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Electrical and Optical Characterisation of 100 MeV ^{197}Au Irradiated GaAs.

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Abstract—**Effect of 100 MeV ^{197}Au implantation, followed by Rapid Thermal Annealing on electrical and optical characteristic is reported. Single crystal n+ GaAs substrates of <100> orientation have been implanted at room temperature with ^{197}Au ions to the doses of $1X10^{12}$, $1X10^{13}$, $1X10^{14}$ ions/cm^2. The as-implanted current-voltage (I-V) characteristic of samples is studied and the optical investigations in IR and mid IR-range have been made. The implanted samples were isochronally annealed by RTA system at different temperatures and the room temperature electrical characterization and the optical investigations are reported.**

Keywords- Ion implantation, electrical characterisation, annealing, optical density.

INTRODUCTION

Ion implantation is well established technique 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. 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. Electrical characteristics shows complex behavior with annealing treatment when GaAs substrate is implanted in MeV range [4, 5].

In this paper we report the effect of the implantation of 100 MeV ^{197}Au in n+ type and semi-insulating GaAs substrates to the dose of $1X10^{12}$ ions/cm^2, $1x10^{13}$ ions/cm^2 and $1x10^{14}$ ions/cm^2. The change in the electrical characteristics of 100 MeV ^{197}Au implanted n+ type GaAs substrates to the dose of 1e12 ions/cm^2 and the IR study to the dose of 1e14 ions /cm^2 implanted and the effects of annealing is reported. These investigations leads to better understanding in basic interaction processes between ion and semiconductor in the high-energy regime.[6]

EXPERIMENTAL DETAILS

A. *Electrical Characterization*

In this experiment one side polished n+ GaAs substrate of size 7 mm X 7 mm and thickness 400 micro meter were used. The samples were carefully cleaned in organic solvents. Implantations were carried out on polished side at room temperature with 100 MeV ^{197}Au ions to the doses of 1e12, 1e13 and 1e14 ions/cm^2 using the NEC 16 MV pelletron acclerator [7]. During implantation the beam current

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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^{0}C. During the alloying process Au-Ge dissolves a thin region of GaAs substrate and later regrowth og Ge doped GaAs takes place which produces a heavily doped n^{++} region that provides the required ohmic contact. For the samples, which are to be annealed below 400^{0}C, the ohmic contacts were made before the implantation and for the samples to be annealed above 400^{0}C, the contacts were made after implantation.

Current-Voltage (I-V) measurements have been carried out for as-implanted samples with the doses 1e12, 1e13, 1e14 ions/cm^2. For the samples implanted to the dose 1e14 ions/cm^2 I-V measurements were made after annealing over a range of temperatures from 100^{o}C to 850^{o}C. The annealing of samples was done isochronally for 10 min up to 550^{0}C in high purity nitrogen ambient in a rapid thermal annealing system (RTA) system [8]. Annealing at 650^{0}C and higher temperatures was done for 10 s in RTA system. To prevent the diffusion of As from the surface of GaAs during annealing above 450^{o}C, 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.

B. Optical Investigations

The annealing behavior of the radiation induced defects as obtained from the near and mid IR spectroscopy in the range 250-20,000 nm for the dose 1e14 ions/cm^2 implanted in the temperature range 150-550^{0}C is studied.

Both side polished semi insulating GaAs substrate of thickness 400 micro meter were used. The samples were carefully cleaned in organic solvents. Implantations were carried out on polished side at room temperature with 100 MeV ^{197}Au ions to the doses of 1e14 ions/cm^2 using the NEC 16 MV pelletron acclerator [7]. During implantation the beam current was held at 6-12 pnA and the Au beam was scanned to bombard the entire sample surface.

The samples were annealed isochronally for 10 min up to 550^{0}C in high purity nitrogen ambient in a rapid thermal annealing system (RTA) system.

For IR measurement, the samples were cleaned in the boiling organic solvents (TCE, acetone and methanol) and then mounted on the sample holder in the ‘sample cell’. An IR run was recorded over the wavelength range of interest (200-3000 nm) . An IR run was also recorded for 100 % transmission without placing the sample on the sample holder. This 100 % transmission run was used latter to normalize the IR plot recorded for the sample under study. This corrects for any inhomogenety in the response of the measurement system of the spectrophotometer over the wavelength range of interest.[9] SHIMADZU UV-NIR-IR UV-3600 spectrophotometer is used for these measurements. The mid-IR measurements in the wavelength range 2000-13000 nm were carried out by using Varian 660-IR.

