Magnetoresistance in a semiconductor

Lab Manual

M.Sc Physics (Sem II)
Solid State Physics Lab

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Objective: To observe the phenomenon of magnetoresistance in a semiconductor and study the magnetic field dependence of the transverse magnetoresistance of a given semiconductor sample.

Apparatus Required: Four probe arrangement, Sample, Magnetoresistance set-up, Electromagnet, Constant Current Power Supply, Digital Gaussmeter.

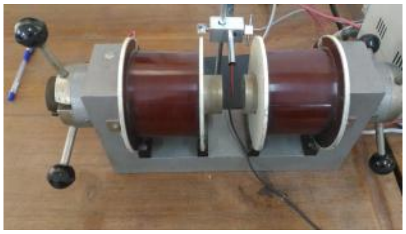

Figure 1: Electromagnet

Figure 2: Gauss meter and Current Source

Figure 3: Magnetoresistance Setup

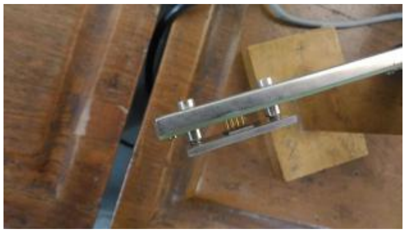

Figure 4: Four Probe

Theory:
Magnetoresistance is a phenomenon in which the electrical resistivity of a material changes in the presence of an external magnetic field.
Magnetoresistance was discovered by Lord Kelvin(William Thomson) in 1851.
Albert Fert and Peter Grunberg were jointly awarded the Nobel Prize for the discovery of Giant Magnetoresistance in 2007.

The magnetoresistance is defined as the ratio of change in resistance of a substance due to application of magnetic field to its resistance in zero field. Under the influence of a magnetic field, the electrons in a solid material do not follow the exact direction of superimposed electric field, instead take a curved path. This results in effective decrease of the mean free path and hence an increase in the resistivity of the sample. When magnetic field is applied normal to the current flow, the effect is termed as transverse magnetoresistance and when field is applied parallel to the current flow, it is termed as longitudinal magnetoresistance.

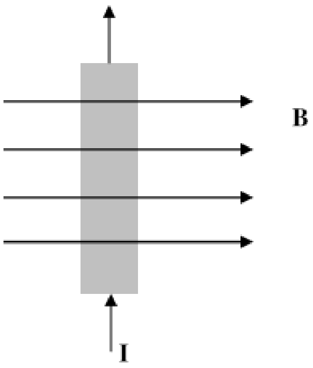

Figure 5: Transverse Magnetoresistance

The conductivity of a semiconductor in a magnetic field (with the field direction being perpendicular to the direction of current flow) can be expressed in terms of zero - field conductivity σ_o, the Hall coefficient R_H, the applied magnetic field B, and a coefficient β:

$$\sigma = \frac{\sigma_o}{1 + \beta\sigma_0^2 R_H^2 B^2}$$

and magnetoresistivity can be written as,

$$\frac{\Delta\rho}{\rho_o} = \beta\frac{R_H^2 B^2}{\rho_o^2}$$

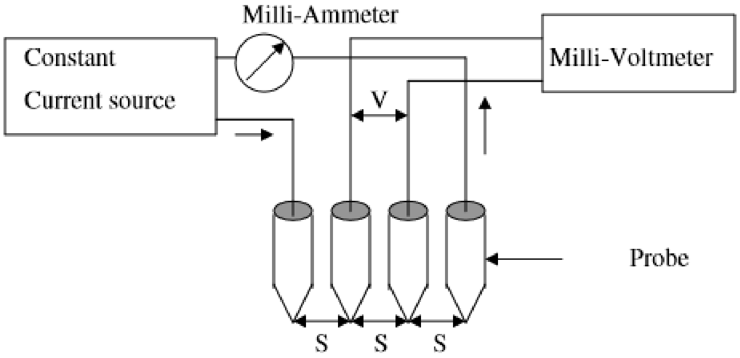

Figure 6: Four Probe

For small field we can write transverse magnetoresistance as:

$$\frac{R - R_0}{R_0} \propto B^2$$

Procedure:
1. Adjust the air-gap between the pole pieces of the electromagnet.
2. Measure the magnetic field in between the pole pieces of the electromagnet as a function of current through it with the help of the probe and gauss meter. Plot the calibration curve.
3. Place the sample in between the pole pieces of the magnet such that magnetic field is perpendicular to the direction of the current.

