National Exams December 2018

# 12-Mtl-B10, Advanced Electronic Materials

**3 Hours Duration**

## NOTES:

1. If doubt exists as to the interpretation of any questions, the candidate is urged to submit, with the answer paper, a clear statement of any assumptions made.

2. This is a CLOSED BOOK exam. An approved Casio or Sharp calculator is permitted.

3. Exam consists of six (6) questions. **Question #6 MUST be answered plus your choice of four (4) more** questions from 1 through 5.

4. Answer questions on this exam paper and show your work. Use exam booklet if required and clearly write 'continued in exam booklet' and then indicate the question number in the booklet.

5. **Question six (6) is worth 40 marks** and questions 1 through 5 are worth 15 marks each for a total of 100 marks.

6. Equations and constants are provided at the end of this examination booklet. Keep in mind that more equations are provided than needed to solve the questions.

NAME: ______________________________________________

**Question 1** **(15 marks)**

Silver is known to have an FCC structure with the lattice parameter of $4.0862 \cdot 10^{-8}$ cm and one valence electron. A 1 m long Ag wire with the diameter of 0.2 cm must carry a 10 A current. The maximum power loss along the silver wire is 4W/m.

a) Calculate the minimum electrical **conductivity** of silver wire in $\mathbf{\Omega^{-1}\ m^{-1}}$ for this application at room temperature (25 °C).

b) If the mobility of an electron in silver is 10 $cm^2/Vs$, determine **%** of the total valence electrons contributing to the electrical conductivity and current flow.

c) Determine the temperature at which the electrical **resistivity** will be reduced two times from that at room temperature. Consider that $\boldsymbol{\alpha_R}$ for silver is 0.0041 1/°C.

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**Question 2** **(15 marks)**

Silicon has a diamond cubic (DC) crystal structure with a lattice parameter of $5.4307 \cdot 10^{-8}$ cm. Mobility of electrons in Si is 1350 $cm^2/Vs$ and mobility of holes is 480 $cm^2/Vs$. The energy gap in Si is 1.11 eV.

a) If the electrical **resistivity** of pure silicon is $2.3 \cdot 10^5$ Ω cm at 27 °C, calculate its electrical **conductivity** at 200 °C. By how many times the electrical **conductivity** of silicon changed when the temperature was raised from 27 to 200 °C?

b) Calculate the fraction of current that is carried by holes in the intrinsic Si.

c) A phosphorus doped Si wafer has an electrical **resistivity** of $8.33 \cdot 10^{-3}$ Ω cm at 27 °C. Determine the number of majority charge carriers per $cm^3$. Calculate the ratio of **phosphorus to silicon** atoms and determine the amount of P in this material in **at. % P**.

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**Question 3** **(15 marks)**

**3.1.** 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

**3.2.** 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 $\varepsilon_o=8.85\cdot 10^{-14}$ F/cm.

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**Question 4** **(15 marks)**

Sketch the schematic of band structure for a) metals, b) semiconductors and c) dielectrics or insulators. Assume that temperature is 0 K. Give approximate values of energy gaps in **eV** for all selected materials.

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**Question 5** **(15 marks)**

Briefly explain:

a) Meissner's effect
b) BCS theory
c) Seebeck and thermocouple effect

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**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 $\mu_o H$ ($\mu_o$ 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)**

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## FORMULA SHEET

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

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

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

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

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

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

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

$q=1.6 \cdot 10^{-19}$ 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: $\left(\frac{C_s - C_x}{C_s - C_0}\right) = erf\left(\frac{x}{2\sqrt{Dt}}\right)$

$h = 4.1375 \cdot 10^{-15}$ eV s, $c = 3 \cdot 10^{10}$ cm/s $\qquad \lambda = \frac{hc}{E}$

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

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

$$C = \frac{A\varepsilon_o \kappa}{d}(n-1) \qquad F = \frac{\sigma_p}{\sigma_p + \sigma_n} \qquad \rho = \rho_{RT}[1 + \alpha_R (T - 25)]$$