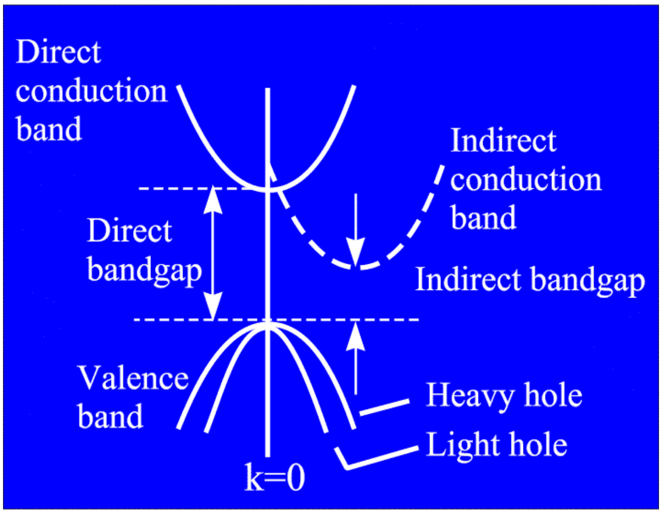
PHYS389 tutorial 1 answers

Question 1

The bottom of the conduction band in some semiconductors occurs at k=0. Such semiconductors are called direct bandgap semiconductors. Examples include, GaAs and InP

If the bottom of the conduction band does not occur at k=0, the semiconductor is termed indirect. Examples include Si and Ge.



Question 2

Electron energy measured from the bandedge ($E-E_c$) = 1.5eV. Effective mass = $0.067m_0$

$$E - E_C = \frac{\hbar^2 k^2}{2m*}$$

$$\begin{aligned}
\hbar k &= \sqrt{2m*(E - E_C)} \\
&= [2(0.067 \times 0.91 \times 10^{-30} kg)(1.5 \times 1.6 \times 10^{-19} J)]^{1/2} \\
&= 1.71 \times 10^{-25} kgms^{-1} \\
k &= 1.62 \times 10^{9} m^{-1} \\
p &= \sqrt{2m_0 E} \\
&= 6.62 \times 10^{-25} kgms^{-1}
\end{aligned}$$

The two momenta are different because the effective crystal momentum is related to the electron energy inside the crystal measured from the conduction band edge (concept of effective mass).

Question 3

Part (a)

A diode has applications in rectifiers, transistors, waveform generators, shapers, lasers, detectors …

Part (b)

Calculate the Fermi level positions in the p and n regions (L3 P21)

$n = N_C\ exp\left[\frac{E_F - E_C}{k_B T}\right]\ where\ n = N_d$ (donor concentration fully ionised)

$$E_{Fn} - E_C = k_B T ln\left[\frac{N_d}{N_C}\right]$$

$$E_F = E_C + k_B T ln\left[\frac{N_d}{N_C}\right]$$

$$= E_C + [1.38 \times 10^{-23} JK^{-1} \times 300K] \times ln\left(\frac{10^{16}}{2.8 \times 10^{19}}\right)$$

$$= E_C - 0.21eV$$

$N_V = 9.84 \times 10^{18} cm^{-3}$ (Valence band DOS)

$$E_{Fp} = E_v - k_B T ln\left[\frac{N_a}{N_v}\right]$$

$$= E_v - \left[1.38 \times 10^{-23} JK^{-1} \times 300K \times ln\left(\frac{10^{18}}{9.84 \times 10^{18}}\right)\right]$$

$$= E_v + 0.06eV$$

Part (c)

The “Law of mass action”.

In intrinsic semiconductors the electron concentration is equal to the hole concentration since each electron in the conduction band leaves a hole in the valence band. The “Law of mass action” states that the product np is independent of the Fermi level and is dependent only on the temperature and intrinsic properties of the semiconductor.

Part (d)

The built in potential for a diode at 300K. Firstly use the law of mass action. They will not have covered this material yet in the lectures (it will be tomorrow). But they have the handouts which show this worked example. It’s important they understand the use of the law of mass action to calculate depletion widths.

$n_n p_n = n_i^2$ Law of mass action (note can also write $n_p p_p = n_i^2$).

$$P_n = \frac{n_i^2}{n_n} = \frac{(1.5 \times 10^{10})^2}{10^{16}}$$

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

Note how small this number is compared with the donor/acceptor densities.

$$
\begin{aligned}
V_{bi} &= \frac{k_B T}{e} ln \frac{p_p}{p_n} \\
&= \frac{1.38 \times 10^{-23} \times 300}{1.6 \times 10^{-19}} \left(\frac{10^{18}}{2.25 \times 10^{4}} \right) \\
&= 0.81V
\end{aligned}
$$

Part(e)

Calculate the depletion width for the n and p regions of the diode under a reverse bias of 0 and 8V and a forward bias of 1V.

$$
\begin{aligned}
W_n(0.81) &= \left(\frac{2\varepsilon V_{bi}}{e} \left[\frac{N_a}{N_d(N_a + N_d)} \right] \right)^{1/2} \\
&= \left(\frac{2 \times 11.9 \times 8.85 \times 10^{-12} \times 0.81}{1.6 \times 10^{-19}} \left[\frac{10^{24} m^{-3}}{10^{22} m^{-3} \times (1.01 \times 10^{24} m^{-3})} \right] \right)^{1/2} \\
&= 0.32\mu m \\
W_p(0.81) &= \left(\frac{2\varepsilon V_{bi}}{e} \left[\frac{N_d}{N_a(N_a + N_d)} \right] \right)^{1/2} \\
&= 3.2nm \\
W_n(8.81) &= \left(\frac{8.81}{0.81} \right)^{1/2} \times 0.32\mu m \\
&= 1.06\mu m \\
W_p(8.81) &= \left(\frac{8.81}{0.81} \right)^{1/2} \times 3.2nm \\
&= 10.6nm \\
W_n(-0.29) &= \left(\frac{-0.29}{0.81} \right)^{1/2}
\end{aligned}
$$

There is <u>no</u> depletion for a forward bias of 1V.

Notice how the depletion width changes as a function of the forward/reverse bias. They need to understand that the application of a reverse bias increases the depletion region.

Question 4

They have not seen this question yet. This is unseen NOT bookwork.

The optical absorption coefficient for GaAs is:

$$\alpha = 5.7 \times 10^4 \frac{\left(\hbar\omega - E_g\right)^{1/2}}{\hbar\omega} cm^{-1}$$

The absorption coefficient for a photon with an energy of 1.8eV (GaAs band gap is 1.43eV).

$$\begin{aligned} \alpha &= \frac{(1.8 - 1.43)^{1/2}}{1.8} \\ &= 1.93 \times 10^4 cm^{-1} \end{aligned}$$

Fraction of absorbed light

$$\begin{aligned} I &= I_0 e^{-\alpha T} \\ &= 1 - exp(-(1.93 \times 10^4 cm^{-1}) \times (0.5 \times 10^{-4} cm)) \\ &= 0.62 \end{aligned}$$

62% of the light is absorbed