Hall Coefficient Measurement System

Ms. Mayuri Thakur
Instrumentation Department
Vivekanand Education Society's
Institute of Technology
Mumbai, Maharashtra 400074
(Email: 2015mayuri.thakur@ves.ac.in)

Mrs. Nilima Warke
Instrumentation Department
Vivekanand Education Society's
Institute of Technology
Mumbai, Maharashtra 400074
(Email: nilima.warke@ves.ac.in)

Dr. P. P. Vaidya
Instrumentation Department
Vivekanand Education Society's
Institute of Technology
Mumbai, Maharashtra 400074
(Email:ppvaidya@ves.ac.in)

Dr. Ajay Singh
Technical Physics Division
Bhabha Atomic Research Center
Trombay, Mumbai, Maharashtra 400085
(Email: 77ajay@gmail.com)

Dr. Subash Pai
Physics Department
Excel Instruments
Vasai, Maharashtra 401201
(Email: subashpai@gmail.com)

Abstract - In this paper, the electrical properties like Carrier concentration (η), Mobility (μ), Resistivity (ρ) of heterogeneous semiconductor samples are measured using Van der pauw algorithm based on Hall Effect principle. Hall coefficient is calculated to characterize the semiconductor materials. These samples are made in Laboratory in form of thin films by assembling semiconductor materials into mechanical structures. All samples are tested in Experimental setup by varying temperature and magnetic field and simulation is done using LabVIEW. The electrical properties of various p-type and n-type heterogeneous samples have improvised results as compared to homogeneous samples. The purpose of this experiment is to develop thermoelectric samples with high thermal conductivity. These samples can then be used to produce Thermoelectric devices to maximize utilization of heat energy.

Keywords- Hall Coefficient, Hall Effect, Van der pauw principle, Mobility, Carrier density, Thermoelectric materials, Heterogeneous Semiconductors

I. INTRODUCTION

Hall Coefficient measurement experiment is performed to obtain Resistivity, Carrier density, Mobility of charge carrier in the semiconductor thin films. This is measured by using Van der pauw algorithm. These thermoelectric semiconductor materials are those which have ability to convert heat into electricity. Thermoelectric modules consist of p- and ntype semiconducting 'legs' sandwiched between electrically insulating plates. All that is needed is a temperature difference between the top and bottom plates, and electricity will flow through an external circuit. The experiment is carried out by principle of Hall effect. The Hall Effect is the production of a voltage difference (the Hall Voltage) across an electrical conductor, transverse to an electric current in the conductor and to an applied magnetic field perpendicular to the current.[1] This technology is based on the Seebeck effect, which relates the voltage (power) generated in the material when a temperature difference is applied across it (heat flux).[2] The electrical properties of various p-type and n-type heterogeneous samples have improvised results as compared to homogeneous samples. This concludes that Compound semiconductors have thus various useful properties for the realization of a large number of high performance devices in the fields of electronics and opto-electronics. The paper comprises of eleven sections. The section I Introduces to the thesis and objective behind the project.

The section II briefs about Hall coefficient principle and Hall Effect. The section III discusses the concept of Hall effect measurement for characterizing material by measuring Hall voltage, Carrier mobility, Hall Coefficient, Resistivity and Carrier Concentration. The section IV describes Van der pauw Algorithm. The section V briefs about Thermoelectric materials, their selection criteria, characteristics and materials of interest. The section VI gives idea of Experimental setup. The section VII consist of Graphical User interface developed using LabVIEW software. The step wise procedure of experiment and application of Heterogeneous samples are given in section VIII. The section IX consists Results and Graphs of the experiment and finally last section concludes the thesis and discusses Future scope of this research.

II. HALL COEFFICIENT PRINCIPLE

Hall Effect is the production of a voltage difference (Hall Voltage) across an electrical conductor, transverse to an electric current in the conductor and to an applied magnetic field perpendicular to the current.[1] Hall coefficient is defined as the ratio of the induced electric field to the product of the current density and the applied magnetic field. It is a characteristic of the material from which the conductor is made, since its value depends on the type, number, and properties of the charge carriers that constitute the current.[1] The Hall effect was discovered in 1879 by Edwin Hall and is due to the nature of the current in a conductor. Current consists of the movement of many small charge carriers, typically electrons, holes, ions or all three. When a magnetic field is present, these charges experience a force, called the Lorentz force. When such a magnetic field is absent, the charges follow approximately straight, 'line of sight' paths between collisions with impurities. However, when a magnetic field with a perpendicular component is applied, their paths between collisions are curved, thus moving charges accumulate on one face of the material. This leaves equal and opposite charges exposed on the other face, where there is a scarcity of mobile charges. The result is an asymmetric distribution of charge density across the Hall element, arising from a force that is perpendicular to both the 'line of sight' path and the applied magnetic field. The separation of charge establishes an electric field that opposes the migration of further charge, so a steady electric potential is established for as long as the charge is flowing.[1]

