NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY
FACULTY OF INDUSTRIAL TECHNOLOGY
BACHELOR OF ENGINEERING DEGREE
DURATION 3 HOURS
MAY 2005
ELECTROMAGNETIC FIELDS AND MATERILS – TEE 2201

INSTRUCTIONS TO CANDIDATES:

1. ANSWER **ALL** QUESTIONS.
2. EACH QUESTION CARRIES EQUAL MARKS.
3. SHOW YOUR STEPS CLEARLY IN CALCULATIONS
4. START THE ANSWER FOR EACH QUESTION ON A FRESH PAGE
5. SEE **APPENDIX**

Q.1.

One of the forms of manganese has a cubic structure with a lattice parameter of 2.326 Å. The density is 7.26 g/cm^3 and the atomic radius is 1.12 Å.

(a) How many atoms are present in each unit cell?
(b) Calculate the packing factor.

[8 points]

Q.2 .

How many energy levels are present in the *2p* band of a pure iron crystal 2 cm x 1 cm x 3 cm in size?

[6 points]

Q.3.

Estimate the probability that an electron can gain sufficient energy in silicon at:

(a) 0° K;
(b) 300° C,
to enter the conduction band.

[8 points]

Q.4.

The electrical conductivity of silicon at 30° C is 5.5 x 10^{-6} Ω^{-1}.cm^{-1}. Calculate:

(a) The number of charge carriers;
(b) The fraction of the total electrons in the valence band that are exited into the conduction band.

[8 points]

Q.5.

Graphically show the Fermi level position as a function of the temperature in:

(a) Intrinsic semiconductor material;
(b) N-type semiconductor material;
(c) P-type semiconductor material.

[6 points]

Q.6.

(a) How many carriers are required to give a conductivity of 100 $\Omega^{-1}.cm^{-1}$ in the exhaustion region of silicon?
(b) How many antimony atoms would have to be added to silicon?

[8 points]

Q.7.

Explain the nature of:

(a) Diffusion current;
(b) Drift current,
in semiconductor materials.

[6 points]

Q.8.

Compare a silicon rectifying diode and a Schottky diode with respect to the following: structure, current carriers, threshold voltages, noise, power loss, frequency response.

[8 points]

Q.9.

Define the capacitances associated with a **P-N** junction.

[6 points]

Q.10.

For a silicon varicap diode calculate the C_3/C_{25} ratio if the maximum capacitance is 80 pF and the construction parameter is 1/3.

[6 points]

Q.11.

Determine the energy associated with the photons of red light and green light.

[6 points]

Q.12.

A single solar cell has a short – circuit current of 25 μA at temperature of 25 °C when the illumination is 400 lux. The dark current is 10 nA and the minimum open-circuit voltage of 12V is required from an array of cells, when the illumination is of 700 lux and the temperature is 80 °C. How many cells are required and how should they be connected?

[6 points]

Q.13.

Calculate the polarization that occurs when electrons in a body centered cubic (BCC) tungsten are displaced 1.5×10^{-9} Å by an electric field.

[6 points]

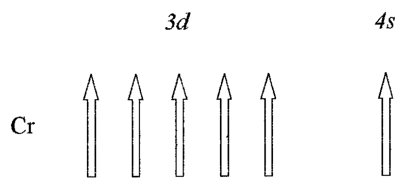
Q.14.

A simple parallel plate capacitor is to be made that can store 6×10^{-5} C at potential of 10 000 V. The separation between the plates is to be 0.04 cm. Calculate the area of the plates required if the dielectric is barium titanate.

[6 points]

Q.15.

The electron spins in *3d* and *4s* energy levels for chromium are shown below. Calculate the maximum magnetization that is expected in chromium.



[6 points]

