Lawrence Berkeley National Laboratory

Recent Work

Title

EFFECT ON ELECTRICAL PROPERTIES OF SEGREGATION OF IMPLANTED P+ AT DEFECT SITES
IN Si

Permalink

<https://escholarship.org/uc/item/90c9r1nf>

Author

Sadana, D.K.

Publication Date

1980-07-01

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Materials & Molecular Research Division

Submitted to the Journal of Applied Physics

EFFECT ON ELECTRICAL PROPERTIES OF SEGREGATION
OF IMPLANTED P^+ AT DEFECT SITES IN Si

D.K. Sadana, M. Strathman, J. Washburn, C.W. Magee,
M. Maenpaa, and G.R. Booker

July 1980

TWO-WEEK LOAN COPY

*This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 6782*

Prepared for the U.S. Department of Energy under Contract W-7405-ENG-48

LBL-11319

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

EFFECT ON ELECTRICAL PROPERTIES OF SEGREGATION
OF IMPLANTED P^+ AT DEFECT SITES IN Si^*

D.K. Sadana, M. Strathman, J. Washburn
Lawrence Berkeley Laboratory, University of California
Berkeley, CA 94720

C.W. Magee
RCA Laboratories, Princeton, NJ 08540

M. Maenpaa
California Institute of Technology, Pasadena, CA 91125

G.R. Booker
Department of Metallurgy, University of Oxford, Oxford (England)

ABSTRACT

The aim of this work was to study the furnace annealing behavior of buried amorphous layers formed due to P^+ implantation into Si and to investigate the effects of annealing on the electrical properties of the implanted layer. For this purpose, P^+ was implanted into (111) Si in a non-channelling direction at 120 KeV to a dose of $3 \times 10^{14}/\text{cm}^2$ at RT. The implanted samples were subsequently annealed at 750°C. 90° cross-sectional TEM, MeV He^+ channelling, SIMS and electrical results were obtained from the same specimen. The TEM results showed that the annealing at 750°C resulted in the formation of two discrete damage layers at depths of 600Å and 1100Å. However, the MeV channelling measurement indicated the presence of three damage regions; the third region being beyond the second damage layer observed by TEM. The SIMS measurements showed pronounced 'pile-ups' of phosphorous atoms at three damage regions. The carrier concentration profile followed the atomic distribution curve. However, the mobility profile showed decreases only at the the two deeper lying damage regions.

*Prepared for the U.S. Department of Energy under
Contract W-7405-ENG-48.

The regrowth behavior of ion-implantation induced damage layers in Si and GaAs using transmission electron microscopy (TEM) has been studied extensively by earlier workers.¹⁻⁵ The results obtained by TEM showed that the geometry and type of secondary defects left after subsequent furnace annealing depended critically on the implantation conditions.^{3,6,7} For example, cross-sectional TEM work showed that if the starting damage configuration consisted of a buried amorphous layer, the subsequent furnace annealing at 950° gave rise to the formation of two discrete layers of dislocation loops.⁸ However, if the starting damage configuration consisted of a continuous amorphous layer extending to the specimen surface, the resulting residual damage after subsequent furnace annealing consisted of a high density of twin lamellae, dislocation networks and dislocation loops. This study is aimed at understanding the formation of secondary defect layers and their effect on the electrical properties in the regrown material.

Boron doped (111) Si wafers with resistivities of 5-10 ohm cm were implanted at room temperature with 120 KeV P⁺ ions in a non-channelling direction to a dose of $3 \times 10^{14}/\text{cm}^2$ using a few kHz scanning phosphorous ion beam. These implantation conditions corresponded to an LSS theoretical projected range of 1500Å with a straggling of 530Å.⁹ Furnace annealing of the implanted wafers was carried out in the temperature range 400-1050°C in a nitrogen ambient. However, only the results for a 750°C specimen has been included in this paper to demonstrate the impurity interaction with the secondary structural defects.

