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Geometry Driven Hall Effect Analysis for Development of a Sensitive Hall Effect Sensor

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Abstract

Hall voltage and Hall resistance manifest, as various metals and semiconductors are exposed to electric and magnetic fields in specific directions. In this work, we first generated the classical Hall effect and then attempted to generate the quantum Hall effect in various metallic thin films, to analyze the generated Hall resistance. This analysis provides the backbone for building the sensor. The Hall voltage developed depends on parameters like input current, magnetic field, input voltage, and distance of magnets from the specimen. Studies suggest that there is linearity between magnetic field and Hall voltage induced. Hall effect studies have importance in determining basic magnetic properties of metals and useful in metallurgical and mining industry. This implies that 0.5 mm thickness is not sufficient to induce the quantum Hall effect and the dimension of the sample must be reduced to much less than 0.5mm so that we can observe a staircase pattern as observed in Quantum Hall effect.

Keywords: *Classical Effect, Hall Effect, Linearity, Quantum*

1.0 Introduction

The basics of solid-state physics deal with the analysis of the Hall effect which functions as an important diagnostic tool for the characterization of different materials like metals and semiconductors. Hall sensors have many applications and are used as a key component for contact less measurements of linear micro-displacements, proximity sensing, angular positioning, rotation measurement, and electric currents[1]. G Bradley Armen studied quantum hall effect on an aluminum sample[2]. Fabrication is done using an aluminum specimen and analysis is done of Quantum Hall effect (QHE) along with different plots involving various measuring parameters. Real-world values of Hall Resistance R_H are dependent on several parameters such as temperature, sample purity, and even magneticfield. C. Wouters, V. Vrankovic have studied the feasibility of the proposed Hall sensor and it has been proven in a prototype with an active volume as small as 200□m□200□m□200□m^3. It provides a high spatial resolution of 30 □m □ 30 □m □ 1 □m for each field component, full-field vector measurements practically at a single point in space and time; and a reduction of the planar Hall effect by a factor of 35. Robert Joynt and colleagues studied Quantum Hall effect and found that all physically reasonable disordered potentials should exhibit the effect at the limit of a large field (with electron density increased proportionally to the field)[4].

2.0 Materials and Dimensions

The most convenient geometry for a Hall sensor is the plate-like configuration[5]. The metal foil is generally 3-dimensional in space, which has some thickness associated to it. This simply means that the electron is allowed to flow in all the 3 dimensions. The Quantum Hall effect is very hard to achieve in this 3D metal sample,

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so there is a requirement of only a 2D metal sample. This can be achieved by gradually reducing the thickness as much as possible so that one dimension is squeezed and almost no longer exists[6]. And hence electron flow will be only in these 2 dimensions, where QHE is possibly seen. So, we firstly selected a metal sample (copper, aluminum, steel, brass, and titanium) of 2 mm and then later reduced its thickness as much as possible (up to 0.5mm) for obtaining proper results.

3.0 Methodology and Fabrication

For a typical setup, the aluminum sample with dimensions of 25 mm x 25 mm and thickness 2mm is chosen. Clean the sample before use. Have the leads of the sample face each other so that one of the opposite edges is connected to the constant source and the other opposite edge is connected to the multi meter (to measure the Hall voltage developed). To prevent a short circuit, this pattern is insulated with copper plates and some rubber insulation to develop a resistance to minimize the short circuit (Figure 1). The rubber piece is cut to the same size as the metal specimen. Then we drilled holes across the corners of all the specimens to fix them with rubber insulators. At the edges of the metal test piece, copper plates that act as an electrode are screwed to create a potential difference between the metal and copper test pieces. Now the metal piece is sandwiched between two rubber pads of the same size as the metal using a screw system. One edge of this fabricated sample is then connected to the input voltage to provide current, and the other edge is connected to a fluke meter to measure the developed Hall voltage. Place all of these settings on the sample holder along with the necessary wiring, being careful to maintain the polarity of the leads. Select magnets of different sizes and shapes for variable magnetic fields applied to the sample perpendicular to the sample. The current flows through the sample through copper plates when the whole setup is placed in the magnetic field. The magnets are chosen of different shapes and sizes with a field strength of about 36G, 40G,45G, 50G, and 55G (Figure 3). Now, the other terminal develops a voltage known as the Hall



