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Defect Study of Alpha Irradiated Undoped InSb Using Positron Annihilation Spectroscopy

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ABSTRACT: The positron annihilation technique has been employed to study the defect recovery in 40MeV alpha-irradiated undoped InSb. After irradiation the sample has been subjected to an isochronal annealing over temperature region of 25-400^{O}C with an annealing time of 30 minutes at each set temperature. After each annealing the Doppler broadening annihilation line-shape measurements are carried out at room temperature. Radiation induced defect formation in the sample due to ion implantation and its recovery with annealing temperature have been investigated. The increase in the line-shape parameter S along with defect specific parameter R in the temperature region 75 to 150^{O}C and 200 to 300^{O}C indicate the migration of vacancies and the formation of vacancy clusters. The defects start disappearing between 300 and 400^{O}C.

KEYWORDS: Positron Annihilation, Doppler broadening, S-parameter, R-parameter, Defects

I. INTRODUCTION

InSb is a narrow-band-gap (0.17eV) semiconductor material from the III-V group used in infrared detectors, including thermal imaging cameras, FLIT systems, infrared homing missile guidance systems and in infrared astronomy. Undoped InSb possesses the largest ambient temperature electron mobility (78000Cm^2/V*s) [1] and electron drift velocity [2] of any known semiconductor. Indium antimonide semiconductor devices are also capable of operating with voltages under 0.5V, reducing their power requirements.

The role of defects in the performance of semiconducting devices has been considered as interesting subject of investigation. The influence of the defects on the electronic and optoelectronic properties of the semiconducting materials is significant because they interact with free carriers and act as scattering and recombination centers or carrier traps. Also their effect is non-negligible even when their concentration is very small compared with the free carrier concentration.

Defects not only exists in as-grown bulk materials, but also be produced through irradiation with various particles such as α-particles [3], electrons [4], protons [5]-[7], neutrons [6], heavy ions [8] etc. Lattice defects arising in semiconductors due to heavy ion bombardments and post-irradiation annealing are considerably important due to their influence in the material properties used for the production of a wide variety of electronic devices. Through such studies on the involved carrier recombination process, radiation defect formation and their recovery with temperature are also interesting from the point of view of investigation. Therefore it is very important to study the physical behaviour of these defects. Positron annihilation technique (PAT) has been proved to be a useful supplement among other techniques like electron paramagnetic resonance (EPR) [9], Fourier transformed infrared spectroscopy (FTIR)

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[10], deep level transient spectroscopy (DLTS) [11] and electrical measurements for studying radiation damage effects in materials. Very little numbers of investigation on particle induced radiation damage in InSb have been performed by PAT. A great deal of progress has been made in recent years in regard to the basic understanding of the electronic properties of InSb. A. Sengupta et al. [12] used PAT to study the isothermal annealing behaviour of defects in un-irradiated InSb sample over a temperature region -148 to 220^{O}C in Doppler broadening measurements. They found monovacancy type defects and the probable monovacancies are V_{In} (vacancy at In site) as it needs lower displacement threshold energy.

In this paper the effect of alpha irradiation and subsequent isochronal annealing on the positron annihilation parameters in the undoped InSb compound semiconductor has been studied.

II. EXPERIMENTAL DETAILS

The undoped InSb sample has been used for the study. A circular piece of 10mm diameter and of 0.5mm thickness has been subjected to irradiation by 40MeV alpha beam to a total dose of 10^{17}alpha/Cm^2 for 32hours with an average beam current 500nA at room temperature.

A ^{22}Na positron source has been evaporated on a thin Ni foil of 5µm thickness and an identical foil has been covered the source. The activity of 7µCi has been achieved during source preparation. The source has been sandwiched between two identical cut pieces of un-irradiated reference and irradiated InSb sample under study.

Isochronal annealing has been performed at different temperatures in the irradiated sample from room temperature (25^{O}C) to 400^{O}C in a vacuum of 10^{-6}Torr. The annealing time has been 30minutes duration at each set temperature. The sample has been cooled down to room temperature in vacuum.