(3)

For TEM studies, '90° cross-sectional' and 'plan' view specimens were prepared. For the 'cross-sectional' specimens, the implanted wafer was cleaved, mechanically polished and subsequently thinned using a low energy (6 keV) Ar^+ ion-beam. Strong beam bright-field and weak-beam dark-field methods were used to image the defects present in the annealed specimen. A 1.5 MeV He^+ beam channelled along a $\langle 111 \rangle$ direction was also used to detect the disorder present in the as-implanted and also in the subsequently annealed specimen.¹⁰ The carrier concentration vs depth and mobility vs depth profiles were obtained by van der Pauw's method in conjunction with anodic stripping. The atomic profiles of phosphorous were obtained by secondary ion mass spectrometry (SIMS) using a positive Cs ion source.¹²

Figures 1 and 2 show results from unannealed and annealed P^+ implanted samples, respectively. For the unannealed sample, the TEM cross-section specimen showed a buried amorphous layer, 1350Å wide, located at a mean depth of 1100Å (Fig. 1a). The microdiffraction pattern taken from different regions of 'Q' using convergent beam method indicated that the central region (~300Å) in this layer was amorphous in nature.¹³ The MeV He^+ channelling measurements indicated the presence of a buried damage layer (Fig. 1b). The SIMS measurements gave a standard gaussian distribution of phosphorous atoms with a projected range of 1330Å for the above specimen (Fig. 1c).

The TEM results showed that as the annealing temperature was increased, the regrowth of the amorphous layer became rapid above 550°C.¹³ For 650°C annealing, no amorphous layer remained but the specimen showed two discrete layers of secondary damage. The first layer

(4)

was well defined and consisted of dislocation loops while the second layer consisted of fine defects. The channelling spectrum from this specimen also showed that no amorphous material remained; however, there was still a considerable amount of dechannelling in the deeper part of the crystal indicating the presence of residual disorder in this region. The SIMS measurements showed an onset of phosphorous redistribution near the secondary damage regions (micrographs and profiles not included in the text).

The TEM cross-section micrograph of a 750°C annealed specimen showed two well defined damage layers 'S' and 'T' at mean depths of 600Å and 1100Å (Fig. 2a). Both these layers contained dislocation loop defects. The analysis of these defects indicated that the Burgers vectors of the loops were of two types, $a/2\langle 110 \rangle$ and $a/3\langle 111 \rangle$. The mean diameter of the loops was 150Å. The channelling spectrum from the same specimen showed that the material was a single crystal but there were three damage regions at depths of 600Å, 950Å and 1700Å respectively, as indicated by three peaks, namely, 'A2', 'B1' and 'C' in Fig. 2b. The peaks 'A2' and 'B1' corresponded to the layers 'S' and 'T' of dislocation loops seen in the TEM cross-section micrograph (Fig. 2a). Peak 'C' at a depth of 1700Å corresponding to the damage region beyond layer 'T' in Fig. 2a is thought to arise due to interstitial point defects or their clusters at that depth. The phosphorus atomic profile obtained by the SIMS measurements showed two pronounced peaks 'P2' and 'P3' at depths of 950Å and 1520Å respectively. There was also a shoulder 'P1' at a depth of 600Å in the atomic profile. Shoulder 'P1' and the first peak 'P2' in Fig. 2c corresponded to two damage layers 'S' and 'T' respectively in the TEM micrograph (Fig. 2a), and also to peaks 'A2' and 'B1' respectively in the

(5)

channelling spectrum (Fig. 2b). However, peak 'P3' in Fig. 2c corresponded to peak 'C' in Fig. 2b but there was no detectable coarse damage in the TEM micrograph at this depth. The electrical profiles, namely, carrier concentration vs depth, and mobility vs depth taken from another part of the same specimen, showed that the carrier distribution very closely followed the atomic distribution as obtained by the SIMS measurements. The carrier concentration profile showed three peaks at 600Å, 1000Å and 1700Å corresponding to peaks 'P1', 'P2' and 'P3' respectively in Fig. 2c. However, the mobility profiles showed two pronounced dips at depths of 900Å and 1700Å respectively, corresponding to the deeper lying damage layers.