Figure 2. Fabricated specimen with copper plate and rubber insulation

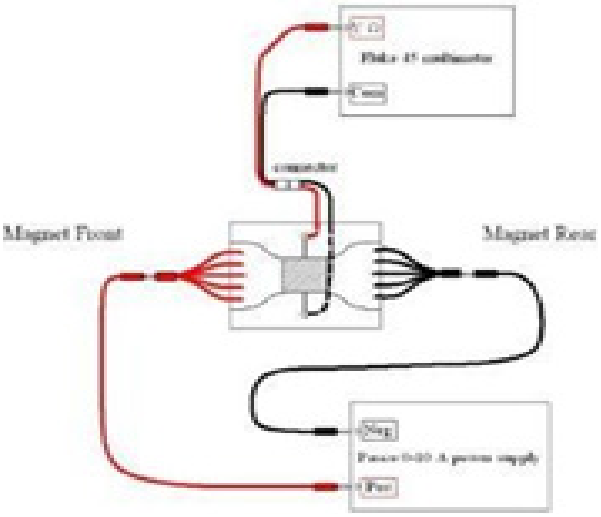


Figure 1. Circuit diagram for fabrication.



Figure 3. Magnets used of different sizes and shapes.

voltage, which can be measured with a Fluke meter or multi meter. Vary the magnetic fields by swapping out at least five different pairs of magnets of different sizes and shapes and reading the Hall voltage developed. Knowing the hall voltage, we can easily calculate the hall resistance using Ohm's law. Different curves are then drawn for different parameters, and the Hall effect is analyzed.

4.0 Results and Discussion

The analysis is performed when a small Hall voltage occurs, as the various parameters Change accordingly (Figure 4).

If the thickness of the metal sample is 2mm, the hall voltage will be lower because it is thicker in the same magnetic field. Since aluminum has a higher Hall coefficient than copper, the Hall voltage generated is superior to other metals and is proportional to the magnetic field[7]. The hole coefficient of alloys is relatively low compared to pure metals. These plots show that a thickness of 0.5 mm is not enough to achieve quantization and should be reduced until quantization is observed in the metal sample.

4.1 Results for Magnetic Field *vs* Varying Distance

Figures 5a, b, c, d, e show variations of hall voltage *vs* magnetic field when the magnets are positioned at varying distance from the sample.

