NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2013-2014

EE1003 – INTRODUCTION TO MATERIALS FOR ELECTRONICS

November/December 2013 Time Allowed: 2 hours

INSTRUCTIONS

1. This paper contains 4 questions and comprises 8 pages.
2. Answer all 4 questions.
3. All questions carry equal marks.
4. This is a closed-book examination.
5. A Table of Physical Constants is provided in Appendix A on page 6, the periodic table is provided in Appendix B on page 7, and a List of Selected Formulae is provided in Appendix C on page 8.

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1. (a) Given that Copper (Cu) has two naturally occurring isotopes with mass numbers 63 and 65. The atomic masses of Cu with mass numbers 63 and 65 are 63 amu and 65 amu respectively. Calculate the % abundance of Cu with mass numbers 63 and 65.

(5 Marks)

(b) The electron of a He^{1+} ion is in the ground state. Photons are used to excite the electron to $n = 4$. Calculate

(i) the maximum wavelength of the photons (in nm) to excite the electron,

(ii) the possible angular momentums and the components of the angular momentums in the z direction (in J·s) of the electron in the excited state.

(10 Marks)

Note: Question No. 1 continues on page 2

(c) The total potential energy of a secondary bond between two atoms can be described by

$$E_N = -\frac{A}{r^6} + \frac{B}{r^{12}}$$

where A and B are constants and r is the interatomic distance. The equilibrium interatomic distance is 0.40 nm and the bonding energy is −0.01 eV.

(i) Express the magnitude of the attractive and repulsive forces in terms of the constants A, B and r. Give also the directions of these forces.

(ii) Calculate the constants A and B (give the units in terms of J and m).

(10 Marks)

2. (a) A mass spectrometer is used to measure the mass of element X. Figure 1 on page 3 shows the schematic diagram of the mass spectrometer. The ions X are all positively charged. The magnitudes of the magnetic fields $\boldsymbol{B}_1$ and $\boldsymbol{B}_2$ are 10 mT and 20 mT respectively, and their directions are out of the paper. In the velocity selectors, the velocity of the ions that travel in a straight line is 6000 m/s. In the detection section, the ions move in semicircular paths with the radii of curvature of 4 cm and 8 cm.

(i) Calculate the magnitude of the electric field in the velocity selector (in V/m) and give the direction of the electric field.

(ii) Sketch the semicircular paths of the ions in the detection system and indicate the velocity and the force acting on the ions.

(iii) Explain why two semicircular paths with the radii of curvature of 4 cm and 8 cm are observed. Calculate the mass of element X (in amu).

(10 Marks)

