03.10.2023

Density of charge-carriers in Intrinsic & Extrinsic Semiconductors

$$n(E,T) = \int_{E_c}^{\infty} \underbrace{f(E)}_{\text{Probability of occupancy}} \cdot \underbrace{D(E)\, dE}_{\text{Number of electrons in CB in } cm^{-3}}$$

$$n = \int_{E_c}^{\infty} \frac{1}{1+\exp\left(\frac{E-E_F}{k_B T}\right)} \cdot K\sqrt{E-E_c} \cdot dE$$

"FERMI-INTEGRAL"

Approximate Soln:

$$n = N_c\, e^{-(E_c-E_F)/k_B T} \quad (\text{in } cm^{-3})$$

where, N_c = effective density of energy states in C.B.

$$N_c = 2\left(\frac{2\pi m_e^* k_B T}{h^2}\right)^{3/2} \sim 10^{19}\, cm^{-3}$$

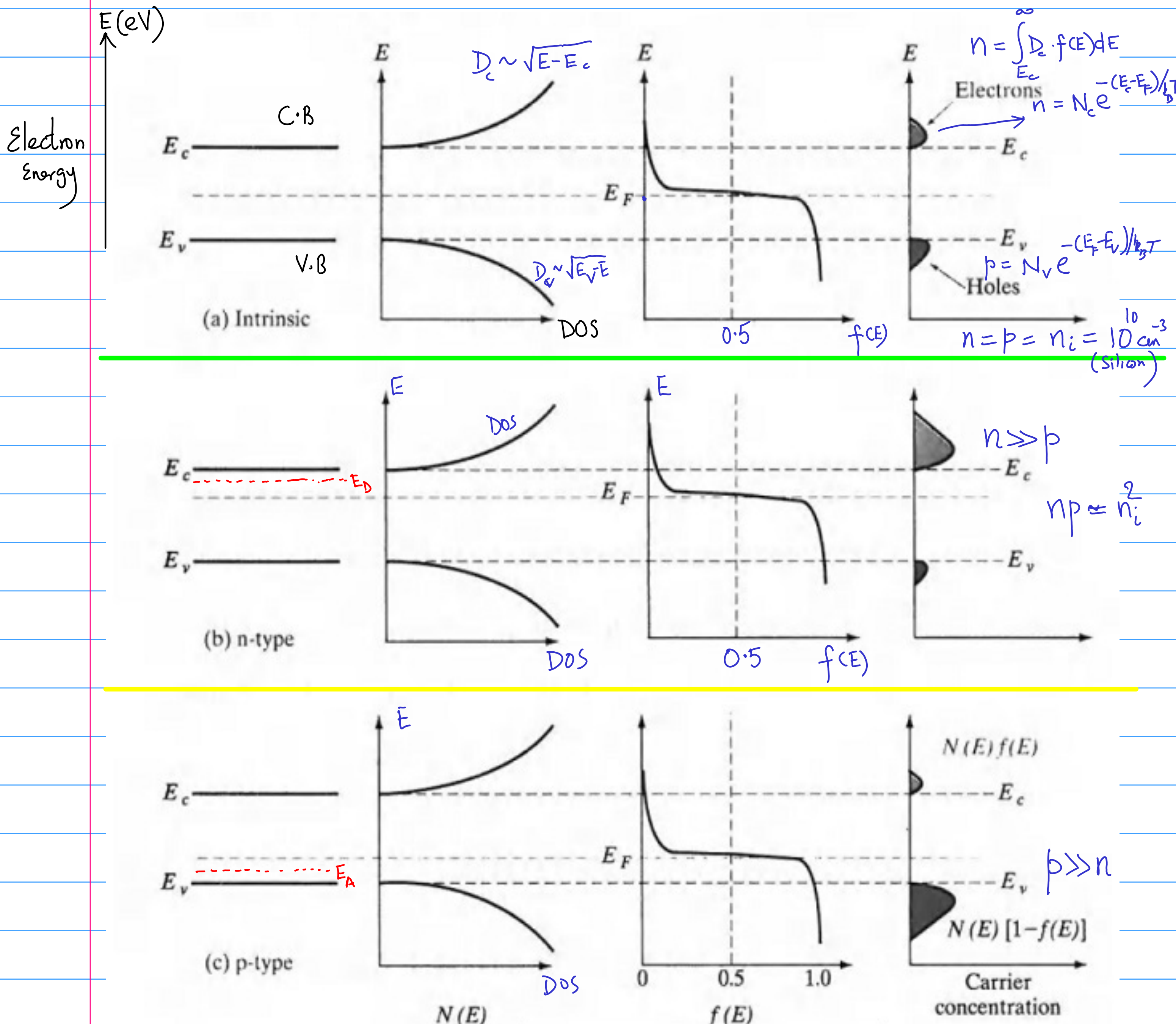
for n-type Silicon at 300K

Similarly,

$$p = N_v\, e^{-(E_F-E_v)/k_B T}$$

where N_v = effective DOS in V.B. $= 2\left(\frac{2\pi m_p^* k_B T}{h^2}\right)^{3/2}$

