ELECTRICAL CHARACTERIZATION OF HIGH ENERGY ^{197}AU IMPLANTATION IN GAAS

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ABSTRACT
It is interesting to study the effect of high energy irradiation of semiconductor by swift heavy ions in MeV range and removal of defects after annealing. Single crystal n^+ GaAs substrates of <100> orientation have been implanted at room temperature with ^{196}Au ions at energy 100 MeV to the doses of $1x10^{12}$, $1x10^{13}$, $1x10^{14}$ ions/cm^2. The as implanted current-voltage (I-V) characteristic of samples have been obtained. The substrate implanted with a dose $1x10^{12}$ ion/cm^2 shows comparatively higher resistance which may be due to mid-gap damage related levels. The substrate implanted with a dose $1x10^{13}$ ion/cm^2 and $1x10^{14}$ ion/cm^2 shows comparatively lower resistance which may be due to hopping from damage site to site.
The samples implanted to the dose of $1x10^{12}$ ions/cm^2 were isochronally annealed for 10 minutes by RTA system at different temperatures in the range of 100^0 C to 550^0 C and for 10 seconds in the range of 650^0 C to 850^0 C. To avoid evaporation of As at high annealing temperature, samples are covered by virgin GaAs substrate while annealing above 550^0 C. The room temperature I-V curves for samples annealed at different temperatures were studied from which their effective resistance have been estimated. For low dose $1x10^{12}$ ions/cm^2 implanted samples, an annealing stage is evident between 350 to 450^0 C where the resistance after annealing to 550^0 C decreases to 3 Ω. This indicates that the charge carriers trapped in the energy levels in the band gap due to defects have been returned to the conduction band after annealing.

Keywords: *Ion implantation, GaAs, Electrical characterization.*

1. INTRODUCTION

Ion implantation is essential process for the production of modern devices and integrated circuits in Si and compound semiconductor technologies. In case of III-V semiconductor, there are two important applications. The first is the implantation of dopants to establish proper n- or p-type conductivity. The second is the implantation of suitable ions to convert a doped layer to highly resistive one. This latter application is called implant isolation or isolation by ion irradiation [2]. Area of active research in MeV implantation includes studies on damage formation and disordering of GaAs super lattices. However the extension of the implantation energy to the MeV range raises an interesting question about radiation induced defects and their annealing behavior. The damage resulting from the penetration of MeV ion irradiation can form amorphous layer below the surface which needs to be removed by an annealing process. As such, The annealing process of MeV implantation seems to be complicated than that of ion implantation at KeV energies [3]. It has been reported that in case of GaAs, the implantation in the MeV range has diverse applications and also diverse areas of studied. The initial technological driving force was to form deep conducting layers in silicon and this application stimulated keen interest in specifically studying damage production by MeV ions and its removal by thermal annealing Electrical characteristics shows complex behavior with annealing treatment when substrate is implanted in MeV range [4, 5]. In this paper we attempt to understand the change in the electrical characteristics of 100 MeV ^{196}Au implanted n^+ type GaAs substrates to the dose of $1x10^{12}$ ions/cm^2 and effects of annealing.

2. EXPERIMENTAL DETAILS

The samples used in this experiment were one side mirror polished n^+ type GaAs substrates having an area of 7 mm x 7 mm and thickness of 400 µm. All the samples were carefully cleaned in organic solvents. Implantations were carried out on polished side at room temperature with 100 MeV ^{196}Au ions to a does of $1x10^{12}$, $1x10^{13}$ and $1x10^{14}$ ions/cm^2 using the NEC 16 MV pelletron acclerator [6]. During the implantation the beam current was held at 6-12 pnA and the Au beam was scanned to bombard the entire sample surface. The ohmic contacts were fabricated by vacuum deposition of uniform coating of Au-Ge-Ni alloy coating, both on the lower surface of each sample and dots with an area 0.0045 cm^2, through a metal mask on the upper surface of each sample. The contacts made were then alloyed for 1 min in pure hydrogen ambient at 450^0C. For the samples, which are to be annealed below 400^0C, the ohmic contacts were made before the implantation and for the samples to be annealed above 400^0C, the contacts were made after annealing.

