Seat number

King Mongkut's University of Technology Thonburi
Midterm Examination
Physics of **Semester 2 – Academic Year 2012**

Subject: EIE 311 Electronic Materials and Devices

For: Electronics and Telecommunication students, 3rd Yr (International Program)

Exam Date: Monday 4th March, 2013 **Time:** 13:00-16:00 hrs.

Instructions:-

1. This exam consists of 5 problems with a total of 6 pages, including the cover.
2. This exam is a closed-book/closed-note exam.
3. Answer each problem on the given booklet.
4. A calculator compiling with the university rule is allowed.
5. **Do not** bring any exam papers and answer sheets **outside** the exam room.
6. Please do your work to 4 significant figures.
7. Formula sheets are allowed to be parted from the exam.

Remarks:-

- **Raise your hand when you finish the exam to ask for a permission to leave the exam room.**
- **Students who fail to follow the exam instruction might eventually result in a failure of the class or may receive the highest punishment with university rules.**
- **Carefully read the entire exam before you start to solve problems. Before jumping into the mathematics, think about what the question is asking. Investing a few minutes of thought may allow you to avoid twenty minutes of needless calculation!**

Exam No.	1	2	3	4	5	TOTAL
Full Score	20	20	20	20	20	100
Graded Score						

Name ______________________________ **Student ID** ______________

This examination is designed by
Dr. Apichai Bhatranand; Tel. 9063.

This examination has been approved by the committees of the ENE department.

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1. (20 points) The Hall Effect experiment shown in figure 1 has following parameters:

   L = 0.1 cm, W = 0.01 cm, d = 0.001 cm, I_x = 1 mA, V_x = 12.5 V, B_z = 500 gauss, and V_H = -6.25 mV.

   Determine: a) Hall field (E_H) b) Are majority carriers 'holes' or 'electrons'? Please explain your reason. c) Majority carrier concentration and its mobility.

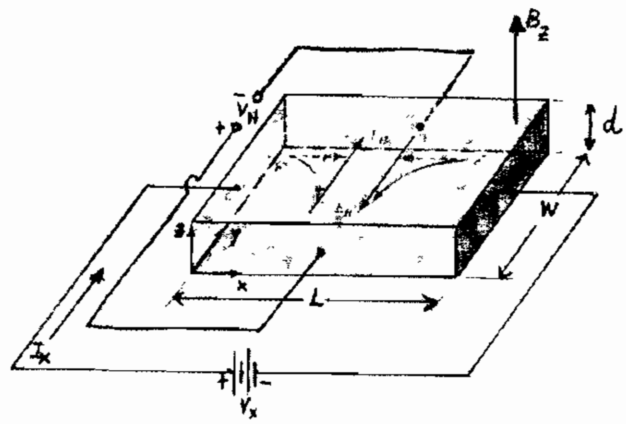


Fig. 1 Hall Effect setup.

2. (20 points) An electron is bound in a one-dimensional infinite potential well with a width of 10 Å.

   a) Calculate the first three energy levels that the electron may occupy.

   b) If the electron drops from the third to the second energy level, what is the wavelength of a photon that might be emitted?

3. (20 points) Find

   a) The Miller indices for the following planes in figure 2 and 3.

   Note: a, b, and c correspond to x-, y-, and z- axes, respectively.

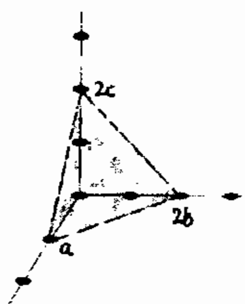


Fig. 2

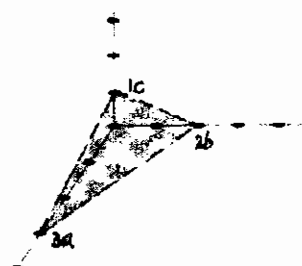


Fig. 3

b) What is the structure of a cubic in figure 4? Also, calculate the surface density of atoms on the (110) plane in the unit of atoms/cm^2. Note: A lattice constant is 5 Å.

