Atomic Structure and Semiconductor

Lecture - 30

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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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➢ Conductivity When Intrinsic Charge Carrier Densities are Neglected

⇨ In case density of charge carriers available intrinsically is negligible as compared to the added impurity atoms (whether of donor or a acceptor type), then the formulae for conductivity given by **Equation (9)** and **Equation (11)** from **Lecture – 29**,

⇨ The **Conductivity** in such an **n-type semiconductor** is given by,

$$\therefore \text{Conductivity} = \sigma_n = n_n e \mu_e \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

and

⇨ The **Conductivity** in such a **p-type semiconductor** is given by,

$$\therefore \textbf{Conductivity} = \sigma_p = p_p e \mu_h \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

⇨ Now the above **Equation (9)** and **Equation (11)** will be changed as follows:-

(a) For N-type semiconductor

⇨ As seen from **Equation (9)** above, the conductivity is given by,

$$\sigma_n = n_n e \mu_e \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where, n_n = represents **electron density** after doping.

⇨ In this relation, **intrinsic hole density** has already been neglected. The remaining **electron density** is also made up of the following two components:-

1. Intrinsic hole density due to holes available in a pure semiconductor;
2. Electron density N_d contributed by added donor impurity.

⇨ However, if we further neglect the **intrinsic electron density**, then we get,

$$\therefore \textbf{Conductivity} = \sigma_n = N_d e \mu_e \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

(b) For P-type semiconductor

⇨ As seen from **Equation (11)** above, the conductivity is given by,

$$\sigma_p = p_p e \mu_h \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where, p_p = represents **hole density** after doping.

⇨ Again, in this relation, **intrinsic electron density** has been already neglected. This **hole density** further consists of the following two components:-

1. Intrinsic hole density due to holes available in a pure semiconductor;
2. Hole density $\mathbf{N_a}$ contributed by added acceptor impurity.

⇨ However, if we further neglect the **intrinsic hole density**, then

$$\therefore \text{ Conductivity } = \sigma_p = N_a \, e \, \mu_h \quad \text{.......................................} \quad (4)$$

➢ Conductivity of Pure and P-type Germanium

⇨ As shown in **Equation (7) of Lecture – 27,** the **Conductivity** of Pure or Intrinsic Germanium is given by,

$$\sigma = n_i \, e \, (\mu_e + \mu_h) \quad \text{...} \quad (5)$$

$$\sigma = p_i \, e \, (\mu_e + \mu_h) \quad \text{...} \quad (6)$$

⇨ When **germanium ($_{32}$Ge)** is doped by a trivalent impurity like indium, it becomes a **p-type semiconductor.** After doping, its conductivity depends on the number of charge carriers available in it. The law of Mass Action can be used for finding this number. For acceptor impurity, the law may be stated as follows:-

$$n_p \, p_p = n_i \, p_i = n_i^2 \, p_i^2 \quad \text{..} \quad (7)$$

where $\mathbf{n_p}$and $\mathbf{p_p}$ represent the 'free' electron and hole densities respectively in the semi-conductor after doping and $\mathbf{n_i}$ and $\mathbf{p_i}$, the electron and hole densities before doping **i.e.,** in an intrinsic semiconductor.

⇨ Put in another way, it simply means that, at constant temperature, the product of the number of electron carriers and the number of hole carriers is independent of the density of acceptor atoms.

⇨ In physical terms, it means that the introduction of **p-type impurity** fills some of the electron levels produced by thermal action.

⇨ By calculating $\mathbf{n_p}$ and $\mathbf{p_p}$ from above and knowing $\boldsymbol{\mu_e}$ and $\boldsymbol{\mu_h}$, conductivity after doping can be found out as illustrated by the following example.

(a) Pure Germanium

⇨ $$\boldsymbol{\sigma = n_i\, e\, (\mu_e + \mu_h) = p_i\, e\, (\mu_e + \mu_h)} \quad \text{.............................} \quad \textbf{(8)}$$

⇨ Let, $\mathbf{n_i} = \mathbf{p_i} = 2 \times 10^{19}$ per m^3,

⇨ $\boldsymbol{\mu_e} = 0.36\ m^2/V\text{-}s$

⇨ $\boldsymbol{\mu_h} = 0.17\ m^2 / V\text{-}s$ and

⇨ $\mathbf{e} = 1.6 \times 10^{-19}$ C

$$\therefore\ \boldsymbol{\sigma = 2 \times 10^{19} \times 1.6 \times 10^{-19}\ (0.36 + 0.17) = 1.69\ S/m.}$$

$$\therefore\ \boxed{\boldsymbol{\sigma = 1.69\ S/m.}}$$

(b) P-type Germanium

⇨ Here,

⇨ $$\boldsymbol{\sigma_p = e(n_p\, \mu_e + p_p\, \mu_h)} \quad \text{...} \quad \textbf{(9)}$$

⇨ Suppose, we add **10^{22} atoms/m^3** of indium and that $\mathbf{n_i} = 2 \times 10^{19}$ charge carriers (either electrons or holes) per m^3.

⇨ Then, $\mathbf{n_p}\ \mathbf{p_p} = \mathbf{n_i^2} = (2 \times 10^{19})^2 = 4 \times 10^{38}$ and

⇨ $\mathbf{p_p} - \mathbf{n_p} = 10^{20}$

∴ $\mathbf{p_p} - 4 \times 10^{38}/\mathbf{p_p} = 10^{20}$

or, $\mathbf{p_p^2 - 10^{20}\ p_p - (4 \times 10^{38}) = 0}$ .... **(10)**

⇨ Solving the **above quadratic equation** and taking positive value only, we get,

⇨ $\mathbf{p_p} = 1.04 \times 10^{20}$ and $\mathbf{n_p} = 0.04 \times 10^{20}$

∴ $\boldsymbol{\sigma_p} = \mathbf{1.6 \times 10^{-19}\ (0.04 \times 10^{20} \times 0.36 + 1.04 \times 10^{20} \times 0.17) = 3.1\ S/m^*}$

∴ $\boxed{\boldsymbol{\sigma_p} = \mathbf{3.1\ S/m^*}}$

⇨ It is seen that **conductivity is almost doubled.**

to be continued ....

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