THE BEHAVIORS OF 48 keV Si IONS IMPLANTED INTO (100) GaAs

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ABSTRACT

The behaviors of Si ions implanted into (100) GaAs at liquid nitrogen temperature with energy of 48 keV at the doses of 1×10^{15}—5×10^{15} ions / cm^2 has been investigated in this study. The Rutherford backscattering-channeling (RBS-C) combined with particle induced X-ray emission (PIXE) has been used to determine the sites of the Si atoms in the GaAs substrate. The four-point probe was used to measure the resistance of the GaAs before and after Si ions implantation. The experimental results show that Si atoms occupy not only on Ga site but also on As site. The sheet resistivity of GaAs reduced from $1\times10^{9}\Omega/\Box$ to $4.5\times10^{6}\Omega/\Box$ after Si ions implanted, and to 4.0×10^{4} $\Omega/\Box$ after annealing at 850°C in argon. These results are consistent with some other investigations, for instance, the results of G.Braunstein *et al* and R. S. Bhattacharya *et al*, although the implantation condition is not the same.

Keywords RBS-C, PIXE, GaAs, Ion implantation

1 INTRODUCTION

The investigation of impurity implanted into GaAs has much been reported in the past decade[1—5]. The damage of implantation in GaAs, its recovery and lattice sites of implanted impurity are more complex than that in Si. Rutherford backscattering-channeling (RBS-C) is widely used to determine damage profile and impurity lattice sites in Si. It is well known that RBS-C is a very powerful method to measure the heavier impurities in the lighter substrates, however it is not useful for lighter impurities in heavier substrates. Therefore the PIXE-Channeling technique is developed to compensate this inadequacy, for example using it to study Mg, Si, S in GaAs. This is a good method as it can determine not only the damage of GaAs induced by implantation but also the lattice sites, substitutional site or interstitial site, occupied by implanted impurities. For instance, the S atoms go to substitutional lattice site after annealing at high temperature for the sample of GaAs implanted with

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S ions[6]. It might be that all of the substitutional S atoms are only occupied As site in GaAs[7]. In Ref.[8], the results reveal substitutional Si atoms locating either in the Ga or in the As site by the photoluminescenece (PL) and electrochemical capacitance-voltage profiling ($C-V$) methods. In this work, we attempt to determine the lattice sites of Si implanted into GaAs by the RBS-C combined with the PIXE measurement.

It is well known that the semi-conductor GaAs has a zine-blende structure. The <110> axis is made up of atomic strings containing only one of the two types of matrix atoms, but the distances between Ga-As and As-Ga rows are different, as shown in Fig.1. Therefore it has different probability of initially striking when ion beam is incident parallel to the {110} plane from an angle $+\theta$ and $-\theta$ for the same atom row, and also, it has different initially striking probability with a same angle for different atom row. So, an asymmetry channeling dip can be observed for a complete angular scanning. J.U.Anderson *et al* have investigated the asymmetry dip of GaP[9]. After getting the impurity channeling dip and comparing with the substrate channeling dip, the lattice sites at which impurity atoms located can be determined in the substrate.

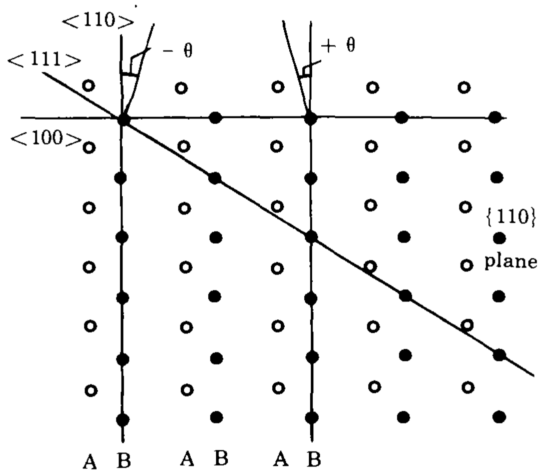

Fig.1 A diagram of zinc—blende structure of CaAs

In this paper, He ion beam with an energy of 1.2 MeV was used to determine the damage of GaAs crystal induced by 48 keV Si ion implantation, and lattice sites of Si atoms in GaAs before and after annealing, using the connection of PIXE-C and RBS-C. Meantime electrical measurements were also carried out before and after implantation.

