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Ge-on-insulator tunneling FET with abrupt source junction by snowplow effect of NiGe

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Abstract

A snowplow effect of NiGe combined with low energy BF_2^+ implantation has been investigated to realize an abrupt p^+/n Ge junction applicable for Ge tunneling FETs (TFETs). By employing this technique, a junction with very steep B profiles (~5 nm/dec) has been realized. Operation of Ge-on-insulator (GOI) FETs with this source junction has been demonstrated with the increase of I_{on}/I_{off} ratio and the decrease of S.S. values.

1. Introduction

To increase performance of Ge-based tunneling field effect transistors (Ge TFETs), it is essential to realize source junctions with abrupt dopant concentration profiles [1]. Some research groups reported that by forming metal-semiconductor alloy after implantation of dopant into semiconductor substrates, dopant segregation and redistribution, i.e., snowplow effect, occur [2-4]. Here, in this study, we have investigated the snowplow effect of NiGe combined with low energy BF_2^+ implantation to realize abrupt p^+/n Ge junctions. This method is applied to form source regions of GOI TFETs and the device properties are evaluated.

2. Investigation of snowplow effect of NiGe

The snowplow effect of NiGe was firstly investigated on Ge substrates. Here, BF_2^+ ion implantation (dose: 4×10^{15} cm^{-2} and 5×10^{14} cm^{-2} at 4 keV) was performed to n-type Ge substrates. Then, Ni was deposited (initial thickness t_{Ni}: 0 – 20 nm) on the implanted regions by sputtering, followed by annealing at 400ºC for 1min (Fig.1 (a)). After removing unreacted Ni by HNO_3, top (Al on Ni) and bottom (Al) electrodes were deposited to fabricate the diode structure (Fig. 1(b)).

The I-V characteristics of the fabricated diodes (t_{Ni}: 10 nm) are shown in Fig. 2. The high I_{on}/I_{off} ratio (~10^4) and the excellent ideality factor (~1.02) were obtained, indicating that dopant atoms were successfully activated by annealing. The SIMS profiles of B concentrations in n-Ge substrates after implantation (4 keV, $5x10^{14}$ cm^{-2}) and after annealing with initial Ni thickness (t_{Ni}) of 10 nm are shown in Fig. 3. It is found that the B peak shifts from the top surface to the NiGe/Ge interface after annealing, which supports the existence of the snowplow effect.

The abruptness of p^+/n junction obtained by the B concentration profiles are summarized as a function of the initial Ni thickness in Fig. 4. Here, it is clearly observed that the p^+/n junctions become shallower by introducing 2-10 nm Ni, and the junction abruptness has the minimum value (~5.2 nm/dec for 5 x 10^{14} cm^{-2} dose and ~7.2 nm/dec for 4 x 10^{15} cm^{-2} dose) at 4-nm-thick Ni. These results support that the snowplow effect of NiGe is very useful to increase abruptness of B in Ge junctions.

3. Application for source of GOI n-TFETs

The realized junction was applied to the source region of GOI TFETs. Here, Ge-on-insulator (GOI) substrates with 100-nm body thickness were used. After cleaning the substrates by acetone and HCl, the drain region was formed by Sb spin-on-glass diffusion (650ºC, 30 min). BF_2^+ ion implantation (dose: 5×10^{14} cm^{-2} at 4 keV) and Ni deposition (t_{Ni}: 0 – 10 nm) were performed in the source region, followed by annealing at 400ºC for 1 min. After 1.3-nm-thick Al_2O_3 was deposited by atomic layer deposition (ALD), electron cyclotron resonance (ECR) plasma post oxidation was introduced to form the Ge-O_X/Ge interface [5]. After that, additional 3.0-nm-thick Al_2O_3 and 30-nm-thick W were deposited by ALD and sputtering, respectively, as a gate stack. Al/Ni bilayer was used for the source and drain contact (Fig. 5).

The I_d-V_d characteristics (t_{Ni}: 0 and 4 nm, V_g: 0.5 - 2.0 V), shown in Fig. 6, have proved the TFET operations. The I_d-V_g characteristics of TFETs with various t_{Ni} at V_d of 50 and 500 mV are shown in Fig. 7(a) and (b), respectively. It is found here that the on current of TFETs with Ni thicker than 4 nm becomes about 4 times higher than that without Ni. The I_{on}/I_{off} ratio and the minimum value of S.S. obtained from the I_d-V_g curves as a function of the initial Ni thickness of the source regions are summarized in Fig. 8(a) and (b), respectively. It is clearly shown that the I_{on}/I_{off} ratio is enhanced by introducing Ni in the source regions. Moreover, the S.S. values are also improved by introducing Ni and show the minimum value at the initial Ni thickness of 4 nm, which is in good agreement with the SIMS results. These results support that enhancement of the steepness of B profiles in source junctions due to the snowplow effect of NiGe is very useful to improve the electrical properties of Ge TFETs.

4. Summary

In this study, the impact of the snowplow effect of NiGe on the abruptness of B profiles in Ge p^+/n junctions was investigated. The junction abruptness was improved by tuning the initial Ni thickness, leading to realization of very steep junctions. This phenomenon was applied to the source region formation in GOI TFETs and the enhancement of the device performance such as I_{on}/I_{off} ratio and S.S. value has been demonstrated.

Acknowledgement

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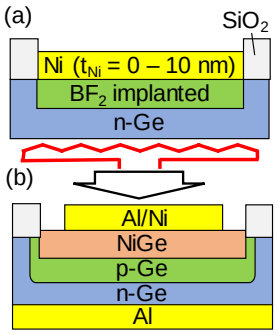


Fig. 1 Schematic of (a) sample before annealing and (b) fabricated diode.

