Atomic Structure and Semiconductor

Lecture - 44

(29/04/2021)

B.Sc (Electronics)
TDC PART - I
Paper – 1 (Group – B)
Chapter – 4
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➢ Hall Effect (PART – 3)

(3) Hall Angle(θ_H):-

⇨ The net **Electric Field** **E** in the Specimen Conductor is a **vector sum of Electric Field component in the X-direction** because of flow of **current,** E_x and **Electric Field** due to **Hall Effect** i.e., E_H, as shown below in **Figure (3).**

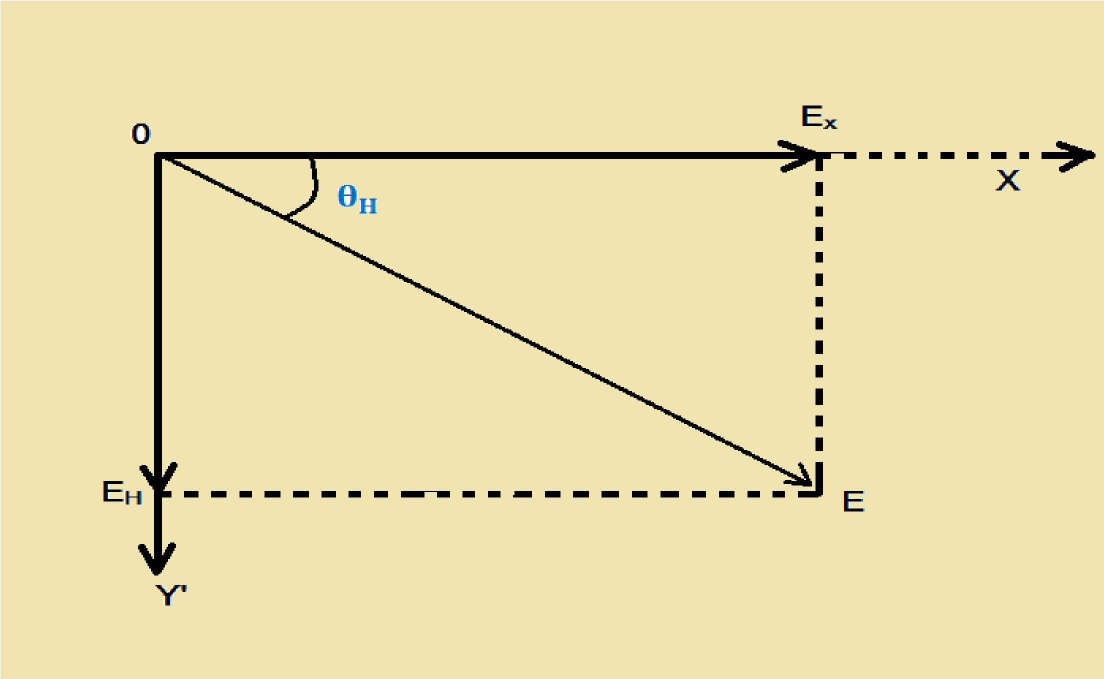

Fig. (3) Shown The net **Electric Field** E in the specimen is a **vector sum of Electric Field component in the X-direction** because of flow of **current,** E_x and **Electric Field** due to **Hall Effect** i.e., E_H.

⇨ So **Resultant Electric Field E** acts at an **angle of** θ_H to the **X-axis** and **this angle is called Hall Angle.**

⇨ Thus, **Hall Angle**, $\theta_H = \tan^{-1}\frac{E_H}{E_x}$ .... **(30)**

⇨ Now from **equation (3)** of **Lecture - 43,** we have,

$\because$ **Electric Field,** $E_H = \frac{V_H}{d}$ .... **(3)**

⇨ and **Electric Field** component in the **X-direction,** we have,

$\therefore E_x = \frac{\text{Voltage drop along the length}}{\text{Length of Specimen}}$ .... **(31)**

or, $E_x = \frac{I\,R}{l}$ .... **(32)**

or, $E_x = \frac{I \times \text{resistivity} \times l}{l \times a}$ .... **(33)**

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$$\text{or, } E_x = \frac{I}{a} \times \text{resistivity} \quad \ldots\ldots (34)$$

$$\text{or, } E_x = J \times \frac{1}{\sigma} \quad \ldots\ldots (35)$$

$$\text{or, } E_x = \frac{J}{\sigma} \quad \ldots\ldots (36)$$

⇨ Now substituting the values of $E_H = \frac{V_H}{d}$ from **equation (3)** of **Lecture – 43** and $E_x = \frac{J}{\sigma}$ from above **equation (36)** in expression for **Hall Angle,** we have,

$$\because \theta_H = \tan^{-1}\frac{E_H}{E_x} \quad \ldots\ldots (30)$$

$$\therefore \theta_H = \tan^{-1}\frac{V_H/d}{J/\sigma} \quad \ldots\ldots (37)$$

