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Impact of Ge Fraction to Bulk Resistivity and Work Function of NiSiGe Alloys

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Abstract

The electrical properties of the $NiSi_{1-x}Ge_x$ alloys with different Ge fraction were investigated. It is found that the resistivity of $NiSi_{1-x}Ge_x$ alloy decreases with an increased Ge fraction. Additionally, a **larger work function can be obtained for the NiSiGe alloys compared with the NiSi and NiGe alloys.**

1. Introduction

It has been increasingly difficult to further improve the performance of Si MOSFETs. To overcome this bottleneck, high mobility semiconductors, such as SiGe and Ge, have been considered as the alternative channel materials to decrease the channel resistance in future CMOS technology [1]. In order to maintain the benefits of high mobility SiGe or Ge channel in ultra-scaled MOSFETs, it is important to sufficiently suppress the source/drain (S/D) parasitic resistance (R_{SD}) [2]. As shown in Fig. 1, the bulk resistance of contact metal and the specific contact resistance between contact metal and S/D region play important roles in the R_{SD} of a MOSFET device. From the viewpoint of process integration, the metal-germanosilicide and metal-germanide are the most promising candidates among all the available contact metal materials for SiGe and Ge MOSFETs. However, the bulk resistivity of the metal-germanosilicide and metal-germanide have not been systematically examined yet, in spite of importance. Additionally, the work functions of the metal-germanosilicide and metal-germanide are also not clear yet, which may severely affect the specific contact resistance between the contact metal and S/D region.

In this study, the bulk resistivity and the work function of NiSiGe and NiGe alloys have been investigated. It is found that the NiSiGe exhibits a lower bulk resistivity and a smaller work function when the Ge fraction is increased.

2. The bulk resistivity of NiSiGe

TLM structures of the $NiSi_{1-x}Ge_x$ alloy were fabricated, as shown in Fig. 2. Ge and Si fimls were deposited on SiO_2/Si substrates by thermal evaporation. After that a thermal annealing was performed at 700 ºC for 10 min in N_2 ambient to ensure that the Si and Ge are fully mixed to obtain a uniform $Si_{1-x}Ge_x$ layer. The $NiSi_{1-x}Ge_x$ alloys were formed by thermal evaporation of Ni followed by a thermal annealing at 400 ºC. Finally, the Ni contact pads were deposited and patterned for electrical characterization.

The XPS spectra of $NiSi_{1-x}Ge_x$ layers with different chemical compositions are shown in Fig. 3. The Ge and Si fractions of the $NiSi_{1-x}Ge_x$ layers were obtained from the Ge *3d* and Si *2p* core levels, with consideration of the atom sensitivity factors. The bulk resistivities of the $NiSi_{1-x}Ge_x$ alloys were extracted as the resistance obtained from the TLM structures (Fig. 4) and divided by the physical thicknesses of the $NiSi_{1-x}Ge_x$ layers. As shown in Fig. 5, the bulk resistivity is reduced with the increase of Ge fraction, suggestting that it is necessary to increase the Ge fraction if a lower bulk resistivity is desired for $NiSi_{1-x}Ge_x$. It is found that the bulk resistivity of NiGe (~80 μΩ·cm) is larger than those previously reported values [3]. This could be attributable to the larger defect density in the thermal evaporation SiGe layers.

3. The work function of NiSiGe

In order to evaluate the work function of $NiSi_{1-x}Ge_x$, the n-Si MOS capacitor structures were fabricated by following the process shown in Fig. 6. The 7-nm-thick SiO_2 was fabricated by thermal oxidation. The 2-nm-thick TiN were deposited on SiO_2 surface before the $NiSi_{1-x}Ge_x$ were formed as the gate metal, in order to eliminate the impact of defect density difference caused by the different $NiSi_{1-x}Ge_x$ composition.

The *C-V* characteristics of a $NiSi_{1-x}Ge_x$/TiN/SiO_2/n-Si MOS capacitors are shown in Fig. 7 [4]. It is found that the V_{FB} shifts with different Ge fractions in $NiSi_{1-x}Ge_x$ due to the work function difference (Fig. 8). The work function of $NiSi_{1-x}Ge_x$ was evaluated using a series of M/TiN/SiO_2/n-Si MOS capacitors (M=Al, Ni, Pd) as reference samples (Fig. 9). The effectiveness of this approach is also confirmed by the valence band spectra taken from the $NiSi_{1-x}Ge_x$ alloys (Fig. 10).

