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Performance enhancement of GOI tunneling FETs with source junctions formed by low energy BF_2 ion implantation

T. Katoh, R. Matsumura, R. Takaguchi, M. Takenaka, and S. Takagi
The University of Tokyo
2-11-16 Yayoi, Bunkyo-ku, Tokyo, 113-0032, Japan
Phone: +81-3-5841-6733 E-mail: takagi@ee.t.u-tokyo.ac.jp

Abstract

GOI (Ge-On-Insulator) n-channel TFETs with source tunnel junctions formed by low energy BF_2 ion implantation (I/I) are fabricated and the device characteristics are presented. It is shown that BF_2 I/I can realize much steeper B profiles than B I/I, leading to higher on current and lower sub-threshold slope.

1. Introduction

GOI TFETs are expected as a steep slope device with high on current and steep subthreshold slope [1, 2]. Here, formation of the source junctions with the high impurity concentration and the steep impurity profile is a critical issue [3]. However, there are few experimental studies on the relationship between the source impurity profile and the TFET performance. In order to realize n-channel TFETs, careful formation of p-type source regions is needed. A typical way of introducing p^+ impurities into Ge is I/I of B. However, implantation of BF_2 is more favorable for forming steep B profiles. In this study, the BF_2 ion implantation conditions for formation of source junctions in Ge n-TFETs are examined and the relationship between the properties of the source junctions and the electrical characteristics of Ge n-TFETs is experimentally investigated.

2. Experiments and discussions

First, the pn junction properties formed by B and BF_2 I/I were evaluated. Fig. 1 shows the SIMS profiles of B concentrations for 4 keV B and 20 keV BF_2 I/I into Ge. The almost same B profiles are obtained in spite of the difference in the implantation energy, indicating that much steeper B profile can be obtained for BF_2 under a lower limitation of the implantation energy. Fig. 2 shows the I-V characteristics of the p^+-n Ge junctions after activation annealing at 400 ^oC for 4 keV B and 20 keV BF_2 I/I. The similar electrical properties with low I_{off} and high I_{on}/I_{off} for both I/I conditions suggest that BF_2 I/I does not create any additional defects. We have also confirmed no thermal diffusion of B after the activation annealing at 400-600 ^oC. Fig. 3 shows the comparison of the B profiles among 3 keV BF_2 I/I with an implanted dose of $4x10^{14}$ cm^{-2}, 6 keV BF_2 I/I with $6x10^{14}$ cm^{-2} and 4 keV B I/I with $3x10^{14}$ cm^{-2} after the activation annealing for 3 min. at 400 ^oC. The 3 keV BF_2 I/I provides the B profile with 5.7 nm/dec, which is much steeper than those in 6 keV BF_2 (9.3 nm/dec) and 4 keV B (20 nm/dec) I/I, demonstrating the effectiveness of lower energy BF_2 I/I. Fig. 4 summarizes the sheet hole concentration of BF_2-implanted Ge regions, evaluated by the CTLM method as a function of the implanted dose. The activation rate of around 10 % is obtained, independent of the dose, which can be explained by the lower activation rate of B near Ge surfaces [4]. Fig. 5 shows the benchmark of the relationship between the abruptness of the B profiles and the averaged active hole concentrations for reported data on B-implanted Ge regions [5-9]. It is found the present results can achieve the steepest abruptness under a hole concentration acceptable as the source region in n-TFETs.

N-channel TFETs with the BF_2 or B-implanted sources were fabricated by using a process flow shown in Fig. 6 under the same I/I conditions as in Fig. 3. Here, the n^+ drain regions were formed by Sb diffusion from Sb-doped SOG. $W/Al_2O_3/GeO_x/Ge$ with plasma post oxidation [10] was employed as the gate stacks. The operation of n-channel GOI TFETs is clearly confirmed in the I_d-(V_g–V_{min}) characteristics with the sources formed by 3 keV BF_2 I/I with a dose of $4x10^{14}$ cm^{-2} at 300 (RT) and 10 K (Fig. 7). Here, V_{min} was defined as V_g corresponding to the minimum I_d. I_{on}/I_{off} is significantly improved from 60 to 10^5 by reducing temperature from RT to 10 K, because of the suppression of the junction leakage current due to any defects. The minimum S.S. value of 130 mV/dec is obtained at 10 K. Fig. 8 shows the I_d-V_g characteristics of GOI n-TFETs with changing the BF_2 I/I dose at 3 keV. It is found that the increase in the dose particularly increases I_{on}.

