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Electrical Properties of InxGa1-xAs Thin Film Prepared by MBE

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Abstract

Electrical resistivity and Hall Effect measurements were made on Thin Films of InxGa1-xAs. Films used in this study were grown on single crystal GaAs substrate by Molecular Beam Epitaxial method. Measurements were made at 77K and in a temperature region between 273K to 323K.

From the measurements it is found that GaAs and $In_{0.14}Ga_{0.86}As$ samples are n-type and samples of $In_{0.185}Ga_{0.815}As$ and $In_{0.205}Ga_{0.795}As$ are of p-type. Resistivity of GaAs and $In_{0.14}Ga_{0.86}As$ at room temperature are 65.3 Ohm-cm and 7.77×10^{-1} Ohm-cm respectively and for samples with $x \approx 0.185$ and ≈ 0.205 resistivity at room temperature are 1.06×10^3 Ohm-cm and 2.54×10^3 Ohm-cm respectively. Hall coefficient, Hall mobility and Carrier concentrations were calculated for all samples. Temperature variations of these values are presented and the results are compared with the previous works. Results obtained are explained in the light of the existing theories and they are found to be in good agreement with theories and also with the published results of other workers.

Keywords: Thin Film, Resistivity, Hall Effect, Mobility, Carrier Concentration, Substrate etc.

Introduction

The studies of thin film phenomena have attracted considerable attention in past three decades because of their potential applications such as heterojunction solar cells, liquid crystal displays, infrared reflective coatings, a variety of active and passive microminiaturized components and devices, radiation detections, magnetic memory devices (such as ROM, RAM etc.) and interference filters to the modern civilization. At present, for solar cell technology, the low cost production of semiconducting thin film has become a necessary precondition. The most modern development in the field of thin film physics is that of optoelectronic devices, photovoltaic, photoconductive and solid state laser devices are now under consideration of the experimental physicists of this respect.

The development of high speed high frequency opto-electronic devices as well as their integrated modulus and circuits shows the necessity of obtaining defect free III-V semiconductor compounds, substrates and active layers. The epitaxial growth technique is a method to obtain this improvement. Epitaxial film of III-V compounds are grown by three techniques: a) Liquid Phase Epitaxy (LPE[1]); b) Vapor Phase Epitaxy (VPE[2-4]); c) Molecular Beam Epitaxy (MBE[5]). The films used are deposited on a single crystal GaAs substrate by MBE. The thickness of all samples were 2.5 μ and size of the samples were square and the surface area of each film was 5.64 mm^2. All measurements were made at atmospheric pressure.

Experimental Measurements

Electrical resistivity

Electrical resistivity of various samples of $In_xGa_{1-x}As$ were measured at 77K and from 273 K to 323 K. Van-der Pauw's method was used to measure the electrical resistivity of the specimens. Four electrical contacts were made at the four corners; say A, B, C & D (fig. 2.1) of the sample with silver paste. When a dc was passed through any two terminals of the sample, say A & B; an electrometer (Keithley 614) was used to measure the dc passing through AB, it produced a potential difference between the contact CD and a digital voltmeter was used to measure the voltage developed between C & D. A copper-constantan thermocouple was used to measure the temperature. If $I_{AB,}$ the dc entering a specimen through AB and $V_{CD,}$ the potential difference between CD, then the resistance $R_{AB,CD}$ is defined as V_{CD}/I_{AB}. Similarly $R_{BC,DA}$ and $R_{AC,BD}$ are defined as V_{DA}/I_{BC} and V_{AC}/I_{BD} respectively.

For our square shaped and constant thickness samples, the resistivity ρ is given by the expression

$\rho = 2.266t(R_{AB,CD}+R_{BC,DA})$ ohm-cm ------------- (iii)

where **t** is the thickness of the film.

