IR INVESTIGATIONS OF HIGH ENERGY ^{197}Au IMPLANTATION IN GaAs

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ABSTRACT
We report the annealing studies of the near and mid IR investigations of single crystal semi-insulating GaAs substrates of <100> orientation, having 400 μm thickness that were implanted with ^{197}Au ions at an energy of 100 MeV to a dose 1×10^{14} ions/cm^2. The sample was isochronally annealed for 10 minutes in nitrogen ambient in the temperature range 100-600 °C with a step of 50 °C by using the RTA system. The dependence of the optical density (αx) versus photon energy on annealing temperature, for the sample implanted is reported. The investigations have been compared with similar study of 70 MeV ^{56}Fe implantation in GaAs. The results indicate that these annealing stages are independent of the amount of damage or that of 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]. Recently, ion implantation in GaAs has been used as the most attractive technique for the formation of small dimension channel or contact regions for digital integrated circuit applications. GaAs also has a direct band gap of 1.4 eV that is wider than the indirect band gap 1.1 eV of Si, making it especially useful both for optoelectronic devices and for operation at elevated temperatures. Another advantage is its exceptional radiation hardness. The disadvantages compared to Si include the inability to fabricate high performance bipolar transistors because of the low minority carrier life time, the lower thermal conductivity of GaAs, the dissociation of the surface during high temperature processing, especially implant activation and lack of a stable surface oxide with low interface state density. The use of GaAs based heterostructure devices promise further improvement in speed and will eventually lead to the fabrication of monolithic, integrated optoelectronic circuits [2]. Various research groups have investigated modifications in the various properties of GaAs after the ion implantation of swift heavy ions. Irradiations have been performed by fast electrons [3-6], fast neutrons [5-7], and also with low energy (energy ranging from a few keV to hundreds of keV) ions [8-11]. The motivation behind this work was to introduce defects inside GaAs lattice in a controlled manner and study their characteristics. A few research groups, mainly nineties onwards have carried out investigations of modifications of various properties of GaAs due to swift heavy ion implantation. The purpose of these investigations was to study implant profile, projected range, electrical properties, radiation damage and annealing studies of implanted semiconductors [12-16]. These investigations have given better understanding in basic interaction processes between ion and semiconductor in the high-energy regime. Technologically, these studies are useful to simulate the effect of cosmic rays on electronic devices used in space satellites [17].

Experimental:

Radiation Induced Damage And Annealing Studies:

One of the important effects of ion implantation is radiation induced damage in the target substrates. As the ion slows down and comes to rest in a crystal, it makes a number of collisions with the lattice atoms [18-21]. In these collisions, sufficient energy may be transferred from the ion to displace an atom from its lattice site. The displaced atom can in turn displace other atoms and so on, thus creating a cascade of atomic collisions. This leads to a distribution of vacancies, interstitials and other types of lattice disorder in the region around the ion track. As the number of ions incident on the crystal increases the individual disordered regions begin to overlap. The total amount of disorder and the distribution in depth depend on ion species, temperature, energy, total dose and channeling effects.

The creation of vacancies and interstitials by energetic particles increases the free energy of the crystal and must be followed by changes which eventually restore thermodynamic equilibrium. Therefore one expects the initial properties of the crystal to be restored sooner or later, depending upon the heat treatment, if the crystal was initially in equilibrium and if contamination by impurities can be avoided during warming cycles. Nevertheless the path to recovery is usually indirect, for if the annealing is carried out slowly, the crystal will frequently experience a number of metastable states before recovery is complete. If these metastable states are well separated in energy the recovery will tend to occur in separate stages, i. e. different annealing processes will tend to occur in different temperature ranges. The optical investigations of annealed samples provide the tool to study this recovery process.

2. OPTICAL INVESTIGATIONS OF ION-IMPLANTED SEMICONDUCTORS:

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

Silicon implantation in GaAs has been studied in details by number of researches. P. Kraisingdecha et al. [22] have studied distribution of damage in semi insulating GaAs resulting due to implantation of low energy (50 and 90 keV) ^{28}Si ions, using differential reflectance spectroscopy. They report effects of substrate temperature (30-300°C) and crystal orientation {(100), (110) and (111) directions} on the damage profiles. K. Xie and C. R. Wie [20] have reported the depth profiles of carrier concentration and mobility values obtained by Vanderpauw Hall measurements by successive chemical etching of semi insulating GaAs substrates implanted with 1.0 MeV and 1.5 MeV ^{28}Si ions. Their concentration depth profiles suggest defect assisted diffusion of the dopants and the mobility profile showed a broad minimum due to residual damage. Zhao and Wang [23] studied the damage accumulation and amorphization using Rutherford back scattering and channeling techniques at doses ranging from 5 x 10^{13} to 4 x 10^{15} ions/cm^2. They found that the total amount of damage increases linearly with implanted dose up to certain threshold dose, above which amorphization occurs. Near IR and XRD studies on semi insulating GaAs substrates implanted with ^{120}Sn and ^{28}Si ions at energies in the range 50-70 MeV to different doses in the range 1x10^{12} -1x10^{14} ions/cm^{2}have been performed by Uma Bhambani et al [24]. Recently, near IR investigations in photon energy range 0.7-1.4 eV of semi insulating GaAs implanted with 100 MeV 28Si ions have been reported by Damle et al [30]. They observed formation of an amorphous layer at a depth of about 24-25 μm.

