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Chapter 1: Materials for Energy Systems

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Investigation of Photoresponse on GaSb Thin Films for Photodetectors

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Abstract—**A low cost near infrared photodetectors from thin films of Gallium antimonide (GaSb) was fabricated. In this method, physical vapor deposition was used for the growth of GaSb films on mica substrate using individual Ga and Sb evaporation sources. It was observed that growth temperature play major role in the material quality and surface morphology of the film analyzed by X-ray diffraction (XRD) measurements and scanning electron microscopy (SEM). The morphology of the grains varied with the change in the substrate temperature during deposition. Optical band gaps of the GaSb thin films show red shift when the growth temperature decreases. This red shift was up to 0.07 eV. The IR photodectors grown from GaSb thin film at 500 ^{O}C, show the best photo response with low noise.**

Index Terms— **XRD, SEM, styling, Photoresponse.**

I. INTRODUCTION

III-V Semiconductors having narrow band gap been used in the fabrication of the several electronic a optoelectronic devices. Among them, GaSb is most attractive material due to its unusual characteristics [1- GaSb thin film responded to near infrared region of 2-5 µm [6, 7] which corresponds to the direct band g of 0.72 eV. Due to this significant property of the GaSb, it is used for the fabrication of the photonic devic such as photodetector, laser diode [8, 9] and optical communications [1]. Thermo-photovoltaic c synthesized from the GaSb thin film is another promising property [3, 8]. Fabrication of GaSb photodiod with a high breakdown voltage was reported [1]. In the last decade, numerous methods have been report on the growth of GaSb thin film [9 - 11]. However, the major shortcoming applying GaSb in the nea infrared devices is the high cost, which is related to the GaSb sources itself as well as the performance on t device. To overcome this major drawback, mica substrates are used in this experiment. On the other han fabrication of devices at large scale from mica substrate will lead to reduce production cost. There are on two reports on synthesizing GaSb films by the coevaporation technique [2, 12]. Q. Zaixiang et al. and Jian-ming et al. deposited GaSb thin film on soda-lime glass substrates and on ordinary glass substrates usi evaporation method.

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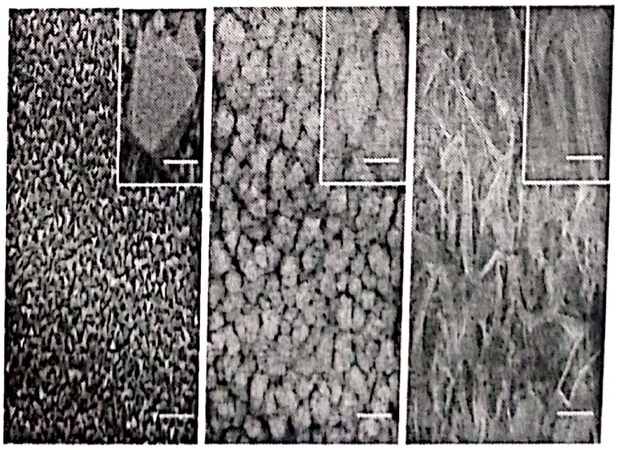
In this paper, we reported a successful growth of GaSb thin film using pure Antimony and Gallium shot in furnace tube while mica substrates placed as downstream. SEM analysis was carried out to observe the surface morphology of the grown films whereas XRD was used to observe the crystalline quality of the growing films. Energy-dispersive X-ray spectroscopy (EDX) was used for compositional analysis. While optical measurements demonstrate that the calculated optical band gaps corresponding to infrared regime. Finally, the IR photodetector devices properties grown at different temperatures had been carried out.

II. EXPERIMENTAL

Alumina tube furnace has been used for the synthesis of the GaSb thin film as shown in our previous publication.[8] Thin films of the GaSb were grown on mica substrates which were thoroughly cleaned with alcohol and acetone several times before mounting in the furnace tube. Three highly cleaned mica substrates were placed at specific temperature zone with gradient of ~500 °C, 300 °C, and 200 °C respectively which is already determined by a thermocouple. The precursors with purity of 99.999%-Alfa Aesar have been used. These high purity Gallium ingots with weight of 0.421 g and 0.415 g of antimony shot were mounted central zone of the furnace tube. Furnace tube is kept at 850 °C for over 180 min. At the end, furnace tube is allow to cool down naturally and quartz boat contain samples were taken out. Field emission scanning electron microscope (FE-SEM-JEOL JSM 5800LV) was used to characterize the surface morphology of the GaSb thin films at 20 kV. For EDX analysis accelerating voltage of 200 kV has been used in JEOL JEM 2010 SEM. Jordan Valley's D1 Evolution have been used for the X-ray diffraction (XRD) analysis to reveal the structural quality of the grown films. This system is equipped with filter of Cu Kα, k=1.5406 Å using glancing angle incidence of 1.5°. Bruker Optics IFS 66V/S Fourier transform infrared (FTIR) spectrometer was used to measure transmission. UV-Vis spectrometer JASCO (V-670) used to measure the transmission hence band gap of the grown thin films. The conductive graphite paste was applied with electrodes and the electrical measurement of the fabricated device were carried out in dark and illuminated conditions with SAN-EI 3A solar light simulator (XES-301S, 300W) and Keithley 2400 source meter.

