National Exams May 2013

10-Met-B10, Advanced Electronic Materials

3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. This is a CLOSED BOOK exam. A Casio or Sharp approved calculator model is permitted. This Exam contains 6 questions.
3. A complete paper consists of answering question # 6 (40 marks) which is mandatory and any 4 remaining questions (15 marks each) from the remaining 5 questions (1-5).
4. Where appropriate explain your answers as brief as possible.
5. Equations and constants are provided at the end of this examination. Keep in mind that more equations are provided than needed to solve the attached questions.

Front Page

Question 1 **(15 marks)**

An electrical contact material is produced by first making porous tungsten compact with a mass of 125 g. Liquid silver is then introduced into the compact. Measurements indicate that 105 g of silver is infiltrated. The final density of composite is 13.8 g/cm^3. Calculate:

a) the volume fraction of the original compact that is interconnected porosity
b) the volume fraction that is closed porosity (no silver infiltration).

Question 2 **(15 marks)**

Copper has an FCC structure with a lattice parameter of 3.6151 Å and one valence electron per atom. The electrical conductivity of copper is $5.98 \cdot 10^5\ \Omega^{-1}cm^{-1}$ and mobility (μ) of electrons is 70 cm^2/Vs.

a) Determine the % of electrons that are carrying electrical charge.
b) A current density of 50,000 A/cm^2 is applied to a copper wire when voltage is 1000 V and resistance is 5 Ω. Determine the length of Cu wire in meters.
c) Determine the diameter of copper wire under the conditions described in part b).
d) Determine the drift velocity of the electrons in copper wire in cm/s.

Question 3 **(15 marks)**

We would like to produce an extrinsic semiconductor having an electrical conductivity of 2000 $\Omega^{-1}cm^{-1}$. Determine the amount of phosphorous and the amount of gallium in at %. Which types of semiconductors are produced by doping Ge with P and Ga? Consider that the mobilities of electrons and holes in Ge are $\mu_n = 3800\ cm^2/Vs$, $\mu_p = 1820$ cm^2/Vs respectively.

Question 4 **(15 marks)**

If the number of charge carriers in the intrinsic GaAs is $1.5 \cdot 10^{12}$ carriers/m^3 at 25 °C, determine:

a) Conductivity of GaAs at room temperature in $\Omega^{-1}cm^{-1}$.
b) Temperature in °C required to double the electrical conductivity of GaAs from room temperature value (25°C)
c) Fraction of current that is carried by holes.

Data for GaAs are as follows: $\mu_n = 0.720$ m^2/Vs, $\mu_p = 0.020$ m^2/Vs, $E_g = 1.47$ eV, $k_B = 8.62 \cdot 10^{-5}$ eV/K (n relates to electrons and p to holes, μ is the mobility).

Question 5 **(15 marks)**

5.1. Consider that the energy gap in pure Si is E_g=1.07 eV and that the acceptor energy in In doped Si is E_a=0.16 eV. Determine the wavelength of photons produced when electrons excited into the conduction band of In doped Si

a) drop from the conduction band to the acceptor band
b) drop from the acceptor band to the valence band

5.2. Determine the number of Al_2O_3 sheets, each 1.5cm x 1.5cm x 0.001 cm required to obtain a capacitance of 0.0142 μF in a parallel plate capacitor. The dielectric constant, κ, of alumina is 6.5 and the dielectric permittivity of the free space is ε_o=$8.85 \cdot 10^{-14}$ F/cm.

Choose any 4 questions from 1 -5

Question 6 **(40 marks)**

Sketch the following:

a) Output as I=f(t) (I-current, t-time) when a sinusoidal signal V=f(t) (V-voltage, t-time) is applied to a p-n junction (**5marks**)

b) Dependence of dielectric constant on temperature for ferroelectric materials.(**5marks**)

c) Dependence of magnetic field on temperature for superconducting materials. Clearly label axes, critical temperature, critical field and show the regions of superconductive and normal state. Give at least two (2) examples of superconductive materials currently used in practice (**5marks**).

d) Dependence of electrical conductivity on temperature for metals (**3marks**)

e) Dependence of electrical conductivity on temperature for extrinsic semiconductors (**3marks**)

f) Dependence of electrical conductivity on temperature for ionically bonded materials (**3 marks**)

g) Dependence of remanent magnetization on temperature for ferromagnetic materials (**5marks**)

h) Flux density as a function of $\mu_o H$ (μ_o is the magnetic permeability of vacuum and H is the magnetic field) for i) diamagnetic, ii) paramagnetic, iii) ferrimagnetic and iv) ferromagnetic materials. Clearly distinguish all of the above materials at the same diagram. Give at least two examples of each of mentioned materials. (**6marks**)

i)Sketch the hysteresis loop for the ferromagnetic materials and clearly label remanence and coercivity. Give at least two examples of ferromagnetic materials (**5marks**)

Must answer question # 6

FORMULA SHEET

$$\textit{Number of atoms} = \frac{\text{mass} \times N_A}{\text{Atomic Mass}}$$

$$\rho = \frac{m}{V} \qquad PF = \frac{\textit{Number of atoms per unit cell} \times V_{at}}{V_{uc}};$$

$$\sigma E = nq\nu;\ \sigma = \frac{1}{\rho};\ E = \frac{V}{\lambda};\ \sigma = nZq\mu;\ \sigma = \mu nq;\ R = \rho\frac{\lambda}{A};\ J = \frac{1}{A};\ J = nqv;\ J = E\sigma$$

$$\sigma = nq(\mu_n + \mu_p);$$

$$n = n_0 \exp(-\frac{E_g}{2k_B T})$$

Volume of cubic cell= a_o^3; Volume of HCP cell = $0.866\ a_o^2 c_o$, $c_o = 1.633 a_o$

$$D = D_0 \exp(-\frac{Q}{RT});\quad \mu = \frac{ZqD}{k_B T};$$

$q = 1.6 \cdot 10^{-19}$ C; $k_B = 1.38 \cdot 10^{-23}$ J/K = $8.63 \cdot 10^{-5}$ eV/K

First Fick's Law: $J = -D\frac{dc}{dx}$; Second Fick's Law: $\left(\frac{C_s - C_x}{C_s - C_0}\right) = erf\left(\frac{x}{2\sqrt{Dt}}\right)$

$h = 4.375 \cdot 10^{-15}$ eV s, $c = 3 \cdot 10^{10}$ cm/s $\qquad \lambda = \frac{hc}{E}$

$N_A = 6.023 \times 10^{23}$ atoms/mol; $\qquad$ R= 8.314 J/mol·K;

$$V = \frac{4}{3} r^3 \pi$$

$$V_{comp.} = \sum V_i$$

$$f_A = \frac{V_A}{V_{comp}};$$

$V_{comp} = V_A + V_B + \ldots$; $1 = f_A + f_B + \ldots$

$$C = \frac{A\varepsilon_0\kappa}{d}(n-1) \qquad F = \frac{\sigma_p}{\sigma_p + c\,\tau_h}$$