Doppler broadening annihilation line-shape measurements have been carried out using HPGe detector having energy resolution of 1.8keV for 662keV gamma-line with ^{137}Cs source. All measurements are carried out at room temperature. Annihilation line-shape parameter, S has been obtained from Doppler broadening measurements. The line-shape parameter has its usual definition as the ratio of Central Area (background subtracted) to the normalized total area (background subtracted) under the curve. Similarly the W-parameter has been calculated as the ratio of the area of the high momentum part (wings) of the spectrum for a fixed energy interval to the total area under the curve.

III. RESULTS AND DISCUSSIONS

In figure-1, the Doppler broadening annihilation line-shape parameter, 'S' has been plotted against the annealing temperature. S-parameter detects the change in nature of trapping defect sites. Figure-2 shows a plot of the defect specific parameter, 'R' versus the annealing temperature. The R-parameter is defined as $R= (S_d - S_b)/ (W_d - W_b)$, where W represents the core annihilation (wings). The suffix'd' represents the irradiated sample and 'b' represents the pre-irradiated sample i.e. the bulk sample. R-parameter is independent of the concentration of defects and only depends on the size of the trapping sites. It increases with the size of the trapping site which is predominant among several other trapping centers present at any time. The value of R-parameter is a minimum for monovacancies. The variation of S-parameter with annealing temperature shows a two stage recovery of radiation induced defects over a broad range of temperature from 25-400^{O}C. The dotted line in figure-1 represents the S value for the reference InSb sample. Irradiation in semiconductors is known to cause atomic displacements, resulting into the formation of vacancy-interstitial pairs. High energy heavy ion (40MeV alpha) irradiation in low band-gap InSb introduce defects which are more complex than those induced by other lighter particle irradiations such as electrons. This is due to the fact that the ion implantation causes cascade damage to produce even higher order defects. This is directly evidenced from the increase in S-parameter value of irradiated sample compared to un-irradiated bulk sample as shown in figure-1. The probable defects could be vacancies at In-site (V_{In}), vacancies at Sb-site (V_{Sb}), antisites and other higher order defects. In fig.1, S value is almost stable up to 75^{O}C. In this temperature region i.e. from 25^{O}C to 75^{O}C R-parameter is also stable as in fig.2 and indicates that the predominant defect size is unchanged.

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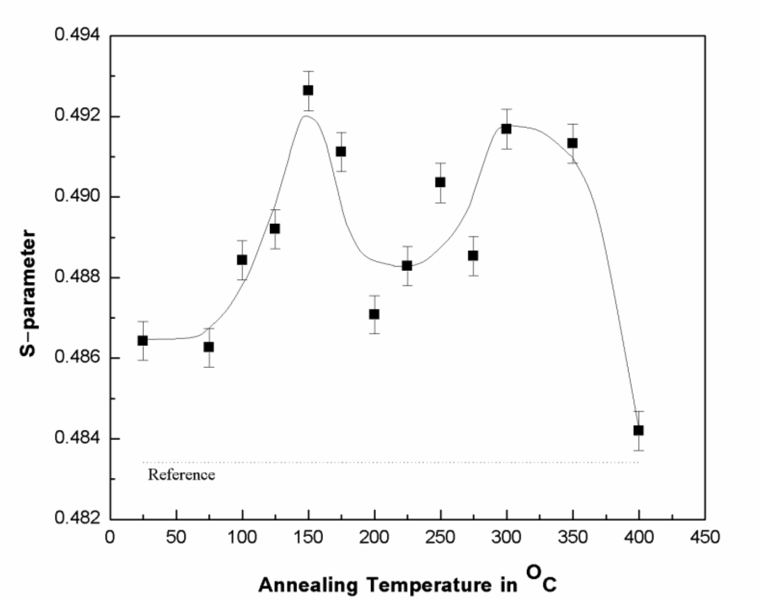

Fig. 1 Variation of S-parameter with annealing temperature in alpha irradiated undoped InSb. The dotted line is for unirradiated reference InSb sample.

