UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2012/2013 Academic Session

June 2013

EBB 215/3 – Semiconductor Materials
[Bahan Semikonduktor]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains TEN printed pages and SIX pages APPENDIX before you begin the examination.
[Sila pastikan bahawa kertas peperiksaan ini mengandungi SEPULUH muka surat beserta ENAM muka surat LAMPIRAN yang bercetak sebelum anda memulakan peperiksaan ini.]

This paper consists of SEVEN questions. ONE question in PART A, THREE questions in PART B and THREE questions in PART C.
[Kertas soalan ini mengandungi TUJUH soalan. SATU soalan di BAHAGIAN A, TIGA soalan di BAHAGIAN B dan TIGA soalan di BAHAGIAN C.]

Instruction: Answer **FIVE** questions. Answer **ALL** questions from PART A, **TWO** questions from PART B and **TWO** questions from PART C. If a candidate answers more than five questions only the first five questions answered in the answer script would be examined.
*[**Arahan**: Jawab **LIMA** soalan. Jawab **SEMUA** soalan dari BAHAGIAN A, **DUA** soalan dari BAHAGIAN B dan **DUA** soalan dari BAHAGIAN C. Jika calon menjawab lebih daripada lima soalan hanya lima soalan pertama mengikut susunan dalam skrip jawapan akan diberi markah.]*

The answers to all questions must start on a new page.
[Mulakan jawapan anda untuk semua soalan pada muka surat yang baru.]

You may answer a question either in Bahasa Malaysia or in English.
[Anda dibenarkan menjawab soalan sama ada dalam Bahasa Malaysia atau Bahasa Inggeris.]

In the event of any discrepancies, the English version shall be used.
[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah digunapakai.]

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PART A / *BAHAGIAN A*

1. [a] Briefly explain the important advantages of silicon compared to other semiconductor materials.

Terangkan dengan ringkas kelebihan-kelebihan utama silikon berbanding bahan semikonduktor lain.

(40 marks/*markah*)

[b] Define drift and diffusion current by deriving the appropriate equations for both transport mechanisms of semiconductor materials.

Takrifkan arus hanyut dan resap dengan menerbitkan persamaan yang sesuai untuk kedua-dua mekanisma pembawaan arus untuk bahan semikondutor.

(30 marks/*markah*)

[c] Describe the qualitative view of current flow in a p-n junction diode by sketching the energy band diagram of the junction under equilibrium, forward and reverse biased. Explain your diagrams.

Perihalkan pandangan kualitatif pergerakan arus pada diod simpang p-n dengan melakarkan gambarajah jalur tenaga di dalam keadaan keseimbangan, pincang hadapan dan pincang terbalik. Terangkan gambarajah anda.

(30 marks/*markah*)

PART B / *BAHAGIAN B*

2. [a] By giving appropriate examples, describe the following defects:

(i) Area or two-dimensional defects

(ii) Volume or three-dimensional defects

Dengan memberikan contoh yang bersesuaian, jelaskan kecacatan berikut:

(i) Kecacatan luas atau dua-dimensi

(ii) Kecacatan isipadu atau tiga-dimensi

(30 marks/*markah*)

[b] Consider a beryllium nucleus, of charge *+4q*. Calculate the first four electron energies for an electron in a Be^{4+} ion using the Bohr model. You may use equations in Appendix 1.

Ambilkira nukleus berilium dengan cas +4q. Kirakan empat tenaga elektron pertama untuk ion Be^{4+} *dengan menggunakan Model Bohr. Anda boleh menggunakan persamaan dalam Lampiran 1.*

(40 marks/*markah*)

[c] Metal, ceramic and semiconductor have different physical properties. Briefly explain why these materials behave differently.

Logam, seramik dan semikonduktor mempunyai sifat fizikal yang berlainan. Terangkan dengan ringkas kenapakah bahan-bahan ini mempunyai pelakuan yang berbeza.