Fig. 9 and 10 show the comparison in the I_d-V_g characteristics at RT and 10 K, respectively, with the source regions formed by 3 and 6 keV BF_2 and 4 keV B I/I, whose conditions are corresponding to the SIMS profiles shown in Fig. 3. It is found that I_{on} increases by a factor of 10 and the S.S. value at 1×10^{-11} A/μm decreases from 180 to 130 mV/dec by changing the I/I condition from 4 keV B to 3 keV BF_2. These results indicate that the steep B source profile realized by low energy BF_2 I/I can significantly improve n-channel TFET performance.

3. Conclusions

The operation of GOI n-TFETs with source junctions formed by 3 keV BF_2 I/I, which can realize steep B profiles has been demonstrated. It has been shown that steeper B profiles can enhance the GOI TFET performance.

Acknowledgements

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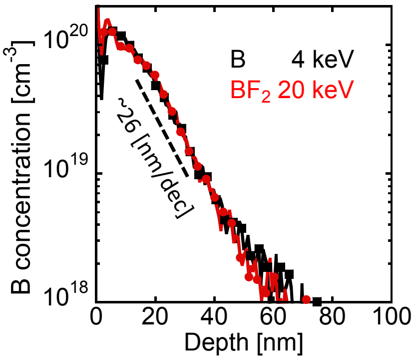

Fig. 1 SIMS profiles of B concentrations in Ge after B (4 keV) and BF_2 (20 keV) I/I.

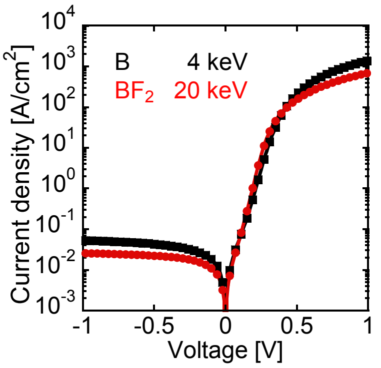

Fig. 2 I-V characteristics of Ge p^+-n junctions formed by B (4 keV) and BF_2 (20 keV) I/I.

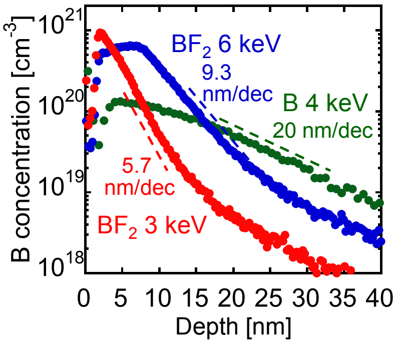

Fig. 3 SIMS profiles of B concentrations in Ge after B (4 keV) and BF_2 (6 and 3 keV) I/I.

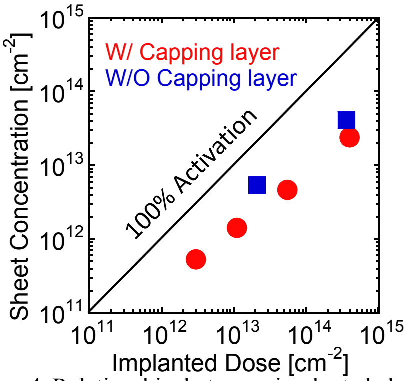

Fig. 4 Relationship between implanted dose and sheet concentration for BF_2 (20 keV) I/I with and without 2-nm-thick Al_2O_3 capping on Ge.

