(30 pts)

1. A cleaved-facet GaInAsP/InP SCH-MQW Fabry-Perot laser is constructed for lasing at 1550 nm. The MQW material consists of four-7 nm wide InGaAs lattice-matched wells and three-7 nm wide 1.25 μm-Q material barriers as characterized in Fig. 4.25. The rest of the SCH waveguide consists of this same 1.25 μm-Q barrier material with an index of 3.37. Its total thickness is 350 nm. InP with an index of 3.17 clads the slab waveguide top and bottom. The injection efficiency is 0.7 and the average modal loss is 10 cm^{-1}. Neglect lateral effects on current density and effective index—assume a lateral width of 3 μm if necessary.

(a) Using a perturbation approach (calc three-layer guide and then add MQW) determine the effective modal index of the waveguide?

(b) For a length of 500 μm, what is the threshold modal gain?

(c) What is the threshold current density at the terminals for this length?

(70 pts)

2. A 1550 nm directional coupler is formed in InGaAsP/InP system, as illustrated in Figure 2. The waveguide spacing, *s* is 3 μm, the same as the widths of the waveguides. The waveguides have a lateral effective index step of 0.015. Neglect the coupling between the waveguides that occurs beyond the region indicated by the Figure 2.

5 (a) Determine the effective index of the waveguides

5 (b) Determine the lateral k_y and γ_x

10 (c) Determine the coupling constant, κ, between the two waveguides in the coupling region, and the coupling length L_{c1}

5 (d) What length, L_{coup} should be chosen for a 3dB coupler: 50% of the input power to each output?

Now we have fabricated the structure, using the value for L_{coup} from part (d). Due to the photoresist reflow, the waveguide widths ended up being 3.3 μm, leaving a 2.7 μm gap between the waveguides.

10 (e) What will the new coupling constant κ be?

5 (f) For case (e), what will the output power ratio between the top and the bottom waveguides be?

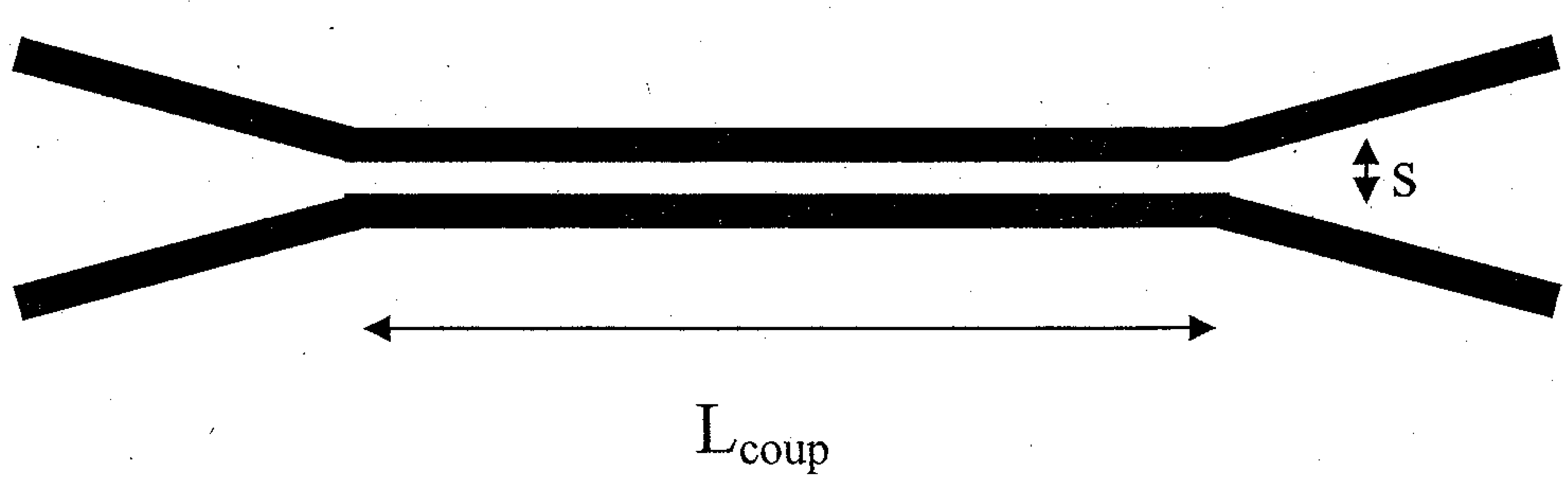
Finally, in trying to fix our fabrication process, we ended up with the output waveguide wider that the input waveguide (whose width ended up being 3 μm precisely), so that $\beta_2 - \beta_1 = 0.8(\pi/L_{c1})$.