4. Outer two probes of the four probe arrangement are to be used for passing current and inner two probes for the voltage measurement.
5. Measure the resistance R_0 without any magnetic field by recording the voltage drop as a function of current.
6. Measure the resistance R for different magnetic fields.
7. Verify $\frac{R-R_0}{R_0} \propto B^2$ by suitable plots.

Observations:

Least Count of constant current source = 0.01A
Least Count of digital millivoltmeter = 0.1mV
Least Count of digital milliammeter = 0.01mA

Current, I (A)	**Magnetic Field, B (kG)**
0.14	0.001
0.24	0.073
0.5	0.258
0.75	0.443
1.01	0.638
1.25	0.825
1.5	1.02
2	1.41
2.5	1.80
3	2.18
3.5	2.55
4.01	2.92
4.36	3.15

Table 1: **Calibration of B with I**

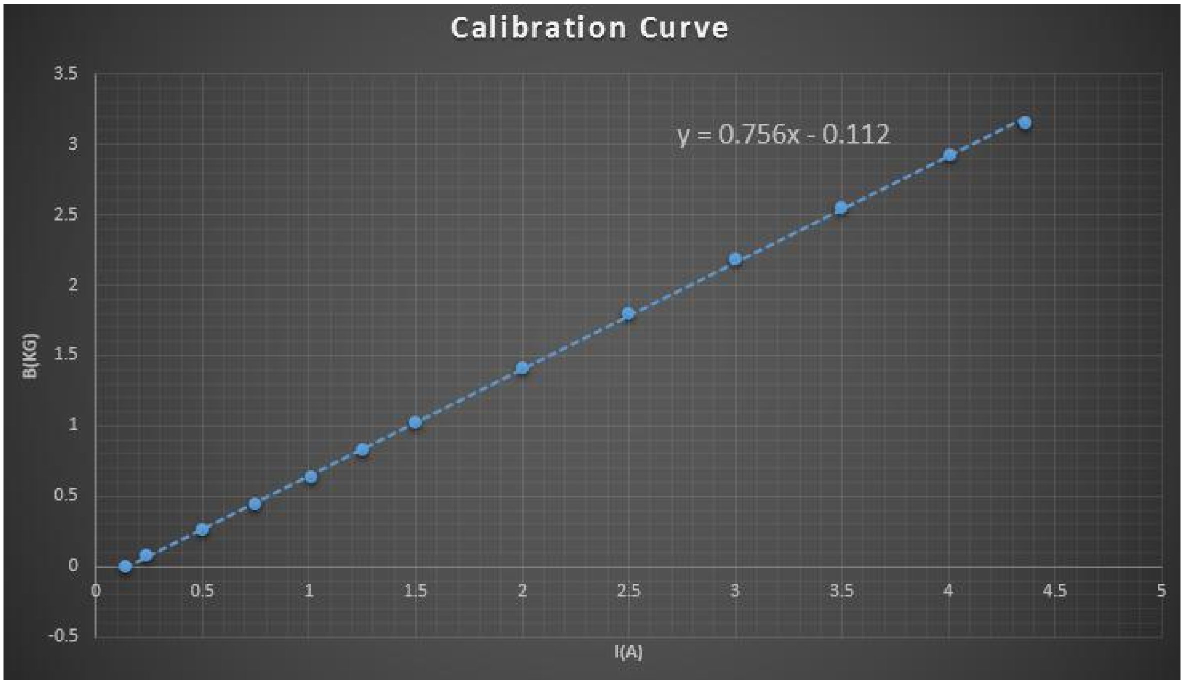

Figure 7: Calibration Curve

With magnetic field turned off,
I = 4mA
V = 328.0 mV
Therefore, Resistance without magnetic field, $R_0 = \frac{V}{I} = 82\Omega$

