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A Comparative study of IR Investigations of High Energy ^{197}Au and ^{56}Fe Implantation in Ga As

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ABSTRACT

Single crystal semi-insulating GaAs substrates implanted with 70 MeV ^{56}Fe ions with doses varying from 5×10^{12} ions/cm^2 to 1×10^{14} ions/cm^2 and 100 MeV ^{197}Au ions with dose 1×10^{14} ions/cm^2 have been annealed and investigated in near and mid-IR transmission range 250-20,000 nm to study the annealing behavior of defect states after Rapid Thermal Annealing. The transmission spectra of the virgin and implanted samples were measured at the room temperature for the samples implanted with both the ions and optical density (αx) values of the samples with the dose 1×10^{14} ions/cm^2 were calculated. The comparative study of the annealing behavior of the optical density in above optical energy range for the same doses is reported. The results indicate that these annealing stages slightly modified and are almost dependent of that of the implanted ion and its energy.

Keywords: *Annealing, Optical density*.

1. INTRODUCTION

Ion implantation is extensively used to obtain n-, p- and i-type layers in III-V semiconductors because no reliable diffusion technology exists due to the low incongruent evaporation temperature of group V species. In the III-V compounds ion implantation creates local deviations from stoichiometry which influence the implant activation and redistribution process [1]. Ion implantation is also an important technique in fabrication of devices in GaAs [2]. These devices are sensitive to radiation induced defects and study of effect of annealing on them is desirable. Incorporation of impurities into the semiconductors by high-energy implantation can lead to the modification of the composition, structure, electronic properties and topography etc. [3]. Thus, if the doping of semiconductors by implantation at room temperature is to be a successful method of device fabrication, the lattice damage has to be removed and this is achieved by thermal annealing. Recently the investigations of 70 MeV ^{120}Sn and 100 MeV ^{28}Si implanted in GaAs have been reported [2, 3]. In this work we report the comparative study of IR investigations of high energy ^{197}Au and ^{56}Fe implantation in GaAs.

Optical spectroscopic methods have been adopted by several groups for the characterization of implanted semiconducting materials because of their advantage of giving qualitative and quantitative information concerning the defect states and annihilation process in implanted semiconducting wafers. In addition, these methods represent nondestructive and contact-less techniques. [4-6]

Ion irradiation induced defects related optical properties are very much depend on various parameters such as ion dose, energy, ion mass and substrate temperature during implantation. [7-9] Belekar et. al. [10] had studied the optical investigations of 70 MeV ^{56}Fe doped GaAs to confirm the recovery of radiation induced damages after annealing effects.

The question of swift heavy ion induced modifications in the optical properties of GaAs is still open and needs further investigations typically of heavier ion induced defects which may give

different defect structure and show different annealing behaviour. The optical investigations of the GaAs substrates implanted with the dose of 1x10^{14} ions/cm^2 of 100 MeV ^{197}Au are reported here.

2. MATERIALS & METHODS

The samples were prepared by cutting 400 micron thick both side polished wafer of single crystal GaAs of <100> orientation to a size of 7 mm x 7 mm and cleaning in organic solvents (TCE, acetone, methanol). For both the samples were then implanted at room temperature by 70 MeV energy beam of ^{56}Fe ions with dose varying from 5x10^{12} to 10^{14} and by 100 MeV of ^{197}Au ions with dose varying from 10^{12} to 10^{14} ions/cm^2 by using . 15 UD 16-MeV Pelletron accelerator at Inter-University Accelerator Center (IUAC), New Delhi, India.

Optical investigations are made to compare annealing behavior of radiation induced defects due to 100 MeV Au implantation in GaAs at a dose of 10^{14} ions/cm^2 to that due to 70 MeV Fe implantation in GaAs at the same dose.

The annealing kinetics has been studied by isochronal annealing of the substrate at different temperatures in the range 150-550°C in high purity nitrogen ambient for 10 minutes by using a Rapid Thermal Annealing (RTA) system. We report the annealing behavior of the radiation induced defects as obtained from the near and mid IR spectroscopy in the range 200-20,000 nm.

