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High Performance NiGe/n-Ge Junctions and pMOSFETs Fabricated with Dopant Segregation

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Abstract

The NiGe metal source/drain structures with high Schottky barrier height and low resistivity were realized using the dopant segregation technique. In this work, a Schottky barrier height larger than the germanium E_g is achieved for the NiGe metal source/drain by optimizing the dopant segregation process. As a result, sufficiently suppressed OFF-state leakage current is obtained in the NiGe metal surce/drain pMOSFETs, suggesting that the OFF-state leakage current will not be a critical issue for Ge metal source/drain structures.

1. Introduction

Ge is a promising candidate for the future high-performance CMOS technology due to its high hole and electron mobility [1, 2]. In order to obtain high performance Ge MOSFETs, one of the critical issues is the reduction of source/drain (S/D) parasitic resistance R_{SD}. Due to the low solubility and the large diffusion coefficient of dopants in Ge, it is difficult to realize low R_{SD} S/D structures by conventional ion implantation technique for Ge MOSFETs [3]. Thus, the Ge metal S/D (Schottky junction) structure is considered as one of the possible solutions to overcome this bottleneck. However, the junction leakage in Ge metal S/D is relatively large due to the strong Fermi-level-pinning effect, which results in an insufficient Schottky barrier height (SBH) [4, 5]. Although the dopant segregation (DS) method has been employed to increase the SBH for Ge metal S/D (Fig. 1) [6-8], further reduction of the junction leakage is still desired. In this work, DS SBH NiGe-S/D pMOSFETs with high SBH are fabricated by optimizing the dopant segregation process. The impact of SBH on the junction leakage has been examined using Ge pMOSFETs with DS-NiGe metal S/D. It is found that the junction leakage can be effectively suppressed by increasing the SBH. For the NiGe metal S/D with a SBH larger than E_g, very low junction leakage, similar with those of the ion implanted p+/n S/D, has been realized.

2. DS-NiGe/n-Ge Schottky junctions

The fabrication process of DS NiGe/n-Ge Schottky junctions is shown in Fig. 1. After pre-cleaning of (100) n-Ge substrates (1~10 Ω·cm), SiO_2 field oxide was deposited and the active area is defined by etching off the SiO_2. Boron ion implantation (10^{15} cm^{-2}, 10 keV) was performed and Ni was deposited by thermal evaporation. The RTA (1 min, N_2 ambient) was carried out at different temperature to form the NiGe alloy with DS. Finally, Al back contact was formed by thermal evaporation. The NiGe/n-Ge Schottky junctions without dopant segregation and the Boron ion implantation p+/n junctions (10^{15} cm^{-2}, 10 keV, 400 ºC activation) were also fabricated as control samples.

In order to evaluate the SBH of the DS NiGe/n-Ge Schottky junction, the I-V characteristics were measured at different temperatures (Fig. 2). The Arrhenius method was used to extract the SBH at a reverse voltage of -0.5 V (Fig. 3). As shown in Fig. 4, the SBH of NiGe/n-Ge Schottky junctions is enhanced by ~0.15 eV u tilizing the DS process. It is also found that the larger SBH could be realized for the DS NiGe/n-Ge Schottky junctions with increased RTA temperature. With 500 ºC RTA, a SBH (0.72 eV) even larger than the Ge E_g (0.67 eV) has been achieved for the DS NiGe/n-Ge Schottky junction. The increase of SBH results in a significant reduction of the junction leakage and an obvious increase of the ON/OFF ratio. The junction leakage of the NiGe/n-Ge junction is comparable with that of the conventional p+/n junctions when the SBH is approaching E_g of Ge (Fig. 5).

