HW #7
solutions

Physics 406

1. O chapter 6 P 15

For Silicon $E_g = 1.1$ eV

a) Transparent in the IR

$E_{IR} < E_g$ so IR radiation will not be absorbed by Si and it will appear transparent in this regime

b) Metallic Lustre in Visible light

By contrast $E_{vis} > E_g$

$(400 \text{ nm} < \lambda_{vis} < 700 \text{ nm} \Rightarrow$

$1.77 \text{ eV} < E_{vis} < 3.0 \text{ eV})$

so that visible light will be absorbed. The dielectric function, and hence the index of refraction, will have a finite imaginary part in this frequency range so that there will be partial reflection. Therefore the silicon surface will appear shiny in the visible regime.

2. 0 chapter 6 P 19

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

$\mu(300\,K) = 3900\ cm^{+2}/V\text{-}s \Rightarrow D$

$$D = \frac{\mu k_B T}{e}$$

a) D at T = 300 K.

$$\mu = 3900\ \frac{cm^2}{V-s}$$

$$D = (3900)\ \frac{.025\ \cancel{eV}}{\cancel{eV}}\ \frac{cm^2}{s}$$

$$D_{300} = 97.5\ cm^2/s$$

b)
$$\frac{D_{77}}{D_{300}} = \frac{\mu_{77}\,(k_B T)_{77}}{\mu_{300}\,(k_B T)_{300}}$$

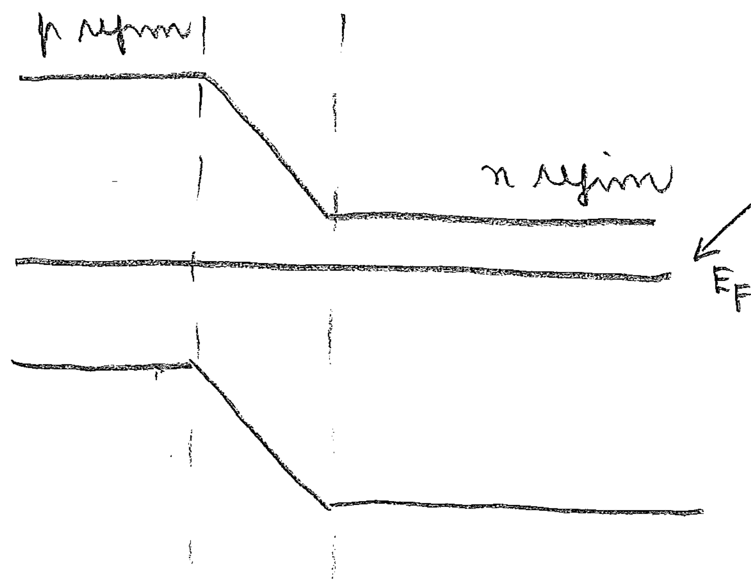
$$\Downarrow$$

$$D_{77} = D_{300}\left(\frac{300}{77}\right)^{1.66}\left(\frac{77}{300}\right)$$

$$= D_{300}\left(\frac{300}{77}\right)^{0.66} =$$

$$D_{77} = 239 \ \mathrm{cm^2/s}.$$

3. O chapter 7 Q1.



n-type E_F closer to VB ⇒ larger # conduction electrons

p-type Fermi level closer to VB (material has larger # free holes)

4. Omar chapter 7, Pr. 1

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).