⇨ Now putting the value of $V_H = \frac{B\,I}{\rho\,w}$ from **equation (12) of Lecture – 43,** into the above **equation (37),** then we gets,

$$\because \theta_H = \tan^{-1}\frac{V_H/d}{J/\sigma} \quad \ldots\ldots (37)$$

$$\therefore \theta_H = \tan^{-1}\frac{\frac{B\,I}{\rho\,w}/d}{J/\sigma} \quad \ldots\ldots (38)$$

$$\text{or, } \theta_H = \tan^{-1}\frac{B\,I/\rho w d}{J/\sigma} \quad \ldots\ldots (39)$$

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⇨ Now again putting the value of **I = w d J** into the above **equation (39)** then we get,

$\because\ \mathbf{J = \frac{I}{w\,d}}$ From **equation (8) of Lecture - 43**, we have**,**

$\therefore\ \mathbf{I = w\,d\,J}$

$$\because\ \theta_H = \tan^{-1}\frac{BI/\rho wd}{J/\sigma} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (39)$$

$$\therefore\ \theta_H = \tan^{-1}\frac{B\,w\,d\,J/\rho wd}{J/\sigma} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (40)$$

$$\text{or, } \theta_H = \tan^{-1}\frac{B\,J/\rho}{J/\sigma} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (41)$$

$$\text{or, } \theta_H = \tan^{-1}\frac{B\,\sigma}{\rho} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (42)$$

⇨ Now again putting the value of $\mathbf{R_H = \frac{1}{\rho}}$ into the above **equation (42)** then we get,

$\because\ \mathbf{R_H = \frac{1}{\rho}}$ From **equation (25) of Lecture - 43**, then we have

$$\because\ R_H = \frac{1}{\rho} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (25)$$

From above **equation (37)** we have,

$$\because\ \theta_H = \tan^{-1}\frac{B\,\sigma}{\rho} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (42)$$

$$\therefore\ \theta_H = \tan^{-1}\sigma\,B\,R_H \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (43)$$

⇨ In any **Extrinsic semiconductor**, the **Conductivity** is due to charge of one type.

Hence the **conductivity σ** is given as,

$$\therefore\ \sigma = \rho\,\mu \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (44)$$

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⇨ Now again if the **conductivity** σ is measured together with the Hall Coefficient, the **Mobility** μ can be determined from the relation,

$$\therefore \ \mu = \sigma R_H \quad \text{...} \quad (45)$$

⇨ Now again putting the above value of $\mu = \sigma R_H$ into the above **equation (43)** then we get,

⇨ From above **equation (43)** we have,

$$\because \ \theta_H = \tan^{-1} \sigma B R_H \quad \text{...} \quad (43)$$

⇨ **Final Expression for Hall Angle is,**

$$\therefore \ \theta_H = \tan^{-1} \mu B \quad \text{...} \quad (44)$$

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(4) Hall Effect Experiment:-

A rectangular sample of the given material having **Thickness d meters** and **Width w meters** is taken and a **current of I amps** is allowed to pass through the sample by connecting it to a **Battery (DC)** V_B shown below in **Figure (4).**

