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Anomalous Residual Defects in Silicon after Annealing of Through-Oxide Phosphorus Implanted Samples

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In conventional applications of ion implantation to silicon planar technology, some of the ions are inevitably implanted through the oxide at the edge of the oxide window. Cass and Reddi[1)] have reported the formation of "anomalous residual defects" (ARD) in through-oxide As implanted Si followed by annealing at 1000°C. Moline and Cullis[2)] have suggested that the ARD were produced by recoil oxygen. For this reason, the formation of defects in Si by through-oxide implantation is a matter of concern.

We have also observed the formation of ARD in the case of through-oxide P implantation into Si. Additionally, the formation of ARD has been investigated in detail for various implant doses, oxide thicknesses, ion energies, and annealing conditions.

Fig. 1 shows a typical example of the residual defects observed by a transmission electron microscope (TEM) in Si implanted with $2x10^{16}/cm^2$ P at 180 keV through various thickness of oxide layers and annealed at 1000°C in dry N_2 for 30 min. It is clear from the figure that P implanted into bare Si led to the formation of extensive dislocation networks as reported before.[3)] However, P implanted through thin oxide layers yielded dense defect structures of different characters, i.e., ARD. The density of the ARD became maximum in the case of implantation through an oxide layer of 1650 Å, the thickness being about the projected range of P ions in the oxide. No defects were observed in the sample when the oxide layer was thicker than 3500 Å.

By comparing the above results with the ones for oxygen implants and with the calculated recoil oxygen yield, it became apparent that the recoil oxygen from the oxide layer was responsible to the formation of the ARD as in the case of As implantation.

From the analysis of the depth distribution and characterization of the ARD by the combination of anodic stripping and TEM observations, two distinct regions of different natures were observed in through-oxide implanted layers. They were a highly damaged surface region (0 to 1000 Å in depth) responsible for the recoil oxygen, and a deeper region that contained irregular dislocation networks and faulted loops formed by the implanted phosphorus.

The recoil oxygen yield in P implantation was expected to be less than 1/2 of the As case. However, ARD were markedly high for P ion doses higher than $7 \times 10^{15}/cm^2$ in the case of 180 keV implantation. This suggests that the ARD are formed in the region of the mask edge for doses used commonly to make bipolar transistor emitters and MOS FET sources and drains.

When the acceptor concentration in Si was less than $10^{18}/cm^3$, the p-n junction was located outside the highly defective region and no difficulties occured. However, when the junction was formed in such a defective region including ARD, the junction characteristics were affected by the ARD.

The effects of the recoil oxygen atoms on the formation of the ARD are discussed and the implantation and post-annealing conditions necessary to avoid the ARD formation are also described.

References

1) T. R. Cass and V. D. K. Reddi: Appl. Phys. Letters, 23, 268 (1973)

2) R. A. Moline and A. G. Cullis: Appl. Phys. Letters, 26, 551 (1975)

3) T. Ikeda, M. Tamura, M. Yoshihiro, and T. Tokuyama: Proc. 6th Conf. on Solid State Devices, Tokyo, 1974

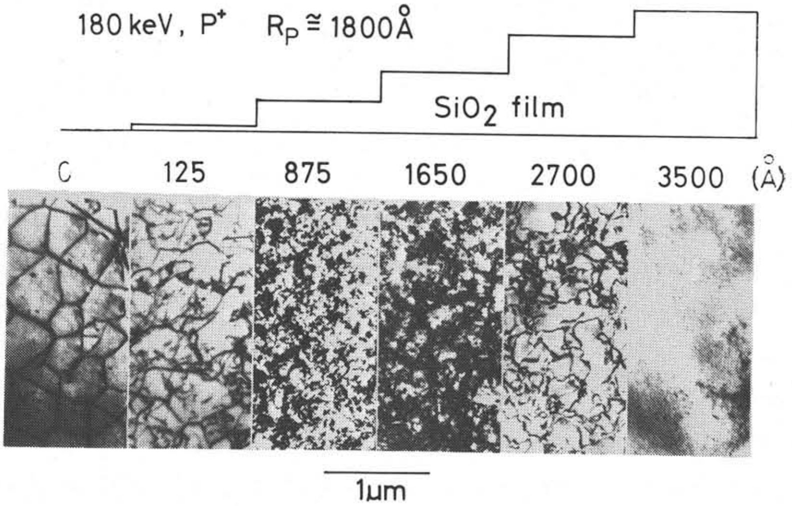

Fig. 1 The residual defects in Si implanted with $2 \times 10^{16}/cm^2$ P at 180 keV through varous thickness of oxide layers and annealed at 1000°C in dry N_2 for 30 min. (Transmission electron microscope observation.)