

Rutherford back scattering and optical band gap of In/Sb thin films

R K Mangal^{a,b}, Y K Vijay^a, D K Avasthi^c & B R Shekhar^d

^aDepartment of Physics, University of Rajasthan, Jaipur 302 004, India

^bJaipur Engineering College and Research Centre, Jaipur 303 905, India

^cInter University Accelerator Center, Aruna Asaf Ali Marg, New Delhi 110 067, India

^dInstitute of Physics, Sachivalaya Marg, Bhubaneswar 751 005, India

Received 9 January 2006; accepted 10 April 2007

Thin films having constant thickness of indium over varying thickness of antimony are deposited on glass substrates using vacuum evaporation method. Films are irradiated by Ag^{12+} heavy ions of energy 160 MeV at the fluence 2.2×10^{13} ions/cm². The optical absorption spectra have been recorded at room temperature of as-deposited and Ag^{12+} ion beam irradiated samples which show mixing of In/Sb bilayer. Rutherford back scattering (RBS) spectra also carried out using α -particles of energy 3 MeV. The optical band gap data of irradiated films found in the range of In/Sb semiconductor. RBS spectra also support mixing of bilayer. These results show mixing of In/Sb bilayer by swift heavy ion beam irradiation processes.

IPC Code: H01C17/075

Among III-V group compounds the indium antimonide is an important semi conducting material. Due to its narrow band gap¹ (0.180eV) it is widely used for infrared detection in the spectral range of 3-5 $\mu\text{m}^{2,3}$. It shows mobility of electrons about 76000 $\text{cm}^2/\text{V-s}$ (ref.4). It is well known semi conducting compounds and is considered to be the most attractive material for extremely sensitive devices⁵. The deposition of InSb thin films is more suitable for fabricating photo-electronic⁶, magnet-electric⁷ conversion devices, and antenna-coupled infrared detectors⁸. Thin films of InSb may be deposited by different methods like r.f. Sputtering⁹, MBE¹⁰, CVD¹¹, flash evaporation¹² and vacuum evaporation¹³. The stack elemental layer deposition method has been used for CdTe¹⁴, copper indium diselenide thin films¹⁵, ZnSe and InSb thin films^{13,23} and for AlSb thin films¹⁶. It is particularly suitable for deposition of compound semiconductor thin films. It provides good control of composition¹³. Ion beam mixing in Fe/Si and Ta/Si bilayer was observed by Connell *et al.*¹⁸ on the basis of the RBS that analyses in case of the Fe/Si system, where the ion (Ar^{1+} to Ar^{8+}) charge was observed to have an influence on the mixing rate. But in case of Ta/Si system there was no influence of the charge state on sputtering and a thermal mixing rate was observed in the case of the

Ta/Si system. The In-Sb films were prepared on glass substrate by evaporation of In and Sb from individual sources and a bilayer structure was deposited. The large-scale production of electronic devices such as galvanomagnetic sensors still depends on the process of thin film deposition using a simple vacuum evaporation technique.

This paper reports the method of preparation of thin films, mixing of bilayer thin films and characterized by optical absorption spectra and Rutherford back scattering spectrometry.

Experimental Procedure

The high purity indium (99.99%) powder and pure antimonide (98.5%) have been obtained from BDH Chemicals Ltd. (England) for preparation of In-Sb bilayer thin films. Bilayer thin films of In/Sb were deposited on to ITO coated conducting glass substrates by thermal evaporation method at the pressure 10^{-5} torr using HIND HI VACUUM unit. The glass substrates were placed in the substrate holder above the boats carrying materials. The material first evaporated antimony and latter indium to prepare bilayer of InSb thin films. The deposited thickness of indium layer is 3000 Å on each substrate over antimony layer having thickness 1000Å, 1500Å and 2000Å respectively. Thickness of the samples was measured by digital quartz crystal thickness monitor. The Ag^{12+} ions of energy 160 MeV of the

* For correspondence (Email: rkmangal2@yahoo.com)

fluence 2.2×10^{13} ions/cm² allowed to fall on In-Sb bilayer thin films of all thickness in General Purpose Scattering Chamber at Inter University Accelerator Centre, New Delhi. The absorption spectra of as-deposited and ion mixed samples were recorded using Systronics Spectrophotometer Model – 117. The RBS data have been recorded at the Institute of Physics, Bhubuneshwer, using pelletron facility with alpha particle beam (He^{2+}) of 3 MeV. The back-scattered alpha particles were recorded at angle 160° using a surface barrier detector.

