EE 232
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Final Exam
EE 232 – Lightwave Devices

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1. A tensile-strained quantum well has a heavy hole bandedge of -0.2 eV and a light hole bandedge of -0.1 eV. The effective masses of the well material are

Effective masses	Longitudinal	Transverse
Heavy Hole	$m_{hh}^{z} = 0.5m_0$	$m_{hh}^{t} = 0.05m_0$
Light Hole	$m_{lh}^{z} = 0.1m_0$	$m_{lh}^{t} = 0.2m_0$

Is it possible to adjust the quantum well width so that the TE and TM transitions have the same photon energy? If yes, find that width. You can use infinite barrier height to simplify calculation.

2. A double heterostructure (DH) edge-emitting laser has an intrinsic loss of 10 cm^{-1}, a confinement factor of 50%, and power reflectivity of 36.8% for the front facet (note $e^{-1} = 0.368$) and 100% for the back facet. The bandgap energy is 1.4 eV, and the effective refractive index is 3. The laser gain can be modeled as $g(N) = a(N - N_{tr})$ where $a = 10^{-16}$ cm^2 is the differential gain, $N_{tr} = 10^{18}$ cm^{-3} is the transparency carrier concentration. The current density is related to the carrier concentration by $J(N) = A \cdot N \cdot qd$ where $A = 10^9$ s^{-1}, q is the electron charge, and d = 0.1 μm is the thickness of the active layer. The laser is 1 μm wide and 100 μm long. Assume the electrical injection efficiency is 100%.
   a) Find the threshold gain and threshold current.
   b) Find the quantum efficiency of the laser in terms of both % and W/A.
   c) Construct the L-I curve (optical output power versus current) for the laser. Label the threshold current, I_{th}, and the current corresponding to 10 mW output power.

3. Consider a forward-biased quantum well laser with a quasi-Fermi levels of F_C and F_V for electrons and holes, respectively.
   a) Show the Fermi-Dirac distribution for electrons is $f_C = 1 - e^{-N/n_c}$ where N is electron concentration in the first subband. What is the expression for n_c? *[Hint: what is the general expression of electron concentration in the first subband of a quantum well?]*
   b) Show the Fermi-Dirac distribution for electrons $f_V = e^{-P/n_v}$ where P is the hole concentration. What is the expression for n_v?
   c) Using the results from a) and b), what is the equation for transparency carrier concentration?
   d) Compare two semiconductors: (A) $m_e^* = m_h^* = 0.1m_0$ and (B) $m_e^* = m_h^* = 1m_0$, what are the ratios of their transparency carrier concentration?
   e) What is the ratio of the optical gain for the two semiconductors in Part d) when the carrier concentrations in both semiconductors are equal to the n_c of semiconductor-B: $N = n_{c,B}$? Assume these two semiconductors have the same matrix element and photon transition energy.

4. Consider spontaneous emission in a bulk semiconductor (ignore the contributions from excitons). At low injection level, the spontaneous emission spectrum has a peak near, but above, the bandgap. Find the photon energy of the peak. Your answer should be *xx* meV above E_g. You can make reasonable approximation to simplify your calculation.