University of California, Santa Barbara Spring 2011
Department of ECE

ECE228B
Fiber Optic Components and Systems
Homework #2 Solutions

Problem 1:
Consider a 1.55 μm InGaAsP /InP bulk laser 400 μm in length with confinement factor Γ=.05, internal quantum efficiency of 80% and internal loss of 10 cm-1. cleaved facets, 0.2 mm thick active region, 0.1 ps lifetime for the linewidth calculation.

a. Plot the gain versus wavelength

b. Plot the peak gain versus carrier density

c. What is the mirror loss?

$$\alpha_m = \frac{1}{L}\ln\left(\frac{1}{R}\right) = \frac{1}{.04cm}\ln\left(\frac{1}{.32}\right) = 28.46\ \text{cm}^{-1}$$

d. What is the threshold modal gain?

$$\Gamma g_{th} = \alpha_{Total}$$
$$\alpha_{Total} = \alpha_i + \alpha_m = 10.00\ \text{cm}^{-1} + 28.46\ \text{cm}^{-1} = 38.46\ \text{cm}^{-1}$$
$$g_{th} = \frac{\alpha_{Total}}{\Gamma} = \frac{38.46\ \text{cm}^{-1}}{.05} = 769.2\text{cm}^{-1}$$

e. What is the differential quantum efficiency?

$$\eta = \frac{\eta_i \alpha_m}{\alpha_t} = \frac{(0.8)28.46}{38.46} = 0.59$$

f. What is the axial mode spacing?

Assume $N_g = 3.5$

$$\Delta\lambda = \frac{\lambda^2}{2n_g L} = \frac{(1.55)^2}{(2)(3.5)(400x10^{-4})} = 0.85nm$$

Problem 2:

Consider a DFB laser with a 400 μm long grating, an effective mode index 3.5 and a grating corrugation period 0.22 μm. Calculate the symmetric modes (wavelengths) that the laser will operate at assuming no λ/4 phase shift in the grating. What will be the output wavelength if the grating is fabricated with a λ/4 phase shift in the grating?

For DFB with $\lambda/4$ shift, single mode will operate at $\Delta\beta L = 0$, which gives

$\lambda = 2 n_{eff} \Lambda = 2 \times 3.5 \times 0.22\ \mu m = 1.54\ \mu m$.

For DFB without $\lambda/4$ shift, there will be two modes, and $\Delta\beta L$ depends on κL.

If $\kappa L = 1$, then $\Delta\beta L = \pm 2.5$, $\Delta\beta = \pm \frac{2.5}{400 \mu m} = \pm 0.0063\ \mu m^{-1}$.

$\beta = \beta_0 \pm \Delta\beta = \frac{2\pi}{1.54 \mu m} \pm 0.0063\ \mu m^{-1} = 4.0737\ \mu m^{-1},\ 4.0863\ \mu m^{-1}$.

$\lambda = \frac{2\pi}{\beta} = 1.5424\ \mu m,\ 1.5376\ \mu m$.

Problem 3:

Consider a ridge waveguide bulk InGaAsP /InP bulk laser with internal quantum efficiency of 80% and internal loss of 10 cm-1, cleaved facets, 0.2 μm thick 1.55 μm composition active region, differential gain 2000 cm-1 and transparency carrier density of 2.8 x 1018 cm-3. a) What is the transverse confinement factor? (use na=3.5, nc=3.17) B) How many transverse modes exist? C) Assuming the structure below with a 200 μm cavity length, calculate the lateral confinement factor and threshold current as a function of the width of the waveguide. D) For a 2μm waveguide width, plot the threshold current versus cavity length.

