# THE DAMAGE MEASUREMENT OF ION– IMPLANTED COMPOUND SEMICONDUCTOR GaAs BY PIXE– CHANNELING TECHNIQUE

Liu Huizhen (刘惠珍), Sheng Kanglong (盛康龙), Zhu Dezhang (朱德彰), Yang Guohua (杨国华), Zhu Fuying (朱福英), Cao Jianqing (曹建清) and Tang Lijun(唐立军)

*(Shanghai Institute of Nuclear Research, Academia Sinica, Shanghai 201800, China)*

(Received November 1989)

## ABSTRACT

A combined PIXE– RBS channeling measurement system to examine III– V compound semiconductors has been established. Preliminary results on studying $Si^+$ and $Te^+$ implanted GaAs have been presented and discussed.

**Key words:** Ion implantation Compound semiconductor GaAs PIXE– channeling technique

## I . INTRODUCTION

In recent years, ion implantation of compound semiconductors has interested groups of people in both research institutions and the industries. The effective mass of electrons in GaAs, for example is about 7% denser than in Si, leading to higher operating speeds of GaAs devices. GaAs has a direct bandgap of 1.4 eV, which is wider than the indirect bandgap of Si(1.1 eV), making it especially useful for opto– electronic devices and allowing GaAs circuits to operate at elevated temperatures. Additionally, GaAs is advantageous for its exceptional radiation hardness[1]. For ion implantation into GaAs, however, the subsequent damage removal and dopent activation steps are considerably more complex than what have been doing for implantations in silicon, as have been reviewed by several authors[2–4].

Rutherford backscattering (RBS) with 2 MeV $He^+$ ions is one of the techniques that are extensively used for near surface analysis in silicon. Unfortunately, the atomic masses of Ga and As are so close to each other that the 24 keV energy difference between helium particles scattered from Ga and As at 170° to the 2 MeV $He^+$ beam incidence limits the ability of a backscattering– channeling system to determine the damages in an ion– implanted GaAs. It is also difficult for a conventional RBS system to measure light impurities in compound semiconductors. For these reasons, particle induced X– ray emission (PIXE) combining with RBS and ion channeling is becoming an important technique to examine ion implanted GaAs and other compound semiconductors[5–6].

In this paper, we will report on our attempt of establishing a combined PIXE– RBS channeling measurement system and studying ion implanted GaAs samples. Experimental considerations and technical details will be described in section Ⅱ, while some preliminary experimental results will be given and discussed in section Ⅲ..

## Ⅱ. EXPERIMENTAL

The samples under investigation were $Si^+$ and $Te^+$ implanted GaAs single crystals. The GaAs wafers were implanted with 40 keV $Te^+$ to a dose of $1.03\times10^{15}$ ions/cm$^2$ or 120 keV $Si^+$ to a dose of $1.0\times10^{15}$ ions/cm$^2$. The $Te^+$– implanted GaAs was treated by white– light annealing.

GaAs is one of the Ⅲ – V compound semiconductors that are made up of a binary compound lattice in the zinc– blende structure. The <110> axis is made up of atomic strings containing only one of the two matrix atoms. In order to examine the implantation induced damages to the GaAs lattice with PIXE under channeling conditions, Ga and As *K* X– rays would be of our primary interest. And by considering the X – ray productions as the particles go dechanneling in the lattice and absorptions as the X– rays pass through the matrix, low energy protons would be of our first choice. At the moment, we could get from a 4 UH pelletron accelerator 1 MeV proton beams with desired stability in flux to facilitate aligning the GaAs crystals.

