RBS ANALYSIS OF DAMAGE AND ANNEALING OF ION IMPLANTED InP:Fe

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ABSTRACT

Rutherford backscattering spectroscopy (RBS) with channeling technique has been used to analyze the damage and its annealing of Si^+ and P^+ implanted InP:Fe. 150 keV Si ions and 160 keV P ions were implanted with doses ranging from 1×10^{13} to $1\times10^{15}/cm^2$ at room temperature, 200 °C and 77K. Thermal annealing was performed in a conventional open tube furnace under flow of pure N_2 for 15 minutes. Annealing temperature was chosen from 150 °C to 800 °C. It was found that a dose of $8\times10^{13}/cm^2$ Si^+ was sufficient to produce an amorphous layer at room temperature and its epitaxial regrowth takes place at temperature below 150 °C. The epitaxial regrowth of amorphous layer produced by $1\times10^{14}/cm^2$ Si ions occurs from both substrate and surface while that produced by co-implantation of $1\times10^{14}/cm^2$ Si ions with the same dose of P ions takes place from substrate only. It was also noticed that for the former sample, its amorphized layer can be nearly completely recrystallized by epitaxial growth at 650 °C, but for the latter much residual disorder remains even after annealing at 750 °C. As for 77K implant at dose as low as $5\times10^{13}/cm^2$, Si ions begin to produce an amorphous layer that can be wholly reordered at 750 °C. Samples implanted at 200 °C remain crystalline only with small fraction of disorder due to self-annealing effect during the implantation. The damage annealing in the implanted layer corresponds to the change of electrical parameters got from Hall measurements.

Keywords: InP Ion implantation RBS analysis Damage

I. INTRODUCTION

InP is an important material for a wide variety of microwave, high speed integrated circuits and optoelectronic devices. Ion-implantation created damage and its annealing in InP have been investigated by many authors[1-4] In order to enhance the activation of Si implanted into InP, co-implantation of P was performed in our experiments. We evaluated the damage and its annealing behavior using RBS channeling technique. In addition, electrical measurements have been made to provide some insight into the effect of residual disorder on electrical property.

II. EXPERIMENTAL

Semi-insulating (100) InP wafers doped with Fe were used in this work. The implantations were performed at energies of 150 keV for Si^+ and 160 keV for P^+ at 77K, room temperature (RT) and 200 °C. The doses applied were from 1×10^{13} to 1×10^{15} ions/cm^2. For implantations at room temperature, the target was cooled by freon and the current density was kept less than 0.2 μ A/cm^2. Si_3N_4 encapsulated samples were annealed at temperatures from 150 to 800 ° C for 15 minutes under N_2 flows. The damage induced by implantation and its recrystallization were analyzed by RBS channeling technique with 2.0 MeV He^+ ions. The electrical property of the implanted layer was investigated by Hall measurements.

III. RESULTS AND DISCUSSION

InP samples were implanted with different doses of the Si and P ions at room temperature to observe the dose effect on disorder production. For an individual InP sample, the doses of the two ion species were the same. The number of displaced In atoms (NdIn) generated by implantation of 150 keV Si^+ and 160 keV P^+ as a function of ion dose is shown in Fig.1 (a).

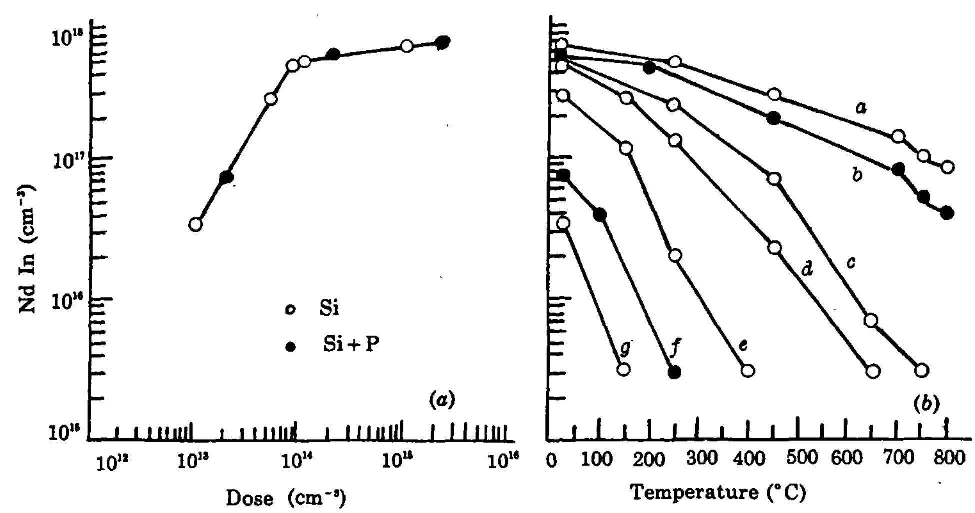

Fig 1. Displaced In atoms as a function of ion doses (*a*) and annealing temperature (*b*)

a. Si 1×10^{15}/cm^2 *b*. Si-P 2×10^{14}/cm^2 *c*. Si 1×10^{14}/cm^2 *d*. Si 8×10^{13}/cm^2

