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Control of Interstitial Density in the Preamorphized Si by Carbon Implantation

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In preamorphized Si, the effects of carbon implantation on secondary defects at the original amorphous/crystal (a/c) interface, boron diffusion, and the junction leakage current of the p^+/n junction are studied as a function of the dose of carbon implantation. The preamorphized depth was 230nm. The carbon was implanted at 65-90keV at $2x10^{12}$-$2x10^{15}/cm^2$. The boron was implanted at 20keV at $1x10^{15}/cm^2$. The size and density of dislocation loops near the a/c interface decreased with increasing C^+ dose. The transient enhanced diffusion of B was observed even in the preamorphized region, and was reduced by the C^+ implantation. These findings indicate that the implanted carbon acts as a sink for excess interstitials. The junction leakage current was also reduced by the C^+ implantation.

1. Introduction

The preamorphization method has been widely investigated to form shallow junctions for future ULSI. The principal concern of preamorphization is the end-of-range damage located near the original amorphous/crystal (a/c) interface. The secondary defects induced by this damage increase the junction leakage current and deteriorate the device performance. These defects are considered to be due to the concentration of excess interstitials generated by Si^+ ion implantation.[1] Excess interstitials also induce an initial transient enhanced B diffusion.[2] However, it is believed that there is no transient diffusion in the preamorphized region because excess interstitials are absorbed by secondary defects at the a/c interface.[3] In this report, we will show that with C^+ implantation the secondary defects are eliminated and that the transient diffusion of B, which occurs even in the preamorphized region, is eliminated at proper C^+ doses. The electric properties of the p^+/n junction formed by these procedures are also shown. Preliminary results of this work have been presented elsewhere.[4]

2. Experimental

N-type (100) silicon wafers were used in this experiment. Active regions with $1x10^{17}/cm^3$ were formed by a LOCOS process. Si^+ ions were implanted at $2.0x10^{15}cm^{-2}$ at 115kev, then at the same dose at 50keV, which formed a 230nm-thick amorphous layer at the surface region. Then, B^+ ions were implanted at $2x10^{15}/cm^2$. After that, C^+ ions were implanted at $2.0x10^{15}/cm^2$-$2.0x10^{12}/cm^2$ at 65-110keV in half of the wafer. After the implantations, the wafers were annealed at 600°C for 1h, and then at 950-1000°C for 15-90 sec in dry N_2.

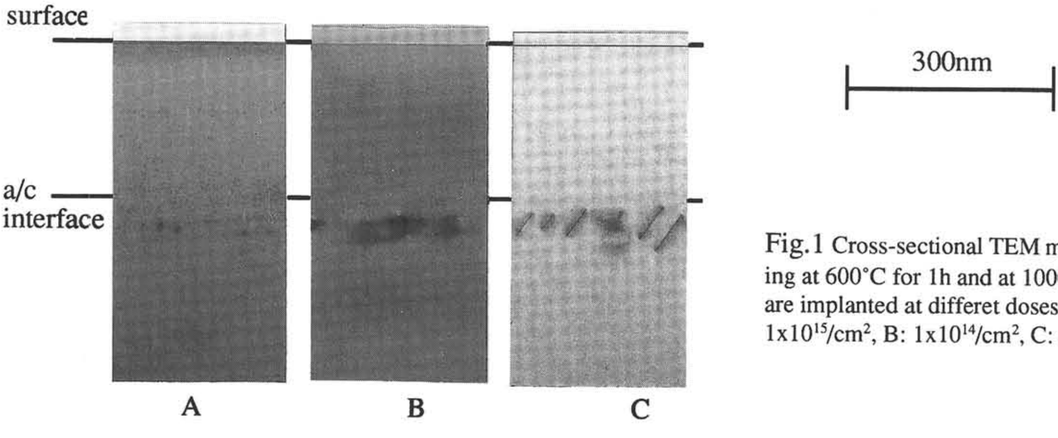

Fig. 1 Cross-sectional TEM micrographs after annealing at 600°C for 1h and at 1000°C for 75sec. Samples are implanted at differet doses of C^+ at 78keV as; A: $1x10^{15}/cm^2$, B: $1x10^{14}/cm^2$, C: no-carbon implanted.

3. Results and Discussion

Figure 1 shows cross-sectional TEM photographs of samples after the annealing. Beneath the original a/c interface, secondary defects (dislocation loops) can be seen in all samples. The size and the density of the dislocation loops decrease with increasing dose of C^+. The positions and dimensions of dislocation loops were measured on the cross-sectional TEM photographs of 10^5 magnification. On the assumption that these dislocations are a/3[111] partial dislocations and that their shape is circular, the density of atoms bound by these dislocation loops was calculated and is shown in Fig.2. The bound atoms are distributed near the a/c interface, and the peak of the distribution is about 260nm in depth. With increasing carbon dose, the density of atoms on the surface side of the profiles decreases, and then, the peak height decreases. The total concentrations of bound atoms are $5.9\times10^{14}/cm^2$ for samples without C^+ implantation and $2.6\times10^{13}cm^{-2}$ for the sample with C^+ implantation at doses of $1.0\times10^{15}/cm^2$.