Fig. 11 shows the work functions of $NiSi_{1-x}Ge_x$ alloys with different Ge fractions. It is observed that the work function of $NiSi_{1-x}Ge_x$ alloys changes parabolically with the increase of Ge content. These results i that the NiSi and NiGe are suitable for SiGe and Ge nMOSFET, and the NiSiGe with medium Ge fraction is suitable for SiGe and Ge pMOSFET, from the view point of specific contact resistivity reduction.

4. Conclusions

In this study, the bulk resistivity and work function of $NiSi_{1-x}Ge_x$ have been investigated. It is found that the bulk resistivity decreases with the increase of Ge fraction. On the other hand, the work function of $NiSi_{1-x}Ge_x$ is confirmed which is larger than that of either NiSi or NiGe.

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References [1] Yeo Y.C, *IWJT*, (2010) 1. [2] Saraswat K.C, et al, ECS Transactions, **75** (2016) 513. [3] Spann J.Y, et al., IEEE Electron Device Letters, **26** (2005) 151. [4] Misra, Abhishek, et al, Emerging Electronics (ICEE), (2012) 1.

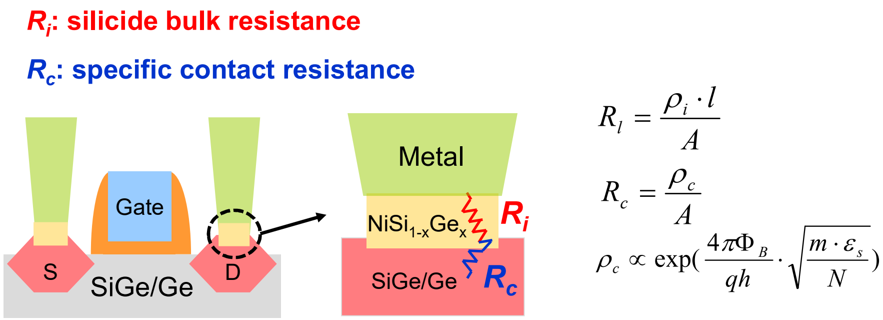

Fig. 1. The bulk resistance of contact metal and the specific contact resistance between contact metal and S/D region.

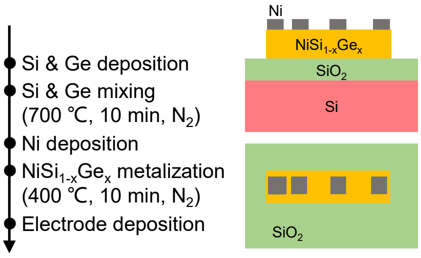

Fig. 2. The processing flow and device structure of Eesistance model.

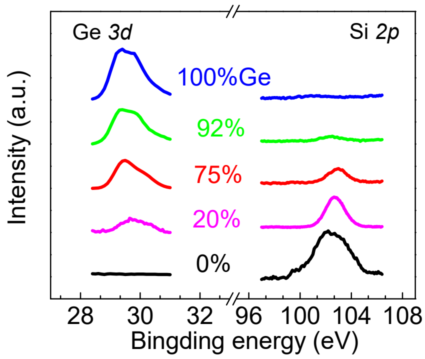

Fig. 3. The XPS spectra of $NiSi_{1-x}Ge_x$ layers with different chemical compositions.

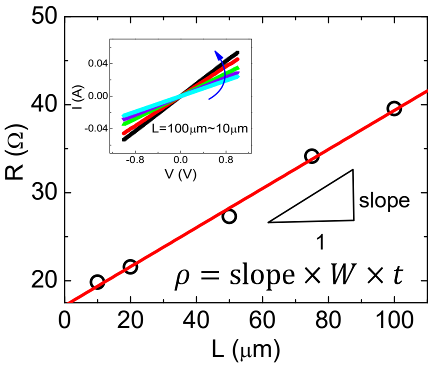

Fig. 4. The *I-V* behaviors of TLM patterns of $NiSi_{1-x}Ge_x$.