APPENDIX TEE 2201 ELECTROMAGNETIC FIELDS AND MATERIALS

I. LIST OF PARAMETERS

Metal	Chemical Symbol	Atomic Number	Crystal Structure	Lattice Parameter (A)	Atomic mass (g.g.mole)
Aluminum	Al	13	FCC	4.04958	26.981
Antimony	Sb	51	hex	a = 4.307 c = 11.273	121.75
Arsenic	As	33	hex	a = 3.760 c = 10.548	74.9216
Barium	Ba	56	BBC	5.025	137.3
Beryllium	Be	4	hex	a = 2.2858 c = 3.5842	9.01
Bismuth	Bi	83	hex	a = 4.546 c = 11.86	208.98
Boron	B	5	rhomb	a = 10.12 $\alpha = 65.5^{\circ}$	10.81
Cadmium	Cd	48	HCP	a = 2.9793 c = 5.6181	112.4
Calcium	Ca	20	FCC	5.588	40.08
Cerium	Ce	58	HCP	a = 3.681 c = 11.857	140.12
Cesium	Cs	55	BCC	6.13	132.91
Chromium	Cr	24	BCC	2.8844	51.996
Cobalt	Co	27	HCP	a = 2.5071 c = 4.0686	58.93
Copper	Cu	29	FCC	3.6151	63.54
Gadolinium	Gd	64	HCP	a = 3.6336 c = 5.7810	157.25
Gallium	Ga	31	ortho	a = 4.5258 b = 4.5186 c = 7.6570	69.72
Germanium	Ge	32	FCC(DC)	5.6575	72.59
Gold	Au	79	FCC	4.0786	196.97
Indium	In	49	tetra	a = 3.2517 c = 4.9459	114.82
Iron	Fe	26	BCC FCC	2.866 3.589	55.847
Lanthanum	La	57	HCP	a = 3.774 c = 12.17	138.91
Lead	Pb	82	FCC	4.9489	207.19
Lithium	Li	3	BCC	3.5089	6.94
Magnesium	Mg	12	HCP	a = 3.2087 c = 5.209	24.312
Manganese	Mn	25	cubic	8.931	54.938
Mercury	Hg	80	rhomb		200.59
Molybdenum	Mo	42	BCC	3.1468	95.94
Nickel	Ni	28	FCC	3.5167	58.71
Niobium	Nb	41	BCC	3.294	92.91
Paladium	Pd	46	FCC	3.8902	106.4
Platinum	Pt	78	FCC	3.9231	195.09
Potassium	K	19	BCC	5.344	39.09

Metal	Chemical Symbol	Atomic Number	Crystal Structure	Lattice Parameter (A)	Atomic mass (g.g mole)
Rhenium	Re	75	HCP	a = 2.760 c = 4.458	186.21
Rhodium	Rh	45	FCC	3.796	102.99
Rubidium	Rb	37	BCC	5.7	85.467
Selenium	Se	34	hex	a = 4.3640 c = 4.9594	78.96
Silicon	Si	14	FCC (DC)	5.4307	28.08
Silver	Ag	47	FCC	4.0862	107.868
Sodium	Na	11	BCC	4.2906	22.99
Strontium	Sr	38	FCC BCC	6.0849 4.84	87.62
Tantalum	Ta	73	BCC	3.3026	180.95
Tellurium	Te	52	hex	a = 4.4565 c = 5.9268	127.6
Thorium	Th	90	FCC	5.086	232
Tin	Sn	50	FCC (DC)	6.4912	118.69
Titanium	Ti	22	HCP BCC	a = 2.9503 c = 4.6831 3.32	47.9
Tungsten	W	74	BCC	3.1652	183.85
Uranium	U	92	ortho	a = 2.854 b = 5.869 c = 4.955	238.03
Vanadium	V	23	BCC	3.0278	50.941
Yttrium	Y	39	HCP	a = 3.648 c = 5.732	88.91
Zink	Zn	30	HCP	a = 2.6648 c = 4.9470	65.38
Zirconium	Zr	40	HCP BCC	a = 3.2312 c = 5.1477 3.6090	91.22

The electronic configuration for elements

Atomic Number	Element	K	L		M			N				O			P	
		1s	2s	2p	3s	3p	3d	4s	4p	4d	4f	5s	5p	5d	6s	6p
1	Hydrogen	1														
2	Helium	2														
3	Lithium	2	1													
4	Beryllium	2	2													
5	Boron	2	2	1												
6	Carbon	2	2	2												
7	Nitrogen	2	2	3												
8	Oxygen	2	2	4												
9	Fluorine	2	2	5												
10	Neon	2	2	6												
11	Sodium	2	2	6	1											
12	Magnesium	2	2	6	2											
13	Aluminum	2	2	6	2	1										

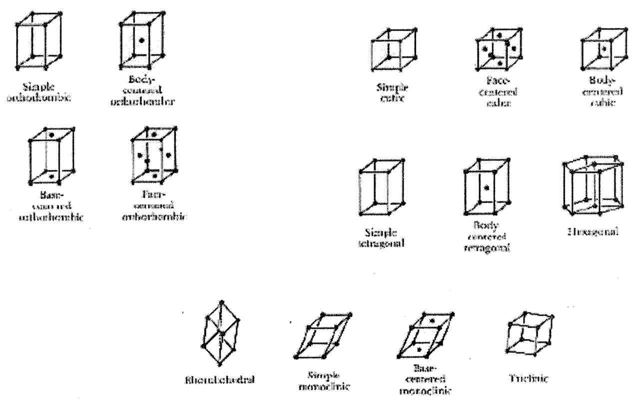
The electronic configuration for elements

