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Magneto Resistance of $In_xGa_{1-x}As$ Thin Film Prepared by MBE

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Abstract - Magnetoresistance measurements were made on Thin Films of $In_xGa_{1-x}As$ from Electrical resistivity and Hall Effect measurements. Films used in this study were grown on single crystal GaAs substrate by Molecular Beam Epitaxial method. Measurements were made at room temperature and up to field strength of 5.5KG.

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 ≈0.185 and ≈0.205 resistivity at room temperature are 1.06× 10^3 Ohm-cm and 2.54 × 103 Ohm-cm respectively. Hall coefficients were calculated for all samples. Temperature variations of these values are presented in a temperature region 273K to 323K. From the measurements it is found that GaAs and $In_{0.14}Ga_{0.86}As$ samples $\Delta R/R_0$ show a linear variation with magnetic field. But for $In_{0.185}Ga_{0.815}As$ and $In_{0.205}Ga_{0.795}As$ films $\Delta R/R_0$ initially decreases and then increases with increasing fields. 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.

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I. Introduction

The studies of thin film phenomena have attracted considerable attention in past three decades because of their potential applications such as magnetic memory devices (such as ROM, RAM etc.), hetero junction solar cells, liquid crystal displays, a variety of active and passive microminiaturized components and devices, radiation detections, and interference filters to the modern civilization. At present, for magnetic memory device 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 optoelectronic 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 thicknesses of all samples were 2.5 μ and shape of the samples were square and the surface area of each film was 5.64 mm^2. All measurements were made at atmospheric pressure.

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II. Experimental Measurements

a) Electrical Resistivity

Electrical resistivity of various samples of $In_xGa_{1-x}As$ was measured at 77K and from 273 K to 323 K. Vander 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 (Figure. 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

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

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

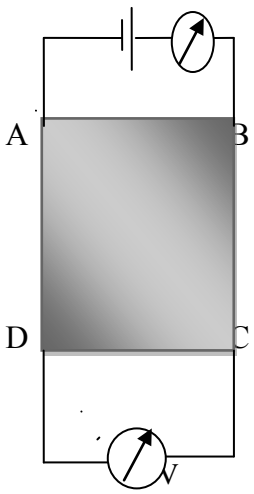

Figure 2.1 : Electrical contact of a film

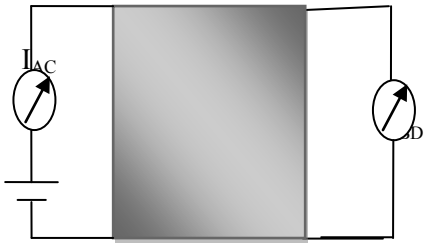

Figure 2.2 : Circuit for Hall Effect Measurement

b) 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 Figure. 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.

c) 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

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

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

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

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

d) Magnetoresistance

The magnetoresistance of a crystal refers to the change of electrical resistance of a crystal when placed in the magnetic field. This effect is due to the fact that when the magnetic field is applied, the path of the electron becomes curved and do not go exactly in the direction of the superimposed electric field. If R_0 is the resistance of the film in zero fields at a given temperature and ΔR be the increase of resistance caused by the application of a magnetic field, then the ratio $\Delta R/R_0$ increases proportionally to H^2 for comparatively low values of the field, but proportionally to H for higher values.

Considering the material of the film have two types of carriers with same relaxation time τ. Then $\Delta R/R_0$ comes out as a function of τH. But τ itself will then be inversely proportional to the resistance R_0 ; we can write the Kohler's rule[20]

$$\frac{\Delta R}{R_0} = F\left(\frac{H}{R_0}\right) \qquad \text{(iv)}$$

where F is a function depending on the nature of the material itself.

III. Results

a) Electrical Resistivity

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 (Figure 3.1).

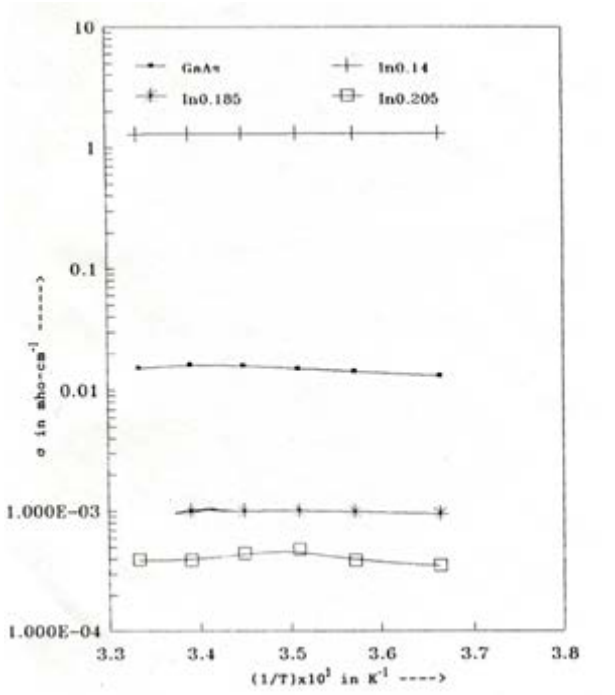

Figure 3.1 : Variation of conductivity with temperature of $In_xGa_{1-x}As$

b) Hall Effect

Measurements of Hall voltage are a natural compliment to resistivity measurements in studies of transport phenomena of crystalline semiconductors. Van-der Pouw's 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 also observed. 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 $1.20x10^5$, $1.8x10^3$, $1.7x10^5$ and $2x10^6$ 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.

c) Magnetoresistance

The magnetoresistance of a crystal refers to the change of electrical resistance of a crystal when placed in the magnetic field. This effect is due to the fact that when the magnetic field is applied, the path of the electron becomes curved and do not go exactly in the direction of the superimposed electric field. Transverse magnetoresistance measurements were made on $In_xGa_{1-x}As$ (with x=0, 0.14, 0.185 & 0.205) at room temperature up to a field strength of 5.5 KG. Fig 3.2 shows the plot of $\Delta R/R_0$ versus H for different samples at 300 K. For films with x=0 and x=0.14 composition $\Delta R/R_0$ shows a liner variation with field. But for films with x=0.185 and x=0.205 composition $\Delta R/R_0$ initially decreases and then increases with increasing field.