2 EXPERIMENTAL

The (100) GaAs samples were implanted with 48 keV Si ions at the liquid nitrogen temperature. The implantation dose range is from 1×10^{15} to 5×10^{15} ions / cm^2. The implantation was performed at the Microelectronics and Material Technology Centre, Royal Melbourne Institute of Technology. The projected range for 48 keV Si ions in GaAs is about 46.5 nm calculated by TRIM91. Then the GaAs sample was capped by a

Si_3N_4 film with a thickness of about 200 nm using chemical vapour deposition (CVD) to protect As atoms escaping from samples during annealing. A furnace annealing was performed at 850°C for a half hour in argon atmosphere. The As outdiffusion during annealing process was tested using the GaAs wafer covered by silicon wafer with face to face. It is found that there were a large amount of As atoms getting out from GaAs surface and some of them geting into the silicon sample, that was confirmed by RBS. So it is important to use Si_9N_4 as a capsule during annealing. After annealing, the Si_9N_4 film was washed away from GaAs crystal using the diluted hydrofluoric acid with 4 % concentration. The electronic measurement was performed on all sample by the four-point probe.

He ion beam with an energy of 1.2 MeV was used for RBS-C and PIXE measurements on 4UH pelletron in LNAT. A Si(Li) detector with an energy resolution of 165 eV at 5.9 keV was located at 135° with respect to the beam incidence for measuring X-ray. At 170° to the beam line a surface barrier detector (SBD) was used for RBS measurement and channeling alignment. The sample was mounted on a two-axis goniometer in the target chamber. The signals from the Si(Li) and SBD detectors are amplified, analyzed and accumulated in an AT-PC multi-channel analyzer.

3 RESULTS AND DISCUSSION

Table 1 shows the results of electrical measurements of the GaAs before and after Si ions implantation and annealing. For virgin GaAs, the sheet resistance is $1\times10^9\,\Omega/\square$. After implanting with different doses and annealing at 850°C in argon atmosphere sheet resistance is all reduced. We found that it is the lowest value for the case of a dose of 1×10^{15}ions / cm^2.

Table 1

Sample	Si dose / 10^{15} ions · cm^{-2}	Resistivity / Ω · cm	Sheet resistance / $\Omega\cdot\square^{-1}$
Virgin	0		1×10^9
As implanted	1	22	4.5×10^6
	3	29	5.0×10^6
	5	30	5.9×10^6
Annealed	1	0.2	4.0×10^4
	3	0.2	4.0×10^4
	5	10	2.0×10^6

Fig.2 shows the RBS spectra of Si wafers which were covered on GaAs with and without a Si_9N_4 capsule, respectively, after furnace annealing at 850°C for a half hour. It indicates that the Si_9N_4 film can prevent As outdiffusion efficiently during annealing.

Fig.3 shows random and aligned RBS spectra of the GaAs with Si implantation. The damage induced by implantation is mostly recovered after furnace annealing at 850°C for a half hour. This can be seen from the another paragraph.

