Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 452-453

P-1-26

Xe Preamorphization Implantation for Transient Enhanced Diffusion Suppression of As in Ge Substrate

[1,2]T. Fukunaga, [1,2]K. Hosawa, [1]T. Hosoi and [1,2]K. Shibahara
[1]Research Center for Nanodevices and Systems, Hiroshima University
[2]Graduate School of Advanced Sciences of Matter, Hiroshima University
1-4-2 Kagamiyama, Higashi-Hiroshima, Hiroshima, 739-8527 Japan
Phone: +81-824-24-6265, Fax: +81-824-24-3499, e-mail: ttfukunaga@hiroshima-u.ac.jp

1. Introduction

Incorporation of Ge with a Si device is a challenging way to exceed the scaling limit of Si MOS devices. Mobility and carrier injection speed enhancement with Ge components will be beneficial for MOSFET performance improvement [1]. Though a lot of pioneering works of semiconductor devices were done with Ge, later research activities on Ge had been limited because of Si device prosperity. As a result, research on doping, the fundamental of semiconductor process, has not been sufficient. We have investigated Sb^+ shallow implantation into Ge as a step to accumulate knowledges on doping to Ge, and found the anomalous deep depth profile [2].

In this paper, we report Xe^+ PAI (Pre-amorphization implantation) that is effective to eliminate the anomalous profile broadening and to suppress TED (Transient Enhanced Diffusion). Amorphization is helpful to form shallow junctions for Si, since it suppresses channeling and reduces TED [3,4]. As TED suppression with Xe^+ PAI in Ge is demonstrated for the first time.

2. Origin of anomalous profile and countermeasure

It is well known that shallow junction formation in Ge with donors is difficult because of their large diffusivity [5]. Therefore, we are investigating junction formation with donors, such as As and Sb. Figure 1 shows examples of Sb profiles. Though high dose ($3x10^{15}$ cm^{-2}) implantation that accompanies amorphization resulted in the profile broader than one predicted by TRIM, ion implantation simulator. The origin of such a deep profile was amorphized layer roughening shown in Fig. 2 (a). It was reported that the amorphized layer roughening was a common issue for various ion species [6,7]. The roughening was relieved by depositing thin SiO_2 film on Ge prior to the implantation, as shown in Fig. 2 (b). However even with the SiO_2 film, honeycomb like voids formation under the SiO_2 film was reported. We can skip the SiO_2 deposition by changing ion species to Xe^+ that dose not give rise to the roughening, as shown in Fig. 2 (c). Therefore, we can combine PAI process by Xe^+ implantation with any donor atoms, as long as donor dose is limited not to roughen the surface.

3. Junction formation with As^+ and Xe^+ PAI

Ge (100) wafers whose resistivity was 20 Ωcm were used to form n^+/p junctions with As. Figure 3 shows as-implanted As profiles. The profile tail for the specimen with the PAI was steeper than that without PAI because of channeling suppression. However, in the region shallower than 25 nm, the PAI case shows deeper As penetration. This is attributed to spherical void formation shown in Fig. 4. The voids are considered to be the result of Xe precipitation in Ge, since average void center depth 10 nm well agrees with Xe peak depth obtained with TRIM. Figure 5 shows Xe TRIM profiles for various implantation doses and amorphized layer depths measured with TEM and spectroscopic ellipsometry. This implies that critical amorphization concentration of Xe is around $1x10^{18}$ cm^{-3}. In the series of junction formation for this investigation, Xe^+ dose was mainly $3x10^{15}$ cm^{-2}. However, considering such a low critical amorphization concentration, Xe^+ dose can be reduced less than $1x10^{14}$ cm^{-2}. Such a dose reduction would reduce the spherical voids by reducing peak Xe concentration.

Figure 6 shows As profiles after annealing heated with halogen lamps for 15 s. Xe^+ PAI showed drastic reduction of As diffusion. Similarly to Si, it is considerable that PAI increased point defect recombination rate and reduced TED. Figure 7 (a) and (b) show sheet resistance and junction depth as functions of annealing temperature. Sheet resistances for specimens with the PAI were higher than that for without PAI. A possible origin of the higher sheet resistance for the PAI cases is shallower profile. However, bad influence of existence of Xe for As activation cannot be denied. To clarify this point, data with PAI at lower Xe^+ dose should be obtained by further investigation. Annealing at 700°C resulted in very low sheet resistance. However, junction was so deep that annealing at this temperature is not practical even with the PAI for junction formation.

