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Interaction of Sn atoms with Defects Introduced by Ion Implantation in Ge Substrate

T. Arahira, M. Fukudome, N. Taoka, W. Takeuchi, M. Sakashita, O. Nakatsuka, and S. Zaima
Graduate School of Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
E-mail: tarahira@alice.xtal.nagoya-u.ac.jp

Abstract

Interaction of Sn atoms with defects introduced by ion implantation in Ge substrates was investigated through comparison between Ge and Sn implantations. It was found that the defect concentrations for the Sn-implanted sample are much higher than that for the Ge-implanted sample after high temperature annealing. These results are attributed to the interaction of Sn atoms with the induced defects.

Introduction

Control of defect density and energy level of defect states in a Ge substrate is quite important for realizing Ge devices because the defects significantly impact on junction leakage current at a drain in a Ge MOSFET and dark current of a Ge photo detector. Sn incorporation is effective for modulate energy level of defect states in a Ge substrate because Sn-vacancy complex, which have a deep energy level of 0.19 eV from the valence band minimum of Ge is formed[1]. Therefore, the Sn incorporation has attracted much attention as one of technologies for controlling carrier concentration due to reduction of vacancies. Howeve, an interaction between Sn atoms and defects has not fully investigated yet.

In this study, the interaction of Sn atoms with defects introduced by ion implantation has been investigated by the deep level transition spectroscopy (DLTS) and I-V and C-V characteristics of the Ge Schottky diodes.

Experimental procedure

The fabrication procedure of Ge Schottky diodes including defects induced by ion implantation is shown in Fig. 1. Ge or Sn ions were implanted to n-type Ge substrates. Subsequently, the Ge substrates were annealed at the various temperatures in N_2 or H_2 ambient condition for 60 min. After removing the native oxide layer, Al electrodes were formed by vacuum evaporation method. Defects with deep energy levels and shallow energy levels were characterized by the DLTS technique and C-V, I-V methods, respectively.

Results and discussion

Depth profiles of the implanted Sn and Ge atoms were confirmed by SIMS and simulations using SRIM code (Fig. 2). It is found that the Sn depth profile measured by SIMS has a peak at 100 nm. Also, the measured peak position is in good agreement with the calculated results for Sn and Ge atoms. This suggests that the profile of the implanted Sn atoms in the Ge substrate is identical to that for the Ge implantation.

High dose ion implantation typically induces amorphization of a surface. The amorphization and recrystallization of the surfaces were confirmed.Figure 3 shows Raman spectra for the samples annealed at various temperatures in N_2 ambient condition before Al deposition. At less than 200°C, there is no peak because of the amorphizaion, while the obvious peaks associated with the Ge-Ge vibration mode are observed at higher than 300°C, suggesting that the recrystallization was occurred. Similar trend was observed in the Ge-implanted samples.

Figure 4 shows DLTS signal of the Ge-implanted sample without annealing. The two peaks are clearly observed at around 130°C (Peak1) and 180°C (Peak2). Also, the peak e by changing Tw are observed, meaning that the peaks are signals related with a thermal activated process. Figure 5 shows Arrhenius plots of τT^2 for the Peak1 and Peak2[2]. Here, the solid and open marks mean the measured and reported data, respectively. It is found that the measured data well corresponds to that of the reported data for both peaks, meaning that the measured and reported defects are the same defects. As a result, Peak1 and Peak2 can be assigned as Di-vacancy and Sb-Vacancy complex, respectively. Furthermore, it is found that the annealing leads the changes of the defect structures (Fig. 6). After the annealing at 100°C and 200°C, a defect related with Sb and interstitial and Sb-Vacancy with the (0/-) nature were observed, respectively. Observed defects for the Ge-implanted samples with the annealing in N_2 ambient condition are summarized in Table 1. In the case of the Sn implantation and the H_2 ambient annealing, almost same defects were observed. However, any defects associated with Sn atoms did not observed in the as-implanted and the annealed sample at 100°C and 200°C. On the other hand, at the high temperature annealing, some defects, which cannot determine defect structures, observed (Fig. 7). In Fig. 7, it should be noted that, in the Sn-implanted sample, defects with high defect concentrations are observed. The defects might be related with the defect interacted with Sn atoms.

