

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering
And Computer Science

6.977 Semiconductor Optoelectronics – Fall 2002

Problem Set 8 – Complex Optical Resonators

Problem #1 *Surface emitting laser cavity design.* A surface emitting laser consists of a 40nm thick GaAs active region embedded in the **center** of a $1-\lambda$ long $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$ cavity. Distributed Bragg reflectors are grown above and below the cavity. These mirrors consist of **between** 20-21 *periods* of quarter-wavelength thick AlAs/ $\text{Al}_{0.1}\text{Ga}_{0.9}\text{As}$. The top DBR is between the cavity and air. The bottom DBR is between the cavity and the GaAs substrate.

$$n(\text{GaAs}) = 3.63 \quad n(\text{Al}_{0.1}\text{Ga}_{0.9}\text{As}) = 3.51 \quad n(\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}) = 3.4 \quad n(\text{AlAs}) = 2.94$$

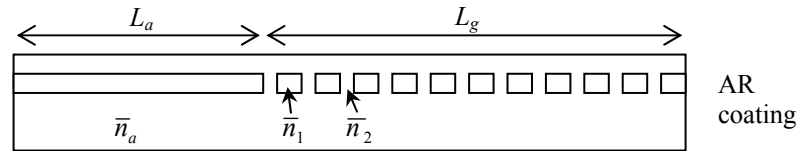
- Calculate the thickness of the AlAs and $\text{Al}_{0.1}\text{Ga}_{0.9}\text{As}$ layers in the DBR for optimal reflectance at the emission wavelength
- Should the AlAs or $\text{Al}_{0.1}\text{Ga}_{0.9}\text{As}$ layer be nearest the cavity ? Nearest the air interface? Nearest the substrate ?
- What is the exact number of dielectric layers in the top and bottom mirrors for optimal reflectance?
- What is the power reflectivity at the Bragg wavelength of the bottom DBR as seen from the laser cavity ($\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$)? If the cavity had an index $n=1$, what would the power reflectivity at the Bragg wavelength be as seen from the laser cavity ?

Problem #2 *Surface emitting laser design.* Consider again the laser structure from Problem #1 except where the DBRs have been replaced by idealized reflectors.

- Determine the T-matrix for an ideal mirror that has a field reflectivity of $r=+0.99985$ and is lossless.
- Use T-matrices to estimate the threshold material gain for the entire laser structure when the total cavity length is *one-wavelength* long. Remember to use complex indices for the reflection between the active material (GaAs) and the cavity material ($\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$) as well as a complex propagation constant while propagating through the active region.
- Determine the threshold gain for a cavity length of $1.5-\lambda$ and $2-\lambda$. Explain the difference in threshold gain.

Problem #3 Tunable laser design. Consider a tunable laser with a cavity length $L_a=150 \mu\text{m}$. One reflector for the laser is a cleaved facet with a reflectivity (R) of 30% and a second reflector formed by a grating $L_g=300 \mu\text{m}$. The grating consists of alternating segments of waveguide with effective indices \bar{n}_1 and \bar{n}_2 .

- Given that the average index is $\bar{n}=(\bar{n}_1+\bar{n}_2)/2=3.2$. Calculate the indices \bar{n}_1 and \bar{n}_2 if $\kappa L_g=2$.
- From this determine the grating period (Λ) and the length of each high index and low index waveguide segment. The desired Bragg wavelength (in free space) is $1.55 \mu\text{m}$.
- What is the longitudinal mode-spacing in this laser cavity? Include the effects of the reflected phase from the grating. Assume that the cavity index is equal to the average index of the grating. (The effective cavity length model in Section 3.5.3 in Coldren and Corzine will be useful in solving this problem).
- Consider a laser with two electrical contacts: one for the active region and one for the grating. The current bias on the grating changes the carrier density in this region. This change in carrier density is accompanied by a change in the index of refraction. Assume that the refractive index changes as follows: $\Delta n \sim 1.3I_g$ where I_g is the grating current in amps. Plot κL_g , r_g and the Bragg wavelength as a function of the grating current for $I_g = 0-0.5 \text{ A}$.



Problem #4 Threshold for a DFB Laser. This problem explores that threshold properties of a distributed feedback laser. The Bragg wavelength is $1.55 \mu\text{m}$ and the average index is 3.2.

Consider laser with a uniform grating and AR coatings on both facets.

- From the transmission for a DFB laser (Eq. 6.40 in Coldren and Corzine), derive a transcendental equation that relates $I\bar{g}_{th}L_g$, $\alpha_i L_g$, κL_g and δL_g . Show that for $\kappa L_g = 0.5$ the solutions of this equation are what is plotted in Figure 3.18.

Consider a DFB laser with a multiple quantum well active region. Consider an active region with 8 quantum wells where each well is 7 nm thick. The active region is $2 \mu\text{m}$ wide and $300 \mu\text{m}$ long. The injection efficiency is $\eta_i=80 \%$. The confinement factor is 16% and the internal waveguide loss is $\alpha_i=20 \text{ cm}^{-1}$.

- Using Figure 3.18 in Coldren and Corzine, determine the threshold gain *and* the lasing wavelength for the DFB.
- What is the threshold current density?