UNIVERSITI SAINS MALAYSIA

Kursus Semasa Cuti Panjang
Academic Session 2003/2004

April 2004

ZAT 389E/3 - Low Dimensional Semiconductor Structures
[Struktur Semikonduktor Dimensi Rendah]

Duration: 3 hours
[Masa: 3 jam]

Please check that the examination paper consists of **SIX** pages of printed material before you begin the examination.

*[Sila pastikan bahawa kertas peperiksaan ini mengandungi **ENAM** muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]*

Instruction: Answer any **FOUR (4)** questions. Students are allowed to answer all questions in Bahasa Malaysia or in English.

*[**Arahan**: Jawab mana-mana **EMPAT** soalan. Pelajar dibenarkan menjawab semua soalan sama ada dalam Bahasa Malaysia atau Bahasa Inggeris.]*

1. (a) Explain (with the help of suitable figures) the energy bands in
[(a) Terangkan dengan jelas (berbantukan rajah-rajah yang bersesuaian) jalur tenaga di dalam skim zon

(i) extended,
(i) diperluaskan,

(ii) reduced and
(ii) diperkecilkan dan

(iii) periodic
(iii) berkala

zone schemes, for a nearly free electron in a one dimensional lattice with lattice constant a.
bagi elektron hampir bebas di dalam kekisi satu dimensi dengan pemalar kekisi a.]

(30/100)

(b) Discuss the origin of the energy gap for the electron in question (a).
[(b) Bincangkan asal usul jurang tenaga bagi elektron di dalam soalan (a).]

(20/100)

(c) Figure 1 shows the schematic first Brillouin zone of a rectangular Bravais lattice with lattice constants π Å (x axis) and 2π Å (y axis).
[(c) Rajah 1 secara berskema mewakili zon Brillouin pertama bagi suatu kekisi Bravais segiempat tepat dengan pemalar kekisi π Å *(paksi x) dan* 2π Å *(paksi* y*).*

(i) Determine the electron wavevectors at Γ, X and L.
(i) Tentukan vektor gelombang elektron pada Γ, X *dan* L.

(ii) Draw the energy bands for a free electron moving from Γ to L, to X and back to Γ.
(ii) Lukiskan dengan jelas jalur tenaga bagi suatu elektron bebas yang bergerak dari Γ *ke* L, *ke X dan kembali ke* Γ.

(iii) Draw similar energy bands on the same graph if the electron is now nearly free. Discuss the main differences between them.
(iii) Lukiskan jalur tenaga yang setara di atas graf yang sama jika elektron tersebut adalah hampir bebas. Bincangkan perbezaan utama mereka.]

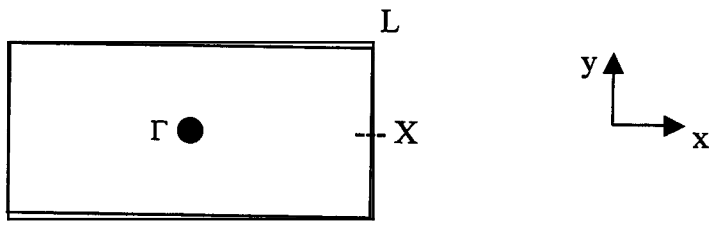

Figure 1
[Rajah 1]

(50/100)

2. (a) Discuss the conduction and valence band structures of Si and Ge in the [111] and [100] directions.

[(a) Bincangkan struktur jalur konduksi dan valens bagi Si *dan* Ge *dalam arah* [111] *dan* [100].*]*

(30/100)

(b) The energy band gap of $Al_xGa_{1-x}Sb$ alloys at Γ point can be represented by

[(b) Jurang jalur tenaga bagi aloi $Al_xGa_{1-x}Sb$ *pada titik* Γ *dapat diwakili oleh persamaan]*

$$E_g(x) = 0.726 + 1.129x + 0.368x^2 \text{ (eV)}$$

Determine the amount of Al so that a light emitting diode with an active optical layer of $Al_xGa_{1-x}Sb$ can emit light of wavelength 1.47 μm.
[Tentukan kandungan Al supaya suatu diod pemancar cahaya dengan lapisan optik aktif $Al_xGa_{1-x}Sb$ *dapat menghasilkan cahaya berjarak gelombang 1.47* μm.*]*

(20/100)

(c) The lattice constants for GaAs, AlAs and InAs are 5.6419 Å, 5.6611 Å and 6.0584 Å, respectively.

[(c) Pemalar kekisi bagi GaAs, AlAs dan InAs masing-masing ialah 5.6419 Å, 5.6611 Å dan 6.0584 Å.]

(i) Draw on the same graph the changes in lattice constants for $Al_xGa_{1-x}As$ and $In_xGa_{1-x}As$ alloys.

[(i) Lukiskan perubahan pemalar kekisi bagi aloi $Al_xGa_{1-x}As$ *dan* $In_xGa_{1-x}As$ *di atas graf yang sama.]*

(ii) From the graph, discuss the possibilities of growing $Al_xGa_{1-x}As$ alloys on $In_xGa_{1-x}As$ alloys without the introduction of significant strains.

[(ii) Daripada graf tersebut, bincangkan kemungkinan menumbuh aloi $Al_xGa_{1-x}As$ di atas aloi $In_xGa_{1-x}As$ tanpa kewujudan tegasan yang ketara.]

50/100

3. (a) Describe the important components of a metal-organic chemical vapour deposition (MOCVD) reactor and their functions in the growth of semiconductor thin films.

