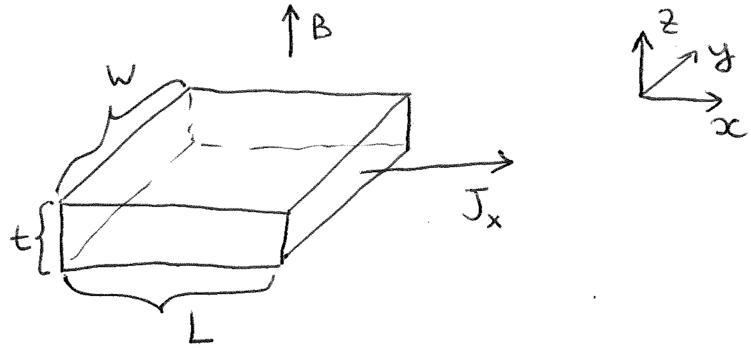
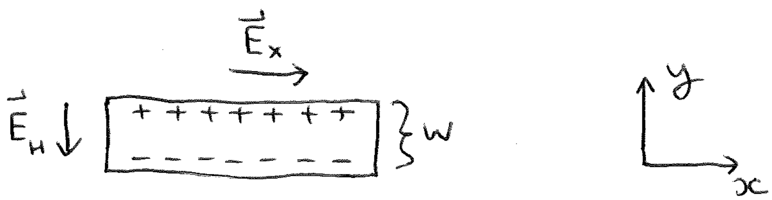
Physics 406
2013

HW #7
solutions

(1) θ Ch. 6, Pr. 9





$L = 5\ \mathrm{cm}$ $\quad W = 0.5\ \mathrm{cm}$ $\quad t = 1\ \mathrm{mm}$

$B = 0.6\ \mathrm{Wb/m^2}$ $\quad J_x = 10\ \mathrm{mA}$

$n = 10^{16}\ \mathrm{cm^{-3}} = 10^{22}\ \mathrm{m^{-3}}$

(a) $$|R_H| \equiv \frac{E_y}{J_x B_z} = \frac{1}{ne}$$

$$|R_H| = \frac{1}{(10^{22}) \times (1.6 \times 10^{-19})} = 6.25 \times 10^{-4}\ \frac{\mathrm{m^3}}{\mathrm{C}}.$$

(b) $$\underset{\frac{V_H}{W}}{\underset{\parallel}{E_y}} = R_H J_x B_z$$

$$\Rightarrow V_H = W R_H J_x B_z =$$

$$= (5 \times 10^{-3})(6.25 \times 10^{-4})(10^{-2})(0.6) \simeq$$

$$\simeq 1.9 \times 10^{-8}\ \mathrm{V}.$$

(2) Omar Ch. 6, Pr. 11

a) Use $\frac{dN}{dE} = \frac{dN}{dV}\frac{dV}{dE}$

✓ Spherical energy surface:

$$V = \frac{4\pi}{3}k^3 = \frac{4\pi}{3}\left(\frac{2mE}{\hbar^2}\right)^{3/2}$$

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

$$\frac{dN}{dE} = \underbrace{\frac{1}{(2\pi)^3}}_{\frac{dN}{dV}} \underbrace{2\pi\left(\frac{2m}{\hbar^2}\right)^{3/2} E^{1/2}}_{\frac{dV}{dE}} =$$

$$= \frac{1}{(2\pi)^2}\left(\frac{2m}{\hbar^2}\right)^{3/2} E^{1/2}.$$

✓ Ellipsoid:

$$V = \frac{4\pi}{3}k_\perp^2 k_z, \quad \text{where}$$

$$\begin{cases} k_\perp = \sqrt{\frac{2E}{\hbar^2}m_\perp}, \\ k_z = \sqrt{\frac{2E}{\hbar^2}m_z} \end{cases} \qquad \begin{cases} m_z \equiv m_l \\ m_\perp \equiv m_t \end{cases}$$

Then

$$\frac{dN}{dE} = \frac{1}{(2\pi)^3} \frac{d}{dE}\left(\frac{4\pi}{3} \frac{2m_\perp}{\hbar^2} \left(\frac{2m_z}{\hbar^2}\right)^{1/2} E^{3/2} \right) =$$

$$= \frac{1}{(2\pi)^2} (m_\perp^2 m_z)^{1/2} \left(\frac{2}{\hbar^2}\right)^{3/2} E^{1/2} ,$$ and