B profiles after annealing are shown in Fig.3 where almost all B impurities diffuse into the preamorphized region. For comparison with the standard diffusion, the diffusion profile is calculated from the as-implanted profile with the parameter values used in SUPREM.[5)] Without C^+ implantation, the diffusion of B is enhanced compared with the simulated result, but the profile of the sample with C^+ implantation coincides very well with the simulated one, except for the tail region. For samples annealed for different time intervals with and without C^+ implantation, the measured B depth profiles are fitted with calculated ones. Here, we used the conventional expression of the diffusion constant as $D=D^0+D^+(p/n_i)$. Using the obtained parameter sets as D^0 and D^+, the effective diffusion coefficients ($D_{eff}=D^0+D^+$) are calculated and shown in Fig.4. This parameter is the time-averaged diffusion coefficient in the case where the doping concentration is less than the intrinsic carrier concentration. This figure shows that D_{eff} for samples with C^+ implantation is almost constant and the same as the value of SUPREM, but that D_{eff} for samples without C^+ implantation is much larger. This finding indicates that enhanced B diffusion occurs even in the preamorphized region, is not affected by the existence of secondary defects at the a/c interface, and decreases with increasing annealing time. On the other hand, the enhancement is eliminated completely by the C^+ implantation. We can see from Fig.5 that the elimination of the enhanced diffusion depends on the dose of implanted C^+. Here, the junction depths in the part of the wafer with C^+ implantation are plotted as a function of depth in the other part without C^+ implantation for each wafer annealed at different conditions. The enhancement is eliminated by C^+ implantation at a dose higher than about $1\times10^{15}/cm^2$.

As shown in Fig.6, after 1000°C annealing for 75 seconds, carbon concentrations even in the case of a dose of $2\times10^{13}/cm^2$ are much higher than the solid solubility limit of C in Si (which is about $10^{17}/cm^3$ at the melting point). The excess C probably segregates to

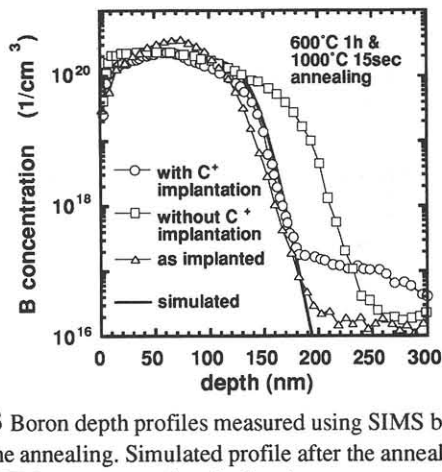

Fig.3 Boron depth profiles measured using SIMS before and afte the annealing. Simulated profile after the annealing using SUPREM parameter values is also shown.

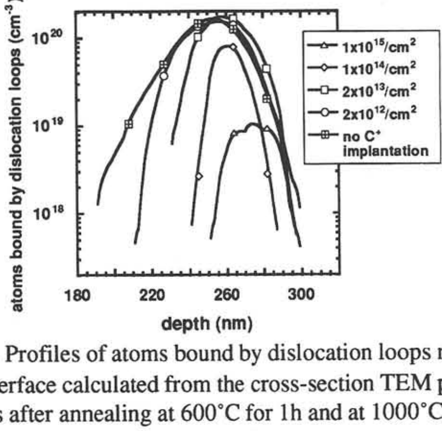

Fig.2 Profiles of atoms bound by dislocation loops near the a/c interface calculated from the cross-section TEM photographs after annealing at 600°C for 1h and at 1000°C for 75 sec for various carbon deses at 78keV.

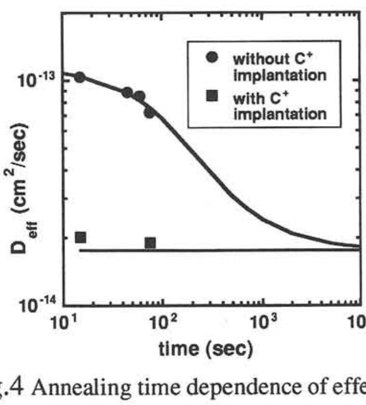

Fig.4 Annealing time dependence of effective diffusion constant (D_{eff}) with and without carbon ion implantation at 78keV at $1\times10^{15}/cm^2$.

