# Chapter - 7

# CONCLUSION AND FUTURE SCOPE

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## 7.1 Summary of the Thesis

This research work focuses on the study of bulk growth of GaSb and GaSb thin films with an intended use in ICs, optical devices and VLSI applications.The earlier part of the thesis concentrates on the growth and characterisation of bulk GaSb and GaSb thin films, and the later part concentrates on characterisation of devices fabricated using bulk GaSb and GaSb thin films on glass substrate for the demonstration of its suitability in optical and VLSI device applications. Mainly, the thesis highlightsthe importance of the metal-semiconductor, semiconductor-semiconductor and metal-oxide-semiconductor interfaces. Accordingly experimental and simulation work havebeen carried outand a correlation has been purposed between the experimental evidence with the theory in the Results and Discussion sections. Based on the important and interesting results described inChapter-III to Chapter-VI, the following conclusions have been drawn:

- Bulk GaSb has been grown by a low cost and simple method,ThermoVertical Directional Solidification (TVDS), developed in our lab. A small piece of sample was then taken to deposit a uniform GaSb thin film on glass substrate by the Thermal Evaporation Technique. The procedure for the synthesis of the bulk GaSb crystal was selected considering that itdoes not need any seed crystal initially. In the TVDS technique, the temperature profile of the vertical furnace was calibrated repeatedly until a predefined profile has been maintained. Later, charge (pieces of both Ga and Sb)has slowly been allowed to pass through the highest temperature zone of a vertical furnace allowing solidification of the material to start from the bottom. The convex solid-liquid interface moves upward starting from the bottom. Thus, the ingot grows with no contact withthe walls of the ampoule even in absence of a seed crystal. A high purity Quartz ampoule was taken to avoid sticking effect of ingot with the inner wall of the ampoule. A small cross-section of the ingot has been taken as the target material in the thermal-evaporation set-up for the growth of GaSb thin film son glass substrates. The structural and microstructural study clearly emphasises the good quality of the thin film which has been used for various further studies.

Again, the morphological and electrical properties of bulk GaSb grown by the VDS method and GaSb thin films deposited on glass substrate by Thermal Evaporation method were studied at room temperature. In addition, theoretical or simulated characterisation of the materialswerebeen carried out using ATLAS TCAD tool. XRD studies have shown that the synthesized sample of GaSb has face-centred cubic structure like zinc blende with a GaSb lattice parameter of 6.092 Å.This result is also well supported by Raman Spectroscopicstudies. The overall surface morphology of the evaporated GaSb thin film on glass substrate is uniform, without hairline cracks or groves. It is observed that with the increase in the thickness of the GaSb thin-film, the resistivity and mobility increases. Hall Coefficient ($R_H$) of the thin-film ranges from $73.8\times10^6$ $m^3/C$ to $0.893\times10^6 m^3/C$ as thickness increases. This indicates the increase in carrier concentration in case of GaSb thin-film with the increase of film thickness (T) and that may be due to enhancement in native defects.Apart from experimental characterisations, simulated analyses were also carried out on bulk GaSb using SILVACO TCAD tool. Material analysis shows that at 300K the hole mobility of bulk *p*-GaSbis 461 $cm^2/Vs$. At lower temperatures, mobility is affected by impurity scattering. In contrast, at higher temperatures, acoustic, polar optical and non-polar optical scattering processes dominate in affecting the mobility. Like other semiconductor materials the intrinsic carrier concentration and bandgap of GaSb shows a strong relationship with that of temperature.

- Considering the importance of GaSb, metal-semiconductor interface studies have been carried out on Au/*n*-GaSb structure and correlation studies have been done on both experimental and simulation observations. Both the reverse and forward currents were found higher for the simulated contact as compared to that of fabricated Schottky contact. This may be due to the non-idealities present in the fabricated structure. The ideality factor and barrier heights were also calculated and were found to be 2.1 and 0.48eV for the Schottky contact fabricated whereas for the simulated structure they were 1.4 and 0.56eV respectively.The barrier height and ideality factor were found for both experimentally fabricated contact and simulated structuresshowingstrong temperature dependence.It is interesting to note that the barrier height determined from the I-V characteristics is simple and direct, whereas the barrier heightobtainedfrom the C-V characteristics is bit complex, but is more

reliable and consistent. This is probably because the I-V method is based upon forward bias condition with high current passing through the Schottky diode while the C-V method is based upon reverse bias conditions contributing reverse leakage currents.

