Ge Shallow Junction Formation with Preamorphizing Technique

Kentarō SHIBAHARA, Tetoya FUKUNAGA, and Takuji HOSOI

1Research Institute for Nanodevices and Bio Systems, Hiroshima University
2Research Center for Nanodevices and Systems, Hiroshima University
3Graduate School of Advanced Sciences of Matter, Hiroshima University
1-4-2 Kagamiyama, Higashi-Hiroshima, Hiroshima, 739-8527 Japan
Phone: +81-82-424-6267, Fax: +81-82-424-3499
e-mail: ksshiba@hiroshima-u.ac.jp

1. Introduction

Recently Ge is extensively investigated as an alternative material to Si because of its higher mobility and injection velocity [1]. A lot of work is done concerning gate stack to develop practical Ge MOS devices and 100-nm-scale MOS devices [2,3] were already reported. However, activities of investigation on doping and shallow junction formation are limited compared with them. Although the majority of Ge researchers seem to give priority to the gate stack, doping technology is not an easy subject.

Different from Si, donors in Ge diffuse faster than acceptors. Therefore, n+/p shallow junction is difficult to form. We have tried fabricating it with Sb. However, Sb implantation gave rise to severe surface roughening [4,5]. This roughening issue is common for most ion species especially for heavy ions [6]. However, we found that Xe is an exception [4]. Although Xe is not a dopant for Ge, it is usable for PAI (Preamorphization implantation). PAI is popularly used for Si shallow junction formation. By amorphizing wafer surface, ion channeling can be reduced. In addition, PAI is sometimes useful for slowing down dopant diffusion. In an amorphized layer recovers crystallinity by solid phase epitaxy. This process effectively reduce point defects formed by ion implantation. In Si and Ge, interstitial and vacancy dominate diffusion process, respectively. These points defects sometimes accelerate dopant diffusion by forming a pair of a point defect and a dopant. Although pre-dominant defects are not same in Si and Ge, it is expectable that PAI and the following annealing processes, to reduce points defects utilizing solid-phase regrowth, can decelerate the dopant diffusion.

Previously, we have reported that Xe⁺ PAI was effective to suppress TED (Transient Enhanced Diffusion) [4]. However, Xe⁺ PAI formed “bubbles” in Ge. Although the bubbles are observed as huge voids by XTEM (Cross-sectional Transmission Electron Microscopy), they originate from Xe precipitation in Ge. In this report, issues originated from the bubbles and how to eliminate them are described.

2. Experiments

Ge(100) p-type substrates were used for experiments. After removal of the native oxide by diluted HF solution dipping, Xe⁺ was implanted at the energy of 30 keV for PAI. Xe⁺ implantation dose was reduced from 3x10¹⁵ cm⁻² (high dose) that was used for the previous work to 1x10¹⁴ cm⁻² (medium dose) or 1x10¹³ cm⁻² (low dose). After PAI, As⁺ was implanted into Ge at 5 keV for 1x10¹⁵ cm⁻² as a dopant.
Activation annealing was carried out by RTA (Rapid Thermal Annealing). Annealing temperature was 600°C. Crystallinity, As depth profile and sheet resistance were evaluated by XTEM, SIMS (Secondary Ion Mass Spectrometry) and four-point probe method, respectively.

