3.46 PHOTONIC MATERIALS AND DEVICES

Homework Assignment 6—April 5, 2006

Due: April 12, 2006

Note: For further guidance, see the reading "Semiconductors Lasers," by E. H. Sargent

1. The five wells of a multi-quantum well laser each provide a local (as distinct from modal*) gain given by $g_{local}(N) = a(N - N_{tr})$, where *a* is the differential gain and N_{tr} is the transparency condition carrier density. The transparency condition carrier density is 1 x 10^{18} cm^{-3}. Previous experiments showed that at a carrier density of 2 x 10^{18} cm^{-3} the peak gain is 2000 cm^{-1}. The peak gain is at 1.55 μm.

   Find a way to estimate the modal gain function g_{modal} for the lowest-order mode confined to the laser active region ($g_{modal} = \Gamma g_{local}$, where Γ is the confinement factor). The waveguide consists of the following layers:

   - Outer cladding with refractive index n = 3; treat as semi-infinite away from waveguide core
   - Inner cladding refractive index n = 3.5; thickness 0.2 μm
   - Five quantum wells, each 5 nm thick (local material gain same as above) and with real part of refractive index n = 4
   - The wells are separated by four barriers, each 10 nm thick, with refractive index n = 3.5
   - Inner cladding refractive index n = 3.5; thickness 0.2 μm
   - Outer cladding with refractive index n = 3; treat as semi-infinite away from waveguide core

   Do not try to solve the full boundary condition problem precisely. Instead, use an approximate and/or graphical approach.

2. Suppose the laser cavity is 250 μm long. Feedback is provided by mirrors placed at the interface between the laser cavity and air (n = 1). Assume that the effective index is n_{eff} = 3.2 and:

   - recombination occurs only within the quantum wells (i.e. they constitute the active region volume)
   - all current injected from the electrodes goes into the active region volume

---

* In the above question, "modal gain function" means the functional relationship between modal gain and carrier density.

- the combined effect of all non-stimulated recombination mechanisms can be modeled by $R = \frac{N}{\tau}$ where:
    - o R is the rate of recombination per unit of volume
    - o N is the carrier density per unit of volume
    - o τ = 1 ns = the (non-stimulated) lifetime
- the intrinsic loss along the laser cavity due to scattering, etc. is given by 10 cm^{-1}

(a) Find the threshold current.

(b) Find the external differential efficiency.

(c) Draw an L-I curve (optical power vs. injected current) for light coming out of <u>one</u> of the facets.

3. Calculate the modulation resonance frequency ω_R, given by the relation:

$$\omega_R = \left(\frac{v_g \Gamma a \quad {}_{p0}}{\tau_p} \right)^{1/2}$$

where N_{p0} is the photon number at the modulation point, τ_p is the net photon cavity lifetime at this modulation point, and v_g is the group velocity. (You can estimate the group velocity as c/n_{eff}.) when it is operating at a power of 5 mW per facet.