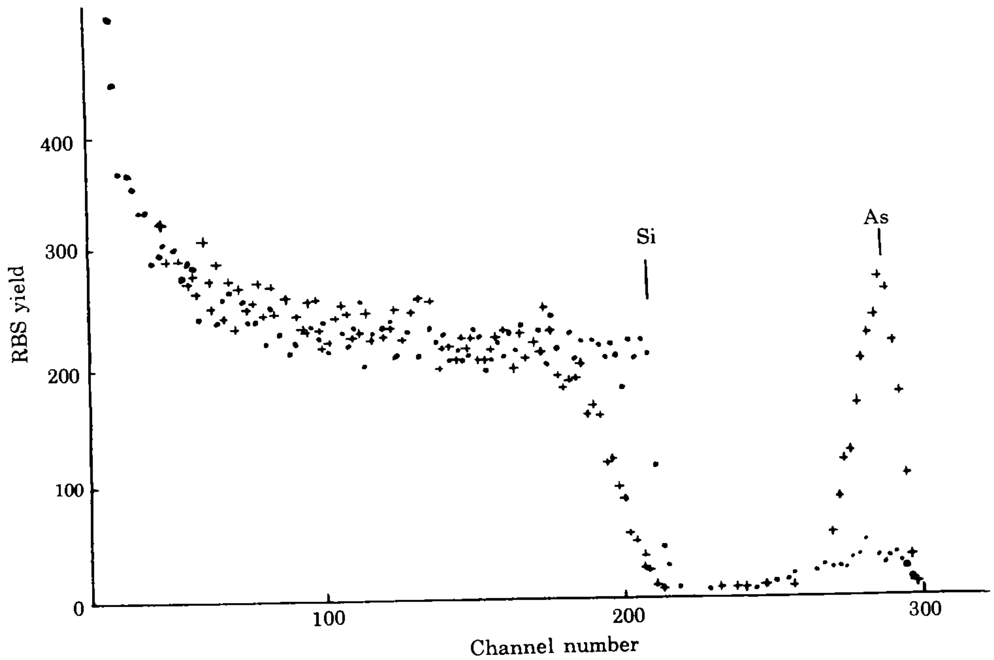

Fig.2 The RBS spectra of Si samples which covered on GaAs wafers during annealing

The dot and plus are presented with and without Si_3N_4 capsule, respectively

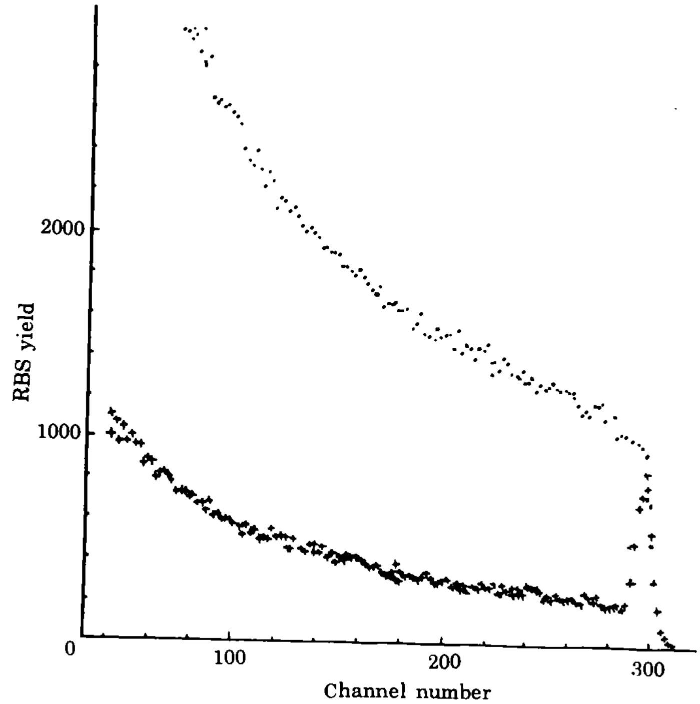

Fig.3 The random and aligned RBS spectra of GaAs sample after Si implantation before annealing, the dot and plus are indicated them, respectively

Fig.4 shows PIXE spectrum for as implanted (100) GaAs. We find that the characteristic Kα-ray of the Ga atoms and the As atoms were separated clearly. And the Ga-Kβ(10.26 keV) peak overlaps with the As-Kα(10.54 keV). The aligned spectrum of as-implanted sample is very close to the random one due to amorphization at surface of GaAs. After annealing at 850°C for a half hour, the

