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Depth Profile and Retained Dose in SiO_2/Si Structure for $B_{18}H_X^+$ Implantation

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1. Introduction

$B_{18}H_X^+$ implantation has been used for the advanced source-drain extension (SDE) formation to obtain the boron doped layer of shallower than 10 nm. Such extremely shallow junction formation is often suffered from reduction in retained dose and surface sputtering. The dose loss is basically attributable to backscattering of implanted boron atoms due to elastic collision against Si atoms and kick-out effect due to B-B interaction. In addition, it was reported that, in the B^+ implantation energy region lower than 0.5 keV, the amount of boron atoms lost by surface SiO_2, such as a native oxide, depended on implantation energy and wet cleaning condition after implantation [1]. The surface sputtering is a severe issue for high dose implantation of heavy ion such as As^+ [2]. The sputtering effect is negligible for ordinary light B^+ implantation. However concerning $B_{18}H_X^+$ which is heavier than As^+, whether the sputtering is noteworthy issue or not is not clear yet.

Based on these backgrounds, we have precisely investigated boron profile for $B_{18}H_X^+$ implantation. SiO_2 capping was used for some cases, to discuss sensitivity of the profile against surface condition. A SiGe marker was introduced to evaluate sputtering depth during cluster boron implantation.

2. Experimental

As illustrated in Fig. 1, two types of samples were prepared as implantation targets. Both substrates commonly have a buried SiGe layer grown with thickness of 40 nm on a Si substrate. The Ge content in the SiGe layer was 20%. Seven nm Si epitaxial layer was grown on the SiGe layer. The SiGe layer played a role of Ge marker to evaluate the thickness of surface Si layer. Some samples were capped with SiO_2 film of 2 nm. The SiO_2 cap was deposited at 680˚C by low temperature CVD with TEOS (Tetra Ethyl Ortho Silicate) to avoid the diffusion of Ge and maintain steepness of Si/SiGe interfaces.

B^+ or $B_{18}H_X^+{}_{(X\leq22)}$ was implanted to the samples explained above. The implantation condition was summarized in Table 1. Ion energy for B^+ or $B_{18}H_X^+$ was 0.2 keV and 4 keV, respectively. Assuming proportional distribution of the ion energy against atomic mass, $B_{18}H_X^+$ implantation at 4 keV is equivalent to 0.2 keV B^+ implantation. B^+ dose or effective boron dose for $B_{18}H_X^+$ implantation was 1×10^{15} cm^{-2}. Ion beam incidence angle was fixed at 0˚.

After implantation, boron depth profile was obtained by SIMS analysis. Primary beam for the SIMS analysis was O_2^+ with oblique incident angle and no O_2 flooding technique was utilized. The O_2 flooding is known as one of the methods that enable sequential quantification throughout stacked structure of SiO_2 and Si. However, the O_2 flooding sometimes leads to unrealistic boron peak near the Si surface as a result of boron segregation. The protocol which we used allows the realistic profile shape even near the surface with native oxide or inside SiO_2 because of the precise correction by the variable relative sensitive factor calculated from Si and SiO_2 reference materials [3]. The SIMS protocols without surface artifacts are essential to estimate retained boron dose by integrating the SIMS boron profile.

3. Results and Discussion

Figure 2 shows boron profiles in both substrates after B^+ or $B_{18}H_X^+$ implantation. The profiles for no cap and capped cases are shown in Fig. 2(a) and 2(b) respectively. In the case of B^+ implantation, the SiO_2 capping did not affect the boron profile much. Different from this B^+ implantation case, $B_{18}H_X^+$ implantation with the cap resulted in broader peak and lower boron concentration compared with no cap case. Retained boron doses obtained from these profiles are shown in Fig. 3. In this figure, the retained doses for the capped substrates are separated into two, that for in SiO_2 and that for in Si. Although the difference in the retained dose between B^+ and $B_{18}H_X^+$ implantations for no cap samples was only 6%, by capping the SiO_2, the retained dose for $B_{18}H_X^+$ implantation decreased down to 25% compared to B^+ implantation. Retained dose in the SiO_2 layer for $B_{18}H_X^+$ implantation reduced to 54% compared with B^+ implantation. As a result, the retained dose in the Si layer for $B_{18}H_X^+$ implantation became larger by 1.5 times than that for B^+ implantation.
Surface sputtering by heavy $B_{18}H_X$ would cause profile change. In Figs. 4 and 5, secondary Ge and O ions profiles are plotted. From the shift due to the SiO_2 capping the capping thickness was estimated to be 1.8 nm and no evidence of thinning was found in Fig. 4. Good agreement of Ge and O profiles between B^+ and $B_{18}H_X^+$ implantations also supports that the surface sputtering are negligible.