$$g(E) = \underset{\substack{\uparrow \\ \text{spin}}}{2} \frac{dN}{dE} .$$

b) In Ge, $\begin{cases} m_e = 1.6\, m_0, \\ m_t = 0.08 m_0 \end{cases}$

Then $m_d = (m_t^2 m_e)^{1/3} =$

$$= \left((0.08)^2 \times 1.6\right)^{1/3} m_0 \simeq 0.22\, m_0 .$$

3. ⓪ Ch. 6, Pr. 19

$$\mu \sim T^{-1.66}$$

$$\mu(300\,K) = 3900 \ \frac{cm^2}{V \cdot s}$$

Then $D = \dfrac{\mu k_B T}{e} \Rightarrow$

$$\Rightarrow D(300\,K) = 3900 \times 0.025 \ \frac{cm^2}{s} =$$

$$= 97.5 \ \frac{cm^2}{s}.$$

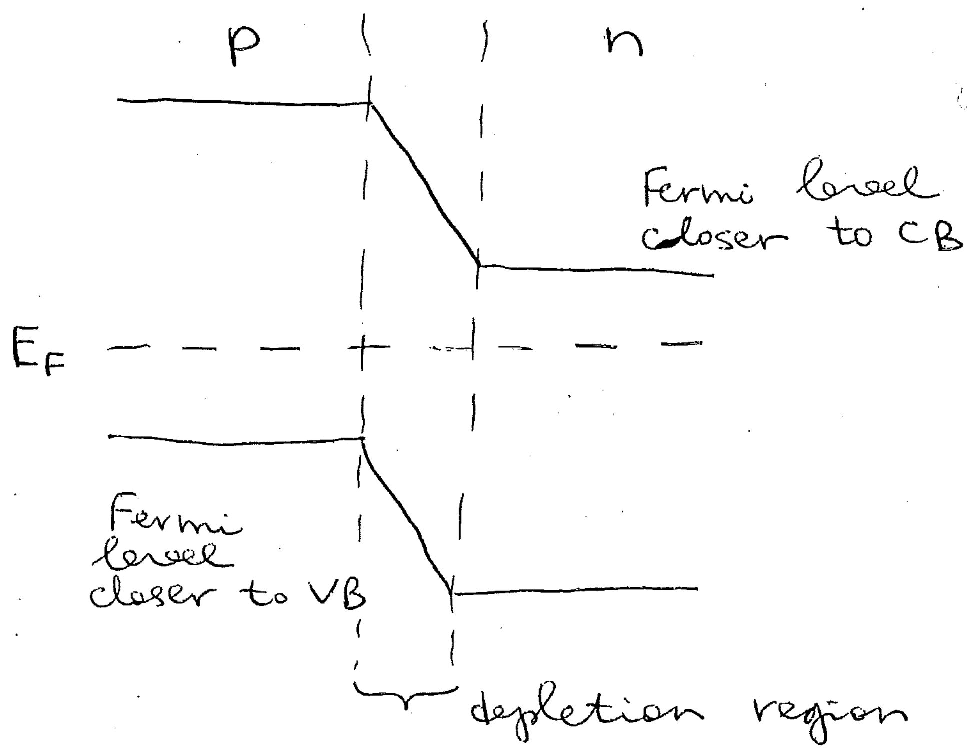
$$\frac{D(77\,K)}{D(300\,K)} = \frac{\mu(77\,K)\,(k_B \overset{77\,K}{T})}{\mu(300\,K)\,(k_B \underset{300\,K}{T})}, \text{ or}$$

$$D(77\,K) = D(300\,K)\left(\frac{300}{77}\right)^{1.66}\left(\frac{77}{300}\right) \simeq$$

$$\simeq 239 \ \frac{cm^2}{s}.$$

4.

0. Ch. 7, Q. 1


p
n
Fermi level closer to CB
E_F
Fermi level closer to VB
depletion region

(5.) Q. Ch. 7, Q.8

Addition of P to GaAs increases the sc bandgap, since

$$E_g \simeq \frac{hc}{\lambda}$$

& λ was reduced. This process is called "bandgap engineering" and is often used in sc industry, e.g. to make sc lasers w/ the desired wavelength.

Omar chapter 7, Pr. 1

(6.) Forward-biased p-n junction:

$$J_{pg} = J_{pg,0}$$ generation current does not change, even w/ decreased barrier

$$J_{pr} = \underbrace{J_{pr,0}}_{= J_{pg,0}} e^{eV_0/k_B T}$$ recombination current increases since barrier is reduced in height

Electric current:

$$I_p = e(J_{pr} - J_{pg}) = e J_{pg,0}\left(e^{eV_0/k_B T} - 1\right),$$

using the fact that generation & recombination currents are equal at equilibrium if $V_0 = 0$ (no bias).