Atomic Number	Element	K 1s	L 2s	2p	M 3s	3p	3d	N 4s	4p	4d	4f	O 5s	5p	5d	P 6s	6p
14	Silicon	2	2	6	2	2										
15	Phosphorus	2	2	6	2	3										
16	Sulfur	2	2	6	2	4										
17	Chlorine	2	2	6	2	5										
18	Argon	2	2	6	2	6										
19	Potassium	2	2	6	2	6		1								
20	Calcium	2	2	6	2	6		2								
21	Scandium	2	2	6	2	6	1	2								
22	Titanium	2	2	6	2	6	2	2								
23	Vanadium	2	2	6	2	6	3	2								
24	Chromium	2	2	6	2	6	5	1								
25	Manganese	2	2	6	2	6	5	2								
26	Iron	2	2	6	2	6	6	2								
27	Cobalt	2	2	6	2	6	7	2								
28	Nickel	2	2	6	2	6	8	2								
29	Copper	2	2	6	2	6	10	1								
30	Zink	2	2	6	2	6	10	2								
31	Gallium	2	2	6	2	6	10	2	1							
32	Germanium	2	2	6	2	6	10	2	2							
33	Arsenic	2	2	6	2	6	10	2	3							
34	Selenium	2	2	6	2	6	10	2	4							
35	Bromine	2	2	6	2	6	10	2	5							
36	Krypton	2	2	6	2	6	10	2	6							
37	Rubidium	2	2	6	2	6	10	2	6			1				
38	Strontium	2	2	6	2	6	10	2	6			2				
39	Yttrium	2	2	6	2	6	10	2	6	1		2				
40	Zirconium	2	2	6	2	6	10	2	6	2		2				
41	Niobium	2	2	6	2	6	10	2	6	4		1				
42	Molybdenum	2	2	6	2	6	10	2	6	5		1				
43	Technetium	2	2	6	2	6	10	2	6	6		1				
44	Ruthenium	2	2	6	2	6	10	2	6	7		1				
45	Rhodium	2	2	6	2	6	10	2	6	8		1				
46	Palladium	2	2	6	2	6	10	2	6	10						
47	Silver	2	2	6	2	6	10	2	6	10		1				
48	Cadmium	2	2	6	2	6	10	2	6	10		2				
49	Indium	2	2	6	2	6	10	2	6	10		2	1			
50	Tin	2	2	6	2	6	10	2	6	10		2	2			
51	Antimony	2	2	6	2	6	10	2	6	10		2	3			
52	Tellurium	2	2	6	2	6	10	2	6	10		2	4			
53	Iodine	2	2	6	2	6	10	2	6	10		2	5			
54	Xenon	2	2	6	2	6	10	2	6	10		2	6			
55	Cesium	2	2	6	2	6	10	2	6	10		2	6		1	
56	Barium	2	2	6	2	6	10	2	6	10		2	6		2	
57	Lanthanum	2	2	6	2	6	10	2	6	10	1	2	6		2	
……..	……..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	

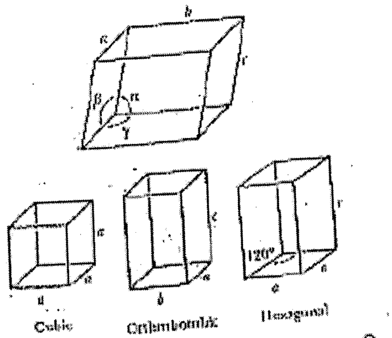
The electronic configuration for elements