Results and Discussion

Optical properties

Figures 1 and 2 shows wavelength versus absorption spectra of as-deposited and ion irradiated In-Sb bilayer thin films. Fig. 2 shows sharp variation as compared to Fig. 1 in the wavelength region 7000-7400 nm, which shows mixing of bilayer at interface. The decrease in optical absorption is related to the increase in grain size of the films with increasing substrate temperature Holloway *et al.*¹⁷. In irradiated films the optical absorption edge produced by transitions between two state densities, both of which rapidly change as a function of energy, corresponds to the valence and conduction band edges for the ideal stable continuous random network structure as proposed by Connell *et al.*¹⁸. The optical band gap of these films was calculated using relation²⁴

$$\alpha h\nu = A(h\nu - E_g)^n$$

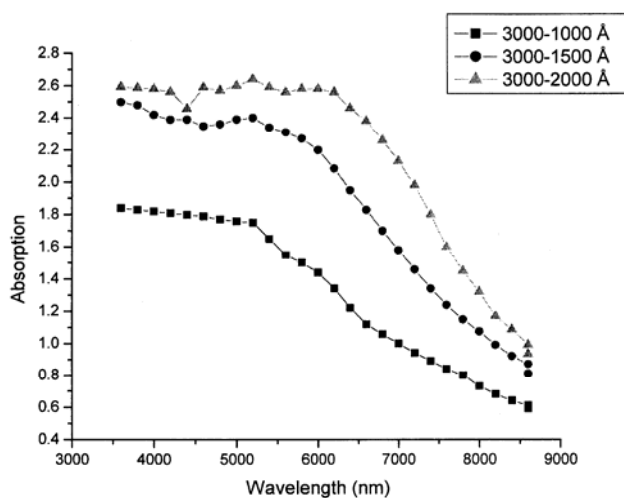


Fig. 1— Wavelength versus absorption spectrum of as deposited In-Sb bilayer thin films for thickness (a) 3000-1000 Å, (b) 3000-1500 Å and (c) 3000-2000 Å

where, $h\nu$ is photon energy, α is absorption coefficient, E_g is band gap, A is constant, $n = 0.5$ for direct band gap material, $n = 2$ for indirect band gap material. Figure 3 shows variation of photon energy with $(\alpha h\nu)^2$ for silver ion beam irradiated InSb thin films for different thicknesses. Since In-Sb is a direct band gap material so in the present study we have used $n = 0.5$ and also the intercept of straight line to energy axis $(\alpha h\nu)^2 = 0$ used to find the optical band gap. It is observed that the value of optical band gap found to be within the range of material with small variation. It may be due to change in the inter diffusion ratio of In and Sb at interface of bilayer. In the present case optical band gap observed from range 0.169-0.167 eV for InSb, which is given in Table 1.

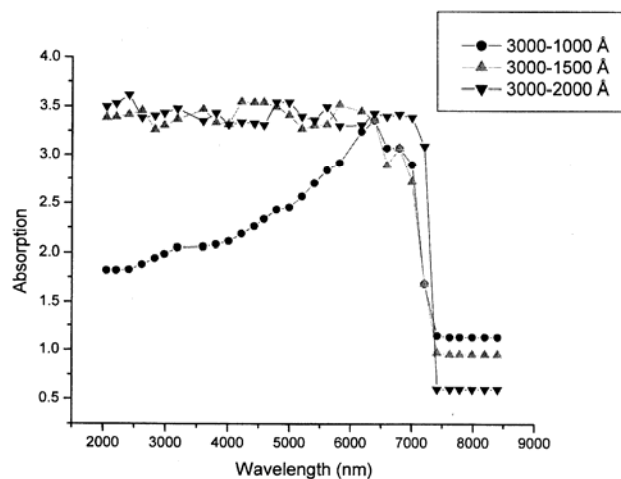


Fig. 2— Wavelength versus absorption spectrum of ion beam irradiated In-Sb bilayer thin films for thickness (a) 3000-1000 Å, (b) 3000-1500 Å and (c) 3000-2000 Å

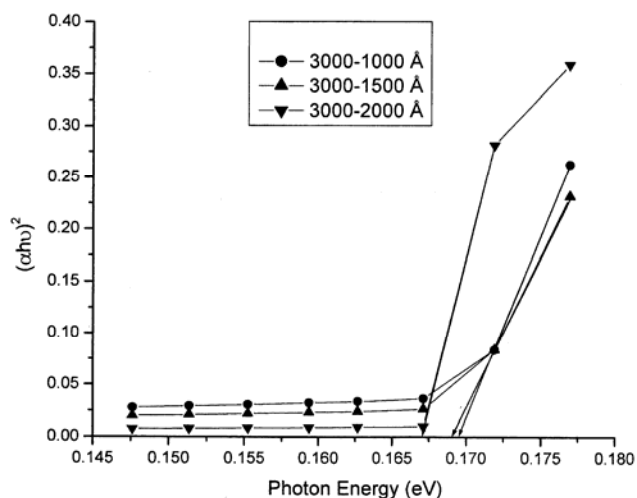


Fig. 3— Photon energy versus $(\alpha h\nu)^2$ for silver ion beam irradiated In-Sb bilayer thin films for thickness (a) 3000-1000 Å, (b) 3000-1500 Å and (c) 3000-2000 Å