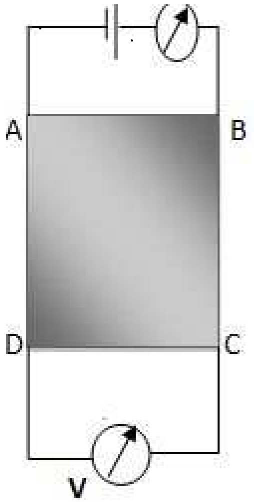


Fig. 2.1: Electrical contact of a film

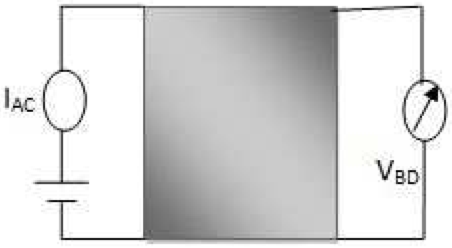


Fig. 2.2 Circuit for Hall Effect Measurement

Hall Effect

Van-der Pouw’s method was also used for the measurement of Hall Effect. The (Van-der Pouw’s) specimen provided with four electrical contacts was used for this measurement. The electrical circuit used in Hall Effect measurements is shown in fig. 2. The specimen with the heating arrangement was placed in between parallel pole-pieces. The sample was placed between the pole faces in such a way that magnetic lines of forces are perpendicular to the faces of the sample. In our work the gap between pole-pieces was kept at 4 cm and fields from 0 to 5.5 KGs were used.

Hall effects were measured using conventional dc method. The current drawn from a voltage regulated power supply unit. Currents and voltages were measured by a digital electrometer (Keithley 614) and a digital multimeter. A dc from the power supply unit was passed between the contacts A and C. Variable magnetic field was then applied normal to the faces of the specimen and the corresponding Hall voltage was measured between the points B and D. That voltage was measured carefully with the help of a high precession digital multimeter.

Calculation Of Hall Constant

For a constant current between A and C terminals, voltages induced between B and D in zero field, say V_1 and at any other applied field, say V_2 were measured. Then the change in resistance $\Delta R_{AC,BD}$ was calculated by using the relation

$\Delta R_{AC,\,BD} = (V_2 - V_1)/I$ ---(iv)

Nernst and Righi-Ledue effects were eliminated by reversing the current and the magnetic field and taking the average of the readings. Four sets of readings were taken first with **I** in positive direction and a pair of readings with the magnetic field normal and reversed and then reversing the current and another pair of readings with the magnetic field normal and reversed were taken. Average of these four readings eliminates all errors and Hall voltage was calculated by using the relation

$R_H = \Delta R_{AC,\,BD}\,(10^8 t/H)$ cm^3/Coul. --------------- (v)

where the magnetic field **H** is in Gauss and the film thickness **t** is in cm.

Calculation of Mobility and Carrier Concentration

The Hall mobility μ and the carrier concentration **n** were calculated from the relations

$\mu = R_H/\rho$ cm^2/v.s ------------------------------------- (vi)

and

$n = 1/R_H e$ cm^{-3} ------------------------------------- (vii)

respectively.

Result

Resistivity and Conductivity

In the present work resistivity and Hall Effect of $In_xGa_{1-x}As$ films of 2.5 μ thicknesses were studied at liquid nitrogen temperature (77K) and also within 273K to 313K temperature range. The temperature variation of resistivity for different concentration of In are observed. For pure GaAs i.e. for x=0 the curve shows that with the increase in temperature, resistivity decreases gradually goes through minima around room temperature and then increases with temperature. For x=0.14 resistivity does not show such minima but there is a small but continuous increase in its value with the increase in temperature. For films with x=0.185 and x=0.205 Indium concentrations resistivity first increases then pass approximately through a flat region and then again increase with the decrease in temperature. In both the samples, the observed flat region appears slightly below the room temperature. A comparison of the resistivity of all films shows that the resistivity of the sample with x=0.14 Indium concentration is less than the value for GaAs by almost two order of magnitude but films with x = 0.185 and x = 0.205 Indium concentration the resistivity is higher than the value obtained for GaAs and this value increases with increasing concentration of Indium.

