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# B−6−8 Implantation into an $Al_{1-x}Ga_xAs/GaAs$ heterostructure

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There has been an increasing number of the works relating to or involving $Al_{1-x}Ga_xAs/GaAs$ heterostructures. Recent advance in the technology in this field demands us to develop the processing technique necessary for their application to new and/or more sophisisticated devices. However, the available data on the doping of the impurities into the grown heterostructures are still limited, except for a few studies on the Zn diffusion into $Al_{1-x}Ga_xAs/GaAs$ structures. This is the first time, at least to our knowledge, to report the experimental results for the ion implantation into a heterostructure. In the present paper, we will discribe about the n-layer formation by Si implantation into an $Al_{1-x}Ga_xAs/GaAs$ heterostructure grown by MBE. The possible effects of ion bombardment and high temperature heat treatment on the electrical properties of the interface will be also discussed.

The samples used for the present study were $Al_{1-x}Ga_xAs/GaAs$ heterostructures grown by MBE on the semi-insulating GaAs substrates. The value of x was 0.70-0.73. Implantation of Si ions was carried out at an energy between 130 and 250 keV to a dose ranging from $1x10^{12}$ to $6.7x10^{13}$ $cm^{-2}$, followed by annealing at a temperature between 600 and 800°C for 20 min using a reactive sputtered AlN film of 0.1 μm in thickness as a surface encapsulant.

The carrier profile measured by the C-V method for the sample implanted to a dose of $1x10^{13}$ $cm^{-2}$ and annealed at 700°C is shown in Fig. 1, along with the calculated range distribution of 130 keV Si ions in the dual structure. The layer of $Al_{1-x}Ga_xAs$ was 0.18 μm in thickness and doped with $6x10^{17}$ $cm^{-3}$ of Si atoms during the MBE growth. As can be seen from the figure, a considerably high electrical activity of about 60% can be attained in GaAs. Contrarily, in $Al_{1-x}Ga_xAs$, it is lower than 20% if we take account of the initial doping concentration in this layer. It is interesting to note that the implantation and the subsequent heat treatment did not make a remarkable change in the spike, locating at the interface, which is an indicator of an abrupt change in the composition and the discontinuity of the conduction band edge at the interface. The spike was also found to remain unchanged after annealing up to 800°C. An implantation of $4x10^{12}$ Si ions $cm^{-2}$ was also performed into a selectively doped N-$Al_{1-x}Ga_xAs/GaAs$ heterostructure to study the effect of implantation on the 2DEG accumulating at the interface. The parallel layer analysis of the measured mobility data has proven that the 2DEG still existed at the interface although the mobility at 77K decreased from 40000 to 8000 $cm^2$/v.sec, probably due to the scattering by the ionized Si atoms implanted in GaAs. From these observations, we can draw a conclusion that neither the knock-on effect at the interface nor the interdiffusion of GaAs and $Al_{1-x}Ga_xAs$ is so crucial as to cause any detrimental metallurgical change in the heterostructure interface in the dose range below $10^{13}$ $cm^{-2}$ and annealing at temperature below 800°C.

In Fig. 2, the measured electrical activities of the implanted Si atoms in $Al_{1-x}Ga_xAs$ and in GaAs are compared as a function of the annealing temperature. In GaAs, the implanted Si atoms were found to be activated after the annealing at the temperature as low as 625°C, indicating a very low density of defects or residual impurities acting as compensators or traps in the implanted MBE layer. It is worth emphasizing that the activation of the implanted atoms at temperature lower than 700°C will make a selective doping possible while maintaing the high electron mobility of the 2DEG at the interface. On the other hand, the electrical activation in $Al_{1-x}Ga_xAs$ starts taking place at temperature above 700°C, and the activity gradually increases with increasing annealing temperature. This is probably due to the formation of the stabler defects in this layer than in GaAs. Another possible explanation is that a high density of traps exist in this layer. It is also suggested that the $Al_{1-x}Ga_xAs$ layer acts as a good passivation film for GaAs during the annealing process, since both are lattice matched and the thermodynamical properties are very close to each other.

In summary, we have studied Si implantation into an MBE grown $Al_{1-x}Ga_xAs$/GaAs heterostructure to form n-layer. Although the activation of the implanted Si atoms requires the annealing temperature higher than 700°C, temperature lower than this suffices to activate Si atoms in GaAs. These results demonstrate a possibility of the selective doping into the heterostructure while maintaining the essential electrical properties of the 2DEG at the interface.

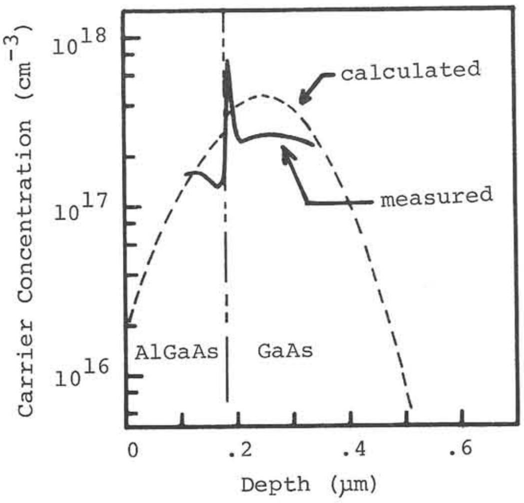

Fig. 1
(left)

Fig. 2
(right)