Table 1—Variation of optical band gap with thickness of ion irradiated InSb thin films

Thickness of In/Sb (Å)	Band gap of irr. film (eV)
3000-1000	0.169
3000-1500	0.169
3000-2000	0.167

RBS spectrometry

The RBS spectrometry is a single rapid, sensitive and non-destructive depth profiling technique and it is most suitable technique for quantitative analysis to explain intermixing of bilayer. Figures 4 and 5 have been with the help of RUMP programme, which show the graphs between channel no. (energy in MeV) versus normalized yield for as-deposited and ion beam irradiated In-Sb thin films of thickness 3000-1500Å. Figure 4 may be divided in to three parts. In first part, the highest peak found around 775 channel no. corresponding to energy 3 MeV. It is also observed that the peak of indium (at channel number 650) overlapped with peak of antimony. The overlapping is due to small atomic mass difference between elements. In the second part, we found the intermediate peak around channel no. 500 down to around channel no. 300, which is due to the cations Sn in ITO coated layer. In the third part, peaks found to be at the low energy region, it is due to SiO₂ inside the glass substrate.

Figure 5 shows the spectrum recorded after Ag¹²⁺ ion irradiation. The effect of ion dose clearly observed in spectrum as a kink on overlapped region of highest peak towards low energy side. It is due to mixing of elements. It is also justified by reduction of lower edge of the antimony peak towards kink and front edge of indium towards kink, the mixing occurs after irradiation at the In/Sb interface. In the second part, intermediate peak of ITO sharply down around channel no. 440 supported to the broadening of overlapped peak. In the third part, SiO₂ peak step up around channel no. 300 towards lower energy side indicates base line shifted towards higher energy side. The mixing of elements can be related with shifting of base line, reduction in slope, broadening and kink in the rising part of material reported in literature^{13,20,21,23}. Our results well agree with Avasthi *et al.*²⁰. Similar results also carried out by Checchetto *et al.*²¹ in the case of Fe-Al multilayer annealed at 573 K for 240 min. They notice significant degree of atomic mixing between Fe and Al layers. It is also observed that peak to base ratio in irradiated film has diminished, indicating substantial inter diffusion.

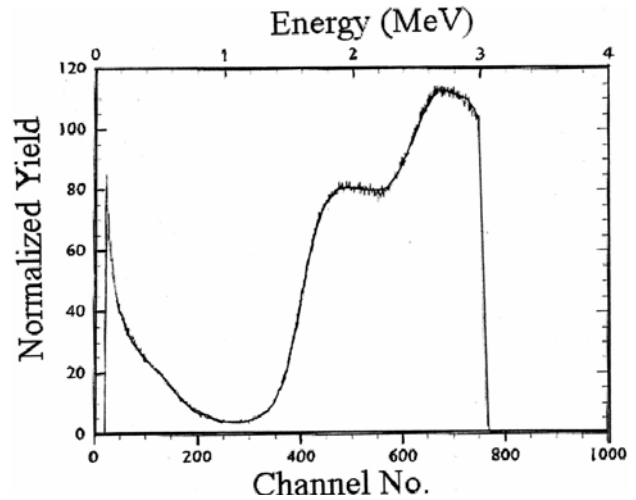


Fig. 4— Rutherford back scattering spectrum of as deposited InSb bilayer thin film of thickness 3000-1500 Å

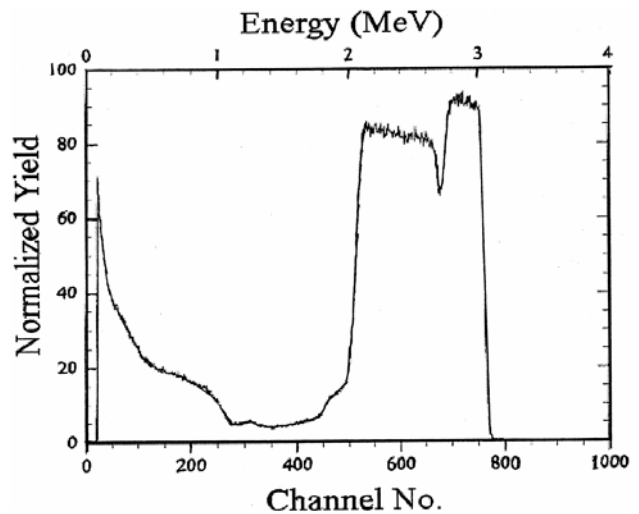


Fig. 5— Rutherford back scattering spectrum of ion irradiated InSb bilayer thin film of thickness 3000-1500 Å