The reasons for formation of the secondary damage layer 'S' at a depth of 600Å ($\sim 0.35 R_p$) is not yet clear but this could probably arise due to clustering of vacancies formed during implantation near the upper edge of damage layer 'Q'. Collision of an incoming phosphorous atom with a host Si atom causes a vacancy near the surface and two interstitials (deflected Si and P atoms) deeper into the material. Subsequent annealing at 750°C should cause clustering of these vacancies resulting in the formation of the observed dislocation loops (100-150Å across) at layer 'S'. Similar vacancy clustering to form stacking fault tetrahedra has been reported previously.¹³ The second damage layer at a depth of ~ 1100 Å ($\sim 0.7 R_p$) forms at the center of the original amorphous layer 'Q'. This is caused by regrowth of the layer beginning simultaneously both at its upper and lower boundary during annealing. The oppositely moving interfaces eventually meet at the depth of the middle of the original amorphous region Q. The extra silicon and phosphorous interstitials contained within the amorphous layer form the interstitial

(6)

dislocation loops seen in layer 'T'. Segregation of the phosphorous atoms at secondary damage regions 'S' and 'T' is thought to occur during the annealing process. Some of the phosphorous atoms in the amorphous layer are probably swept along with the moving amorphous/crystalline interfaces or with migrating vacancies giving the 'pile-up' regions in the atomic profile (Peaks 'P1' and 'P2' in Fig. 2c). Peak P3 in Fig. 2c probably does not arise from concentration of phosphorous atoms but rather due to the presence of a zone denuded of phosphorous atoms on the left side of it. However, a significant migration of phosphorous atoms does occur to depths of $\sim x 3R_p$ to $\sim x 4R_p$ (notice the broadening of phosphorous profile, Fig. 2c); i.e., well beyond the projected range, indicating that point defects are formed or migrate into the implanted material much deeper than speculated earlier.

Although the segregation of impurities at the damage regions has been suspected for the last several years, we believe this is the first study of its kind that gives a direct experimental evidence. From the practical point of view these findings are important because a significant fraction the of implanted ions become concentrated in the damage regions.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support of the Department of Energy through the Materials and Molecular Research Division and the Department of Instrument Techniques of Lawrence Berkeley Laboratory.

REFERENCES

1. K. Seshan and J. Washburn, Rad. Eff. 37, 147 (1978).
2. D.K. Sadana and G.R. Booker, Rad. Eff. 42, 35 (1979)
3. J. Fletcher and G.R. Booker, Proc. 9th Intern. Congr. On Electron Microscopy, Toronto, 1978, Vol. 3, p. 364.
4. R.W. Bicknell, J. Micrsc. 98(2), 165 (1979).
5. M.L. Jenkins, D.J.H. Cockayne and M.J. Whelan, J. Micsosc. 98(2), 155 (1979).
6. R.M. Drosd, Ph.D. Thesis (Nov 1979), Univ. of California, Berkeley, pp 15-41, Report No. LBL-9990.
7. D.K. Sadana (unpublished).
8. D.K. Sadana, J. Fletcher and G.R. Booker, Elec. Lett. 13, 632 (1977).
9. J.F. Gibbons, W.S. Johnson and S.W. Myglorie, Projected Range Statistics, John Wiley and Sons, Inc. (1975).

(8)

10. H.R. Pettit and G.R. Booker, IOP London Conf. Series 10, 290 (1971).

11. W.K. Chu, J.W. Mayer and M-A. Nicolet, Backscattering Spectrometry (Academic Press, 1978), Chapt. 4, pp. 89-122.

12. C.W. Magee, J. Electrochem. Soc. 126, 660 (1979)

13. D.K. Sadana and G.R. Booker (unpublished).

FIGURE CAPTIONS

Fig. 1 $P^+ \rightarrow (111)$ Si, 120 KeV, $3 \times 10^{14}/\text{cm}^2$, RT.

- a. TEM cross-section micrograph showing a buried amorphous layer.
- b. Channelling spectrum (1.56 MeV He^+) from the same specimen (continuous line).
- c. Phosphorous (SIMS) distribution curve for as-implanted Si from the same specimen.

Fig. 2. $P^+ \rightarrow (111)$ Si, 120 KeV, $3 \times 10^{14}/\text{cm}^2$, 750°C annealed for 20 minutes.

- a. TEM cross-section micrograph showing two discrete layers of dislocation loops.
- b. Channelling spectrum (1.56 MeV He^+) from the same specimen (continuous line).
- c. Phosphorous (SIMS) (continuous line), carrier concentration (broken line X) and Hall mobility (broken line $\blacktriangle$) distribution curves from the same specimen.

XBB 806-7153

Figure 1

XBB 806-7152

Figure 2

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720