2

3.3

An unknown semiconductor has $E_g = 1.1\ eV$ and $N_c = N_v$. It is doped with $10^{15}\ cm^{-3}$ donors, where the donor level is $0.2\ eV$ below E_c. Given that E_F is $0.25\ eV$ below E_c, calculate n_i and the concentration of electrons and holes in the semiconductor at $300\ K$.

Answer

$n_i = \sqrt{N_c N_v} e^{-E_g/2kT}$

$n_i = n_0 e^{(-0.5E_g + E_c - E_F)/kT}$

$n_i = 9.12 \times 10^9$

$p_0 = \frac{n_i^2}{n_0} = 8.3 \times 10^4$

$n_0 = 10^{15}\ cm^{-3}$

$p_0 = 8.3 \times 10^4\ cm^{-3}$

3.8

a

A Si sample is doped with $10^{16}\ cm^{-3}$ boron atoms and a certain number of shallow donors. The Fermi level is $0.36\ eV$ above E_i at $300\ K$. What is the donor concentration N_d?

Answer

$p_o + N_d = n_0 + N_a$

$N_d = n_0 + N_a - p_0$

$N_d = N_a + n_i \left(e^{\frac{E_f - E_i}{kT}} - e^{-\frac{E_f - E_i}{kT}} \right)$

$N_d = N_a + \sqrt{N_c N_v} e^{-E_g/2kT} \left(e^{\frac{E_f - E_i}{kT}} - e^{-\frac{E_f - E_i}{kT}} \right)$

$N_d = 1.904 \times 10^{16}\ cm^{-3}$

b

A Si sample contains $10^{16}\ cm^{-3}$ In acceptor atoms and a certain number of shallow donors, the In acceptor level is $0.16\ eV$ above E_v, and E_F is $0.26\ eV$ above E_v at $300\ K$. How many (cm^{-3}) In atoms are un-ionized (i.e., neutral)?

Answer

Since the atom is an acceptor, occupation of the energy state implies ionization.

$f_{ion} = \frac{1}{1+e^{E_a - E_F/kT}}$
$f_{neu} = 1 - f_{ion}$
$N_{neu} = N_a f_{neu} = N_a(1 - \frac{1}{1+e^{E_a - E_F/kT}})$

$N_{neu} = 2.047 \times 10^{14}$

3.11

A new semiconductor has $N_c = 10^{19}\ cm^{-3}$, $N_v = 5 \times 10^{18}\ cm^{-3}$, and $E_g = 2\ eV$. If it is doped with 10^{17} donors (fully ionized), calculate the electron, hole, and intrinsic carrier concentrations at $627\ ^{\circ}C$. Sketch the simplified band diagram, showing the position of E_F.

✓ Answer

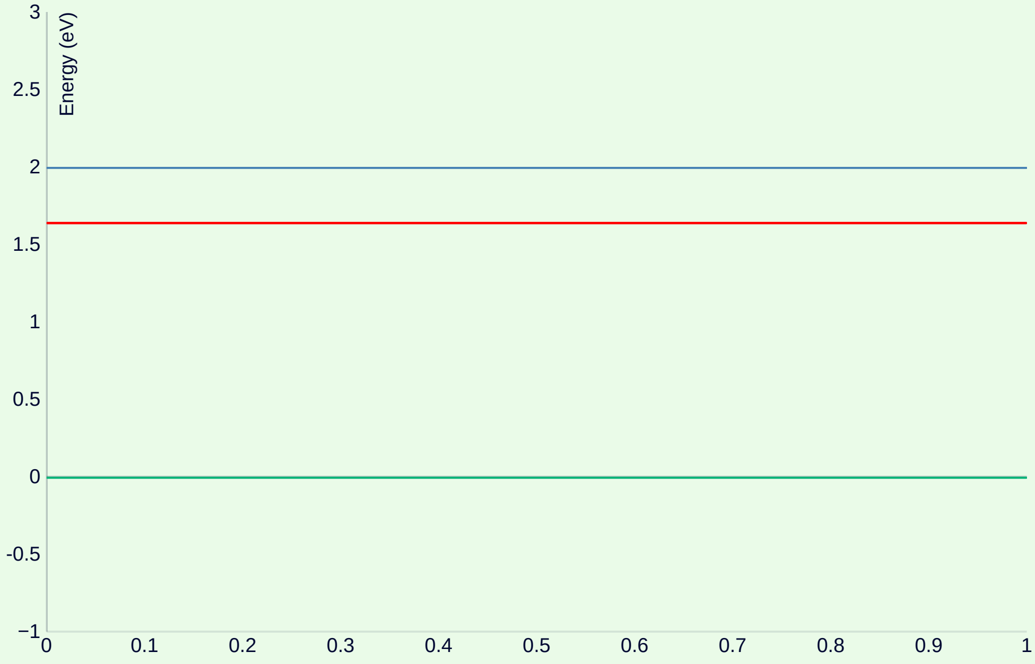
$n_i = \sqrt{N_c N_v} e^{-E_g/2kT}$
$n_i = 1.777 \times 10^{13}\ cm^{-3}$

Since $n_i \ll N_d$
$n_0 \approx N_c = 10^{17}\ cm^{-3}$

$p_0 = \frac{n_i^2}{n_0} = 3.158 \times 10^9\ cm^{-3}$

$n_0 = N_c \frac{1}{1+e^{(E_c - E_F)/kT}}$
$E_c - E_F = kT \ln(\frac{N_C}{n_0} - 1)$
$E_c - E_F = 0.356\ eV$

$n_i = 1.777 \times 10^{13}\ cm^{-3}$
$n_0 = 10^{17}\ cm^{-3}$
$p_0 = 3.158 \times 10^9\ cm^{-3}$
$E_c - E_F = 0.356\ eV$



red: E_F
blue: E_c
green: E_v

The Fermi level is much closer to the conductance energy than it is to the valence energy