♣ In continuation withthe interface studies, semiconductor-semiconductor interface structured have been fabricated using *n-type* ZnO (wide bandgap) and *p*-type GaSb (narrow bandgap) on a glass substrate. Structural and morphological studies of the ZnO film on GaSb/glass substrate showsthat non-c-axis orientation peak of ZnO dominates. Furthermore, as per published literature, in general the most intense peak of ZnO is observed on the <002>plane whereas in case of the ZnO film grown on GaSb, the maximum intensity was observed on the <101>plane. The diagonal lattice parameter of ZnO is 6.0284 Å which is only 0.106 Å different from the lattice of GaSb. Thus the lattice mismatch between ZnO and GaSb was found to be only 1.05%. Thisindicates that the <101>plane of ZnO gives better sticking conditions at the ZnO-GaSb interface. From the electrical study of the ZnO film on GaSb/glass substrate, the Hall Co-efficient was found to be *n*-type along with an increase in carrier concentration, thereby reducing the resistivity of the *p*-GaSb/*n*-ZnO heterojunction in comparison with that ofthe individual samples of *p*-GaSb and *n*-ZnO.The magneto-resistance of the *p*-GaSb/*n*-ZnO heterojunction was found to be in between the magneto resistance values found for *p*-GaSb and *n*-ZnO films on glass substrates separately,thus confirming that an electrical interface was formed between the *p*-GaSb and the *n*-ZnOfilms. Basing on Anderson's model, considering the band discontinuities between valence band minima and conduction band maxima, the heterojunction formed was found to be type-II in nature. The energy barrier for the electrons to flow from ZnO to GaSb in the conduction band was $\Delta E_c$=0.59eV, whereas the barrier for the holes was been found to be $\Delta E_v$=2.06eV. This explains that electron injection from n-ZnO into p-GaSb would be greater than the hole injection from p-GaSb into n-ZnO. Thus, the current transport mechanism in case of our proposed structure should be dominated by electrons. The current-voltage (I-V) characteristic of the heterostructurewas found to be rectifying in nature, rising exponentially after the built-in potential (0.5V). The ideality factor and barrier height were computed and they are found to be 4.7 and 0.61eV respectively.

- ♣ Since the available infrastructure did not have the facility to fabricate MOSCAPs, therefore the ideal behaviour of the oxide-semiconductor interface was simulated using ATLASTCAD tool. The Au/ZnO/n-GaSb MOSCAP structure showed a very high value of interface trap density indicating a low-quality interface has formed between ZnO and GaSb from the point of view of suitability for MOSCAPs. In place of ZnO, the chosen high-$KAl_2O_3$ dielectric, was not only a good thermally stable insulator material for a highly reactive substrate like GaSb but also showed better interface properties with GaSb.It is interesting to note that the $D_{it}$ of $Al_2O_3$/InAs/n-GaSb and $HfO_2$/InAs/n-GaSb with respect to $Al_2O_3$/n-GaSb were reduced by 34% and 65% respectively.Basing on this interface study of the entire four proposed structures it may be concluded that $HfO_2$/InAs/GaSb structure was the better choice for the fabrication of high-performance deep submicron *p*-MOSFETs devices.

In a brief, it can be summarised that the synthesis methods adopted by us for the growth of GaSb and various types of interfaces investigated are low cost and advantageous for the fabrication of devices and to study their fundamental properties before focussing on the application of these materials. The novel part of this research was the fabrication and characterisation of *n*-ZnO/*p*-GaSb heterojunction diodes.

## 7.2 Future Scope

In general, any research opens up new areas for further work. It is important to mention here that in some cases;the extreme range of the material and device parameters could not be studied because of the equipment limitations. All these limitations will be overcome in my ongoing future research work.

ZnO has a good interfacial property with Gallium Antimony (GaSb) substrate. To obtain good electrical properties, the bulk and the interface of stacked ZnO/GaSb thin films need to be studied in context of suitability for IC applications.

The study of structural and morphological properties of ZnO thin film over GaSb ensures that strain plays a vital role in altering the lattice constant of GaSb so as to provide better sticking conditions at the ZnO-GaSb interface, so that optical devices can be designed using *n*-ZnO/*p*-GaSb heterostructures.