4-1

Low Energy Implantation of Boron into Silicon

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Low energy implantation of boron into silicon has a possibility to give a fine process in fabricating shallow p-n junctions, such as those in extra high frequency devices. Although shallowness of impurity distribution itself presents peculiar features which will be pointed out later, it seems to have drawn less attention of experimental workers than it actually deserves.[1, 2] In this paper careful study on annealing and redistribution of shallow boron implantation will be presented.

Boron was implanted at room temperature into n-type [111] silicon at an energy of 5 to 20 keV to a dose of 10^{13} to 10^{15} ions/cm^2. [111] axis of the specimen was set several degrees off the beam axis to avoid channeling during implantation. After annealing in dry nitrogen gas, carrier concentration was obtained by Hall and sheet resistivity measurements using the van der Pauw's pattern, together with successive anodic stripping.

Figure 1 shows a carrier distribution of 5 and 10 keV implants after 906°C, 20 min. annealing. The distribution of 10 keV, 10^{15} ions/cm^2 implant extended over a wider range than that of 10^{14} ions/cm^2 implant. When 800 Å thick surface layer was etched off before annealing, however, the tails of the two distributions coincided if factor of 10 in the difference in the implant dose was taken into account. This effect suggests that the wider distribution in the higher-dose implant was resulted from the enhancement of diffusion caused by the higher defect density in the near-surface region. The enhancement of diffusion was also observed, as shown in figure 2, when lower dose implant was annealed at a temperature below 900 °C. A similar effect has been reported for hot antimony implant.[3]

The 5 and 10 keV, 10^{14} ions/cm^2 implants in figure 1 exhibits gaussian distribution. The peak depth, therefore, must have some relation to the projected range of implanted boron. These values, however, must be corrected for the effect of annealing, which, for a constant annealing condition, is heavier when the distribution is shallower and narrower.

For this purpose the diffusion equation was solved for the case of perfect reflection of diffusant at the surface, with gaussian initial impurity distribution having its peak near the surface. A result of calculation is shown in figure 3, which have two distinct features. First, impurity distribution in the near-surface region becomes flat after some annealing, when in the deeper region

the distribution remains almost gaussian. Secondly, the peak of the distribution remains at the depth of that of the initial distribution, i.e. the projected range, when the annealing is short. This result supports that the experimental peaks in figure 1 correspond to the projected range of boron at respective energy of implant.

Experimental projected range thus obtained are plotted in figure 4 against energy of implant, with the results of other theoretical and experimental works.[4-6] Experimental values of this work are about 1.4 times larger than those of LSS calculation,[4] contrary to the relation of them in the higher energy range.

The former feature in the result of present calculation is not prominent in the higher energy case where the width of the initial distribution is large, because impracticably long annealing is required to exhibit such effect. A new method of process control utilizing these features will be discussed.

This work was supported financially by the Research and Development Corporation of Japan.

REFERENCES: 1) J. M. Shannon et al: Canad. J. Phys. 48, 229, ('70), 2) R. Bader et al: Appl. Phys. Lettrs 16-1, 13, ('70), 3) K. Gamo et al: Proc. Riken Symposium 61, ('70), 4) W. S. Johnson, J. F. Gibbons: Projected Range Statistics in Semiconductors, Stanford Univ. Book Store ('69), 5) F. Eisen et al: Atomic Collision Phenomena in in Solids, North Holland ('70) pp. 111-127, 6) T. E. Seidel: Int'l Conf. on Ion Implantation, Garmish, ('71)

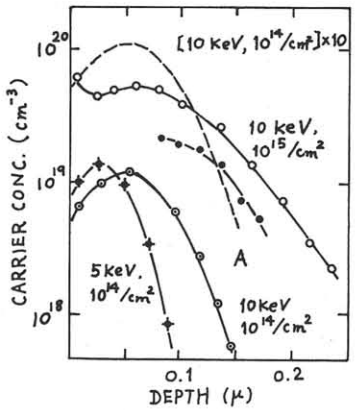

Fig. 1 Carrier distribution of implanted boron. A: 10 keV, $10^{15}/cm^2$ implant. 800 Å etched before annealing.

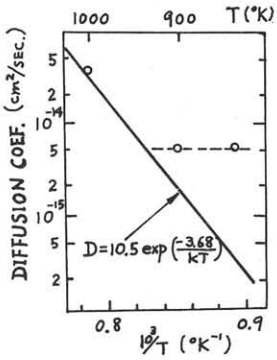

Fig. 2 Diffusion coefficient vs. annealing temperature of implanted boron. ● This work. — Ordinary diffusion.

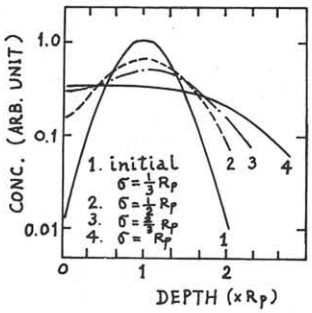

Fig. 3 Diffusion from a gaussian distribution; a result of calculation.

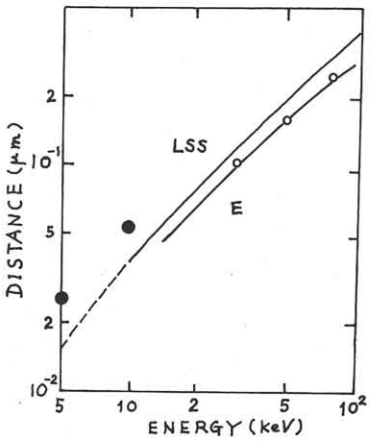

Fig. 4 Projected range vs. energy of implant of boron implantation. ● This work O T. E. Seidel. LSS: Johnson et al. E: Eisen.