III. RESULTS AND DISCUSSION

Morphological studies were carried by SEM on the GaSb film grown on mica-substrate at three different temperatures are shown in Fig. 1(a-c). Fig. 1(a) shows the growths of GaSb at 200 °C, with triangular micro-sized structures have been observed. While at the growth temperature of the 300 °C shown in Fig. 1(b), the small grains of the order of nanometer are grown with regular symmetries reduces surface roughness that give birth to more regular shapes. This is measured by tilting sample stage during field emission SEM [13]. With increase in growth temperature up to ~ 500 °C, leaves with spikes like GaSb structures grown on mica as shown in Fig. 1(c). A more detail view reveals very smooth surface of the GaSb with no out growth at nano-scale: one is very smooth surface of GaSb and other is micro-size clusters. It is observed that surface morphologies of the antimonide films are regular which may be suppressed the low dimensional growth. Thermal effects on the surface of the thin films have been observed, where the size of the GaSb nanoparticles decrease as the growth temperature decrease which ultimately increases optical band gap have been reported [15, 22].



(a) (b) (c)

Fig. 1. SEM images of thin film grown on mica at (a) ~200 °C, (c) ~300 °C, and (d) 500 °C. The scale bar of the inset is 500 nm while 10 μm for the larger

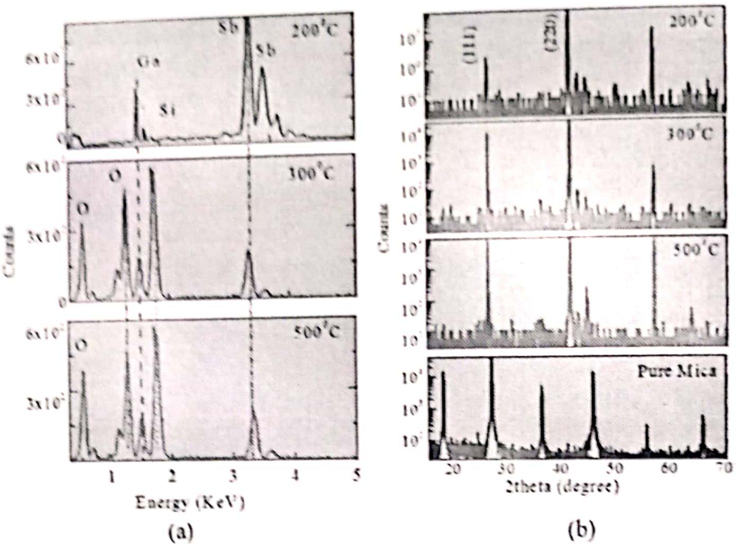


Fig. 2 (a) Elemental analysis by EDX and (b) XRD of the grown films at ~200 °C, ~300 °C, and 500 °C whereas, for comparison, mi diffraction peaks are plotted

EDX was carried out for elemental analysis of the grown GaSb films. It has been revealed that at the grow temperature of 500°C, the quantitative ratios of Ga and Sb contents almost equal as shown in Fig. 2(Through this analysis, significant variations in the ratios of Ga and Sb have been monitored at 200 °C, 300 and 500 °C. EDX spectra demonstrate that stoichiometric ratios of the grown GaSb films were chang significantly depending on growth temperatures. Incorporation of Ga contents decrease significantly at low growth temperature while the antimony increased at low temperature. For example, quantity of the Ga w significantly reduced at growth temperature of 200 °C, as shown in Fig. 2(a). With the increase temperature, content of the Ga also increases as well. This decrease of Sb concentration versus temperat can be explain as; at lower temperature, growth zone is away from source which reduces the vapor press of Sb as compared with Ga. The detected O and Si were due to surface contamination of the films during t formation of native oxide (gallium and antimony oxides) and from the mica substrate at high temperatu respectively [16]. Successful growth of gallium antimonide (GaSb) thin films were also confirmed by XF measurement for all samples as shown in Fig. 2(b).A significant peak ~25.288° have been observed t corresponds to the GaSb (111) diffraction peak. Another high intensity peak at ~41.88° has been shown Fig. 2(b) that comes from the GaSb with (220) plane correspond to PDF#89-4298, ICSD#044979. It is cl from these two diffraction peak that GaSb film grown on mica substrates may indicate well-orient microcrystals structures also reported in [17].

