Expt. 8 Hall effect and measurement of parameter

Ⅰ. Purpose

(1) Use the Hall Effect to investigate the performance of semiconductor materials.

(2) Use the "Symmetry Measuring Method" to eliminate the influence of secondary effects.

Ⅱ. Apparatus

Hall Effect experiment instrument, Hall Effect experiment combiner, Hall Effect magnetism measuring instrument, teslameter, multimeter, etc..

Ⅲ. Principle

1. Hall Effect

If an electric current flows through a conductor in a magnetic field, the magnetic field exerts a transverse force on moving charges which tends to push them to one side of the conductor. A build up of charges at sides of the conductor results in additional transverse electric field in a direction perpendicular to the direction of magnetic field. This phenomenon is called Hall Effect.

As shown in Figure 8 - 1, we apply a current I_S in the y direction of the semiconductor sample and we apply a magnetic field B in z direction. This causes electric charge to accumulate on the x axis, generating a Hall voltage U_H. The electric field E_H caused by the electric potential difference is called the Hall field. If we assume that the carrier concentration is n, then the relation between the Hall voltage U_H, the magnetic induction density B and other quantities such as carrier concentration, n, is

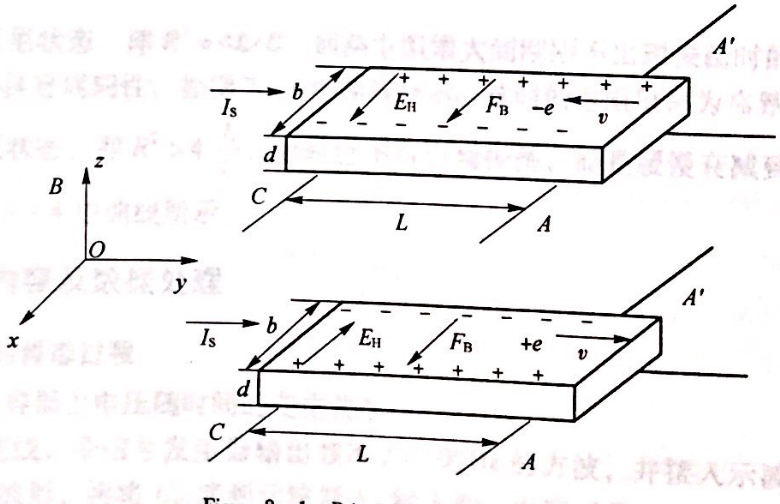

Figure 8 - 1 Principle of the Hall Effect

$$U_H = \frac{I_S B}{ned} = R_H \frac{I_S B}{d} = K_H I_S B \qquad (8-1)$$

Where: $R_H = 1/ne$, R_H is called the Hall coefficient. This is an important parameter which reflects magnitude of the Hall Effect in the material. $K_H = R_H/d = 1/ned$, where K_H is Hall element sensitivity, unit inV/ (A · T).

The positive or negative sign of the Hall voltage (or value for R_H) and the direction of magnetic field determine the conduction type of the sample. Semiconductor materials can be divided into P type (hole type) and N type (electron type). If the measured $U_H > 0$, then R_H is positive and the sample is P type. If $U_H < 0$, then R_H is negative and the sample is N type.

The Hall element sensitivity K_H is a constant, in general the bigger the better. If we measure the values of the Hall current I_S and corresponding Hall voltages U_H we can determine the magnitude of the magnetic induction density B; this is the principle of the measurement of magnetic field using the Hall Effect.

