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Modulation of NiGe/Ge Schottky Barrier Height by Dopant and Sulfur Segregation during Ni Germanidation for Metal S/D Ge MOSFETs

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1. Introduction

A fully depleted (FD) Ge-on-insulator (GOI) MOSFET [1] is an attractive device structure with performance boosters for future high performance CMOS, because of its high mobility of Ge channel and high short-channel-effect immunity due to the thin body. However, low solubility and high diffusion constant of dopants in Ge make it difficult to fabricate the aggressively scaled MOSFETs with low series resistance. Thus, we have been proposed Metal Source/ Drain (MSD) MOSFETs with GOI channels [2,3] which offer low series resistance and low parasitic capacitance.

This structure with abrupt SD/channel interface can also be free from deep S/D formation, extension implantation and activation annealing processes. On the other hand, if Schottky barrier height (SBH) at source/channel junction is high, drive current is significantly degraded. The strong Fermi level pinning feature of Metal/Ge junctions including germanide/Ge systems provides low SBH for pMOSFETs (holes) [3,4], while it is a bottleneck for the drive current of nMOSFET due to high SBH for electrons. As a result, a control of SBH at interfaces of germanide/ Ge, which are one of the most practical MSD junction for Ge, is a key issue to realize the FD-GOI channel MSD-CMOSFETs.

In this paper, we demonstrate, for the first time, the modulation of SBH for Ge by a couple of techniques. One is a dopant segregation technique and the other is modulation of Fermi level position by using segregation of sulfur at germanide/Ge interfaces.

2. Experimental

Nickel germanide /Ge Schottky diodes were fabricated on n-type (Sb dope) (100) Ge substrates with a resistivity of 0.1-0.3Ωcm. The fabrication process flow is summarized in Fig. 1. After formation of field isolation, As or Sb ions at energy 1keV in the dose range from $2x10^{14}$ to $1x10^{15}$ cm^{-2} were implanted for dopant segregation (DS) in the later process step. Subsequently, a 30nm-thick nickel film was deposited by e-beam evaporation. For diode samples with sulfur segregation, S ions at energy of 10keV in the dose range from $5x10^{13}$ to $1x10^{15}$ cm^{-2} were also implanted before Ni evaporation. Germanidation was carried out by RTA(200-500^{o}C) in N_2 ambient.

3. Schottky Barrier Height of Germanide/Ge

Figure 2 shows the TEM micrograph and EDX depth profiles of the nickel germanide/(100)Ge heterostructures. After 400^{o}C germanidation, nickel-monogermanide (NiGe) was formed. Figure 3 compares SBH for nickel (metal work function (WF) = 4.5 eV) and platinum (metal WF = 5.3 eV) germanide/(100) n-Ge[3]. The SBH values were ～0.6eV, and were less dependent on metal WF and germanide formation temperature (germanide phases). This result suggests the strong Fermi level pinning feature of germanide/Ge junctions.

4. Modulation of Schottky Barrier Height of NiGe/Ge

4-1 Effect of dopant (As,Sb) segregation

The dopant segregation technique for modulating SBH has been proposed by Thornton [5] and successfully applied to Si channel MSD-MOSFETs by Kinoshita et al. [6]. Dopant atoms segregated at metal/semiconductor (MS) interfaces can effectively modulate SBH, because of the image force and high electric field at the interfaces. It was found in backside SIMS depth profiles (Fig. 4) that implanted As and Sb atoms were segregated around the interfaces of NiGe/(100) Ge and the steep doping profiles were realized by a snowplow fashion. It should be noted that the doping region was perfectly consumed by NiGe during germanidation and, thus, the profiles were determined only by segregation.

Figures 5 shows the I-V characteristics of NiGe/(100) n-Ge Schottky diodes with and without Sb implantation. It was found that the effective SBH of NiGe/(100) n-Ge were successfully modulated by As or Sb dose.(Fig. 6)

4-2 Effect of Sulfur segregation

It is believed that the existence of large amount of interface states causes the Fermi level pinning and, as a result, makes SBH less dependent on the metal WF. It has been reported that valence-mending adsorbates can eliminate dangling bonds at MS interfaces, leading to the modulation of the interface Fermi level position. It has recently been shown [7] that sulfur segregation allows to tune SBH for NiSi/(100)Si system. Thus, we have introduced sulfur atoms to germanide/Ge interfaces. Figure 7 shows the I-V characteristics of NiGe/nGe(100) Schottky diodes with and without sulfur implantation. It was found in Fig. 8 that SBH of NiGe decreases with increasing sulfur dose. This result suggests that the implanted sulfur atoms can work as valence-mending adsorbates even for Ge MS interfaces, resulting in modulation of the Fermi level position of NiGe/Ge interface.

5. Summary

We have successfully demonstrated the SBH modulation by two different methods. By As segregation, the effective SBH for NiGe/nGe(100) was modulated by 0.14eV. Sulfur implantation has also modulated SBH by 0.08eV. The combination of these two methods and the process optimization are expected to tune SBH of NiGe/Ge junctions in a much wider range.