e. Si 5×10^{13} *f*. Si-P 2×10^{13}/cm^2 *g*. Si 1×10^{13}/cm^2

At the dose of 8×10^{13} Si^+/cm^2, the displaced In atoms increase up to a saturation level which corresponds to the formation of amorphous layer. From the annealing behavior of disordered layer shown in Fig.1 (b) and Fig.2, we find that there is a critical dose Nc, i.e. 1×10^{14} Si^-/cm^2 in our experimental condition. The disordered layer produced by dose larger than Nc could not be completely reordered even at temperature as high as 800 °C. The RBS spectra also illustrated that the epitaxial regrowth in these samples proceeded from substrate only, while that in the recovered samples proceeded from both substrate and surface. TEM analysis revealed a thin single crystalline layer at the surface of the reordered samples. This is in agreement with the result reported by Auvray[3]. A possible explanation for the remaining disordered layer may be that if the disordered layer is too thick, a crystal with random orientation could be nucleated at the site near the surface before the epitaxial regrowth from the substrate reaches the surface.

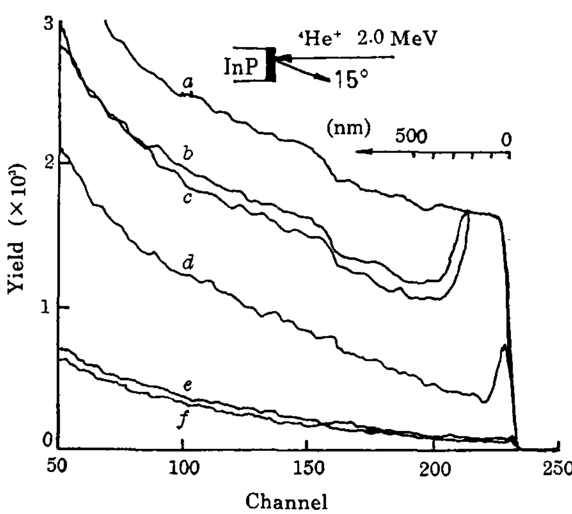

Fig.2 RBS spectra for InP implanted at RT with 150 keV Si^- and 160keV P^- and annealed at 750 °C 15 min

a. random b. Si – P $2\times10^{14}/cm^2$
c. Si $1\times10^{14}/cm^2$ d. Si – P $2\times10^{14}/cm^2$ annealed
e. Si $1\times10^{14}/cm^2$ annealed f. unimplanted

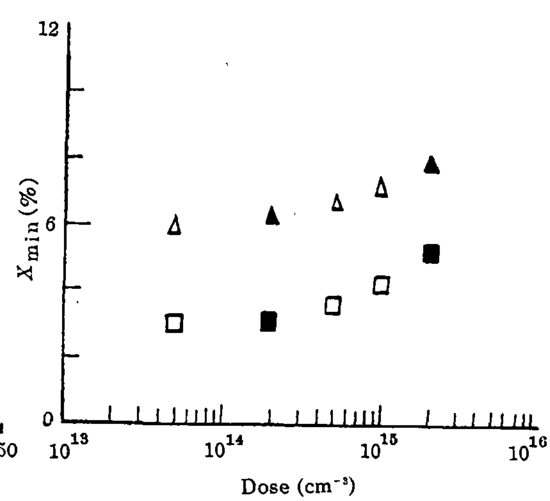

Fig.3 Damage parameter X_{min} as a function of ion doses

△ Si unannealed ▲ Si+P unannealed
□ Si annealed ■ Si+P annealed

The target temperature dependence of disorder was also studied. It is found that a dose of 5×10^{13} Si^-/cm^2 implanted at 77K is sufficient to produce an amorphous layer in the sample. For samples implanted at 200 °C, the disorder is negligible. The damage parameter X_{min} as a function of ion doses is plotted in Fig.3 for 200 °C implanted samples, either unannealed or annealed at 750 °C for 15 min. Though X_{min} becomes smaller after annealing of the samples implanted with different doses, the dechanneling in the RBS spectra of the samples implanted with doses higher than 5×10^{14} Si^-/cm^2 rise rapidly. It can be considered that that is caused by the complex defects which were formed during the thermal annealing upon the higher point defect density or small defect clusters created by self-annealing process during the hot implantation.

From the data listed in table 1, the effect of residual disorder on carrier mobility is evident. It is also striking that coimplantation of P can enhance the activation of dopant Si for both room temperature and 200 °C implantations.

Table 1

Electrical property obtained using Hall measurement on 150 keV Si^- and 160 keV P^- implanted InP:Fe followed by furnace annealing at 750 °C for 15 min

Implanted Ion	Implanted temperature	Dose(cm^{-2})	Electrical activation	Mobility (cm^2 v.s)
Si	RT	1×10^{14}	75%	1223
+ Si	RT	1×10^{14}	95%	899
P	RT	1×10^{14}		
Si	200 °C	1×10^{14}	87%	1746
+ Si	200 °C	1×10^{14}	99%	1677
P	200 °C	1×10^{14}		

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