(30 marks/*markah*)

3. [a] There are seven general classifications of semiconductor materials. By giving appropriate examples, explain the two out of seven semiconductor materials as follow:

(i) Binary compound
(ii) Layered semiconductor

Terdapat tujuh klasifikasi umum untuk bahan semikonduktor. Dengan memberikan contoh-contoh yang bersesuaian, terangkan dua daripada tujuh bahan semikonduktor seperti berikut:

(i) Sebatian binari
(ii) Semikonduktor berlapis

(30 marks/*markah*)

[b] Briefly describe the typical bonding forces in the following semiconductor materials:

(i) InP
(ii) ZnS
(iii) CuCl

Jelaskan dengan ringkas daya ikatan yang tipikal dalam bahan semikonduktor berikut:

(i) InP
(ii) ZnS
(iii) CuCl

(50 marks/*markah*)

[c] Semiconductor materials can be classified according to nature of current carriers, crystal structure and chemical compositions. What are the natures of the current carriers?

Bahan semikonduktor boleh diklasifikasi melalui sifat pembawa arus, struktur hablur dan komposisi bahan kimia. Apakah sifat pembawa arus?

(20 marks/*markah*)

4 [a] Explain the following types of semiconductor materials with the aid of energy band diagrams and atomic bonding. Give one example for each type.

(i) Intrinsic semiconductor

(ii) P-type doping

(iii) N-type doping

Terangkan jenis bahan semikonduktor berikut dengan bantuan gambarajah jalur tenaga dan ikatan atom. Berikan satu contoh untuk setiap jenis.

(i) Semikonduktor intrinsik

(ii) Terdop jenis-P

(iii) Terdop jenis-N

(30 marks/*markah*)

[b] Silicon behaves differently at 0K and 300K. With the help of atomic bonding and energy band diagrams sketches, describe how does temperature affects the properties of silicon.

Silikon bersifat berbeza pada 0K dan 300K. Dengan bantuan lakaran gambarajah-gambarajah ikatan atom dan jalur tenaga, jelaskan bagaimana suhu mempengaruhi sifat-sifat silikon.

(40 marks/*markah*)

[c] Energy band diagram can be developed by tight binding approximation (atomistic) or one electron approach. Briefly explain how does energy band diagram can be developed using the tight binding approximation.

Gambarajah jalur tenaga boleh dibina dengan menggunakan 'tight binding approximation' atau 'one electron approach'. Terangkan dengan ringkas bagaimana gambarajah jalur tenaga boleh dibina dengan menggunakan 'tight binding approximation'.

(30 marks/*markah*)

PART C / *BAHAGIAN C*

5. Two silicon wires 100 μm long and 5 μm^2 in cross section are given to you. One wire is an intrinsic semiconductor the other one is an extrinsic semiconductor. Given the energy gap of silicon (intrinsic) is 1.2eV and $n_i = 10^{16} m^{-3}$ and the mobilities of electrons and holes are 0.135 $m^2V^{-1}s^{-1}$ and 0.05 $m^2V^{-1}s^{-1}$ respectively. Answer the following questions.

Dua dawai silikon panjangnya 100 μm dan 5 μm^2 telah diberikan kepada anda. Satu dawai ialah semikonduktor intrinsik dan satu lagi ialah semikonduktor ektrinsik. Diberikan jurang tenaga silikon (intrinsik) ialah 1.2eV dan $n_i = 10^{16} m^{-3}$ dan kebolehgerakan elektron dan lohong ialah 0.135 $m^2V^{-1}s^{-1}$ dan 0.05 $m^2V^{-1}s^{-1}$ masing-masing. Jawab soalan-soalan di bawah.

(a) State and explain a characterisation technique that can be used to differentiate between intrinsic and extrinsic semiconductor.

Nyatakan dan terangkan satu teknik pencirian yang boleh digunakan untuk membezakan antara semikonduktor intrinsik dan ektrinsik.

(20 marks/*markah*)

(b) Determine the probability of occupancy of a state at the bottom of the conduction band of the intrinsic silicon wire.

Tentukan kebarangkalian pengisian di dalam aras pada bawah jalur kekonduksian pada dawai silikon intrinsik ini.

