HW#1 SOLUTION

1)

a). Bohr postulate can be expressed as:

$$L_n = m_0 v r_n = n\hbar \quad , \quad n = 1, 2, 3, \cdots$$

m_0 is electron rest mess, v is linear electron velocity, r_n is the radius of orbit.

· Centripedal force on the electron must balance the Coulombic attraction between the nucleus and orbiting electron.

$$\frac{m_0 v^2}{r_n} = \frac{q^2}{4\pi\varepsilon_0 r_n^2} \quad \text{—— ①}$$

· Kinetic energy $= \frac{1}{2} m_0 v^2 = \frac{1}{2} \cdot \frac{q^2}{4\pi\varepsilon_0 r_n}$ by using eq ①.

· from eq ①

above eq can be $\frac{m_0 q^4}{2(4\pi\varepsilon_0 n\hbar)^2} = \frac{13.6}{n^2}$ eV

· so,

$$v = \sqrt{\frac{2 \times 13.6 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}} \times \frac{1}{n} = \frac{2.19 \times 10^6}{n} \text{ m/sec}$$

∴ if $n=1$, $v = 2.19 \times 10^6$ m/sec

$n=2$, $v = 1.095 \times 10^6$ m/sec

$n=3$, $v = 0.73 \times 10^6$ m/sec

b) from Figure A.2,

i) $E_3 - E_2 = \Delta E_{32} = 1.89\text{eV} = \frac{hc}{\lambda}$

$$\Rightarrow \lambda = \frac{hc}{1.89\text{ eV}} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.89 \times 1.6 \times 10^{-19}} = 658 \text{ nm.}$$

(red color)

ii) $E_4 - E_2 = \Delta E_{42} = 2.55$ eV

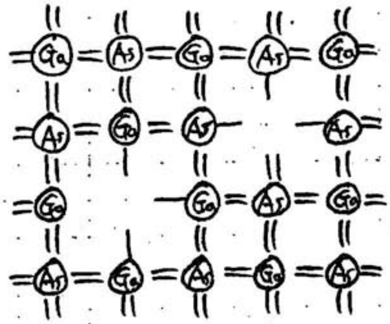
$$\Rightarrow \lambda = \frac{hc}{2.55\text{ eV}} = 487 \text{ nm (between green and blue)}$$

iii) $E_5 - E_2 = \Delta E_{52} = 2.86$ eV

$$\Rightarrow \lambda = \frac{hc}{2.86\text{ eV}} = 435 \text{ nm (indigo color)}$$

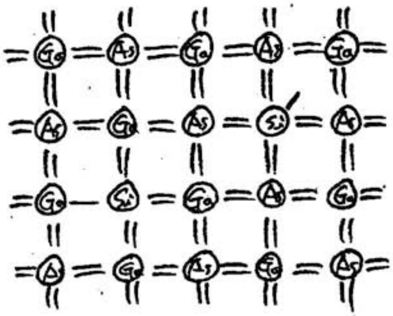
2)

a)



the removal of Ga atom with three valence electrons leaves five dangling bonds.
the removal of As atom with five Valenc electrons leaves three dangling bonds.

b)



When a Si atom with four Valence electron is inserted into the missing Ga site, there is one extra electron.
when a Si atom is inserted into the missin As site, there are one too few bonds to complete the bonding scheme. there is a hole in the bonding schem

c) n-type

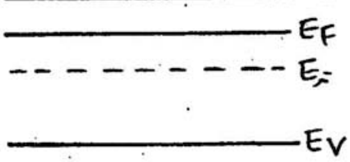
the extra electron is released / yielding an increase in the electron concentration.

d) p-type

The missing bond is filled yielding an increase in the hole concentration.

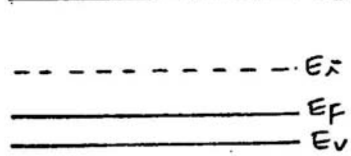
e)

i)



n-type

ii)



