2. Theory

When an electric current passes through a conductor along the direction perpendicular to an external magnetic field, an electric potential difference is created in the direction perpendicular to both current and magnetic field across the two ends of the conductor. This phenomenon is known as the Hall effect, found by American physicist Hall in 1879. In general, the Hall effect in metals and electrolytes is very small, but is more notable in semiconductors such as N-type germanium, InSb, phosphorus indium arsenide, or gallium arsenide (GaAs). GaAs Hall elements are usually used for the measurement of magnetic field due to their high sensitivity, wide linear range, and lower temperature coefficient. Hall elements are known for ease of use, small probe size, and suitability for magnetic field measurement in a small region. The relative uncertainty of the Hall-effect technique is about 10^{-2}-10^{-3}.

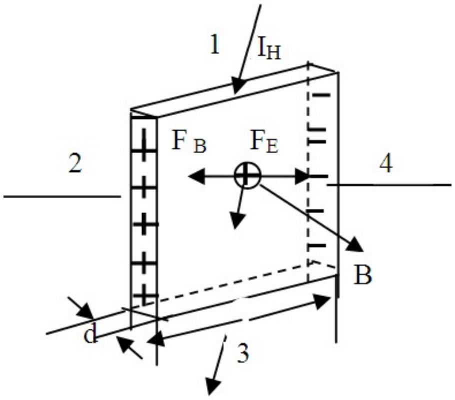

Figure 1 Schematic diagram of the generation of Hall voltage

As shown in Fig. 1, when an electric current I_H goes through a p-type Hall element for example, holes have a certain drift velocity υ, and thus the applied perpendicular magnetic field *B* creates a Lorentz force *F* on the moving charge (carrier):

$$\vec{F}_B = q\ (\vec{\upsilon} \times \vec{B}) \tag{1}$$

where *q* is the electron charge. The Lorentz force deflects the carriers in horizontal direction to accumulate at the border of the sample creating a transverse electric field *E*. This accumulation process continues until the electric field ($F_E=qE$) and the magnetic field (F_B) forces exerted on the carrier are canceled out, as

$$q\ (\vec{\upsilon} \times \vec{B}) = q\,\vec{E} \tag{2}$$

As a result, the charges are no longer deflected in the sample, creating a Hall electric potential difference by the electric field.

For an n-type sample, the transverse electric field is opposite to that of a p-type sample, so that the Hall potential differences of n-type and p-type samples have opposite signs that can be used to determine the conductive type of a Hall element. If a p-type sample has carrier concentration *p*, width ω and thickness *d*; and the current through the sample is I_H ($I_H=pq\upsilon\omega d$), then the speed of holes is $\upsilon=I_H/pq\omega d$. From Eq. (2), we have:

$$E = \left|\vec{\upsilon} \times \vec{B}\right| = I_H B / pq\omega d \tag{3}$$

If Eq. (3) is multiplied by ω on both sides, we get:

$$U_H = E\omega = I_H B/pqd = R_H \times I_H B/d \tag{4}$$

where $R_H = 1/pq$ is called the Hall coefficient. In practice, Eq. (4) is usually written as:

$$U_H = K_H I_H B \tag{5}$$

where coefficient $K_H = R_H/d = 1/pqd$ is the sensitivity of a Hall element in unit of mV/(mA·T). Generally, the larger K_H is the better. As K_H is inversely proportional to carrier concentration p and the carrier concentration in semiconductor is far smaller than that in metal, semiconductor materials are preferred for making Hall elements. K_H is also inversely proportional to thickness d, so Hall elements are made very thin, only 0.2 mm in thickness.

From Eq. (5), once Hall sensitivity K_H is known, both Hall current I_H and Hall voltage U_H are measured, magnetic field strength B can be hence calculated. This is the basis of magnetic field measurement using a Hall element.

Although theoretically $U_H=0$ when no magnetic field (i.e. $B=0$) is applied to a Hall element, in practice, the measured voltage is not zero with a digital voltmeter, as caused by the additional potential difference due to the uneven semiconductor crystal materials and the asymmetry of electrodes. This potential difference U_0 is known as residual voltage.

With the advent of science and technology, novel integrated components (IC's) are developed. This experiment uses a SS95A integrated Hall sensors (its structure is shown in Figure 2) with high-sensitivity, consisting of a Hall element, an amplifier, and a thin film resistor for compensating residual voltage. It has large output signal and the influence of residual voltage is eliminated. SS95A integrated Hall sensor has three leads, namely: "V+", "V-" and "V_{out}". "V+" and "V-" are "Current Input" terminals, and "V_{out}" and "V-"are Hall "Voltage Output" terminals. In experiment, when no magnetic field (i.e. zero magnetic field) is applied, the output voltage of the Hall sensor should be adjusted to 0.

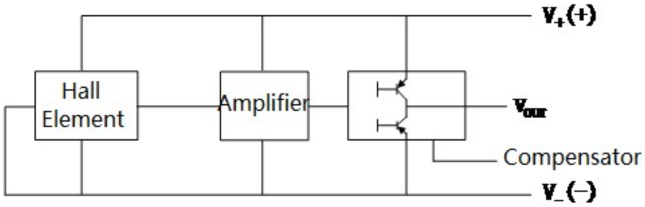

Figure 2 Internal structure of 95A integrated Hall sensor

In the presence of magnetic field B and a standard current applied to the Hall sensor, similar to Eq. (5), we have:

$$B = \frac{U}{K}.$$

where U is the output voltage of the sensor after compensation (i.e. V_{out}), K is the sensor sensitivity.