(20 marks/*markah*)

(c) Compare the resistivity of the two wires given by performing the calculation of resistivity. The extrinsic semiconductor is a doped semiconductor with $N_D = 10^{20}\ m^{-3}$. The mobilities of electrons and holes are $0.135 m^2V^{-1}s^{-1}$ and $0.05 m^2V^{-1}s^{-1}$, respectively.

Bezakan kerintangan dawai-dawai yang diberikan dengan melakukan pengiraan kerintangan. Semikonduktor ektrinsik ialah semikonduktor yang didopkan dengan $N_D = 10^{20}\ m^{-3}$. *Kebolehgerakan elektron dan lohong masing-masing ialah* $0.135\ m^2V^{-1}s^{-1}$ *dan* $0.05\ m^2V^{-1}s^{-1}$.

(30 marks/*markah*)

(d) The extrinsic wire was exposed to p-type dopant by chemical vapour process as to form a p-n junction. Sketch the energy band diagram of the wire before and after the junction has been created.

Dawai ektrinsik didedahkan kepada bahan dop jenis-p dengan kaedah wap kimia untuk menghasilkan simpang p-n. Lakarkan gambarajah jalur tenaga dawai sebelum dan selepas simpang terbentuk.

(30 marks/*markah*)

6. You are given a doped silicon wafer (E_g = 1.12eV) with $10^{14}cm^{-3}$ antimony. Answer the following questions.

Anda telah diberikan dengan wafer silikon (E_g = 1.12eV) yang didopkan dengan $10^{14}cm^{-3}$ antimoni. Jawab soalan-soalan di bawah.

(a) Sketch a simplified band diagram for this doped wafer indicating the type of the wafer and the position of the energy level of the dopant.

Lakarkan gambarajah mudah jalur tenaga untuk wafer yang didopkan dengan menunjukkan jenis wafer dan kedudukan jalur tenaga untuk bahan dop.

(10 marks/*markah*)

(b) The semiconductor is now exposed to light at wavelength in the range of 200 - 400 nm. Describe the possible generation and recombination processes.

Semikonduktor tersebut didedahkan kepada cahaya dengan jarak gelombang 200 - 400 nm. Terangkan proses-proses generasi dan kombinasi semula yang berkemungkinan berlaku.

(30 marks/*markah*)

(c) Calculate the electron and hole concentrations at 300 K in this wafer giving that $n_i = 1.5 \times 10^{10}$ cm^{-3}.

Kirakan kepekatan elektron dan lohong pada 300 K untuk wafer ini, diberikan $n_i = 1.5 \times 10^{10}$ cm^{-3}.

(20 marks/*markah*)

(d) The mobilities of the electron and hole are 1300 cm^2/Vs and 470 cm^2/Vs respectively, calculate the drift current density if the applied field is E = 12V/cm at room temperature. Explain also what happens when the semiconductor is now heated to 500 K.

Kelincahan elektron dan lohong masing-masing ialah 1300 cm^2/Vs dan 470 cm^2/Vs, kirakan ketumpatan arus hanyut jika medan yang dibekalkan ialah E = 12V/cm pada suhu bilik. Terangkan juga apa yang akan berlaku jika semikonduktor ini dipanaskan pada 500 K.

(40 marks/*markah*)

7. One application of a p-n junction is to form a diode. Answer the following questions.

Satu aplikasi simpang p-n ialah untuk menghasilkan diod. Jawab soalan-soalan di bawah.

(a) Describe the formation of a space charge region by using appropriate sketches and explanations.

Perihalkan bagaimana kawasan ruang cas dihasilkan dengan menggunakan lakaran-lakaran dan penjelasan yang sesuai.

(20 marks/*markah*)

(b) Compare the distribution of charges, electric field and potential of an abrupt junction, one sided junction and when an Ohmic metal-semiconductor junction is created. Use Poisson equation in your answer.

Bandingkan taburan cas, medan elektrik dan keupayaan bagi simpang mendadak, simpang sebelah dan apabila Ohmic logam-semikonduktor dibentuk. Gunakan persamaan Poisson untuk jawapan anda.

