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Growth and Characterisation of $Ga_xIn_{1-x}Sb$ Thin Films for Infrared Detectors

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Growth of $Ga_xIn_{1-x}Sb$ (x = 0.1 to 0.5) thin films was carried out using hot wall epitaxy system on high purity quartz glasses and high resistive silicon as substrates. The source material for the growth of film was grown in the laboratory using vertical Bridgmen method in microprocessor controlled high temperature furnace. The grown films were characterized using grazing angle X-ray diffraction analysis and found to be polycrystalline in nature. XPS studies on the films showed non-stoichiometry compared to the bulk crystals. Band gap measurements using FTIR confirms the formation of energy gap in IR region, but the value does not exactly tally with the expected value of x. SEM studies on the films confirm the formation of pits on the surface which attributes to the non-stoichiometry in the films. Electrical characterization of the film, *viz.*, Vander Pauw resistivity, Hall-mobility, surface carrier concentration, etc. measurement is under progress to study the interplay between the microstructure and electronic properties of polycrystalline semiconducting thin films. Finally Au/$Ga_xIn_{1-x}Sb$ Schottky diodes were fabricated on the grown films and electrically characterised for IR detectors.

Key Words: Growth, Characterisation, $Ga_xIn_{1-x}Sb$, Thin films, ınfrared detectors.

INTRODUCTION

Recently $Ga_xIn_{1-x}Sb$ has received renewed interest because of its good IR detection properties useful for fibre optic communication in the wavelength range 1.3 to 1.7 μm.[1] Since gallium, indium and antimony do not possess any vapour pressure problems, processing of $Ga_xIn_{1-x}Sb$ at high temperature is easier compared to GaAs, InP and other compounds related to arsenic and phosphorus[2]. Growth of stoichiometric tailor-made band gap $Ga_xIn_{1-x}Sb$ thin films using hot wall epitaxy system on high purity glasses and high resistive silicon as substrate is a subject of interest. To the best of our knowledge till date no such reports have been presented yet. In the present work thin films of $Ga_xIn_{1-x}Sb$ were grown and characterised optically and electrically. XRD analysis and XPS studies were carried out on the film to know the crystallinity and the chemical composition of the film. While band gap measurements were carried out using FTIR, the surface studies were carried out using SEM. Finally the film was electrically characterised by Vanderpauw resistivity and Hall mobility. An attempt has also been taken by fabricating Au/$Ga_xIn_{1-x}Sb$ Schottky diodes to study the interplay between the ideality factor corresponding to the value of x.

EXPERIMENTAL

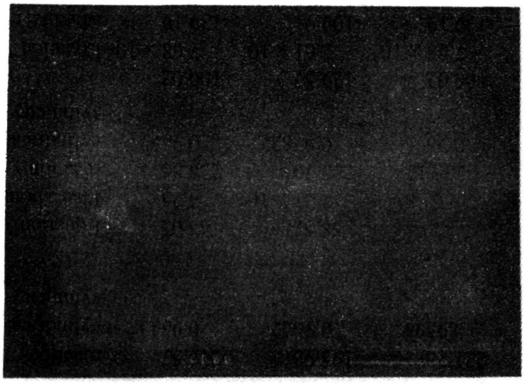
$Ga_xIn_{1-x}Sb$ (x = 0.1 to 0.5) samples were obtained from crystals grown by vertical Bridgman technique in our laboratory. The samples and the substrates (high resistive silicon and high purity quartz) were cleaned with TCE, acetone, methanol and millipore deionized water in succession. The samples were finally etched with $1HF : 1HNO_3 : 50H_2O$ for 1 min and repeatedly washed with deionized water. For silicon substrate a normal procedure of etching with CP4 was done followed by thorough cleaning with deionized water.

The growth of thin films was carried out in hot wall epitaxy system from Scientific India Ltd. The substrate was kept at an optimum temperature of 50°C above the room temperature to have good adhesion of the film on it. The XPS analysis and SEM micrographs of the film were carried out using Escalab MK-II spectrometer and Camscan MK-II (UK) scanning electron microscope. FTIR used for band gap determination was from Perkin-Elmer (UK).

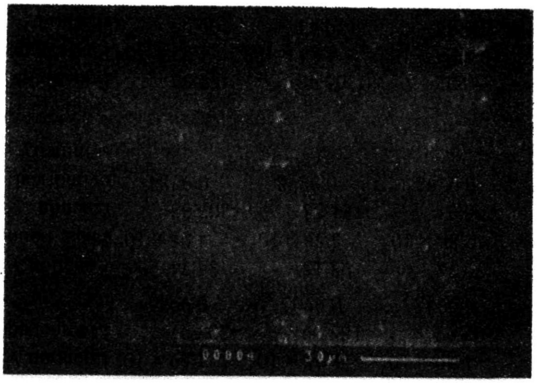
For electrical characterisation, *viz.*, Vander Pauw resistivity and Hall mobility, aluminium metal (which acts as an ohmic contact) dots were thermally evaporated on the films followed by annealing at 150°C for 5 min in high purity argon atmosphere. Finally gold metal dots were evaporated on the films to fabricate Au/$Ga_xIn_{1-x}Sb$ diodes and study the Schottky behaviour of the films.

