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Q)

Tutorial

→ A particular metal has 10^{28} $\bar{e}$s ~~per~~ density. Find E_F, V_F.

Fermi energy

$$\boxed{E_F = \frac{\hbar^2}{2m_0}(3\pi^2 n)^{2/3}}$$

$$= \frac{1.05 \times 10^{-34} \text{ J-s} \times}{2 \times 9.1 \times 10^{-31} \text{ Kg}} \left(3\pi^2 \times (10^{28} m^{-3})\right)^{2/3}$$

$= 1.72 \text{ eV}$

Fermi Velocity : $\boxed{V_F = \frac{\hbar}{m_0} \times (3\pi^2 n)^{1/3}}$

$$= \frac{1.05 \times 10^{-34} \text{ J-s}}{9.1 \times 10^{-31}} (3\pi^2 \times 10^{28})^{1/3}$$

$= 7.52 \times 10^5 \text{ m/s}$

Q) Determine the thermal equilibrium $\bar{e}$ and hole conc. in Si at $T = 300K$ for given doping concentration.

a) Let $N_d = 10^{16} cm^{-3}$ and $N_a = 0$

b) Let $N_d = 5 \times 10^{15} cm^{-3}$ and $N_a = 2 \times 10^{15} cm^{-3}$

~~c) Let N_d =~~

Recall that $n_i = 1.5 \times 10^{10} cm^{-3}$ in Si at $T = 300K$.

Ans) $\boxed{n_0 = \frac{N_d - N_a}{2} + \sqrt{\left(\frac{N_d - N_a}{2}\right)^2 + n_i^2}}$

a) $n_0 = \frac{10^{16}}{2} + \sqrt{\left(\frac{10^{16}}{2}\right)^2 + 1.5 \times 1.5 \times 10^{20}}$

$= 5 \times 10^{15} + \sqrt{25 \times 10^{30} + 2.25 \times 10^{20}}$

$\cong 10^{16} cm^{-3}$

hole concentration : $\boxed{P_0 = \frac{n_i^2}{n_0}}$

$$= \frac{1.5 \times 1.5 \times 10^{20}}{10^{16}}$$

$= 2.25 \times 10^4 cm^{-3}$

b) Similarly

Q) Silicon at T=300K contains an acceptor impurity conc at of ~~n~~= $N_A = 10^{16}\ cm^{-3}$. Determine the conc. of donor impurity é's that must be added, so that the Si is n-Type and the Fermi energy is 0.20 eV below the conduction band.

Ans) $$\boxed{E_c - E_F = KT \ln\left(\frac{N_c}{N_d - N_a}\right)}$$

$$\boxed{N_d - N_a = N_c . exp\left[\frac{-(E_c - E_F)}{KT}\right]}$$

c) $$N_d - N_a = 2.8 \times 10^{19} . exp\left[\frac{-0.2}{0.0259}\right]$$

$$N_d = 1.24 \times 10^{16} + 10^{16}$$

$$= 2.24 \times 10^{16}\ cm^{-3}$$

Q) Consider a Galium Arsenide sample with doping power conc N_d = $N_A = 0$ at T=300K. Assume complete ionization and é's mobility to be 8500 cm^2 at 400 cm^2 per Volt second respectively. Calculate drift current density if the applied electric field is E= 10 V/cm, given $n_i = 1.8 \times 10^6$ cm^{-3} for of GaAs at room temperature.

Ans) Electron concentration,

$$n_o = \frac{N_d - N_a}{2} + \sqrt{\left(\frac{N_d - N_a}{2}\right)^2 + n_i^2}$$

$$\cong 10^{16}\ cm^{-3}$$

$$p_o = \frac{n_i^2}{n_o} = \frac{1.8 \times 1.8 \times 10^{12}}{10^{16}}$$

$$= 3.24 \times 10^{-4}\ cm^{-3}$$

$$\boxed{n = N_d - N_a}$$

for $N_d > N_a$

If $N_a < N_a$, $n = N_a - N_d$

For n-type semiconductor, drift ~~velo~~ current density is:

$$J_{drift} = e(\mu_n n + \mu_p p) E$$

$$J_{drift} = e(\mu_n \cdot N_d E)$$

$$= 1.6 \times 10^{-19} \times 8500 \times 10^{16} \times 10 = 136\ A/cm^2$$

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Q) Consider compensated n-type semiconductor Si, at T=300K, $\sigma = 16 (\Omega\text{-cm}^{-1})$ and acceptor doping conc of $10^{16}\ cm^{-3}$. Determine the $\bar{e}$ mobility, given $N_d = 3.5 \times 10^{17}\ cm^{-3}$

Ans) $\boxed{\sigma = n \cdot e \cdot \mu_n}$

$n = N_d - N_a$

$= 3.5 \times 10^{17} - 10^{17} = 2.5 \times 10^{17}$

$$\mu_n = \frac{\sigma}{n \cdot e} = \frac{16}{2.5 \times 10^{17} \times 1.6 \times 10^{-19}}$$

$$= \frac{10000}{25} = 400\ cm^2\text{-}V/s$$

Q) Assume that in an n-type GaAs semiconductor at T=300K, the $\bar{e}$ conc varies linearly from 1×10^{18} to $7 \times 10^{17}\ cm^{-3}$ ~~offer~~ over a distance of 0.1 cm. Calculate the diffusion current density if $\bar{e}$ diffusion constant, $D_n = 225\ cm^2/s$

