UNIVERSITI SAINS MALAYSIA

KSCP Semester Examination
Academic Session 2004/2005

May 2005

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 **SEVEN** pages of printed material before you begin the examination.

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

Instruction: Answer **FOUR** questions only. Students are allowed to answer all questions in Bahasa Malaysia or in English.

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

1. (a) (i) Sketch the energy bands for a nearly free electron in the first three Brillouin zones of a one-dimensional lattice with lattice constant a.
[Lakarkan jalur tenaga bagi suatu elektron hampir bebas di dalam tiga zon Brillouin terawal bagi suatu kekisi satu dimensi a.*]*

(ii) Determine the reciprocal lattice vectors for translating these bands into the reduced zone scheme and sketch their structure.
[Tentukan vektor-vektor kekisi resiprokal bagi mentranslasikan jalur ini ke dalam skim zon diperkecilkan dan lakarkan strukturnya.]

(iii) Explain briefly the origin of energy gaps at the centre and edges of the first Brillouin zone.
[Terangkan secara ringkas asalan jurang-jurang tenaga di pusat dan pinggir-pinggir zon Brillouin pertama.]

(30/100)

(b) Figure 1 shows the first Brillouin zone of a square lattice with lattice constant a.
[Rajah 1 menunjukkan zon Brillouin pertama bagi suatu kekisi segiempat sama dengan pemalar kekisi a.*]*

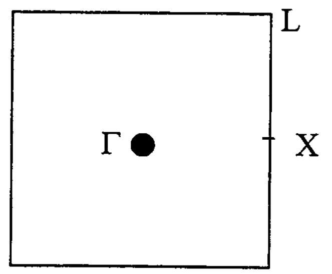

Figure 1 *[Rajah 1]*

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

(ii) Indicate clearly in your drawing the presence of energy gaps if such an electron is nearly free.
[Tandakan dengan jelas di dalam lukisan anda kewujudan jurang-jurang tenaga jika elektron tersebut adalah hampir bebas])

(40/100)

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(c) Describe the characteristics of Γ_7 and Γ_8 valence bands in unstrained silicon (Si) at the centre of the Brillouin zone and for finite electron wavenumber.
[Terangkan ciri-ciri jalur valens Γ_7 and Γ_8 di dalam silikon (Si) tak tegasan di pusat zon Brillouin dan bagi nombor gelombang elektron terhingga.]

(30/100)

2. (a) Figure 2 shows the dependence of the band gap of unstrained $Si_{1-x}Ge_x$ alloys as a function of the Ge fraction.
[Rajah 2 menunjukkan kebersandaran jurang jalur aloi-aloi $Si_{1-x}Ge_x$ tak terikan sebagai satu fungsi pecahan Ge.]

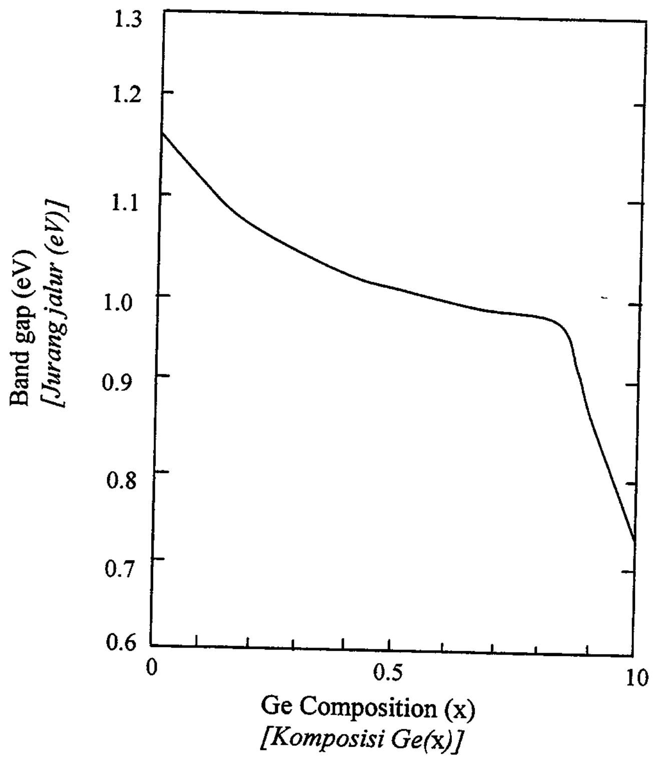

Figure 2 *[Rajah 2]*

(i) Discuss the behaviour of the conduction band minima as the Ge composition increases.
[Bincangkan kelakuan minimum jalur konduksi apabila komposisi Ge ditingkatkan.]

