys. Lett. **104**, 132109 (2014).
[9] G. E. Chang *et al.*, IEEE. J. Quantum Electron. **46**, 12 (2010).
[10] K. Kobinata *et al.*, *in Ext. Abstr. of* SSDM 704 (2014).
[11] S. Gupta *et al.*, J. Appl. Phys. **113**, 073707 (2013).
[12] O. Nakatsuka *et al.*, Solid-State Electron. **83**, 82 (2013).

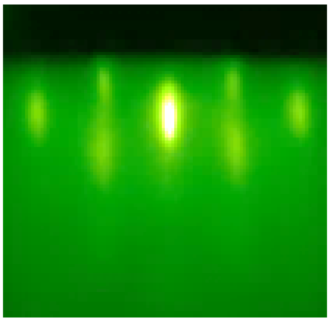

Fig. 1 RHEED pattern of the $Sn_{0.60}Ge_{0.40}$/Ge sample.

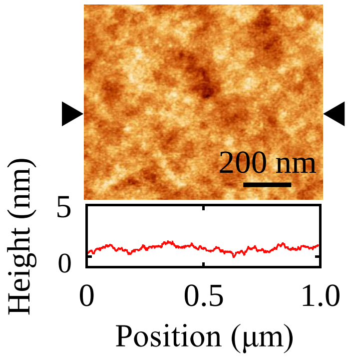

Fig. 2 The surface AFM image and line profile of the $Sn_{0.60}Ge_{0.40}$/Ge sample.

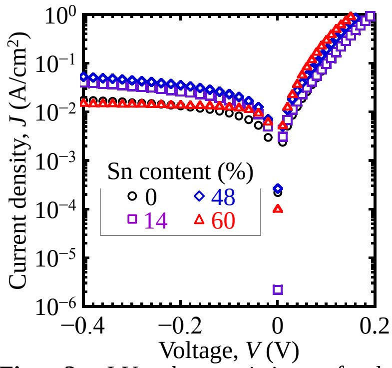

Fig. 3 *J-V* characteristics of the Al/Sn_xGe_{1-x}/n-Ge(001) Schottky diodes at 300K

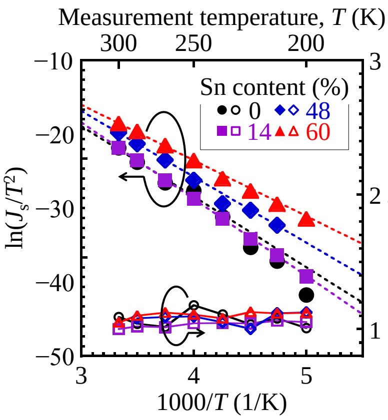

Fig. 4 Arrhenius plots of the saturation current density for the Al/Sn_xGe_{1-x}/n-Ge(001) Schottky diodes. The ideality factors are also shown.

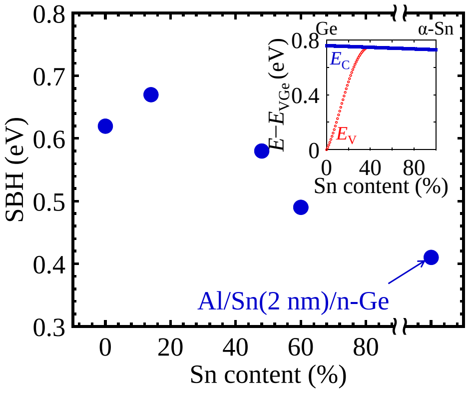

Fig. 5 The Sn content dependence of SBHs of the Al/Sn_xGe_{1-x}/n-Ge(001) Schottky diodes.
(inset) Energy band structure of $Sn_{1-x}Ge_x$ layer as a function of the Sn content. E_C, E_V, and E_{VGe} mean the valence band maximum and the conduction band minimum of Sn_xGe_{1-x}. , and the valence band maximum of Ge, respectively.