The conductivity σ of a semiconductor is given by:

$$\sigma = \frac{I_S L}{U_{CA} S} \qquad (8-2)$$

Carrier mobility μ: the relationship between conductivity σ, carrier concentration n and mobility μ is as follows:

$$\mu = |R_H| \sigma \qquad (8-3)$$

2. Elimination of secondary effects in the Hall Effect

The Hall Effect is accompanied by multiple secondary effects which create voltages superimposed on the Hall voltage, causing errors to the measurement of the Hall Effect. These secondary effects can all be decreased or eliminated by changing the direction of the operating current or magnetic field. We change the current direction and the magnetic field direction in turn and take measurements under four conditions: $(+B, +I_S)$, $(-B, +I_S)$, $(+B, -I_S)$ and $(-B, -I_S)$. We take the average value of each "Hall voltage" to give:

$$U_H = \frac{1}{4}(|U_1| + |U_2| + |U_3| + |U_4|) \qquad (8-4)$$

3. Coupling degree of a pair of coaxial coils

When the span "a" of a pair of coaxial coils equals the radius R of each coil, they form the so called "Helmholtz coils". These coils have a uniform distribution of magnetic field intensity H on the axis but when $a \neq R$, the H on the axis will be non-uniform. The coupling degree of the two coils (for example under-coupling, over-coupling) can be measured by the Hall Effect.

Ⅳ. Experimental

(1) Measure the electromagnet excitation curve, i. e. $I_M - B$ Curve, by Teslameter.

The Teslameter is the instrument which uses the principle of the Hall Effect to measure magnetic induction density, B. Measure the magnetic induction density B at the centre of the electromagnet for the magnet current values I_M (0.100 – 0.800 every 0.100). Draw the $I_M - B$ curve.

Notes: The Hall probe is made of extremely thin semiconductor material, which is very fragile. Be very careful when using it! Protect it by the casing tube whenever it is not in use.

(2) Fixing I_M, measure $U_H - I_S$ curve.

Take $I_M = 0.50$A. Adjust I_S, the sample current, making I_S at certain value, such as $I_S = 1.00$mA, then using the method to eliminate the secondary effects; get U_H values in the range of $I_S = 1.00 - 10.00$mA. Measure corresponding U_H values for each increase in 1.00mA, and draw the $U_H - I_S$ relation curve.

(3) Fixing I_S, measure $U_H - I_M$ curve.

Make $I_S = 5$mA. Adjust I_M, making $I_M = 0.100$A, 0.200A, ..., 0.800A. Use the method to eliminate secondary effects to get corresponding U_H value and draw the $U_H - I_M$ relation curve.

(4) Under zero magnetic field ($B = 0$), $I_S = 0.20$mA, measure the value of U_{CA}.

(5) Based on the formula, calculate the Hall sensitivity K_H, the Hall coefficient R_H and the carrier concentration n, finally determine $\overline{K_H}$, $\overline{R_H}$, $\overline{n}$.

(6) Use the formula to calculate the values of conductivity and carrier mobility. For the Hall plate $b = 4$mm, $L = 3$mm, $d = 0.5$mm.

(7) Determine the conduction type of the sample from the sign of the Hall voltage. Whether it is N type or P type?

(8) Observe the coupling degree of a pair of coaxial coils (see Figure 8 – 2).

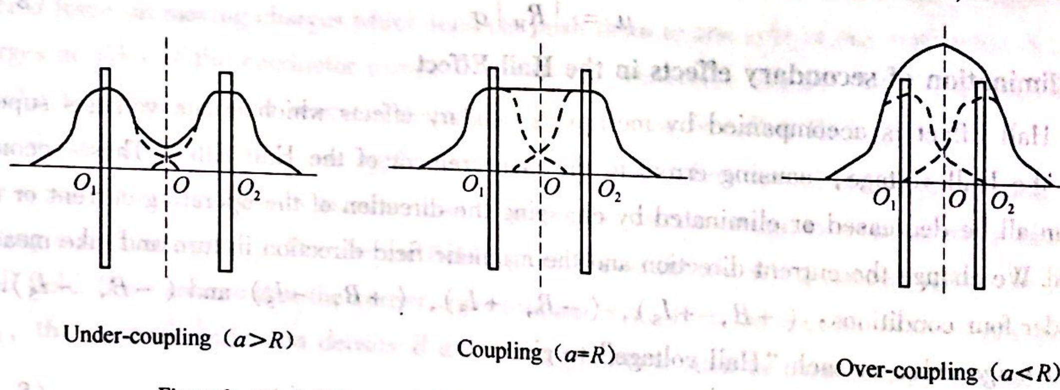

Figure 8 – 2 Relation of Distribution of Magnetic Field and Coil Spacing on the Axis

First of all connect the two coaxial coils in series, then adjust the exciting current of the Hall Effect combiner to 0.80A. Set the current of Hall Effect magnetism measuring instrument to 8mA. Alter the distance "a" between the two coaxial coils, by making, in turn, $a > R$, $a = R$, $a < R$. Measure the values of "a" and R.

