ELEC-E3210 Optoelectronics **Jan 31, 2019**

Exercise 3: Lasers II

1. Let's consider atoms with three energy levels 0, 1, and 2. A system of such atoms is pumped with an outside energy source (e.g. electric current, flashlight or another laser) that lifts atoms from energy level 0 to level 2 with a rate P_2. The atoms relax from level 2 via level 1 to the ground state. The transition rates are governed by the respective lifetimes τ_2 and τ_1. Assume, that the population at level 0 is so large that pumping does not affect it.
   a) Write down the rate equations $\frac{\partial N_1}{\partial t}$ and $\frac{\partial N_2}{\partial t}$ for states 1 and 2.
   b) Give the expressions for populations N_1 and N_2 as functions of time. Hint: the system of equations can be solved with trial functions $N_i(t) = a(t) \cdot \exp(-t/\tau_i)$. Assume that initially (when the pump is ignited) all the atoms are at the ground state.
   c) Calculate N_1 and N_2 at the steady state using constant values of τ_1 = 1 µs, τ_2 = 2 µs and P_2 = 1020 cm^{-3}s^{-1}.

2. a) The differential quantum efficiency of an InP laser is 30%. A voltage of 2.5 V is applied over the component. Calculate the external efficiency of the laser neglecting the losses inside the cavity. b) The following parameters are known about the laser: emission wavelength 850 nm, threshold current 12 mA, differential quantum efficiency below threshold 2%, and differential quantum efficiency above threshold 25%. Calculate the emitted power, when a current of 18 mA flows through the laser.

3. Let's compare surface-emitting and edge-emitting lasers that are manufactured from the same active material having material parameters of $n_{trans} = 1.7 \times 10^{18}$ cm^{-3}, $\partial g / \partial n$ = 1.5×10^{-16} cm^2, η_i = 0.8, τ_r = 6 ns and γ = 8 cm^{-1}. The length of the side-emitting laser is 300 μm, the thickness of the active region is 0.1 μm, the reflectivity of the mirrors is 0.3 and the optical confinement factor is 0.6. The thickness of the surface-emitting laser is 1 μm and the reflectivity of the mirrors is 0.95. a) Calculate the threshold current density for both components. b) What are the threshold currents of the components if the active region width of the edge-emitting laser is 3 μm and the diameter of the surface-emitting laser is 1 μm?

4. The grating period of a GaAs DFB-laser is 249.6 nm. The grating operates at second order diffraction wavelength. Let the refractive index be 3.59 and the cavity length 500 µm. a) What is the Bragg the wavelength? b) Calculate the two main emission wavelengths of the DFB laser.

5. The length of a GaAs laser is 680 µm, the thickness of the active region is 1 µm and the width of the current-limiting stripe is 50 µm. The refractive index of GaAs is 3.6, recombination time is 1 ns and the attenuation of the laser cavity is 10 cm^{-1}. Assume that the emission spectrum of GaAs is triangle-shaped with a peak energy of 1.476 eV and the width of the amplification band is 43 meV. Compute a) the wavelength of the peak energy emission, b) the FWHM of the amplification band in [Hz], c) amplification at laser threshold, and d) the minimum value for the electrical power fed in the laser when the population inversion (injected carrier concentration) in the active region is 10^{16} cm^{-3}.