EI-27003: Electronics Devices and Circuits
Lecture - 17

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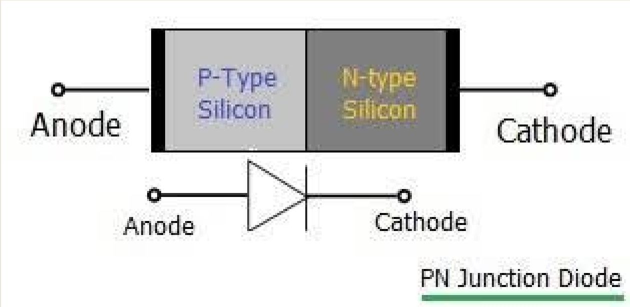
LECTURE - 17

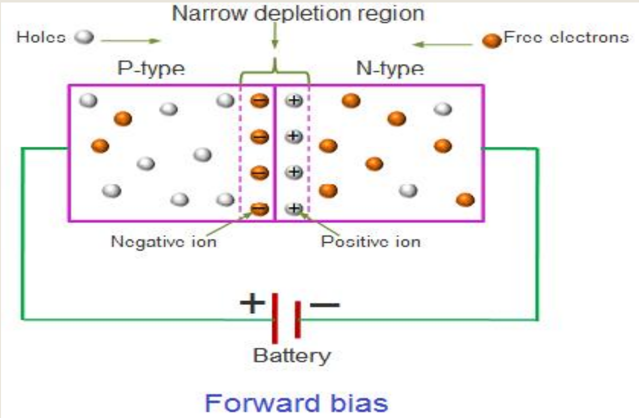
Year: 2020-21

Unit – 2/3 : Diode and BJT Modeling

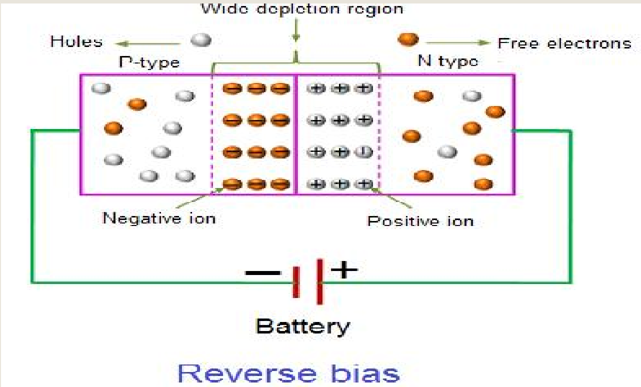
- PN Junction Diode



- Forward Bias Diode:



- Reverse Bias Diode:



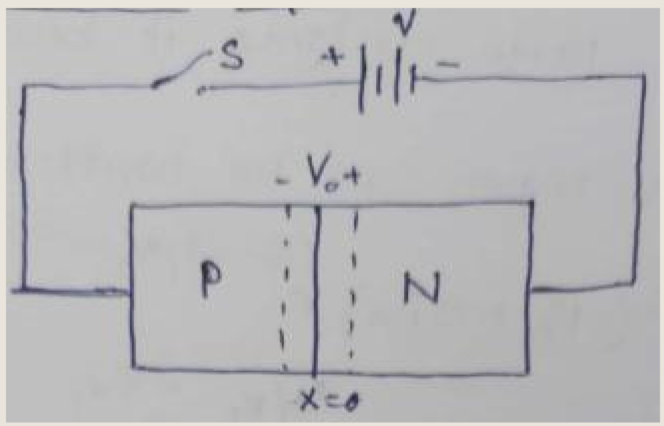
Diode Equations

- Here we will obtain the equations:

➢ Diode current Equation: I_D

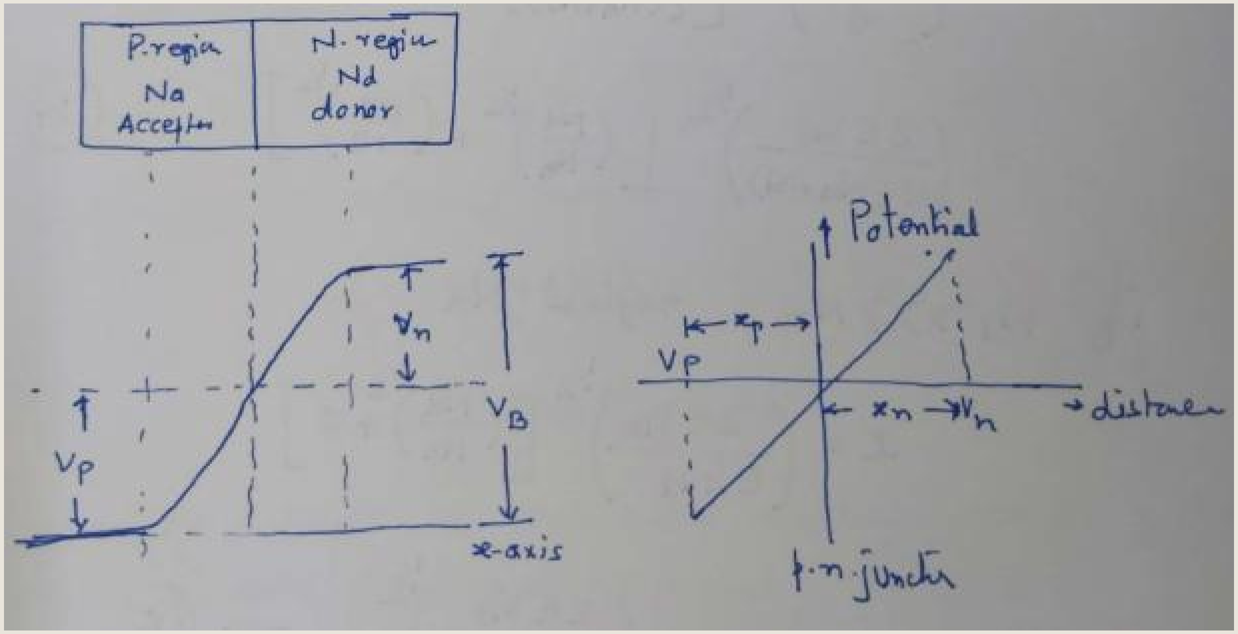
➢ Built-in Potential V_0

➢ Width of Depletion layer W



Width of Depletion Layer

- Consider the fig below.



- The potential V_B is given by:

$$V_B = |V_P| + |V_n| \quad \text{------ eq.(1)}$$

Where : V_P = Potential fall in p-region

V_n = Potential rise in n-region

Width of Depletion Layer

- Width of depletion region: $x = x_p + x_n$ ------(2)
- Where : x_p and x_n are widths of depletion layers of p and n regions respectively.
- To find out the distribution of barrier potential in space charge region, use Poisson's equation
  - $\frac{d^2V}{dx^2} = \frac{-\rho}{\varepsilon}$ -----(3)
  - Where ρ = charge density

    ε = permittivity of medium
- The charge density in p-side of space charge region is given by:
  - ρ = -eNa --- (4)

  Where Na= density of Acceptor atoms

  e= charge.

  Hence eq.(3) becomes

  $\frac{d^2V}{dx^2} = \frac{eNa}{\varepsilon}$ -----(5)

Width of Depletion Layer

- Integrating eq.(5), it gives:
  - $\frac{dV}{dx} = \frac{\text{eNa}}{\varepsilon}x + \text{C1}$ ----(6)
  - C1 is constant of integration and can be obtained by using boundary condition
  - At x = - x_{p} , $\frac{dV}{dx} = 0$
  - Hence eq(6) becomes

$$0 = -\frac{\text{eNa}}{\varepsilon}x_{\text{p}} + \text{C1}$$

Hence $\text{C1} = \frac{\text{eNa}}{\varepsilon}x_{\text{p}}$ -----(7)

Substitute eq(7) in eq(6)

$$\frac{dV}{dx} = \frac{\text{eNa}}{\varepsilon}x + \frac{\text{eNa}}{\varepsilon}x_{\text{p}} = \frac{\text{eNa}}{\varepsilon}(x + x_{\text{p}}) \text{ -------(8)}$$

Width of Depletion Layer

- Again integrating eq.(8)
  - V= $\frac{\text{eNa}}{\varepsilon}(\frac{x^2}{2} + x.x_p)$ + C2 ------(9)
  - C2 is integration constant. Again apply boundary condition
  - At x=0, V=0 ----(10)
  - 0= $\frac{\text{eNa}}{\varepsilon}(0+0)$ + C2 OR C2=0
  - eq(9) becomes : V= $\frac{\text{eNa}}{\varepsilon}(\frac{x^2}{2} + x.x_p)$
  - For p-region, at x = -x_p, V= V_P
  - Hence V_P = $\frac{\text{eNa}}{\varepsilon}(\frac{{x_p}^2}{2} + {x_p}^2)$ = - $\frac{\text{eNa}}{\varepsilon}\frac{{x_p}^2}{2}$ ----(10)