III. HALL EFFECT FOR CHARACTERIZING MATERIAL THROUGH ELECTRICAL PROPERTIES

Hall coefficient and Hall effect is used to characterize the semiconductor materials. The electrical properties of heterogeneous semiconductor samples like Carrier concentration (η), Mobility (μ), Resistivity (ρ) are measured using Van der pauw algorithm based on Hall Effect principle. Usefulness of a thermoelectric devices is determined by Efficiency and Power factor.[1] These are determined by materials Electrical conductivity (σ), Thermal conductivity (), Seebeck coefficient (S) and its behavior under changing temperature (T). The ability of given material to efficiently produce thermoelectric power is related to its dimensionless Figure of merit (ZT). In recent years, theories have predicted an enhancement in the figure of merit of low-dimensional materials, and the improved performance of Thermoelectric devices has been proven by experiments.[4] Lower the Figure of merit, higher is thermal conductivity. Homogeneous semiconductor have high Figure of merit and thus low thermal conductivity whereas Heterogenous semiconductor have Low Figure of merit and thus high thermal conductivity. [8] This influenced the intermixing of semiconductor materials to form Heterogeneous materials so as to increase efficiency of samples and generate more thermoelectricity.

IV. VAN DER PAUW ALGORITHM

The Van der Pauw Method is a technique commonly used to measure the resistivity and the Hall coefficient of a sample.[3] Its power lies in its ability to accurately measure the properties of a sample of any arbitrary shape, so long as the sample is approximately two-dimensional (i.e. it is much thinner than it is wide), solid (no holes), and the electrodes are placed on its perimeter. Van der pauw algorithm using correction factor table is used to calculate electrical properties of heterogenous semiconductor samples like Resistivity, Carrier Concentration and Moblility and can be formulised as below:

RESISTIVITY:

$$\rho_A = \frac{\pi}{\ln 2} f_A . t_s \left[\frac{R_{21,34} + R_{12,43} + R_{43,12} + R_{34,21}}{4} \right]$$

CARRIER CONCENTRATION:

$$\boxed{n = \frac{1}{R_{Havg} . q} \left(cm^{-3} \right)}$$

MOBILITY:

$$\boxed{\mu_H = \frac{\left| R_{Havg} \right|}{\rho_{avg}}}$$

V. THERMOELECTRIC MATERIALS OF INTEREST

Thermoelectric materials are the materials which have ability to convert heat into electricity. Thermoelectric materials which perform best and have good room temperature thermoelectrics with best figure-of merit, ZT, are: Bismuth chalcogenides and their nanostructures, Lead telluride, Inorganic clathrates, Magnesium group IV compounds, Silicides etc. [6] Bismuth is a chemical element with symbol Bi and atomic number 83. It is a pentavalent post-transition metal and one of the pnictogens with chemical properties resembling its lighter homologs arsenic and antimony. [6] A selenide is a chemical compound containing a selenium anion with oxidation number of 2, much as sulfur does in a sulfide. The chemistry of the selenides and sulfides is similar. Tellurium is a chemical element with symbol Te and atomic number 52. It is a brittle, mildly toxic, rare, silver white metalloid. Tellurium is chemically related to selenium and sulfur. [6] For the experiment, Heterogeneous semiconductor samples considered are Bismuth selenide (Bi2Se3), Bismuth telluride selenium (Bi2Te2.7Se0.3), Bismuth selenide tellurium (Bi0.5Sb1.5Te3), p-type Silicon germanium (SiGe) and n-type Silicon germanium (SiGe). [10]

VI. EXPERIMENTAL SETUP

The experimental setup consists of Electromagnet, Polytronic Power supply for magnet, Digital gaussmeter, Experimental chamber, Hall resistivity setup, Rotary pump, Pirani gauge, Water chiller, PID controller, Keithley Current source, Keithley Nanovoltmeter Hall Controller.