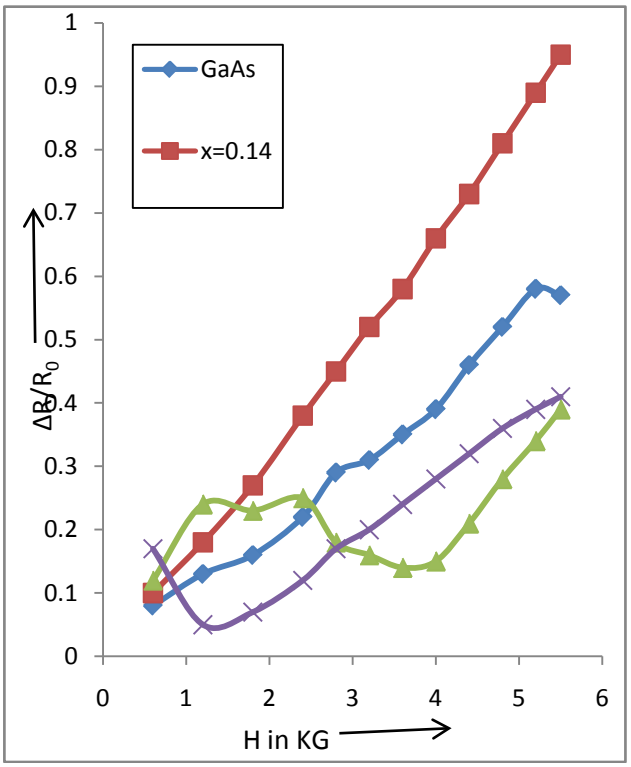

Figure 3.2 : $\Delta R/R_0$ versus H graph for $In_xGa_{1-x}As$

IV. 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 imperfections 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. For pure GaAs and with x=0.14 when the temperature is increased conductivity increases.

As mentioned in the theory of magnetoresistance when a magnetic field is applied perpendicular to the direction of current flow in a metal or semiconductor, a change of resistance is observed. The magnetoresistance is usually measured as a change of resistance ΔR relative to the resistance in zero magnetic field R_0. Magnetoresistance arises because groups of conduction electrons have different mean velocities. Hence although the transverse electric field on the average balances the effect of magnetic field, individual electron will travel in a curved path. In crystal line semiconductors, measurements of magnetoresistance in a magnetic field, like Hall Effect, can be used to determine carrier motilities and also gives information concerning the energy surface near the edge of the conduction and valance bands.

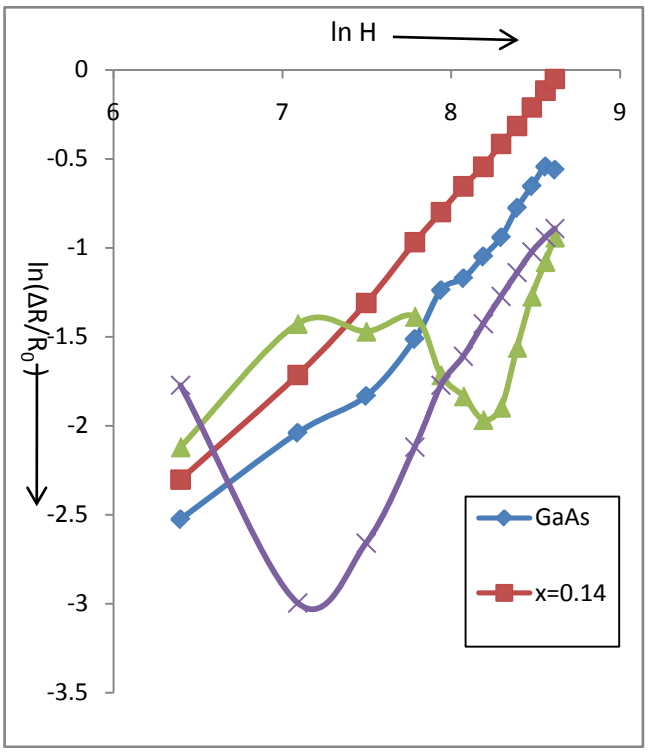

Figure 3.3 : ln ($\Delta R/R_0$) vs lnH graph for $In_xGa_{1-x}As$

Normally $\Delta R/R_0$ is positive and proportional to B^n, with n=2 for low field and n=1 for high field. Magnetoresistarice measured at 300 K on GaAs and $In_xGa_{1-x}As$ as presented in Figure 3.2 shows that for GaAs and for x=0.14 composition magnetoresistance is positive. From $\ln(\Delta R/R_0)$ vs. lnH graph (Figure3.3) we obtained the value of n=1, that is magnetoresistance for these two samples are found to be proportional to H up to 5.5 KG field. So the behavior follows the Kohler's rule approximately[20]. For sample with x=0.185, n=2 at low field up to 2.0 KG, within a field of 2.3 KG n=2 and above this field n=1.2. But for sample with x=0.205 of In concentration, value of n was more than 2. These two samples also do not follow the Kohler's rule. This is the evidence that in our films particularly films with x=0.185 and x=0.205 In composition different types of scattering mechanism are in operation and they are having different effect on the different group of carriers.

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