Move the probe bar of the Hall element along the axial direction between the two coils. Record the probe bar travelling distance X and the corresponding Hall voltage value. Take more than 10 different position points for each of the three coupling states separately, and design the data table by yourself. Draw the $U_H = f(x)$ relation curve of the coaxial coils in the three coupling states.

Notes: The Hall plate only uses a very small current. NEVER mistakenly connect it to the exciting current of the Hall Effect Combiner!

V. Questions

1. What precautions should you take when using a teslameter to measure magnetic field?
2. What requirements are there on a material used to manufacture a Hall plate?

实验八　霍尔效应及其参数测定

一、实验目的

（1）掌握利用霍尔效应研究半导体材料性能的方法。

（2）学习用“对称测量法”消除副效应影响的方法。

二、实验仪器

霍尔效应实验仪，霍尔效应实验组合仪，霍尔效应测磁仪，特斯拉计，万用表等。

三、实验原理

1. 霍尔效应

置于磁场中的载流体，如果电流方向与磁场垂直，则在垂直于电流和磁场的方向会产生一附加的横向电场，这一现象叫做霍尔效应。

如图 8－1 所示，在半导体试样的 y 方向通电流 I_S，z 方向加磁场 B，则在 x 方向产生电荷的积累，从而产生霍尔电压 U_H，该电势差引起的电场 E_H 称为霍尔电场。设载流子浓度为 n，则霍尔电压 U_H 与磁感应强度 B 及载流子浓度等量间的关系为

$$U_H = \frac{I_S B}{ned} = R_H \frac{I_S B}{d} = K_H I_S B \tag{8-1}$$

式中：$R_H = 1/ne$，R_H 称为霍尔系数，它是反映材料霍尔效应大小的重要参数；

$K_H = R_H/d = 1/ned$，K_H 为霍尔元件的灵敏度，单位为 V/（A·T）。

根据霍尔电压的正负（或 R_H 的符号）及磁场的方向可以判断样品的导电类型，半导体材料有 P 型（空穴型）和 N 型（电子型）两种。由图 8－1 可看出，若测得的 $U_H > 0$，则 R_H 为正，样品为 P 型。若 $U_H < 0$，则 R_H 为负，样品为 N 型。

对于确定的霍尔元件，灵敏度 K_H 是一个常数，一般要求越大越好。若测得霍尔电流 I_S 和相应的霍尔电压 U_H 值，则可求得磁感应强度 B 的大小，这就是利用霍尔效应测磁场的原理。

半导体的电导率 σ：

$$\sigma = \frac{I_S L}{U_{CA} S} \tag{8-2}$$

载流子迁移率 μ：电导率 σ 与载流子浓度 n 及迁移率 μ 之间有如下关系

$$\mu = |R_H| \sigma \tag{8-3}$$

2. 实验中的副效应及其消除法

在霍尔效应产生的同时，会伴随着多种副效应，这些副效应产生的电压叠加在霍尔电压上，对霍尔效应的测量带来了误差。这些副效应均可通过改变工作电流或磁场的方向来减小

或消除。即依次改变电流方向、磁场方向，在 $(+B, +I_S)$、$(-B, +I_S)$、$(+B, -I_S)$、$(-B, -I_S)$ 四种条件下进行测量，取各测量值的平均值。近似可得：

$$U_H = \frac{1}{4}(|U_1| + |U_2| + |U_3| + |U_4|) \qquad (8-4)$$

3. 一对共轴线圈的耦合度

当一对共轴线圈的间距 a 等于线圈的半径 R 时，构成所谓的"亥姆霍兹线圈"，此时轴线上的磁场强度 H 分布是均匀的，当 $a \neq R$ 时，其轴线上的 H 将是不均匀的，会出现欠耦合、过耦合状态。两线圈的耦合度可以通过霍尔器件来检测。