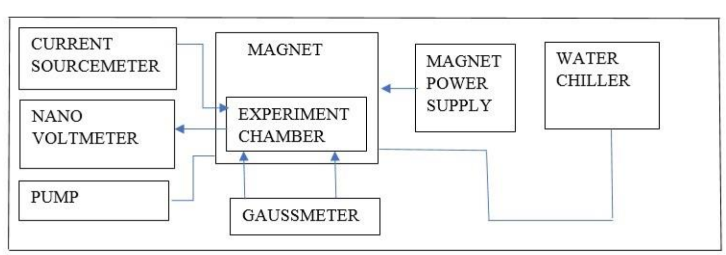

Fig. 1. Block diagram of Hall coefficient System

VII. GRAPHICAL USER INTERFACE (GUI) USING LABVIEW SOFTWARE

Graphical user Interface of System is developed using LabVIEW. 2 modes are provided on LabVIEW i.e. Manual mode and Auto mode for user-friendly operation of system.

A. Manual Mode

Manual Mode shows actual display of Keithley Sourcemeter, Keithley Voltmeter, PID and Magnet power supply. It allows the user to operate and control them.

Fig. 2. Manual mode GUI

B. Auto Mode

Auto mode allows user to enter all parameters at once i.e. Current criteria, Temperature criteria, Magnetic field criteria and results i.e. Carrier concentration and Mobility can be observed on Graph.

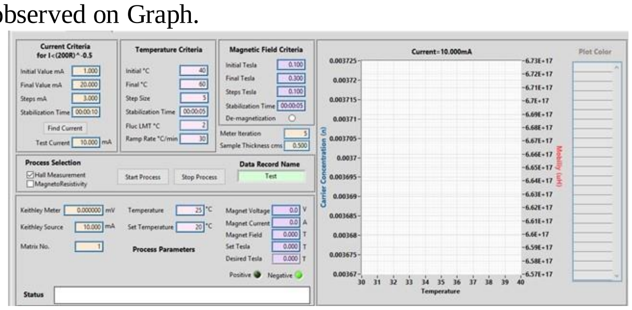

Fig. 3. Auto mode GUI

VIII. STEPWISE PROCEDURE AND APPLICATIONS

The interfacing of Magnetic with simulation devices is done by 9-pin remote control present on back side of Magnet power supply. This 9-pin control represent Voltage control, Current control and Adjustment knob present on front panel of Power supply. Testing is done for +/- 60 Volts with +/-60 Amps for 0-1 Tesla (i.e. 0 to 10000 Gauss). Software is developed for Van der pauw algorithms for measuring Resistivity, Magnetoresistivity and Hall voltage. All the Electronic devices are connected to power supply. The Rotary pump develops vacuum upto 1.02 bar inside experimental chamber which is measured by Pirani gauge. The water chiller maintains temperature in chamber upto 18 deg cel. The heterogenous samples to be tested are placed on sample holder on Hall setup inside Chamber. The selected current is sourced by Keithley DC Current Sourcemeter to the sample. By entering Initial temp, Final temp, Initial tesla, Final tesla, Step size, Stabilization time, Ramp rate and other sample parameters clicking 'Start Process' , PID sets on Auto-tuning mode with Output power=70 percent. Now the temperature will rise to Set value entered in Initial temp text box. This temp is sensed by thermocouple and can be seen on PID display. Once the temperature are stablilized, the Current Sourcemeter sources current to the sample and Nanovoltmeter takes 5 readings and gives their average as Reading no-1. Likewise, 8 matrix readings are taken. Meter iteration is provided to get more accurate readings. The Voltage and Current readings give Resistance value. The Resistance and Resistivity readings are taken in presence of Positive and Negative Magnetic field. These readings gives Average resistivity in case of Magnetoresistivity. For Hall Voltage measurement, 8 matrix readings are taken without Magnetic field which gives Resistivity without Field. Further 4 matrix readings are taken in presence of Positive and Negative Magnetic field which gives Carrier Concentration Mobility with Field.