10 (g) What is the effective index of the output waveguide?

10 (h) What is the output power ratio between the top and the bottom waveguides?

We have decided to use a general interference based MMI, whose width is 9 um, and the access waveguides are 3 um, using the same waveguide structure.

10 (i) What is the optimum length of this 3dB coupler?



(1)

a) $\bar{n}_{SCH} = ?$ $V = \frac{2\pi}{\lambda} \cdot d \sqrt{n_2^2 - n_1^2} = \frac{2\pi}{1.55} \cdot 0.35 \sqrt{3.37 - 3.17} =$

$= 1.6226$

$$b = 1 - \frac{\ln\left(\frac{V^2}{2} + 1\right)}{V^2/2} = 0.3619$$

$$\bar{n}_{SCH} = \sqrt{b n_2^2 + (1-b) n_{InP}^2} = 3.244$$

$$\Delta\bar{n} = \frac{n_A \cdot \Delta n_A}{\bar{n}} \; \frac{\iint_A |U_1|^2 dA \approx U_0^2 \, d_{QW} \cdot \#wells}{\iint |U_1|^2 dA \cong U_0^2 \frac{d_{eff}}{2}}$$

$$k_x = \frac{2\pi}{\lambda} \sqrt{3.37^2 - \bar{n}^2} = 3.70$$

$$\gamma_x = \frac{2\pi}{\lambda} \sqrt{3.244^2 - 3.17^2} = 2.79 \qquad d_{eff} = d + \frac{2}{\gamma_x} = 1.067 \mu m$$

$$\Delta\bar{n} = \frac{3.55 \cdot 0.18}{3.2438} \cdot \frac{7 \cdot 4.2 \cdot 10^{-3}}{1.067} = 0.0103$$

$$\boxed{\bar{n}_{QW} = 3.254}$$

b) $\Gamma g_{th} = \langle\alpha_i\rangle + \alpha_m = 10\ cm^{-1} + \frac{1}{500 \cdot 10^{-4}} \ln \frac{1}{0.32} = 32.8\ cm^{-1}$

c) $\Delta\bar{n} = \Gamma \cdot \Delta n_A \Rightarrow \Gamma = \frac{\Delta\bar{n}}{\Delta n_A} = \frac{0.0103}{0.18} = 0.0572$

from 4.25, $g = 583 \ln \frac{J}{81\ A/cm^2}\ cm^{-1} \Rightarrow$

$$J = 81\ A/cm^2 \cdot e^{\frac{g}{583\ cm^{-1}}} = 81\ A/cm^2 \cdot e^{\frac{578.64}{583}} = 218.5 \frac{A}{cm^2}$$

$$J_{total} = \frac{4 \cdot J}{\eta_i} = 1248.77\ A/cm^2$$

(2)

2/2

a) $V = \frac{2\pi}{1.55\mu m}(3\mu m)\sqrt{3.185^2 - 3.17^2} = 3.754$

$b = 1 - \frac{\ln\left(\frac{V^2}{2}+1\right)}{\frac{V^2}{2}} = 0.704 \Rightarrow \bar{n} = 3.1806$