A schemetic arrangement of the experimental set– up is shown in Fig.1. The 1 MeV

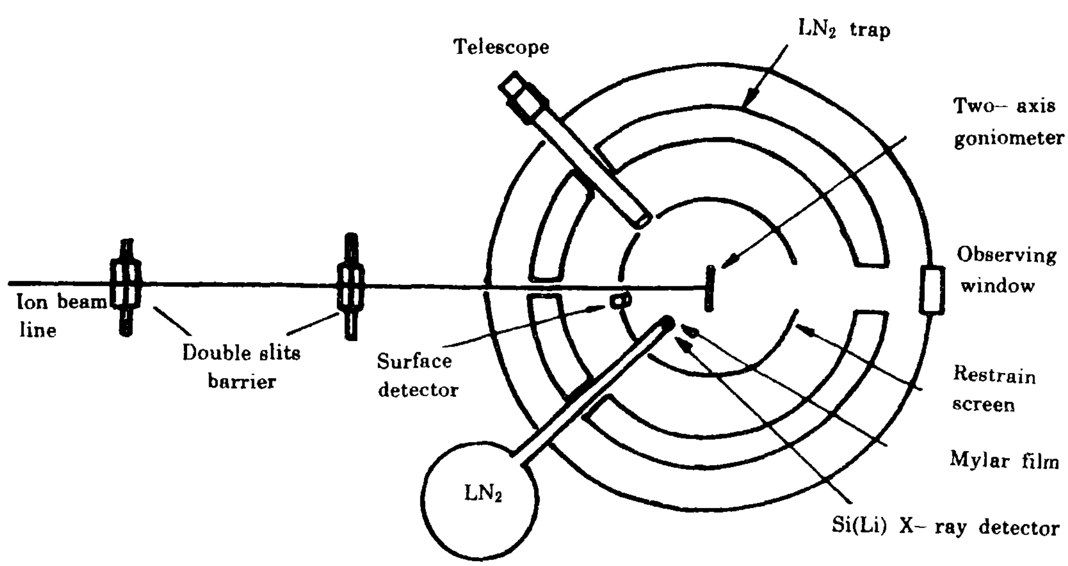


**Fig.1 Schematic experimental arrangement of the PIXE– RBS channeling system**

proton beam was collimated to 1 mm × 1 mm and conducted into the cylindrical target chamber in which a $399.99\times10^{-6}$ Pa vacuum was maintained. The beam, with a current density of about 1—2 nA, hit the GaAs that was mounted on the target holder of a two- axis goniometer. A Si(Li) detector of 165 eV in energy resolution at 5.9 keV was located at 135° with respect to the beam incidence. For the detection of light impurities in the GaAs, we used a 1.8μ m thick Mylar film instead of the thicker Be window. This could create a series of technical problems, because, among other things, an annular liquid nitrogen trap had to be placed in the chamber to keep molecular residuals from building up at the Si(Li) surface. At 170° to the beam incidence was a surface barrier detector (SBD), by which the GaAs was aligned with the protons before PIXE measurement could be carried out. The signals from the Si(Li) and SBD detectors were amplified, analyzed and accumulated in an Apple- Ⅱ micro- computer- based multi- channel analyzer.

## Ⅲ. RESULTS AND DISCUSSION

In Fig.2 is shown the typical PIXE spectra of a <100> GaAs crystal under random and aligned conditions while submitting it to 1 μ C of proton exposure. The characteristic $K$ X- rays of Ga and As are depicted in cross for the random condition and circle for <110> axial orientation. The $K$ shell ionization cross- sections of Ga

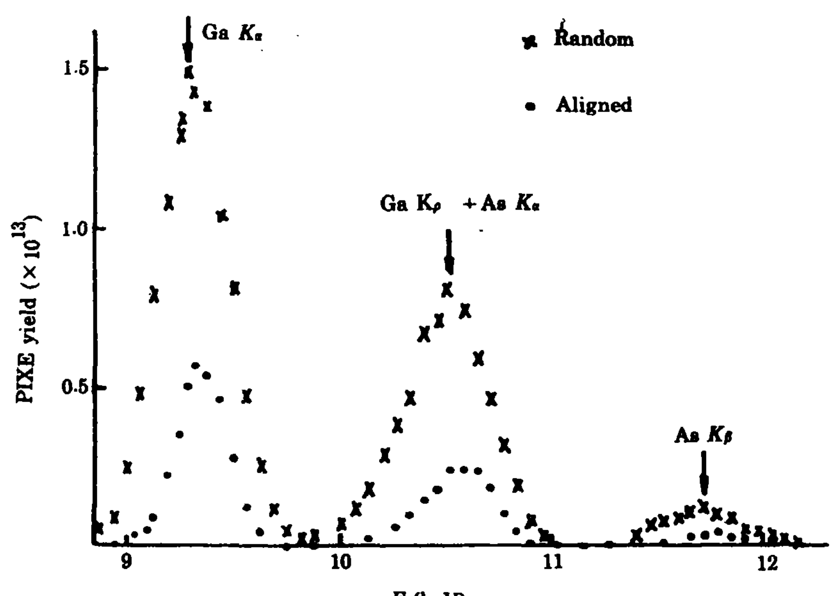


**Fig. 2 PIXE spectra of a GaAs single crystal exposed to 1 MeV protons**

and As by 1 MeV protons are about the same. The apparently low yield of As $K_\alpha$ rays is due to the fact that Ga $K_\beta$ shell absorption energy (10.37 keV) is just close to As $K_\alpha$ rays (10.54 keV). And during the proton bombardment, Ga atoms underwent secondary excitations by the As X- rays, resulting in a considerable increase in the Ga X- ray production. The Ga $K_\beta$ rays (10.26 keV) overlap with As $K_\alpha$ rays. However, the contribution of Ga $K_\beta$ rays is known as 19.4% of its $K_\alpha$ ray intensity. One is able to obtain the As yield by either making the subtraction from the Ga $K_\beta$ + As $K_\alpha$ peak or directly from the As $K_\beta$ peak.