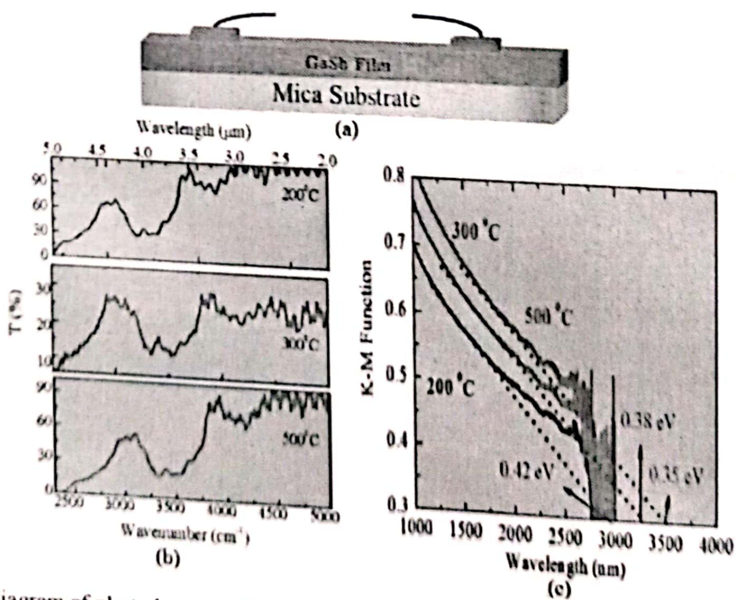


Fig. 3. (a) Schematic diagram of photodetector. (b) Transmission spectra of the GaSb thin film grown on mica grown at elevated temperatures. (c) Tauc plot obtained from transmission measurements for three GaSb films annealed at 200 °C, 300 °C and 500 °C. Optical band gaps of the GaSb thin films show red shift which increases with decrease in growth temperature up to 0.07 eV

Before going to the fabrication of photodetector, it is necessary to calculate the band gap of the fabricated thin films. For this purpose, Optical transmission and K-M function versus wavelength obtained from the thin films grown at elevated temperatures were observed by FTIR and UV-Vis-NIR spectrometer in Fig. 3 (b-c), respectively. Distinct absorption peaks have been observed in FTIR Spectra in the near-infrared region. While UV-Vis-NIR spectrometer have been used to measure absorption spectra. By comparing both these spectra, 3000 cm^{-1} and 3750 cm^{-1} are the absorption peaks common in both FTIR and UV-Vis-NIR of GaSb films was observed. It is observed that thicker film will lower transmission grown at 300 °C. It also observed that transmission may decreases due to incorporation of antimony in excess [18] shown in Fig. 3(b). Absorption measurement and optical band gap by plotting Kubelka Monk Function versus wavelength shown in Fig. 3(c). This Tuac plot verified by FTIR measurement too, as the 3000 cm^{-1} and 3750 cm^{-1} corresponds to band gap energy value of 0.38 eV and 0.45 eV respectively which have been demonstrated [19-22]. These result strongly demonstrate that the growth temperature significant effect the band gap of the GaSb. With increasing growth temperature, optical band gap increases that show a red shift which is property of semiconductor [23]. There is a distinction between "optical band gap" and "electrical band gap. The optical band gap is the threshold for photons to be absorbed, while the electrical band gap is the threshold for creating an electron–hole pair that is not bound together. (The optical band gap is at a lower energy than the electrical band gap) [24]. Nonetheless the excellent structural quality revealed by XRD and optical absorption in the near infrared region make GaSb thin film a promising candidate for application in optoelectronics.

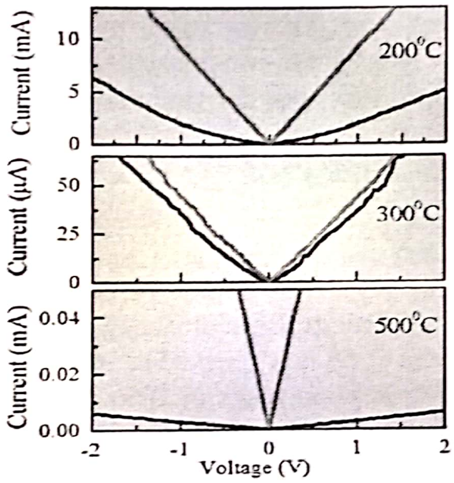


Fig. 4. Current density-voltage (J-V) characteristics of fabricated photodetectors. Here black lines represent the dark current while photo current measured under illumination is represented by colored lines

