Atomic Structure and Semiconductor

Lecture - 43

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B.Sc (Electronics)
TDC PART - I
Paper – 1 (Group – B)
Chapter – 4
by:

Dr. Niraj Kumar

Assistant Professor (Guest Faculty)

Department of Electronics

L. S. College, BRA Bihar University, Muzaffarpur.

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➢ Hall Effect (PART – 2)

(2) Hall Voltage (V_H):-

⇨ A **Semiconductor Bar** carrying a **Direct Current** **I** in the **Positive** **X-direction** and placed in a **Magnetic Field** **B** acting in the **Positive** **Z-direction** is illustrated and shown below in **Figure (2).**

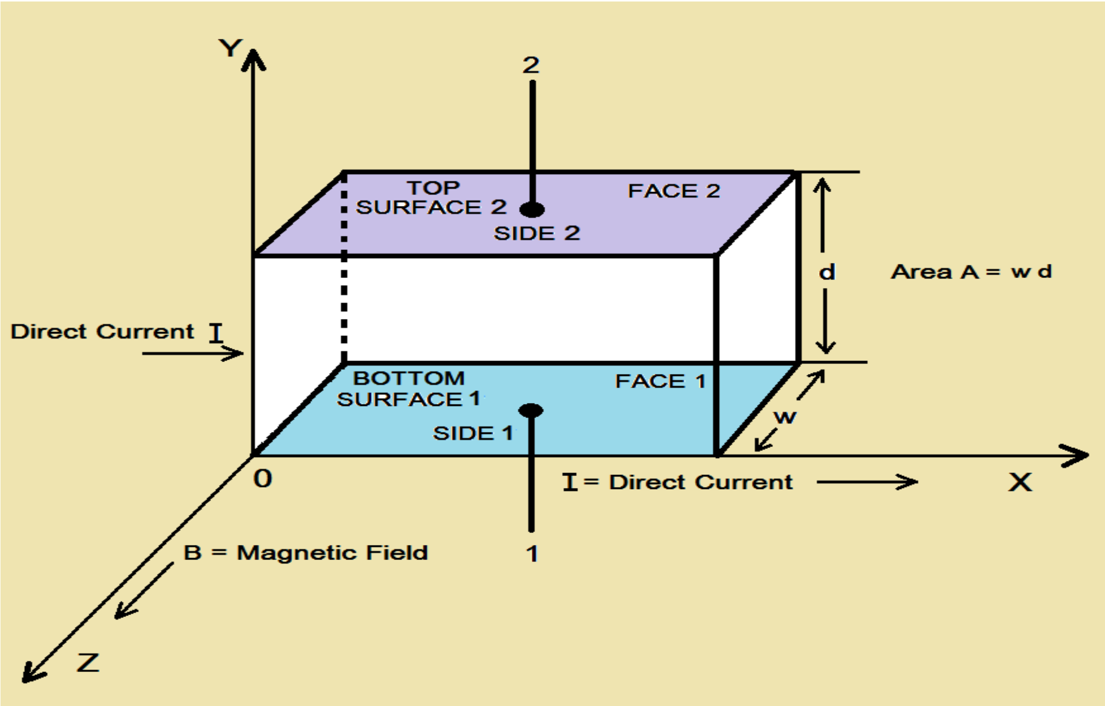

Fig. (2) Shown a semiconductor bar carrying a **Current I** in the **Positive X-direction** and placed in **Magnetic Field B** acting in the **Positive Z-direction.**

- Now a **Force is exerted** on the **charge carriers (Electrons or Holes)** in the **Negative Y-direction.** If the **Semiconductor Bar** is of **N-type**, so that the **current** is **carried** by **Electrons,** these electrons will be forced downward toward **Side-1** and **Side-1** becomes **Negatively Charged with respect to Side-2. Thus a Potential Difference** V_H **called the Hall Voltage** is developed between **Bottom Surface-1** and **Top Surface-2. The Polarity of Hall Voltage** V_H **enables us to determine whether the Semiconductor specimen Bar is N-type or P-type.** In case of **P-type semiconductor, Side-1** will become **Positively Charged with respect to Side-2.**

- If E_H is the **Hall Field** in the **Y-direction**, the **force due to this Hall field on a Carrier** of charge **e** is $e\ E_H$. The **Average Lorentz Force on a Carrier is** $B\ e\ v$ where, v is the **Drift Velocity** in the **X-direction.** In equilibrium these two force balance, i.e.,

- In **other word** we can say the above statement as, in the **equilibrium state** the **Electric Field Intensity** E_H due to **Hall Effect** must exert a force on the **charge carriers e** is $e\,E_H$ **which just balances the Magnetic Force on a Carrier is** $B\,e\,v$, i.e.,

$$\therefore\quad e\,E_H = B\,e\,v \quad \text{..........} \quad (1)$$

$$\text{or, } E_H = B\,v \quad \text{..........} \quad (2)$$

Where, **e** is the **Magnitude of charge on electron or hole** and **v is the Drift Velocity**.

