Study of Thickness Dependence Optical Bandgap of InSbBi Thin Films

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Abstract

InSbBi thin films were grown at room temperature on to glass subtract under a pressure of 10^{-4} Pa by thermal evaporation technique. The room temperature deposited films of InSbBi of various thicknesses were obtained. The optical absorption spectra of thin films were obtained in the wave number range 510cm-1 to 6000 cm-1. the optical bandgaps evaluated from these data were found to be inverse functions of square of thickness, particularly for thicknesses about 2000Å or less. This dependence is explained in terms of quantum size effect. For thicker films, the bandgap is found to be independent of film thickness and approaches to the bulk value. The results are discussed in the view of quantum size effect.

Introduction

InSbBi compounds were widely used as long wavelength infrared detector attain cut-off wavelength (8-12μm) [1-2]. Long wavelength Photodetectors operating at room temperature widely used for many military and civilian applications.[3]. The III-V ternary compound is expected to be better than II-VI HgCdTe system because it suffer from thermal instability and poor compositional uniformity over a large area due to high Hg vapour pressure and weak Hg bond. InSb and several its solid solution offers range of well developed IR detector materials are used to detect 3-5 μm wavelength[4]. Extension of cut-off wavelength λc beyond 8μm appears feasible if we incorporate Bi into InSb. In this paper we are discuss about the optical properties of thin film of InSbBi material.

Experimental details

The stoichiometric amount of In,Bi and Sb materials each of 5N purity were sealed in the quartz ampoule under a pressure 10-4 Pa. The ampoule was kept horizontally in an alloy mixing furnaceat temperature 1000C greater than melting point of material for 48 h. The ampoule was rocked and rotated for proper mixing and reaction. The ingot was then cooled to room temperature over a period of 24 h. The ingot was then subjected to Bridgman method for crystallization. Small chips of single crystal InSbBi were taken to prepare thin films of various thickness using Vacuum coating unit(HHV,Bangalore). The thin films were grown on a (001) face of NaCl crystal substrate using the thermal Evaporation technique atroom temperature. An FTIR spectrophotometer (BOMEN,Canada) was used oto IR spectra. The optical absorption was measured in the wavenumber range 510 cm-1 to 6000cm-1. The band gap has been evaluated from this data which was found to depend on the film thickness.

Results and Discussion

The plots of $(\alpha h\nu)^2$ versus $h\nu$ obtained for films InSbBi prepared by thermal evaporation of the compounds are given in Fig- 1 with the thickness of 500 Å. The plots are observed to be straight lines in the region of high absorption. Hence by extrapolating the linear portion to $h\nu = 0$ (zero abscissa), the band gap was evaluated [5]. The band gap variation with thickness of films is discussed in table-1.

The optical band gap E_g plotted versus Inverse Square of film thickness (t) is shown in fig.-2 for InSbBi thin films. Such thickness dependence of the band gap has been explained in terms of quantum size effect and dislocation density. In semimetals and semiconductors, the quantum size appears when their film thickness is comparable with or less than the mean free path or effective de Broglie wavelength of carriers. Because of small thickness of the films, the transverse component of quasi momentum of carriers is quantized and it assumes discrete values along the thickness dimension. The energy spectrum represents a system of the discrete levels with the separation between them given by uncertainty principles.