These results well agreed with Hollway *et al.*¹⁷ and Singh *et al.*^{13,23}. The effect of ion doses also observed by Kac *et al.*²² for the film of Fe/Cr bilayer and suggested that intermixing increases with ion doses. The mixing of RBS study is also supported our optical band gap calculations that shows band gap of InSb semiconductor. It is only possible when mixing available at the interface of In and Sb elements.

Conclusions

The following conclusions may be drawn from this study: (i) the swift heavy ion irradiation is suitable technique for mixing the bilayer of InSb thin films and (ii) Rutherford back scattering analysis also shows mixing of bilayer and preparation of InSb semi conducting system.

References

- 1 Raghavan V, *Material Science and Engineering*, 5th ed, edited by Raghavan V (Printice- Hall India Private Limited, New Delhi), 2004, 368.
- 2 Wei K I, Wang E A, Taft J J, Sawab M, Gibbons M D, Davern W & Brown D M, *IEEE Trans Electron Devices*, 27 (1980) 170.
- 3 Thom R D, Koch T L, Lagan J D & Parrish W J, *IEEE Trans Electron Devices*, 27 (1980) 160.
- 4 Yasuoka Y, Okuda T & Inoue N, *Jpn J Appl Phys*, 27 (1998) 2886.
- 5 Kaur Suriender, Singh Taminder, Singh Amarjeet & Bedi R K, in *Semiconductor Materials*, edited by Bedi R K (Publisher ?), 1998, 67.
- 6 Osborn G C, *J Vac Sci Technol*, B2 (1984) 176.
- 7 Oi T, Kotera N, Shigeta J, Yamamoto N & Nakashima N, *Jpn J Appl Phys*, 17 (1978) 407.
- 8 Yasuoka Y, Okuda T & Inoue N, *J Appl Phys*, 17 (1978) 407.
- 9 Milyazaki T, Mori M & Adachi S, *Appl Phys Lett*, 58 (1991) 116.
- 10 Chyi J A, Biswanas D S, Iyer V, Kumar N S & Morkoe H, *Appl Phys Lett*, 54 (1989) 1016.
- 11 Chang P K & Bedair S M, *Appl Phys Lett*, 46 (1985) 383.
- 12 Carrolnand J A & Spivak J F, *Solid State Electron*, 9 (1966) 383.
- 13 Singh M & Vijay Y K, *Appl Surf Sci*, 239 (2004) 79.
- 14 Cruz L R & De Avillez R R, *Thin Solid Films*, 373 (2000) 15.
- 15 Carter M J, Anson II, Knowles A & Hill R, *Proc 19th IEEE Photovoltaic Specialists Conf*, IEEE New Orleans, NY, 1987, 1275.
- 16 Mangal R K, Tripathi B, Singh M & Vijay Y K, *Proc Int Symp Advanced Materials and Processing 2K4*, IIT Kharagpur, 2 (2004) 1110.
- 17 Holloway K & Sinclair R, *J Appl Phys*, 4 (1987) 61.
- 18 Connell G A N & Willian P, *J Non-Cryst Solids*, 8 (1972) 215.
- 19 Dhar S, Schaaf P, Lieb K.P, Bibic N, Milosavljevie, Sajavaara T, Keinonen J & Traverse A, *Nucl Instrum & Meth Phys Res B*, 205 (2003) 741.
- 20 Avasthi D K, Assmann W, Nolte H, Mieskes H, Haber D, H, Subramaniyan E T, Tripathi A & Ghose S, *Nucl Instrum & Meth Phys Res B*, 156 (1999) 143.
- 21 Checchetto R, Tosello C, Miotello A & Principi G, *J Phys Condens Matter*, 13 (2001) 811.
- 22 Kac M, Toulemod M, Jaworski J, Juraszek J, Kruk R, Protenko S, Tokman V & Marszalek M, *Vacuum*, 78 (2005) 661.
- 23 Singh M & Vijay Y K, *Indian J Pure & Appl Phys*, 43 (2005) 383.
- 24 Tauc J, in *Amorphous and liquid Semiconductors*, edited by J Tauc (Plenum, New York), 1974, 159.