Waveguide structure of hetero-lasers
The Fabry-Perot etalon

The separation between the mirrors is equal to an integer number of $\lambda/2$, where $\lambda$ is the wavelength of electromagnetic radiation.

In a laser, one of the mirrors partially transmits light, allowing for the output of the electromagnetic radiation. Typically, mirrors are formed by two polished or cleaved parallel surfaces of the device.
Cleaved facets as a Fabri-Perot etalon in heterolasers

The power reflection coefficient for the mirror is $R$
Wave amplitude reflection coefficient is $R^{1/2}$
Laser Equation

Under the equilibrium lasing condition, the electromagnetic wave should remain unaltered after a round trip.

\[(R_1 R_2)^{1/2} \exp(2ikL) = 1,\]

where \(R_1\) and \(R_2\) are the reflectivities of the end faces in the longitudinal direction, \(k\) is the complex propagation constant \((ik = \alpha + i\beta)\) and \(L\) is the length of the active region.

\[\lambda = 2n_r L/n,\]

\[\alpha = -(1/2L) \ln(1/R_1 R_2),\]
Laser Equation

Find the value of the integer $n$ for operation at 1.4 $\mu$m, assuming $n_r = 3.5, L = 250 \mu$m.

$$\lambda = \frac{2n_r L}{n},$$

$n \approx 1250$

The separation between modes:

$$\Delta \lambda \approx \frac{\lambda}{n} \left( \frac{n_r}{n_g} \right),$$

$n_g$ is the group refractive index. For AlGaAs/GaAs structure, $n_g \sim 4$.

1. Derive this equation

2. Find $\Delta \lambda$ for the above example.

$$\Delta \lambda \sim 1 \text{ nm}.$$
Carrier and light intensity distribution in the transverse direction

![Diagram showing carrier and light intensity distribution.](image-url)
Electrical and optical confinement in heterostructure lasers

Layer 3 \( (p - \text{Al}_x\text{Ga}_{1-x}\text{As}) \)
Layer 2 \( (\text{GaAs/AlGaAs QWs}) \)
Layer 1 \( (n - \text{Al}_x\text{Ga}_{1-x}\text{As}) \)
Electrical and optical confinement in heterostructure lasers

(a) Single Quantum Well Laser

(b) Separate confinement Multiple Quantum Well Laser
Optical gain as a function of injected carrier concentration

The Gain must be greater or equal to the total loss in the cavity for the lasing. The loss comes from the cavity loss outside the QW and from the leak through the mirrors.
Laser characteristics

The resulting photon population is controlled by three processes:
(a) the generation by stimulated emission,
(b) the absorption through various other processes, e.g., free-carrier absorption, interface scattering, inter-valence band absorption and
(d) the spontaneous emission.

The rate equation for the photons may be written as

\[
\frac{dN_{ph}}{dt} = GN_{ph} - \gamma N_{ph} + R_{sp},
\]

where \(N_{ph}\) is the total photon number in the cavity.

- \(GN_{ph}\) is the net rate of generation of photons resulting from generation through stimulated emission,
- \(\gamma N_{ph}\) is the net rate of photon decay through intrinsic absorption and end-surface loss,
- \(R_{sp}\) is the rate at which photon number is enhanced by spontaneous emission.

The steady-state photon number is given by

\[
N_{ph} = R_{sp} (\gamma - G)^{-1}
\]
The threshold current

\[ J_{th} = |e| d n_{th} / \tau_e(n_{th}), \]

- \( d \) is the active layer width,
- \( n_{th} \) is the carrier density under the threshold condition,
- \( \tau_e(n_{th}) \) is the carrier-recombination time corresponding to the threshold carrier density.

Carrier recombination time
(neglecting stimulated recombination at the threshold!)

\[ \tau_e(n_{th}) = (A_{nr} + B n_{th} + C n_{th}^2)^{-1}, \]
Above the threshold, the photon density increases linearly with the current density:

\[ n_{\text{ph}} = \eta_i \tau_p (J - J_{\text{th}}) / |e| d, \]

- \( \tau_p \) is the photon lifetime,
- \( \eta_i \) is the internal quantum efficiency, given by the ratio of the radiative and the total recombination rate including the non-radiative recombination.

The light output from the device from one facet, assuming the two facets to be identical with reflectivity \( R \) is

\[ P_{\text{out}} = (1/2) \hbar \omega n_{\text{ph}} V \alpha_m v_g, \]

where \( V \) is the total volume of the active layer, \( v_g \) is the group velocity at the lasing frequency \( \omega \) and \( \alpha_m \) is related to the mirror loss

\[ \alpha_m = -(1/L) \ln R. \]
Laser emission spectrum

At the threshold

Above the threshold (@ 5mW)