Final Examination
2018/2019 Academic Session

June 2019

# JIF418 – Semiconductor and Devices
## *(Semikonduktor dan Peranti)*

Duration : 3 hours
*(Masa : 3 jam)*

Please check that this examination paper consists of **SEVEN (7)** pages of printed material before you begin the examination.

*[Sila pastikan bahawa kertas peperiksaan ini mengandungi **TUJUH (7)** muka surat yang bercetak sebelum anda memulakan peperiksaan ini].*

**Instructions** : Answer **ALL** questions. You may answer **either** in Bahasa Malaysia or in English.

*[**Arahan** : Jawab **SEMUA** soalan. 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].*

Answer **ALL** questions.

*Jawab **KESEMUA** soalan*.

1. With appropriate illustration/equation (if any), give your comments on the **truthfulness** of the following statements:

   *Dengan menggunakan ilustrasi/persamaan yang bersesuaian (jika ada), berikan komen anda terhadap **kebenaran** pernyataan berikut:*

   (a). Ionised donor atoms create holes in the valence band.

   *Atom penderma yang terion membentuk lohong dalam jalur valens.*

   (5 marks/*markah*)

   (b). The Fermi level is constant in a $p$-$n$ junction during equilibrium.

   *Aras Fermi adalah malar dalam simpang $p$-$n$ semasa keseimbangan*.

   (5 marks/*markah*)

   (c). For charge carriers in a semiconductor at a specific temperature, their mobility can be known after measuring their diffusion coefficient.

   *Bagi pembawa cas dalam satu semikonduktor pada suhu tertentu, kelincahan mereka dapat diketahui selepas mengukur pekali resapan.*

   (5 marks/*markah*)

   (d). Majority carrier injection that occurs during reverse bias in a $p$-$n$ junction is dependant on the height of the potential barrier.

   *Suntikan pembawa majoriti yang berlaku semasa pincang songsang dalam satu simpang $p$-$n$ bersandar pada ketinggian sawar keupayaan*.

   (5 marks/*markah*)

2. Polycrystalline silicon is loaded into a crucible with $5$ mg Boron to achieve $10^{15}\,\text{cm}^{-3}$ doping in a Czochralski growth.
*Polihablur silikon dimasukkan ke dalam satu mangkuk pijar bersama dengan $5$ mg Boron bagi mendapatkan pendopan $10^{15}\ cm^{-3}$ dalam satu pertumbuhan Czochralski.*

(a). Calculate the mass of the polycrystalline Si.
*Hitung jisim polihabur Si tersebut.*

(10 marks/*markah*)

(b). With the help of diagrams and equations, elaborate on how to produce the polycrystalline Si.
*Dengan bantuan gambar rajah dan persamaan, huraikan cara bagi menghasilkan polihablur Si tersebut.*

(10 marks/*markah*)

3. A Si sample at $300$ K is doped with $10^{16}$ phosphorus $\text{cm}^{-3}$.
*Satu sampel Si pada $300\ K$ didopkan dengan $10^{16}$ fosforus $cm^{-3}$.*

(a). Calculate the difference in the energy between the Fermi level and conduction band edge.
*Hitung perbezaan tenaga di antara aras Fermi dan pinggir jalur konduksi.*

(10 marks/*markah*)

(b). The sample is then steadily illuminated. If the steady state optical generation rate is $2\times10^{22}$ EHP $\text{cm}^{-3}\ \text{s}^{-1}$ and the recombination coefficient is $10^{-7}\ \text{cm}^3\ \text{s}^{-1}$, calculate the steady state excess carrier concentration.
*Sampel tersebut kemudiannya disinari secara mantap. Jika kadar penjanaan optikal keadaan mantap ialah $2\times10^{22}\ EHP\ cm^{-3}\ s^{-1}$ dan pekali rekombinasi ialah $10^{-7}\ cm^3\ s^{-1}$, hitung kepekatan pembawa lebihan keadaan mantap.*

(10 marks/*markah*)

4. (a). A light having an energy of $2.5\ \text{eV}$ and a power of $8\ \text{mW}$ illuminates a $0.3\ \mu\text{m}$ thick semiconductor. If the absorption coefficient at the wavelength of light is $5.1\times10^{4}\ \text{cm}^{-1}$, how many photons per second will be emitted during the luminescence?

*Satu cahaya dengan tenaga $2.5\ eV$ dan kuasa $8\ mW$ menyinari satu semikonduktor yang ketebalannya $0.3\ \mu m$. Jika pekali penyerapan pada panjang gelombang tersebut ialah $5.1\times10^{4}\ cm^{-1}$, berapakah foton per saat akan dilecitkan semasa luminesens?*

(10 marks/*markah*)

(b). The electron concentration in a semiconductor is given by

*Kepekatan elektron dalam satu semikonduktor diberikan oleh*

$$n(x)=10^{16}\left(1-\frac{x}{L}\right)\text{cm}^{-3}$$

between $0\le x\le L$, where $L = 10\ \mu\text{m}$. The semiconductor has a constant total current density of $-85\ \text{A cm}^{-2}$ over the given $x$ range. If the electron diffusion coefficient is $26\ \text{cm}^2\,\text{s}^{-1}$ and electron mobility is $1000\ \text{cm}^2\,\text{V}^{-1}\,\text{s}^{-1}$, determine the electric field at $x = 2\ \mu\text{m}$.

