ECE310- Lecture 8

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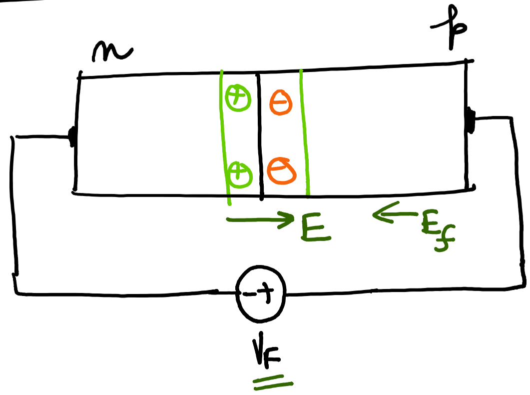
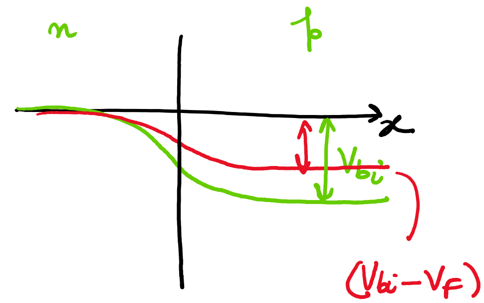
pn- junction forward Bias :



net electric field
$(E - E_f)$



Energy barrier is reduced by the forward bias voltage, V_F.

+ In reverse or zero bias, the potential/Energy barrier stopped the flow of carriers
  ↳ V_F → lowers the potential barrier by weakening the electric field
    ↳ Allows greater diffusion current

Current flow is due to DIFFUSION.

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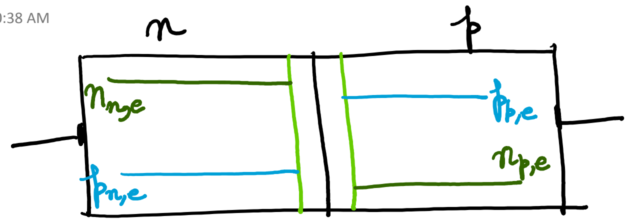
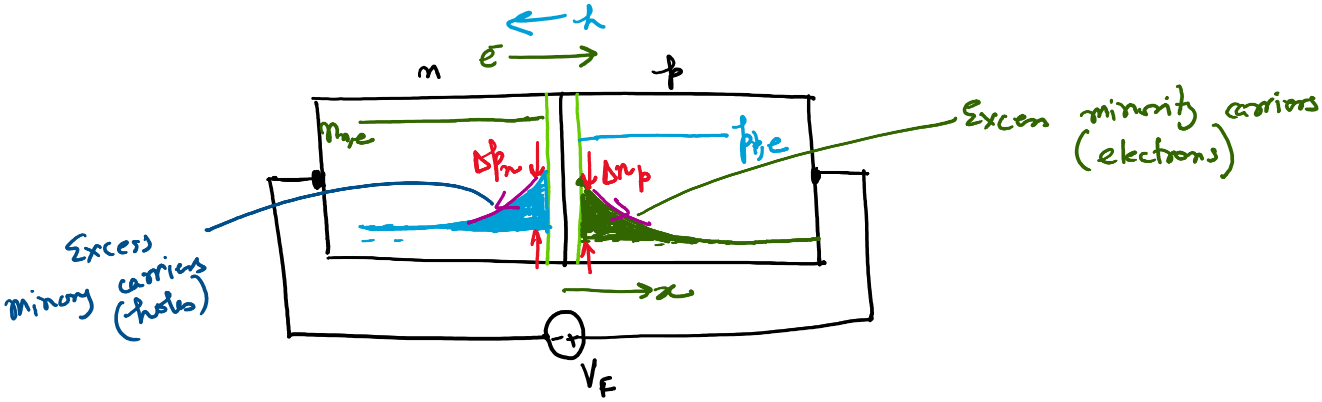
Subscript
$e \triangleq$ Equilibrium





* the minority carrier concentrations increase exponentially on both the sides
* majority carrier concentration is almost unchanged

change in hole concentration (n-Si)

$$\Delta p_n = p_{n,f} - p_{n,e}$$

$$= \frac{p_{p,f}}{e^{\frac{V_{bi}-V_F}{V_T}}} - \frac{p_{p,e}}{e^{V_{bi}/V_T}}$$

$$\simeq \frac{\overset{N_A}{p_{p,e}}}{e^{V_{bi}/V_T}}\left(e^{V_F/V_T} - 1\right)$$

$$\Delta p_n \simeq \frac{N_A}{e^{V_{bi}/V_T}}\left(e^{V_F/V_T} - 1\right)$$

Also, $$\Delta n_p \simeq \frac{N_D}{e^{V_{bi}/V_T}}\left(e^{V_F/V_T} - 1\right)$$

