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Reduction of Schottky Barrier Height for n-type Ge Contact by using Sn Electrode

Akihiro Suzuki[1], Shunsuke Asaba[1], Jun Yokoi[1], Osamu Nakatsuka[1], Masashi Kurosawa[1,2], Kimihiko Kato[1], Mitsuo Sakashita[1], Noriyuki Taoka[1], and Shigeaki Zaima[1]
[1]Graduate School of Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
[2]The Japan Society for the Promotion of Science Reserach Fellow (PD), Japan
Phone: +81-52-789-2759, Fax: +81-52-789-2760, E-mail: nakatuka@alice.xtal.nagoya-u.ac.jp

Abstract
The Schottky barrier height (SBH) as low as 0.35 eV is achieved with a tin (Sn)/n-germanium (Ge) contact formed at room temperature. Sn electrode exhibits abnormal dependence of the SBH on the work function compared to other metal/n-Ge contacts whose SBHs are higher than 0.5 eV due to the Fermi level pining (FLP) phenomenon. We also found that the SBH value of the Sn/n-Ge sample increases with annealing above 150°C.

1. Introduction

Ge is one of promising candidates for channel material of next generation metal-oxide-semiconductor field effect transistors (MOSFET) because of its high carrier mobility for both electrons and holes. One of serious issues for realizing high performance Ge-MOSFET is difficulty of lowering SBH of metal/n-Ge contact due to the FLP phenomenon. There are some reports of lowering SBH of metal/n-Ge contact by using dielectric intermediate layers [1,2], third element incorporation such as sulfur [3], epitaxial layers [4-6], and TiN [7]. However, the origin of FLP has not been understood in detail yet and the technique to control SBH still has to be developed. It is essentially important to investigate the electrical conducting characteristic of various metals to clarify FLP phenomenon.

We focused Sn electrode for Ge contact. Ge-Sn system is eutectic type and there is no composition metal alloy. The equilibrium solid solubility of Sn for Ge is very low of about 1%. In this study, we found that a Sn electrode prepared at room temperature realizes the SBH as low as 0.35 eV for n-type Ge(001) contact. We investigated the electrical properties and SBH of Sn/n-Ge Schottky contacts with comparing to Al and Au contacts. We also examined thermal stability of Sn/Ge contact for annealing treatment.

2. Sample preparation

N-type Ge(001) wafer with a resistivity of 1-2 Ωcm were used for substrate. After chemical cleaning of a substrate with diluted HF solution and deionized water, a 700 nm-thick Sn layer was deposited at room temperature by using e-gun deposition with metal mask on Ge substrate to form Schottky contact. The area size of electrode was 8×10^{-2} mm^2. The vacuum pressure was below 10^{-3} Pa during the deposition. Then, backside Al electrode was formed. We also prepared Schottky diodes with Al and Au electrode for comparison.

3. Results and discussion

Current density-voltage (J-V) characteristics of Schottky diodes were measured to estimate SBH. Figure 1 shows the J-V characteristic at various measurement temperatures for the Sn/n-Ge(001) sample prepared at room temperature. The J-V characteristics show good thermionic emission current conduction at wide temperature range. We estimated the SBH of Sn, Au, and Al/n-Ge contact by using an equation of thermionic emission current of Schottky contact. Figure 2 shows the Arrhenius plot of $\ln(J_s/T^2)$ and the ideality factor for the Sn/n-Ge sample. The SBH is estimated from the slope of the Arrhenius plot in the range where the ideality factor is near to unity.

Figure 3 shows estimated SBH values from J-V characteristics of Sn, Al, and Au/n-Ge(001) samples as a function of metal work function. Previously reported values of SBH are also summarized in Fig. 3 [8]. The broken line in Fig. 3 indicates the work function dependence of SBH assuming the Schottky limit. SBH value of the Sn/n-Ge(001) sample is estimated to be as low as 0.35 eV, which is near the value estimated with assuming the Schottky limit. On the other hand, SBH values of Al and Au/n-Ge(001) samples in this study are estimated to be 0.56 eV and 0.59 eV respectively. These SBH values hardly depend on the metal work function similar to previous reports.

We also prepared a Sn/n-Ge(111) diode at room temperature and measured the J-V characteristics. The SBH of the Sn/n-Ge(111) contact is estimated to be as low as 0.33 eV. These results mean that Sn/n-Ge contacts promise low SBH independently on the substrate orientation contrary to epitaxial metal/Ge contact [4,5].

We investigated the influence of thermal annealing on the electrical property of Sn/Ge contact. Figure 4 shows the annealing temperature dependence of SBH values for Sn/n-Ge samples. The SBH for the sample annealed at 150ºC shows a higher value of 0.52 eV than that just prepared at room temperature. The SBH of the Sn/n-Ge samples increases with the annealing temperature. This result is considered to be due to mixing between Sn and Ge at the Sn/Ge interface with low temperature annealing below 150°C.