Optical measurements proved that the thin films of GaSb are active in infrared regime hence it can also act as photodetectors as illustrated in Fig. 3(a). Current density-voltage (J-V) characteristics are measured at room temperatures of three photodetectors with different growth temperature under illumination as well in the dark conditions as shown in Fig. 4. Good ohmic contacts are shown for the three photodetectors based on the linear dependence of the bias voltage with current curves. A significant difference between dark and photo current for the GaSb films grown at lower temperature had been observed. On the other hand, best photoresponse has been observed for the film grown at 500 °C whose surface morphology shown leaf-like textures. For film grown at 500 °C, a distinct improvement in the photocurrent has been observed upon illumination. This improved performance of the photodetector device fabricated from the films grown at higher temperature may results due to high crystalline quality [25]. Although these deficiencies in the contents measured by EDX will lead to poor performance of the devices but it can be optimized by controlling growth conditions. It is also observed that excess of Sb will contribute to dark current instead of photocurrent.

Fig. 5. Time dependent photoresponse devices fabricated from GaSb films grown at (a) 200 °C (b) 300 °C, and (c) 500 °C at different bias voltages. Where switch on and off for illumination is 30 s.

Fig. 5. Show transient behavior of the GaSb thin films. Here these grown thin films demonstrate significant photoresponse under dark and illumination. However, transient response gets due to high dark current. Dark current corresponds to density of surface state which is much higher making thin films more conductive. At zero bias voltage there is no response form the thin films which is property of photoconductive device. As the bias voltage e linearly depend on on/off ratio that can be improved with better time dependence of photo-

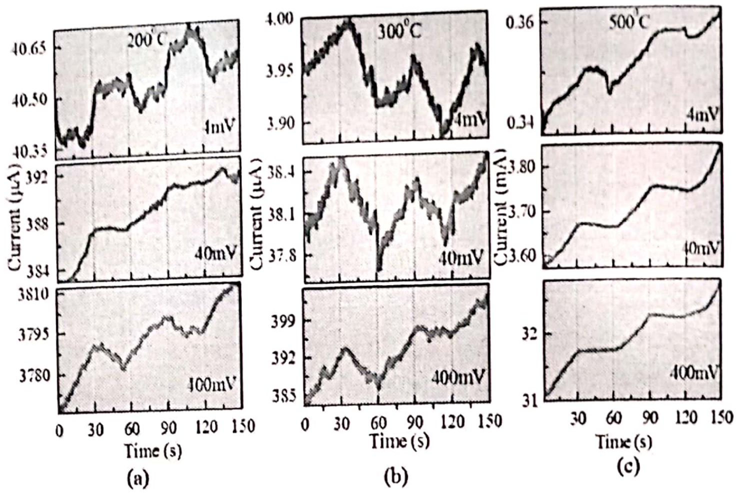


Fig. 5. Time dependent photoresponse devices fabricated from GaSb films grown at (a) 200 °C (b) 300 °C, and (c) 500 °C at different bias voltages. Where switch on and off for illumination is 30 s

generated carriers. Trap states in GaSb thin films are responsible for poor response time that enhance performance of the devices ultimately. These surface states slow down the transient response due to trapping/detrapping of photoexcited carriers [20]. For example, holes traps states related to oxygen at the surface of GaSb can prolong photoresponse. Inferior signal to noise ratio is observed for the detector fabricated from thin film grown at low temperature which is consistent with J-V and EDX measurements. It is expected that passivation of the surface states can decrease rise and decay time and hence improve on/off ratios.

IV. Summary and Conclusions

Physical vapor deposition technique used to grow GaSb thin films on mica substrates. Surface morphology accessed by SEM while XRD for the crystalline quality of the thin films. Depending on the growth conditions, these grown films are uniformly covered with nano or micro crystalline textures. XRD analysis exhibited that the excellent quality of the GaSb thin films while distinct absorption peak in the near infrared region have been observed by FTIR. Absorption peaks of 3000 cm^{-1} have been revealed corresponding to near-infrared region limited mica absorption. Band gap calculations show red shift because of the decrease in band gap with increase in growth temperature. Prototype infrared photodetector have been fabricated based on these results. It is concluded that improved response time, signal to noise ratios and photocurrent can be obtained by increasing growth temperatures for the thin films. Whereas, surface passivation and reduction in trap states may improve the performance of the device. Best crystalline quality and optical absorption studies show that GaSb is excellent candidate for future applications in optoelectronics industry. The technique introduce in this paper can be superlative alternate to low cost near-infrared technology.

Acknowledgment

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