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Fabrication and characteristics of Ni-germanide Schottky contacts with Ge*

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In this study, Ni germanide Schottky barrier diodes on n-Ge (100) substrate were fabricated by sputtering metal Ni on Ge, followed by annealing in N_2 atmosphere from 300 to 500°C in a furnace. The results of x-ray diffraction (XRD) show that the Ni germanide was formed and the diffraction line of (111) was observed in all samples. The structure of Ni germanide is orthorhombic with lattice parameters a=5.811, b=5.381, c=3.428. However, the lines (121) and (002) were observed only in the samples annealed at a temperature higher than 400°C. The influence of annealing temperature on the electrical properties of Ni germanide Schottky barrier diodes on n-Ge (100) substrate was investigated. Experimental results indicated that Schottky barrier diodes on n-Ge (100) with current–voltage (I–V) rectifier characteristics were obtained. The I_{on}/I_{off} ratio of the Schottky diode obtained by using a 300°C annealing process is the highest. The Schottky barrier heights were evaluated by the capacitance–voltage method.

Keywords: nickel germanide, Schottky contact
PACC: 7360, 7755

1. Introduction

As the scaling of silicon complementary metal–oxide–semiconductor (CMOS) devices becomes more and more challenging, both innovative structures and new materials with high carrier mobility are needed to continue improving the device performance.[1−15] Schottky barrier (SB) metal–oxide–semiconductor field effect transistor (MOSFET), as a promising candidate structure for the 45nm technology node and beyond,[1] has been extensively studied.[2−8] Ge or GeSi devices have also received much attention due to their high carrier mobility and smaller band-gap.[9−11] Compared to Si, pure Ge offers two times higher mobility for electrons and four times higher mobility for holes. Recently, Ge MOSFETs have attracted much attention due to its high low-field carrier mobility.[12,13] However, high Ge pn junction leakage is an issue to be concerned with due to the narrow Ge band gap. In this paper, the germanide/Ge Schottky barrier process is experimentally investigated. The Ni germanide/n-type Ge(100) Schottky contact with ∼0.4eV barrier height is demonstrated experimentally. The leakage currents between Ge pn junction and Ge Schottky barrier are compared with each other.

2. Experiment

The Ni germanide Schottky barrier diode (SBD) was formed on n-type germanium substrate. The n-type Ge (100) wafers with resistivity ∼ 0.4Ω·cm were first wet cleaned using acetone and dilute-HF and dried with N_2 before gate growth. Nickel layers were deposited afterwards at room temperature by ion beam sputtering Ni target. Then the samples were annealed at different temperatures from 300 to 500°C for 5min.

The forward and reverse electrical characteristics of diode samples were measured at room temperature using a Hewlett Packard 4156 semiconductor parameter analyser, while the C–V characteristics of the diode samples were measured using Keithley 590 C–V analyser. For microstructural analysis of the samples the x-ray diffraction (XRD) method was employed.

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3. Results and discussion

The XRD patterns shown in Fig.1 indicate that Ni germanide was formed after the samples were annealed at temperatures higher than 300°C. The structure of Ni germanide is orthorhombic with lattice parameters a=5.811, b=5.381, c=3.428. The diffraction line of (111) (at 2θ=34.6°) is observed in all samples. However, the (121) and (002) lines are observed only in the samples annealed at a temperature higher than 400°C.

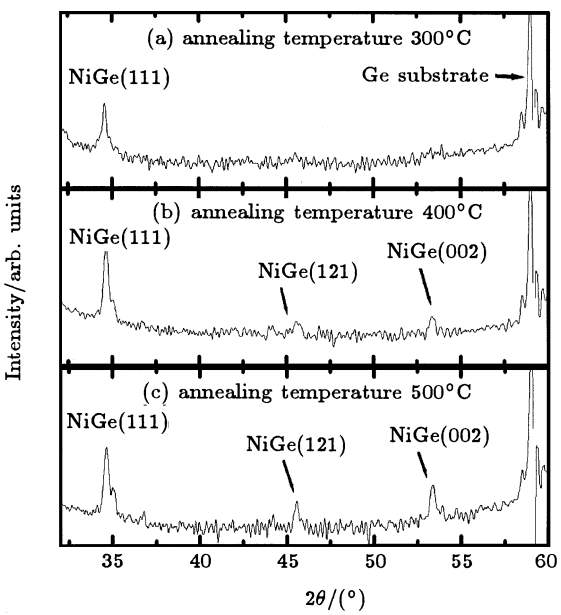


Fig.1. XRD patterns for the Ni germanide contacts on n-Ge, obtained after annealing at temperatures from 300 to 500°C.

Figure 2 plots the semi-logarithmic current–voltage(I–V) characteristics of fabricated NiGe/Ge Schottky barrier diodes with annealing temperature changing from 300 to 500°C. The typical I–V rectifier characteristics of the Schottky barrier diode are shown. The influence of annealing temperature on the I–V characteristics of Ni germanide Schottky barrier diodes is shown in the figure.

The I_{on}/I_{off} ratios of the Schottky barrier diodes under various annealing temperatures are shown in Fig.3. I_{on} is the forward current at V=2V, and I_{off} is the reverse current at V=–2V. Experimental data indicate that the Schottky barrier diodes annealed at 300° have the highest I_{on}/I_{off} (~800).