3. Results and Discussions

Figure 1 shows XTEM images for just after Xe\(^+\) PAI. For every specimens, Ge surface was amorphized. Since, in the case of low dose, columnar crystal phase remained in the amorphized layer (Fig. 1(c), the Xe dose must be larger than the low dose for device application. On the other hand, high dose PAI resulted in the Xe bubble formation, as shown in Fig. 1(c). Homogeneous amorphous layer without the bubble was obtained only for the medium dose (Fig. 1(b)). As depth profiles obtained by SIMS measurement for after As\(^+\) implantation are shown in Fig. 2. PAI made the As depth profile tail steeper by suppressing ion channeling. However, the As profile for the high dose is slightly deeper than that for the medium dose. In the high-dose specimen a lot of bubbles exist. Ion stopping power in the bubbles are considered to be smaller than that in bulk Ge. Therefore, As\(^+\) ions implanted into Ge with high-dose PAI can go deeper through the bubbles. Although no bubbles are observed in the Ge with medium-dose PAI shown in Fig. 1(b), bubble formation by annealing was anxious. However, no bubbles are seen in after annealing at 600°C for the medium dose, as shown in Fig 3(b). On the other hand, craters are seen for the Fig. 3(a) high dose specimen despite the fact that bubbles were vanished.

---

![XTEM images of Ge substrates after Xe\(^+\) implantation. Implantation energy was 30 keV and doses are (a) 3x10\(^{15}\) cm\(^{-2}\), (b) 1x10\(^{14}\) cm\(^{-2}\) and (c) 1x10\(^{13}\) cm\(^{-2}\).](image)

**Fig. 1** XTEM images of Ge substrates after Xe\(^+\) implantation. Implantation energy was 30 keV and doses are (a) 3x10\(^{15}\) cm\(^{-2}\), (b) 1x10\(^{14}\) cm\(^{-2}\) and (c) 1x10\(^{13}\) cm\(^{-2}\).

![Implanted As SIMS depth profiles. Xe\(^+\) PAI was performed for some specimens prior to As implantation.](image)

**Fig. 2** Implanted As SIMS depth profiles. Xe\(^+\) PAI was performed for some specimens prior to As implantation.

![XTEM images of Ge substrates after Xe\(^+\) implantation and annealing at 600°C for 15 s.](image)

**Fig. 3** XTEM images of Ge substrates after Xe\(^+\) implantation and annealing at 600°C for 15 s.
The fact that craters are larger than the bubbles imply growth of the bubbles during annealing. Assuming the growth, crater formation process can be speculated as follows and as illustrated in Fig. 4. The bubbles in Ge growth larger reducing its number, in other words the bubbles shows Ostwald ripening. Once the top of the grown bubbles reaches to the Ge surface, the bubbles blow up and craters remain.

Figure 5 shows As depth profiles after annealing at 600°C. In the case of 15 s annealing, diffusion for the medium dose PAI was slowest. However, by extending the annealing time to 30 s, diffusion depths for both the medium dose and high dose became almost same. The model to explain this tendency is schematically shown in Fig. 6. In the early stage of the annealing, As atoms are captured to Xe clusters smaller than bubbles and lose mobility. During annealing the Xe cluster decompose gradually triggered by out diffusion of Xe. As a result the As atoms are released and recover mobility. Assuming Xe
concentration in Ge bulk for the high dose PAI is lower than that for the medium dose by the formation of bubbles, slower redistribution in the medium PAI specimen can be understood. Figures 7(a) and 7(b) indicate sheet resistance and resistivity roughly estimated using junction depth obtained by SIMS measurements are shown. The medium dose PAI resulted in the highest sheet resistance and resistivity. It seems that Xe in Ge bulk prevent activation of As. Since lowering of activation rate by Ge$^+$ PAI was also reported [7], further investigation is necessary to make clear the mechanism of activation degradation.

4. Conclusion

By reducing Xe$^+$ implantation dose, bubbles and craters formation were eliminated. In spite of reducing the dose, diffusion deceleration was remarkable. However, Xe PAI showed sideeffect against dopant activation.

Acknowledgments

Part of this work was supported by Grant-in-Aid for scientific research (C), 19560344, 2007 and “Interdisciplinary Research on Integration of Semiconductor and Biotechnology at Hiroshima University” based on “Creation of Innovation Centers for Advanced Interdisciplinary Research Areas” the Special Coordination Funds for Promoting Science and Technology, from the Ministry of Education, Culture, Sports, Science, and Technology of Japan.

References