UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2002/2003 Academic Session

February - March 2003

ZAT 389E/3 - Low-Dimensional Semiconductor Structures

Time : 3 hours

Please check that the examination paper consists of **NINE** printed pages before you commence this examination.

Answer any FOUR questions. Students are allowed to answer all questions in English OR Bahasa Malaysia OR combination of both.

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.

(ii) Determine the reciprocal lattice vectors for translating these bands into the reduced zone scheme and sketch their structure.

(iii) Explain briefly the origin of energy gaps at the centre and edges of the first Brillouin zone.

(30/100)

(b) Diagram 1 shows the first Brillouin zone of a square lattice with lattice constant a.

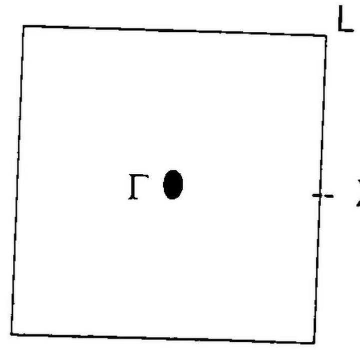

Diagram 1

(i) Draw the energy bands for a free electron moving from Γ to X, to L and back to Γ.

(ii) Indicate clearly in your drawing the presence of energy gaps if such an electron is nearly free.

(40/100)

(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.

(30/100)

2. (a) The band gap at Γ-point for $Al_xGa_{1-x}As$ alloys can be represented by $E_g(x) = 1.42 + 1.247x$. Describe the behaviour of the true band gap (energy difference between lowest minimum in the conduction band and highest maximum in the valence band) in $Al_xGa_{1-x}As$ as x changes from zero to unity.

(40/100)

(b) Discuss the origin of point defects and their role in the determination of band structure in semiconductors.

(20/100)

(c) Consider a metal forming an interface with a p-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 p-type semiconductor.

(40/100)

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.

(30/100)

(b) Table 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.

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	Energy gap E_g (eV)	Energy difference between minima of conduction bands ΔE_c (eV)	Energy difference between maxima of valence bands ΔE_v (eV)
$In_{0.53}Ga_{0.47}As$	0.75		
InP	1.35	0.26	0.34
$In_{0.52}Al_{0.48}As$	1.44	0.25	-0.16
$In_{0.53}Ga_{0.47}As$	0.75	0.47	0.22

(i) Draw and describe the alignment of the bands at the heterojunctions using Anderson's rule.

(ii) Discuss the confinement of electrons and holes in each heterojunction.

(40/100)

(c) (i) Give reasons for using strained layers in the growth of heterostructures.

(ii) Discuss the effects of compression and tension of the lattice in the plane of the junction on the valence bands.

(30/100)

4. (a) The total energy for electrons moving in the x-y plane of an infinitely deep square quantum well (potential energy depends only on the z coordinate) is given as

$$E_n(\mathbf{k}) = \varepsilon_n + \frac{\hbar^2 \mathbf{k}^2}{2m}$$

where n (= 1, 2, 3...) is the subband index, ε_n is the energy of a bound state in the z direction, and **k** (= k_x, k_y) is the electrons wavenumber.

Sketch and describe the total energy for the first three subbands in a GaAs well of width 10 nm and their corresponding density of states.

(50/100)

(b) (i) Discuss the energy of electrons confined in one-dimension (such as in a quantum wire) by assuming the confining potential to be a function of **r** (= x, y) so that the electrons remain free to move along z.

(ii) Sketch and describe the density of states of the resulting subbands.

(50/100)

5. (a) Discuss the Fermi's golden rule for a harmonic perturbation given by

$$\hat{V}(t) = 2\hat{V}\cos\omega_0 t = \hat{V}\left(e^{-i\omega_0 t} + e^{+i\omega_0 t}\right)$$

where $\hat{V}$ is the amplitude and ω_0 is the frequency.

(50/100)

(b) Diagram 2 shows electronic bound states (wave functions along z with energy levels) in a quantum well aligned along z formed by the conduction bands of a heterostructure. Consider light propagating in the plane of the well such that its electric field is normal to the quantum well. By considering the matrix element between two bound states in the transition rate equation show that

(i) optical transitions are vertical,

(ii) absorption occurs at frequencies corresponding to the separation of bound states in the well, and

(iii) the selection rule for optical absortion is if one state is even the other must be odd.

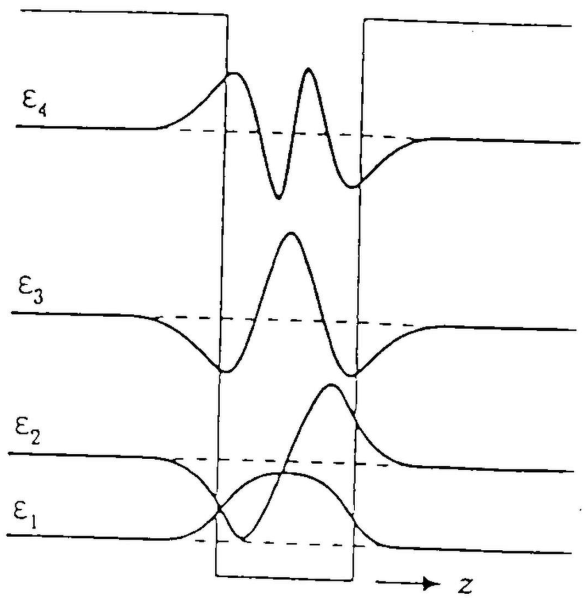

Diagram 2

(50/100)

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