Exercise 3.1

A particular Fabry-Perot laser diode has the following characteristic parameters:

Scattering losses: $\alpha_s = 2000\ m^{-1}$

Cavity length: $L = 500\ \mu m$

Active region refractive index: $n = 3.5$

Material gain: $g_m = g_p - \gamma(\lambda - \lambda_p)^2$

Peak material gain: $g_p = 7875\ m^{-1}$

Peak wavelength: $\lambda_p = 1.55\ \mu m$

Curvature factor: $\gamma = 5.25 \cdot 10^{19}\ m^{-3}$

Confinement factor: $\Gamma = 1$

1) Identify the central (main) mode and its offset with respect the peak gain.
2) How many modes will oscillate?.
3) Calculate the required curvature factor γ to have a single-mode cavity.
4) Calculate the required cavity length L to have a single-mode cavity.
5) Calculate the required mirror reflectivity R to have a single-mode cavity.

Exercise 3.2

A particular Fabry-Perot laser diode has the following characteristic parameters:

Scattering losses: $\alpha_s = 2000\ m^{-1}$
Cavity dimensions: $L = 500\ \mu m\ ,\ W = 10\ \mu m\ ,\ d = 1\ \mu m$
Active region refractive index: $n = 3.5$
Carrier lifetime: $\tau_r = 1\ ns$
Material gain: $g_m = a(N - N_0) - \gamma\left(\lambda - \lambda_p\right)^2$
Gain coefficient: $a = 1.5 \cdot 10^{-19}\ m^2$
Transparency: $N_0 = 10^{22}\ m^{-3}$
Peak wavelength: $\lambda_p = 1.55\ \mu m$
Curvature factor: $\gamma = 5.25 \cdot 10^{19}\ m^{-3}$
Confinement factor: $\Gamma = 1$

When the laser is driven by an electrical current I, in the initial instant the carrier concentration N is maximum and can be related to I as $N = \tau_r(I/qV)$. Once the laser is stabilized, the carrier concentration saturates and so does the gain.

1) Find the applied current if the peak gain is $g_p = 7875\ m^{-1}$.

Exercise 3.2

The threshold current for such multimode laser has been measured to be $I_{th} = 40\ mA$. Knowing that, the same formula as in single-mode lasers can be used to estimate the total output power.

2) Find the total output optical power.
3) Find the output power assuming only the fundamental mode oscillates.
4) Find the output power assuming only the 10^{th} secondary mode oscillates.

The effective gain is defined as the margin between the initial gain and the losses $g_e = g - \alpha_t$. The output optical power corresponding to each longitudinal mode is proportional to g_e.

5) Find the side-mode suppression ratio (SMSR). Give its value for the 10^{th} side mode.

Exercise 3.3

1) *2 points of the light-current characteristic of a laser diode have been measured. When the driving current is* $40\ mA$ *and* $60\ mA$*, the output power is* $1\ mW$ *and* $2\ mW$*, respectively. Estimate the laser's threshold current* I_{th}.

2) *Given a required extinction ratio of the optical signal of* $ER = 10\ dB$ *and a maximum driving current of* $I_{sat} = 3 \cdot I_{th}$*, determine the best modulation current for intensity modulation in terms of amplitude and bias.*

3) Estimate the response time of the laser in such case. Assume that:

$$\frac{2qV}{v\Gamma a} = 1.2 \cdot 10^{-22}\ A \cdot s^2$$

What is the maximum modulation speed if the response time must be less than 20% of the bit period?

Exercise 3.4

A particular Fabry-Perot laser diode has the following characteristic parameters:

Cavity dimensions: $L = 300\ \mu m\ ,\ W = 10\ \mu m\ ,\ d = 2\ \mu m$

Active region refractive index: $n = 3.5$

Carrier lifetime: $\tau_r = 2\ ns$

Gain coefficient: $\Gamma a = 2 \cdot 10^{-19}\ m^2$

The temperature dependence of the laser's threshold current can be modeled as $I_{th}(T) = I_0 e^{(T-T_0)/6T_0}$ where $I_0 = 30\ mA$ is the threshold current at the reference temperature $T_0 = 25^o C$. Such laser is intensity modulated with driving currents $I_{on} = 60\ mA$ and $I_{off} = 36\ mA$.

1) Find the maximum modulation speed at the reference temperature imposing that the response time must be smaller that 20% of the bit period.
2) If the temperature raises up to $T = 75^o C$, find the new maximum modulation speed.
3) Find the maximum temperature deviation to guarantee the laser stays in the lasing zone. Find the peak power oscillations in such case.

Exercise 3.5

A particular Fabry-Perot laser diode has the following characteristic parameters:

Scattering losses: $\alpha_s \approx negligible$

Cavity dimensions: $L = 500\ \mu m\ ,\ W = 10\ \mu m\ ,\ d = 1\ \mu m$

Active region refractive index: $n = 3$

(Treated) Mirrors Reflectivity: $R = 1/e$

Carrier lifetime: $\tau_r = 0.5\ ns$

Transparency: $N_0 \approx negligible$

Threshold Current: $I_{th} = 20\ mA$

Under such conditions, the laser's electro-optical transfer function reads:

$$|M(\omega)|^2 = \frac{1}{\left[1-\left(\frac{\omega}{\omega_c}\right)^2\right]^2 + \left[2\alpha\frac{\omega}{\omega_c^2}\right]^2} \qquad \alpha = \frac{1}{2\tau_r}\left(\frac{I_0}{I_{th}}\right) \qquad \omega_c^2 = \frac{1}{\tau_r\tau_p}\left(\frac{I_0}{I_{th}}-1\right)$$

Where ω is the modulation frequency, ω_c is the resonance frequency, α is the damping factor, I_0 is the modulation signal's DC level and τ_p is the photon's lifetime.

Exercise 3.5

1) Find the condition under which the resonance is eliminated.
2) Find the corresponding DC level I_0 to satisfy such condition.
3) Find the resulting 3-dB bandwidth B_{3dB} in such case.
4) Find the 3-dB bandwidth when $I_0 = 2I_{th}$.