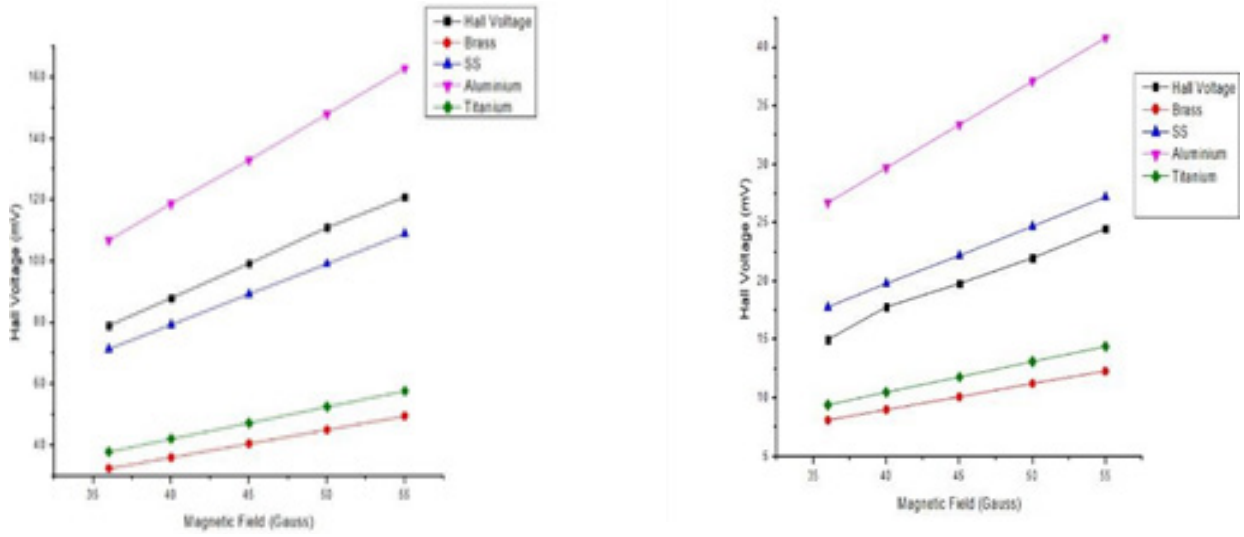
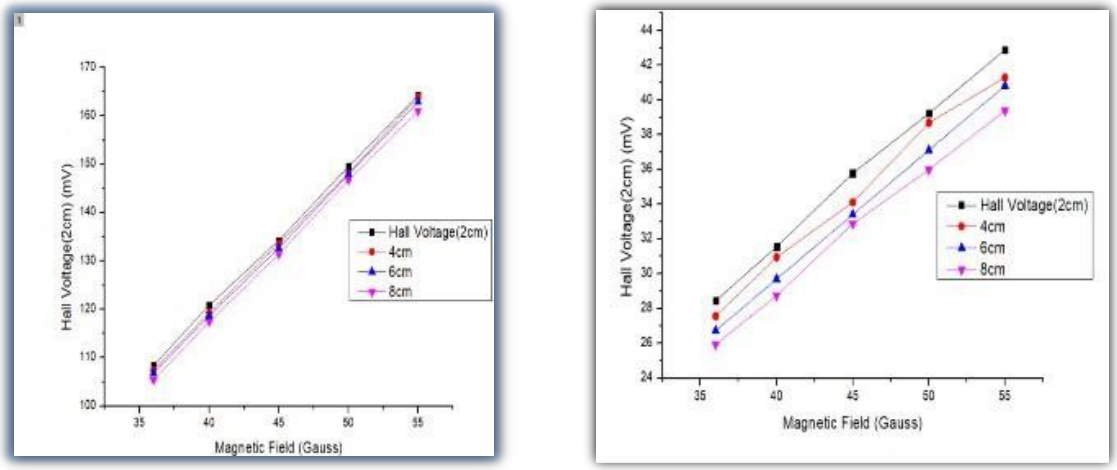


Figure 4. Plot for magnetic field vs Hall voltage for different samples.



(a)

