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Formation and Properties of Epitaxial NiGe/Ge(110) Contacts

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1. Introduction

Ge is an attractive channel material for metal-oxide-semiconductor field effect transistor (MOSFET) realizing high-speed and low power consumption devices because of its high carrier mobility. The highest hole mobility is expected by using Ge(110) channel orientation. The metal/Ge contact with high thermal stability and low parasitic resistance is required for high performance Ge MOSFET. There is concern of high Schottky barrier height (SBH) of metal/n-type Ge contacts due to Fermi-level pinning (FLP) [1]. In this study, we focus NiGe as a contact material because of its several advantages such as low formation temperature, low Ge consumption, and low resistivity [2]. There are several report about the formation and properties of NiGe layers on Ge(001) [3, 4]. However, the crystalline and electrical properties of NiGe layers on Ge(110) have not been understood in detail yet.

In this study, we investigated NiGe thin films on Ge(110) and NiGe/Ge Schottky contact. We found the epitaxial growth and high thermal robustness of a NiGe layer on Ge(110) in contrast to polycrystalline NiGe/Ge(001). We also found the characteristic Schottky behavior of the epitaxial NiGe/Ge(110) contacts.

2. Experimental

After chemical cleaning of a n-type Ge(110) substrate, a 10 or 20 nm-thick Ni layer was deposited on the substrate with e-beam evaporation at room temperature in an ultra high vacuum chamber. Then, the sample was taken out to atmosphere and annealed at a temperature ranging from 350 to 600°C for 30s in N_2 ambient using rapid thermal annealing (RTA) system. Top and backside Al electrodes were prepared for Schottky diodes.

3. Results and discussion

Crystalline properties of NiGe thin film on Ge(110)

The cross-sectional transmission electron microscopy (TEM) and x-ray diffraction (XRD) revealed that an epitaxial NiGe layer is formed on Ge(110) after annealing at 350ºC, and there is the relationship of NiGe(100)// Ge(110) and NiGe[001]//Ge[100] as shown in Fig. 1 and 2. This result is contrast to that a polycrystalline NiGe layer is generally formed after annealing Ni/Ge(001) system.

Fig. 3 shows the scanning electron microscopy (SEM) images of Ni/Ge(110) and Ni/Ge(001) samples annealed at a temperatures of 400ºC~550ºC. In the case of conventional Ni/Ge(001) system, the agglomeration of NiGe occurs after annealing at above 400°C and the film morphology becomes severely poor at 500°C. By contrast, the morphology of the epitaxial NiGe layer on Ge(110) in this study is smooth and uniform even after annealing at 550°C. This result is considered to be due to the stable interface structure between the epitaxial layer and substrate.

Figure 4 shows the annealing temperature dependence of the sheet resistance of Ni germanide layers on Ge(110) and Ge(001) substrates. The sheet resistance keeps as low as 10 Ω/sq. which is as well as the value for a NiGe layer (9.98 Ω/sq.) estimated from the resistivity of NiGe (22 μΩcm [1]), as indicated with the broken line. In contract, for polycrystalline NiGe layers on Ge(001), the sheet resistance significantly increases with the annealing temperature over 450ºC due to the agglomeration of NiGe.

Schottky characteristics of NiGe/Ge(110) contacts

We measured the current density-voltage (J-V) and capacitance-voltage (C-V) characteristics for NiGe/ n-Ge(110) Schottky diodes. Figure 5 shows J-V characteristics of the NiGe/n-Ge(110) sample annealed at 550°C for various measurement temperatures. J-V curves show good thermionic emission current characteristics and SBHs estimated from J-V characteristics was 0.45~0.48 eV. These values were relatively lower than SBH values (~0.61 eV) reported for conventional NiGe/Ge(001) system.

On the other hand, SBHs of NiGe/Ge(110) from C-V characteristics were estimated to be as high as 0.61~0.71 eV. The discrepancy between the J-V and C-V characteristics is considered to be that the NiGe/Ge(110) interface consists of mixed areas having high and low SBHs. Similar trend of lowering the SBH of epitaxial metal layer/Ge contacts was also reported for epitaxial Fe_3Si/Ge(111) and epitaxial Mn_5Ge_3/Ge(111) systems [5, 6].

4. Conclusions

We demonstrated the potential of NiGe/Ge(110) contact for Ge MOSFET. An epitaxial NiGe layer can be formed on Ge(110) after germanidation of Ni/Ge(110) system. We found the high thermal robustness of the epitaxial NiGe layer on Ge(110) due to its stable interface. We also found that lowering the SBH in the epitaxial NiGe/Ge(110) contact compared to conventional polycrystalline NiGe/ Ge(001) contacts. This result suggest the possibility of solving FLP in the epitaxial NiGe/Ge(110) contact.

Acknowledgement

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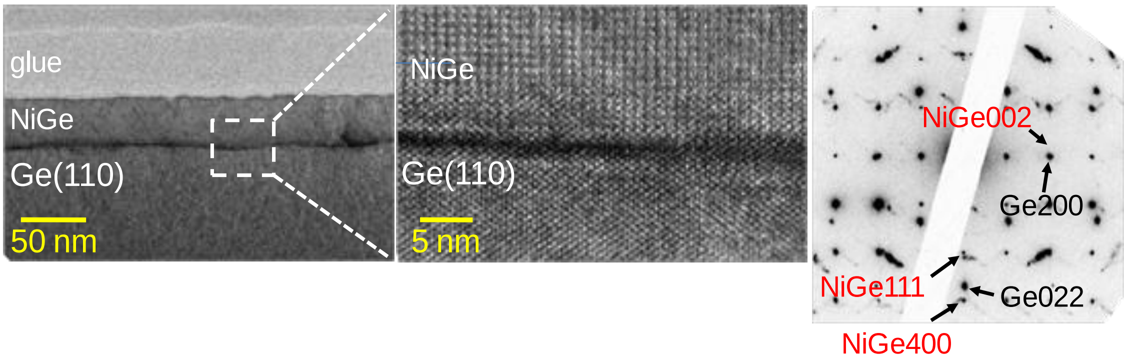

Fig. 1 Cross-sectional TEM images and the TED pattern of the NiGe/Ge(110) sample after annealing at 350°C.