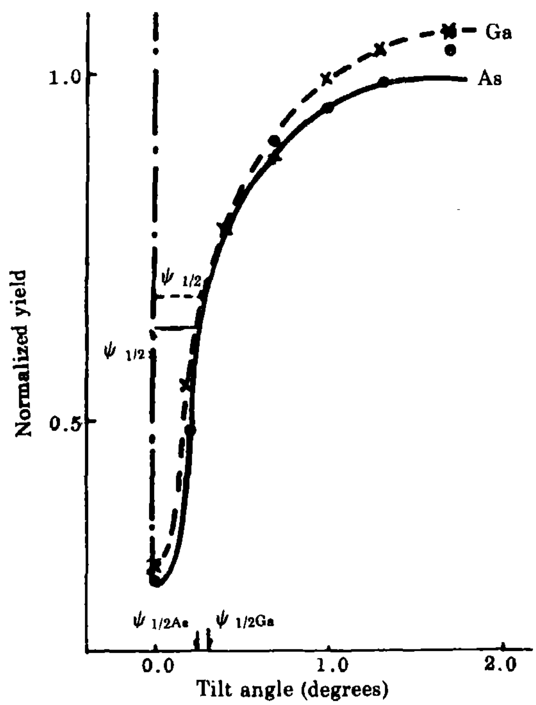


**Fig.3 Angular scan of a 40 keV Te⁺ implanted GaAs across the ⟨ 110⟩ axial channel while remaining inside the ⟨ 110⟩ plannar channel**

Angular scan of the GaAs samples were perfomed across the <110> axial direction while remaining inside the <110> planar channel. In Fig.3 is the experimental results of such a scan for the $Te^+$ implanted GaAs. The yields have been normalized to unity with respect to the random. The dashed and solid lines represent the Ga and As K X– ray yields, respectively.

**Table 1**

**Minimum yield of the ⟨ 100⟩ and ⟨ 110⟩ axial orientation of $Si^+$ and $Te^+$ implanted GaAs**

| | Ga ($K_\alpha$) | As ($K_\beta$) | [(Ga– As)/Ga] × 100% |
|---|---|---|---|
| | ⟨ 100⟩ 0.694 | 0.607 | 12.5 |
| $Si^+$ | ⟨ 110⟩ 0.612 | 0.553 | 9.6 |
| | ⟨ 100⟩ 0.249 | 0.202 | 18.9 |
| $Te^+$ | ⟨ 110⟩ 0.287 | 0.270 | 5.9 |

In Table 1 is given the minimum yield, $X_{min}$, of Ga $K_\alpha$ and As $K_\beta$ lines from the $Si^+$ and $Te^+$ implanted GaAs, with the protons incident along ⟨ 100⟩ and ⟨ 110⟩ axial channels. The results of the $Te^+$– implanted does not show that the implantation induced damage had been completely removed by the white– light annealing. It may be explained by the fact that the protons are apparently still too high in energy to be stopped within the ranges of the implanted $Te^+$ ions. One notices that the damages to Ga atoms were about 10% greater than that to As, no matter what ($Si^+$ or $Te^+$) had been implanted. From the elastic collision kinetics, the energies transferred to Ga or As atoms would not be so different as to cause such a damage difference. And generally, it is As that is more likely to be disordered than Ga while submitting to ion bombardment. a possible explaination is the Ga atoms' secondary excition by the *K* X– rays emitted from the disordered As atoms. Further investigations are needed to find out other problems and to clarity the phenomenon. The implanted species could not be detected. Improvements are needed to reduce the spectrum background at especially the lower energy region. Also some critical absorption films are to be used to reduce the *K* X– rays from the substrate atoms. What we have done in this work is just the very begining of our efforts in this field. Further works is under planning to improve the whole system and systemetic studies on GaAs and other Ⅲ — V compound semiconductors are to be carried out.

## ACKNOWLEDGEMENT

The authors acknowledge the Shanghai Institute of Metallurgy, Academia Sinica, for the sample preparation.

## REFERENCES

[1] S.J.Pearton et al., *Nucl. Instr. Meth.*, **B19/20** (1987),369.

[2] F.H.Eisen, *Radiat. Eff.*, **47** (1980), 99.

[3] H.Nishi, *Nucl. Instr. Meth.*, **B7/8** (1985), 395.

[4] D.K.Sadana, *Nucl. Instr. Meth.*, **B7/8** (1985), 375.

[5] R.S.Bhattacharya and P.P.Pronko, *Appl. Surf. Sci.*, **18** (1984), 1.

[6] J.S.Williams, Personal communication.