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On MeV He^+ Dechanneling from Secondary Defects in Si

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ABSTRACT

Transmission electron microscopy and MeV He^+ channeling have been used to study dechanneling from secondary defects in Si. Samples containing dislocation networks or dislocation loops or point defect clusters or a combination of these defects were chosen for comparison. The results show that dechanneling from three dimensional dislocation networks can be distinguished from that from small dislocation loops and smaller point defect clusters. Small dislocation loops were found to be least effective in producing dechanneling.

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Transmission electron microscopy (TEM) and Rutherford backscattering (RBS) in a channeling configuration are extensively used as routine methods for characterization of defects and disorders present in semiconducting materials and devices. The former method when applied to a cross-sectionally thinned specimen, gives a direct view of the damage-depth distribution while the latter method gives an estimate of the disorder and its depth distribution. However, the RBS method is non-destructive and less time consuming as compared to cross-sectional transmission electron microscopy. Therefore, the present work was aimed at improving the interpretation of channeled RBS for various kinds of defects and their depth distributions by comparing the channeling results with cross-sectional transmission electron microscopy results. Comparison studies on defect structures involving single and multiple amorphous layers in ion-implanted Si have already been reported elsewhere.¹ Similar studies on secondary defect structures have also been discussed in the literature,²⁻⁵ however, the precise depth distribution of these defects was unknown. Furthermore, very little high resolution weak-beam transmission electron microscopy work was performed on the samples that were used for the channeling analysis and the contribution of the small defects (≤ 20 Å) if present was not taken into account. In this paper, channeling effects of different types of defects are investigated separately.

Phosphorus was implanted into (111) Si wafers at 120 keV in the dose range $5 \times 10^{14} - 10^{16}/\text{cm}^2$ at temperatures RT-400°C. The implanted samples were subsequently furnace annealed in the

temperature range 400°–1050°C. All of the TEM examinations for the cross-sectional specimens were performed using the bright-field strong contrast method. However, for the plan-view specimens, in addition to the bright-field, dark-field weak-beam contrast was used. The details of the channeling set-up are described elsewhere.¹ The energy of the incident beam in the present experiment was 1.56 MeV and the backscattered particles were detected by a Si surface barrier detector with a resolution of 6 kV at 170° with respect to the incident beam.

Figure 1 shows results from a sample that was implanted at 400°C to a dose of $10^{16} \text{P}^+/\text{cm}^2$ and subsequently furnace annealed at 850°C for 20 minutes. The TEM plan-view micrograph (Fig. 1a) shows a dislocation network together with small dislocation loops. A weak-beam plan view micrograph from the same sample revealed a high density of fine point defect cluster damage ($\leq 20 \text{ \AA}$ across) near the surface together with the dislocation network and loops (Fig. 2a). In order to find the depth distribution of the fine damage, a surface layer of a few hundred $\text{\AA}$ thickness was removed by ion-beam milling. The weak-beam micrograph showed mainly faulted dislocation loops and rods and some long dislocations but no fine point defect cluster damage (Fig. 2b). The corresponding cross-sectional TEM micrograph (Fig. 1b) shows a 250 $\text{\AA}$ wide dense band of fine defect clusters at the surface. Below this band was present a three dimensional dislocation network that extended to a depth of 2300 $\text{\AA}$. A band of dislocation loops was also present in the depth range 1700 $\text{\AA}$ to 3000 $\text{\AA}$; a part of this band overlapped with the dislocation network. The mean diameters and the density of the loops were 600 $\text{\AA}$ and $10^{11}/\text{cm}^2$, respectively. The

MeV He^+ channeling spectrum from the same sample indicated the following: a damaged surface (peak A), a lightly disordered region at a mean depth of 550 Å (peak B), and an increasing disorder in the depth range 650 Å to 250 Å (note the steep dechanneling slope C beyond peak B).

