Solid State Science and Technology, Vol. 15, No 2 (2007) 98-102
ISSN 0128-7389

ANNEALING EFFECTS ON ELECTRICAL CHARACTERISTICS OF GaAs IMPLANTED WITH 100 MeV ^{56}Fe and ^{120}Sn IONS

Yousuf Pyar Ali[a], K.V. Sukhatankar[b], A. M. Narsale[c]

[a]*Department of Physics, Hadharamout University, Mukalla, Yemen*
[b]*Department of Physics, Gogate-Jogalekar College, Ratnagiri- 415612, India*
[c]*Department of Physics, University of Mumbai, Vidyanagari, Mumbai-400098, India*

ABSTRACT

Single crystal n-GaAs substrates have been implanted at room temperature with 70 MeV ^{56}Fe and ^{120}Sn ions to a fluence of $1x10^{18}$ ions/m^2. The electrical characteristics were investigated after implantation and annealing up to 850°C by current voltage measurements. Low temperature resistance measurements of these samples show that the ^{56}Fe implanted samples annealed to 350°C and ^{120}Sn implanted samples annealed to 450°C are dominated by a variable range hoping conduction, whereas for the ^{56}Fe implanted samples annealed to 450°C and 550°C and ^{120}Sn implanted samples annealed to 550°C and 650°C the electrical conduction is due to hoping between neighboring defect sites.

INTRODUCTION

High energy ion implantation is gaining importance because of its potential applications for the fabrication of devices requiring buried layers far below the surface of the semiconductor substrates with modified physical properties [1]. The nature of damage caused by such implants as well as their annealing behaviour is quite different than that of low energy implantations [2]. The partial separation of the regions of electronic and nuclear energy deposition, at MeV ion energies depends upon the ions species and energy. Therefore, a detailed study of the influence of these parameters in damage production and annealing is necessary. In the present paper, a comparative study of the influence of ^{120}Sn and ^{56}Fe ions on the electrical characteristics of n-GaAs substrates due radiation induced defects associated with high energy ion implantation and their annealing behaviour is studied.

EXPERIMENTAL DETAILS

The samples used in this experiment were mirror polished <100> silicon doped n- type GaAs substrates with background doping concentration of $2x10^{16}$ cm^{-3} and having an area of 7 mm x 7 mm and thickness of 400 µm. All the samples have been carefully cleaned and then implanted at room temperature using ^{120}Sn and ^{56}Fe ions at energy of 100 MeV to a fluence of $1x10^{18}$ ions/m^2 in a non channeling direction using NEC 16

MV pelletron accelerator at the Nuclear Science Center, New Delhi, India. Cleaning procedure of the samples and implantation details were described elsewhere [3]. The implanted samples were proximity capped annealed for 10 min at different temperatures up to 850°C in pure hydrogen ambient. The caped samples were used as reference to monitor any surface degradation. Back ohmic contacts were made by evaporating a uniform coating of Au-Ge-Ni. The top ohmic contacts were made by evaporating 0.0045 cm^2 area dots of Au-Ge-Ni through a metal mask. The contacts were then alloyed at 450°C for 1 min in pure hydrogen. Ohmic contacts were made before the implantation for the samples to be annealed at temperatures less than 450°C. The current voltage (I-V) measurements of the as implanted samples and samples annealed up to 850°C were carried out over a temperature range (100-300 K) by using a programmable voltage source, Keithley digital electrometer (model 617) and a variable temperature cryostat.

RESULTS AND DISCUSSION

Room temperature current voltage (I-V) characteristics of ohmic contact device structures have been measured for the implanted samples before and after annealing at different temperatures up to 850°C. We observed that the I-V curves for the ^{56}Fe implanted samples and samples annealed to 100°C show weak non linear behaviour, which then showed a linear characteristics after annealing treatment between 150-550°C. After annealing the samples to 650°C, the I-V curves show nonlinear I-V characteristics tending towards a p-n junction like behaviour, which then shows p-n junction characteristics after 750°C annealing. Further annealing the samples to 850°C again show nonlinear I- V characteristics. On the other hand, the I-V curves of the samples implanted with ^{120}Sn ions and annealed up to 450°C were linear and then showed a weak non linearity for the samples annealed to 550°C and 650°C. The non linearity of the I-V characteristics increases considerably as the annealing temperature increases to 750°C and shows p-n junction like behaviour after 850°C annealing. I-V curves of the reference unimplanted samples remains linear and their measured resistance values over the annealing temperatures range is about 6-8 ohms. This suggests that there is no material degradation during annealing treatment.

To understand the complex I-V characteristics, the resistances values of these samples were estimated from various I-V curves. For linear I-V curves the resistance values were obtained directly, whereas for nonlinear and p-n junction like characteristics the resistances were estimated from the high current region where the series resistance dominant.