Figure 8 shows $1/C^2$-V characteristics for the Sn- and Ge implanted samples and the sample without implantation. The slopes for the Sn- and Ge-implanted samples are much smaller than that for the sample without implantation, meaning that the defects induced by the implantations have a large amount of charges in the Ge substrates. Figure 9 shows annealing temperature dependences of the impurity concentration evaluated from the $1/C^2$–V characteristics for the Sn- and Ge-implanted samples. After the Sn and Ge implantation, the impurity concentrations are almost same. At less than 300°C, the defect concentrations hardly change. On the other hand, at more than 300°C, the impurity concentrations decrease with increasing the annealing temperature, indicating that the induced defect concentration decreased. Furthermore, it should be noted that, at the annealing temperature of 500°C, the defect concentrations for the Ge-implanted samples are identical to that for the sample without implantation, while, the defect concentrations for the Sn-implanted samples are still higher than that for the sample without implantation. These results strongly indicate that the defects induced by the ion implantation interact with Sn atoms. Reflecting the difference of the defect concentration, the reverse bias currents of the I-V characteristics for the Sn-implanted samples are much higher than those for the Ge-implanted samples(Fig. 10).

Conclusion

The interaction of the Sn atoms with the defects in the Ge substrates was experimentally observed. DLTS reveals the existence of the defects, which interact with the implanted Sn atoms, with the deep energy levels and high defect concentrations. Also, the C-V and I-V characteristics clarify that the defects with interacted with the Sn atoms, which have shallow energy level, were observed.

References

[1] V. P. Markevich *et al*., J. Appl. Phys. **109** (2011) 083705 [2] F. D. Auret *et al*., NIM B, **257** (2007) 169-171

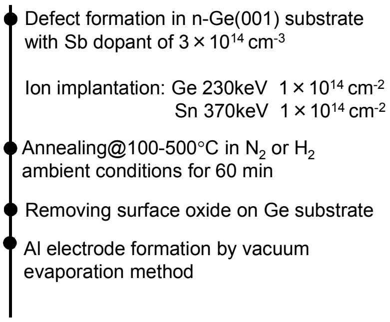

Fig. 1: Fabrication process flow of the Al/Ge Schottky diodes with defects induced by ion implantations.

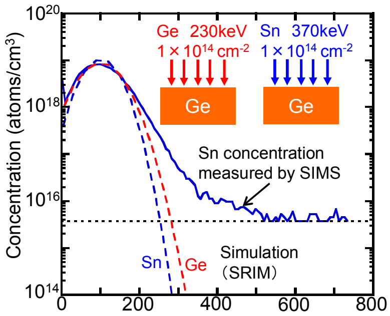

Fig. 2: Depth profiles of the implanted Ge and Sn atom concentration. Solid and dashed lines mean the results measured by SIMS and calculated by SRIM code.

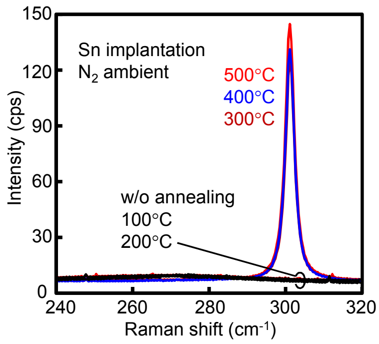

Fig. 3: Raman spectra for the samples annealed at various temperatures in N_2 ambient before Al deposition.

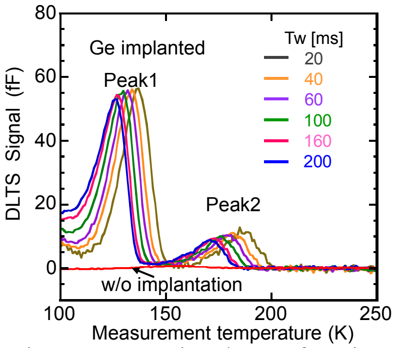

Fig. 4: DLTS signal as a function of measurement temperature for various Tw. Here, Tw means an interval time for the capacitance measurement during transient response.