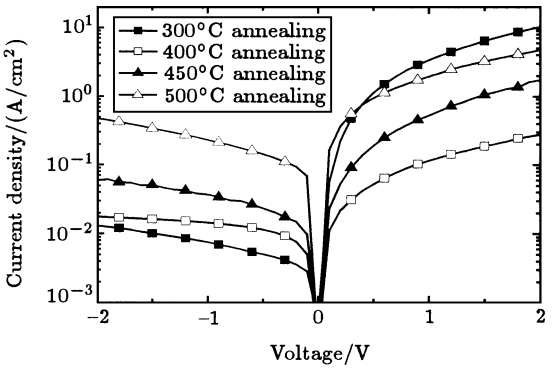


Fig.2. I–V characteristics of fabricated NiGe/Ge Schottky barrier diodes annealed at different temperatures from 300 to 500°C.

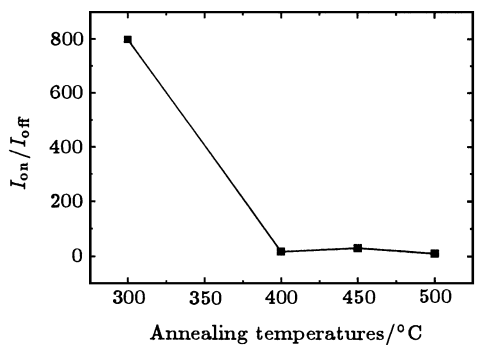


Fig.3. I_{on}/I_{off} ratio versus annealing temperature.

The capacitance–voltage (C–V) characteristics of Ni Schottky barrier diodes grown on n-Ge at different annealing temperatures ranging from 300 to 500° are shown in Fig.4.

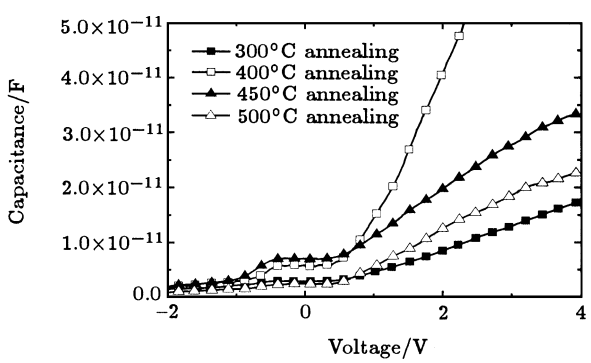


Fig.4. The C–V characteristics of fabricated NiGe/Ge Schottky barrier diodes annealed at different temperatures from 300 to 500°C.

The Schottky barrier height (SBH) was evaluated by the C–V method.[16] Figure 5 shows the SBH of the Ni germanide contact on n-Ge versus the annealing temperature. The value of SBH ranges from 0.38 to 0.43eV. When the annealing temperature is higher than 500°C the reverse current will increase.

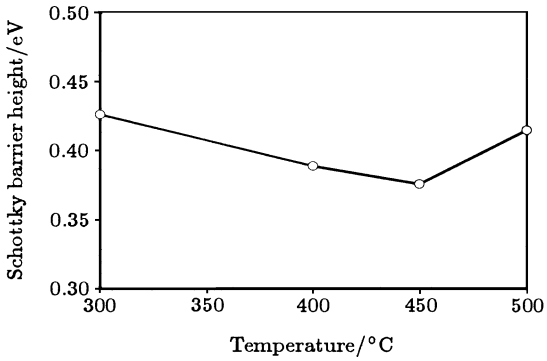


Fig.5. Schottky barrier height of the Ni germanide contact on n-Ge versus annealing temperature.

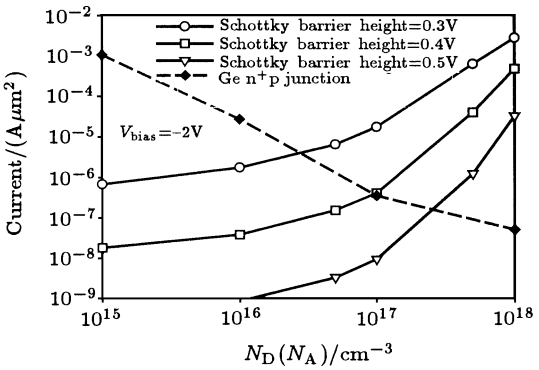


Fig.6. Comparison of the reverse currents between Ge Schottky barrier diode and n^+p junction. The doping concentration of n^+ is fixed at $1\times10^{20}cm^{-3}$.

With SBH changing from 0.3 to 0.5eV, the comparison of reverse currents between Ge SBD and n^+p junction is shown in Fig.6. During simulation the doping concentration of n^+ region in n^+p junction is fixed at $1\times10^{20}cm^{-3}$, which is corresponding to the case in conventional MOSFET S/D region. The reverse current of Ge SBD increases with the increasing doping of Ge due to the tunnelling effect. But the reverse current in n^+p junction decreases as the dopant in p region increases. The reverse current of Ge n^+p junction is higher than the Ge SBD reverse current within the typical channel doping. This implies that Ge Schottky barrier MOSFET has the potential to solve the high pn junction leakage problem existing in the conventional Ge MOSFET.

4. Conclusion

Ni germanide Schottky barrier diodes were fabricated by sputtering pure metal Ni on the n-Ge (100) substrates followed by a furnace annealing process. The results of the XRD show that the Ni germanide is formed on the n-type Ge substrate. The electrical properties of Ni germanide on n-Ge (100) substrate were investigated, and the Schottky barrier diode on n-Ge (100) with typical I–V rectifier characteristics was obtained. The results showed that the I_{on}/I_{off} ratio of the Schottky barrier diode obtained by using a 300°C annealing process is the highest. The results obtained will be helpful to the fabrication of Ge-based SB-FET devices.

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