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I certify that I have not violated the University Code of Conduct during exam

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Q-1 The energy required for an electron to move from the Fermi level into the free space is called Work function.

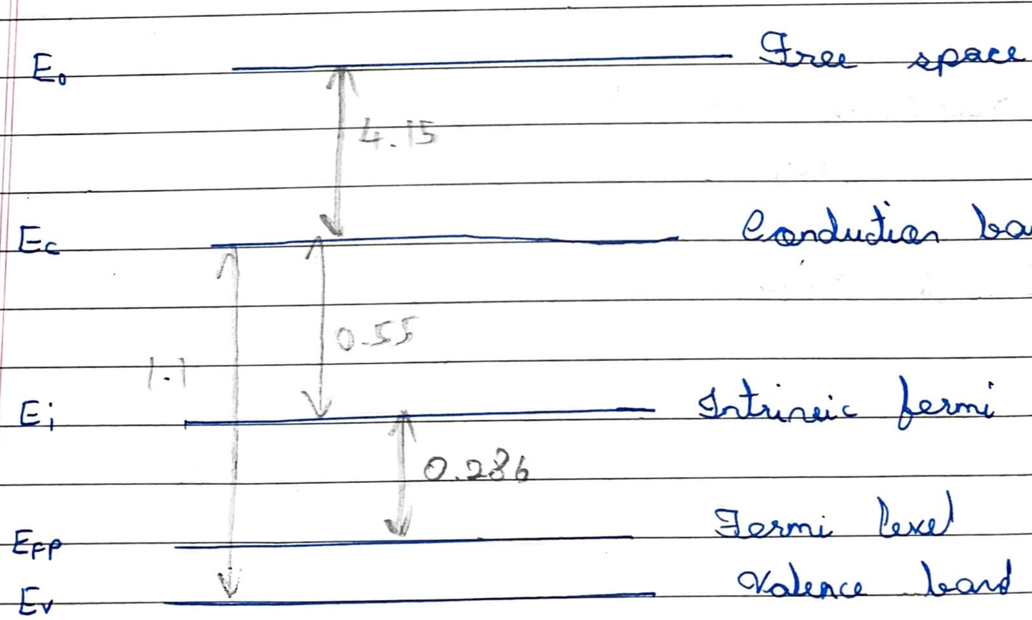
- The fermi potential for a doped p type semiconductor is given by

$$\phi_{FP} = \frac{kT}{q} \ln\left(\frac{n_i}{N_A}\right)$$

The silicon is doped with $10^{14} \times 9 \ cm^{-3}$ Gallium

$$\therefore \phi_{FP} = 26 \ mV \ \ln\left(\frac{1.45 \times 10^{10}}{9 \times 10^{14}}\right)$$

$$= \cancel{1.043} eV \ -0.286 \ eV$$



$$E_0 - E_{FP} = 4.15 + 0.55 - 0.286 = 4.986 \ eV$$

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Q-2 Silicon is dopes with 3×10^{6} cm^{-3} Phosphorus

Since the doping is less than $n_i = 1.45 \times 10^{10}$, there will be no ~~mg~~ majority or no minority charge carriers

- On doping 7×10^{15} cm^{-3} arsenic atoms,
- The majority charge carriers will now become electron
- The minority charge carrier will now become holes
- $n \approx N_D = 7 \times 10^{15}$ $/cm^3$

The minority carrier concentration will be

$$p = \frac{n_i^2}{N_D} = \frac{(1.45 \times 10^{10})^2}{7 \times 10^{15}} = 0.300357 \times 10^{5}$$

$$= 30035.7 \ /cm^3$$

Q-3 Poisson's equation is useful for finding the electric potential distribution when charge density is known. It is

$$\frac{d^2V}{dx^2} = -\frac{d\mathcal{E}}{dx} = \frac{-\rho}{\varepsilon_s}, \quad \rho = q(p-n+N_D-N_A)$$

