EE 232	**<u>Midterm Examination-2</u>**	Fall 2009
11/9/2009	**EE 232 – Lightwave Devices**	Prof. Ming Wu

- If you need additional conditions to solve a problem, please write down your assumptions. **Please put a box around your assumption so it can be seen clearly.**
- 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.

Global Parameters:

Unless stated otherwise in the problem, use the following values for all problems:

Optical matrix element**:**	$M_b^2 = (m_0/6)E_p$, and $E_p = 24\,\text{eV}$
Bandgap energy:	E_g = 1 eV
Relative dielectric constant:	$\varepsilon_r = 9$
Refractive index:	$n_r = 3$

Commonly used constants:

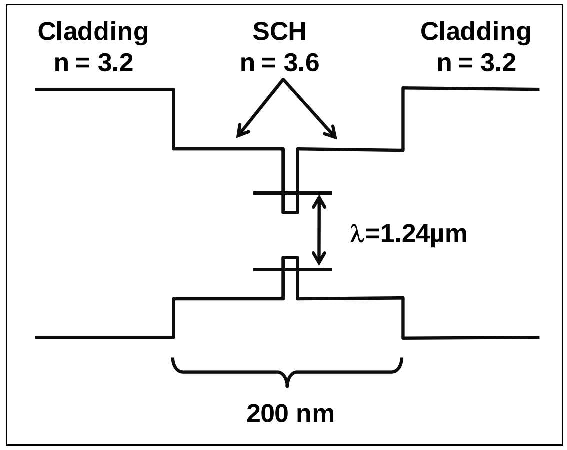
$\hbar = 1.054\times10^{-34}$ J·s	$q = 1.6\times10^{-19}$ C	$m_0 = 9.11\times10^{-31}$ kg
$k_BT = 0.026$ eV at 300K	$k_B = 1.38\times10^{-23}$ J/K	$\varepsilon_0 = 8.854\times10^{-12}$ F/m

Your Name	
Student ID #	
Signature	

Problem	Points	Points Earned
1)	40	
2)	20	
3)	40	
Total	100	

Please write your answer directly under the problem. If you need more space, please use the overflow page at the end of the problems.

1. Consider a separate-confinement heterostructure (SCH) single quantum well laser with an energy band diagram shown on the right. The total SCH layer thickness is 200 nm, and the quantum well thickness of 10 nm. The laser has a width of 1 μm and a length of 500 μm. Assume the internal quantum efficiency is 100%, and the internal loss is 10 cm^{-1}. The gain of the quantum well can be approximated by $g(N) = g_0 \ln\left(N / N_{tr}\right)$, where $g_0 = 1000\ \text{cm}^{-1}$ and the transparency carrier concentration $N_{tr} = 10^{18}\ \text{cm}^{-3}$. For simplicity, assume the carrier recombination lifetime is constant and is equal to 1 ns. The refractive indice of the materials are shown in the figure. The effective refractive index of the SCH waveguide can be calculated from the waveguide structure. But for simplicty, assume it to be $n_{eff} = 3.4$. The laser wavelength is 1.24 μm. Both facets of the laser are cleaved, and have a reflectivity of 30%.



a) Since the quantum well is very thin, its effect on wave guiding can be neglected. Find the confinement factor of the SCH layer (by treating it as a double heterostructure).

b) Estimate the confinement factor of the active quantum well, assuming the field is *uniformly* distributed in the SCH layer.

c) What is the threshold gain of the laser?

d) What is its threshold current (in mA)?

e) What is the quantum efficiency of the laser in both % and mW/mA?

f) What is the output power (in mW) if the laser is biased at two times threshold current ($2 \times I_{th}$)?

g) Calculate the photon density of the laser inside the cavity when it is biased at two times threshold current ($2 \times I_{th}$).

h) What is the relaxation oscillation frequency (in GHz) of the laser when it is biased at $2 \times I_{th}$?

Answer for Problem ___

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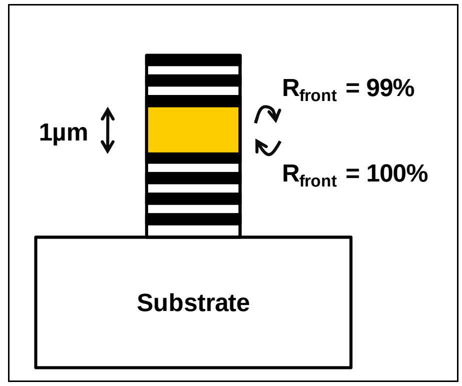
2. Find the quality factor (Q) of a vertical cavity surface-emitting laser (VCSEL) with a cavity length of 1 µm. The top and bottom reflectivities are 99% and 100%, respectively. The internal loss is 10 cm^{-1}, and effective refractive index is 3. The laser wavelength is 1 µm.



Answer for Problem ___

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3. A semiconductor material with the following parameters is grown on a lattice-mismatched substrate:

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	10
	γ_2	1
Electron effective mass	m_e^*	$0.1\ m_0$
Optical matrix element:	$M_b^2 = (m_0/6)E_p$	$E_p = 24\,\text{eV}$
Relative dielectric constant:	ε_r	9
Quantum well width	L_z	5 nm

a) The goal of this problem is to find the strain in the material that will results in *equal energies* for the electron-heavy hole and electro-light hole transitions in the quantum well. **Please indicate whether the strain is tensile or compressive. If you know how to do this, you can skip Part i) to iii), and go straight to Part b).** If you don't know where to start, Part i) to iii) are intended to guide you there.

i) Find the band edge energies of conduction, heavy hole, and light hole bands as a function of strain.

ii) The quantum well has a width of 5 nm. Find the photon energy corresponding to electron-heavy hole and electron-light hole transitions, respectively. Again, these should be functions of strain.

iii) Equate the energies of the two transitions and solve for the strain.

b) Find the *ratio* of the maximum gain for the two optical transitions. Please indicate clearly which transition has *higher* maximum possible gain (i.e., when population is fully inverted).

c) Assume the electron-heavy hole transition has TE polarization, and electron-light hole transition has TM polarization. If you use the strained quantum well materials for semiconductor optical amplifier, would the amplifier be "polarization insensitive" (i.e., equal gain for TE and TM polarization input light)?

d) If your answer in c) is No, please suggest one approach to make polarization-insensitive semiconductor optical amplifier? Your solution has to include the strained quantum well you solved in a) as *part* of the gain media.

Answer for Problem ___

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