5

b) $k_y = \frac{2\pi}{\lambda}\sqrt{3.185^2 - 3.1806^2} = 0.68077\,\mu m^{-1}$

5

$\varkappa_y = \frac{2\pi}{\lambda}\sqrt{3.1806^2 - 3.17^2} = 1.050\,\mu m^{-1}$

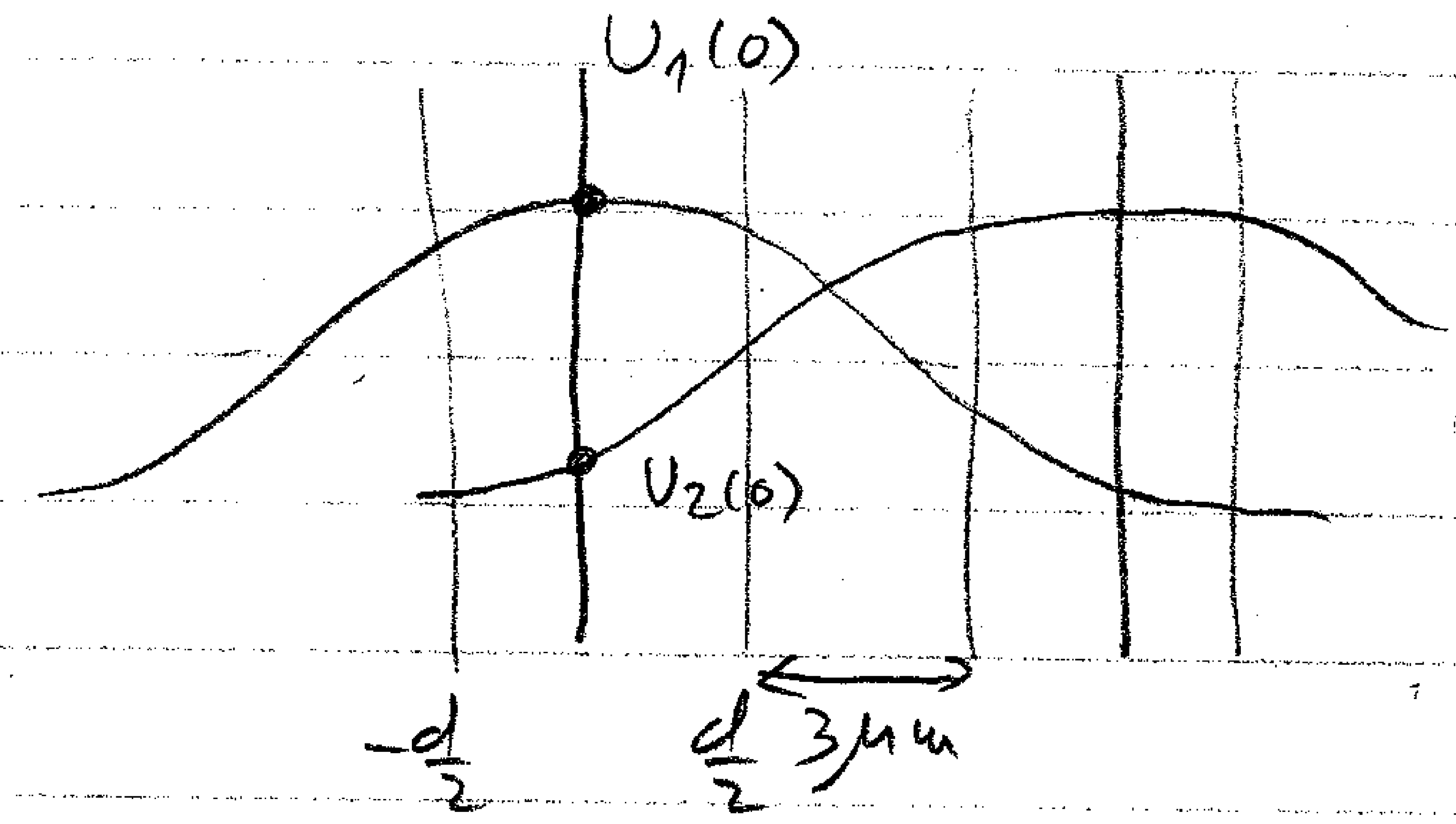
c) $\varkappa$ and $L_c = ?$

10

$\varkappa_{12} = \varkappa_{21} = \frac{\pi}{\bar{n}\lambda}\frac{\int_{G_1} \Delta\varepsilon\, U_1^* U_2\, dA}{\int |U_1|^2 dA}$