- Now **Electric Field** is calculated using above discussion, then we get,

$$\therefore\ \text{Electric Field, } E_H = \frac{V_H}{d} \quad \text{..........} \quad (3)$$

$$\text{or, } V_H = E_H\,d \quad \text{..........} \quad (4)$$

- Now putting the value of $E_H = B\,v$ from above **equation (2)** into the **equation (4),** then we get,

$$V_H = B\,v\,d \quad \text{..........} \quad (5)$$

Where, **d** is the distance between **Surface-1** and **Surface-2.**

- Now if **J** is the **Current Density** in the **X-direction**, then the **Current Density J** is given as,

$$\therefore\ J = \frac{I}{A} \quad \text{..........} \quad (6)$$

⇨ We know that from **Figure (2) Area** $A = w\,d$, then putting the value of **A** in the above **equation (6),** then we get,

$$\therefore\ J = \frac{I}{w\,d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

$$\text{or, } J = \frac{I}{w\,d} = \rho\,v \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

Where, ρ is the **Charge Density** and **w** is the **Width of specimen Conductor.**

⇨ Now from above **equation (8),** we get,

$$\therefore\ v = \frac{I}{\rho\,w\,d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

⇨ Now putting the values of **v** from above **equation (9)** into **equation (5),** then we get,

$$\because\ V_H = B\,v\,d \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

$$\because\ v = \frac{I}{\rho\,w\,d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

$$\therefore\ V_H = B\,\frac{I}{\rho\,w\,d}\,d \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

$$\text{or, } V_H = \frac{B\,I\,d}{\rho\,w\,d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

$$\therefore\ V_H = \frac{B\,I}{\rho\,w} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

⇨ Thus from the above **equation (12), Charge Density** ρ can be determined if the **quantities** **B, I,** V_H and **w** are measured.

⇨ The **Hall Effect** is described by means of the **Hall Coefficient** R_H defined in terms of the **Current Density** **J** by the relation given below,

$$\therefore\ E_H = R_H\, J\, B \quad \text{.......................................} \quad (13)$$

(3) Hall Coefficient (R_H):-

⇨ The **Hall Coefficient** is determined by **measuring** the **Hall Voltage** that generates the **Hall Field**. If V_H is the **Hall Voltage** across a sample of **thickness d** as shown in above **Figure (2)**, then we get,

$$\therefore\ V_H = E_H\, d \quad \text{.......................................} \quad (14)$$

⇨ Using above **equation (13)** we can write,

$$\therefore\ V_H = R_H\, J\, B\, d \quad \text{.......................................} \quad (15)$$

⇨ If **w** is the **Width** of the sample then its **cross-sectional Area** is **dw** and **the Current Density** **J** is given by,

$$\therefore\ J = \frac{I}{d\,w} \quad \text{.......................................} \quad (16)$$

Where **I** is the **Current** flowing through the sample.

⇨ Now from **equation (15)** and **equation (16)** then we get,

$$\therefore\ V_H = \frac{R_H\, J\, B}{w} \quad \text{.......................................} \quad (17)$$

Hence,

$$\therefore\ R_H = \frac{V_H\ w}{I\ B} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (18)$$

⇨ Hence, **Hall Field per Unit Current Density per Unit Magnetic Field** is **called the Hall Coefficient**.

⇨ So **Hall coefficient**, $R_H = \frac{\text{ElectriC Field due to Hall Effect}}{\text{Current Density} \times \text{Magnetic Field}}$ ……………. (19)

$$\therefore\ R_H = \frac{E_H}{J \times B} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (20)$$

⇨ Now putting the value of $E_H = \frac{V_H}{d}$ **from equation (3)** into above **equation (20)** then we get,

$$\because\ R_H = \frac{E_H}{J \times B} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (20)$$

$$\therefore\ R_H = \frac{\frac{V_H}{d}}{J \times B} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (21)$$

⇨ Now, again putting the value of $V_H = \frac{B\ I}{\rho\ w}$ from **equation (12)** into above **equation (21)** then we get,

$$\because\ R_H = \frac{\frac{V_H}{d}}{J \times B} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (21)$$

$$\therefore\ R_H = \frac{B\ I}{\rho\ w} \times \frac{1}{d \times J \times B} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (22)$$

$$\text{or, } R_H = \frac{I}{\rho\, w\, d\, J} \quad \text{.................................... (23)}$$

⇨ Now again putting the value of **I = w d J** into the above **equation (23)** then we get,

$\because\ J = \frac{I}{w\, d}$ From above **equation (8)** then we have,

or, $I = w\, d\, J$

$$\because\ R_H = \frac{I}{\rho\, w\, d\, J} \quad \text{.................................... (23)}$$

$$\therefore\ R_H = \frac{w\, d\, J}{\rho\, w\, d\, J} \quad \text{.................................... (24)}$$

$$\text{or, } R_H = \frac{1}{\rho} \quad \text{.................................... (25)}$$

⇨ Now again putting the value of $\rho = n\, e$ into the above **equation (25)** then we get,

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

$$\therefore\ R_H = \frac{1}{n\, e} = \frac{V_H\, w}{B\, I} \quad \text{.................................... (26)}$$

⇨ A **rigorous treatment** shown that the above value of R_H is actually given by,

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

Where, **r** is a **numerical constant**. In most of the cases the value of **r** does not differ much from **unity**. The error accruing from setting **r = 1** is therefore **not large**.

⇨ 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.**

⇨ 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.**

⇨ Thus, the **sign of the Hall Coefficient tells us whether the sample (conductor) is an N-type or a P-type semiconductor.**

to be continued ....

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