In this work electrical measurements have been carried out for samples implanted with the doses $1x10^{12}$, $1x10^{13}$, $1x10^{14}$ ions/cm^2 and samples implanted to the dose $1x10^{12}$ ions/cm^2 after annealing over a range of temperature from 100^0C to 850^0C. The annealing of samples was done isochronally for 10 min up to 550^0C in high purity nitrogen ambient in a rapid thermal annealing system (RTA) system [7]. Annealing at 650^0C and higher temperatures was done for 10 s in RTA system. To prevent the diffusion of As from the surface of GaAs, during the high temperature (>450^0C) heat treatment, the implanted samples were capped with clean polished pieces of un-implanted n^+ GaAs of the same size, with polished surfaces in contact.

The current-voltage (I-V) measurements between the top and the back contact were carried out at room temperature using Keithley Electrometer 2400. I-V measurements were made on two to three dots on each sample and found to be repeatable. Although I-V measurements have been done on one selected dot on each sample after annealing treatment, in some cases they have been checked on more than one dot and found to be representative of the result reported here.

3. RESULT AND DISCUSSION

Room temperature current-voltage (I-V) characteristics have been measured for as-implanted samples with the doses of 1x1012, $1x10^{13}$, $1x10^{14}$ ions/cm^2. Further I-V characteristics of samples implanted with the dose $1x10^{12}$ ions/cm^2 and annealed in the range of 100 to 850^oC are measured.

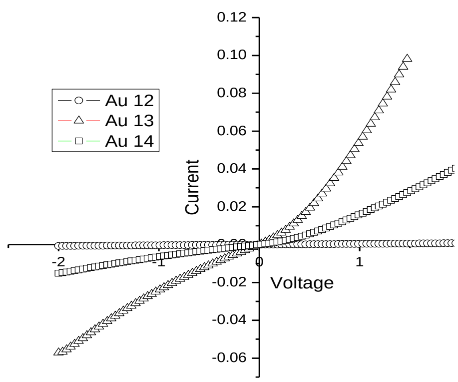

Fig.1

Fig.1 shows the I-V characteristics of as-implanted samples for dose $1x10^{12}$, $1x10^{13}$, and $1x10^{14}$ ions/cm^2. We observe that for a dose, $1x10^{12}$ ions/cm^2, the I-V curve is almost linear with sample resistance of 2.7 KΩ. I-V curve for a dose, $1x10^{13}$ ions/cm^2 and $1x10^{14}$ ions/cm^2 are weakly non-linear. We have estimated effective resistance in the linear portion of the curve where the series resistance is dominant. We observed that resistance of a samples for dose $1x10^{13}$ and $1x10^{14}$ ions/cm^2 are 12Ω and 46Ω respectively. For a dose $1x10^{12}$ ions/cm^2, the sample resistance of 2.7 kΩ which is very much higher as compared to room temperature resistance 6 Ω of un-implanted n+ GaAs [1] and resistance of two other higher dose implanted samples. This higher value of sample resistance for low dose sample may be due to the generation of radiation induced defect states which results into additional energy levels within the forbidden energy gap and which compensates the free carriers in the substrate [8]. For a dose $1x10^{13}$ and $1x10^{14}$ ions/cm^2, we observe comparatively low resistance, indicate conduction via defect states. The electrons trapped in these levels can hop from one site to neighboring defect sites. Thus the electrical conduction in these samples is defect dominated [9].