(45 marks/*markah*)

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(c) The junction is reversed biased: argue why the reverse bias is limited to a certain value from which a breakdown happens, and then explain why capacitance is developed at the junction when reverse biased.

Simpang dipincang terbalik: berikan hujah kenapa pincang terbalik mempunyai satu had di mana kerosakan berlaku dan kemudian terangkan kenapa kapasitan terbentuk pada simpang yang dipincang terbalik.

(35 marks/*markah*)

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APPENDIX 1

LAMPIRAN 1

Possible equations for calculation

$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2} = \frac{-q^2}{4\pi\varepsilon_0 r^2} \ldots\ldots\ldots\ldots\ldots\ldots 1.1$$

$$F = -\nabla E_p = -\frac{dE_p}{dr} \ldots\ldots\ldots 1.2$$

$$dE_p = dE_p(r) = -Fdr = \frac{q^2 dr}{4\pi\varepsilon_0 r^2} \ldots\ldots\ldots 1.3$$

$$E_p(r = \infty) = E_{vac} \ldots\ldots 1.4$$

$$\int_{E_p}^{E_{vac}} dE_p = \int_r^{\infty} \frac{q^2 dr}{4\pi\varepsilon_0 r^2} \ldots\ldots\ldots\ldots 1.5$$

$$E_p = E_{vac} - \frac{q^2}{4\pi\varepsilon_0 r} \ldots\ldots\ldots\ldots 1.6$$

$$\oint P_\theta d\theta = \int_0^{2\pi} mvr\, d\theta = nh \ldots\ldots\ldots\ldots\ldots 1.9$$

APPENDIX 1 (CONTINUE)

LAMPIRAN 1 (SAMBUNGAN)

$$2\pi mrv = nh \ldots\ldots\ldots\ldots 1.10$$

$$mv_n r_n = n\frac{h}{2\pi} = n\hbar \ldots\ldots\ldots\ldots 1.11$$

$$r_n = \frac{4\pi\varepsilon_0 n^2\hbar^2}{mq^2} \ldots\ldots\ldots\ldots 1.12$$

$$v_n = \frac{q^2}{4\pi\varepsilon_0 n\hbar} \ldots\ldots\ldots\ldots 1.13$$

$$E_{K_n} = \frac{1}{2}mv_n^2 = \frac{mq^4}{2(4\pi\varepsilon_0)^2 n^2\hbar^2} \ldots\ldots 1.14$$

$$E_{Pn} = E_{vac} - \frac{mq^4}{(4\pi\varepsilon_0)^2 n^2\hbar^2} \ldots\ldots\ldots\ldots 1.15$$

$$E_n = E_{Kn} + E_{Pn} = E_{vac} - \frac{mq^4}{2(4\pi\varepsilon_0)^2 n^2\hbar^2} \ldots\ldots\ldots\ldots 1.16$$

F= attractive force

r = distance between 2 charges

ε_0 = permittivity of free spaces (8.85 x 10^{-12} Farad/m)

