EE 232 | **Midterm Examination-1** | Fall 2015

4/13/2015 | **EE 232 – Lightwave Devices** | Prof. Ming Wu

1. A single quantum well edge-emitting laser has a cavity length of 100 μm, a width of 1 μm, and a confinement factor of 1%. The thickness of the quantum well is 10 nm. The front and back mirror reflectivity is 50% and 100%, respectively. The intrinsic loss of the cavity is 10 cm^{-1}. The wavelength of the laser is 1 μm, and the effective refractive index of the laser waveguide is 3. Assume a constant carrier lifetime of 1 ns.
   a) What is the threshold gain of the laser?
   b) What is the photon lifetime of the cavity?
   c) What is the optical Q (quality factor) of the cavity?
   d) What is the total quantum efficiency in % and slope efficiency in Watt/Amp?
   e) Use logarithmic gain model of $g(N) = g_0 \ln\left(\frac{N}{N_{tr}}\right)$, where $g_0 = 5000$ cm^{-1} and $N_{tr} = 10^{18}\ \text{cm}^{-3}$, find the threshold current of the laser (in mA).

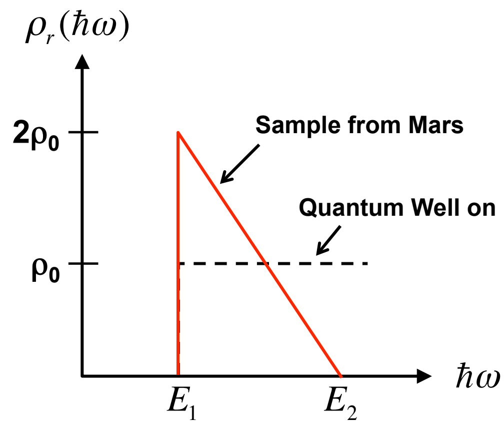
2. Consider a quantum well laser with a 10-nm-wide well and a semiconductor with an electron effective mass of 0.2 m_0 and a hole effective mass of 0.1 m_0, where m_0 is the free electron mass. Assume the holes have a single isotropic effective mass.
   a) Draw the energy band diagram (E-vs-k) of this semiconductor. Pay attention to the curvature of the conduction and valance bands.
   b) Superimpose the quasi-Fermi levels, F_C and F_V, on the energy band diagram in a) when the quantum well is biased at transparency, i.e., at Bernard-Duraffourg condition.
   c) Find the separation between E_C and F_C at transparency. (To simplify calculation, use linear approximation for exponential function: $e^{-x} \approx 1 - x$).
   d) Find the transparency carrier concentration of the quantum well laser. (For your convenience, the generic 2D density of states with free electron mass is $N_0^{2d} = \frac{m_0 k_B T}{\pi \hbar^2 L_Z} = 10^{19}\ \text{cm}^{-3}$ for $L_Z = 10\text{nm}$).

3. A quantum-well infrared photodetector (QWIP) consists of 10-nm-wide quantum wells. The electron and hole effective masses of the well material are 0.1 m_0 and 0.5 m_0 (assume for this problem the hole has only one isotropic effective mass).
   a) What is the peak absorption wavelength if the QWIP is N-doped?
   b) What is the minimum doping concentration to achieve maximum absorption?
   c) What is the peak absorption wavelength if the QWIP is P-doped?
   d) What is the *ratio* of the peak absorptions in N-type and P-type QWIPs (at their respective peak absorption wavelengths)? Assume the refractive indices are the same for all wavelengths.

4. On a mission to Mars, astronauts brought back a sample of semiconductor that exhibits a "triangular-shaped" joint optical density of states function, which is plotted below along with that of a quantum well semiconductor from Earth. These two semiconductors happen to have the same effective bandgap energy.

a) Which semiconductor (Mars sample or Earth quantum well) has higher maximum gain when fully inverted? Explain why.

b) Find the *ratio* of the *peak* optical gains of these two semiconductors when the separation of quasi-Fermi levels is $k_B T$ above the bandgap.



$$E_2 - E_1 >> k_B T$$