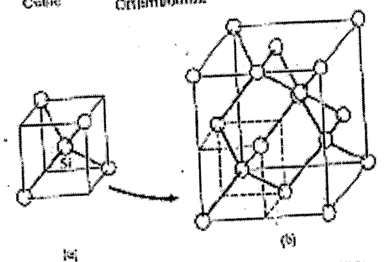
Atomic Number	Element	K 1s	L 2s	2p	M 3s	3p	3d	N 4s	4p	4d	4f	O 5s	5p	5d	P 6s	6p
71	Lutetium	2	2	6	2	6	10	2	6	10	14	2	6	1	2	
72	Hafnium	2	2	6	2	6	10	2	6	10	14	2	6	2	2	
73	Tantalum	2	2	6	2	6	10	2	6	10	14	2	6	3	2	
74	Tungsten	2	2	6	2	6	10	2	6	10	14	2	6	4	2	
75	Rhenium	2	2	6	2	6	10	2	6	10	14	2	6	5		
76	Osmium	2	2	6	2	6	10	2	6	10	14	2	6	6		
77	Iridium	2	2	6	2	6	10	2	6	10	14	2	6	9		
78	Platinum	2	2	6	2	6	10	2	6	10	14	2	6	9	1	
79	Gold	2	2	6	2	6	10	2	6	10	14	2	6	10	1	
80	Mercury	2	2	6	2	6	10	2	6	10	14	2	6	10	2	
81	Thallium	2	2	6	2	6	10	2	6	10	14	2	6	10	2	1
82	Lead	2	2	6	2	6	10	2	6	10	14	2	6	10	2	2
83	Bismuth	2	2	6	2	6	10	2	6	10	14	2	6	10	2	3
84	Polonium	2	2	6	2	6	10	2	6	10	14	2	6	10	2	4
85	Astatine	2	2	6	2	6	10	2	6	10	14	2	6	10	2	5
86	Radon	2	2	6	2	6	10	2	6	10	14	2	6	10	2	6

II. LATTICE STRUCTURES

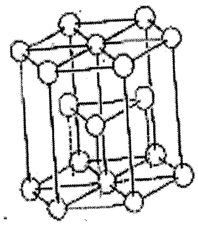


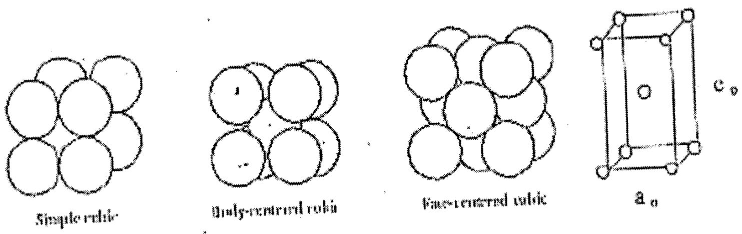
*See **Note** on page A8





(a) Tetrahedra and (a) the diamond cubic (DC) unit cell. This open structure is produced because of the requirements of covalent bonding.





III. CONDUCTORS AND SEMICONDUCTORS PARAMETERS

Elecronic structure and electrical conductivity of the Group IV A elements at 25 °C

Metal	Electronic Structure	Electrical Conductivity ($\Omega^{-1}.cm^{-1}$)
C (diamond)	$1s^2 2s^2 2p^2$	$< 10^{-18}$
Si	$1s^2 2s^2 2p^6 3s^2 3p^2$	5×10^{-6}
Ge	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^2$	0.02
Sn	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^2$	0.9×10^5

The temperature resistivity coefficient for selected metals

Metal	Room Temperature Resistivity (25 °C) ($\times 10^{-6}$ Ω.cm)	Temperature Resistivity Coefficient (α) (Ω.cm/ °C)
Be	4.0	0.0250
Mg	4.45	0.0165
Ga	3.91	0.0042
Al	2.65	0.0043
Cr	12.9	0.0030
Fe	9.71	0.0065
Co	6.24	0.0060
Ni	6.84	0.0069
Cu	1.67	0.0068
Ag	1.59	0.0041
Au	2.35	0.0040
Sn	11.1	

Energy gaps and mobilities for semi - conducting compounds

Compaund	Energy gap (eV)	Electronm Mobility (cm^2/V.s)	Hole Mobility (cm^2/V.s)
ZnS	3.54	180	5
ZnTe	2.26	340	100
CdTe	1.44	1 200	50
GaP	2.24	300	100
GaAs	1.35	8 800	400
GaSb	0.67	4 000	1400
InSb	0.165	78 000	750
InAs	0.36	33 000	460
ZnO	3.2	180	
CdS	2.42	400	
CdSe	1.74	650	
PbS	0.37	600	600
PbTe	0.25	1 600	600
$CdSnAS_2$	0.26	22 000	250

The donor and acceptor energy gaps in electron volts when Silicon and Germanium semiconductors are doped