p-type

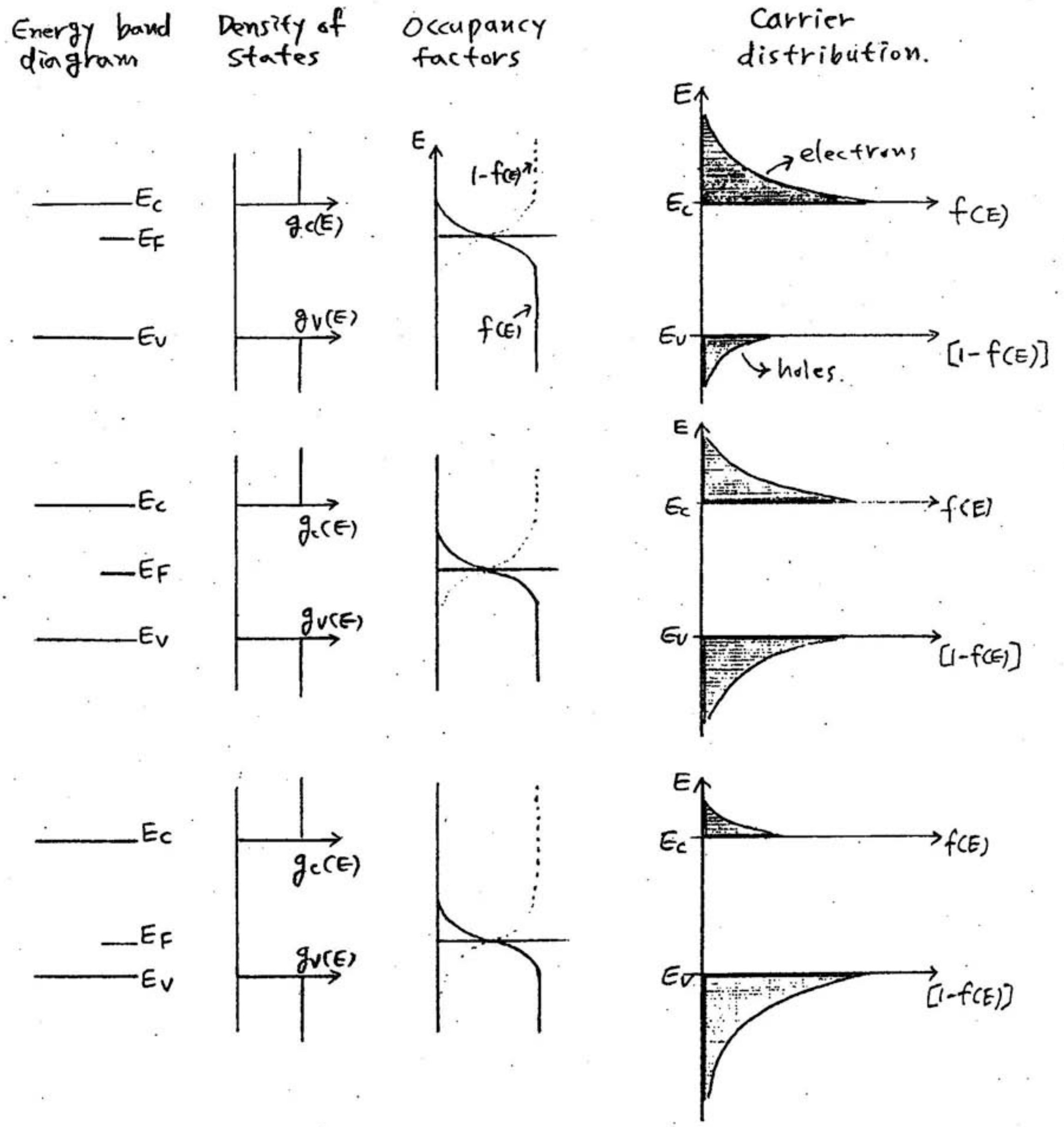
3) We assume semiconductor is nondegenerate.

the electron distribution is:

$$g_c(E)f(E) = \frac{N_c}{kT}\cdot\frac{1}{1+e^{(E_c-E_F)/kT}} \simeq \frac{N_c}{kT}e^{-(E-E_F)/kT}$$

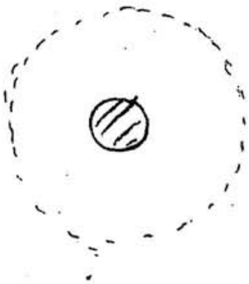
the hole distribution is:

$$g_v(E)[1-f(E)] = \frac{N_v}{kT}\cdot\frac{1+e^{(E-E_F)/kT}-1}{1+e^{(E-E_F)/kT}} \simeq \frac{N_v}{kT}\cdot\frac{1}{1+e^{(E_F-E)/kT}}$$



4. (a) $r = \frac{13.1}{0.06} \times 0.529\ \AA = 115.5\ \AA$

The volume of the impurity is then -



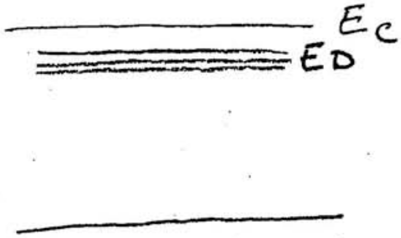
$V_{imp.} = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi \times (115.5 \times 10^{-8})^3\ cm^3$

$= 6.454 \times 10^{-18}\ cm^3$

∴ doping concentration density.