Optical density (αx) as the function of photon energy curves for the sample implanted to the dose of 1×10^{14} ions/cm^2 and annealed at different temperatures in the range 150 – 550^{0}C for 10 minutes in the RTA system is reported.

RESULTS AND DISCUSSIONS

Figure 1. shows the electrical characteristics of as-implanted samples for dose 1X10^{12}, 1X10^{13}, and 1X10^{14} ions/cm^2. For a dose, 1X10^{12} ions/cm^2, the I-V curve is almost linear with sample resistance of 2.7 KΩ. For a dose, 1X10^{13} ions/cm^2 and 1X10^{14} ions/cm^2 the I-V curves are weakly non-linear. We have estimated effective resistance in the linear portion of the curve where the series resistance is dominant. We observe that resistance of a samples for dose 1X10^{13} and 1X10^{14} ions/cm^2 are 12Ω and 46Ω respectively.

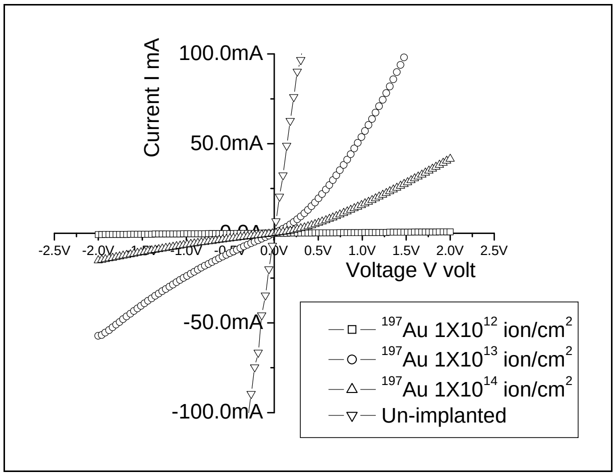

Figure 1. I -V Characteristics of as implanted samples.

For a dose of 1X10^{14} 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 also as compared to 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 [10]. For a dose 1X10^{13} and 1X10^{14} ions/cm^2, we observe comparatively low resistance, indicate conduction via defect states. The density of the defect states for higher dose implantation must be reasonably high so that 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 [11].

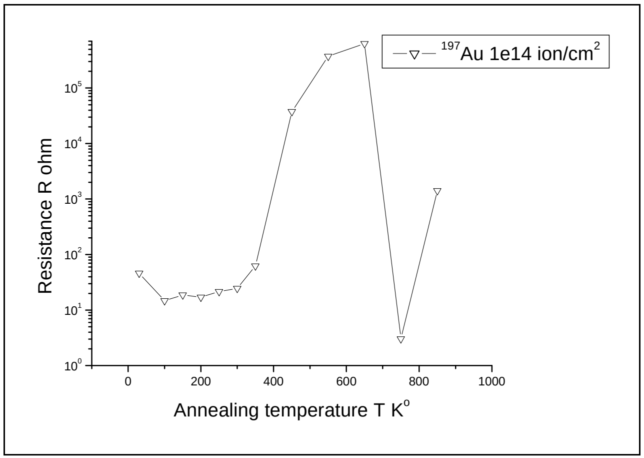

Figure 2. Effective resistance variation with annealing temperature.

Figure 2 shows room temperature values of effective resistance measured for different annealing temperatures for the sample implanted with the dose of 1X10^{14} ion/cm^2. We observe that there is not a much change in the substrate resistance for annealing up to 300^0 C. This indicates that the conduction mechanism for the samples annealed up to 300^{o}C may be hopping between the defect states.

After annealing to 450^0 C, resistivity of the sample increases suddenly. After this annealing stage at 450^{o}C, the defects must have been annealed out and density of defect states in the band gap has been reduced so that hopping conduction no longer prevails, and therefore resistivity has suddenly increased. This higher value of resistance also indicates that the carriers are trapped by the defect states still existing in the band gap. Second annealing stage is evident at 650^{o}C at which sample resistance decreases suddenly. This indicates that there is further removal of defects.