T = 300K



E(eV)
Electron Energy
E c
E v
C.B
V.B
E
$D_c \sim \sqrt{E-E_c}$
$D_v \sim \sqrt{E_v - E}$
DOS
E F
0.5
f(E)
$n = \int_{E_c}^{\infty} D_c \cdot f(E) dE$
Electrons
$n = N_c e^{-(E_c-E_F)/k_BT}$
$p = N_v e^{-(E_F-E_v)/k_BT}$
Holes
$n = p = n_i = 10^{10} cm^{-3}$ (Silicon)
(a) Intrinsic
E D
$n \gg p$
$np \simeq n_i^2$
(b) n-type
E A
N(E) f(E)
$p \gg n$
N(E) [1−f(E)]
(c) p-type
0
1.0
N(E)
Carrier concentration

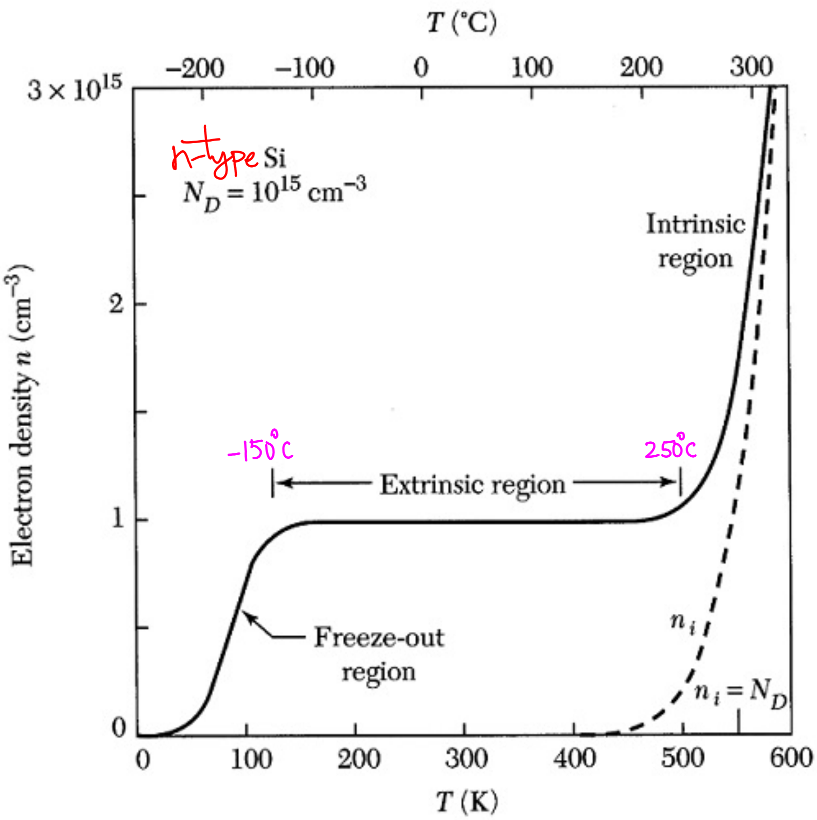
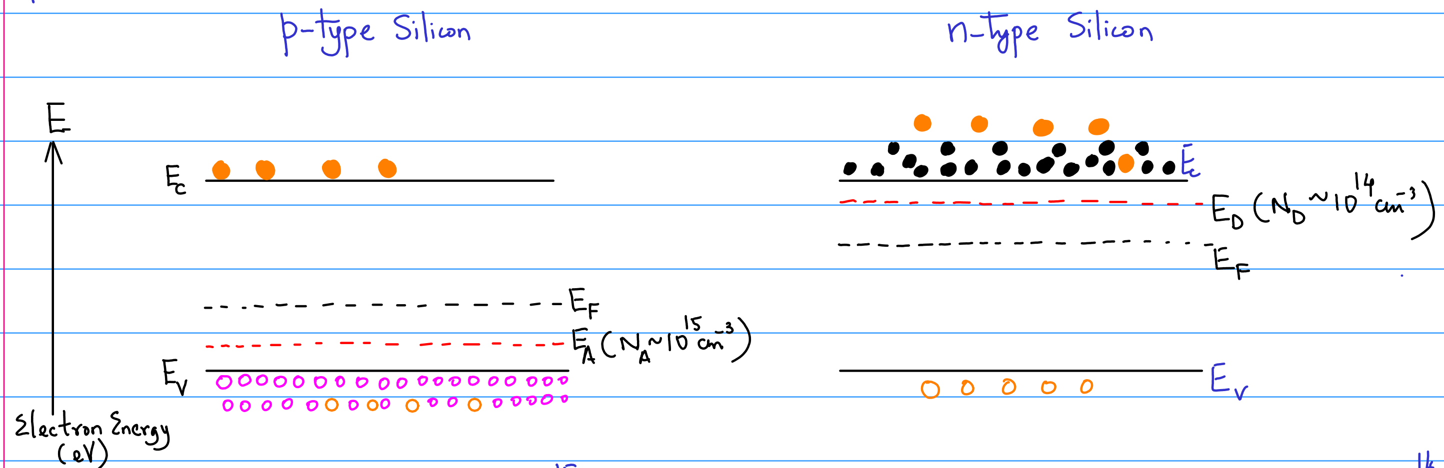