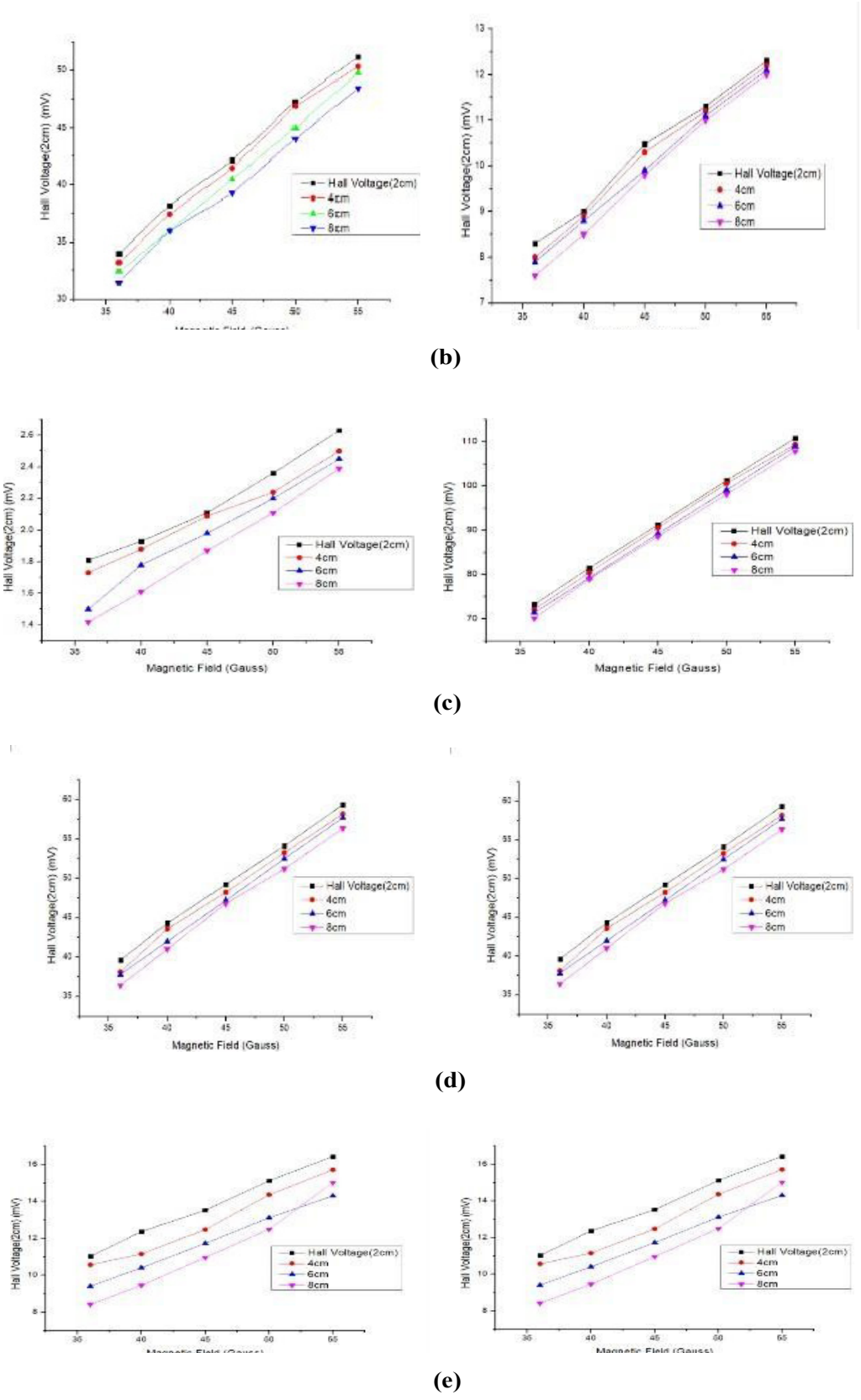
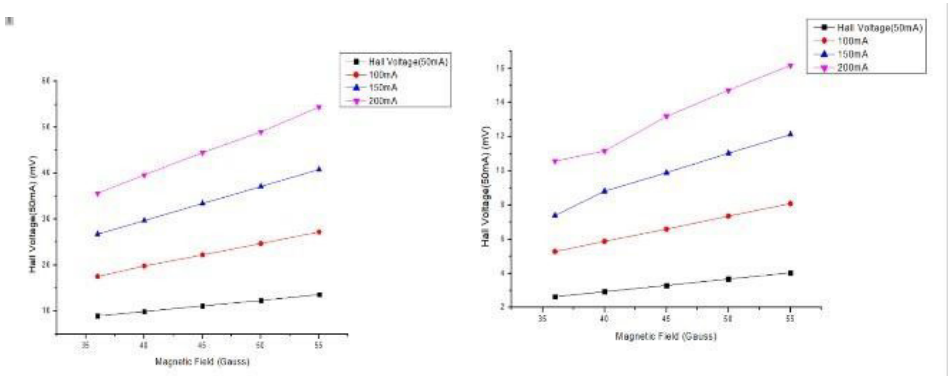


Figure 5. Magnets placed at varying distances **(a)** Aluminum **(b)** Brass **(c)** Copper **(d)** Steel **(e)** Titanium.