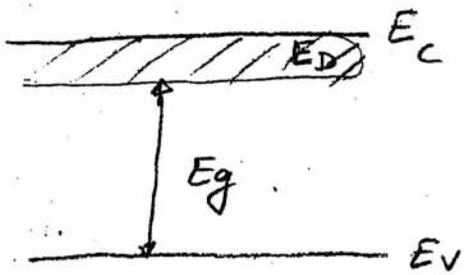
$N_d = \frac{1}{6.454 \times 10^{-18}}\ cm^{-3} = 1.55 \times 10^{17}\ cm^{-3}$

(b) Due to impurity orbitals overlap, an impurity band is created.
According to pauli exclusion principles, two electrons cannot be the same quantum state. So they become in spitted state.



(c) Under extremely high doping, ① the impurity band merge with the conduction band or valence band, As a result the band gap reduced. There are other mechanism which are also responsible to reduce the band gap -

② Charge screening.
③ Loss of the periodic potential due to the introduction of impurity.



5)

a) zero.

by charge neutrality,

there are no net charges.

b) material is n-type.

free electron density is 8×10^{15} electrons/cm^3

c) $np = n_i^2$

$$p = \frac{n_i^2}{n} = \frac{1.21 \times 10^{20}}{8 \times 10^{15}} = 1.51 \times 10^4 \ cm^{-3}$$

d) ionized donor density is $1.5 \times 10^{16} \ cm^{-3}$

e) neutral donor density is
very small compare with d)

[Solution to problem 1, midterm exam #1, spring 2007]

(1.) a) Degeneracy ⟹ 3kT away from band edge

$$n = N_c e^{-\frac{3kT}{kT}}$$

$$n = N_c e^{-3} \implies n = 10^{20} e^{-3}$$

degenerate for $\underline{n > 5 \times 10^{18}\ cm^{-3}}$ (or N_d)

for p-type material

$$p = N_v e^{-3} \quad p = 10^{16} e^{-3}$$

degenerate for $\underline{p > 5 \times 10^{14}\ cm^{-3}}$ (or N_a)

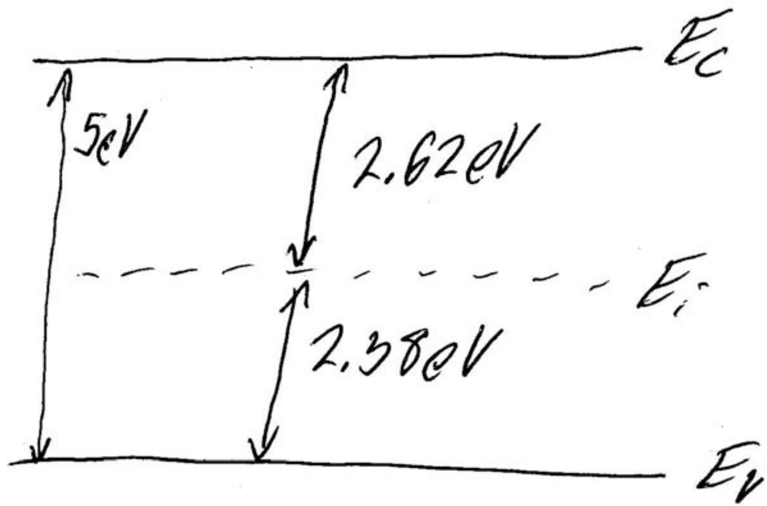
Degeneracy means that the simple Boltzman approximation to Fermi-Dirac statistics cannot be used & we have to calculate n, p from numerical integration.

b) $n_i^2 = N_c N_v e^{-E_g/kT}$

$$n_i \approx 1.7 \times 10^{-24}$$

$\boxed{n_i \approx 0}$ ⟹ huge bandgap!

c.)



$$E_i = \frac{E_C + E_V}{2} + \frac{kT}{2} \ln \frac{N_V}{N_C}$$

$$E_i = 2.5\,eV - .12\,eV$$