Fig.1 shows room temperature values of resistances for different annealing temperatures. It has been observed that for the samples implanted with ^{56}Fe ions, the room temperature resistance of the as implanted sample is about $5x10^2$ Ω, which increase with increasing annealing temperature. The resistance value after 150°C is $3x10^6$ Ω, and reaches maximum value of about $3x10^9$ Ω after annealing to 550°C. Further annealing at 650°C, causes a drastic decrease in the resistance value to $5x10^3$ Ω which again increases to about 10^4 Ω after annealing at 850°C. On the other hand, the resistance of the ^{120}Sn implanted samples is $2.5x10^2\ \Omega$ which increase with an increase in annealing temperature and reaches a value $2x10^7\ \Omega$ for the sample annealed at 650°C. However, the samples annealed at 750°C show a large reduction in the resistance values and reaches a value of $3.5x10^3\ \Omega$ for the sample annealed at 850°C.

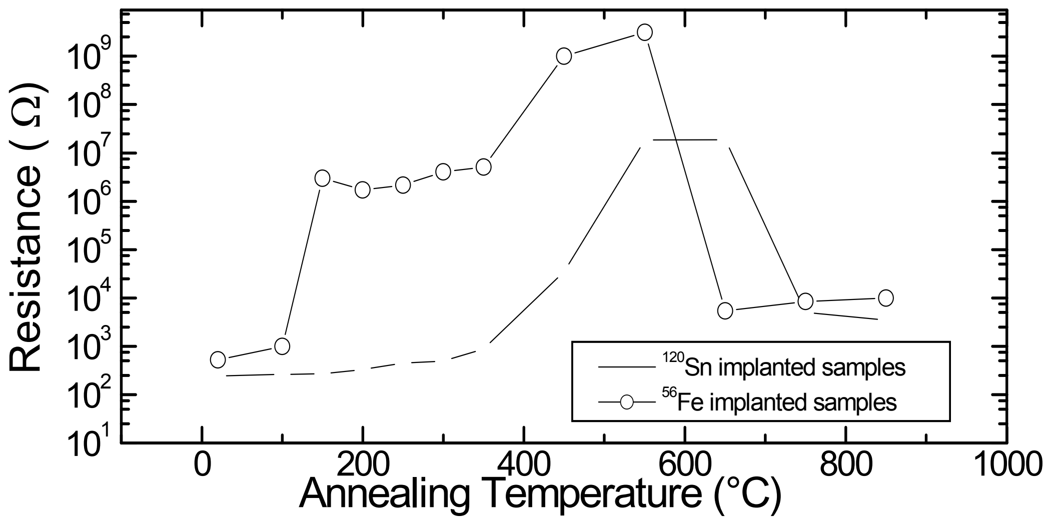

Figure 1: Resistance values of the implanted samples versus annealing temperatures

It is clearly observed from Figure 1 that the samples implanted with ^{56}Fe ions show an annealing stage between room temperature and 150°C which are not observed in the case of ^{120}Sn implanted samples. This suggests that for the samples implanted with heavy ^{120}Sn ions large defect concentrations which are responsible for the nonlinear I-V characteristics in the case of ^{56}Fe as implanted sample may be annealed by bulk annealing during ^{120}Sn implantation process. The nonlinear I-V characteristics of ^{56}Fe implanted sample suggest p-type conductivity due to defect complexes produced by implantation processes and compensated by low temperature (~150°C) annealing treatment. Some investigations involving high dose proton and neutron irradiation suggest that the irradiated layers are p-type [4]. The p-type conductivity was enhanced after 650°C and 850°C annealing for ^{56}Fe and ^{120}Sn implanted samples respectively. This is possibly due to a formation of primary defect impurity complexes which acts as acceptors.

Temperature dependence of resistance of the as-implanted sample and the samples annealed at different temperatures up to 650°C were examined next. It was observed that ^{56}Fe as implanted samples and samples annealed up to 350°C, and ^{120}Sn as implanted samples and samples annealed up to 450°C satisfy the relation $\log R \propto T^{-1/4}$ in the temperature range (110 K-270 K). These observations suggest that up to these annealing temperatures, the samples still have a large concentration of defect states and the conductivity mechanism in the low temperature range is dominated by variable range hopping between defect energy levels in the forbidden gap and may be described by [5]:

$$\rho = \rho_0 \exp(T_0/T)^{1/4} \qquad (1)$$

The values of T_0 are obtained from the slopes of $\log_e R$ vs. $T^{-1/4}$ linear graph and are given in Table 1. The localized states density at Fermi level $N(E_F)$ can be estimated by using T_o value according to [6]: $N(E_F) = (C^4\alpha^3 / T_0 k)$, $C^4 \cong 20$, $\alpha(cm^{-1}) = (2m^* / \hbar^2)^{1/2}(E_g/2)^{1/2}$, E_g is the band gap and m* is the effective mass of the electron. The values of N (E_F) are also listed in Table 1. It is observed that N (E_F) of ^{56}Fe as implanted sample is larger than N (E_F) of ^{120}Sn as implanted sample and after 150°C annealing, the N (E_F) of ^{56}Fe implanted samples are comparable to that of ^{120}Sn as implanted samples. This supports our previous speculation that some of the defect states are annealed during the implantation of heavy ^{120}Sn ions. The departure from $T^{-1/4}$ behaviour for the 450°C annealed ^{56}Fe implanted samples and 550°C annealed ^{120}Sn implanted samples suggests that the high concentration of the damage states is annealed and the tunnel assisted hopping conduction mechanism no longer exists.

Table 1: T_0 values and corresponding N (E_F) for the samples implanted with ^{56}Fe and ^{120}Sn ions after annealing to different temperatures

Annealing Temperature (°C)	**Samples implanted with ^{56}Fe ions**		**Samples implanted with ^{120}Sn ions**	
	T_0x10^7 (K)	**N(E_F)x10^{19} (cm^{-3}.eV)**	**T_0x10^7 (K)**	**N(E_F)x10^{19} (cm^{-3}.eV)**
As- implanted	0.22	18.23	1.25	3.209
100	0.40	10.03	1.26	3.183
150	1.28	3.134	1.31	3.062
200	1.48	2.710	1.35	2.971
250	1.98	2.026	1.84	2.180
300	2.36	1.700	2.00	2.006
350	2.91	1.378	2.45	1.637
450	*	*	2.93	1.369

*Thermal activated hoping conduction dominant this sample.

The resistance values of ^{56}Fe implanted samples after 450°C and 550°C annealing and ^{120}Sn implanted samples after 550°C and 650°C annealing satisfy the relation $\log R \propto T^{-1}$ in the temperature range (110 K-270 K). These observations and the high resistance values of these samples suggests that the conduction mechanism is due to hoping between neighboring defect sites and satisfy the relation

$$\rho = \rho_0 \exp(E_a / kT) \qquad (2)$$

where E_a is the hoping activation energy [7]. The E_a values are calculated from the slopes of $\log_e R$ versus 1/T linear graphs and were found to be in the range 70-100 meV. This activation energy is attributed to the energy needed for motion of trapped electrons by hoping from one closely spaced damage site to another [8]. Further annealing the samples to higher temperatures reduced the resistance values drastically indicating reduction of the defect states and the conduction mechanism requires further investigations.

CONCLUSION

We have implanted ^{56}Fe and ^{120}Sn ions in single crystal n-GaAs substrates at energy of 100 MeV. The electrical behaviour has been studied by measuring the resistance values from I-V curves. ^{56}Fe implanted sample show p-type conductivity which is compensated by annealing the sample to about 150°C. The first annealing stage occur in ^{56}Fe implanted samples between room temperature and 150°C was not seen in the ^{120}Sn implanted samples, possibly due to bulk annealing during implantation. The temperature dependence of resistance of the implanted and annealed samples show that ^{56}Fe implanted samples and annealed up to 350°C and ^{120}Sn implanted samples and annealed up to 450°C follow variable range hoping conduction at low temperatures, while the conduction mechanism of the ^{56}Fe implanted samples after 450°C and 550°C annealing and ^{120}Sn implanted samples after 550°C and 650°C annealing is dominated by hoping between neighboring defect sites. Annealing to higher temperatures, both ^{120}Sn and ^{56}Fe implanted samples show defect related p-type conductivity. Further investigations are in progress to understand the conduction mechanism and the nature of the p-type conductivity after high temperature annealing.

REFERENCES

[1] Thompson, P.E. (1991); *Nucl. Instr. and Meth. B*, **59/60,** 592.
[2] Rao, M. V. (1993); *IEEE Trans. Electron Dev*. **40**, 1053.
[3] Ali, Y.P., Narsale, A.M., Bhambani, U., Damle, A., Salvi, V., Arora, B., Shah, A. and Kanjilal, D. (1996); *Nucl. Instr. and Meth. B*, **117,** 129.
[4] Brudnyi, M.A., Krivov, M.A. and Potapovet, A.I. (1980); *Solid State Commun*. **34,** 117.
[5] Davis, E.A. and Mott, N.F. (1970); *Philos. Mag*. **22**, 903.
[6] Bottger, H. and Bryksin, V.V. (1976); *Phys.Status Solidi (b)*, **78**, 9
[7] Kato, Y., Shimada,T., Shiraki, Y. and Komatsubara, (1974); *J. Appl. Phys*. **45**, 1044.
[8] Short, K.T. and Pearton, S.J. (1988); *J. Electrochem.Soc*. **135**, 2835.