HW #5
Due Nov. 6 (Tuesday) in class

1. In this problem, you will analyze a double heterostructure (DH) waveguide. Consider the same DH that you calculated in HW#4: P-$Al_{0.4}Ga_{0.6}As$ / i-GaAs / N-$Al_{0.4}Ga_{0.6}As$ with $N_a = 3x10^{17}$ cm^{-3} and $N_d = 3x10^{17}$ cm^{-3}. The GaAs is intrinsic. The thickness of the GaAs layer is 0.1µm. Use the material properties listed in the Table below.

	Unit	**GaAs**	**$Al_xGa_{1-x}As$, 0<x<0.45**
Bandgap Energy	eV	1.424	1.424 + 1.247x
Electron Effective Mass	m_0	0.067	0.067 + 0.083x
Hole Effective Mass	m_0	0.5	0.5 + 0.29x
Dielectric Constant	ε_0	13.1	13.1 – 3x
Conduction Band Discontinuity	%	-	ΔE_C ~ 67% ΔE_g
Valence Band Discontinuity	%	-	ΔE_V ~ 33% ΔE_g

The conduction and valence band density of states are

$$N_C = 2\left(\frac{\pi m_e^* k_B T}{2\pi^2\hbar^2}\right)^{3/2} = 2.5\times10^{19}\left(\frac{m_e^*}{m_0}\cdot\frac{T}{300}\right)^{3/2}$$

$$N_V = 2\left(\frac{\pi m_h^* k_B T}{2\pi^2\hbar^2}\right)^{3/2} = 2.5\times10^{19}\left(\frac{m_h^*}{m_0}\cdot\frac{T}{300}\right)^{3/2}$$

a. Find the index profile of the DH. Assign origin at the center of the core layer in DH.
b. Use the transcendental equation in class, solve the effective refractive index of the TE mode numerically.
c. Plot the electric field distribution in the DH.
d. Find the confinement factor. Compare the value calculated numerically from the electric field distribution with the approximate expression given in class.
e. Is this a single mode waveguide?

2. Consider a DH laser using the same waveguide as the one in Problem 1. The DH is now forward biased to provide gain. The laser is 300 µm long and 1 µm wide. Both mirrors are cleaved facet with a power reflectivity of 30%. The residue loss (internal loss) is 10 cm^{-1}. Assume the internal quantum efficiency is 90%, and the carrier lifetime is 1 ns (a constant value, which is an approximation). Use the following linear gain approximation for the GaAs active layer:

$$g = a\cdot(N - N_{tr}) \quad \text{where } a = 10^{-16}\,cm^2 \quad \text{and } N_{tr} = 2\times10^{18}\,cm^{-3}$$

Note that you need to multiply the gain with the confinement factor to get “modal gain”.

a. Find the threshold gain of the laser, and its threshold current.
b. Construct the L-I (light-vs-current) curve, with light output power in mW and current in mA. What is the external quantum efficiency of the laser (in %)?
c. What is the lasing wavelength? (Hint: assume lasing energy is at bandgap energy0

d. Ignore the material dispersion, find the mode spacing of this laser (in wavelength, with unit of nm).

3. Now consider a single quantum well (QW) laser. The quantum well is embedded in the same DH as in Problem 1. The QW is 10 nm thick. Assume the electric field profile is not affected by the addition of QW. Use the same parameters as in Problem 2 unless specified otherwise here. The internal loss of the QW is lower, assume that to be 2 cm^{-1}. Assume the lasing wavelength of the QW laser is at 980nm. The gain curve of QW laser is better approximated by a logarithmic relationship:

$$g = g_0 \ln\left(\frac{N}{N_{tr}}\right) \quad \text{where } g_0 = 2400 cm^{-1} \quad \text{and } N_{tr} = 2\times10^{18} cm^{-3}$$

a. Find the confinement factor of the quantum well active region. (Hint: you can approximate the confinement factor by the ratio of the QW thickness to the full-width-at-half-maximum (FWHM) of the field profile in Problem 1).

b. Find the threshold gain of the QW laser. Is this higher or lower than the maximum available gain of the QW? If it is lower, than the laser will lase in the first quantized level. If not, it will lase in higher quantized levels).

c. Use the logarithmic gain curve above, find the threshold current of the QW laser.

d. Find the external quantum efficiency of the QW laser.