3. Ge pMOSFETs with DS-NiGe/n-Ge junctions

In order to examine the effectiveness of DS-NiGe S/D structure, the (100)/<110> Ge pMOSFETs were fabricated using a gate-first process (Fig. 6). The normal operations of Ge pMOSFETs with DS-NiGe S/D have been confirmed by the I_d-V_g and I_d-V_d characteristics (Figs. 7 and 8). The sheet resistivity of DS-NiGe S/D was measured for these Ge pMOSFETs. It is confirmed that the NiGe S/D w/ and w/o DS exhibit similar sheet resistivity, indicating that the DS process does not introduce extra resistance to the S/D structure (Fig. 9). Additionally, the much smaller R_{SD} is obtained for the DS NiGe metal S/D compared with p+/n S/D, which is beneficial to the suppression of R_{SD} (Fig. 9). The I_d curves for Ge pMOSFETs with different S/D structures are plotted as a function of V_g-V_{th} in Fig. 10. It is found that the OFF current I_{Off} in DS NiGe metal S/D devices decreases with an increasing SBH. Furthermore, as the SBH approaching the Ge E_g, I_{Off} of the DS NiGe S/D device is comparable with that of the conventional ion implantated devices (Fig. 11). For NiGe/n-Ge Schottky junctions w/o DS, the junction leakage is dominant by thermal emission. Thus, the insufficient SBH leads to a severe junction leakage. However, the sufficient increase of SBH suppresses the thermal emission current, yielding a junction leakage comparable to that of the conventional ion implantation device which is limited by the band-to-band tunneling (Fig. 12).

4. Conclusion

The NiGe/n-Ge metal S/D structures with SBH larger than the Ge $E_g$have been realized using the DS method. It is confirmed that the junction leakage is effectively suppressed without sacrifying the low resistivity for the DS NiGe metal S/D structures. These phenomena indicate the feasibility of DS NiGe metal S/D structures in future Ge CMOS technology.

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Reference

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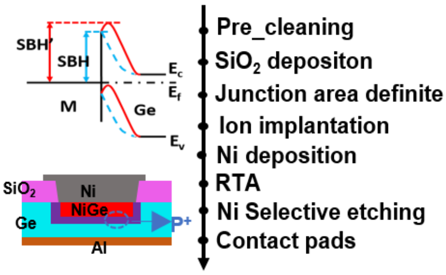

Fig. 1. The DS NiGe/n-Ge Schottky junctions energy band diagram and fabrication process.

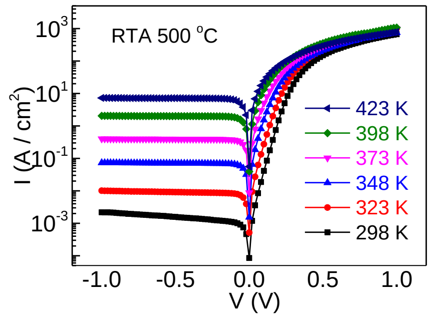

Fig. 2. The example of I-V curves for DS NiGe/n-Ge Schottky junctions.

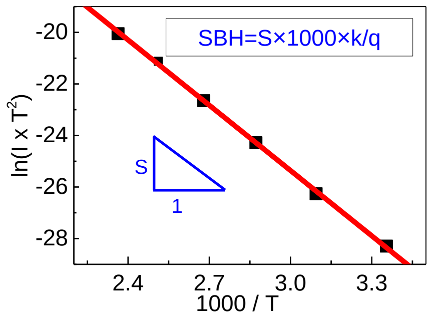

Fig. 3. The SBH calculation example for Schottky junctions by Arrhenius method.

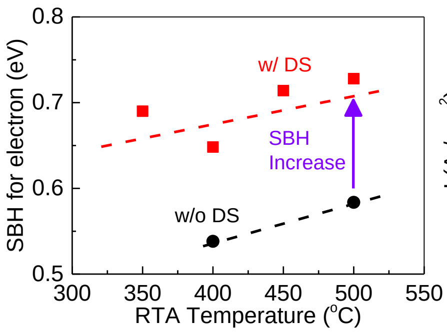

Fig. 4. The SBH w/ or w/o DS of NiGe/n-Ge Schottky junctions with different RTA tempratures.

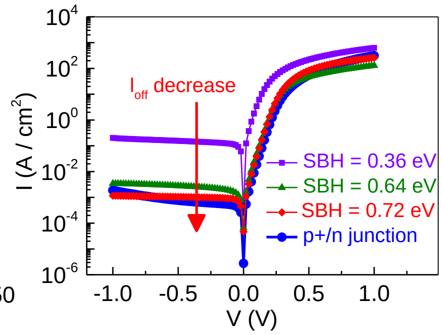

Fig. 5. The I-V curves of NiGe/n-Ge Schottky junctions with different SBHs and p+/n junctions.