Kachare et al. [25] performed normal incidence reflection and transmission measurements on GaAs and GaP – implanted wafers at high dose (about 10^{17} cm^{-2}) and high energies (E = 3 MeV). Brown et al. [26] performed electroreflectance measurements on ion implanted GaAs and Brierley, Lehn and Grabinski [27] performed infrared transmission measurements on Si+ implanted GaAs for mapping the implanted dose distribution.

Implantation of 2 MeV Fe ions in n-type InP at elevated temperature of 200 °C has been investigated by A. Gasparotto et al [28], to determine the Fe lattice location and to study electrical activation of Fe as compensating deep acceptor.

Belekar et. al.[29] had studied the optical investigations of 70 MeV ^{56}Fe doped GaAs to confirm the recovery of radiation induced damages after annealing effects.

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.

The question of swift heavy ion induced modifications in the optical properties of GaAs is still open and needs further investigations typically with still heavy ion induced effects which may give different defect structure and different annealing behaviour. The optical investigations of the GaAs substrates implanted with 1x10^{14} ions/cm^2 is reported here.

3. MATERIALS & METHODS:

The samples were prepared by cutting 400 micron thick one side polished wafer single crystal GaAs of <100> orientation to a size of 7 mm x 7 mm and cleaned the by suitable methods.

Irradiation of the samples was carried out by 100 MeV energy beam of ^{197}Au ions to different doses from 10^{12} to 10^{14} ions/cm^2. The n-type semi-insulating GaAs samples were implanted with 100 MeV ^{197}Au at room temperature. The implantation was done to the dose of 1x10^{12}, 1x10^{13} and 1x10^{14} ions/cm^2. To study the annealing behavior and the optical investigations the GaAs substrate implanted with 1x10^{14} ions/cm^2 is reported here.

The annealing kinetics have 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 250-20,000 nm.

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 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. This corrects for any inhomogenety in the response of the measurement system of the spectrophotometer over the wavelength range of interest.[30] SHIMADZU UV-NIR-IR UV-3600 spectrophotometer is employed 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 to the dose of 1×10^{14} ions/cm^2 annealed at different temperatures in the range 150 – 550°C for 10 minutes in the RTA system. are shown in FIGURE 1.

4. RESULTS AND DISCUSSION

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 for 10 minutes in the RTA system. are shown in FIGURE 1. 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. [31] 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 in case of 70 MeV ^{56}Fe doped GaAs. This indicates that no significant annealing of defects occurs at 100-150 °C irrespective of the size of heavy ions. 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. Further annealing of the sample to 550 °C results into decrease in the (αx) value by $\cong$ 0.3 at 0.7and by 2.5 at 1.35 eV as compared to the sample annealed at 350°C.

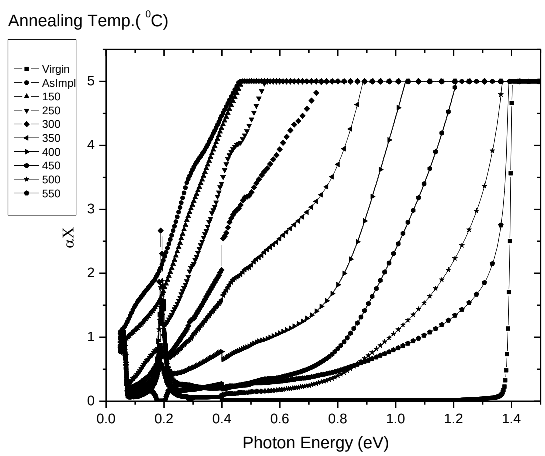

FIGURE 1. Dependence of the optical density (αx) versus photon energy plot on annealing temperature,for the sample implanted to a dose of 1×10^{14} ions/cm^2.

This indicates a rapid decrease in the concentration of near band edge defect states as compared to the concentration of deep lying defect states in this annealing temperature range. At annealing temperature of 550 °C, the (αx) values of the implanted sample and the virgin sample are more or less close to each other over the entire photon energy range. This shows that the defect states generated due to the implantation of ^{197}Au ions in GaAs substrates have been almost removed after the annealing treatment at 550° C.
The data of FIGURE 1 is re-plotted in FIGURE 2, 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 and most of these defect states may be completely annealed out after annealing temperature say 600-650 ^{o}C. Study of 70 MeV ^{56}Fe irradiation in GaAs has also resulted in similar annealing stages for the mid-gap and near band edge defect states. This indicates that these annealing stages are nearly independent of the amount of damage or that of implanted ion and its energy [32].

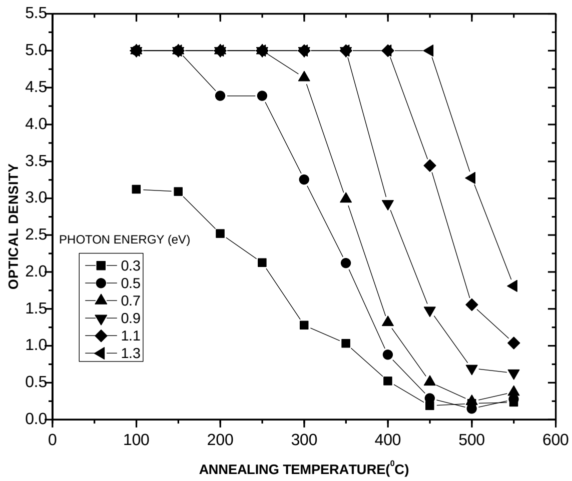

FIGURE 2. Dependence of optical density (αx) at selected photon energies on annealing temperature for the samples implanted to a dose of 1×10^{14} ions/cm^2.

5. ACKNOWLEDGMENTS

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