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Reduction of High Energy P Implantation Induced Secondary Defects in Si by Additional C Implantation

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High energy ion implantation has received increasing interest because of its applicability to many device fabrication processes. However, for high dose ($\geqq 10^{14}$ cm^{-2}) implantation applications, it is necessary to eliminate dislocations generated by implantation and subsequent annealing process[1], since they severely degrade the performance of devices fabricated in implanted regions. Recently, it has been reported that in C implantation, secondary defects are not formed for doses up to 2×10^{16} cm^{-2} and suggested that C implanted layers getter ion implantation induced self-interstitials and prevent their agglomeration into secondary defects[2]. Considering this result, it was expected that if C ions and dopant ions were implanted into the same region, no dislocations would be formed. In this paper, we report on the effect of double ion implantation of P and C into Si substrates on the reduction of secondary defect formation induced by P implantation.

The substrates used were CZ (100) 10Ωcm Si wafers. Implantation energies of C were varied from 1.00 to 1.45 MeV and doses from 1×10^{15} to 1×10^{16} cm^{-2}. P ions were implanted under conditions of 1.5 MeV energy and a 1×10^{15} cm^{-2} dose for all samples. Implanted samples were then annealed at 900℃ for 30 min in an N_2 ambient. Residual defects were observed using cross-sectional transmission electron microscope (X-TEM).

The secondary defects generated by P implantation with and without 1.15 MeV C implantation are compared in Fig. 1. In the only P implanted sample, high density dislocation formation is observed near the P projected range (1.4μm) with some elongated dislocations extended upwards and downwards along <110> direction. In contrast to this result, only a few small dislocation loops are seen in the both P and C implanted sample. This confirms that significant reduction of P implantation induced dislocation formation is achieved by additional C implantation. Dependence of the residual defect characteristics on C implantation energy for a fixed dose of 5×10^{15} cm^{-2} is shown in Fig. 2. It can clearly be seen that a 0.15 MeV difference in C energy, corresponding to approximately 0.2μm shift of projected range, makes a large difference in distribution and type of residual defects. In a 1.00 MeV C implanted sample, many dislocations are seen, but no elongated dislocations extending upwards to the substrate surface are seen and a sharp boundary is observed around 1.4μm under the substrate surface, beyond which few dislocations extended. In the 1.15 MeV case, dislocation density is very low as mentioned above. In 1.30 and 1.45 MeV C implanted samples, dark regions which correspond to C implanted and distorted layers are also seen below the region where dislocations exist. In these cases, C implanted layers are too deep to eliminate P implantation induced dislocations. This result means implanted C should be located close to a layer damaged by P implantation to reduce dislocation generation. This suggests that agglomeration of self-interstitials into dislocations occurs within a range about 0.2μm.

It has been demonstrated that double implantation of P and C is very effective at reducing P implantation induced dislocations. C implantation is also expected to be effective for other dopant species, since residual defects due to other dopant implantations are very similar to those of P implantation[1]. This technique extends the application range of high energy ion implantation at high doses.

References
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2) H. Wong, N. W. Cheung, P. K. Chu, J. Liu and J. W. Mayer, Appl. Phys. Lett. 52, (1988) 1023.

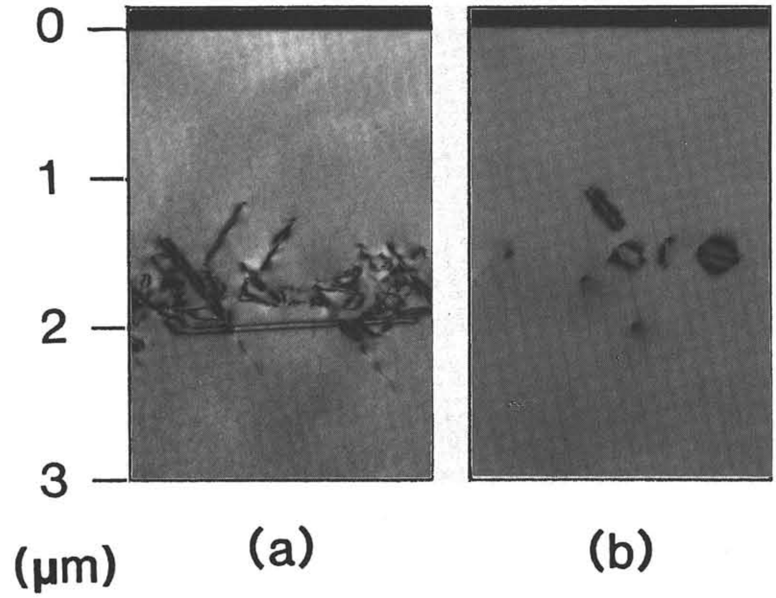

Fig. 1 X-TEM micrographs showing residual defects of 1.5MeV $1\times10^{15}cm^{-2}$ P implanted Si (a) without and (b) with 1.15 MeV $5\times10^{15}cm^{-2}$ C implantation after 900℃ 30min N_2 annealing.

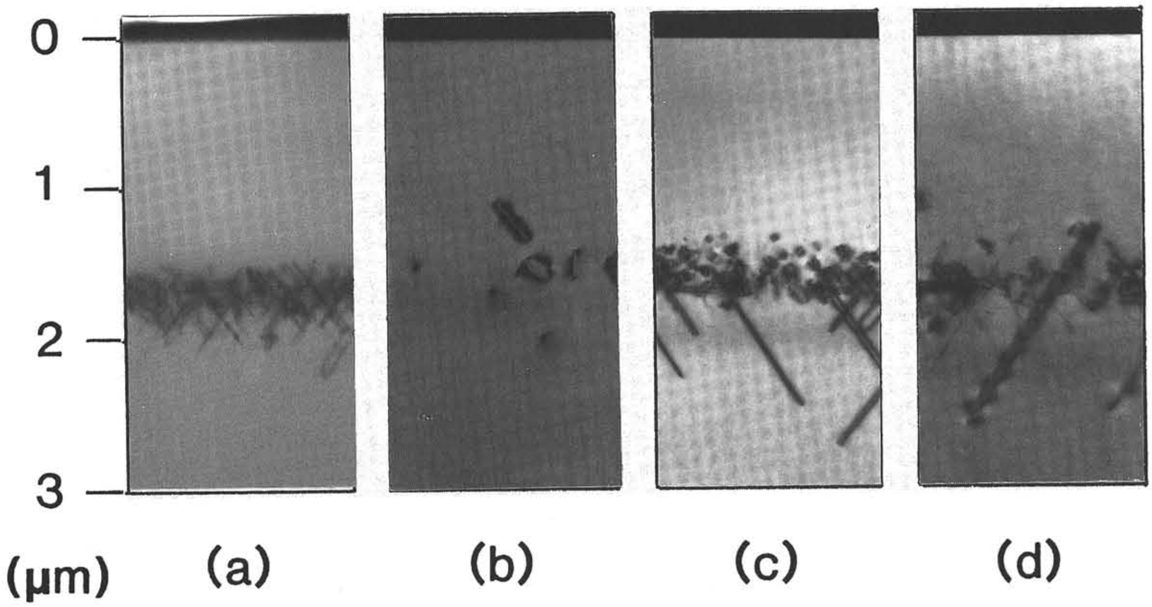

Fig. 2 X-TEM micrographs showing residual defects of 1.5MeV $1\times10^{15}cm^{-2}$ P and $5\times10^{15}cm^{-2}$ C implanted Si after 900℃ 30min N_2 annealing with various C implantation energies. Implantation energies of C are (a) 1.00, (b) 1.15, (c) 1.30 and (d) 1.45MeV.