EE 232	**<u>Midterm Examination-1</u>**	Fall 2006
10/10/2006	**EE 232 – Lightwave Devices**	Prof. Ming Wu

- If you need additional conditions to solve a problem, please write down your assumptions.

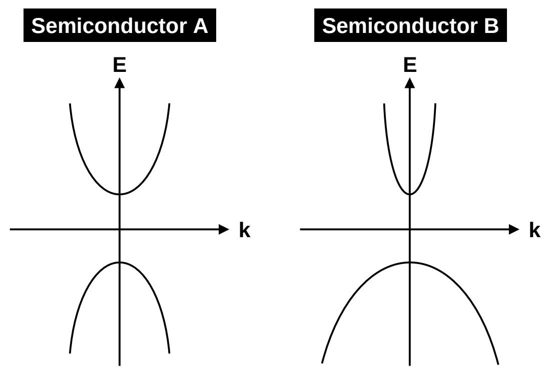
Global Parameters:

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

Optical matrix element:	$\lvert \hat{e}\cdot\vec{p}\rvert^2 = M_b^2 = (m_0/6)E_p$, and E_p = 24 eV
Bandgap energy:	E_g = 1 eV
Relative dielectric constant:	$\varepsilon_r = 9$
Refractive index:	$n_r = 3$

30 pts.

1. Consider two semiconductors with the following energy band diagrams:



$m_e^* = m_h^* = 0.2m_0$

$m_e^* = 0.1m_0$
$m_h^* = 0.4m_0$

Both semiconductors have the same bandgap energy (1 eV) and the same optical matrix element.

a) Which semiconductor has a larger absorption coefficient at a photon energy of 1.1 eV? Explain your answer (as quantitative as possible).

b) Mark the relative position of the quasi-Fermi levels (F_C and F_V) with reference to the conduction band minimum and valence band maximum for Semiconductor A when it is biased at <u>transparency</u> (i.e., net gain = 0).

c) Repeat b) for Semiconductor B.

d) If both semiconductors are forward biased such that the electron and hole concentrations are $N = P = 5\times10^{18}$ cm^{-3}, which semiconductor has a wider gain bandwidth? Explain your answer.

40 pts.

2. Consider a double heterostructure laser with the following parameters:

Optical gain: $g(N) = a \cdot (N - N_{tr})$, where $a = 10^{-16}$ cm^2, $N_{tr} = 10^{18}$ cm^{-3}, confinement factor Γ = 50%, intrinsic loss α_i = 10 cm^{-1}, thickness of the active layer = 0.1 μm, width of the laser = 1 μm, length of the laser = 500 μm, internal quantum efficiency η_i = 90%, laser wavelength = 1.24 μm, carrier lifetime = 1 nsec.

a) Find the threshold gain of the laser if both facets are uncoated (R = 30%).

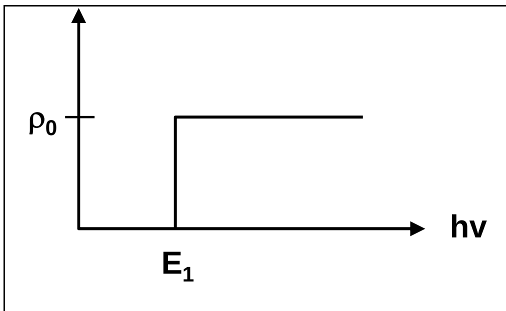
b) Find the threshold current and external quantum efficiency. Construct the L-I curve of the laser. Please be quantitative in your plot.

c) Find the output power (in mW) of the laser when it is biased at 200 mA.

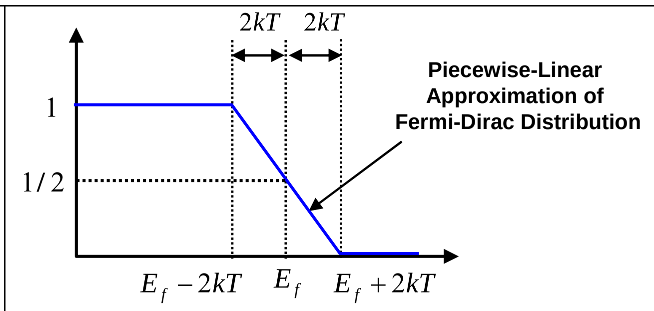
d) What is the total number of photons inside the laser cavity at 200 mA?

30 pts.

3. Consider a quantum well active media with a stepwise joint optical density of states shown below, where $\rho_0 = 10^{20}$ 1/(ev-cm^3) and E$_1$ = 1 eV. To simplify calculation, we use a piecewise-linear function to approximate the Fermi-Dirac distribution. At room temperature, $k_B T$ = 25 meV.



Joint optical density of state function



Piecewise-linear Fermi-Dirac distribution

a) Find the Fermi inversion function (i.e., inversion factor versus photon energy). You can express the function graphically with quantitative labels for all important numbers, or express it analytically by equations.

b) Find the peak gain as a function of the separation of quasi-Fermi levels.

c) Assume $m_c^* = m_h^*$, find the relation between the separation of quasi-Fermi levels and the corresponding carrier concentration.

d) Plot peak gain versus carrier concentration using the relation in c).