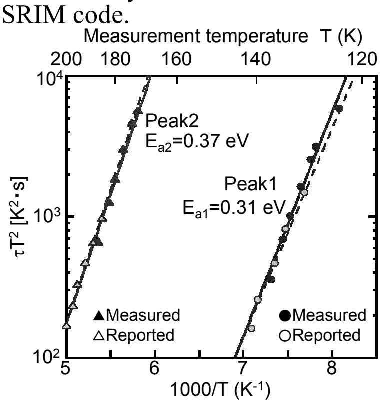

Fig. 5: Arrhenius plots of τT2 for observed peaks in Fig. 7. Here, τ is inverse of emission rate of trapped carriers.

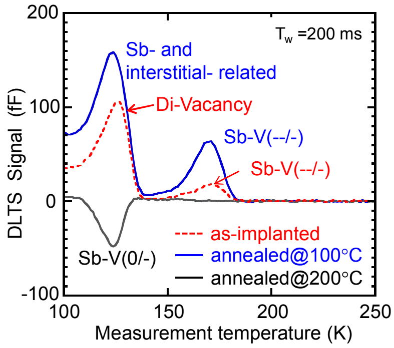

Fig. 6: DLTS signal as a function of measurement temperature for the Ge implanted sample with annealing at 100°C and 200°C in N_2 ambient and without annealing.

Annealing temperature	Defect level (eV)	Capture cross section σ_n (cm^2)	Defect density N_t(cm^{-3})	Defect structure
as-implanted	Ec - 0.31	1×10^{-13}	1.4×10^{15}	Di-Vacancy[1]
	Ec - 0.37	2×10^{-15}	2.5×10^{14}	Sb-V[1] (--/-)
100°C	Ec - 0.23	1×10^{-16}	4.7×10^{15}	Sb- and I-related[1]
	Ec - 0.35	1×10^{-15}	2.2×10^{15}	Sb-V[1] (--/-)
200°C	Ev + 0.31	4×10^{-13}	2.8×10^{15}	Sb-V[2] (0/-)

Table 1: Observed defects for the Ge implanted sample with annealing at 100°C and 200°C in N_2 ambient and without annealing.

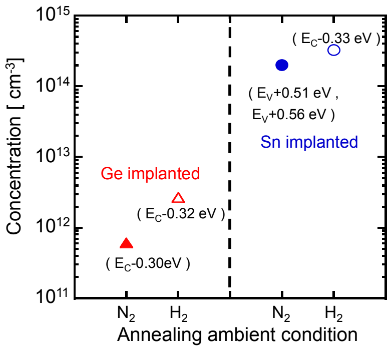

Fig.7: The defect concentration of samples with annealing at 500°C in N_2 or H_2 ambient.

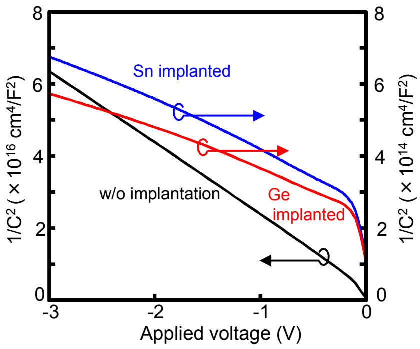

Fig. 8: $1/C^2$-V characteristics for the Sn, Ge and no implanted samples without annealing.

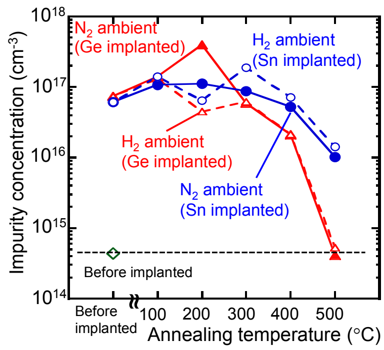

Fig. 9: Annealing temperature dependence of the impurity concentration evaluated from the $1/C^2$-V characteristics.

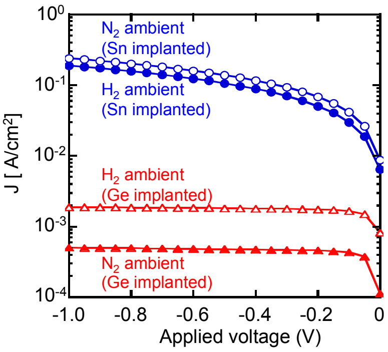

Fig. 10: I-V characteristics for the Sn and Ge implanted samples with annealing at 500°C in N_2 or H_2 ambient.