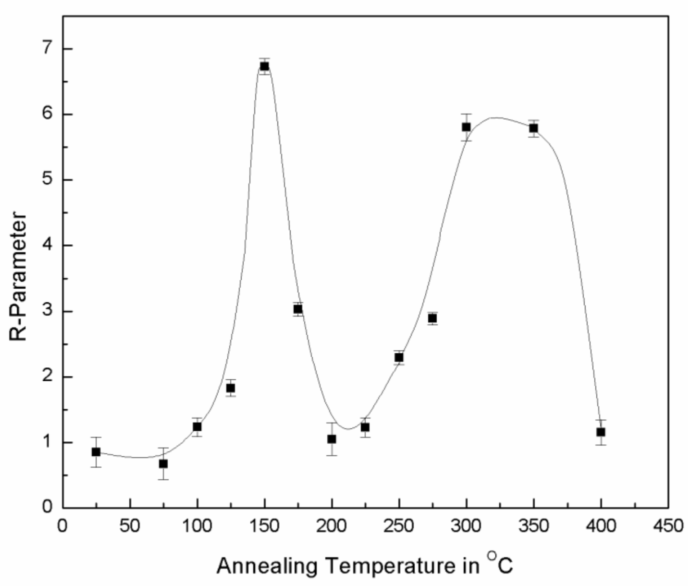

Fig. 2 Variation of R-parameter with annealing temperature in alpha irradiated undoped InSb.

Beyond 75^{O}C, S-parameter increases gradually and reaches its maximum at 150^{O}C. This rise in S-parameter may be due to the migration of vacancies and clustering of those vacancies. However, Karjabinen et al. [13] has explained for such rise as due to the disappearance of some traps giving low shape broadening and retaining a large supply of defects with high broadening effects, presumably dislocations. During this temperature range i.e.75 to 150^{O}C, R-parameter value increases significantly and reaches to a maximum at 150^{O}C. So the possibility of dislocations may be ruled out because R-parameter for dislocations is known to be a minimum, even less than that for monovacancies [15]. Keeping these arguments in mind, conclusion can be drawn that the rise in S-parameter might be due to the migration of vacancies and formation of vacancy clusters. It shows that the positron trapping rate for such clusters is sufficiently large so that this reverse annealing takes place. This increase in R-parameter indicates the formation of higher order defects like divacancies or vacancy clusters. Beyond 150^{O}C, the gradual decrease in both S-parameter and R-parameter up to 200^{O}C, indicate a change in the defect configuration giving rise to a decrease in the size of the positron trapping sites. The rise of S-parameter in the temperature region 200 to 300^{O}C is attributed to the agglomeration of vacancies and formation of vacancy clusters to achieve more stable configuration causing sharp reduction of the number of trapping centers. In this temperature region 200 to 300^{O}C R-parameter also increases gradually which indicates the increase in the defect size. Beyond 300^{O}C, S-parameter starts decreasing and at around 400^{O}C it acquires a value close to the un-irradiated bulk value. This decrease indicates the breaking up of vacancy clusters into vacancies in the process of annealing out of defects. In this temperature region R-parameter also decreases and it agrees well with the behaviour of S-parameter.

IV. CONCLUSION

At room temperature high energy alpha produces vacancy like defects as evident from high S-parameter value of irradiated sample compared to un-irradiated bulk sample. From room temperature to 75^{O}C, both S-parameter and R-parameter are stable which indicate that the predominant defect size is unchanged. In the temperature region 75 to 150^{O}C, S-parameter and R-parameter both increase gradually to a maximum indicating the migration of vacancies and clustering of those vacancies. S-parameter and R-parameter decrease gradually beyond 150^{O}C and reach to a lower value up to 200^{O}C indicating change in the defect configuration. In the temperature range 200 to 300^{O}C the rise of S and R-parameters indicate the agglomeration of vacancies and formation of vacancy clusters. Beyond 300^{O}C, S-parameter and R-parameter start decreasing and finally at 400^{O}C all defects are being annealed out.

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