Note: Question No. 2 continues on page 3

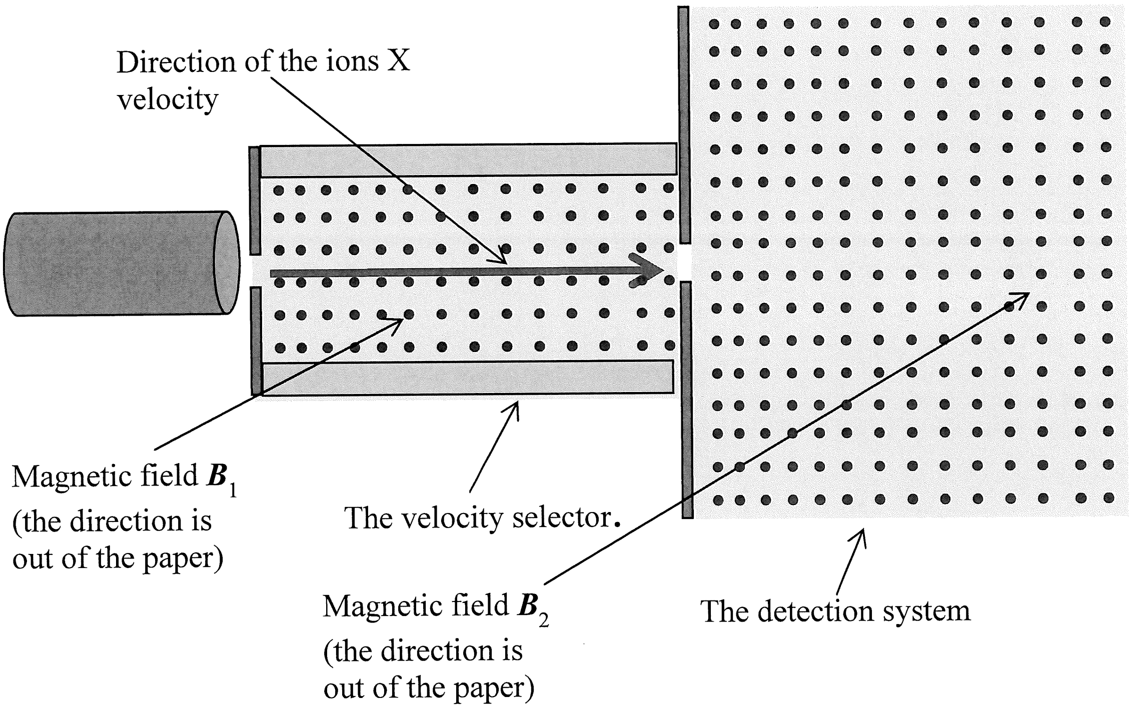

Figure 1

(b) Aluminum (Al) has a face-centered cubic crystal structure with a lattice constant of 0.405 nm at 20 °C. There is one atom at each lattice point and the atoms touch each other with their nearest neighbor. The linear thermal expansion of Aluminum is 24×10^{-6} $°C^{-1}$.

(i) Calculate the atomic radius (in nm) and the mass density (in g/cm^3) of Aluminum at 20 °C.

(ii) Sketch the $(\bar{1}01)$ plane indicating the origin and the axes, and hence calculate the planar atomic density (in cm^{-2}) on the $(\bar{1}01)$ plane at 20 °C.

(iii) Calculate the mass density (in g/cm^3) of the Aluminum if it is heated to 100 °C. Assume that Al is isotropic.

(10 Marks)

Note: Question No. 2 continues on page 4

(c) Germanium (Ge) is a semiconductor material and has the diamond crystal structure. The lattice constant is 0.565 nm.

(i) Write down the electron configuration of Ge.

(ii) Calculate the number of quantum states per unit volume (in cm^{-3}) in the conduction and valence band.

(5 Marks)

3. (a) Briefly describe the following terms for the flow of electrons in a metal: electron mobility, drift velocity, and relaxation time.

(6 Marks)

(b) The resistivities of pure Cu and NiCu with atomic fraction of 5% Ni at different temperatures are shown in Table 1. Calculate the temperature coefficient of resistivity for Cu and composition independent coefficient of CuNi alloy. Assume that the deformation of the metals is negligible.

(6 Marks)

Table 1

Temperature (°C)	Resistivity (μΩ·cm)	
	Cu	CuNi
–50	1.2	6.9
50	1.8	7.5

(c) Define p-type extrinsic semiconductors. Give an example of a material added as dopants to Si to produce p-type extrinsic semiconductor. Why is a hole said to be an imaginary particle? Explain how holes can move in a silicon crystal lattice. Use a sketch to illustrate if it is necessary.

(6 Marks)

(d) The electrical resistivity of pure germanium (Ge) is 0.46 Ω·m at 300 K. The bandgap of Ge is 0.67 eV. The electron and hole mobilities at 300 K are 0.38 $\text{m}^2\text{V}^{-1}\text{s}^{-1}$and 0.18 $\text{m}^2\text{V}^{-1}\text{s}^{-1}$, respectively. Calculate its electron and hole concentrations and electrical conductivity at 425 °C. Assume that the bandgap is independent of temperature.

(7 Marks)

4. (a) Calculate the velocity of light in a material, which has a dielectric constant (relative permittivity) of 2.056 and a magnetic susceptibility of -1.43×10^{-5}.