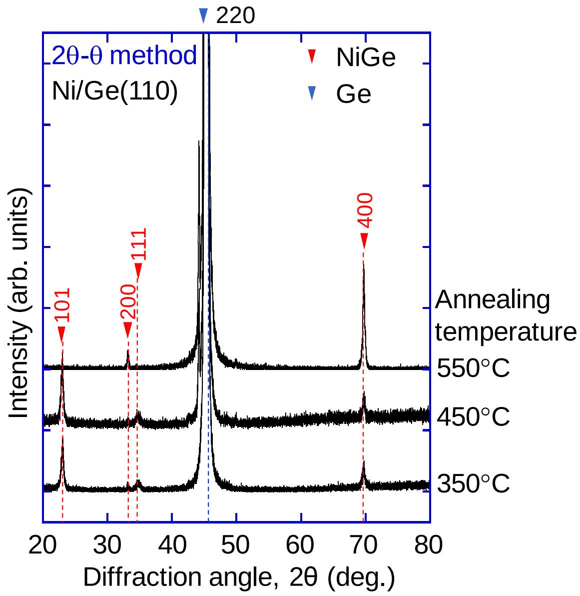

Fig. 2 XRD 2θ/ω-profiles of Ni/Ge(110) samples after annealing at 350ºC, 450ºC, and 550ºC.

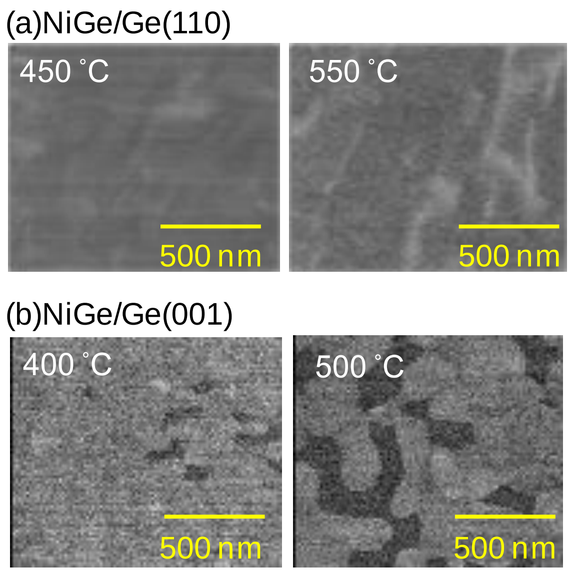

Fig. 3 SEM images of (a) NiGe/Ge(110) after annealing at 450ºC and 550ºC and (b) NiGe/Ge(001) samples after annealing at 400ºC and 500ºC .

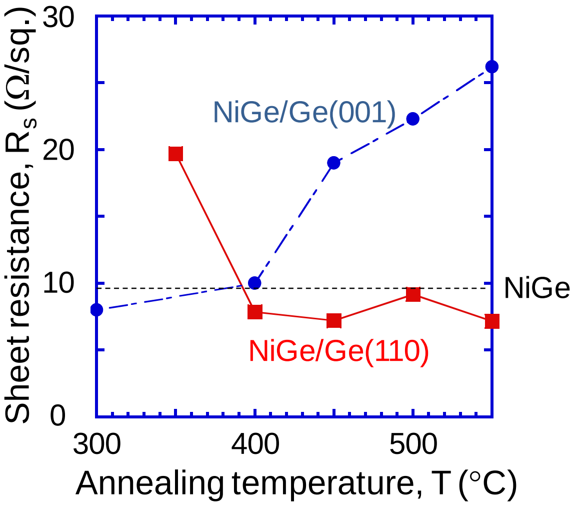

Fig. 4 The annealing temperature dependence of the sheet resistance of Ni germanide layers on Ge(110) and Ge(001) substrates.

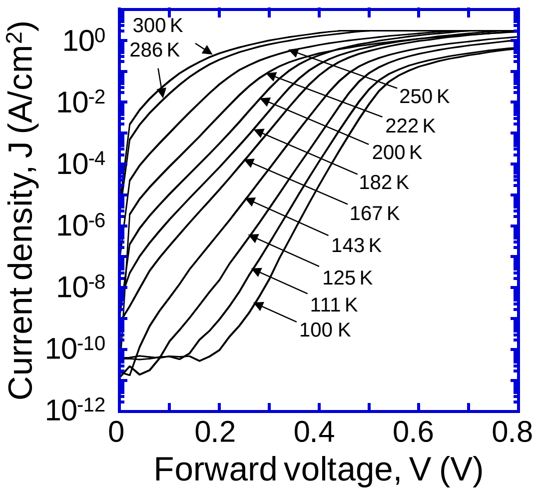

Fig 5 J-V characteristic of the NiGe/Ge(110) Schottky contact after annealing at 550°C for measurement temperatures ranging from 100K to 300K.