[(a) Perihalkan komponen-komponen penting di dalam suatu reaktor pemendapan wap kimia logam-organik (MOCVD) dan fungsi-fungsi mereka dalam penumbuhan filem tipis semikonduktor.]

(30/100)

(b) Table 1 shows the electron affinity χ and the energy gap E_g at 300 K for alloy semiconductors of $In_{0.53}Ga_{0.47}As$, InP and $In_{0.52}Al_{0.48}As$.

[(b) Jadual 1 menunjukkan afiniti elektron χ dan jurang tenaga E_g pada 300 K bagi semikonduktor aloi $In_{0.53}Ga_{0.47}As$, InP dan $In_{0.52}Al_{0.48}As$.]

Table 1
[Jadual 1]

Alloy *Aloi*	χ (eV) χ (eV)	E_g at 300 K (eV) E_g *pada* 300 K (eV)
$In_{0.53}Ga_{0.47}As$	4.64	0.75
InP	4.38	1.35
$In_{0.52}Al_{0.48}As$	4.12	1.44

(i) Determine the band offsets in the conduction and valence bands for heterojunctions of $In_{0.53}Ga_{0.47}As$-InP, InP-$In_{0.52}Al_{0.48}As$ and $In_{0.52}Al_{0.48}As$-$In_{0.53}Ga_{0.47}As$.

[(i) Tentukan ofset jalur konduksi dan valens bagi heterosimpang-heterosimpang $In_{0.53}Ga_{0.47}As$-InP, InP-$In_{0.52}Al_{0.48}As$ dan $In_{0.52}Al_{0.48}As$-$In_{0.53}Ga_{0.47}As$.]

(ii) Draw the band diagrams for each heterojunction in question (i) and identify the type of alignment for each case.

[(ii) Lukiskan gambarajah jalur bagi setiap heterosimpang di dalam soalan (i) dan camkan jenis penjajaran jalur bagi setiap kes.]

(50/100)

(c) A GaAs layer is sandwiched between two layers of AlAs. Draw and discuss possible barriers and wells that could exist in the conduction bands of the sandwiched layer by considering the three lowest conduction bands in an $Al_xGa_{1-x}As$ system.

[(c) Suatu lapisan GaAs diapit oleh dua lapisan AlAs. Lukis dan bincangkan kewujudan sawar dan perigi di dalam jalur-jalur konduksi lapisan yang diapit dengan mempertimbangkan tiga jalur konduksi yang terendah bagi sistem $Al_xGa_{1-x}As$.*]*

(20/100)

4. (a) Discuss the separation of energy bands in one dimensional square, parabolic and triangular potential wells.

[(a) Bincangkan dengan jelas pemisahan jalur-jalur tenaga di dalam perigi keupayaan segiempat sama, parabola dan segitiga satu dimensi.]

(30/100)

(b) Consider a GaAs square potential well sandwiched by AlAs with depth $V_0 = 1$ eV. The width of the well in the z direction is $a = 5$ nm, the effective mass of the electron in the well is $m_W = 0.067$ and the effective mass of the electron in the barrier is $m_B = 0.15$.

[(b) Pertimbangkan suatu perigi keupayaan segiempat sama GaAs diapit oleh sawar AlAs dengan kedalaman $V_0 = 1$ *eV. Lebar perigi dalam arah z ialah* $a = 5$ *nm dengan jisim berkesan elektron di dalam perigi ialah* $m_W = 0.067$ *dan jisim berkesan elektron di dalam sawar ialah* $m_B = 0.15$.*]*

(i) Determine the number of bound states that exist in the well.

[(i) Tentukan bilangan keadaan terikat yang wujud di dalam perigi ini.]

(ii) What happens to the bound states if the value of m_B is increased?

[(ii) Apakah yang terjadi kepada keadaan-keadaan terikat tersebut jika nilai m_B *ditingkatkan?]*

(50/100)

(c) Discuss the electron total energy in question (b) if the electron is also free to move in the x and y directions.

[(c) Bincangkan jumlah tenaga bagi elektron dalam soalan (b) jika elektron tersebut juga bebas bergerak dalam arah x dan y.]

(20/100)

5. (a) Determine the three dimensional, two dimensional and one dimensional free electron density of states as a function of energy.

[(a) Tentukan ketumpatan keadaan elektron bebas tiga dimensi, dua dimensi dan satu dimensi sebagai fungsi tenaga.]

(50/100)

(b) The optical conductivity for interband absorption in a direct band gap semiconductor is given by the real component

[(b) Kekonduksian optik bagi penyerapan antara jalur di dalam suatu semikonduktor jurang jalur terus diberi oleh komponen hakiki]

$$\sigma_1(\omega) \approx \frac{\pi e^2}{m_0^2 \omega} |p_{cv}(0)|^2 n_{opt}(\hbar\omega)$$

where $n_{opt}(\hbar\omega)$ is the optical joint density of states and other terms have the same meaning as in the lecture notes.

[dengan $n_{opt}(\hbar\omega)$ ialah ketumpatan keadaan bersama optik dan sebutan-sebutan lain mempunyai maksud yang sama seperti dalam nota.]

(i) Draw and discuss the theoretical absorption curves for bulk, thin film and quantum wire semiconductors.

[(i) Lukis dan bincangkan lengkung-lengkung penyerapan teori bagi semikonduktor pukal, filem nipis dan dawai kuantum.]

(ii) Explain why these theoretical absorption curves are slightly different from those obtained experimentally.

[(ii) Terangkan kenapa lengkung-lengkung penyerapan teori ini agak berbeza sedikit daripada lengkung-lengkung eksperimen.]

(50/100)