$\eta_i = 80\%$, $\langle\alpha_i\rangle = 10\ cm^{-1}$, $d = 0.2\ \mu m$

$g_0 = 2000\ cm^{-1}$, $N_{tr} = 2.8 \times 10^{18}\ cm^{-3}$.

a) $V = k_0 d \sqrt{n_a^2 - n_c^2} = \frac{2\pi}{1.55 \mu m} \times 0.2\ \mu m \times \sqrt{3.5^2 - 3.17^2} = 1.20$

$\Gamma_x = \frac{V^2}{2+V^2} = 0.42$

b) for $V = 1.20$

there're only two modes, TE_0 and TM_0.

c) $W = 2\,\mu m$

$$V_\ell = k_0 W \sqrt{n_a^2 - n_c^2} = \frac{2\pi}{1.55\,\mu m} \times 2\,\mu m \times \sqrt{3.5^2 - 3.17^2} = \cancel{1.2\times 10}\ 12.0$$

$$\Gamma_y = \frac{V_\ell^2}{2 + V_\ell^2} = 0.99$$

$$I_{th} = \frac{B N_{th}^2 qV}{\eta_i}$$

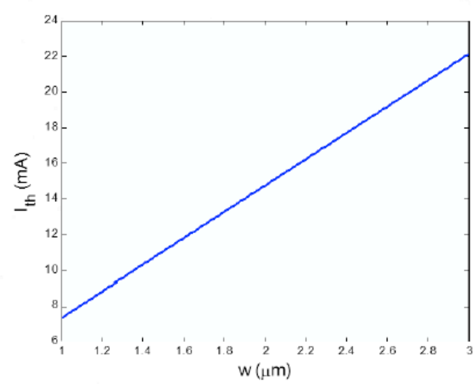
$$N_{th} = N_{tr}\, e^{g_{th}/g_0} = N_{tr}\, e^{(\langle\alpha_i\rangle + \alpha_m)/\Gamma g_0}$$

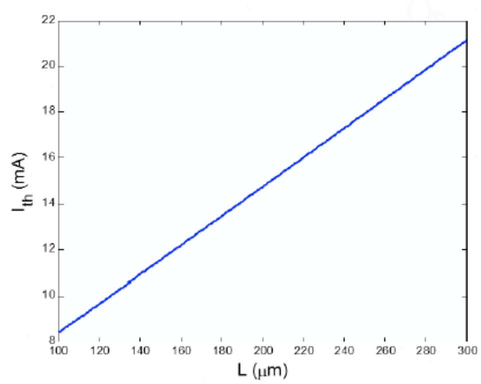
$$\Rightarrow I_{th} = \frac{qVB N_{tr}^2}{\eta_i} e^{2(\langle\alpha_i\rangle + \alpha_m)/\Gamma g_0}$$

$$I_{th} = \frac{q\, dWL\, B N_{tr}^2}{\eta_i} e^{2(\langle\alpha_i\rangle + \alpha_m)/\Gamma g_0}$$

in which $B \sim 10^{-10}\ cm^3/s$, $d = 0.2\,\mu m$, $L = 200\,\mu m$, $\eta_i = 0.8$, $N_{tr} = 2.8\times 10^{18}\ cm^{-3}$, $\langle\alpha_i\rangle = 10\ cm^{-1}$, $\alpha_m = \frac{1}{L}\ln\frac{1}{R}$, $R = 0.32$, $\Gamma = \Gamma_x \Gamma_y \Gamma_z = 0.42$, $g_0 = 2000\ cm^{-1}$.

d) Same equation as in c), just make L the variable instead of W.





Problem 4:

Calculate and plot the wavelength shift vs. tuning current for a tunable Bragg reflector that operates based on the free-carrier plasma effect. Assume λ_g = 1300nm InGaAsP tuning region operated at 1500 nm, $\beta_{pl} = -1.3 \times 10^{-20}\ cm^3$, active region with L = 400μm, d = 0.3μm, w = 2 μm and confinement factor $\Gamma_t = 0.3$. For the material assume an infinite spontaneous recombination time constant, bimolecular recombination constant $B = 10^{-10}\ cm^3/s$ and Auger recombination constant $C = 3 \times 10^{-29}\ cm^6/s$.