Fig. 29 Electron density as a function of temperature for a Si sample with a donor concentration of 10^{15} cm^{-3}.

p-n Junction Diode

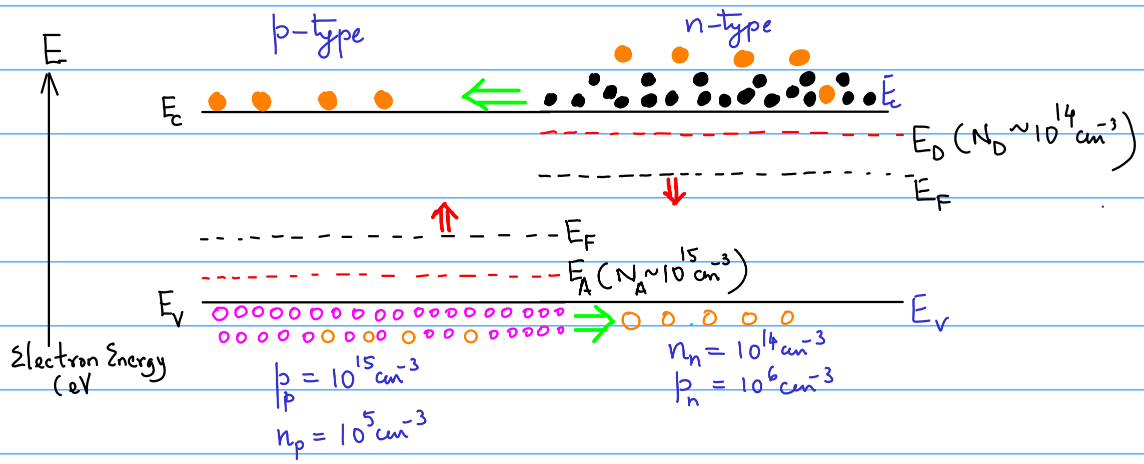
T = 300K



- Majority Carriers, $p_p \simeq N_A \approx 10^{15}$ cm^{-3}
- minority Carriers, $n_p = \dfrac{n_i^2}{p} \approx 10^5$ cm^{-3}

- Majority carriers $n_n \simeq N_D \approx 10^{14}$ cm^{-3}
- Minority Carriers $p_n = \dfrac{n_i^2}{n} = 10^6$ cm^{-3}

