MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering
And Computer Science

6.977 Semiconductor Optoelectronics – Fall 2002

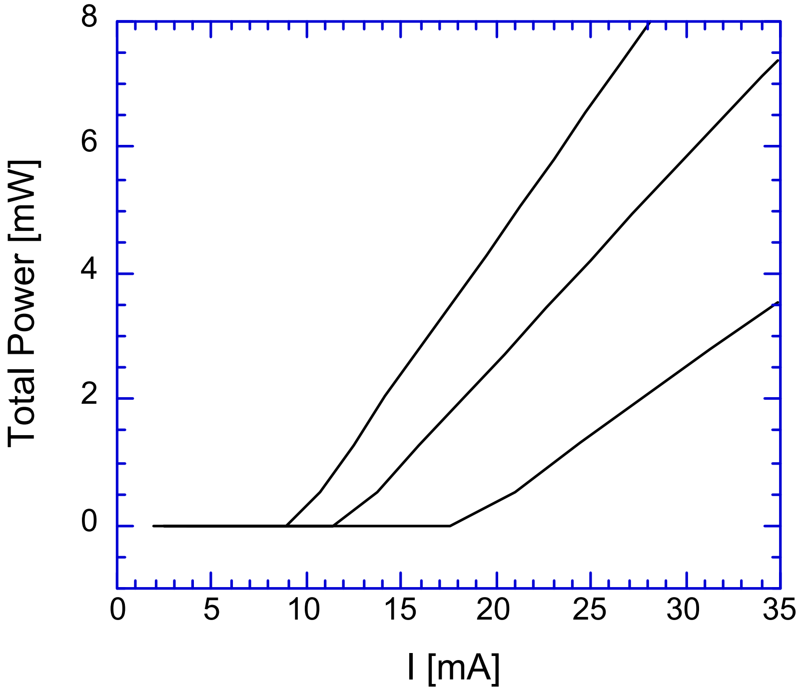
Problem Set 6 – Semiconductor Lasers

Problem #1 *This problem explores the relationship between the cavity and gain parameters and the laser L-I curves*. The following figure shows the L-I curves for a set of cleaved mirror InP Fabry-Perot lasers. The lasers are all fabricated from the same active material. The lasers all emit at a free-space wavelength of 1.55 µm, have a confinement factor of 30%, an effective index of n=3.2, a device width of 2µm, an active region thickness of 200 nm, and a bimolecular recombination coefficient of $B=10^{-10}$ cm^3/s. The lasers are cleaved into three different cavity lengths - 150 µm, 300 µm, and 600 µm.

a) Estimate the internal waveguide loss, α_i, and injection efficiency, η_i,

b) Calculate the transparency carrier density (N_o) and differential gain (a). Since these lasers have bulk active regions assume that the gain curve has the following carrier density dependence:

$$g(N) = a(N - N_o)\,.$$



Problem #2 *This problem relates the spectral properties of a Fabry-Perot laser to the properties of the laser active region.*. The gain of the active region alters the optical spectrum in a Fabry-Perot resonator. Extracting the gain from the measured (below threshold) optical spectrum is known as the Hakki-Paoli method. This problem develops the theory and applies it to a sample spectrum for a resonator containing a gain medium.

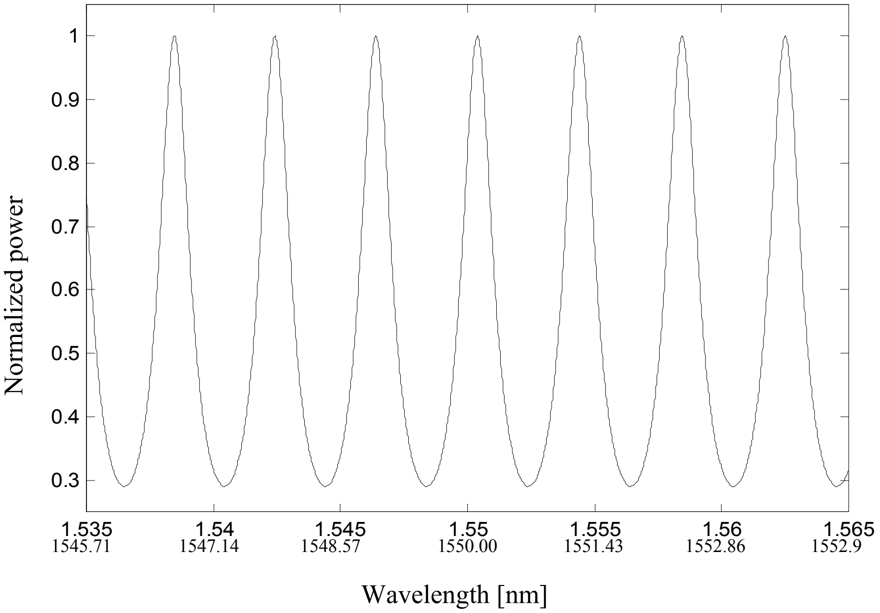
a. Show that the net absorption in the laser resonator can be related to the maximum (P_{max}) and minimum (P_{min}) amplitudes in the Fabry-Perot spectrum. The final expression should have the form:

$$\alpha_i - \Gamma g = \frac{1}{L}\ln\left(\frac{\sqrt{P_{\max}}+\sqrt{P_{\min}}}{\sqrt{P_{\max}}-\sqrt{P_{\min}}}\right) + \frac{1}{2L}\ln\left(R_1 R_2\right),$$

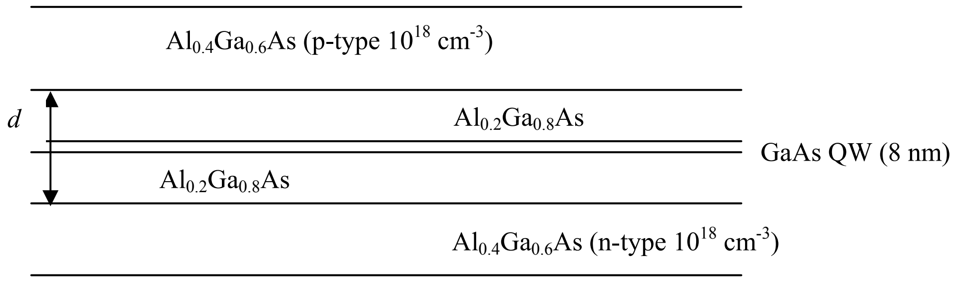
where, L is the length of the laser cavity, R_1 and R_2 are the mirror reflectivities, α_i is the internal loss per unit length and Γg is the modal gain per unit length.

b. Given the location and magnitude of the minima and maxima in the optical spectrum shown below, determine the modal gain (Γg). Use a cavity length of 300 μm, R_1=R_2=0.3 and α_i=20 cm^{-1}.

c. From the data, determine the group index.



Problem #3 *This problem uses the numerical algorithms from problem set 2 to design a low-threshold current laser.* Consider a quantum well laser that is fabricated in the $Al_xGa_{1-x}As$ material system. The quantum wells are fabricated from 8 nm of GaAs – so that the lasing wavelength will be approximately 850 nm. The core of the waveguide region consists of a slab of $Al_{0.2}Ga_{0.8}As$ that has a thickness (*d*). The cladding of the waveguide are semi-infinite slabs of $Al_{0.4}Ga_{0.6}As$ that are doped p-type on one side and n-type on the other.



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a. Assuming a symmetric waveguide with a thickness (*d*=0.4 μm), calculate the overlap of the lowest order mode with the quantum well and with the doped cladding regions.

b. Given that the optical loss in p-type $Al_{0.4}Ga_{0.6}As$ (p-type 10^{18} cm^{-3}) is 10 cm^{-1} and the optical loss in n-type $Al_{0.4}Ga_{0.6}As$ (n-type 10^{18} cm^{-3}) is 1 cm^{-1}, calculate the threshold gain for a cleaved facet laser with a cavity length *L*=300 μm. Again use a waveguide thickness of *d*=0.4 μm.

c. Determine the threshold current density if the only recombination process below threshold is biomolecular recombinatioin $R_{sp} = BNP \approx BN^2$, where $B=10^{-10}$ cm^3/s. The gain as a function of carrier density for the GaAs quantum well varies as:

$$g(N) = g_o \log(N/N_o)\text{, where } g_o = 2400 \text{ cm}^{-1} \text{ and } N_o = 2.6\text{x}10^{18} \text{ cm}^{-3}.$$

d. Determine the waveguide core thickness (*d*) that minimizes the threshold current density. Account for the overlap with the quantum well and with the lossy doped material.

Problem #4 *The purpose of this problem is to explore the optical and electrical properties of a semiconductor laser diode.* Consider again the laser structure in Problem #3 (a-c). Use the same gain curve *g(N),* recombination rate and use a waveguide thickness of *d*=0.4 μm. Also use a $\beta=10^{-6}$.

a. From the laser rate equations, derive expressions for the steady-state photon density and current density as a function of the carrier density.

b. Plot the carrier density as a function of the injected current density. Again, make sure to sweep the current density through threshold.

c. Plot the power output from one facet of the laser as a function of the injected current density. Make sure to sweep the current across the threshold point calculated in part (c) of Problem #3.