For the near-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 also recorded over the wavelength range of interest (200-3000 nm) without placing the sample on the holder i. e. for 100 % transmission. This was used later to normalize the IR plot recorded for the sample under study. 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) versus photon energy curves for the samples implanted by ^{197}Au to the dose of 1×10^{14} ions/cm^2 annealed at different temperatures in the range 100 – 550°C for 10 minutes in the RTA system are shown in Figure 1 while optical density (αx) versus photon energy curves for the samples implanted by ^{56}Fe to the dose of 1×10^{14} ions/cm^2 annealed at different temperatures in the range 100 – 600 °C for 10 minutes in the RTA system are shown in Figure 2. It is seen from Figure 1 that for ^{197}Au and from Figure 2 for ^{56}Fe 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.

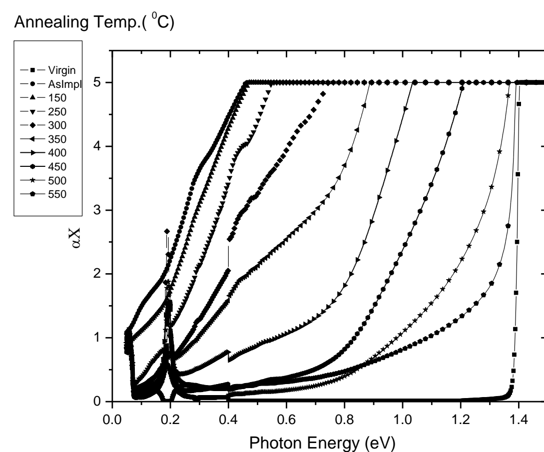

Figure 1. Dependence of the optical density (αx) versus photon energy plot on annealing temperature, for the sample implanted to a dose of 1×10^{14} ions/cm^2 for 100 MeV, ^{197}Au ions.

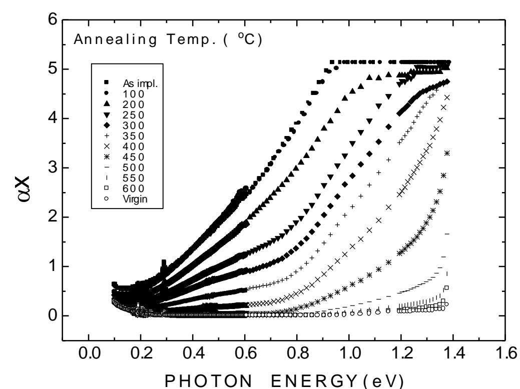

Figure 2. Dependence of the optical density (αx) versus photon energy plot on annealing temperature,for the sample implanted to a dose of 1×10^{14} ions/cm^2 for 70 MeV ^{56}Fe ions.

3. ESULT AND DISCUSSION

For ^{56}Fe implantation, the (αx) value at photon energy 0.7 eV decreases from 5 to 1.6 at annealing temperature of 250 °C and for ^{197}Au implantation the (αx) value at 0.7 eV decreases from 5 to 1.3 at annealing temperature of 400 °C while there is no change in (αx) values at photon energy 1.35 eV as compared to as-implanted sample in both the cases. This shows that annealing of the samples at these temperatures results in to recovery of only deep lying defect states while there is no change in concentration of near band edge defect states.

Annealing of the sample further to 600 °C for ^{56}Fe implantation shows decrease in (αx) values by 1.6 at 0.7 eV and by 4.6 at 1.35 eV while further annealing of the ^{197}Au implanted sample to 550 °C results in to decrease in (αx) values by 1.1 at 0.7 eV and by 3.2 at 1.35 eV. This indicates rapid decrease in concentration of near band edge defect states as compared to concentration of deep lying defect states at these annealing temperatures.