$\Delta\varepsilon = n_2^2 - n_1^2 = 0.095$

$\varkappa_{12} = \frac{\pi \cdot \Delta\varepsilon}{\bar{n}\cdot\lambda} \cdot \Gamma \frac{U_2(0)}{U_1(0)}$



$\Gamma = \frac{V^2}{2+V^2} = 0.876$

$U_2(0) = U_{20}\cos\left(k_y \frac{d}{2}\right) e^{-\varkappa_y\left(3\mu m + \frac{d}{2}\right)} =$

$= U_{20} \cdot 0.00463 = U_1(0) \cdot 0.00463$

$\varkappa_{12} = \frac{\pi \cdot \Delta\varepsilon}{\bar{n}\cdot\lambda} \cdot 0.876 \cdot 0.00463 = 2.46\,cm^{-1}$

$L_c = \frac{\pi}{2\varkappa} = 0.637\ cm$

d) $L_{3dB} = ?$

5

$\left|\frac{a_2(L)}{a_1(0)}\right| = 0.5 = \sin^2 \varkappa L \Rightarrow L\cdot\varkappa = \frac{\pi}{4} \Rightarrow L = 0.319\ cm$

② 2/2

e) same procedure as in part c

10

$V' = V \cdot \frac{3.3}{3} = 4.13$

$b' = 0.736 \qquad \bar{n}' = 3.181$

$k_y' = 0.643\ \mu m^{-1}$

$\gamma_y' = 1.073\ \mu m^{-1}$

$$\kappa = \frac{\pi \cdot \Delta\varepsilon}{\bar{n} \cdot \lambda} \cdot \Gamma' \frac{U_2(0)}{U_1(0)} \qquad \Gamma' = 0.895$$

$\kappa = 2.484\ cm^{-1}$

f) $\left|\frac{a_2(L)}{a_1(0)}\right|^2 = \sin^2 \kappa L = \sin^2(2.484 \cdot 0.319) = 0.5068$

5

g) $\beta_2 - \beta_1 = \frac{2\pi}{\lambda}(\bar{n}_2 - \bar{n}_1) = 0.8 \frac{\pi}{L_{c1}} \Rightarrow$

10

$\bar{n}_2 = \frac{\lambda}{L_{c1}} \cdot \frac{1}{2} \cdot 0.8 + 3.181 = 3.1811$

h) from the book, figure 6.12

10

$a_2 \cong 0.45 \qquad a_1 = 0.55 \Rightarrow \quad \left|\frac{a_1}{a_2}\right|^{\cancel{2}} = \left|\frac{0.55}{0.45}\right|^{\cancel{2}} = \cancel{1.5}\ 1.222$

i) 10 $L = \frac{1}{2} 3 L_\pi \qquad L_\pi = \frac{\pi}{\beta_1 - \beta_0}$

$V = \frac{2\pi}{\lambda}(9\mu m)\sqrt{3.185^2 - 3.17^2} = 11.264$

$m=0: \quad b = 1 - \frac{\ln\left(\frac{V^2}{2}+1\right)}{\frac{V^2}{2}} = 0.934$

$\bar{n}_0 = 3.184$

$m=1:$ use Fig A3.2 $\quad b = 0.77 \Rightarrow \bar{n}_1 = 3.181$

$L_\pi = \frac{\lambda}{\ldots} = 315\ \mu m \qquad L_{3dB} \cong 472 \ldots$