(6 Marks)

(b) A ray of light strikes a polished transparent material from air at normal incident angle. The thickness of the material is 20 mm. The material has a refractive index of 1.6 and a transmissivity of 0.85. The reflections at air/material (material/air) interfaces should be considered, but multiple reflections inside the glass can be ignored.

(i) Derive the transmissivity of the material in terms of reflectivity, absorption coefficient, and the thickness of the sample.

(ii) Determine the thickness of the material that will yield a transmissivity of 0.75.

(6 Marks)

(c) Briefly describe the phenomenon of luminescence. What are the differences between photoluminescence, cathodoluminescence, and electroluminescence? Explain why the emitted light has a down-shift in frequency as compared to that of the exciting light during a photo-luminescence process.

(6 Marks)

(d) Draw a hysteresis B-H loop for a ferromagnetic material and indicate on it: (i) the saturation induction, (ii) the remanent induction, and (iii) the coercivity. Calculate the theoretical value of the maximum magnetization for nickel (Ni), assuming that all unpaired 3d electrons contribute to the magnetization. Note that Ni has a face-centered cubic (FCC) crystal structure with a lattice constant of 0.352 nm.

(7 Marks)

APPENDIX A

Table of Physical Constants

	Symbol	**Value**	**Units**
Planck constant	h	6.63×10^{-34}	J·s
Planck constant/2π	$\hbar$	1.05×10^{-34}	J·s
Speed of light	c	3.0×10^{8}	m/s
Electronic charge	e (or q)	1.6×10^{-19}	C
Boltzmann's constant	k_B (or k)	1.38×10^{-23}	J/K
Free electron rest mass	m_0	9.1×10^{-31}	kg
Proton rest mass	m_p	1.67×10^{-27}	kg
Avogadro's number	N_A	6.02×10^{23}	mol^{-1}
Permeability of free space	μ_0	$4\pi \times 10^{-7}$	H/m
Permittivity of free space	ε_0	8.85×10^{-12}	F/m
Rydberg constant	R_d	1.097×10^{7}	m^{-1}
Bohr radius	a_0	5.292×10^{-11}	m
Gas constant	R	8.31	$\text{Jmol}^{-1}\text{K}^{-1}$
Electron-volt	1 eV	1.6×10^{-19}	J
Thermal voltage ($T = 300$ K)	kT/q	0.0259	V

APPENDIX B

The Periodic Table

Key

29 ← Atomic number
Cu ← Symbol
63.55 ← Atomic weight

▢ Metal
■ Nonmetal
◩ Intermediate

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	0
1 H 1.0080																	2 He 4.0026
3 Li 6.941	4 Be 9.0122											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.064	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.08	21 Sc 44.956	22 Ti 47.87	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.69	29 Cu 63.55	30 Zn 65.41	31 Ga 69.72	32 Ge 72.64	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.4	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.30
55 Cs 132.91	56 Ba 137.33	Rare earth series	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.2	76 Os 190.23	77 Ir 192.2	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.19	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	Acti-nide series	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (281)								

Rare earth series	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.35	63 Eu 151.96	64 Gd 157.25	65 Tb 158.92	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
Actinide series	89 Ac (227)	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

APPENDIX C

List of Selected Formulae

$$1\text{ amu} = \frac{1}{6.02\times10^{23}}\text{g} = 1.66\times10^{-24}\text{ g},\quad \boldsymbol{F}_\xi = e\boldsymbol{\xi},\quad \boldsymbol{F}_{B_1} = e\boldsymbol{v}\times\boldsymbol{B}_1,\quad v=\frac{\xi}{B_1},\quad m=\frac{eB_1B_2r}{\xi},$$

$$E_n = -\frac{m_0\,Z^2\,e^4}{2\left(4\pi\,\varepsilon_0\,n\,\hbar\right)^2} = -\frac{13.6\,Z^2}{n^2}\text{eV},\quad l=0,1,2......(n-1),\quad L=\sqrt{l\left(l+1\right)}\,\hbar,$$