- For electric field, $\mathcal{E}$

$$\frac{d\mathcal{E}}{dx} = \frac{q}{\varepsilon_s}(p-n+N_D-N_A) \quad — (1)$$

The boundary conditions are

$$\mathcal{E}(-x_p) = \mathcal{E}(x_n) = 0$$

Integrating (1), we get

$$\mathcal{E} = -\frac{qN}{\varepsilon_s}x + C_1 \quad — (2)$$

P side $(\mathcal{E}(-x_p) = 0)$

$$\therefore 0 = -\frac{qN_A(-x_p)}{\varepsilon_s} + C_1$$

$$\therefore C_1 = -\frac{qN_A}{\varepsilon_s}x_p \quad — (3)$$

From (2) (3)

$$\therefore \mathcal{E}(x) = -\frac{qN_A}{\varepsilon_s}(x+x_p)$$

N side $(\mathcal{E}(x_n) = 0)$

$$\therefore 0 = -\frac{qN_D}{\varepsilon_s}x_n + C_2$$

$$\therefore C_2 = \frac{qN_D}{\varepsilon_s}x_n \quad — (4)$$

From (2) (4),

$$\therefore \mathcal{E}(x) = \frac{qN_D}{\varepsilon_s}(x-x_n)$$

Note: $NZ_D = N_D$ and $NZ_A = N_A$

- For electrostatic potential, V we know

$$V(x) = \int \mathcal{E}(x)\, dx$$

The boundary conditions are

$$V(-x_p) = 0 \quad ; \quad V(x_n) = V_{bi}$$