四、实验内容

(1) 用特斯拉计测定电磁铁励磁曲线，即 $I_M - B$ 曲线。

特斯拉计是利用霍尔效应原理制成用来测量磁感应强度的仪器。测定电磁铁间隙中心处的磁感应强度 B，作出 $I_M - B$ 曲线。

注意：霍尔探头是由极薄的半导体材料制成的，很脆，易碎，使用必须小心！不用时立即用套管保护好。

(2) 固定 I_M，测定 $U_H - I_S$ 曲线。

令 $I_M = 0.50\text{A}$。调节 I_S，使 I_S 为某一值，例如 $I_S = 1.00\text{mA}$，然后按照消除副效应方法得到一个 U_H，在 $I_S = 1.00 \sim 10.00\text{mA}$ 的范围，每间隔 1.00mA 分别测出所对应的 U_H，并画出 $U_H - I_S$ 关系曲线。

(3) 固定 I_S，测定 $U_H - I_M$ 曲线。

令 $I_S = 5\text{mA}$。调节 I_M，使 $I_M = 0.100\text{A}, 0.200\text{A}, \cdots, 0.800\text{A}$，按照消除副效应方法分别得到各 U_H 值，画出 $U_H - I_M$ 关系曲线。

(4) 在零磁场下 $(B=0)$，$I_S = 0.20\text{mA}$ 时，测出 U_{CA} 值。

(5) 根据公式计算霍尔灵敏度 K_H，霍尔系数 R_H 及载流子浓度 n，最后求出 $\overline{K_H}$，$\overline{R_H}$，$\overline{n}$。

(6) 根据公式计算电导率和载流子的迁移率。

霍尔片 $b = 4\text{mm}$，$L = 3\text{mm}$，$d = 0.5\text{mm}$。

(7) 由霍尔电压的正负判断样品的导电类型，是 N 型还是 P 型。

(8) 观察一对共轴线圈的耦合度。

首先将两个共轴线圈串联相接，然后调节霍尔效应组合仪的励磁电流为一定值 0.80A，将霍尔效应测磁仪的工作电流调为 8mA。改变两个共轴线圈间距 a，分别使 $a > R$，$a = R$，$a < R$，求出 R 值。

将霍尔器件的探针杆在两个线圈间沿轴线方向移动，记录探针杆移动的距离 X 及对应的霍尔电压值，三种耦合状态分别需要各取 10 个以上不同位置点，自己设计数据表格。

做出共轴线圈在三种耦合状态下的 $U_H = f(x)$ 的关系曲线图。

注意：霍尔片允许通过的电流很小，切勿与励磁电流接错！

五、思考题

1. 用特斯拉计测量磁场时要注意什么？
2. 对制造霍尔片的材料有什么要求？

实验十八　霍尔效应及其参数测定

表 1　测定磁感应强度

I_M/A	0.800	0.700	0.600	0.500	0.400	0.300	0.200	0.100
B/mT								

表 2　测量 U_H—I_S 关系数据

I_S/mA	V_1/mV	V_2/mV	V_3/mV	V_4/mV	U_H/mV
1.00					
2.00					
3.00					
4.00					
5.00					
6.00					
7.00					
8.00					
9.00					
10.00					

表 3　测量 U_H—I_M 关系数据

I_M/A	0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800
U_H/mV								

表 4　霍尔灵敏度 K_H，霍尔系数 R_H 及载流子浓度 n 数据

I_S/mA	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
U_H/mV										
K_H										
R_H										
n										
$\overline{K_H}$										
$\overline{R_H}$										
$\overline{n}$										