5.0 chapter 7 P 4.

a) ϕ_0 for p-n junction

$T = 300$ K

$N_d = 10^{18}\ cm^{-3}$

$N_a = 5 \times 10^{16}\ cm^{-3}$

$$\phi_0 = \frac{k_B T}{e} \log \left(\frac{n_{no}\, p_{no}}{n_i^2} \right)$$

** Error in book Should be $\underline{\underline{\ln}}$

$n_{n_0} \sim N_d = 10^{18}\ cm^{-3}$

$p_{no} \sim N_a = 5 \times 10^{16}\ cm^{-3}$

$n_i = 2 \times 10^{13}\ cm^{-3}$

$$\phi_0 = .025\,V \log \left(\frac{10^{18} \cdot 5 \times 10^{16}}{2 \times 10^{13}} \right)$$

$$= .025\,V \left[21 + \log (5/2) \right]$$

$\boxed{\phi_0 = .53\ V}$

** Correction

$\phi_0 = .53 \ (\ln 10) =$

$.53\,(2.3) = 1.2\,V$

b) $$w_n = \left[2\,\varepsilon\varepsilon_0\phi_0 \frac{N_a}{N_d\,(N_d + N_a)\,e} \right]^{1/2}$$

Here continued w/ $\phi_0 = .53$ V ~~&~~

$\Downarrow$ corrected value

$\tilde{w}_n = w_n \sqrt{2.3}$

$= 67\,A\ (1.5)$

$= 101.6$ Å

$\varepsilon = 16$ for Ge

$\phi_0 = .53$ V.

$\varepsilon_0 = 8.854 \times 10^{-12}$ coulomb^2/newton - m^2

$N_a = 5 \times 10^{16}$ cm^{-3} $= 5 \times 10^{22}$ m^{-3}

$N_d = 10^{18}$ cm^{-3} $= 10^{24}$ m^{-3}.

$e = 1.6 \times 10^{-19}$

$$w_n = \left[\frac{2\,(16)\,(8.85 \times 10^{-12})\,(.53)}{(1.6 \times 10^{-19})} \quad \frac{5 \times 10^{22}}{10^{24}\,(5 \times 10^{22} + 10^{24}} \right.$$

$$= \left[\underbrace{\frac{2\,(16)\,(8.85)\,(.53)\,(5)}{(1.6)\,(1.05)}}_{446.7} \quad 10^{-19} \right]^{1/2}$$

$$= \left[4.47 \times 10^{-17} \right]^{1/2} = \left[44.7 \right]^{1/2} \times 10^{-9}\ \text{m}$$

$= 6.69 \times 10^{-9}$ m

$= 67$ Å

$$W_p = W_n \frac{N_d}{N_a}$$

$$W_p = (6.69 \times 10^{-9}) \frac{10^{24}}{5 \times 10^{22}}$$

$$= 1.338 \times 10^{-7} \text{ m}$$

$$= 1338 \text{ Å}$$

** Should be

$W_p = 1338 \ln(10) = 3080$

c) $$E_0 = \frac{2\phi_0}{W} = \frac{2(.53) \text{ V}}{1405 \text{ Å}}$$

$$= \frac{(2)(.53)}{1405 \times 10^{-10} \text{ m}} \text{ V}$$

$$= \frac{(2)(.53)}{1405 \times 10^{-8}} \frac{\text{V}}{\text{cm}}$$

$$= 7.5 \times 10^4 \text{ V/cm}$$

$$= 75 \text{ kV/cm.}$$

**

Should be

$$E_0 = \frac{7.5 \times 10^4}{\ln 10}$$

$$= 3.26 \times 10^4 \text{ V/cm}$$

d) $$C = \frac{\varepsilon\varepsilon_0 A}{W} \Rightarrow \frac{C}{A} = \frac{\varepsilon\varepsilon_0}{W}$$

$$\frac{C}{A} = \frac{\varepsilon \varepsilon_0}{w} = \frac{(16)(8.85 \times 10^{-12})}{1405 \times 10^{-10}}$$