$V_F \uparrow \Rightarrow \Delta p_n \uparrow$

Aside

$$V_{bi} = V_T \ln\left(\frac{p_p}{p_n}\right)$$

$$\Rightarrow p_n = \frac{p_p}{e^{V_{bi}/V_T}}$$

In Equilibrium

$$p_{n,e} = \frac{p_{p,e}}{e^{V_{bi}/V_T}}$$

With forward bias

$$p_{n,f} = \frac{p_{p,f}}{e^{(V_{bi}-V_F)/V_T}}$$

barrier is lowered by V_F

Thermal Voltage $V_T = \frac{kT}{q} = 26\ mV$ @ $T=300K$

Diffusion Current $\propto \frac{\partial}{\partial x}(\Delta p_n)$ & $\frac{\partial}{\partial x}(\Delta n_p)$

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$$I_{tot} \propto \underbrace{\frac{N_A}{e^{V_{bi}/V_T}}\left(e^{V_F/V_T}-1\right)}_{\Delta p_n} + \underbrace{\frac{N_D}{e^{V_{bi}/V_T}}\left(e^{V_F/V_T}-1\right)}_{\Delta n_p}$$

Algebra + Some steps

Covered in Device Physics Course / book

$$\boxed{I_{tot} = I_s\left(e^{V_F/V_T}-1\right)}$$

$$I_s = Aq n_i^2\left(\frac{D_n}{N_A L_n} + \frac{D_p}{N_D L_p}\right)$$ for a long-base device

I_s → reverse saturation current

L_n, L_p → Diffusion lengths for electron and holes

$L = \sqrt{D \cdot \tau_c}$

τ_c → carrier lifetime

I/V characteristics of the Diode

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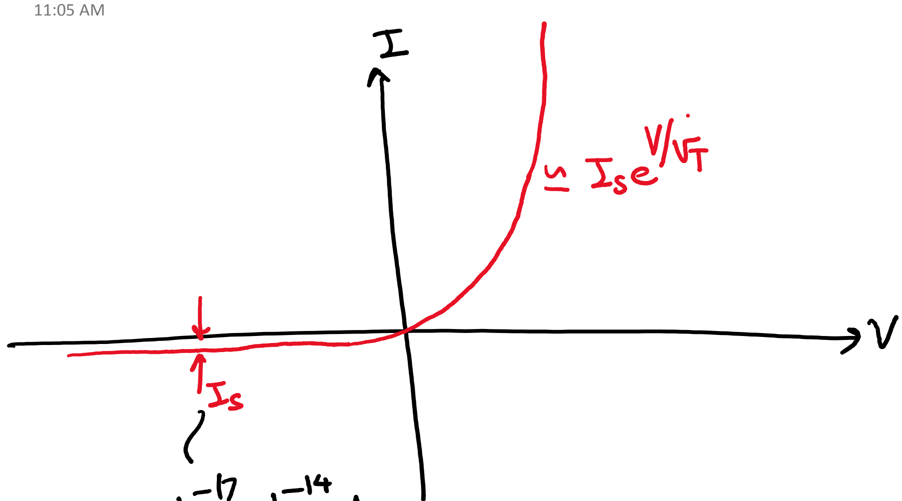
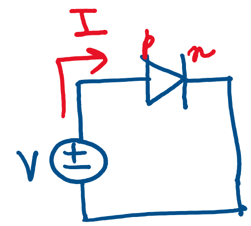


$I_s = 10^{-17} - 10^{-14}$ A



$$I = I_s\left(e^{V_F/V_T} - 1\right)$$

FWD BIAS: $I \simeq I_s e^{V/V_T}$

REV BIAS: $I \simeq -I_s$ → a very very small current

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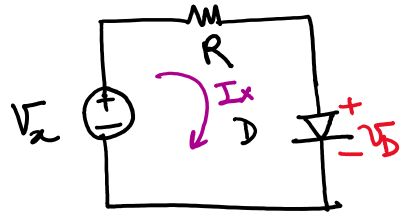
Find current I_x



$V_x = 3V$

$I_S = 10^{-16} A$

$R = 1k\Omega$

$$\boxed{I_x \simeq I_S e^{v_D/v_T}}$$

$$\Rightarrow \frac{I_x}{I_S} = e^{v_D/v_T}$$

$$\Rightarrow v_D = v_T \ln\left(\frac{I_x}{I_S}\right)$$

KVL: $V_x = I_x R + v_D \rightarrow (1)$

$v_D \simeq v_T \ln\left(\frac{I_x}{I_S}\right) \rightarrow (2)$

Solve for I_x

$V_x = I_x R + v_T \ln\left(\frac{I_x}{I_S}\right) \rightarrow$ can't solve directly!

- Solve by iteration
- graphical solution

(1) Assume $v_D = 0.75V$

Compute $I_x = \frac{V_x - V_D}{R} = 2.25 \text{ mA}$

$V_D = v_T \ln\left(\frac{I_x}{I_S}\right) = 799 \text{ mV}$

(2) $I_x = \frac{V_x - V_D}{R} = 2.201 \text{ mA}$

⋮

I_x converge $\simeq 0.2$ mA

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Load-line Analysis

$$V_x = I_x R + v_D$$

$$\underbrace{\frac{V_x - v_D}{R}} = \underbrace{I_x}$$