$$m_l = -l,-l+1,....0....,l-1,l,\quad L_z = m_l\,\hbar,\quad \text{Cos}\,\theta=\frac{L_z}{L},\quad s=\frac{1}{2},\quad S=\sqrt{s\left(s+1\right)}\,\hbar=\frac{1}{2}\sqrt{3}\,\hbar,$$

$$m_s=\pm\frac{1}{2},\quad S_z=\pm\frac{1}{2}\hbar,\quad E_{ph}=hf=\frac{hc}{\lambda},\quad \Delta l=\pm1,\quad \Delta m_l=0,\pm1,\quad \boldsymbol{F}_N=\boldsymbol{F}_A+\boldsymbol{F}_R,\quad E_A=-\int_\infty^r\boldsymbol{F}_A.\boldsymbol{dr},$$

$$E_R=-\int_\infty^r\boldsymbol{F}_R.\boldsymbol{dr},\quad E_N=E_A+E_R,\quad \Delta E_s=\frac{E_T-E_B}{N},\quad \phi=E_{vac}-E_F,\quad C=\frac{dQ}{dT},$$

$$u(x,t)=u_0\text{Cos}\left(\omega t-kx\right),\quad v=\lambda f=\frac{\omega}{k},\quad C_v=AT^3,\quad C_v=3R,\quad \frac{\Delta l}{l_0}=\alpha_l\Delta T,\quad \frac{\Delta V}{V_0}=\alpha_v\Delta T,$$

$$\alpha_v=3\alpha_l,\quad q=-k\frac{dT}{dx},\quad k=k_l+k_e,\quad L=\frac{k}{\sigma T},\quad \rho=R\frac{A}{l},\quad J=\sigma\xi,\quad \mu=\frac{e\tau}{m_e^*},\quad J=en\mu\xi,$$

$$\frac{1}{\mu}=\frac{1}{\mu_l}+\frac{1}{\mu_i},\quad \rho_{total}=\rho_t+\rho_i+\rho_d,\quad \underline{\rho_t=\rho_0(1+\alpha_T T),\quad \rho_i=Ac_i(1-c_i),}\quad \sigma=ne\mu_e+pe\mu_h,$$

$$\sigma=CT^{-3/2}\exp(-\frac{E_g}{2kT}),\quad n_i\propto\exp\left(-\frac{E_g}{2kT}\right),\quad np=n_i^2,\quad C=\varepsilon_r\varepsilon_0\frac{A}{d},\quad p=qd,\quad D=\varepsilon\xi,$$

$$D_0=\varepsilon_0\xi,\quad P=\chi_eD_0,\quad D=\varepsilon_0\xi+P,\quad P_{total}=P_e+P_i+P_o,\quad c=\frac{1}{\sqrt{\varepsilon_o\mu_o}},\quad R+A+T=1,$$

$$I=I_0\exp(-\alpha x),\quad \frac{n_1}{n_2}=\frac{\sin\phi_2}{\sin\phi_1},\quad n=\frac{c}{v},\quad R=\left(\frac{n_2-n_1}{n_2+n_1}\right)^2,\quad H=\frac{NI}{l},\quad \mu=\mu_r\mu_0,\quad B_0=\mu_0H,$$

$$B=\mu_0H+\mu_0M,\quad M=\chi_mH,\quad \mu_B=\frac{eh}{4\pi m_e},\quad M_{sat}=AD\cdot n_B\cdot\mu_B$$

END OF PAPER

EE1003 INTRODUCTION TO MATERIALS FOR ELECTRONICS

Please read the following instructions carefully:

1. **Please do not turn over the question paper until you are told to do so. Disciplinary action may be taken against you if you do so.**

2. You are not allowed to leave the examination hall unless accompanied by an invigilator. You may raise your hand if you need to communicate with the invigilator.

3. Please write your Matriculation Number on the front of the answer book.

4. Please indicate clearly in the answer book (at the appropriate place) if you are continuing the answer to a question elsewhere in the book.