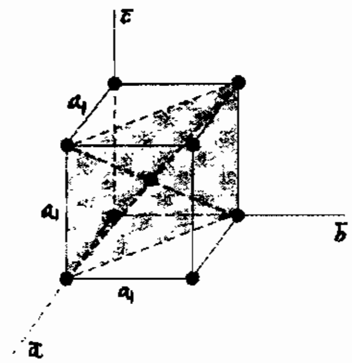


Fig. 4

4. (20 points) Determine

a) The probability that an energy state at $3kT$ above E_F is occupied by an electron.

b) The temperature at which there is a 1 percent probability that a state 0.3 eV below E_F will NOT contain any electron.

5. (20 points)

a) Calculate the hole concentration in silicon at T = 400 K. Assume that the Fermi energy is 0.27 eV above the valence band.

b) Calculate the electron and hole concentrations in silicon at room temperature in which $N_D = 10^{16}$ cm^{-3} and $N_A = 0$.

c) Consider silicon at room temperature with doping concentrations of $N_D = 8 \times 10^{15}$ cm^{-3} and $N_A = 5 \times 10^{15}$cm^{-3}. Determine the position of the Fermi energy level.

Properties of Si and GaAs at 300 K

Properties	Si	GaAs
Atoms/cm^3	5.02×10^{22}	4.42×10^{22}
Atomic weight	28.09	144.63
Breakdown field (V/cm)	$\sim 3 \times 10^5$	$\sim 4 \times 10^5$
Crystal structure	Diamond	Zincblende
Density (g/cm^3)	2.329	5.317
Dielectric constant	11.9	12.4
Effective density of states in conduction band, N_C(cm^{-3})	2.86×10^{19}	4.7×10^{17}
Effective density of states in valence band, N_V(cm^{-3})	2.66×10^{19}	7.0×10^{18}
Effective mass (conductivity)		
Electrons (m_n/m_0)		
Holes (m_p/m_0)		
Electron affinity, χ(V)	4.05	4.07
Energy gap (eV)	1.12	1.42
Index of refraction	3.42	3.3
Intrinsic carrier concentration(cm^{-3})	9.65×10^9	2.25×10^6
Intrinsic resistivity (Ω-cm)	3.3×10^5	2.9×10^8
Lattice constant (Å)	5.43102	5.65325
Linear coefficient of thermal expansion, $\Delta L/L \times T$ (°C^{-1})	2.59×10^{-6}	5.75×10^{-6}
Melting point (°C)	1412	1240
Minority-carrier lifetime (s)	3×10^{-2}	$\sim 10^{-8}$
Mobility (cm^2/V·s)		
μ_n (electrons)	1450	9200
μ_p (holes)	505	320
Specific heat (J/g -°C)	0.7	0.35
Thermal conductivity(W/cm-K)	1.31	0.46
Vapor pressure (Pa)	1 at 1650°C 10^{-6} at 900°C	100 at 1050°C 1 at 900°C

Formula sheet (1/2)

N_A = Avogadro's number = 6.02 x 10^{23} atoms/mole
k = Boltzmann's constant = 1.38 x 10^{-23} J/K
q = electronic charge = 1.6 x 10^{-19} C
eV = electronvolt = 1.6 x 10^{-19} J
m_0 = free electron mass = 9.11 x 10^{-31} kg.
ε_0 = permittivity of free space = 8.85 x 10^{-12} F/m = 8.85 x 10^{-14} F/cm
μ_0 = permeability of free space = 1.26 x 10^{-6} H/m
h = Planck's constant = 6.63 x 10^{-34} J.s
c = light velocity (speed) = 3 x 10^8 m/s
1 Gauss = 1x10^{-4} Wb/m² = 1x10^{-4} Tesla

$$R = \frac{\rho l}{A} = \frac{1}{\sigma}\cdot\frac{l}{A} \qquad J = \sigma E \qquad v_D = \mu_e E \qquad J = N_e . q . v_D$$

$$\sigma = \sigma_e + \sigma_h \qquad \rho = \frac{1}{qn\mu_e + qp\mu_h} \qquad E_H = \frac{B.J}{N_e q}$$