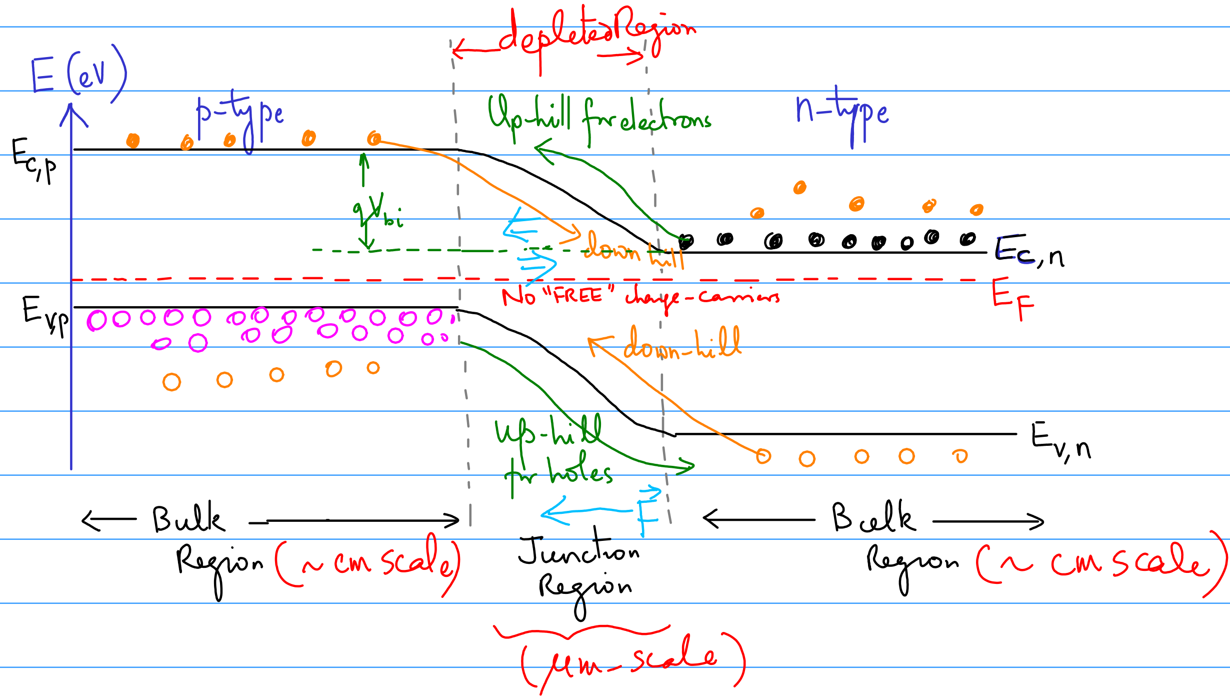
Ques: What happens when you join p-type and n-type semiconductors (here Silicon) together?



High concentration gradient in charge-carriers $\Rightarrow$ DIFFUSION

As a result, the majority charge-carriers flow under the driving force of diffusion until the position of the Fermi-level becomes same in both p- and n-side.

This results in band-bending in the junction region.



In steady-state, the diffusive flux of majority charge-carriers is equal to drift flux of the minority charge-carriers.

Diffusion current (majority carriers) = Drift current. (minority carriers)

This band-bending in the junction region is referred as built-in-potential. (V_{bi})

The depletion width is dependent on the extent of doping level., ie, depends upon the density of dopant atoms.

The depletion width $W = \sqrt{\dfrac{2\epsilon_r\epsilon_0 V_{bi}}{q}\left(\dfrac{N_A+N_D}{N_A \cdot N_D}\right)}$

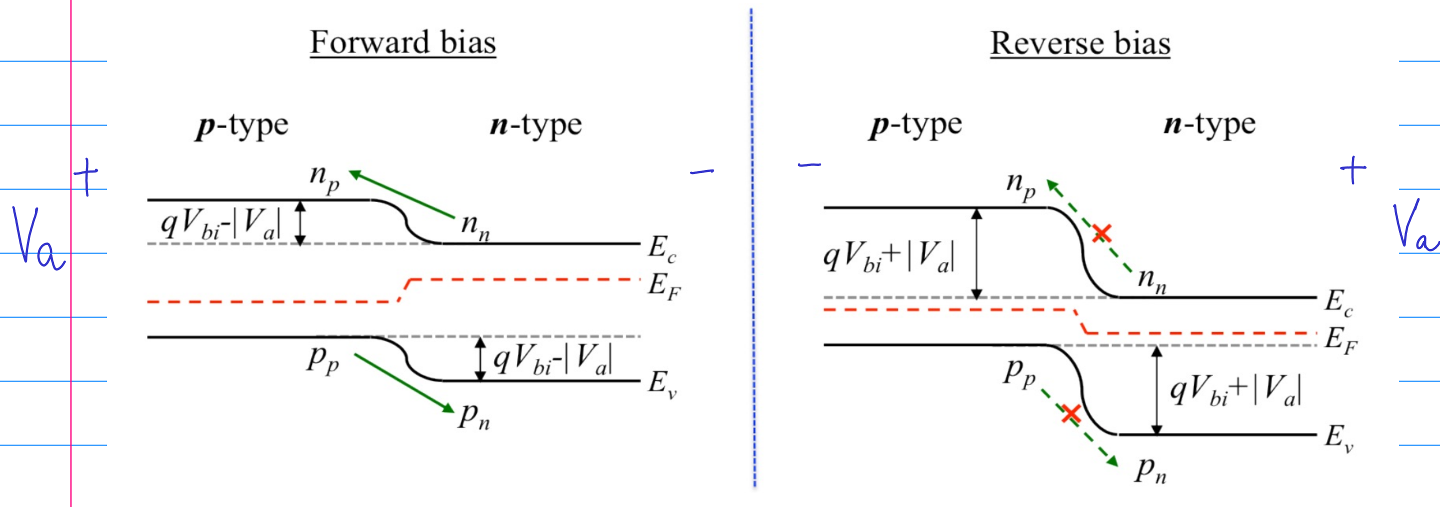
The built-in potential also depends upon the extent of doping level.