The variation of conductivity corresponding to resistivity curves for all these samples are also depicted in graph (Fig. 3.1).

Hall Effect

Measurements of Hall voltage are a natural compliment to conductivity measurements in studies of transport phenomena of crystalline semiconductors. Since the Hall coefficients provides a reliable estimate of the carrier concentration and carrier type, similar to resistivity measurement, Van-der Pouw method was used for Hall Effect measurements.

Hall Effect measurements were made on pure GaAs and on $In_xGa_{1-x}As$ at 77K and also within temperature range of 273 to 313K for magnetic field up to 5.5 KG. At 77K Hall coefficient remains almost constant with field for x=0.14 In composition but for pure GaAs and x=0.205 composition the value decreases with increasing field. At room temperature R value for GaAs and for x=0.14 remains almost invariant with field but for x=0.185 the value decreases first and then remain almost constant with field and for x=0.205 the value increases with field.

Hall coefficients were also measured at various temperatures. Temperature variation of Hall coefficient for these films is alsoobserved. For GaAs, R_H decreases gradually with the increase in temperature, for x=0.l4 the value remain almost constant up to room temperature and then decreases with temperature. For x=0.185 concentration, R_H decreases with temperature similar to GaAs but for x=0.205 the value increases with increasing temperature.

Magnitude of R_H for GaAs, X=0.14, x=0.185, and x=0.205 at 300K are 1.20×10^5, 1.8×10^3, 1.7×10^5 and 2×10^6 cm^3/Coul. respectively.

One interesting fact that was observed from Hall Effect measurement is that for GaAs and $In_xGa_{1-x}As$ with x=0.14 films, Hall coefficients are negative, so these two films are n-type and the carriers are electrons. But samples with x=0.185 and x=0.205 shows positive Hall coefficients, hence they are p-type and the carriers are holes.