$$\frac{1}{\mu} = \frac{1}{\mu_L} + \frac{1}{\mu_I} \qquad R_H = -\frac{1}{qN_e} = \frac{1}{N_e e} \qquad V_H = E_H L$$

$$J_e = -qF = qD_n \frac{dn}{dx} \qquad D_n = \left(\frac{kT}{q}\right)\mu_e \qquad \lambda = \frac{h}{p}$$

$$\frac{d^2\psi}{dx^2} + \frac{2m}{\hbar^2}(E - V)\psi = 0 \qquad E_n = \frac{n^2 h^2}{8mL^2} \qquad E = h\nu = \frac{hc}{\lambda}$$

$$T \cong \exp\left\{-2d\sqrt{\frac{2m_e^*(qV_0 - E)}{\hbar^2}}\right\} \qquad \rho = \left(\frac{nM}{N_A}\right)\cdot\frac{1}{a^3}$$

$$\cos(ka) = \frac{P\sin(\alpha a)}{\alpha a} + \cos(\alpha a) \qquad P = \frac{maV_0 w}{\hbar^2} \qquad \alpha = \frac{1}{\hbar}\sqrt{2mE}$$

Formula sheet (2/2)

$$E_n = -\frac{mq^4}{8\varepsilon_0^2 h^2}\cdot\frac{1}{n^2} = -\frac{13.6\ \text{eV}}{n^2} \qquad n = \int_0^\infty n(E)d(E) = \int_0^\infty N(E)F(E)dE$$

$$N(E) = 4\pi\left(\frac{2m}{h^2}\right)^{3/2} E^{1/2} \qquad F(E) = \frac{1}{1+e^{(E-E_F)/kT}}$$

$$n = N_C \exp\left[-(E_C - E_F)/kT\right] \qquad p = N_V \exp\left[-(E_F - E_V)/kT\right]$$

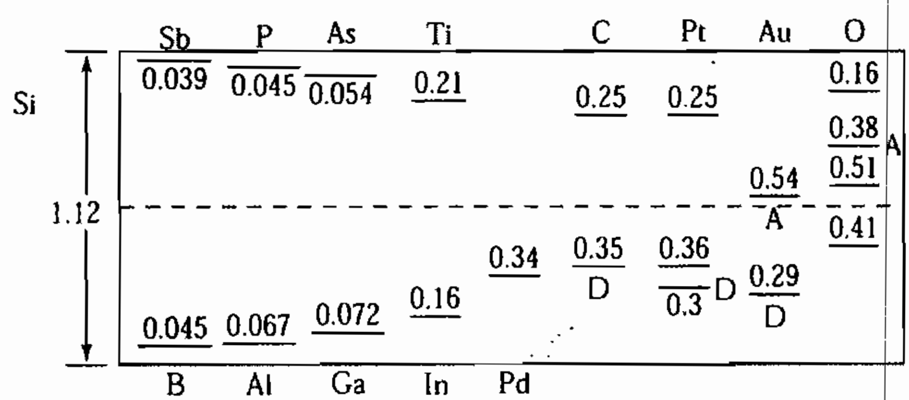
$$n_i = \sqrt{N_C N_V}\exp\left(-E_g/2kT\right) \qquad n.p = n_i^2$$

$$N_C = 2\left(2\pi m_e^* kT/h^2\right)^{3/2} \qquad N_V = 2\left(2\pi m_h^* kT/h^2\right)^{3/2}$$

$$E_F = E_i = \left(E_C + E_V\right)/2 + \left(kT/2\right)\ln\left(N_V/N_C\right)$$

$$E = \frac{-m^* e^4}{8\left(\varepsilon_0\varepsilon_r\right)^2 h^2} \qquad N_D^+ = N_D\left[1 - F\left(E_D\right)\right] \qquad N_A^- = N_A F\left(E_A\right)$$

$$n = n_i \exp\left[\left(E_F - E_i\right)/kT\right] \qquad p = n_i \exp\left[\left(E_i - E_F\right)/kT\right]$$



- Good luck for all your midterm exams -