Probe Current I_m=1mA(Constant for the following set):

Current, I (A)	**Magnetic Field, B (kG)**	**Voltage, Vm (mV)**	**Resistance, $\mathbf{R_m = \frac{V_m}{I_m}(\Omega)}$**	$\mathbf{\frac{R-R_0}{R_0}}$	$\mathbf{B^2}$
0.51	0.273	84.8	84.8	0.03	0.074
1.02	0.659	84.9	84.9	0.04	0.433
1.32	0.885	85.0	85.0	0.04	0.784
1.60	1.10	85.1	85.1	0.04	1.20
2.00	1.40	85.3	85.3	0.04	1.96
2.25	1.59	85.4	85.4	0.04	2.52
2.51	1.78	85.5	85.5	0.04	3.19
3.00	2.16	85.9	85.9	0.05	4.65
3.51	2.54	86.2	86.2	0.05	6.46
3.75	2.72	86.4	86.4	0.05	7.41
4.00	2.91	86.5	86.5	0.05	8.48
4.39	3.21	87.0	87.0	0.06	10.2

Table 2: Observation Set I

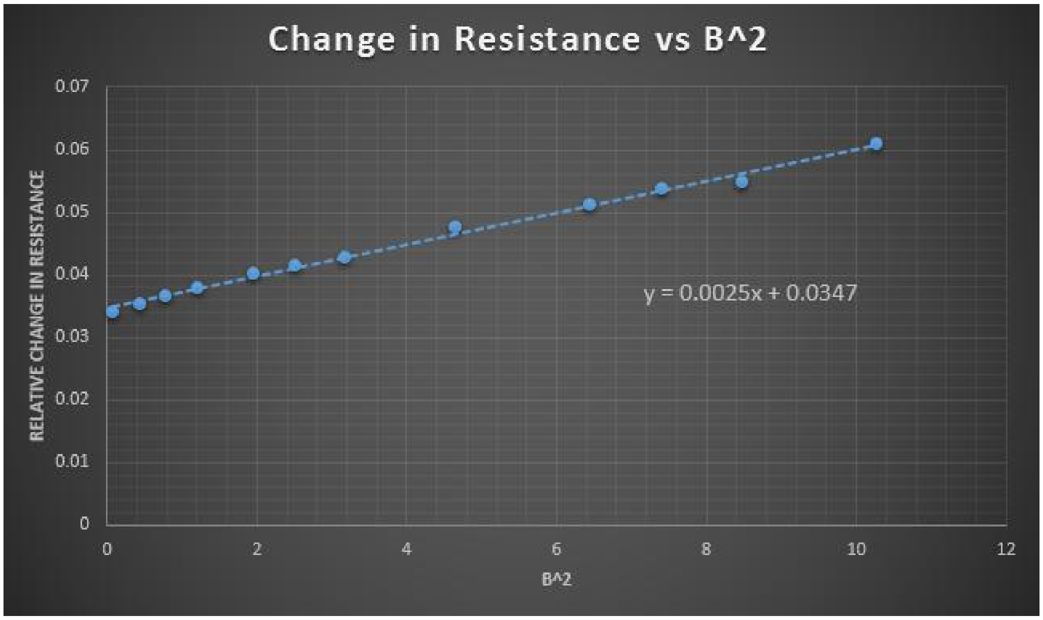

Figure 8: Relative Change in Resistance is proportional to square of magnetic field

Probe Current I_m=2mA(Constant for the following set):

Current, I (A)	**Magnetic Field, B (kG)**	**Voltage, Vm (mV)**	**Resistance, $\mathbf{R_m = \frac{V_m}{I_m}}(\Omega)$**	$\mathbf{\frac{R-R_0}{R_0}}$	$\mathbf{B^2}$
0.25	0.076	168.1	84.1	2.1	0.006
0.50	0.265	168.2	84.1	2.1	0.070
1.01	0.651	168.4	84.2	2.2	0.424
1.51	1.03	168.7	84.4	2.3	1.06
2.00	1.40	169.1	84.6	2.6	1.96
2.51	1.79	169.7	84.9	2.8	3.19
3.01	2.16	170.4	85.2	3.2	4.68
3.51	2.54	171.1	85.6	3.6	6.46
4.00	2.91	171.8	85.9	3.9	8.48
4.44	3.24	172.5	86.3	4.3	10.5

