FOCUSED BORON ION BEAM IMPLANTATION INTO SILICON

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Focused ion beam (FIB) implantation into semiconductors is a promising technology for maskless ion implantation. However, limited reports have so far been published on the nature of FIB implanted materials.[1,2] This paper reports on the electrical characteristics and the lattice disorders of silicon (Si) substrates implanted with focused beams of boron ($^{11}B^+$) ions, using a mass-separarated micro-beam system with a liquid boron-alloy ion source.[3]

The 16 keV B^+ ion beams had beam diameters of 1-2 µm and current densities of 30-50 mA/cm^2. Raster scanned ion implantation was carried out into 200 µm square areas of Si (100) 4° off the axis, with an overlapping percentage above 60% between scanning beams. Ion doses were selected for 6 x 10^{14}, 1 x 10^{15} and 4 x 10^{15}/cm^2 by changing both ion current and beam scanning velocity. For comparison, conventional ion implantations (beam area : ~1 cm^2, ion current: ~40 µA and scanning area: ~100 cm^2) were also carried out into the whole 3"Φ wafers mentioned above.

After implantation, samples were annealed in dry N_2 at a temperature between 400 and 1000°C. Hall effect and sheet resistivity measurements were carried out to obtain isochronal annealing characteristics of carriers, as well as to determine their depth distribution profiles in conjunction with anodic stripping. Crystal quality of as-implanted areas was examined by µ-RHEED (microscopic reflection high-energy electron diffraction) technique.[4] The µ-RHEED technique makes analysis of a very small area of ~(0.1 µm)^2 possible using a field emission electron source. Residual defects after annealing were observed with a Hitachi H-700H electron microscope, operated at 200 keV.

A typical example of sheet resistivity changes with annealing is shown in Fig. 1, compared with conventional implantation results. The FIB results show lower resistivity values in the temperature range below 800°C than those of conventional ones, although well known reverse annealing characteristics are seen in all the specimens. In particular, slower scan speed FIB implantations result in remarkable resistivity reduction. Electrically activated carriers at 600°C annealing are shown in Fig. 2 as a function of implantation dose. As clearly seen from the figure, the fraction of activated carriers of FIB implanted layers increases with ion dose and slower scan speed. Surprisingly enough, the electrical activation of slower FIB implantations is about 14 times as high as the conventional result at 4 x 10^{15} ions/cm^2 dose. This high activation by FIB implantations diminished with annealing temperatures and the electrical activity difference between implantation methods was almost not observed at an annealing temperature of 1000°C.

Next, we investigated, from a view point of defect formation in implanted layers, the cause of such a remarkable high activation by FIB at low annealing temperatures. From μ-RHEED observations of as-implanted layers, FIB implanted layers were found to be completely amorphous at an implantation dose of 4 x 10^{15} ions/cm^2. This critical dose for amorphous layer formation was about one order lower than that of the conventional ion implantation case. The nature of secondary defects observed at annealing temperatures above 600°C was also different for each implantation condition.

Thus, features of FIB B^+ implantation into Si was as follows: the amorphous cluster formation by FIB implantation significantly increased in comparison with the conventional implantation case, because of high dose rate implantation. This amorphous zone increase by FIB implantation may cause high electrical carrier activation at low temperature annealing.

References
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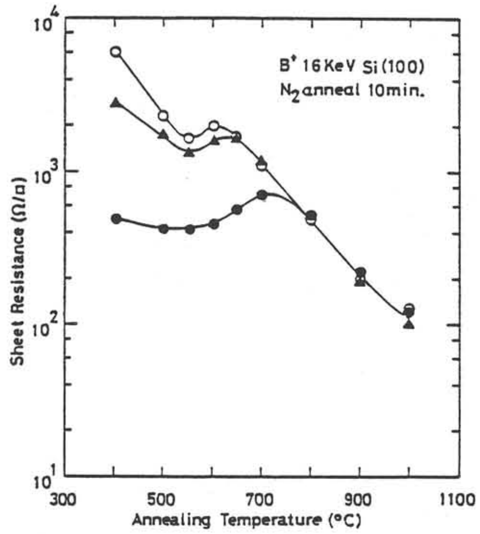

Fig. 1 Annealing characteristics of 1 x 10^{15} B^+/cm^2 implanted Si. O: conventional, ●, ▲: focused. ●: scan speed=4 x 10^{-2} cm/s, ▲: scan speed=9 cm/s.

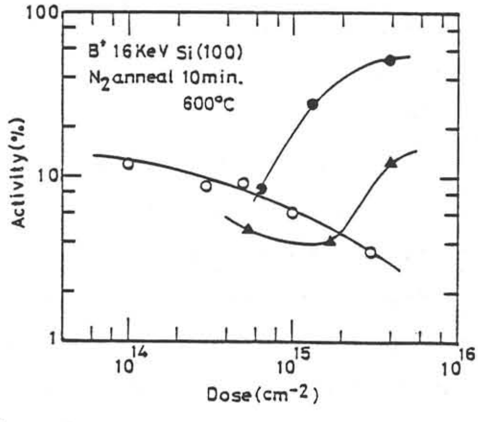

Fig. 2 Electrically activated carriers in B^+ implanted Si as a function of ion dose. 600°C annealing. O : conventional, ●, ▲ : focused. ● : scan speed = 2 x 10^{-2}~9 x 10^{-2} cm/s, ▲ : scan speed = 2~9 cm/s.