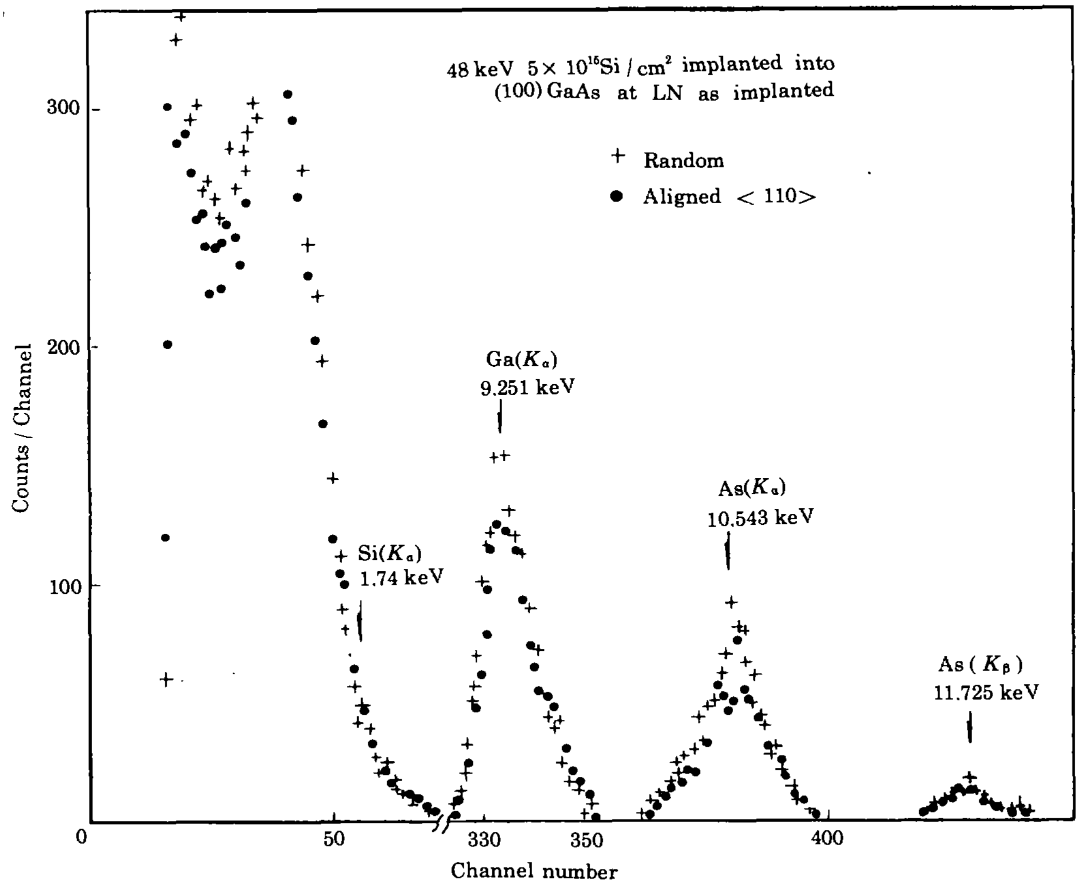

Fig.4 The random and aligned PIXE spectra of GaAs sample after Si implantation before annealing, the plus and dot are indicated them, respectively

recrystallized took place (in Fig.5). Angular scan of the GaAs samples was performed across the < 110> channel in {110} plane. The different energy gaps selected in Fig.5 were used to get the different dips in the same scanning. In Fig.6 and Fig.7 are shown the experimental results for a dose of 5×10^{15} ions / cm^2 and a one of 3×10^{15}ions / cm^2, respectively. The dip curve of RBS is generated by taking the integrated counts from the backscattering spectra over a depth interval in the order of the implantation range which is about 46.5 nm in this case. The typical PIXE dip curves are generated by measuring the area of Si-Kα, Ga-Kα and As-Kα rays peaks as a function of the

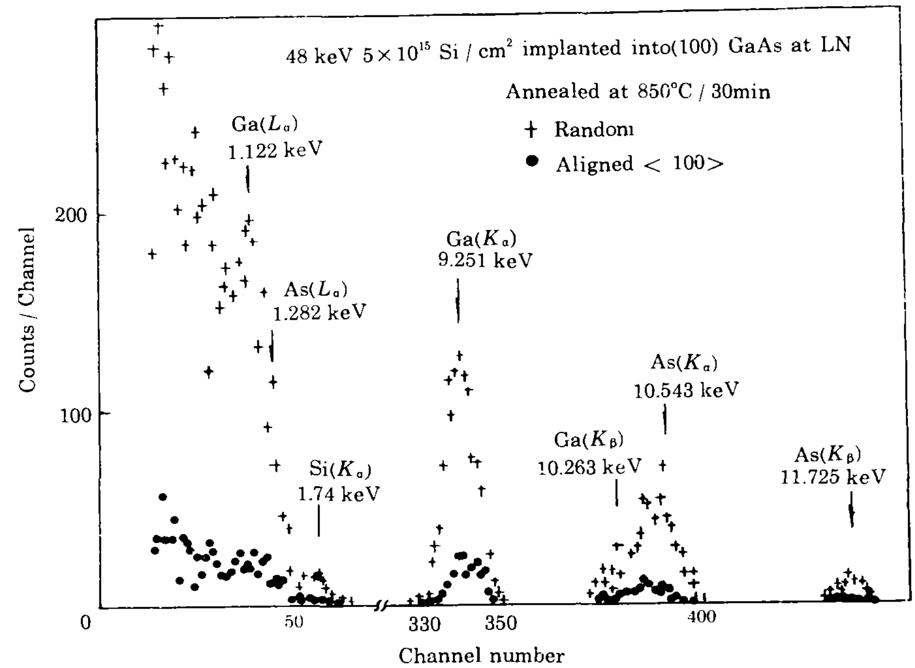

Fig.5 The random and aligned PIXE spectra of GaAs sample after Si implantation after annealing, the plus and dot are indicated them respectively