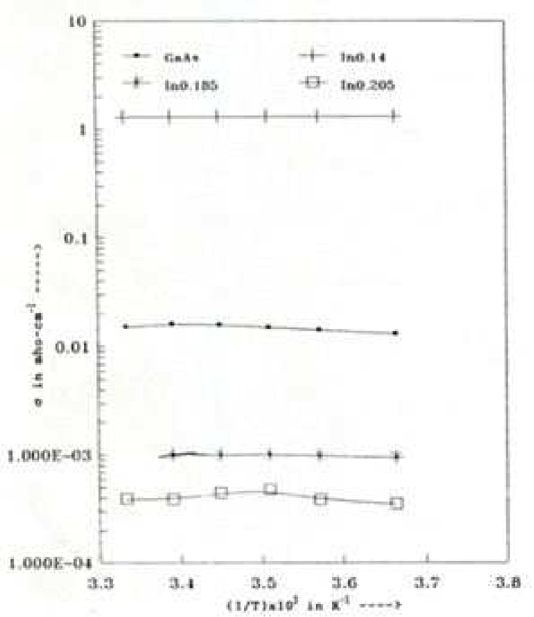


Fig. 3.1 Variation of conductivity with temperature of $In_xGa_{1-x}As$

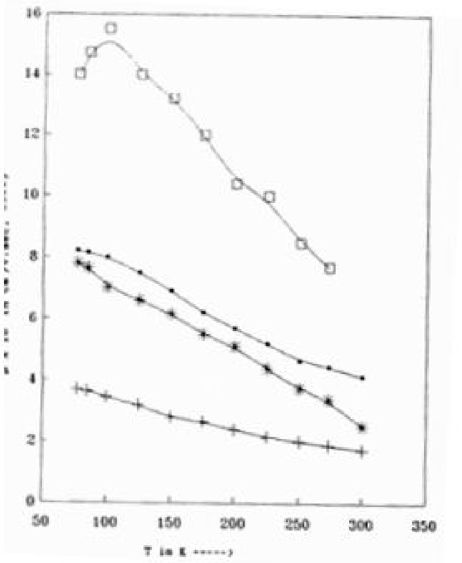
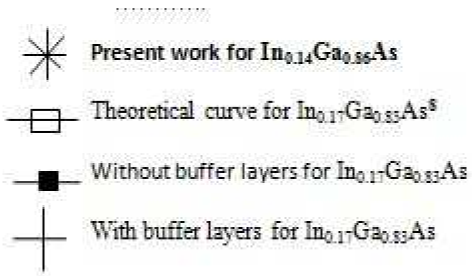


Fig. 3.7 Temperature dependence of mobility in InxGa1-xAs



Mobility and Carrier Concentration

Hall mobility of GaAs and $In_xGa_{1-x}As$ were calculated from Hall Effect measurements. The variations of mobility with temperature from 77K to 323K for all four samples were observed. For GaAs and with x=0.14 Indium concentration, mobility gradually decreases with increasing temperature whereas in case of films with x=0.185 and x=0.205 Indium concentration its value increases with the rise of temperature region. In fig 6.23 we plotted the mobility values as a function of alloy composition for different temperatures. At 77K, mobility decreases very rapidly with increasing composition of x. As we go to the higher temperature region the decrease in mobility value with concentration is quite slow.

Carrier concentrations were calculated from Hall Effect measurements. Temperature variations of carrier concentration for GaAs and $In_xGa_{1-x}As$ within temperature range from 273K to 313K were observed. In this temperature region carrier concentration for all samples increases with the increasing temperature.

For sample with x=0.14 composition carrier concentration is one order higher and for x=0.205 Indium concentration it is one order less than the value of GaAs. For x=0.185, the value is of the same order of magnitude with GaAs.

4. DISCUSSIONS

Compounds formed by the elements of the third and fifth column of the periodic table crystallize with spherelite structure. In this compound since each group III atom is tetrahedrally surrounded by group V atoms and vice-versa it is reasonable to assume that, on the average each atom has four valence electrons. This suggests that the bonding has a covalent character and that the semiconducting properties of these types of compounds are similar to those of the corresponding group IV elements.

Single phase solid solutions of ternary III-V mixed crystal system such as $In_xGa_{1-x}As$ alloy can be prepared over the complete compositional range[9] $0 \leq x \leq 1$. Optical-absorption measurements show that the band gap varies monotonically from GaAs to InAs[9-11] and is believed to remain direct in the alloy system.

In the preparation of our samples a crystalline GaAs was used as a substrate for the epitaxial growth of $In_xGa_{1-x}As$. Since lattice constant of $In_xGa_{1-x}As$ is larger than that of GaAs, a difference of the lattice constants between GaAs and $In_xGa_{1-x}As$ gives rise to lattice mismatching at the interface. Crystal imperfection due to this lattice mismatching cause a degradation of electrical characteristics of the epitaxial layers. The surface of $In_xGa_{1-x}As$ layer in the case of small composition 'x' usually is smooth as that of GaAs epitaxial layers. The surface degrades with increasing In composition. The degradation of the crystal is attributed to accumulation of the strain due to the lattice mismatching. These lattice mismatches induces defects into the epitaxial layer and thus greatly influence the electrical properties of the layers.

Therefore the cause of resistivity must be sought in the deviations from the perfect regularity of the potential in which the electrons move. Deviations from the periodicity of the potential causing resistivity are due to (i) Lattice vibration, (ii) Lattice defects such as vacancies, interstitial and dislocations, (iii) The order in the lattice, and (iv) Grain boundaries.

According to electronic theory of solids the electrical conduction or electrical resistivity results from the scattering of these electrons by lattice. Electron can pass through a perfect lattice without any attenuation. Actually no lattice is perfect. Even a lattice which has no structural defects or foreign atoms cannot be completely regular at any temperature.