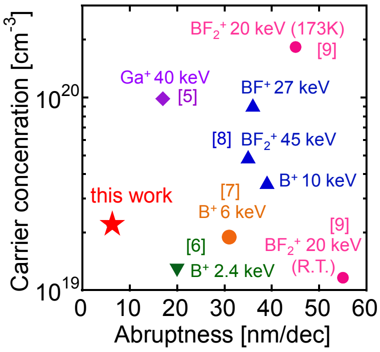

Fig. 5 Benchmark of abruptness of B profiles and hole concentrations in BF_2 or B-implanted Ge

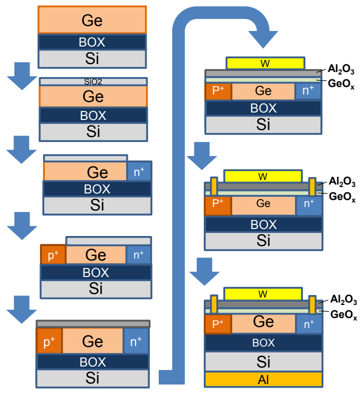

Fig. 6 Fabrication process flow of GOI TFETs with source junctions formed by B or BF_2 I/I

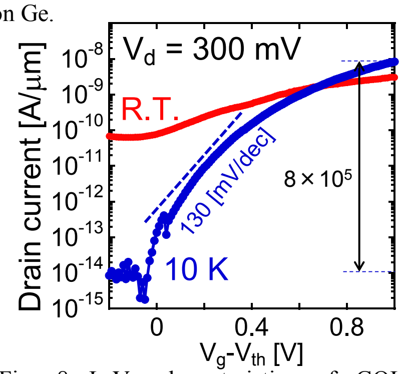

Fig. 8 I_d-V_g characteristics of GOI n-TFETs with V_d of 300 mV measured at 300 and 10 K.

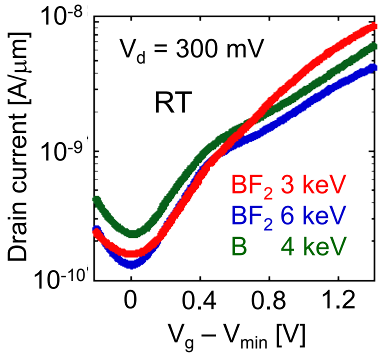

Fig. 9 I_d-V_g characteristics of GOI n-TFETs with sources formed by B (4 keV) and BF_2 (6 and 3 keV) I/I at 300 K.

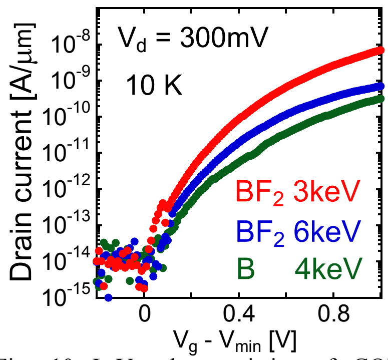

Fig. 10 I_d-V_g characteristics of GOI n-TFETs with sources formed by B (4 keV) and BF_2 (6 and 3 keV) I/I at 10 K.

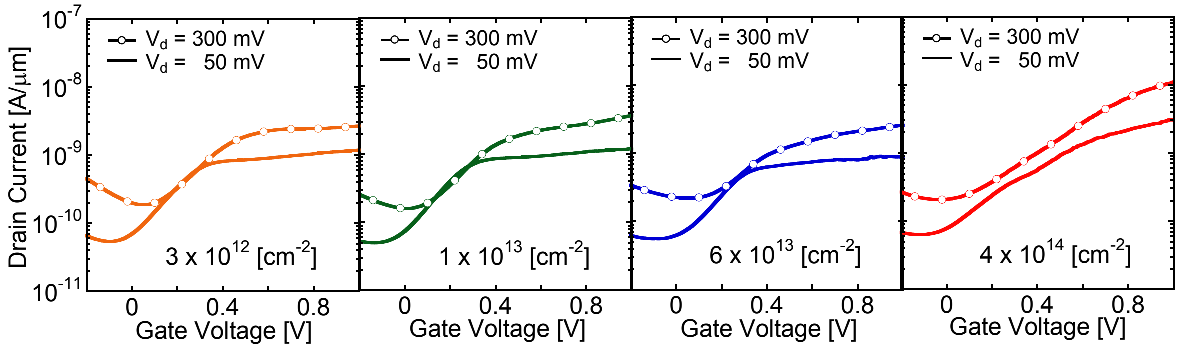

Fig. 7 I_d-V_g characteristics of fabricated GOI TFETs with V_d of 50 and 300 mV as a parameter of implanted dose of BF_2 I/I at 3 keV.