	Silicon		Germanium	
Dopant	E_d	E_a	E_d	E_a
P	0.045		0.0120	
As	0.049		0.0127	
Sb	0.039		0.0096	
B		0.045		0.0104
Al		0.057		0.0102
Ga		0.065		0.0108
In		0.160		0.0112

Energy gaps and mobilities for semicoducting metals

Metal	Energy Gap (eV)	Electron Mobility (cm^2/V.s)	Hole Mobility (cm^2/V.s)
C (diamond)	5.4	1 800	1 400
Si	1.107	1 900	500
Ge	0.67	3 800	1 820
Sn	0.08	2 500	2 400

IV. LIGHT WAVELENGTH

2000 3000 | 4000 5000 6000 7000 | 8000 9000 10 000 11 000 12 000 13 000 14 000 A

Ultraviolet | ← Visible range → | Infrared | Wavelength

Violet, Blue, Green, Yellow, Orange, Red

V. DIELECTRIC PROPERTIES

Properties of selected dielectric materials

Material	Dielectric constant			Resistivity (Ω.m)	Dielectric strength (V/m) x 10^6
	60 Hz	10^6 Hz	10^8 Hz		
Phenol – formaldehyde	7.5	4.7	4.3	10^{10}	12
Polyethylene	2.3	2.3	2.3	10^{13}-10^{16}	20
Teflon	2.1	2.1	2.1		
Polystyrene	2.5	2.5	2.5	10^{16}	20
Polyvinyl chloride (amorphous)	7	3.4		10^{14}	40
Polyvinyl chloride (glass)	3.4	3.4			
6,6 - Nylon		3.3	3.2		
Rubber	4	3.2	3.1		20
Epoxy		3.6	3.3		
Paraffin wax		2.3	2.3	10^{13}-10^{17}	10
Fused silica	3.8	3.8	3.8	10^{9}-10^{10}	10
Fused quartz		3.9			
Soda – lime glass	7	7		10^{13}	10
Pyrex glass	4.3	4		10^{14}	14
Alumina	9	6.5		10^{9} - 10^{12}	6
Barium titanate		3 000		10^{6} - 10^{13}	12
TiO_2	14-110			10^{11}- 10^{16}	8
Mica		7		10^{11}	40
Water	78.3			10^{12}	
Gases		1.0006-1.02		10^{11}	
Vacuum		1			

VI. LIST OF CONSTANTS

$q = 1.6 \times 10^{-19}$ C
1 eV = 1.6×10^{-19} J
$\varepsilon_o = 8.85 \times 10^{-12}$ F/m
$\kappa = 8.63 \times 10^{-5}$ eV/°K
$h = 4.14 \times 10^{-15}$ eV.s
$\mu_o = 4\pi \times 10^{-3}$
Avogardo number, $N_A = 6.02 \times 10^{23}$ atoms/g.mole
Bohr Magneton = 9.27×10^{-24} A.m^2

VII. LIST OF FORMULAS

$$\text{Packing factor} = \frac{\text{(number of atoms/cell).(volume of each atom)}}{\text{volume of unit cell}}$$

$$\text{Density} = \frac{\text{(atoms/cell).(atomic mass of each atom)}}{\text{(volume of unit cell).(Avogardo number)}}$$

$$f(E) = \frac{1}{1 + \exp[(E - E_f) / \kappa T]}$$

$$n_{total} = n_{od} \cdot \exp(- E_d/\kappa T) + 2n_o.\exp(-E_g/2\kappa T]$$

$\sigma = q \cdot \mu \cdot n$ $\quad$ $P = Z \cdot q \cdot d$ $\quad$ $W = H \cdot f$

$$C_T(V_R) = \frac{C(0)}{[1 + |V_R/V_T|]^n}$$

$$V_{OC} = \kappa T.\ln[1 + (I_{sc}/I_{sat})$$

*The right position of this table is on page A5, at the right upper corner

Characteristics of the seven crystal systems		
Structure	Axes	Angles between Axes
Cubic	$a_1 = a_2 = a_3$	All angles equal 90°
Tetragonal	$a_1 = a_2 \neq c$	All angles equal 90°
Orthorhombic	$a \neq b \neq c$	All angles equal 90°
Hexagonal	$a_1 = a_2 \neq c$	Two angles equal 90° One angle equal 120°
Rhombohedral	$a_1 = a_2 = a_3$	All angles are equal and none equal 90°
Monoclinic	$a \neq b \neq c$	Two angles equal 90° One angle not equal to 90°
Triclinic	$a \neq b \neq c$	All angles are different and none equals 90°