Ans) $\boxed{J_n = e \cdot D_n \cdot \frac{dn}{dx}}$

$$J_n = 1.6 \times 10^{-19} \times 225 \times \left(\frac{10^{18} - 7 \times 10^{17}}{10^{-1}}\right)$$

$$J_n = 108\ A/cm^2$$

Q) What are ~~n,p~~ n and p in a Si sample with $N_d = 6 \times 10^{16}\ cm^{-3}$, $N_a = 2 \times 10^{16}\ cm^{-3}$ with additional $6 \times 10^{16}\ cm^{-3}$ of acceptors.

Ans)
$$\left.\begin{aligned} n_0 &= N_d - N_a \\ &= 4 \times 10^{16}\ cm^{-3} \\ p &= \frac{n_i^2}{n_0} \\ &= \frac{10^{20}}{4 \times 10^{16}} = 2.5 \times 10^{3}\ cm^{-3} \end{aligned}\right\}\ \text{Before additional doping}$$

If n_i is not given in question, take $n_i = 10^{10}$.

With additional acceptor,

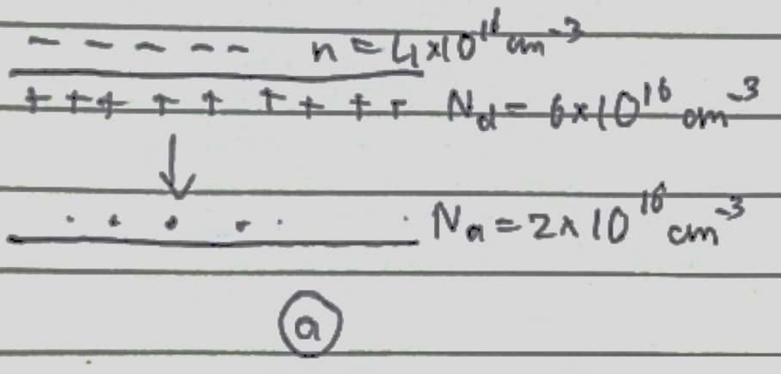
$N_a = 2 \times 10^{16} + 6 \times 10^{16} = 8 \times 10^{16}\ cm^{-3}$

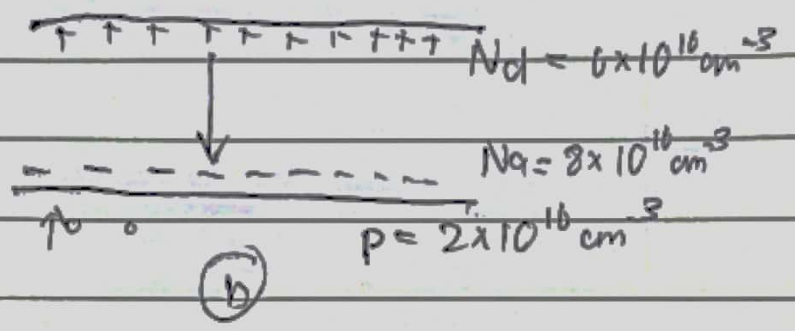
Now as $N_a > N_d$, so the Si has a higher hole conc.

$$p = N_a - N_d$$
$$= 8 \times 10^{16} - 6 \times 10^{16}$$
$$= 2 \times 10^{16}\ cm^{-3}$$

$$n = \frac{n_i^2}{p} = \frac{10^{20}}{2 \times 10^{16}}$$

$$n = \cancel{\ } 5 \times 10^{3}\ cm^{-3}$$





Q) Consider an Si sample with $N_d = 10^{17}\ cm^{-3}$. Find a) the location of E_F, b) the location of E_{FN}, E_{FP} when ~~exchange~~ extra carriers are introduced such that $n' = p' = 10^{15}\ cm^{-3}$

Ans) $n = N_d = 10^{17}\ cm^{-3}$

$$\boxed{N_d = N_c \cdot e^{-(E_c - E_F)/kT}}$$

~~$N_c = N$~~

a) $$E_c - E_F = kT \ln\left(\frac{N_c}{10^{17}\ cm^{-3}}\right)$$

$$= 26\ meV \cdot \ln \frac{\cancel{20}\ 2.8 \times 10^{19}}{10^{17}}$$

$$= 0.15\ eV$$

$\therefore$ E_F is at a distance of 0.15eV energy from E_c.

b) E_{FN}, E_{FP} are quasi-fermi energy levels ($pn \neq n_i^2$)

$$n = n_0 + n'$$
$$= N_d + n' = 1.01 \times 10^{17}\ cm^{-3}$$

$$\therefore 1.01 \times 10^{17} = N_c \cdot e^{-(E_c - E_{FN})/kT}$$

$$\therefore E_c - E_{FN} = 0.15\ eV$$

$$p = p_0 + p' = 10^{15}\ cm^{-3}$$

~~$\therefore E_c - E_{FP} = 0.24\ eV$~~

$$E_{FP} - E_V = 0.24\ eV$$