2-6 Crystal Defects in Ion-Implanted GaAs

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There is still little known about the effects of ion implantation procedures and post annealing treatments on the structures of crystal defects in ion implanted GaAs.[1] The particular study was carried out to obtain relations between electron microscope observations and electrical measurements as a function of annealing temperature, implantation temperature and depth of implanted layers.

The substrates were [100] oriented semi-insulating GaAs ($\rho > 10^8$ Ω·cm) wafers. Si^+ ions were implanted at 50 keV using arc discharge ion source system at the temperatures between 20 and 400°C, with the doses between 10^{11} and $10^{15}/cm^2$. After implantation, samples were annealed in the temperature range of 100-900°C in hydrogen atmosphere. In annealing, samples were coated with Al_2O_3 or polycrystalline Si films to prevent decomposition of GaAs substrates and out-diffusion of dopant atoms from the substrate surface. The degree of lattice disorder was examined by electron diffraction and transmission electron microscope techniques before and after post-implant heat treatments.

Table 1 shows a dependence of the degree of crystalline perfection on doses and annealing temperatures obtained by reflection electron diffraction at 20°C implantation. At the dose of $1 \times 10^{12}/cm^2$, surface layer exhibited diffuse halo pattern with spot pattern. Above the dose of $5 \times 10^{12}/cm^2$, spot pattern was not observed and only halo pattern that is indicative of the formation of complete amorphous layer was detected. The critical dose for the amorphous layer formation was lower by one order than that for Si^+ ion implanted Si.

The amorphous layer was recrystallized epitaxially by annealing at the temperatures up to 500°C. While, the value of sheet resistivity increased with the increase of annealing temperatures up to 500°C and approached that of the substrate resistivity as shown in Fig. 1. This fact will be attributed to the recrystallization phenomenon of the implanted layer. Also, the sheet resistivity value for as-implanted samples increased with the decrease of a dose as clearly seen in Fig. 1. These results implied the reduction of acceptor-like damage centers.[1]

As a result of a measurement of a surface carrier concentration and mobility using the van der Pauw-Hall measurement technique, it became evident that the implanted Si^+ ions in GaAs annealed above 500°C were electrically active as donor impurities.[2] On the other hand, secondary defects were observed in the implanted layers after annealing above about 500°C. Figure 2 shows an example of transmission electron micrographs of samples annealed at temperatures indicated in Fig. 2. As shown in the figure, defects observed at 600°C were many small black dotted ones, while at 800°C, as a result of the growth of black dotted defects, prismatic dislocation loops were observed. Moreover, by comparing Fig. 2(b) with 2(c), it can be seen clearly that dislocation loop densities remarkably increased with the increase of a dose. Such dislocation loops consisted of both interstitial atoms and vacancies. However, defects such as Frank type dislocation loops, stacking faults, precipitates and dislocation networks which have been observed in ion implanted Si layers[3, 4] were not seen in the present study. It was also true for C^+ and Sn^+ ions implanted GaAs layers.

In order to study the thickness of the defective region, the measurements of the combination of the successive chemical etching[5] with reflection electron diffraction were carried out as a function of removed layer thickness. The amorphous layer at 20°C implantation reached down to the depth of 1000 Å for the dose of $1 \times 10^{14}/cm^2$ without annealing (projected range = 447 Å, standard deviation = 226 Å). For the above samples, annealed at 700°C, weak diffuse ring pattern with spot pattern was seen in the depth range of 400-1700 Å. The extension of the defective region by annealing was also confirmed by the junction depth measurement. These results will be discussed together with the ones obtained from elevated temperature implantation.

References

1) R. W. Bicknell et al, Phys. Stat. Solidi 12, k9 (1972).
2) J. Sansbury and J. F. Gibbons, Rad. Effects 6, 269 (1970).
3) M. Tamura et al, Proc. 2nd Conf. Solid State Devices, Tokyo (1970) p. 9.
4) M. Tamura et al, Proc. 2nd Int'l Conf. Ion-Implantation, Garmisch (1971) p. 96.
5) P. N. Favennec, ibid., p. 174.

Table 1. Effects of doses and annealing temperatures on crystalline perfection (20°C Si^+ ion implantation).

Anneal \ Dose	10^{11}	10^{12}	10^{13}	10^{14}	10^{15}
as-impl	S*	D*	H*	H	H
200°C		S	H	H	H
350°C			S+D	D	D
450°C			S	S+D	D+S
550°C				S	S+D

S*=Spot pattern, D*=Diffuse halo pattern, H*=Halo pattern.

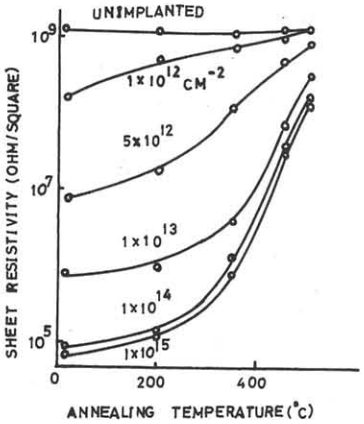

Fig. 1. Changes in the layer resistivity by 1 hour isochronal annealing (20°C Si^+ impl.).

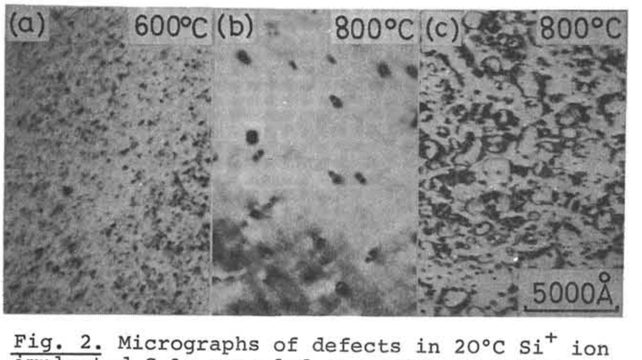

Fig. 2. Micrographs of defects in 20°C Si^+ ion implanted GaAs annealed at various temperatures for 1 hour (Impl: $1 \times 10^{13}/cm^2$ (a) and (b), $1 \times 10^{15}/cm^2$ (c)).