4. Conclusions

We examined the formation of Sn/Ge Schottky contact and have investigated the electrical properties. In contrast to other metal/Ge contacts, we found that a Sn/n-Ge contact prepared at room temperature exhibits a SBH lower than 0.35 eV. This low SBH contact is not stable for thermal annealing above 150°C, and the SBH value increases to 0.65 eV after the annealing at 220°C. We suggest that the mixing with metal and Ge at the interface would be a key factor to suppress FLP of metal/Ge interface.

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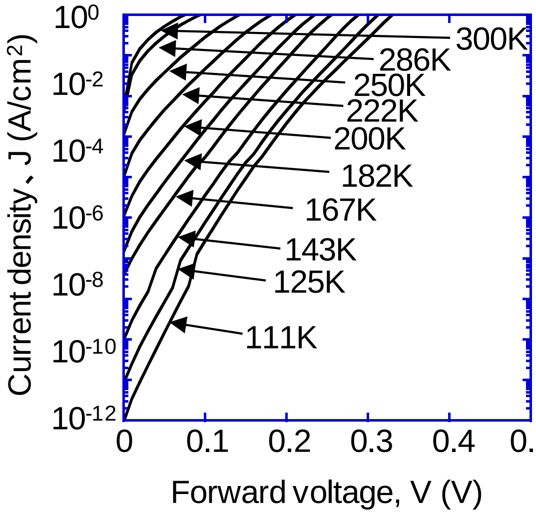

Fig. 1 J-V characteristic of the Sn/n-Ge(001) Schottky contact prepared for various measurement temperature ranging from 111K to 300K.

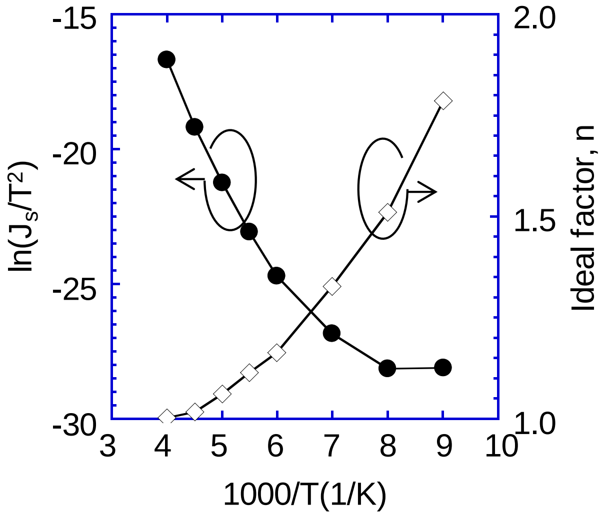

Fig. 2 The Arrhenius plot of $\ln(J_s/T^2)$ and ideality factor of the Sn/n-Ge(001) Schottky diodes.

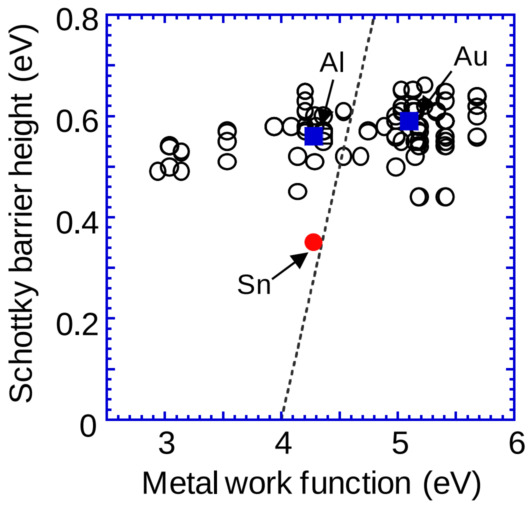

Fig. 3 Schottky barrier heights of Sn, Al, and Au/n-Ge(001) samples. Previously reported values are also shown with open circles. Broken line is the metal work function dependence of SBH assuming the Schottky limit.

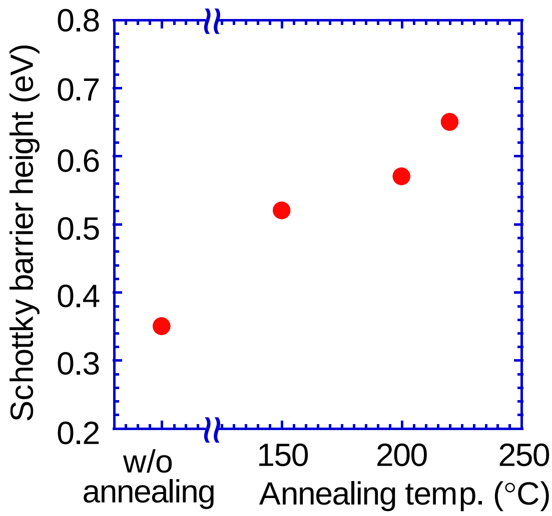

Fig. 4 Annealing temperature dependence of SBH for Sn/n-Ge(001) diodes.