Table: 1 Energy gap variation of InSbBi thin film with thickness

Sample	Thickness Å	Energy gap (eV)
InSbBi	500	0.2
	800	0.18
	1200	0.15
	1500	0.134
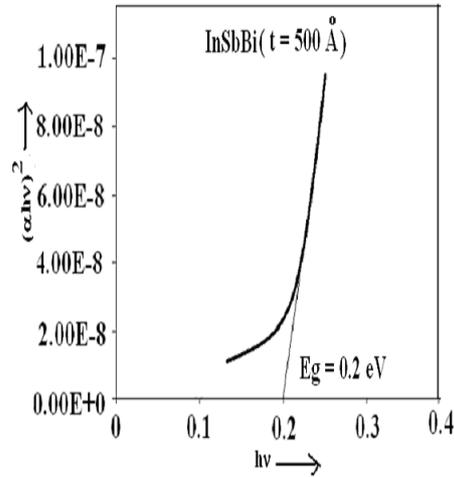
Figure: 1 Band gap of InSbBi thin film having thickness 500 Å
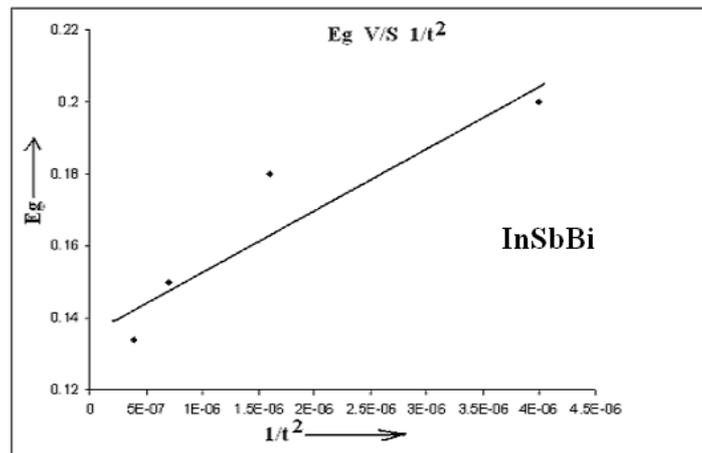
Figure: 2 The plots of E_g verses $1/t^2$ for InSbBi thin films

Due to this quantization, the bottom of the conduction band and top of the valence band are separated by additional amount of ΔE. In the thin film specimens, provided smearing of energy levels by carriers at the film surfaces are not significant, this shift will increase the band gap and affect the optical behaviour of semi conducting films. The absorption is reduced in thinner films as compared with bulk. ΔE is given by

$$\Delta E = \frac{h^2}{8m^*t^2} \tag{1}$$

Here $m*$ is the effective mass of the charge carrier, t = thickness of the film, ΔE is kinetic energy contribution due to motion normal to thin film plane and h = plank's constant.

The plot of E_g versus $1\backslash t^2$ for InSbBi given in fig. -2 is in agreement with the above relation and imply the quantum size effect operative in present case. It is also known that fairly large number of thin films and their density increases as the thickness increases up to a particular thickness beyond which the density is practically constant. However, the dependence of dislocation density on thickness has not been qualified and in any case the dependence is complex. There are considerable lattice disturbances due to dislocations, viz., the local stress fields around a dislocation, disrupted or dangling bond with its specific charge and the space charge domain that forms immediately in semiconductors. The compression and dilation in strain pattern brought about by edge dislocations have an effect in changing the forbidden gap of the semiconductor. This is because of resulting local compression increments in the deformation potential relation. Another influence is due to dangling bond resulting in an energy level within the forbidden gap.

With the increase in film thickness, the effect of the initial granular structure on the optical properties decreases but is not eliminated completely. Therefore, thickness dependence is still observed although the general behavior of the optical parameter, i.e. band gap, follows that of the bulk, at least quantitatively. For very thick crystal, (i.e. ideally infinite thickness) the electron energy is a multi valued continuous function of the quasi momentum. The variation of band gap with the crystallite size has been explained by the modified form of steller's formula [6]. According to him the increased barrier height is given by

$$E = E_0 + C(X - fD)$$
                                                                                                   (2)

Where, C = terms depending on density of charge carriers, electronic charge and dielectric constant of material E_0 = original barrier height, X = barrier width, D = grain dimension, f = factor depending on the charge accumulation and carrier concentration

From literature, it is known that the grain size is approximately proportional to the thickness. Hence grain size increases due to the increase in thickness of the film [7]. So if we replace D, the grain size in above equation by the film thickness t, E should be proportional to $(X - f.t)^2$.

In the present observation we find that the band gap varies inversely as the square of the film thickness. Hence it can be concluded that the observed band gap variation with thickness cannot be attributed to the above effect. The InSbBi thin films the quantum size effect is dominant, (explaining the band gap dependence on film thickness) rather than the effect produced by the dislocation density variation [8].

Conclusions

The optical band gap of InSbBi is found to decreases with increases in thickness of films. So the optical band gap varies with thickness upto value of thickness 1500 Å. So that quantum size effect become effective upto value of thickness 1500 Å, and dependence of band gap on thickness diminishing above 1500 Å.

The plot of E_g versus $1\backslash t^2$ for InSbBi explains the optical band gap of thin films

linearly varies with Inverse Square of film thickness implying quantum size effect operative upto about 500 Å to 1500 Å.

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