EE 232
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Midterm Examination-2
EE 232 – Lightwave Devices

Fall 2010
Prof. Ming Wu

- If you need additional conditions to solve a problem, please write down your assumptions.
- Answer in the space below the problem. If you need additional space, you can use the overflow pages in the back. Please indicate which page the answer continues in the lower-right corner.
- Please put a square box around your final answers for each problem.

Commonly used constants:

$\hbar = 1.054\times10^{-34}$ J·s	$q = 1.6\times10^{-19}$ C	$m_0 = 9.11\times10^{-31}$ kg
$k_B T = 0.026$ eV at 300K	$k_B = 1.38\times10^{-23}$ J/K	$\varepsilon_0 = 8.854\times10^{-12}$ F/m
1 eV $= 1.6\times10^{-19}$ J		

Your Name	
Student ID #	
Signature	

Problem	Points	Grade
1	20	
2	20	
3	20	
4	20	
5	20	
Total	100	

1. A slab waveguide at 1.55 μm wavelength consists of a core layer with a refractive index of 5 and cladding layers with refractive indices of 3.

   a) Find the maximum thickness of core layer for single mode waveguide.

   b) If the thickness of the core layer is 100 nm, what is the confinement factor of the waveguide?

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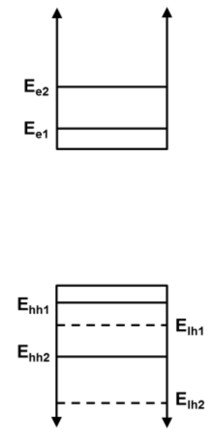
2. Consider a quantum well with 2 electron, 2 heavy-hole, and 2 light-hole subbands, as shown on the right.



a) Identify *all allowed* optical transitions and their *primary* polarizations. The transition can be designated by their electronic and hole quantization levels, e.g., e1-hh1 is from the first electron subband to the first heavy hold subband. <u>Include both *interband* and *intersubband* transitions.</u>

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3. Find the transparency carrier concentration of a single quantum well laser with a well width of 10 nm. The effective masses of the electrons and holes are $0.1m_0$ and $0.2m_0$, respectively. [Note: You can use the approximation: $e^{-x} \approx 1 - x$]

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4. In strained semiconductor, the energy bands are described by

$$E_{HH}(k) = -P_\varepsilon - Q_\varepsilon - \frac{\hbar^2}{2m_0}\left[(\gamma_1+\gamma_2)k_t^2 + (\gamma_1 - 2\gamma_2)k_z^2\right]$$

$$E_{LH}(k) = -P_\varepsilon + Q_\varepsilon - \frac{\hbar^2}{2m_0}\left[(\gamma_1-\gamma_2)k_t^2 + (\gamma_1 + 2\gamma_2)k_z^2\right]$$

where

$$P_\varepsilon = -a_V(\varepsilon_{xx}+\varepsilon_{yy}+\varepsilon_{zz}) = -2a_V\left(1-\frac{C_{12}}{C_{11}}\right)\varepsilon$$

$$Q_\varepsilon = -\frac{b}{2}(\varepsilon_{xx}+\varepsilon_{yy}-2\varepsilon_{zz}) = -b\left(1+2\frac{C_{12}}{C_{11}}\right)\varepsilon$$

The material parameters are listed in the following Table:

Bandgap energy (unstrained)	E_g	1 eV
Deformation potentials	a_c	-5 eV
	a_V	1 eV
	b	-2 eV
Compliance ratio	C_{12} / C_{11}	0.5
Hole effective mass parameters	γ_1	3
	γ_2	1
Electron effective mass	m_e^*	0.1 m_0
Quantum well width	L_z	10 nm

Consider a quantum well with the above material in the well. The width of the quantum well is 10 nm. In the absence of strain, the electron-heavy hole (E-HH) is the lowest energy transition. With sufficiently high tensile strain, the electron-light hole (E-LH) eventually becomes the lowest energy transition. Find the amount of strain at which the E-HH and E-LH have the *same* transition energy.

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5. Consider a multi-quantum well (MQW) laser with *n* quantum wells. Assume the confinement factor *per quantum well* is Γ_0, and the total loss (including mirror and residue losses) of the laser is α. The gain of the quantum well can be approximated by $g(N) = g_0 \ln\left(\frac{N}{N_{tr}}\right)$, where N_{tr} the transparency carrier concentration. The width of each quantum well is L_z. The carrier lifetime τ is constant.

a) Find the analytical expression of the threshold carrier concentration. The expression should contain explicitly *n*, the number of quantum wells.

b) Find the expression of the threshold current density. Again, this expression should contain explicitly *n*, the number of quantum wells.

c) Find the *optimum* number of quantum wells that minimizes threshold current density.

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