Acknowledgements
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References

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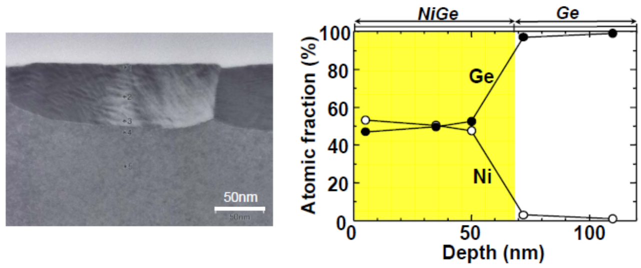

Fig. 2 Cross-sectional TEM image of nickel-monogermanide / Ge heterostructure and its EDX depth profile.

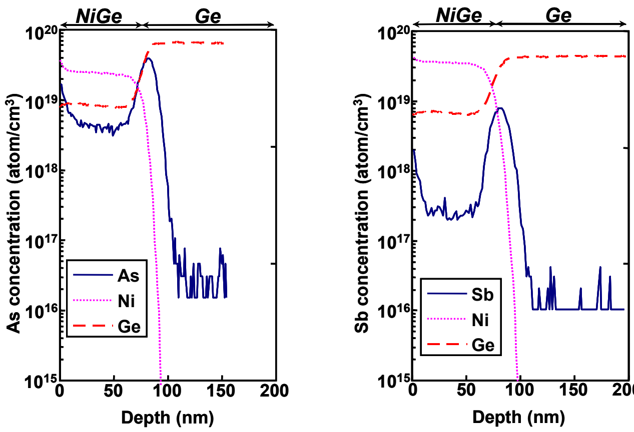

Fig. 4 Backside SIMS profiles of a) As and b) Sb dopant segregation in NiGe/Ge Schottky diodes. Implanted dose was $5x10^{15}cm^{-2}$. Deposited Ni thickness was 30nm.

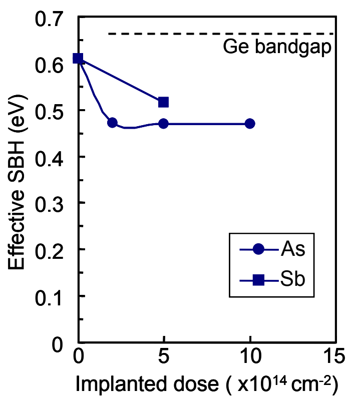

Fig. 6 Effective SBH as a function of implanted As or Sb dose.

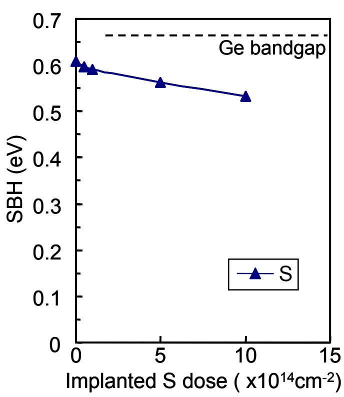

Fig. 8 SBH as a function of S dose.

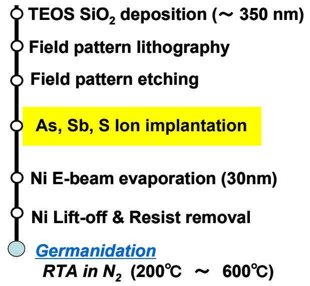

Fig. 1 Fabrication process flow of NiGe / Ge Schottky diodes.

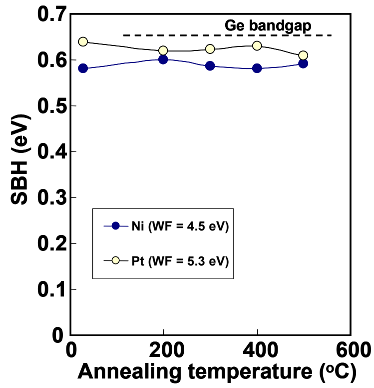

Fig. 3 Annealing temperature dependence of SBH for Nickel germanide / Ge(100) and platinum germanide / Ge(100).

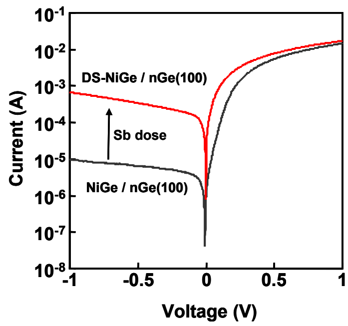

Fig. 5 I-V characteristics of NiGe/Ge (100) Schottky diodes with and without Sb implantation.

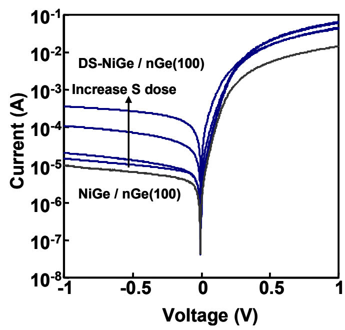

Fig. 7 I-V characteristics of NiGe/Ge (100) Schottky diodes with and without S implantation.