Q_1 = +q = 1.602 x 10^{-19} coulombs (hydrogen nucleus only has 1 proton

Q_2 = elemental charge and charge of e^- = -q

E_p = potential energy of the electron at position r

m = 1.67 x 10^{-27}kg

APPENDIX 2

LAMPIRAN 2

ELEMENT SYMBOLS, ATOMIC NUMBER, ATOMIC WEIGHT AND GROUP

Symbol	Name	At No.	At. Wt.	Group	Comments
Ac	Actinium	89	(227)	Actinides	Radioactive metal
Ag	Silver	47	107.87	11	Transition metal
Al	Aluminium	13	26.98	13	Light metal
Ar	Argon	18	39.95	18	Inert gas
As	Arsenic	33	74.92	15	Metalloid, toxic
At	Astatine	85	(210)	17	Radioactive metal
Au	Gold	79	196.97	11	Transition metal
B	Boron	5	10.81	13	Metalloid
Ba	Barium	56	137.33	2	Alkaline-earth metal
Be	Beryllium	4	9.012	2	Alkaline-earth metal
Bi	Bismuth	83	208.98	15	Metal
Br	Bromine	35	79.90	17	Halogen, liquid
C	Carbon	6	12.01	14	Non metal
Ca	Calcium	20	40.08	2	Alkaline-earth metal
Cd	Cadmium	48	112.41	12	Transition metal, toxic
Ce	Cerium	58	140.12	Lanthanides	Light rare earth element
Cl	Chlorine	17	35.45	17	Halogen, gas
Co	Cobalt	27	58.93	9	Transition metal
Cr	Chromium	24	52.00	6	Transition metal
Cs	Caesium	55	132.91	1	Alkali metal, liquid above 28° C
Cu	Copper	29	63.55	11	Transition metal
Dy	Dysprosium	66	162.50	Lanthanides	Middle rare earth element
Er	Erbium	68	167.26	Lanthanides	Heavy rare earth element
Eu	Europium	63	151.96	Lanthanides	Middle rare earth element
F	Fluorine	9	19.00	17	Halogen, gas
Fe	Iron	26	55.85	8	Transition metal
Fr	Francium	87	(223)	1	Radioactive metal
Ga	Gallium	31	69.72	13	Metal, liquid above 28° C
Gd	Gadolinium	64	157.25	Lanthanides	Middle rare earth element
Ge	Germanium	32	72.64	14	Metalloid
H	Hydrogen	1	1.008	1	Gas,
He	Helium	2	4.003	18	Inert gas
Hf	Hafnium	72	178.49	4	Titanium group metal
Hg	Mercury	80	200.59	12	Transition metal, liquid, toxic
Ho	Holmium	67	164.93	Lanthanides	Middle rare earth element
I	Iodine	53	126.90	17	Halogen, solid
In	Indium	49	114.82	13	Metal

APPENDIX 2 (CONTINUE)

LAMPIRAN 2 (SAMBUNGAN)

Ir	Iridium	77	192.22	9	Transition metal, PGE
K	Potassium	19	39.10	1	Alkali metal
Kr	Krypton	36	83.80	18	Inert gas
La	Lanthanum	57	138.91	Lanthanides	Light rare earth element
Li	Lithium	3	6.94	1	Alkali metal
Lu	Lutetium	71	174.97	Lanthanides	Heavy rare earth element
Mg	Magnesium	12	24.31	2	Alkaline-earth metal
Mn	Manganese	25	54.94	7	Transition metal
Mo	Molybdenum	42	95.94	6	Transition metal
N	Nitrogen	7	14.007	15	Gas non metal
Na	Sodium	11	22.99	1	Alkali metal
Nb	Niobium	41	92.91	5	Transition metal
Nd	Neodymium	60	144.24	Lanthanides	Light rare earth element
Ne	Neon	10	20.18	18	Inert gas
Ni	Nickel	28	58.69	10	Transition metal
Np	Neptunium	93	(237)	Actinides	Radioactive metal
O	Oxygen	8	16.00	16	Gas, non metal
Os	Osmium	76	190.23	8	Transition metal, PGE
P	Phosphorus	15	30.97	15	Non metal
Pa	Protactinium	91	231.04	Actinides	Radioactive metal
Pb	Lead	82	207.19	14	Metal, toxic
Pd	Palladium	46	106.42	10	Transition metal, PGE
Pm	Promethium	61	(145)	Lanthanides	Not naturally occurring
Po	Polonium	84	(210)	16	Metalloid
Pr	Praeseodymium	59	140.91	Lanthanides	Light rare earth element
Pt	Platinum	78	195.08	10	Transition metal, PGE
Pu	Plutonium	94	(244)	Actinides	Radioactive metal
Ra	Radium	88	(226)	2	Radioactive metal
Rb	Rubidium	37	85.47	1	Alkali metal
Re	Rhenium	75	186.21	7	Transition metal
Rh	Rhodium	45	102.91	9	Transition metal, PGE
Rn	Radon	86	(220)	18	Radioactive gas
Ru	Ruthenium	44	101.07	8	Transition metal, PGE
S	Sulphur	16	32.065	16	Non metal
Sb	Antimony	51	121.76	15	Metalloid, toxic
Sc	Scandium	21	44.96	3	Light metal
Se	Selenium	34	78.96	16	Non metal, toxic
Si	Silicon	14	28.09	14	Metalloid
Sm	Samarium	62	150.36	Lanthanides	Middle rare earth element
Sn	Tin	50	118.71	14	Metal/metalloid