Table 3: Observation Set II

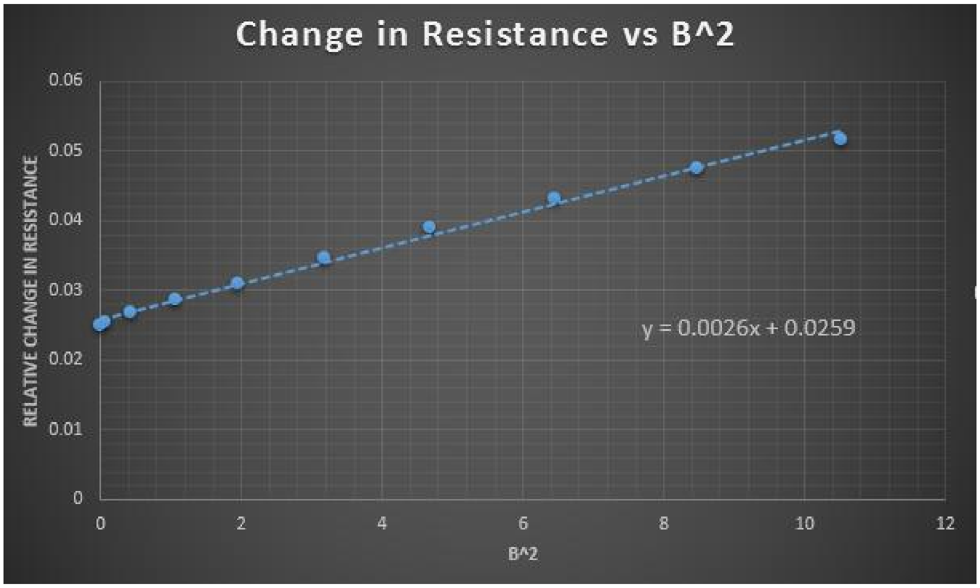

Figure 9: Relative Change in Resistance is proportional to square of magnetic field

Result:
The dependence of resistivity with external applied magnetic field was observed and studied.
The change in resistivity with the square of magnetic field was plotted.
It was observed that the change in resistivity was between 3%-6% with the proportionality constant 0.0025.

Sources of Error and Precautions:
1. Ensure that the specimen is located at the centre between the pole faces and is exactly perpendicular to the magnetic field.
2. To measure the magnetic flux the four probe should placed at the center the pole faces, parallel to the crystal.
3. Check the direction of electromagnet coils so that it generates the maximum magnetic field, this can be check by placing the soft iron near the generated magnetic field, if soft iron attracts forcefully the magnetic field produced is strong, otherwise magnetic field is weak.

Questions:
1. Give some applications of this phenomenon.
2. Do all materials exhibit magnetoresistance?
3. What is AMR(Anisotropic Magnetoresistance)?
4. What is Giant Magnetoresistance?

References:
`http://www.calpoly.edu/~jfernsle/Classes/PHYS452/Labs/452LMExp26W13.pdf`
`http://www.iiserkol.ac.in/~ph324/ExptManuals/Magnetoesistance.pdf`
`http://www.iitg.ernet.in/physics/fac/brboruah/Misc/PH511_2014.pdf`
`https://en.wikipedia.org/wiki/Magnetoresistance`
`https://en.wikipedia.org/wiki/Giant_magnetoresistance`

`https://www.nobelprize.org/nobel_prizes/physics/laureates/2007/advanced-physicsprize2007.pdf`

Author Notes:

- This Lab Manual was created for the Solid States Physics Lab during the II Semester of M.Sc Physics course at University of Delhi.
- Despite extreme caution, some errors or typos may have crept in inadvertently. If you find an error or have a correction or suggestion, then you can either email (manassharma07@live.com) me or drop a comment on this post: http://www.bragitoff.com/2017/01/magnetoresistance-experiment-lab-manual/ on my blog: http://bragitoff.com.
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