RESULTS AND DISCUSSION

The X-ray analysis of the $Ga_xIn_{1-x}Sb$ (x = 0.1–0.5) grown films shows highly polycrystalline nature. The polycrystallinity increases with the decreasing value of x. The decrease in value of x attributes to the increase in In metal in the film composition. As the melting point of $Ga_xIn_{1-x}Sb$ goes on decreasing with the decrease in value of x the incorporation of In in the film goes on increasing abruptly resulting in a polycrystalline film[3]. The results were also supported by the SEM morphology of the films for x = 0.1, 0.3 and 0.5 (Fig. 1). As the value of x goes on increasing the surface morphology of the film becomes better. This may be due to formation of indium clusters in the film during growth resulting in an inhomogenety in the film composition[4]. The surface also shows some pits formed which attributes to the non-stoichiometry in the grown film. This was further confirmed by XPS analysis of the films (Fig. 2) where the intensity values of In and Ga peaks do not match with the x value in the bulk. Moreover, a slight incorporation of oxygen was also observed in the spectra. This oxygen incorporation may be from the source material as the bulk material was grown in high purity quartz ampoules. Although no peak shift was observed and the film growth was carried out at a vacuum of 2×10^{-5} torr, but the formation of preferential oxides, *viz.*, In_2O_3, Ga_2O_5, Sb_2O_3 etc. cannot be ruled out[5]. The band gap measurement using FTIR is presented in Table-1.



(a) SEM micrograph of $Ga_xIn_{1-x}Sb$ thin film at $x = 0.5$



(b) SEM micrograph of $Ga_xIn_{1-x}Sb$ thin film at $x = 0.3$

(c) SEM micrograph of $Ga_xIn_{1-x}Sb$ thin film at $x = 0.1$

Fig. 1. SEM Micrograph for $Ga_xIn_{1-x}Sb$ thin films

TABLE-1
VARIATION OF BAND GAP WITH x

Value of x (in bulk)	Value of x (in film)	Band gap (in bulk) eV	Band gap (in film) eV
0.10	0.085	0.23	0.20
0.20	0.18	0.27	0.24
0.30	0.27	0.33	0.29
0.40	0.38	0.38	0.34
0.50	0.48	0.44	0.40

As observed from the table the value of x and its corresponding optical band gap values in the film do not match with the bulk. These results also confirm the nonstoichiometry in the films compared to bulk crystal.

The electrical characterisation data is presented in Table-2.

TABLE-2a
VARIATION OF RESISTIVITY (ρ) WITH x

Value of x (in bulk)	Value of x (in film)	Resistivity (in bulk) Ω cm	Resistivity (in film) Ω cm
0.10	0.085	2.40×10^{-3}	1.80×10^{-3}
0.20	0.180	3.12×10^{-3}	2.80×10^{-3}
0.30	0.270	3.70×10^{-3}	3.10×10^{-3}
0.40	0.380	4.24×10^{-3}	3.70×10^{-3}
0.50	0.480	5.04×10^{-3}	4.30×10^{-3}

TABLE-2b
VARIATION MOBILITY (μ) WITH x

Value of x (in bulk)	Value of x (in film)	Mobility (in bulk) cm^2/V sec	Mobility (in film) cm^2/V sec
0.10	0.085	80,000	86,000
0.20	0.180	72.000	81,200
0.30	0.270	64,000	73,000
0.40	0.380	56,000	62,000
0.50	0.480	45,000	54,000

Table-2 summarises the results for electrical characterisation of the film and the bulk material. While the resistivity in the film goes on increasing from 2.40×10^{-3} to 5.04×10^{-3} Ω-cm the mobility goes on decreasing from 86,000 to 45,000 cm^2/V sec with the increasing value of x. As the value of x increases the indium concentration goes on decreasing in the film. Since the electronic carrier concentration contributes to the electrical conductivity and the mobility in the film[6], the indium concentration in the film plays an important role. As indium is more metallic than gallium, probably the free conduction electron gives rise to low resistivity and high mobility corresponding to the value of x in the film.

Table-3 summarises the results for the $Au/Ga_xIn_{1-x}Sb$ Schottky diodes.

TABLE-3
VARIATION OF IDEALITY FACTOR (n) AND DARK CURRENT DENSITY(J_0) WITH x

Value of x (in film)	Ideality factor (n)	Dark current density (Jo)A/cm^2
0.085	4.17	1.4×10^{-2}
0.180	3.36	6.6×10^{-3}
0.270	3.09	5.4×10^{-3}
0.380	2.73	4.2×10^{-3}
0.480	2.11	3.4×10^{-3}

From Table-3 it is observed that the value of n and J_0 goes on decreasing from 4.17 to 2.11 and 1.4×10^{-2} to 3.4×10^{-3} A/cm^2 as the value of x goes on increasing. This further resembles the incorporation of indium in the film. Moreover, since the melting point of indium is more than that of gallium, probably some clusters of indium metal can also be formed for low x values. Thus the diode ideality factor has much higher value corresponding to low value of x.

Conclusions

The thin films of $Ga_xIn_{1-x}Sb$ were grown and few optical and electrical properties were studied. The films were non-stoichiometric and highly polycrystalline in nature. However, though the ideality factor and the dark current density of $Au/Ga_xIn_{1-x}Sb$ showed fairly good result, can the material be used for fabrication of IR detectors Although the substrate used for growing the films is high resistive silicon and high purity quartz, but no remarkable variations in results were observed for the two different substrates.

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