(ii) Sketch a curve that represents the band gap of strained $Si_{1-x}Ge_x$ alloys as a function of x with respect to the unstrained band gap.
[Lakarkan satu lengkung yang mewakili jurang jalur aloi-aloi $Si_{1-x}Ge_x$ *terikan sebagai satu fungsi x merujuk kepada jurang jalur tak terikan.]*

(50/100)

(b) Consider a metal forming an interface with a n-type semiconductor. Using suitable band diagrams describe the possible contacts that can be formed at the interface by considering the work functions of the metal and the semiconductor.
[Satu logam membentuk antaramuka dengan satu semikonduktor jenis-n. Gunakan gambarajah-gambarajah jalur yang bersesuaian bagi memerihalkan sentuhan-sentuhan yang mungkin terbentuk pada antaramuka dengan mempertimbangkan fungsi kerja logam dan semikonduktor jenis-n.]

(50/100)

3. (a) Describe the growth of semiconductor thin films using molecular beam epitaxy (MBE) and metal-organic chemical vapour deposition (MOCVD) reactors. Comment on the outstanding features of each growth technique.
[Perihalkan penumbuhan filem nipis semikonduktor menggunakan reaktor epitaksi alur molekul (MBE) dan pemendapan wap kimia logam-organik (MOCVD). Berikan komen tentang ciri-ciri terbaik bagi setiap teknik penumbuhan.]

(30/100)

(b) Table 1 shows the band parameters for growing $In_{0.53}Ga_{0.47}As$-InP-$In_{0.52}Al_{0.48}As$-$In_{0.53}Ga_{0.47}As$ lattice-matched heterostructures.
[Jadual 1 menunjukkan parameter-parameter jalur bagi penumbuhan heterostruktur kekisi-sepadan $In_{0.53}Ga_{0.47}As$-InP-$In_{0.52}Al_{0.48}As$-$In_{0.53}Ga_{0.47}As$.*]*

Table 1 *[Jadual 1]*

	Energy gap E_g(eV) *[Jurang tenaga E_g(eV)]*	Energy difference between minima of conduction bands ΔE_c(eV) *[Perbezaan tenaga di antara minima jalur-jalur konduksi ΔE_c(eV)]*	Energy difference between maxima of valence bands ΔE_v(eV) *[Perbezaan tenaga di antara maksima jalur-jalur valens ΔE_v(eV)]*
$In_{0.53}Ga_{0.47}As$	0.75		
		0.26	0.34
InP	1.35		
		0.25	-0.16
$In_{0.52}Al_{0.48}As$	1.44		
		0.47	0.22
$In_{0.53}Ga_{0.47}As$	0.75		

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(i) Draw and describe the alignment of the bands at the heterojunctions using Anderson's rule.
[Lukis dan perihalkan penjajaran jalur-jalur di heterosimpang-heterosimpang menggunakan petua Anderson.]

(ii) Discuss the confinement of electrons and holes in each heterojunction.
[Bincangkan pengurungan elektron dan lohong pada setiap heterosimpang.]

(40/100)

I (i) Give reasons for using strained layers in the growth of heterostructures.
[Berikan alasan-alasan menggunakan lapisan-lapisan tegasan dalam penumbuhan heterostruktur.]

(ii) Discuss the effects of compression and tension of the lattice in the plane of the junction on the valence bands.
[Bincangkan kesan-kesan mampatan dan regangan kekisi di dalam satah simpang ke atas jalur valens.]