From our Hall Effect measurements we observed that Hall coefficients are negative for GaAs and $In_xGa_{1-x}As$ with x=0.14. So in these samples the electron mobility is greater than the hole mobility. For pure GaAs when the temperature is increased conductivity increases goes through a broad maxima around room temperature. No such maxima were observed for samples with Indium concentration [x=0.14]. Addition of In might have shifted the position of maxima beyond the temperature region we have studied. It can be assumed that the conductivity below room temperature is a combination of intrinsic and extrinsic, with the increase in temperature more and more impurity centers are ionized. Near 300K impurity centers are almost completely ionized and the carrier concentration is constant. In this range conductivity varies only due to change in mobility with temperature.

As mentioned before from Hall Effect measurements, $In_xGa_{1-x}As$ with x=0.185 and x=0.205 are p-type and hence the majority carrier are holes. Mobility of GaAs and $In_xGa_{1-x}As$ measured as a function of temperature shows that temperature dependence become weaker with the increase in concentration of Indium in the film. Mobility at different temperature of $In_xGa_{1-x}As$ as a function of In concentration is shown in fig (3.7) which shows that its value decreases with increasing composition 'x'. Similar results were obtained by T.Stmgino[8]. Thus it is clear that increasing Indium concentration have an effect on the type of scattering in the crystal, since the normal phonon scattering in pure GaAs provides a strong dependence of mobility on temperature[15]. From our measurements, we also observed a strong temperature dependence of mobility on GaAs compared to sample with In composition. Sugino showed that the Poor mobility can be improved by growing a thin buffer layer in between the active layer and the substrate. They also found that the magnitude of the improved mobility is nearly equal to those observed in the vapor[14,15] and liquid[16] phase epitaxial layers. They also showed that the pre-growing buffer layer can relax the misfit strain near the interface, resulting in an increase of mobility. The effect of misfit strain near the interface was also observed in the photoluminescence and photoconductivity spectra as mentioned earlier.

The experimental results on mobility can be compared with the theoretical curve estimated from the relaxation time approximation[17]. Theoretical curves with the experimental results from reference[8] including our results (x= o.14) are plotted in fig 3.7. The theoretical mobility determined by polar optical phonon, ionized impurity and alloy scattering. All the experimental curves do not fit with the theoretical curve. To explain the observed low mobility and small temperature dependence compared to the theoretical value, Sugino suggested a new scattering center with large scattering cross-section. This additional scattering is associated with structural defects and/or inhomogeneous distribution of composition and impurity. This type of scattering may be compared with space charge scattering center in GaAs and InAs as has been suggested by Weisburg[18].

Taking into account a space charge scattering in $In_xGa_{1-x}As$ samples the calculation can be fitted to the experimental results. Glicksman[7] have estimated the electron mobility in $In_xGa_{1-x}As$ in terms of alloy scattering in addition to polar optical phonon and ionized impurity scattering to fit the experiment for relatively high purity samples grown by vapor phase epitaxy. On the other hand Katoda et al[6] have suggested that a reduction in electron mobility in vapor epitaxial grown $In_xGa_{1-x}As$ layers is caused by the space charge scattering. Because of the same, temperature dependence of $T^{-1/2}$ for both alloy and space charge scattering, contribution of these scattering cannot be distinguished by Hall measurement only. To interpret the temperature dependence of mobility in thin epitaxial layer of GaAs[19], the space charge scattering has been taken into account.

It is seen that the carrier concentration also depends on the concentration of In in the samples. For n-type samples i.e. for GaAs and x=0.14 composition carrier concentration n, has increased but for p-type samples i.e. for x=0.185 and x=0.205 composition the value is decreased with increasing In composition. For both n-type and p-type semiconductor the electron concentrations are expected to increase with increasing temperature. Our experimental results agree with this conception.

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