$$V_{bi} = \frac{k_B T}{q}\left[\ln\left(\frac{N_A \cdot N_D}{n_i^2}\right)\right]$$

2. Effect of Biasing the p-n junction : (Biased p-n junction)

p-type = +ve terminal of the source
→ forward bias p-n junction

= −ve terminal of the source.
→ Reverse bias p-n junction.

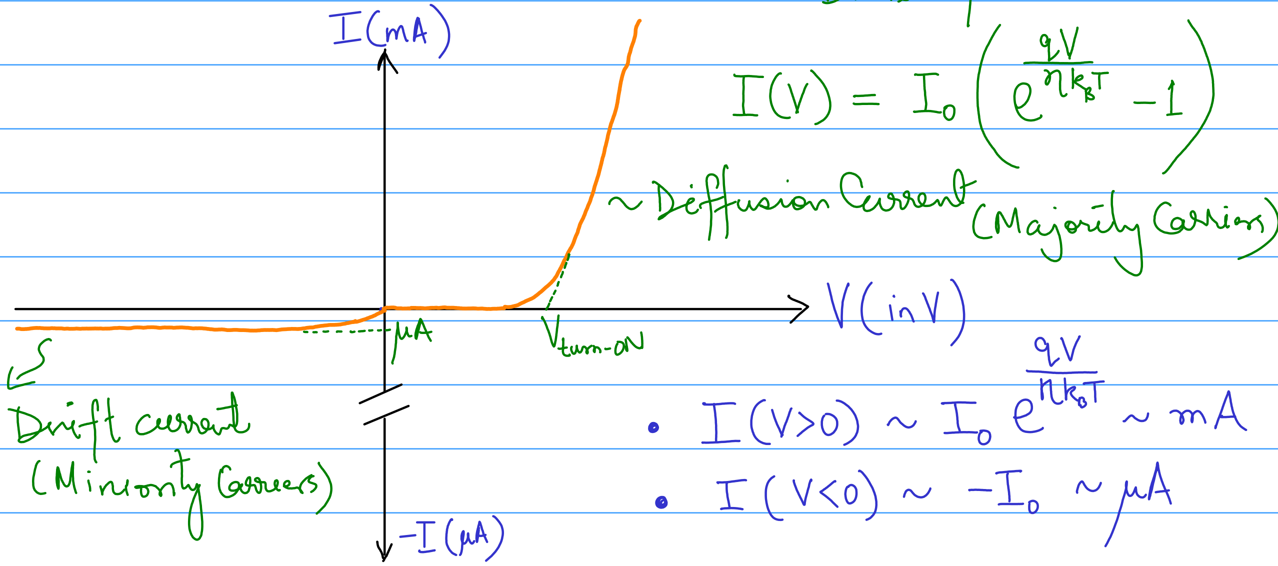


- Applying a +ve potential V_a to p-side increases the diffusion of majority charge-carriers due to lowering of potential barrier.

- Reverse effect will take place when −ve potential is applied to p-side.

Diode-Equation

$$I(V) = I_0\left(e^{\frac{qV}{\eta k_B T}} - 1\right)$$



- $I(V>0) \sim I_0\, e^{\frac{qV}{\eta k_B T}} \sim mA$
- $I(V<0) \sim -I_0 \sim \mu A$

$$\frac{I(V>0)}{I(V<0)} \sim 10^3$$

This behaviour is termed as "Unipolar" (Rectifying)

What kind of devices can be built using p-n junction?

– p-n junction under applied bias: Diode, transistor, LEDs, LASER diode.

- p-n junction under illumination: Solar Cells, photo-detector.

p-n junction is useful in fabricating "Opto-electronic devices"