- P side E

$$\mathcal{E}(x) = \frac{-qN_A}{\varepsilon_s}(x + x_p)$$

$$V(x) = \int \mathcal{E}(x)\, dx$$

$$\therefore \; = \frac{-qN_A}{2\varepsilon_s}(x + x_p)^2 + D_1$$

$$V(-x_p) = 0$$

$$\therefore D_1 = 0$$

$$V(x) = \frac{-qN_A}{2\varepsilon_s}(x + x_p)^2$$

- N side

$$\mathcal{E}(x) = \frac{qN_D}{\varepsilon_s}(x - x_n)$$

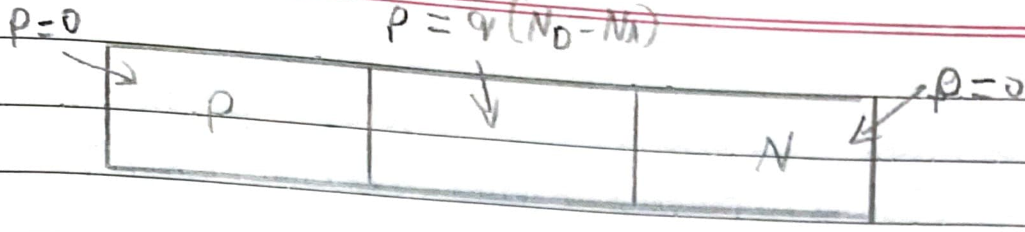
$$V(x) = \int \mathcal{E}(x)\, dx$$

$$= \frac{-qN_D}{2\varepsilon_s}(x_n - x)^2 + D_2$$

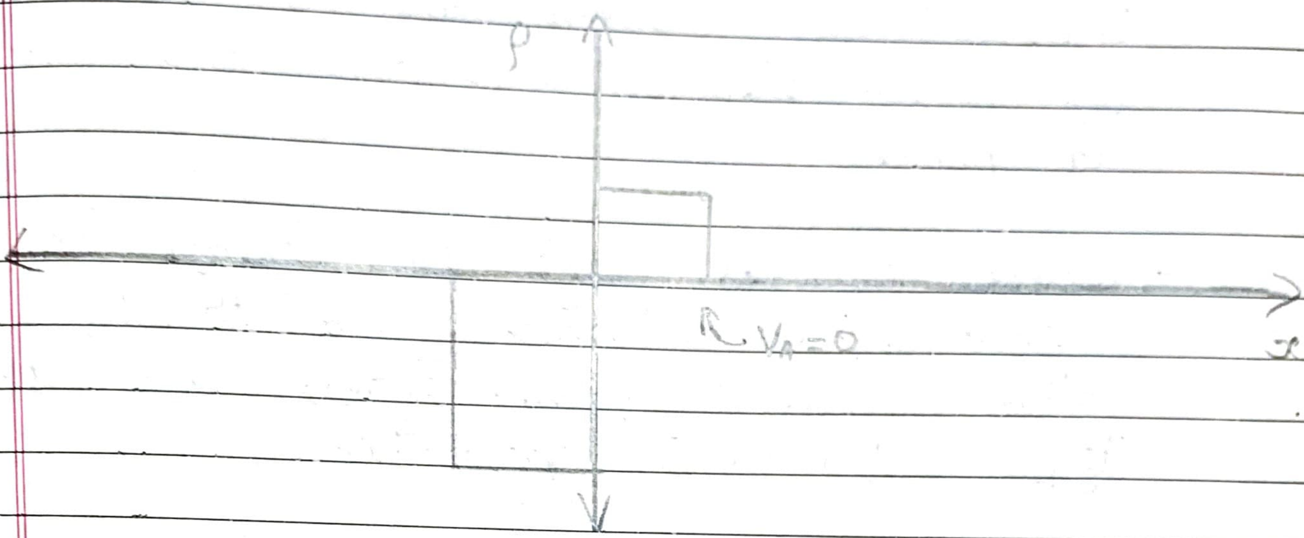
$$V(x_n) = V_{bi}$$

$$\therefore D_2 = V_{bi}$$

$$V(x) = V_{bi} + \frac{qN_D}{2\varepsilon_s}(x_n - x)^2$$

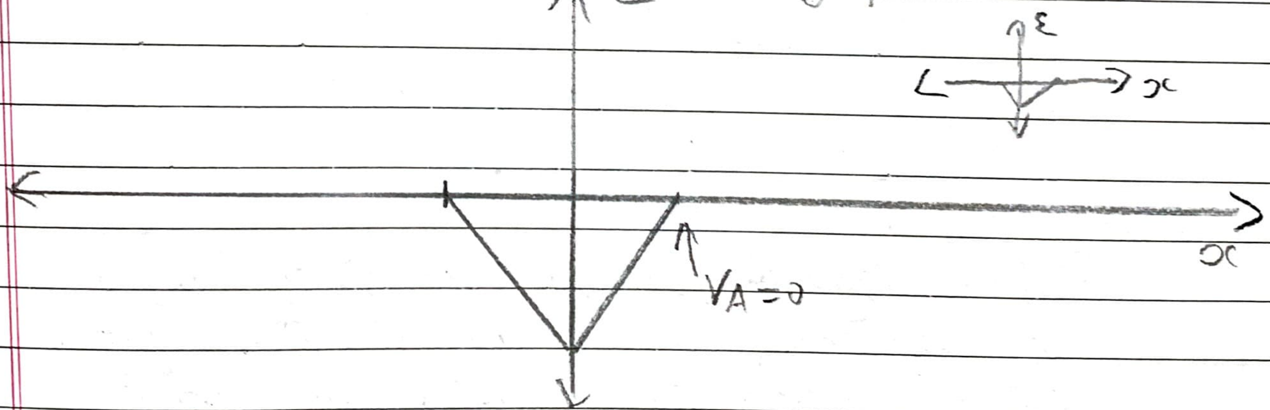


- Charge density

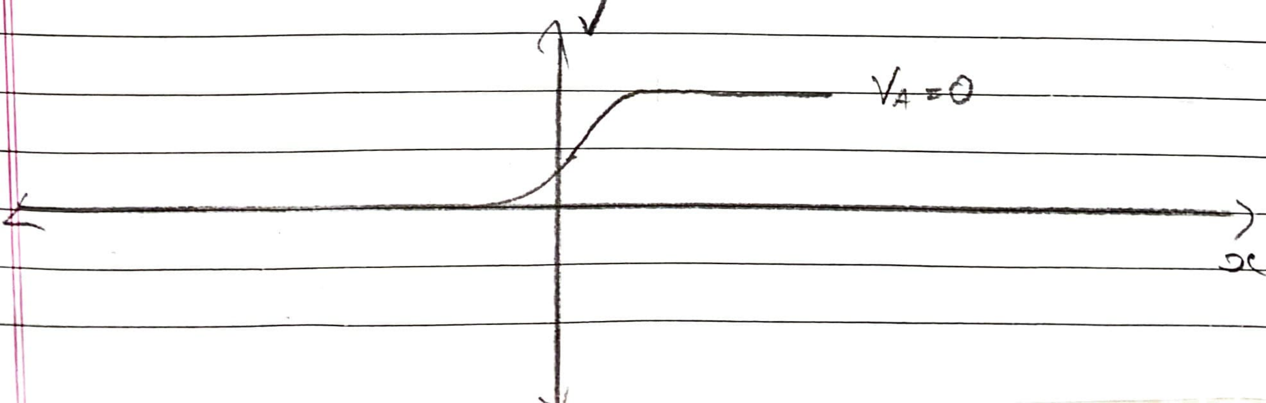


- Electric field

Graph looks like



- Electrostatic potential



Q-4 When diode is kept in reverse bias and the $V_{reverse}$ is so large that the peak electric field exceeds a critical value $\mathcal{E}_{crit}$, then the junction will break down.