θ Ch. 7, Pr. 4

7. a) $\varphi_0 = \frac{k_B T}{e} \log\left(\frac{n_{no} p_{po}}{n_i^2}\right) \simeq$

$\simeq \frac{k_B T}{e} \log\left(\frac{N_d N_a}{n_i^2}\right).$

$n_i = 2 \times 10^{13}\ cm^{-3}$ @ room T
(from before)

$\varphi_0 = 0.025\ V \log\left(\frac{10^{18} \times 5 \times 10^{16}}{4 \times 10^{26}}\right) \simeq 0.47\ \underline{\underline{V}}.$

b) $w_n = \left[2 \epsilon \epsilon_0 \varphi_0 \frac{N_a}{N_d(N_a + N_d)} \frac{1}{e}\right]^{1/2}$

$\epsilon = 16$ for Ge
$\varphi_0 = 0.47\ V$
$\epsilon_0 = 8.85 \times 10^{-12}\ \frac{Coul^2}{N \times m^2}$
$N_d = 10^{24}\ m^{-3}$
$N_a = 5 \times 10^{22}\ m^{-3}$
$e = 1.6 \times 10^{-19}\ Coul$

$w_n = \left[\frac{2 \times 16 \times (8.85 \times 10^{-12}) \times 0.47}{1.6 \times 10^{-19}} \frac{5 \times 10^{22}}{10^{24}(5 \times 10^{22} + 10^{24})}\right]^{1/2} \simeq$

$\simeq 63.1\ \text{Å}.$

$w_p = w_n \frac{N_d}{N_a} = 63.1\ \text{Å}\ \frac{10^{24}}{5 \times 10^{22}} = 1262\ \text{Å}$

c) $E_0 = \dfrac{2\varphi_0}{\underbrace{W}_{W_n + W_p}} = \dfrac{2 \times 0.47\,V}{1325 \times 10^{-8}\,cm} = 7.1 \times 10^{4} \dfrac{V}{cm}$.

d) $C = \dfrac{\epsilon \epsilon_0 A}{W} \Rightarrow \dfrac{C}{A} = \dfrac{\epsilon \epsilon_0}{W} =$

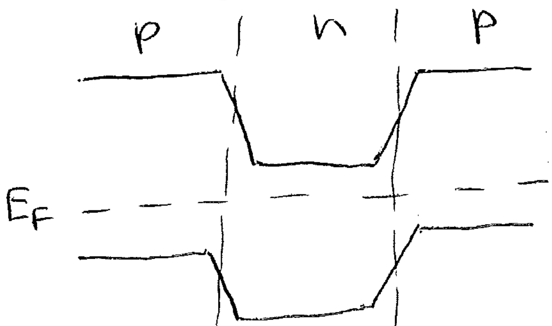
capacitance

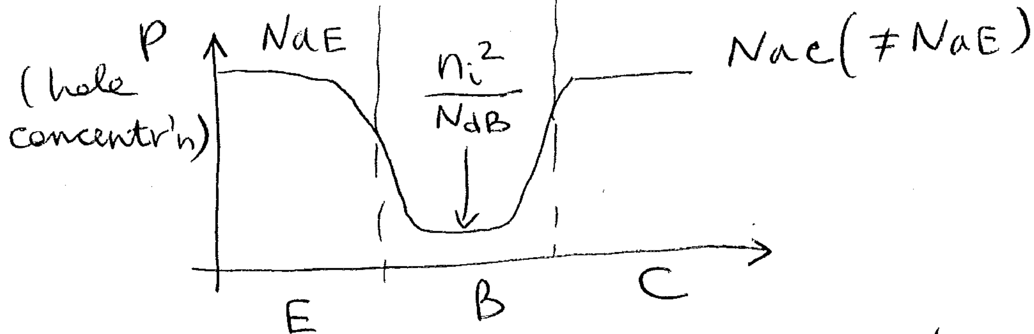
$= \dfrac{16 \times (8.85 \times 10^{-12})}{1325 \times 10^{-10}} \simeq 1.1 \times 10^{-3} \dfrac{\text{Farad}}{m^2}$.

(8.) θ Ch. 7, Pr. 7

p-n-p transistor

Energy band diagram:





N_{aE} = # acceptors/cm^3 in the emitter region, etc.

(9.) Nanoscale electrical & optical devices based on carbon nanotubes

a) Fast-switching FETs with silicon channels replaced by nanotubes; ballistic rather than diffusive transport

b) Ambipolar transistors ($\bar{e}$ & holes injected simultaneously)

c) Use as photoconductors in solar cells - light generates current

d) Use as biosensors: molecules bind, changing field environment & current