$$= \frac{(16)(8.85)}{1405} \times 10^{-2} \quad \text{farad}/m^2$$

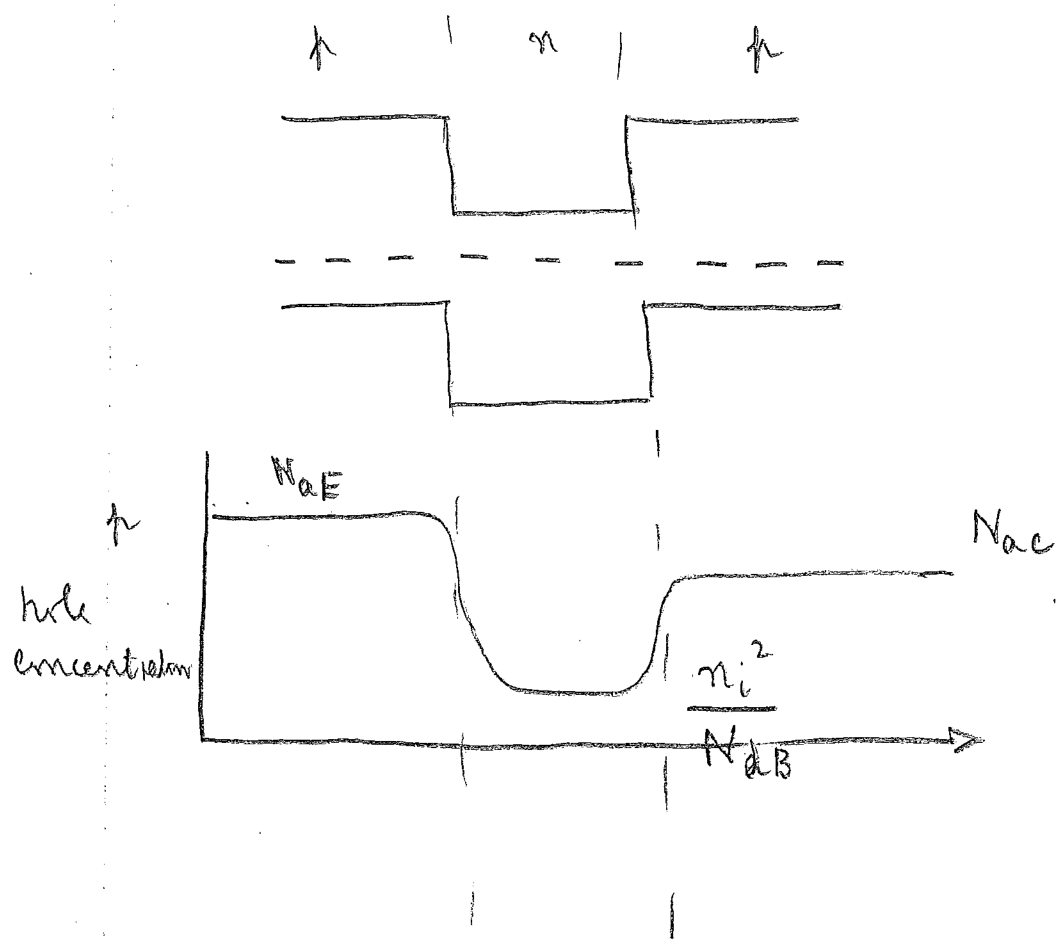
$$= 10^{-3} \quad \text{farad}/m^2$$

** Should be

$$\frac{C}{A} \sim \frac{10^{-3}}{\ln 10} = 4.3 \times 10^{-4} \ \frac{\text{farad}}{m^2}$$

6. Omar chapter 7 P 7

Energy band Diagram for p - n - p junction



E = emitter B = base C = collector

N_a = # acceptors / cm^3

N_d = # donors / cm^3

7. Developments in recent studies of nanoscale electrical and optical devices based on carbon nanotubes

- fast-switching field effect transistor where silicon channel is replaced by nanotube. ballistic transport main origin of speed-up (usually diffusive)
- Ambipolar transistor operation where electrons and holes can be injected simultaneously.
- injection of electrons and holes together to enhance radiative recombination ⇒ light emitting diodes
- use as photoconductors as component of solar cell - light leads to generation of current
- use as biosensors where attachment of molecule changes field environment and generates current.