The critical voltage is given by

$$\mathcal{E}_{crit} = \sqrt{\frac{2qN(V_{bi} + V_{Br})}{\varepsilon_s}}$$

$$\therefore V_{Br} = \frac{\varepsilon_s \mathcal{E}_{crit}^2}{2qN} - V_{bi}$$

- The students will have to keep the diode in reverse bias and keep monitoring the I-V characteristics

- Typically, when the current will start increasing by a significant amount, we can say that breakdown has occured

- Also when $V_{Br} < 5\,V$, it is usually tunneling breakdown

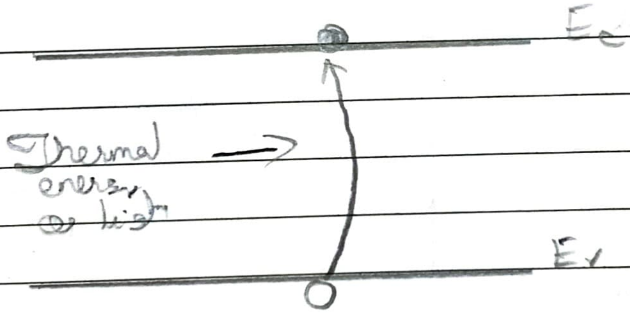
When $V_{Br} > 5V$, it is usually avalanch breakdown

Q-5 Carrier generation is the process by which electrons and holes are created in pair

In contrast, recombination is the process by which electrons and holes are annihilated in pairs

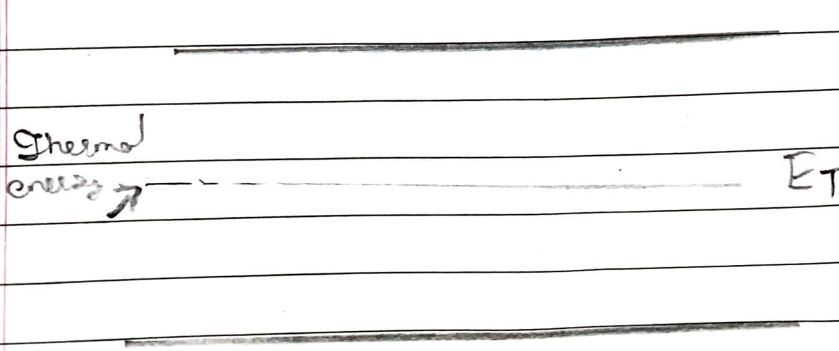
- These process act to change the carrier concentration and thereby affect current flow. There are three types of carrier generation