4. Summary

Ge surface roughening induced by high dose implantation did not take place for Xe^+ implantation. PIA process with Xe^+ was beneficial for junction formation with As because of TED suppression. Further investigation with lower Xe^+ dose is demanded to confirm the reduction of the spherical voids.

Acknowledgements

This work was partly supported by NEDO/MIRAI Project and the 21st Century COE program “Nanoelectronics for Terra-Bit Information Processing” in Hiroshima University from Ministry of Education, Science, Sports and Culture of Japan.

References

[1] S. Takagi, VLSI Symp. 2003, pp. 115–116.
[2] K. Hosawa et al., Ext. Abst. IWJT 2005, pp. 39-40.
[3] K. A. Gabel et al., J. Appl. Phys. **97**, 044501, (2005).
[4] S.-D. Kim et al., Solid-State Electron. **49** pp. 131-135 (2005).
[5] C.O. Chui et al., IEDM Tech. Dig. 2003, pp. 437-440.
[6] T. Janssens et al., USJ Workshop 2005, pp.79-83.
[7] O.W. Holland et al., J. Apply. Phys **54** pp. 2295-2301 (1983).

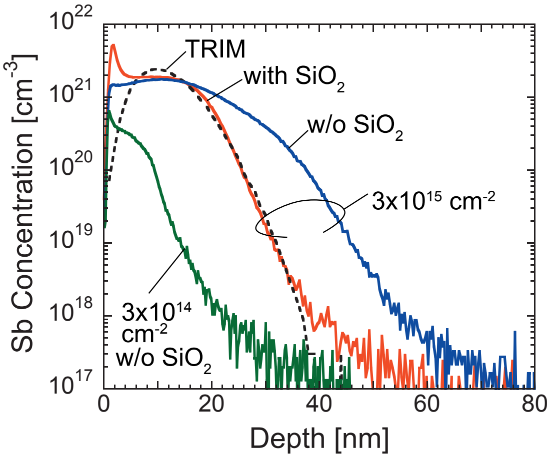

Fig. 1 High dose Sb^{+} implantation resulted in anomalously deep Sb profile. It was suppressed by depositing thin, 2 nm, SiO_2 on Ge or by reducing implantation dose not to give rise to amorphization.

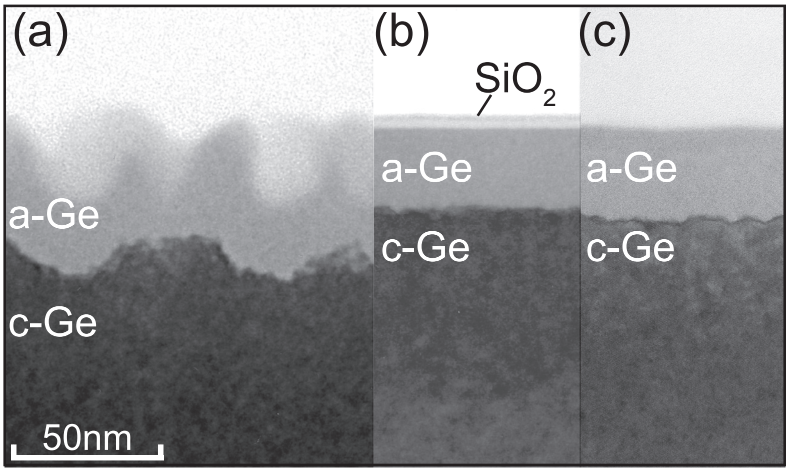

Fig. 2 Cross-sectional TEM images of Ge surface after heavy ion implantation to form an amorphous layer. Sb^{+} implantation into bare Ge resulted in very rough amorphized surface (a), however it was suppressed by adding thin SiO_2 cover (b) or changing the implantation specie to Xe^{+} (c).

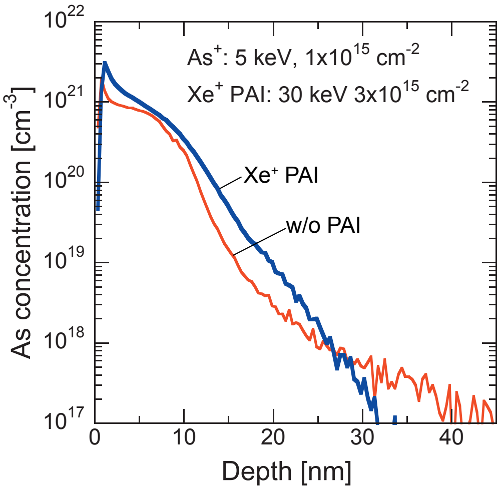

Fig. 3 As-implanted As profiles for specimens with and without a pre-amorphized layer formed by Xe^{+} implantation.