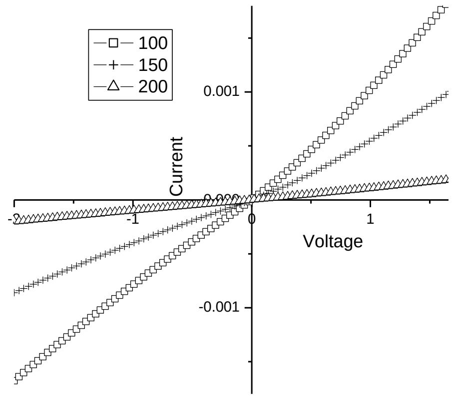

Fig.2

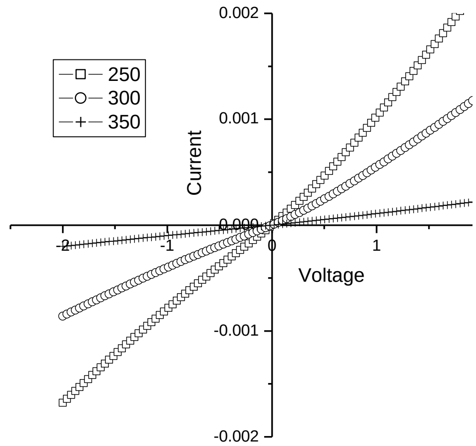

Fig.3

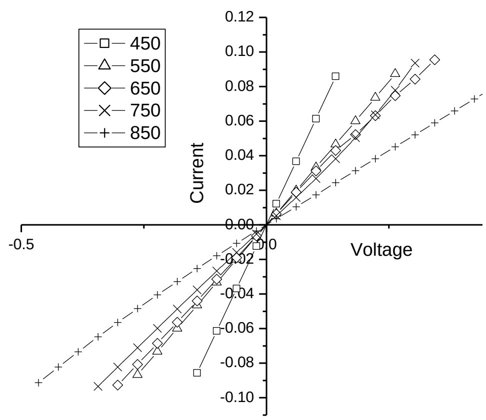

Fig.4

The annealing behavior of the room temperature current voltage curve for samples implanted to the dose of $1x10^{12}$ ions/cm^2 is as shown in fig 2, fig 3 and fig 4. It is observed that the curves are almost linear and there is no considerable change in resistance of the sample up to 350^oC.

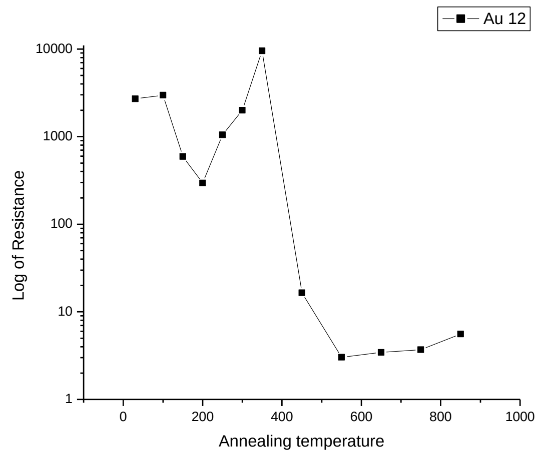

Fig. 5

Fig. 5 shows room temperature values of effective resistance measured for different annealing temperatures. We observe that there is not a much change in the substrate resistance for annealing up to 350^0 C. After annealing to 450^0C resistivity of the sample with dose $1x10^{12}$ ion/cm^2, decreases suddenly and its resistance becomes 16 Ω. There is no considerable change in the resistance after further annealing. This indicates that there is removal of defects produced due to implantation after annealing to 450^0C, for samples with doses $1x10^{12}$ ion/cm^2.

4. CONCLUSION

We have implanted 100 Mev, 196 Au ions in a single crystal n+ GaAs substrates at a fluence of 1x1012, 1x1013 and 1x1014 ions/cm2 . At room temperature the electrical characteristics of the as-implanted samples have been studied by current-voltage measurements and effective resistance was estimated. Current-voltage (I-V) characteristics for 1x1012 ions/cm2 dose implanted sample shows linear behavior while 1x1013 and 1x1014 ions/cm2 dose implanted sample characteristics are weakly nonlinear. Annealing stage is evident after 450oC annealing where resistance of the substrate returns to unimplanted resistivity.

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