APPENDIX 2 (CONTINUE)

LAMPIRAN 2 (SAMBUNGAN)

Sr	Strontium	38	87.62	2	Alkaline-earth metal
Ta	Tantalum	73	180.95	5	Transition metal
Tb	Terbium	65	158.92	Lanthanides	Middle rare earth element
Te	Tellurium	52	127.60	16	Metalloid, toxic
Th	Thorium	90	232.04	Actinides	Radioactive metal
Ti	Titanium	22	47.87	4	Transition metal, TGM
Tl	Thallium	81	204.38	13	Metal, toxic
Tm	Thulium	69	168.93	Lanthanides	Heavy rare earth element
U	Uranium	92	238.03	Actinides	Radioactive metal
V	Vanadium	23	50.94	5	Transition metal
W	Tungsten	74	183.84	6	Transition metal
X	Xenon	54	131.29	18	Inert gas
Y	Yttrium	39	88.91	3	Grouped with REE
Yb	Ytterbium	70	173.04	Lanthanides	Heavy rare earth element
Zn	Zinc	30	65.41	12	Transition metal
Zr	Zirconium	40	91.22	4	Transition metal, TGM

The transition metals have valance electrons in more than one shell and can show multiple oxidation states.
PGE = platinum group element.
TGM = Titanium group metal.

APPENDIX 3

LAMPIRAN 3

List of Physical constants

Constant	**Symbol**	**Value**
acceleration due to gravity	g	$9.8\ m\ s^{-2}$
atomic mass unit	amu, m_u or u	1.66×10^{-27} kg
Avogadro's Number	N_A	$6.022 \times 10^{23}\ mol^{-1}$
Bohr radius	a_0	0.529×10^{-10} m
Boltzmann constant	k	$1.38 \times 10^{-23}\ J\ K^{-1}$
electron charge to mass ratio	$-e/m_e$	$-1.7588 \times 10^{11}\ C\ kg^{-1}$
electron classical radius	r_e	2.818×10^{-15} m
electron mass energy (J)	m_ec^2	8.187×10^{-14} J
electron mass energy (MeV)	m_ec^2	0.511 MeV
electron rest mass	m_e	9.109×10^{-31} kg
Faraday constant	F	$9.649 \times 10^{4}\ C\ mol^{-1}$
fine-structure constant	α	7.297×10^{-3}
gas constant	R	$8.314\ J\ mol^{-1}\ K^{-1}$
gravitational constant	G	$6.67 \times 10^{-11}\ Nm^2kg^{-2}$
neutron mass energy (J)	m_nc^2	1.505×10^{-10} J
neutron mass energy (MeV)	m_nc^2	939.565 MeV
neutron rest mass	m_n	1.675×10^{-27} kg
neutron-electron mass ratio	m_n/m_e	1838.68
neutron-proton mass ratio	m_n/m_p	1.0014
permeability of a vacuum	μ_0	$4\pi \times 10^{-7}\ N\ A^{-2}$
permittivity of a vacuum	ε_0	$8.854 \times 10^{-12}\ F\ m^{-1}$
Planck constant	h	6.626×10^{-34} J s
proton mass energy (J)	m_pc^2	1.503×10^{-10} J
proton mass energy (MeV)	m_pc^2	938.272 MeV
proton rest mass	m_p	1.6726×10^{-27} kg
proton-electron mass ratio	m_p/m_e	1836.15
Rydberg constant	r_∞	$1.0974 \times 10^{7}\ m^{-1}$
speed of light in vacuum	C	2.9979×10^{8} m/s