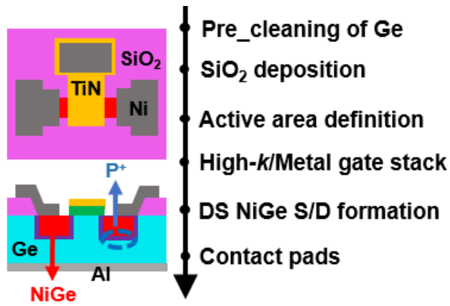

Fig. 6. The fabrication process of pMOSFET with DS-NiGe S/D.

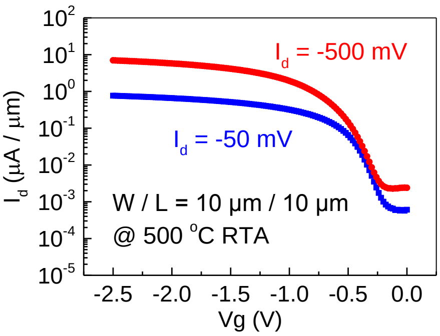

Fig. 7. The I_d-V_g curves for the DS-NiGe S/D pMOSFET with SBH at 0.72eV.

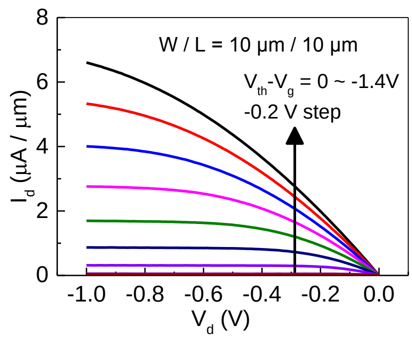

Fig. 8. The I_d-V_d curves for the DS-NiGe S/D pMOSFET with SBH at 0.72eV.

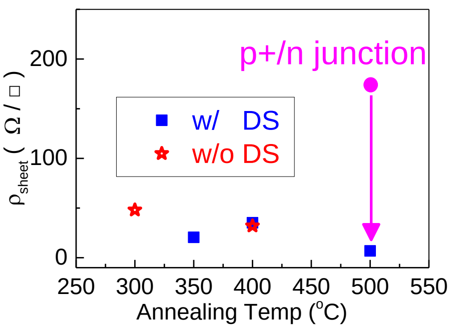

Fig. 9. The sheet resistivity of Schottky junctions w/ or w/o DS.

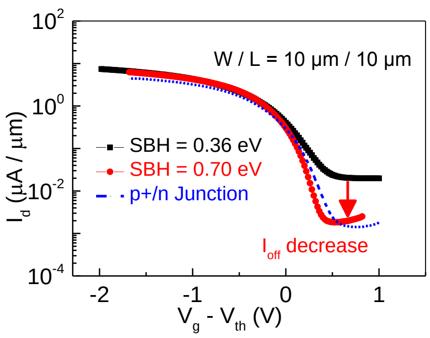

Fig. 10. The comparison of I_d-V_g curves between DS-NiGe S/D pMOSFET with different SBHs.

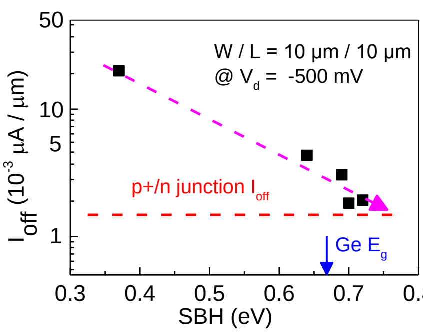

Fig. 11. The relationship between the S/D leakage current and SBH for DS NiGe S/D pMOSFET.

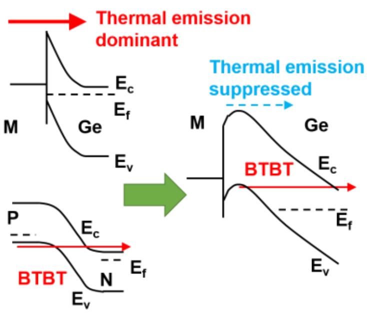

Fig. 12. The diagram of different leakage current types in different junctions.