Width of Depletion Layer

- Similarly, for the potential distribution in space charge region on n-side, the Poisson's equation can be written as:
  - $\frac{d^2V}{dx^2} = \frac{-\rho}{\varepsilon} = \frac{eN_d}{\varepsilon}$ since ρ = - eN_d
  - Where Nd = density of donor atoms
- Proceeding as above and applying the boundary conditions at :
  - At x=0, V=0 and at x = -x_n, $\frac{dV}{dx}$ = 0
  - We get : $V_n = -\frac{eN_d}{\varepsilon}\frac{x_n{}^2}{2}$ -------(11)
- Height of potential barrier is: $V_B = |V_P| + |V_n| = \frac{eN_a}{\varepsilon}\frac{x_p{}^2}{2} + \frac{eN_d}{\varepsilon}\frac{x_n{}^2}{2}$
  - $V_B = \frac{e}{2\varepsilon}[N_a x_p{}^2 + N_d x_n{}^2]$ --------(12)

Width of Depletion Layer

- Since crystal as a whole is electrically neutral, the number of charge carriers on both sides must be equal on both sides must be equal:
  - $\mathrm{Na}.\,x_p = \mathrm{N}d.\,x_n$
  - $x_n = \dfrac{\mathrm{Na}}{\mathrm{N}d}.\,x_p$ ------(13)
  - Substitute eq(13) in eq(12)
  - $V_B = \dfrac{e}{2\varepsilon}[\mathrm{Na}x_p{}^2 + \dfrac{\mathrm{N}^2a}{\mathrm{N}^2d}x_p{}^2]$
  - $V_B = \dfrac{e}{2\varepsilon}\mathrm{Na}x_p{}^2[1+\dfrac{\mathrm{Na}}{\mathrm{N}d}]$
  - $x_p{}^2 = \dfrac{2\varepsilon V_B}{e\mathrm{Na}[1+\dfrac{\mathrm{Na}}{\mathrm{N}d}]}$
  - $x_p = \sqrt{\dfrac{2\varepsilon V_B}{e\mathrm{Na}[1+\dfrac{\mathrm{Na}}{\mathrm{N}d}]}}$

Width of Depletion Layer

- So we have : $x_p = \sqrt{\dfrac{2\varepsilon V_B}{eNa[1+\frac{Na}{N_d}]}}$ similarly $x_n = \sqrt{\dfrac{2\varepsilon V_B}{eNd[1+\frac{N_d}{N_a}]}}$
- Now width of depletion layer: $x = x_p + x_n$
- $x = \sqrt{\dfrac{2\varepsilon V_B}{eNa[1+\frac{Na}{N_d}]}} + \sqrt{\dfrac{2\varepsilon V_B}{eNd[1+\frac{N_d}{N_a}]}}$
- $= \sqrt{\dfrac{2\varepsilon V_B}{e}}\,[\{\dfrac{(N_d/N_a)}{(N_a+N_d)}\}^{1/2} + \{\dfrac{(N_a/N_d)}{(N_a+N_d)}\}^{1/2}]$

- $\boxed{x = \sqrt{\dfrac{2\varepsilon V_B}{e(N_a+N_d)}}\,[(\dfrac{N_d}{N_a})^2 + (\dfrac{N_a}{N_d})^2]}$

Conclusion/ Significance

- So we have :width of depletion layer : $x = \sqrt{\frac{2\varepsilon V_B}{e(N_a+N_d)}[(\frac{N_d}{N_a})^2 + (\frac{N_a}{N_d})^2]}$
- If $N_d \gg N_a$, neglect N_a
- Hence $x = \sqrt{\frac{2\varepsilon V_B}{e(N_a+N_d)}[(\frac{N_d}{N_a})^2 + 0]}$ OR $x = \sqrt{\frac{2\varepsilon V_B}{eN_a}} = (\frac{2\varepsilon V_B}{eN_a})^{1/2}$
- Conclusion: When doping(impurity concentration, N_a) increases, the width of depletion layer decreases.

Attendance

https://forms.gle/JvcE74CWX5kWVU4c9