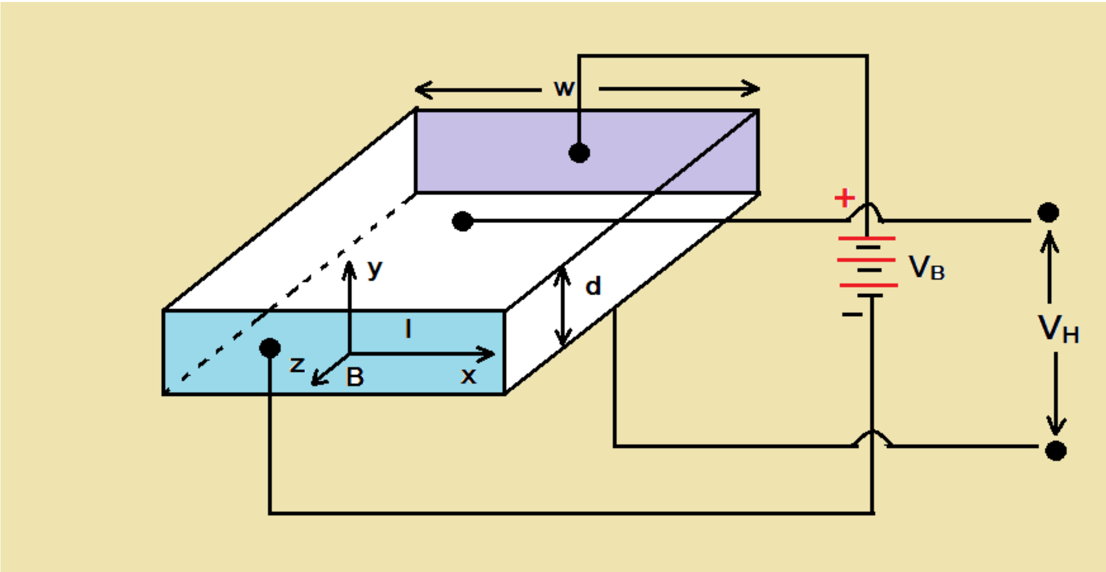

Fig. (3) Shown set up for the measurement of **Hall Voltage V_H.**

The **sample is then placed between two pole pieces of an electromagnet** such that if the current direction **coincides with the X-axis**, the **magnetic flux density B coincides with the Z-Axis**, as shown above in **Figure (4).**

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The **Hall Voltage** V_H is then measured by **placing two probes at the centers** of the top **and** bottom **faces** of the sample. If the **Magnetic Flux Density is B weber/m^3** and the **Voltage is** V_B **volts** then **Hall Coefficient** R_H is obtained from **equation (18)** and **equation (26)** of **Lecture – 43**, in **m^3/coulomb.**

(5) Uses of Hall Effect:-

The Hall Effect may be used to,

(1) Determination of Semiconductor Type

⇨ For an **N-type semiconductor** the **Hall Coefficient** is **Negative,** whereas for a **P-type semiconductor** it is **Positive.** Thus, the **sign** of the **Hall Coefficient** can be used to determine whether a given semiconductor is **N-type or P-type.**

(2) Determination of Carrier Concentration

⇨ By measuring the **Hall Coefficient** the **Carrier Concentration** of a semiconductor can be determined from the **equation (28)** and **equation (29).** Thus,

⇨ If the **current carriers are Electrons**, the **charge** on the **carrier** is **Negative,** and hence,

⇨ $$R_H = -\frac{1}{n\,e} \quad \text{..........} \quad (28)$$

Where, **n** represents the **concentration of Electrons.**

$$\therefore\ n = -\frac{1}{e\,R_H}$$

and

⇨ If the **current carriers are Holes**, the carrier **charge** is **Positive** and therefore,

⇨ $$R_H = +\frac{1}{p\,e} \quad \text{..........} \quad (29)$$

Where, **p** represents the **Holes concentration.**

$$\therefore\ p = +\frac{1}{R_H\,e}$$

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(3) Measurement of Magnetic Flux Density

⇨ Since the **Hall Voltage** V_H is proportional to the **Magnetic Flux Density** **B** for a given **Current** **I** through a sample, the **Hall Effect** can be used as the basis for the design of a **Magnetic Flux Density meter.**

(4) Hall Effect Multiplier

⇨ If the **Magnetic Flux Density** **B** is produced by passing a **Current** **I** through an **air-core coil,** **B** will be **proportional** to **I'**. The **Hall voltage** V_H is thus **proportional** to the product of **I and I'**. **This forms the basis of a Multiplier.**

(5) Measurement of Power in an Electromagnetic Wave

⇨ In an **Electromagnetic wave** in free space the **Magnetic Field** **B** and the **Electric Field E** are at **right angles**. Thus, if a semiconductor sample is **placed parallel to E** it will drive a **Current** **I** in the semiconductor. The semiconductor is subjected simultaneously to a **Transverse Magnetic Field** **B** producing a **Hall Voltage** across **the sample.** The **Hall Voltage** V_H will be proportional to the **product** **EB,** i.e., to the magnitude of the **Poynting vector of the electromagnetic wave**. Thus, the Hall Effect can be used to determine the **power flow in an electromagnetic wave.**

(6) Determination of Mobility

⇨ If the conduction is due to **one type of carrier**, e.g., **Electrons** we have,

$$\sigma = n\,e\,\mu \quad \text{.......} \quad (45)$$

Where, μ is the **mobility of Electrons**.

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⇨ Using **equation (28) of Lecture -43** we get,

$$\therefore \ R_H = -\frac{1}{n\,e} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (28)$$

Where, **n** represents the **concentration of Electrons.**

$$\therefore \ \mu = \sigma\,|R_H| \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (46)$$

i.e., knowing **σ** and determining R_H , the mobility **μ** can be determined. Because of the presence of the **term r** in **equation (27)** from **Lecture – 43**,

$$\therefore \ R_H = \frac{r}{n\,e} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (27)$$

The **Mobility** determined from the **Hall Coefficient** will be different from the **Mobility define in previous Lecture**. The **Mobility** as determined from above **equation (46)** is, therefore, **called the Hall Mobility** to **distinguish it from the actual Drift Mobility**. However, since the **factor r** is not much different from unity, the two **Mobilities are nearly the same.**

THE END
CHAPTER - 4

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