ECE 4300, Fall Semester 2016
Lasers and Optoelectronics

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Final Exam

Please give answers in analytical formulae before plugging in numerical values.
You have **120 minutes**, use them wisely. Present your solutions *neatly*. Show the relevant steps, so that partial points can be awarded. BOX your final answers where applicable. Draw figures wherever necessary. Write your name, email address on the cover of your workbook.

Problem 1 (10 Short Questions), [30 Points]

a) What is a photon ? [2 points]

b) Estimate the number of photons incident every second on a $A = 1 \times 1$ m^2 area solar panel if the electric field amplitude of light on a sunny day is $E_0 = 1000$ V/m. Assume all photons are of wavelength $\lambda_0 \sim 500$ nm, and the impedance of free space is $\eta_0 = 377\ \Omega$. [4 points]

c) What is the origin of optical gain? Explain with figures. [3 points]

d) What are the major ingredients of a laser? Explain with figures. [4 points]

e) If a laser is oscillating in multiple modes, how would you make it single-mode? [2 points]

f) What limits the maximum output power in the continuous-wave (CW) operation any laser? Give typical estimates of typical CW output powers of a table top laser, and a semiconductor laser. [3 points]

g) What is the reason for gain saturation in a laser? [2 points]

h) What is a Q-switched laser? How much higher peak power can a Q-switched laser provide compared to its CW laser counterpart? Give a rough estimate. [4 points]

i) What is a mode-locked laser? What is the time interval between two mode-locked laser pulses? How short can the mode-locked laser pulse duration be? [4 points]

j) Why are semiconductor lasers considered so revolutionary compared to the other forms of lasers? [2 points]

[Continued...]

Problem 2 (Gain in a Saturated Optical Amplifier) [20 Points]

Consider a homogeneously broadened optical amplifier of length $l_g = 10$ cm with a saturation optical intensity $I_s = 1$ W/cm^2 and cross-section $\sigma = 10^{-19}$ cm^2. By measurements, it is found that an input intensity $I(z = 0) = 0.1$ mW/cm^2 produces an output intensity $I(z = l_g) = 10$ mW/cm^2.

a) What is the small signal gain coefficient γ_0 of the optical amplifier?

b) What is the inversion $N_2 - N_1$ necessary to maintain this gain?

c) What is the input intensity at which the net optical gain is $\frac{I(z=l_g)}{I(z=0)} = 5$?

Problem 3 (A Ring Laser) [15 Points]

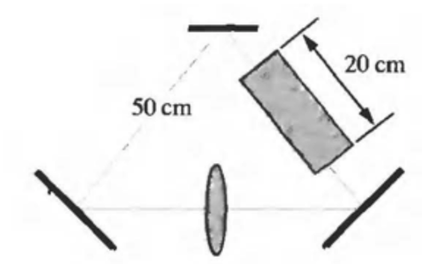

Figure 1: Ring laser geometry for Problem 3.

Consider the laser shown above. The gain medium is inhomogeneously broadened, assumed here to be a Lorentzian line shape with $\Delta\nu = 3$ GHz, with a stimulated emission cross-section $\sigma = 10^{-14}$ cm^2 at line center. In the passive cavity, 97.5 % of the photons survive a round trip.

a) What is the photon lifetime?

b) What should be the population inversion be bring this laser to threshold?

c) If the pumping established a small-signal gain coefficient which is 5 times the threshold value, how many $TEM_{0,0}$ modes would be above threshold?

Problem 4 (Oscillating Modes in a Semiconductor Laser Diode) [10 Points]

By injecting current into an InGaAsP laser diode bar of a lossless resonator length $d = 250$ μm, bandgap energy $E_g = 0.91$ eV, and refractive index $n = 3.5$, the quasi Fermi levels are split to $F_n - F_p = 0.96$ eV. How many longitudinal modes can oscillate?

[Contd...]

Problem 5 (A Semiconductor Double-Heterostructure Laser Diode) [25 Points]

Consider an edge-emitting AlGaAs/GaAs/AlGaAs semiconductor double-heterostructure laser diode. The cavity length is $L_z = 500$ μm, and the GaAs layer thickness is $L_x = 0.2$ μm. The width of the electrical contact is $L_y = 50$ μm. The cavity facets have reflectivities $R_1 = R_2 = 0.3$, and the loss coefficient in the active region is $\alpha = 5$ cm^{-1}.

a) Make a sketch of the laser diode, the electrical contact, and indicate the current flow.

b) Find the threshold gain coefficient γ_{th} required to make the device lase.

c) Write the expression for the gain coefficient and sketch it for various current injection levels.

d) Show from the expression of the gain coefficient that the condition for gain for a semiconductor is $F_n - F_p = h\nu \geq E_g$, where E_g is the bandgap of the semiconductor.

e) Assuming the inversion carrier density to be $n_{th} = 10^{18}/\text{cm}^3$ and lifetime $\tau = 0.1$ ns, find the threshold injection current I_{th}.

f) How is the optical mode guided in such an edge-emitting laser?