The data for ^{197}Au implantation is re-plotted in Figure-3 and the data for ^{56}Fe implantation is re-plotted in Figure 4 where (αx) values at selected photon energies are shown as a function of annealing temperature.

It is seen that, there is no significant annealing of defects up to 100 °C for ^{56}Fe implantation while no significant annealing of defects is seen up to 150 °C for ^{197}Au implantation in GaAs.

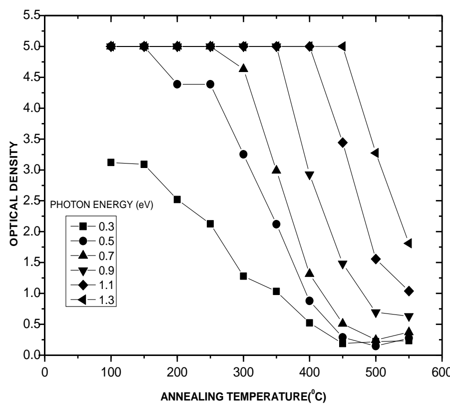

Figure 3. Dependence of optical density (αx) at selected photon energies on annealing temperature for the samples implanted to a dose of 1×10^{14} ions/cm^2 for ^{197}Au.

For ^{56}Fe implantation the (αx) value at photon energy 0.7 eV begins to decrease at annealing temperature of 150 °C while for ^{197}Au implantation it begins to decrease at 300 °C.

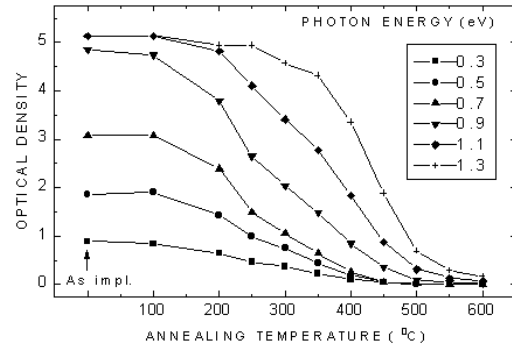

Figure 4. Dependence of optical density (αx) at selected photon energies on annealing temperature for the samples implanted to a dose of 1×10^{14} ions/cm^2 for ^{56}Fe ions.

Also the (αx) value at 0.7 eV decreases from 2.5 to 1.5 over the annealing temperature range 200 °C to 250 °C for ^{56}Fe implantation while for Au implantation the (αx) value 0.7 eV decreases from 4.7 to 1.4 over the annealing temperature range 300 °C to 400 °C. This indicates that for ^{56}Fe implantation recovery of deep lying defect states begins at 150 °C while fastest recovery of these states occurs in annealing temperature range 200 °C to 250°C and these defect states are completely recovered at 450 °C. But for ^{197}Au implantation recovery of deep lying defect states begins at 300 °C showing fastest recovery in annealing temperature range 300 °C to 400 °C while these defect states are completely recovered after annealing at 550 °C

Similarly, for ^{56}Fe implantation the (αx) value at photon energy 1.35 eV begins to decrease at annealing temperature of 300 °C while for ^{197}Au implantation it begins to decrease at 450 °C. Also the (αx) value at 1.35 eV decreases from 3.5 to 0.8 over the annealing temperature range 400 °C to 500 °C for Fe implantation while for Au implantation the (αx) value at 1.35 eV decreases from 5.0 to 1.7 over the annealing temperature range 450 °C to 550 °C.

This indicates that for ^{56}Fe implantation recovery of near band edge defect states begins at 300 °C while fastest recovery of these states occurs in annealing temperature range 400 °C to 500 °C and these defect states are completely recovered at 600 °C. But for ^{197}Au implantation recovery of deep lying defect states begins at 450 °C, showing fastest recovery in annealing temperature range 450 °C to 550 °C while these defect states are completely recovered after annealing at 600 °C.

The results indicate that the annealing stages for recovery of defect states are shifted slightly towards higher temperature side for implantation with heavier ions at higher energies.

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