1) Band to band



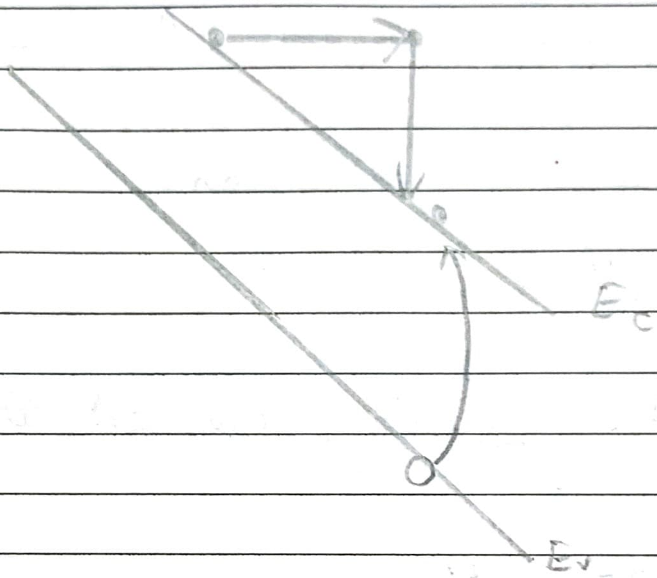
When thermal energy or light is incident on electron, it moves directly from valence band to conduction band

2) R-G center



Due to thermal energy, it the carrier is in a state between E_c and E_v and moves to conduction band

3) Impact ionization



Due to ionization, there is more carrier in conduction band

Q-6 The three types of carrier scattering observed in semiconductor materials and devices are

Phonon
1) Photon scattering (increases with T)

2) Ionized impurity scattering

3) Carrier carrier scattering (significant at high carrier concentration)

Q-7 Silicon is doped with following atoms 3×10^{16} cm^{-3} Arsenic, 4×10^{16} cm^{-3} Boron, 3×10^{16} cm^{-3} Aluminium

The total dopant is given by

$$N = \underset{\text{Arsenic}}{3 \times 10^{16}} + \underset{\text{Boron}}{4 \times 10^{16}} + \underset{\text{Aluminium}}{3 \times 10^{16}}$$

$$= 10^{17}$$

- From the graph, we get the value of mobility as

$\mu_p = 350\ cm^2/Vs$ $\mu_n = 750\ cm^2/Vs$

- The number of negative ~~positive~~ charge carriers is given by

$$n = \frac{n_i^2}{N_A} = \frac{(1.45 \times 10^{10})^2}{7 \times 10^{16}} = 0.3003 \times 10^4$$

- Hence, we can say that resistivity

$$\rho = \frac{1}{q n \mu_n + q p \mu_p} = \frac{1}{q p \mu_p}$$

$$= \frac{1}{1.6\times10^{-19} \times 7\times10^{16} \times 350}$$

$$= 0.2551 \ \Omega/cm$$

- The majourity carrier is p type

$\therefore D_p = \frac{kT}{q} \mu_p = 26 \times 350 \times 10^{-3}$ eV cm^2/s

$= 9.10$ cm^2/s

Q-8 The team of silicon based integrated are working on low temperature application. Hence, the gap between E_d and E_v should be as low as possible

- For p type, (acceptors)

If we maximise the value of $E_a - E_v$, the gap will reduce

$\therefore$ We will use "In" for p type

- For n type, (donors)

If we maximise the value of $E_c - E_d$, the gap will reduce

$\therefore$ We will use "As" for N type

Q-9 a) Energy Band Gap : Yes

b) Charge on electron : No

c) Net charge on semiconductor : No

d) Intrinsic carrier concentration : Yes

e) Mobility of electron : Yes

f) Atomic number : No