(30/100)

4. (a) Explain how a one-dimensional parabolic potential well can be created experimentally in heterostructures of GaAs-AlGaAs.
[Terangkan bagaimana satu perigi keupayaan parabola satu dimensi dapat dibina secara eksperimen dengan heterostruktur GaAs-AlGaAs.*]*

(30/100)

(b) The solutions for bound states of an electron in a square well with width a and finite depth V_o are given by
[Penyelesaian bagi keadaan terikat satu elektron di dalam perigi segi empat sama dengan lebar a *dan kedalaman terhingga* V_o *diberi oleh]*

$$\left\{\begin{matrix}\tan \\ -\cot\end{matrix}\right\}\theta = \sqrt{\frac{mV_o a^2}{2\hbar^2}\frac{1}{\theta^2} - 1} \equiv \sqrt{\frac{\theta_o^2}{\theta^2} - 1}$$

where θ = ka/2, m and k are the mass and wave vector of the electron, respectively.
[dengan θ = ka/2, m *dan* k *masing-masing ialah jisim dan vektor gelombang elektron.]*

(i) Explain clearly with the aid of a suitable graph the steps required to solve the above equation.
[Terangkan secara jelas dengan bantuan satu graf yang bersesuaian langkah-langkah bagi menyelesaikan persamaan di atas.]

(ii) Determine the number of solutions if a = 10 nm, V_o = 0.3 eV and m = $m_o m_e$ where m_e = 0.067. Given that $m_o = 9.11 \times 10^{-31}$ kg and $\hbar = 1.60 \times 10^{-34}$ Js.
[Tentukan bilangan penyelesaian jika a = 10 nm, V_o = 0.3 eV *dan* m = $m_o m_e$ *dengan* m_e = 0.067. *Diberi bahawa* $m_o = 9.11 \times 10^{-31}$ kg *dan* $\hbar = 1.60 \times 10^{-34}$ Js.*]*

(70/100)

5. (a) Discuss the Fermi's Golden Rule for a harmonic perturbation given by
[Bincangkan Peraturan Emas Fermi bagi usikan harmonik yang diberi sebagai]

$$\hat{V}(t) = 2\hat{V}\cos\omega_o t = \hat{V}\left(e^{-i\omega_o t} + {}^{+i\omega_o t}\right)$$

where $\hat{V}$ is the amplitude and ω_o is the frequency.
[di mana $\hat{V}$ ialah amplitud dan ω_o ialah frekuensi.]

(30/100)

(b) Figure 3 shows wavefunctions along z (with energy levels) of bound states in a quantum well formed by the conduction bands of a heterostructure. Consider photons propagating in the plane of the well such that the electric field is normal to the quantum well. By considering the matrix element between two bound states in the transition rate equation show that
[Rajah 3 menunjukkan fungsi-fungsi gelombang di sepanjang z (dengan paras-paras tenaga) bagi keadaan-keadaan terikat di dalam suatu perigi kuantum yang dibentuk oleh jalur-jalur konduksi suatu heterosimpang. Pertimbangkan foton-foton merambat di dalam satah perigi supaya medan elektrik adalah normal kepada perigi kuantum. Gunakan unsur matriks di antara dua keadaan terikat di dalam persamaan kadar peralihan bagi menunjukkan]

(i) optical transitions are vertical,
[peralihan-peralihan optik adalah menegak,]

(ii) absorption occurs at frequencies corresponding to the separation of bound states in the well, and
[penyerapan-penyerapan berlaku pada frekuensi yang sepadan dengan pemisahan keadaan-keadaan terikat di dalam perigi, dan]

(iii) the selection rule for optical absorption is if one state is even the other must be odd.
[petua pemilihan bagi penyerapan optik ialah jika suatu keadaan adalah genap maka keadaan yang suatu lagi mestilah ganjil.]

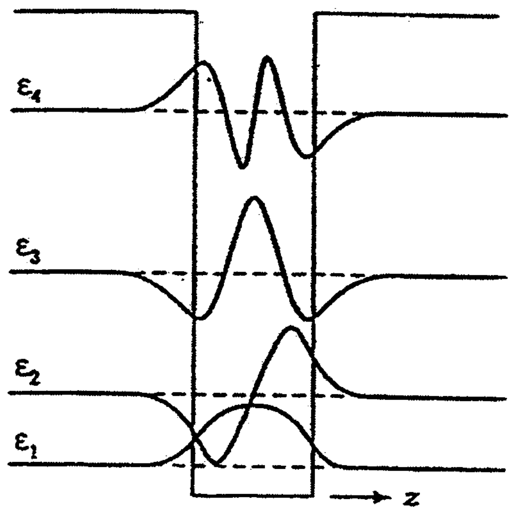

Figure 3 *[Rajah 3]*

(70/100)

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