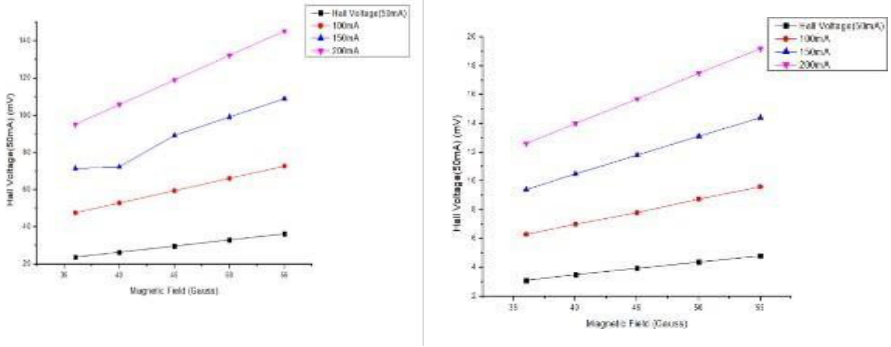
From the plots, we can infer that different distances from the metal sample do affect the Hall voltage developed. As the distance is relatively more from the metal sample, the strength of the magnetic field is exceptionally much less and has less impact on Hall voltage developed irrespective of the magnitude of input current and the input voltage given to it[8]. Then as we decrease the distance from the sample, there's a gradual increase in the Hall voltage due to the higher impact of the magnetic field onto the sample and there is proportional relation developed between the magnetic field and Hall voltage developed at different distance.

4.2 Results for Magnetic Field *vs* Input Current

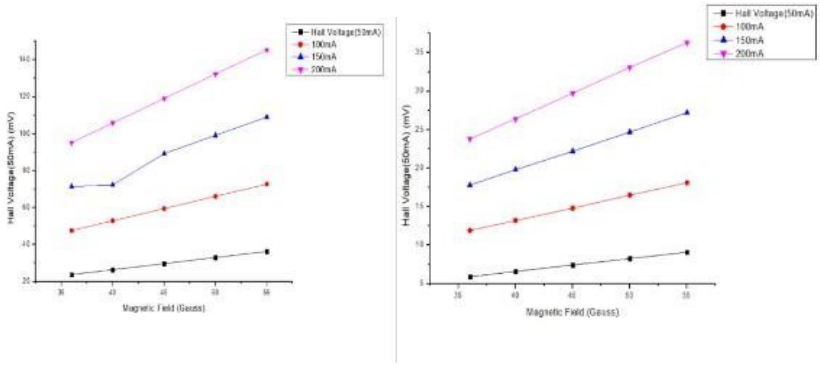
Figures 6 a, b, c, d show variations of hall voltage vs magnetic field when the input currents are varied.



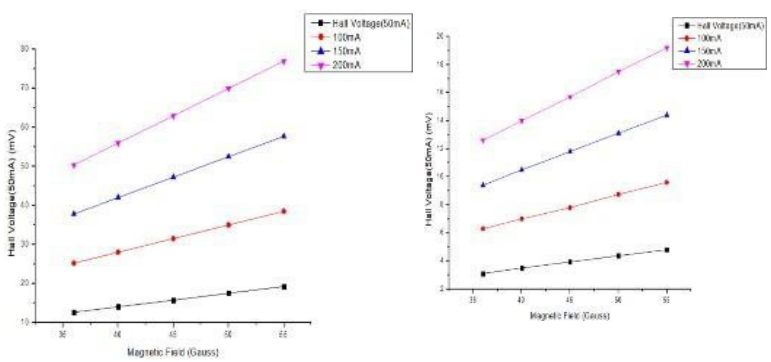
(a)



(b)



(c)



(d)

Figure 6. Hall voltage *vs* magnetic field for different input currents **(a)** Aluminum **(b)** Copper **(c)** Steel **(d)** Titanium.

In the graph, we can see that the input current supplied to the metal sample affects the Hall voltage developed, in a linear relationship with the magnetic field. In the above discussion, one can calculate the Hall resistance if one knows the Hall voltages in the different samples and understands the graphs as shown above.

5.0 Conclusion

The microscopic effects in the metal samples have an adverse effect on sensors and their functional properties. The metal samples are chosen with different thicknesses and with different charge carrier densities. A minute Hall voltage is developed across the sample in a perpendicular direction. This Hall voltage developed depends on parameters like input current, magnetic field, input voltage, and distance of magnets from the specimen. Hall voltage enables basic characterization and is having implications in the metallurgical and mining industry. Studies suggest that there is linearity between magnetic field and Hall voltage induced. This implies that 0.5 mm thickness is not sufficient to induce the quantum hall effect and the dimension of the sample has to be reduced to much less than 0.5 mm so that we can observe a staircase pattern as observed in Quantum Hall effect.

6.0 Acknowledgement

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