To consider the reason of retained dose reduction in the SiO_2/Si structure for $B_{18}H_X^+$ implantation, ion collision process is discussed. Different from atomic ion cases, heavy cluster implantation gives rise to specific relaxation process of impact energy. It was reported through molecular dynamics calculation that the first collision of cluster $B_{18}H_X$ with Si caused the transition to liquid phase around impact point [4]. The flat top around the peak in boron profile, observed in Fig. 2(a) for the uncapped specimen, is one of the features of melting. Because of very fast diffusion in liquid phase, dopant profile becomes flat in the melt region. In the case of capped specimen in Fig. 2(b), Gaussian-like profile is maintained in SiO_2 and narrow flat region is seen in Si just below the SiO_2/Si interface. These results support that $B_{18}H_X$ cluster bombardment causes melting in Si and no melting in SiO_2. It is speculated that boron atoms in liquid phase hardly shows backscattering because of random movement of other atoms. Thus, the relatively larger reduction in retained boron dose for the SiO_2 capped case compared with the uncapped case, can be attributable to absence of surface melting.

4. Conclusions

Retained dose for low energy, equivalently sub-keV, $B_{18}H_X^+$ implantation and surface sputtering was investigated. The surface sputtering was negligible for both SiO_2 capped and no capping cases for the effective boron dose of 1×10^{15} cm^{-2}. However it was found that the retained boron dose for $B_{18}H_X^+$ implantation remarkably decreased due to the surface SiO_2.

Acknowledgements

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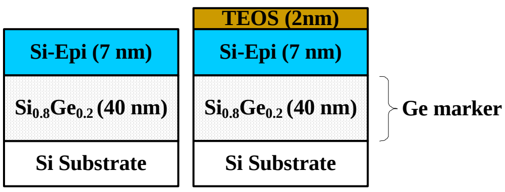

Fig. 1 The cross sectional structure for substrates without and with capped SiO_2.

Table 1 The condition in B^+ and $B_{18}H_X^+$ implantations.

	Ion Energy	Number of Ion	Effective Boron Dose	Incidence Angle
B^+	0.2 keV	1.00×10^{15} cm^{-2}	1×10^{15} cm^{-2}	0°
$B_{18}H_X^+$	4.0 keV	5.56×10^{13} cm^{-2}		

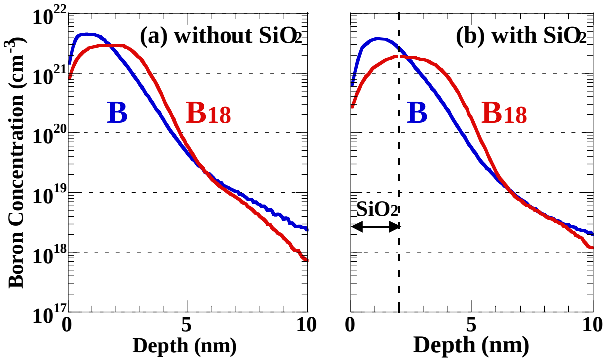

Fig. 2 The boron profiles for without (a) and with (b) capped SiO_2.

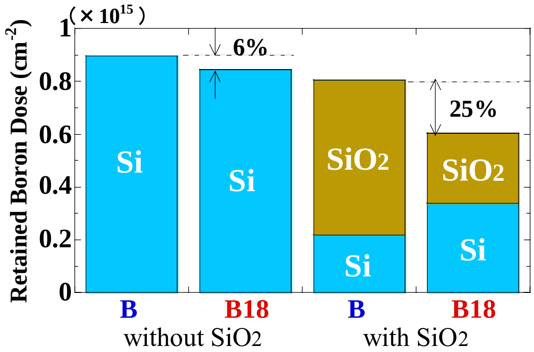

Fig. 3 The retained boron dose integrated from SIMS profiles.

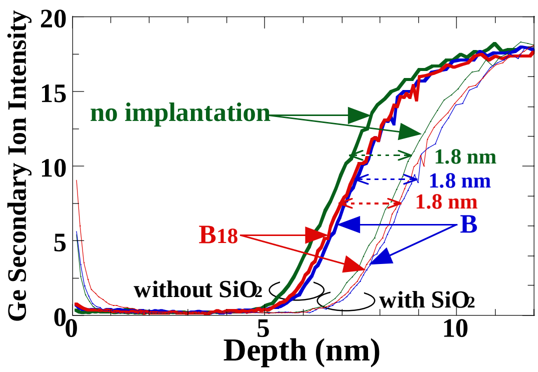

Fig. 4 The Ge profiles in substrates without and with capped SiO_2.

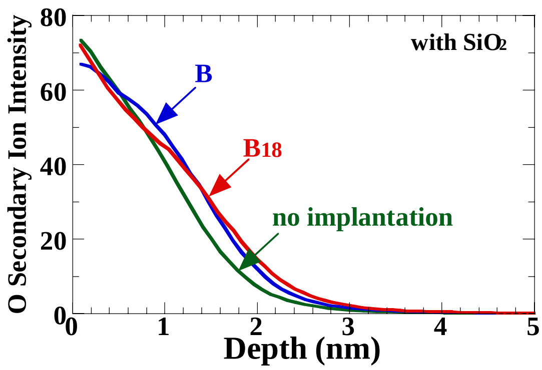

Fig. 5 The O profiles in substrate with capped SiO_2.