Active Volume $V = 400\mu m \cdot 2\mu m \cdot 0.3\mu m$

$= 2.4 \times 10^{-10}\ cm^3$

Current vs. carrier concentration is obtained from rate eqn.

$$\frac{I_g}{qV} = BN^2 + CN^3$$

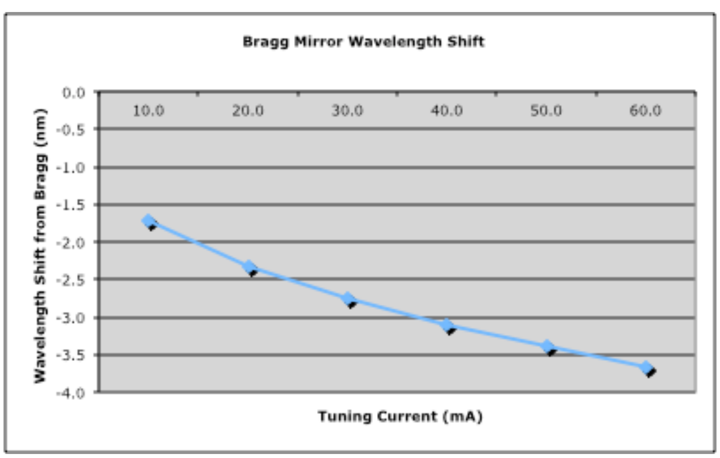
$$I_g = (1.6022\times10^{-19})(2.4\times10^{-10}) \cdot \left[10^{-10}N^2 + 3\times10^{-29}N^3\right]$$

Solving for N for I_g from 0mA to 100mA

I_g (mA)	N	$\Delta\lambda$ (nm)
10	1.35×10^{18}	-1.7
20	1.83×10^{18}	-2.3
30	2.17×10^{18}	-2.8
40	2.45×10^{18}	-2.8
50	2.68×10^{18}	-3.1
60	2.89×10^{18}	-3.7

Using $\Delta\lambda = \dfrac{\beta_{pl}\lambda_g \Gamma_t N}{n_{eff}} = \dfrac{(-1.3\times10^{-20})(1300nm)(0.3)N}{4}$

1.35E+18	-1.30E-20	1.30E-06	3.00E-01	4.00E+00	10.0	-1.7
1.83E+18	-1.30E-20	1.30E-06	3.00E-01	4.00E+00	20.0	-2.3
2.17E+18	-1.30E-20	1.30E-06	3.00E-01	4.00E+00	30.0	-2.8
2.45E+18	-1.30E-20	1.30E-06	3.00E-01	4.00E+00	40.0	-3.1
2.68E+18	-1.30E-20	1.30E-06	3.00E-01	4.00E+00	50.0	-3.4
2.89E+18	-1.30E-20	1.30E-06	3.00E-01	4.00E+00	60.0	-3.7

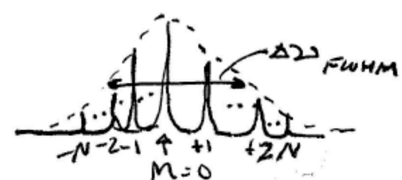


Problem 5:

For a mode-locked laser, assume the envelopes are given by the expression below and that the phases are equal. υ_m is the frequency spacing of mode m, where m=0 coincides with the central frequency of the atomic lineshape. Determine expressions for the mean power, peak power and pulse width (defined at the full-width half-maximum FWHM).

$$A_q = \sqrt{P}\,\frac{\left(\Delta\nu/2\right)^2}{\left(m\upsilon_m\right)^2 + \left(\Delta\nu/2\right)^2}, \text{ m} = -\infty,\ldots,+\infty \text{ p}$$

Assume the gain curve and modes look something as follows



Total # modes
$M = 2N+1$

pulse width : The gain line shape has a FWHM of $\Delta\nu$, so

$$\tau_{pulse} \approx \frac{1}{\Delta\nu}$$

number of modes is given by mode separation υ_m and linewidth

$$M = \frac{\Delta\nu}{\upsilon_m}$$

Mean intensity

$$\bar{I} = M|A|^2 = MP$$

peak intensity

$$I_p = M\bar{I} = M^2 P$$