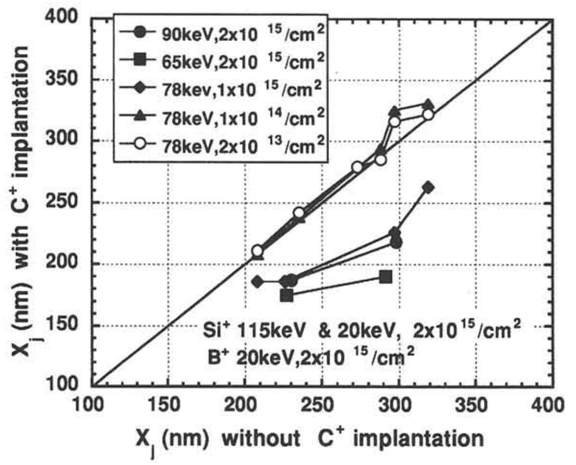

Fig.5 Junction depth(X_j) of carbon-implanted region as a function of X_j of non-carbon-implanted region for various C^+ doses and energies after annealing at 950-1000°C for 15-90sec.

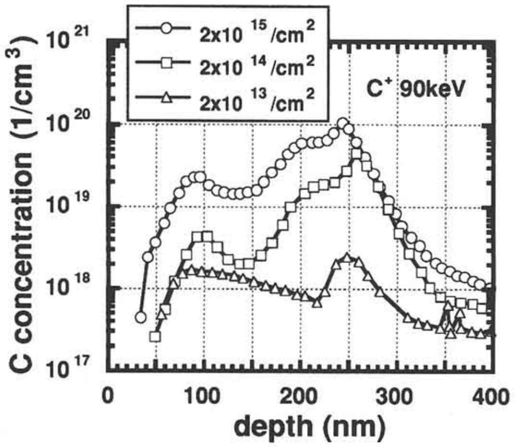

Fig.6 Carbon depth profiles after annealing at 600°C for 1h. and at 1000°C for 75sec. for various carbon doses at 90keV.

form small clusters with self-interstitials to SiC agglomerates [6]; that is, C atoms act as sinks for excess interstitials. The reduction of excess interstitials results in the elimination of the enhanced diffusion of B and the reduction of the density and size of the dislocation loops.

The leakage current of these p^+/n junctions was measured at -5V and is shown in Fig.7. With increasing C^+ dose, the leakage current decreases for the sample with the same X_j up to $1x10^{14}/cm^2$. This may be induced by the shrinkage of dislocation loops. But, SiC agglomeration may act as a generation site, so that the leakage current increases again in the case of the dose of $1x10^{15}/cm^2$.

4. Conclusions

In preamorphized Si, atoms bound by secondary defects which are excess interstitials induced by implantation are eliminated by C^+ implantation. The transient enhanced diffusion of B observed even in the preamorphized region is also eliminated by this implantation. These findings indicate that the density of excess interstitials induced by implantation can be controlled by the C^+ implantation. At the proper dose of C^+, the p^+/n junction leakage current is reduced by two orders of magnitude. Therefore, this method is effective for shallow junction formation.

5.Reference

1) K. S. Jones et al., Appl. Phys. A, **A45**, 1 (1988)
2) R. B. Fair, J. Electrochem. Soc. **137**, 447 (1988)
3) T. O. Sedwick et al., J. Appl. Phys., **63**, 1452 (1988)
4) S. Nishikawa et al., Appl. Phys. Lett., **60**, 2270 (1992)
5) P. M. Fahey et al., Rev. Mod. Phys. **61**, 289 (1989)
6) H. Wong et al., Appl. Phys. Lett., **52**, 1023 (1988)

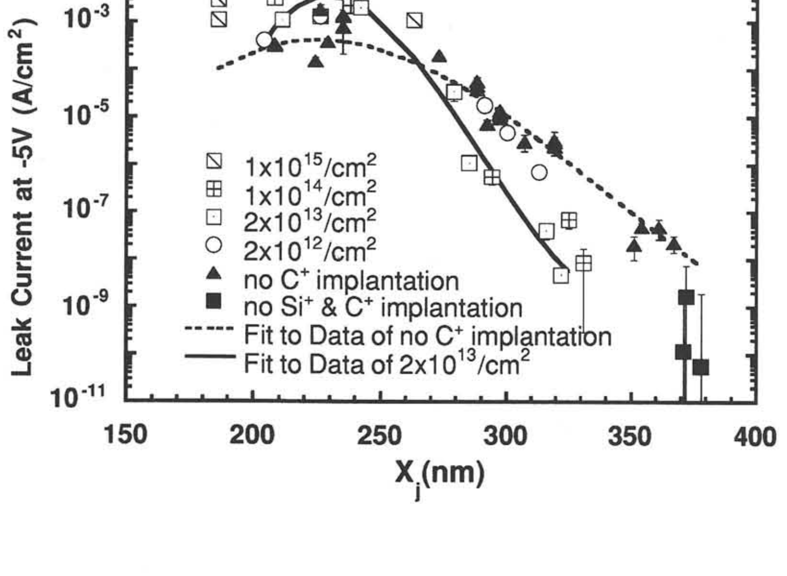

Fig.7 Junction leakage current of p^+/n junction at -5V as a function of junction depth (X_j). Carbon ions are inplanted at various doses at 78keV. Data in the case of no preamorphization with Si^+ are also shown.