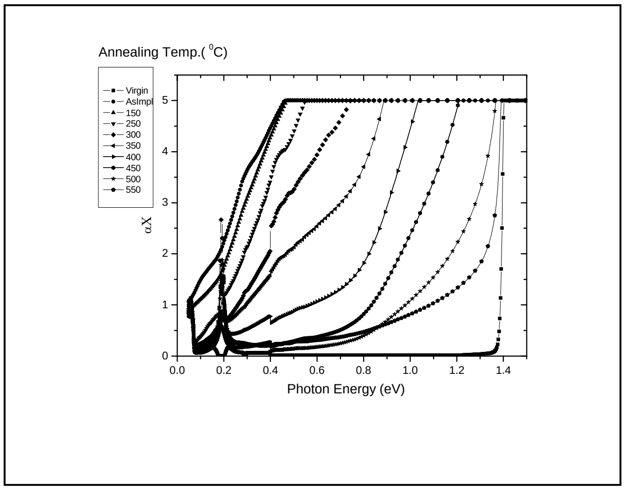

Figure 3. Dependence of the optical density (αx) versus photon energy plot

Annealing of defects is also studied by measuring variation in optical density with annealing temperature. Optical density (αx) versus photon energy curves for the samples implanted to the dose of 1×10^{14} ions/cm^2 annealed at different temperatures in the range 150 – 550°C are shown in Fig 3. It is seen that, the optical density (αx) gradually decreases over the entire photon energy range 0.1-1.4 eV with increase in annealing temperature, indicating an overall reduction in concentration of the defect states caused by the ion implantation. The (αx) values for as implanted sample and the sample annealed to 150°C, remain almost same over the entire photon energy range. Belekar et al. [12], has reported that the variation of (αx) values for as implanted sample and the sample annealed to 100 °C, shows the same trend over the entire photon energy range. This is again indication of no significant annealing of defects occurs at 100-150 °C . At the annealing temperature of 450 °C, the (αx) value decreases from 5.0 to 0.5 at 0.7 eV whereas there is no change in from (αx) values at 1.35 eV as compared to the as-implanted sample. This shows that annealing of the sample at 450 °C results in to a rapid recovery of deep lying defect states, while there is no change in the concentration of near band edge defect states. This reduction of deep lying defect states is also reflected in electrical investigation as sudden increase in resistance at annealing stage of 450^{o}C.

Further annealing of the sample to 550 °C results into decrease in the (αx) value by ≅ 0.3 at 0.7eV and by 2.5 at 1.35 eV as compared to the sample annealed at 350°C. This indicates a rapid decrease in the concentration of near band edge defect states occurs as compared to the concentration of deep lying defect states in this annealing temperature range about 550^{o}C. Probably the second annealing stage of 750^{o}C in the electrical investigations corresponds to the reduction in concentration of near band edge defects. We could not record the IR data beyond 550^{o}Cbecause of surface degradation of sample while further annealing.

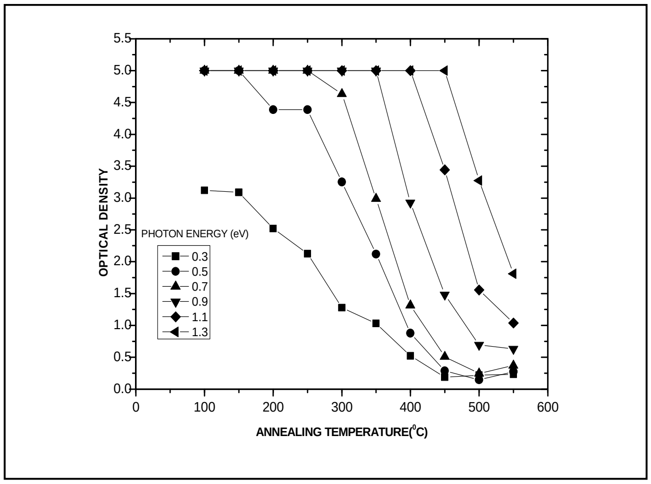

Figure 4. Dependence of optical density (αx) at selected photon energies for various annealing temperatures.

The data of Figure 3 is re-plotted in Figure 4. where (αx) values at selected photon energies are shown as a function of the annealing temperature. It shows that the rate of recovery of mid gap defect states is maximum in the annealing temperature range 300-400°C and these defect states are almost completely annealed out after annealing of the sample at the temperature of 500 °C. The fastest of recovery of near band edge defect states occurs in the annealing temperature range 450-550°C.

CONCLUSION

We have implanted 100 Mev, ^{197}Au ions in a single crystal n+ GaAs substrates at a fluence of $1X10^{12}$, $1X10^{13}$ and $1X10^{14}$ ions/cm^2 . 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 $1X10^{12}$ ions/cm^2 dose implanted sample shows linear behavior while $1X10^{13}$ and $1X10^{14}$ ions/cm^2 dose implanted sample characteristics are nonlinear. Two annealing stages are evident at 350^{o}C and 650°C annealing for the sample implanted with $1X10^{14}$ ions/cm^2 where resistance of the substrate returns to un-implanted resistivity.

The optical investigations done for the dose $1X10^{14}$ ion/cm^2 supports this behavior in the reported temperature range.

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