In order to separate out the effect of dechanneling due to the presence of the loops and fine clusters from that due to dislocations samples containing either only the dislocation loops or the point defect clusters were analyzed. Figure 3 shows the results from a sample that was implanted at 100°C to a dose of $3 \times 10^{14}/\text{cm}^2$ and annealed at 950°C for 20 minutes. The TEM plan view micrograph (Fig. 3a) from the sample showed only dislocation loops with a density ($4.5 \times 10^{10}/\text{cm}^2$) comparable to that shown in Fig. 2a. The weak-beam micrograph from the same sample (Fig. 4) shows that no fine clusters were present. The corresponding TEM cross-section micrograph (Fig., 3b) shows that these loops were distributed in the form of a irregular band 1000 Å wide at a mean depth of 1000 Å from the surface. The channeling spectrum (Fig. 3c) showed that the surface E was lightly damaged but no measurable dechanneling occurred in the region containing the dislocation loops.⁶

Figure 5 shows the results from a sample that was similarly implanted as the sample of Fig. 3 but annealed at 600°C for 20 minutes. The TEM plan view micrograph (Fig. 5c) showed a high density of fine point defect clusters but no other defects. The corresponding cross-sectional TEM micrograph (Fig. 5b) showed a not-so-well-defined damage band at a mean depth of 1100 Å from the surface. The channeling

spectrum (Fig. 5c) showed a disordered surface (peak F) followed by a sharply rising dechanneling background (broad lump H). However, the slope of the dechanneling tail on the low energy side of the channeling specimen was less steep than that of Fig. 1c.

The results presented above show that there is a correlation between the presence of dislocations and increased dechanneling. However, the presence of the fine point defect clusters can confuse the interpretation as is evident from Fig. 5. It is also clear from Figs. 3 and 4 that the dechanneling contribution of small dislocation loops is not significant. Furthermore, from Figs. 1b and 2b it is also clear that the point defect clusters do not extend to the depth where the dislocation loops exist. Therefore, the steep dechanneling slope observed in Fig. 1c is primarily associated with the three dimensional dislocation network. This is in agreement with earlier results.⁷ However, due to the lack of high resolution TEM evidence in the previously published work, it was not clear whether the dechanneling was primarily due to the dislocations.

In conclusion, (i) A three dimensional dislocation network or a region containing numerous small point defect clusters gives rise to a corresponding region of steeply rising dechanneling yield in the channeling spectrum. (ii) Small dislocation loops do not produce measurable amounts of dechanneling. (iii) Electron microscopy is essential to decide whether a steeply rising dechanneling yield indicates the presence of a three dimensional dislocation network or a high density of small point defect clusters.

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Figure Captions

Fig. 1. Comparison of TEM damage with channeling spectrum (a) TEM plan view micrograph (b) TEM cross-sectional view micrograph (c) channeling spectrum. [$P^+ \rightarrow (111)$ Si, $10^{16}/\text{cm}^2$, 120 KeV, Imp. Temp. = 400°C , Ann. Temp. = 850°C].

Fig. 2. Weak-beam TEM micrograph using a (111) type reflection (a) before stripping the surface layer (b) after stripping the surface layer.

Fig. 3. Dechanneling from dislocation loops (a) TEM plan view micrograph (b) TEM cross-sectional view micrograph (c) channeling spectrum. [$P^+ \rightarrow (111)$ Si, $3 \times 10^{14}/\text{cm}^2$, 120 KeV, Imp. Temp. = 100°C , Ann. Temp. = 950°C].

Fig. 4. Weak-beam TEM micrograph corresponding to Fig. 3a using a (111) type reflection.

Fig. 5. Dechanneling from point-defect clusters (a) TEM plan view micrograph (b) TEM cross-sectional view micrograph (c) channeling spectrum. [$P^+ \rightarrow (111)$ Si, $3 \times 10^{14}/\text{cm}^2$, 120 KeV, Imp. Temp. = 100°C , Ann. Temp. = 650°C].

a

b

 $0.2\mu\text{m}$

Fig. 2

XBB813-2726

Fig. 3

XBB813-2727

Fig. 4

XBB813-2730

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