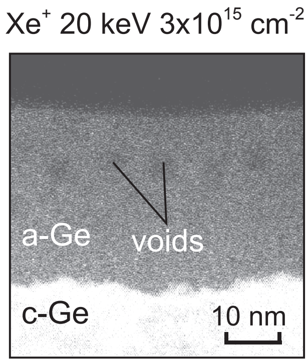

Fig. 4 Spherical voids observed in Xe^{+} implanted Ge. TEM image gradation was reversed to make recognition of voids easier. Average depth of void center was about 10 nm. It was equal to peak depth of implanted Xe profile.

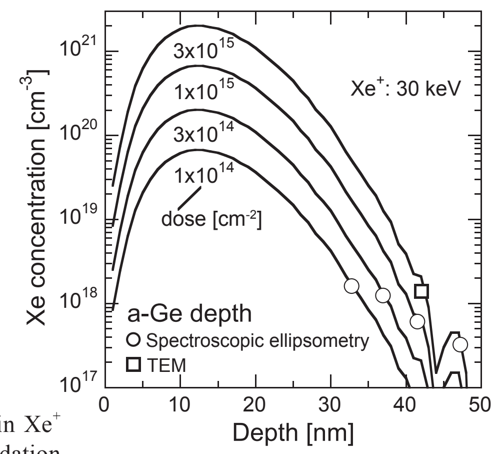

Fig. 5 Xe profiles for various implantation doses obntained with ion implantation simulator TRIM. Amorphized layer thicknesses were also indicated. Critical amorphization Xe concentration was estimated to be around $1x10^{18}$ cm^{-3}.

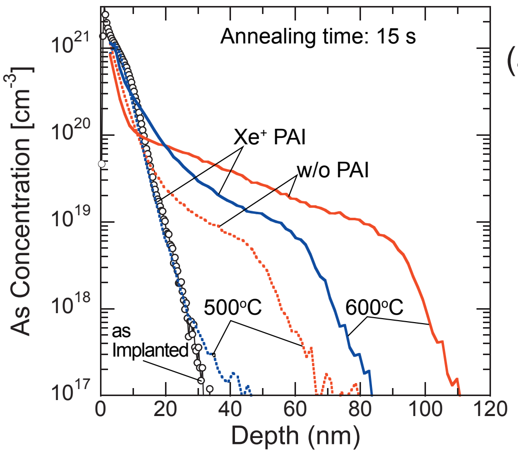

Fig. 6 As profiles after annealing. PAI with Xe^{+} led to shallower profiles. Especially at 500°C, As profile with the PAI was nearly identical to as-implanted one in spite that the junction depth was doubled for the non-PAI case.

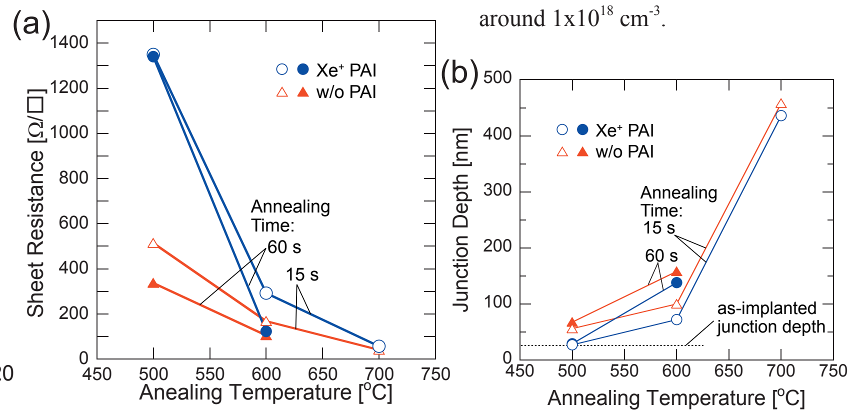

Fig. 7 Annealing temperature dependence of (a) sheet resistance and (b) junction depth. The junction depth was defined at $1x10^{18}$ cm^{-3} of As concentration. It should be recognaized that very low sheet resitance for 700°C annealing was a result of quite deep diffusion.