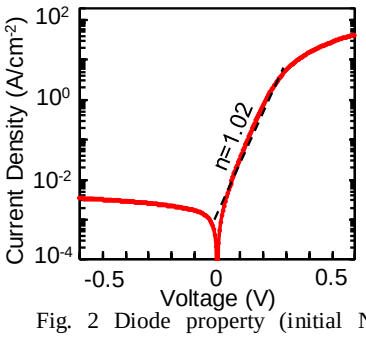


Fig. 2 Diode property (initial Ni thickness: 10 nm)

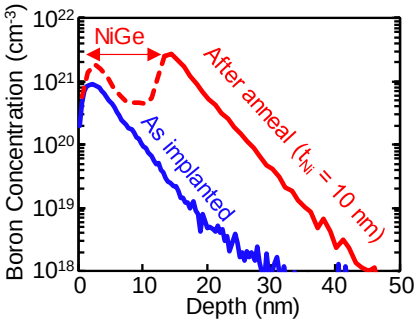


Fig. 3 Boron concentration profiles before and after annealing (initial Ni thickness: 10 nm)

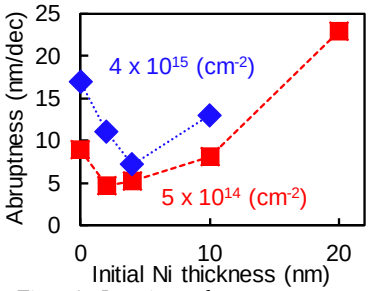


Fig. 4 Junction abruptness as a function of initial Ni thickness.

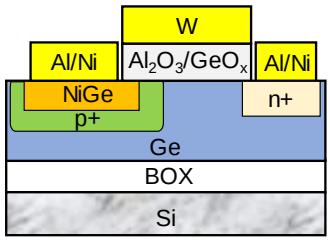


Fig. 5 Schematic of fabricated TFET.

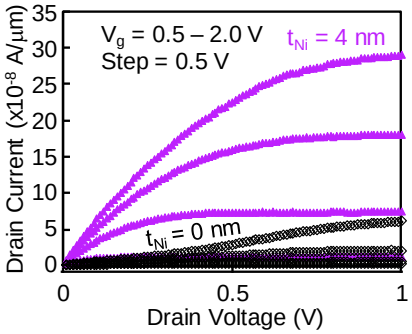


Fig. 6 I_d-V_d characteristic of TFETs.

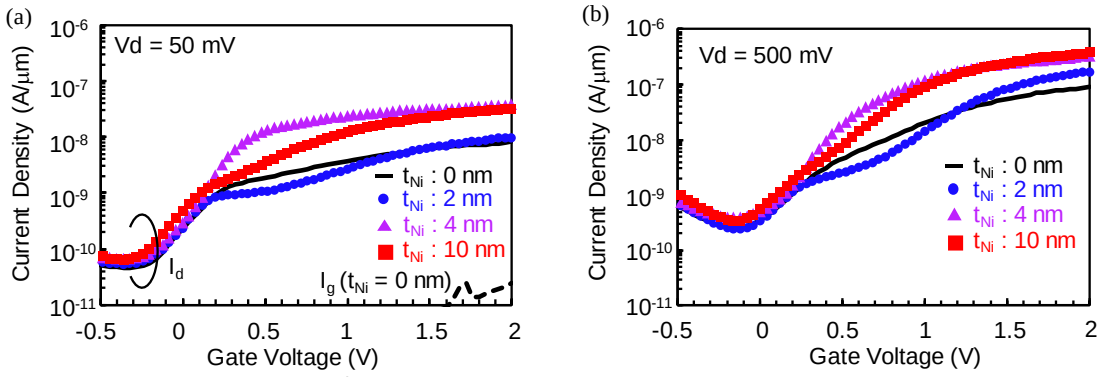


Fig. 7 Id-Vg characteristic of TFETs with various t_{Ni}, where (a) Vd = 50 mV and (b) Vd = 500 mV.

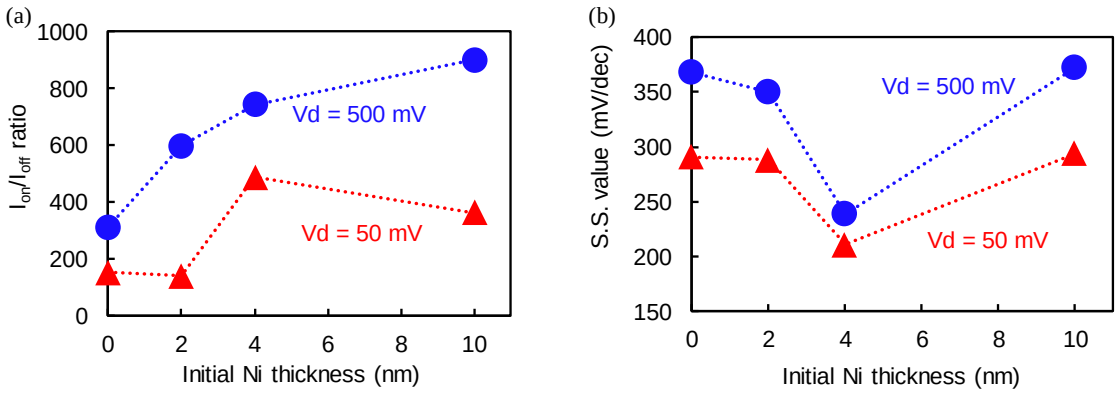


Fig. 8 (a) I_{on}/I_{off} ratio and (b) S.S. value of TFETs as a function of initial Ni thickness of source region.