IX. RESULTS AND GRAPHS

The results are taken for 5 samples namely Bismuth selenide (Bi2Se3), Bismuth telluride selenium (Bi2Te2.7Se0.3), Bismuth selenide tellurium (Bi0.5Sb1.5Te3), p-type Silicon germanium (SiGe) and n-type Silicon germanium (SiGe) . Calculated parameters are plotted below as Resistivity versus temperature, Seebeck coefficient versus temperature, Concentration and Mobility versus temperature.

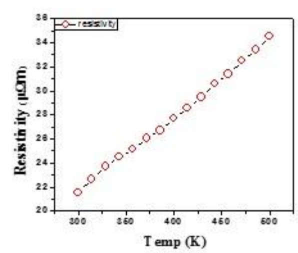

Fig. 4. Resistivity versus Temp

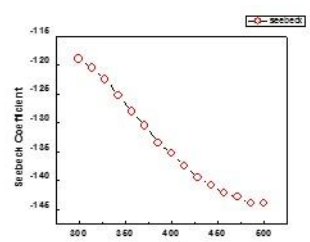

Fig. 5. Seebeck versus Temp

Material	Concentration (1/cmˆ3)	Mobility (cmˆ2/V.s)	Hall Coefficient (cmˆ3/C)
Bi2Se3	2.78 X 10ˆ18	8.23 X 10ˆ2	2.25 X 10ˆ0
Bi2Te2.7Se0.3	8.76 X 10ˆ19	6.40 X 10ˆ1	7.13 X 10-2
Bi0.5Sb1.5Te3	1.14 X 10ˆ20	1.38 X 10ˆ2	4.25 X 10ˆ-2
SiGe	1.79 X 10ˆ20	3.68 X 10ˆ0	3.48 X 10ˆ-2
SiGe	5.15 X 10ˆ20	1.40 X 10ˆ1	1.21 X 10ˆ-2

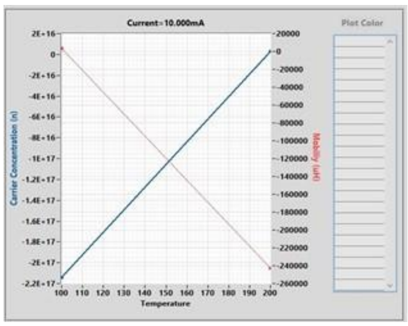

Fig. 6. Carrier Concentration and Mobility versus Temp

X. CONCLUSION

Hall coefficient values calculated through the measured parameters namely Resistivity, Carrier concentration and Mobility for all 5 heterogeneous samples provides clear and improvised results than those for homogeneous samples. Hall coefficient for Silicon-Germanium for n-type and p-type is less but for these heterogeneous samples Hall coefficient is observed to be 4 times greater than that for homogeneous samples. This experiment provides good results compared to the ones already known to us.

The purpose of this experiment is to develop thermoelectric samples with improvised properties so as to develop Thermoelectric devices. The objective is to maximize the utilization of heat energy. Thermoelectric materials are being studied as a way to regenerate electricity from waste heat. [9] This when converted into electricity can be used as an alternative source of energy. The material properties such as mobility of charge carriers, resistivity, charge carrier density of thermoelectric semiconductor materials are measured. [9] The thermoelectric parameters are measured like Electrical conductivity, Thermal conductivity to calculate Figure of Merit and Power factor to identify good thermoelectric materials which can be used for developing Power devices.

XI. FUTURE SCOPE

Using these heterogeneous semiconductor samples with high charge carrier density and mobility we make measurements for voltage i.e. thermoelectricity. [10] This will give us amount of energy being produced by thermoelectric samples which can further be used for thermoelectric devices.

Thermoelectric devices could be used to increase the efficiency of solar cells. The emerge of hybrid vehicles opens a wide application of thermoelectric devices as additional energy source for battery charging . [7] Materials having their maximum figure of merit at relatively low temperatures such as bismuth telluride and its alloys could be used for geothermal power sources. One Energy harvesting application for thermoelectric devices is the exploitation of natural temperature differences between air and soil. Thereby, the soil’s thermal capacity causes a delay in temperature evolution and the temperature difference changes its sign between daytime and night time.[8] The slowly closing gap between the energy consumption of single applications, especially in low power microelectronics, and available devices for providing the energy needed on a regenerative basis is documented by an impressive number of publications. [9] [10] However, there is still a long way to go in order to make thermoelectrics competitive for a wider range of applications by continuous efforts on increasing efficiency and power densities.

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