*di antara $0\le x\le L$, dengan $L=10\ \mu m$. Semikonduktor tersebut mempunyai jumlah ketumpatan arus malar $-85\ \text{A cm}^{-2}$ merentasi julat $x$ tersebut. Jika pekali resapan elektron ialah $26\ cm^2\ s^{-1}$ dan kelincahan elektron ialah $1000\ cm^2\ V^{-1}\ s^{-1}$, tentukan medan elektrik di $x = 2\ \mu m$.*

(10 marks/*markah*)

5. An abrupt Si $p$-$n$ junction is doped with $10^{17}$ cm$^{-3}$ acceptor atoms on the $p$ side and $10^{16}$ cm$^{-3}$ donor atoms on the $n$ side.
*Satu simpang langkah $p$-$n$ didop dengan atom penderma $10^{17}$ cm$^{-3}$ di bahagian $p$ dan atom penderma $10^{16}$ cm$^{-3}$ di bahagian $n$.*

(a). At 300 K,
*Pada suhu 300 K,*

(i). calculate the contact potential.
*hitung keupayaan sentuh.*

(5 marks/*markah*)

(ii). sketch an equilibrium band diagram for the junction. Label the contact potential.
*lakar satu gambar rajah jalur keseimbangan bagi simpang tersebut. Label keupayaan sentuh.*

(5 marks/*markah*)

(b). With the help of diagrams, elaborate on the formation of the forward current in the junction.
*Dengan bantuan gambar rajah, huraikan pembentukan arus depan dalam simpang tersebut.*

(10 marks/*markah*)

**Useful Information:**

Avogadro's number, $N_A = 6.02\times10^{23}$ molecules/mole

Nombor Avogadro, $N_A = 6.02\times10^{23}$ molekul/mol

Boltzmann's coustant, $k = 1.38\times10^{-23}\,\text{J K}^{-1} = 8.62\times10^{-5}\,\text{eV K}^{-1}$

Pemalar Boltzman, $k = 1.38\times10^{-23}\,\text{J K}^{-1} = 8.62\times10^{-5}\,\text{eV K}^{-1}$

Charge of electron, $e = 1.6\times10^{-19}\,\text{C}$

*Cas elektron,* $e = 1.6\times10^{-19}\,\text{C}$

Mass of electron, $m = 9.11\times10^{-31}\,\text{kg}$

Jisim elektron, $m = 9.11\times10^{-31}\,\text{kg}$

Planck's constant, $h = 6.63\times10^{-34}\,\text{J s} = 4.14\times10^{-15}\,\text{eV s}$

*Pemalar Planck,* $h = 6.63\times10^{-34}\,\text{J s} = 4.14\times10^{-15}\,\text{eV s}$

Permittivity of free space, $\varepsilon_o = 8.85\times10^{-12}\,\text{C}^2\,\text{N}^{-1}\,\text{m}^2$

*Ketelusan ruang bebas,* $\varepsilon_o = 8.85\times10^{-12}\,\text{C}^2\,\text{N}^{-1}\,\text{m}^2$

Relative dielectric constant of Si, $\varepsilon_r = 11.8$

*Pemalar dielektrik relatif* Si, $\varepsilon_r = 11.8$

Speed of light, $c = 3\times10^8\,\text{m s}^{-1}$

*Laju cahaya,* $c = 3\times10^8\,\text{m s}^{-1}$

| Ingot | Dopant<br>*Pendop* | Segregation coefficient of dopant, $k_d$<br>*Pekali pemisahan dopan*, $k_d$ | Atomic weight ($g\ mol^{-1}$)<br>*Berat atom* ($g\ mol^{-1}$) |
|---|---|---|---|
| Si<br>$\rho = 2.33\ g\ cm^{-3}$ | B | 0.8 | 10.8 |
| | Al | 0.0028 | 26.9 |
| | P | 0.35 | 30.9 |
| | As | 0.3 | 74.9 |
| GaAs<br>$\rho = 5.31\ g\ cm^{-3}$ | Zn | 0.42 | 65.4 |
| | Si | 2 | 28.1 |
| | Se | 0.1 | 78.9 |
| | Te | 0.064 | 127.6 |

| Constants at 300 K<br>*Pemalar pada* 300 K | Ge | Si | GaAs |
|---|---|---|---|
| Energy bandgap, $E_g$<br>*Jurang jalur tenaga,* $E_g$ | 0.66 eV | 1.12 eV | 1.42 eV |
| Intrinsic carrier concentration, $n_i$<br>*Kepekatan pembawa intrinsik,* $n_i$ | $2.4\times10^{13}\ cm^{-3}$ | $1.5\times10^{10}\ cm^{-3}$ | $1.8\times10^{6}\ cm^{-3}$ |
| Conduction band effective density of states, $N_c$<br>*Ketumpatan berkesan jalur konduksi,* $N_c$ | $1.04\times10^{19}\ cm^{-3}$ | $2.8\times10^{19}\ cm^{-3}$ | $4.7\times10^{17}\ cm^{-3}$ |
| Valence band effective density of states, $N_v$<br>*Ketumpatan berkesan jalur valens,* $N_v$ | $6\times10^{18}\ cm^{-3}$ | $1.04\times10^{19}\ cm^{-3}$ | $7\times10^{18}\ cm^{-3}$ |

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