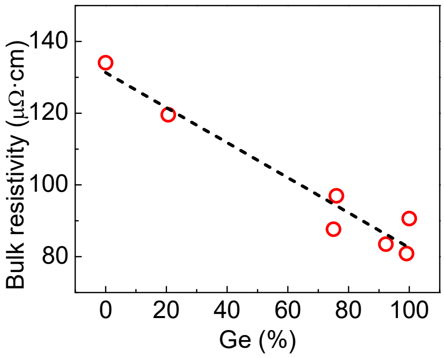

Fig. 5. The comparison of bulk resistivity dependence on different Ge fraction for $NiSi_{1-x}Ge_x$.

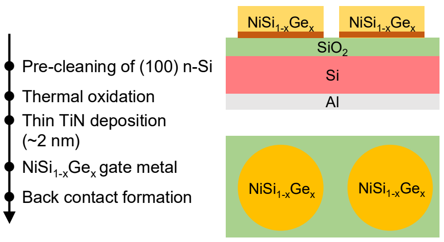

Fig. 6. The fabrication process and the n-Si MOS capacitor structures.

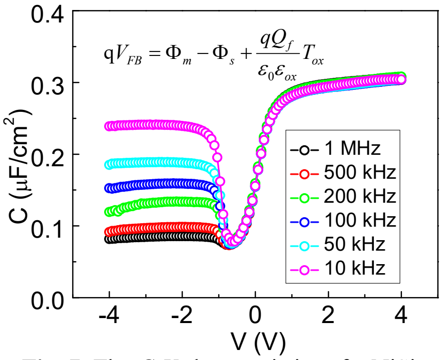

Fig. 7. The *C-V* characteristics of a $NiSi_{1-x}Ge_x$/TiN/SiO_2/n-Si MOS capacitors.

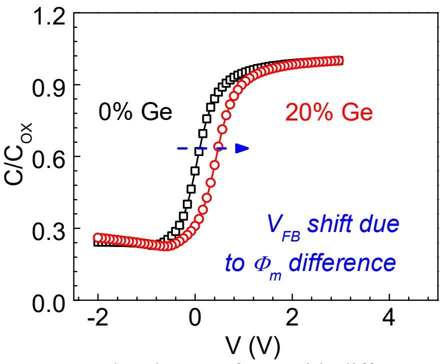

Fig. 8 The change of V_{FB} with different Ge fractions in $NiSi_{1-x}Ge_x$.

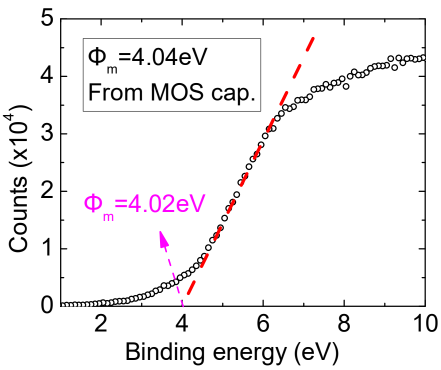

Fig. 9. Normalized low kinetic energy cut-off of XPS.

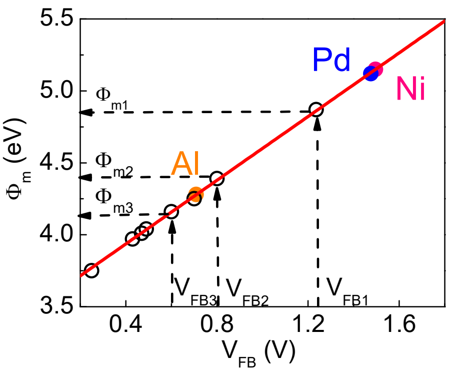

Fig. 10. The relation between Φ_m and V_{FB} using a series of M/TiN/SiO_2/n-Si MOS capacitors (M=Al, Ni, Pd) as reference samples.

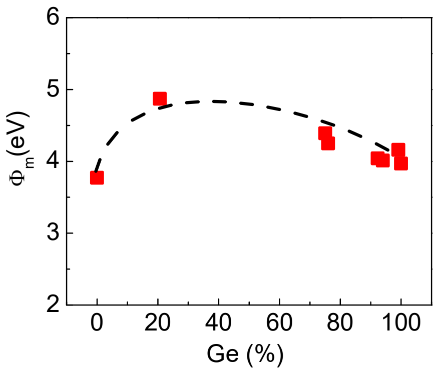

Fig. 11. The work functions of $NiSi_{1-x}Ge_x$ alloys with different Ge fractions.