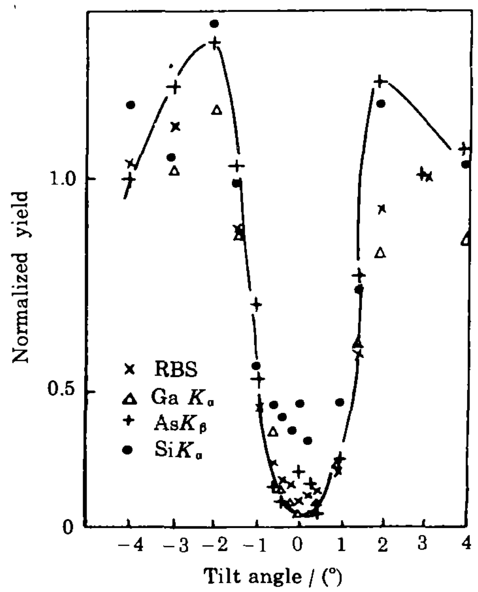

Fig.6 Angular scan across < 110> made parallel to the {110} plane (for 48 keV Si^+, 3 $\times 10^{15}cm^{-2}$) after annealing at 850°C / 30 min

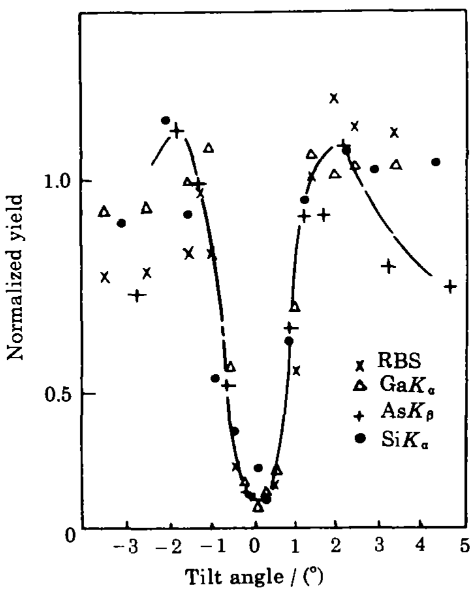

Fig.7 Angular scan across < 110> made parallel to the {110} plane (for 48 keV Si^+, 5 $\times 10^{15}cm^{-2}$) after annealing at 850°C / 30 min

tilt angle. Although the As-Kα peak overlaps with the Ga-Kβ, it is still able to obtain the As- K α intensity from the AsK α + GaK β because that the contribution of GaK β rays, as we have known, is 19.4 % of its K α ray intensity. There exists an asymmetry RBS dip in Fig.6 due to the different cross sections of the backscattering from the Ga atoms and the As atoms and the different scattering probability at a positive and a negative tilted angle from Ga and As. We did not apparently discover the asymmetry of Si dip in the present case. It probably indicates that the Si atoms occupy both Ga and As lattice sites[7,8]. The magnitude of asymmetry depends on the layer thickness from which the signal is observed and also the percentage of dopant occupied the sublattice sites[7]. However it is well known that the Ga and As K X-rays are generated over a total depth of about 1.5 μm, but the depth of Si ions implanted in GaAs with an energy of 48 keV is only ~46.5 nm much less than the depth of Si K X-ray. Therefore it might also explain why the asymmetry of Si dip is not too large.

4 CONCLUSIONS

a. All samples are amorphized at the GaAs surface by implantation of Si ions with an energy of 48 keV at different doses.

b. The surface amorphous layers are recovered after annealing at 850°C for a half hour.

c. Implanted Si ions occupy both the Ga and As lattice sites.

d. Electrical properties of GaAs are improved by the Si ions implantation and even more improved after annealing.

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