Single Frequency Lasers
Read: Kasip, Chapter 4
Yariv, Chapter 15,16
Coldren/Corzine Chapter 3,5
Agrawal/Dutta Chapter 6,7,8

ECE 162C

Lecture #13

Prof. John Bowers

Large Signal Modulation

The analysis is based on the rate equations:

$$\frac{dS}{dt} = \Gamma v_g a(N - N_{tr})S - \frac{S}{\tau_p} + \frac{\beta \Gamma N}{\tau_n}$$

$$\frac{dN}{dt} = \frac{I}{qV} - v_g a(N - N_{tr})S - \frac{N}{\tau_n}$$

For simplicity gain non-linearities are omitted.

With the small-signal approximation no longer valid, the equations must be solved numerically

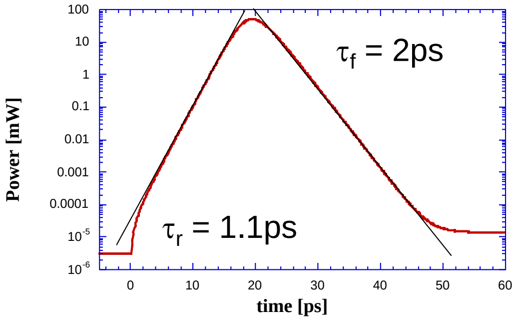
Large Signal Modulation
Impulse Response

Consider a laser with initial carrier density N_i, excited with a charge impulse at t = 0

$$N = \begin{cases} N_i & t < 0 \\ N_i + \dfrac{Q}{qV} & 0 < t < t_{on} \end{cases}$$

Ignoring spontaneous emission we get:

$$\frac{dS}{S} = \left(\Gamma v_g \left(N(t) - N_{tr} \right) - \frac{1}{\tau_p} \right) dt$$



With the solution

$$S = S_0 e^{t/\tau_r}$$

$$\frac{1}{\tau_r} = \Gamma v_g a \left(\frac{Q}{qV} + N_i - N_{tr} \right) - \frac{1}{\tau_p}$$

Large Signal Modulation Impulse Response

The fall-time depends on how far below threshold the carrier density can be brought. Unless charge is extracted electrically $N > N_{tr}$, which means:

$$\frac{1}{\tau_f} = \frac{1}{\tau_p} - \Gamma v_g a \left(N - N_{tr} \right)$$

$$\frac{1}{\tau_f} < \frac{1}{\tau_p}$$

$$\tau_f > \tau_p \approx 1 ps$$

This is best case, more often τ_f is on the order of 10-20 ps

Large Signal Modulation
Impulse Response

Example:

$$\Gamma = 0.1$$

$$v_g = 10^8 \ {}^{m}\!/_{s}$$

$$a = 3 \cdot 10^{16} cm^2$$

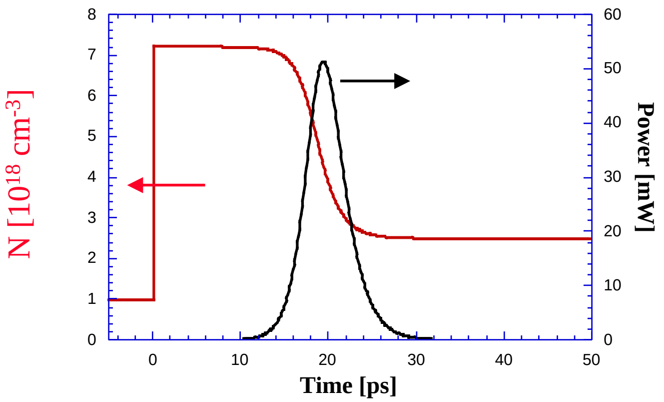
$$V = 300 \cdot 1 \cdot 0.1 \mu m^3 = 30 \mu m^3$$

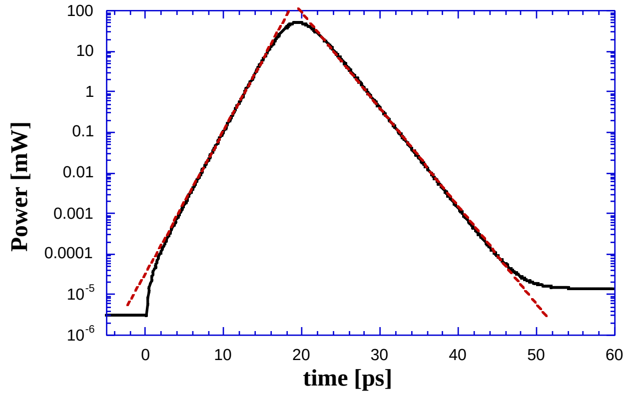
$$N_{tr} = 10^{18} cm^{-3}$$

$$N_i = 10^{18} cm^{-3}$$

$$\tau_p = 1 ps$$

$$Q = 6 \cdot 10^{-11} C$$





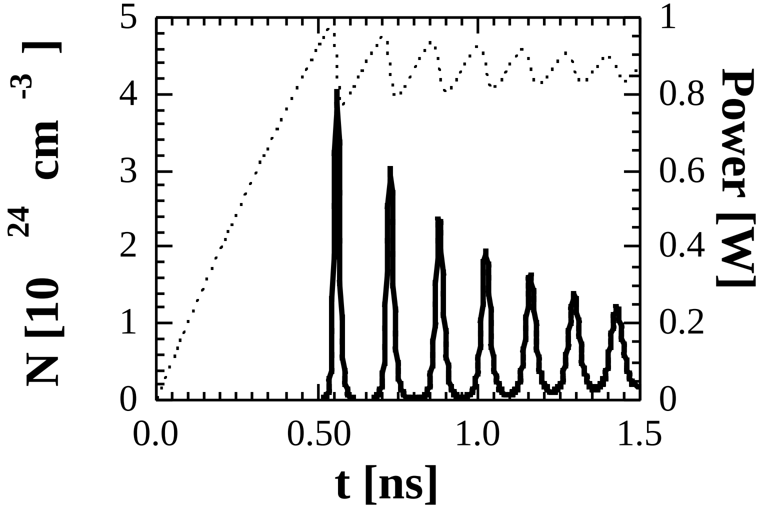
Large Signal Modulation
Step Response

Turn-on delay:

$$\tau_d = \tau_n \ln\left(\frac{I - I_b}{I - I_{th}}\right)$$

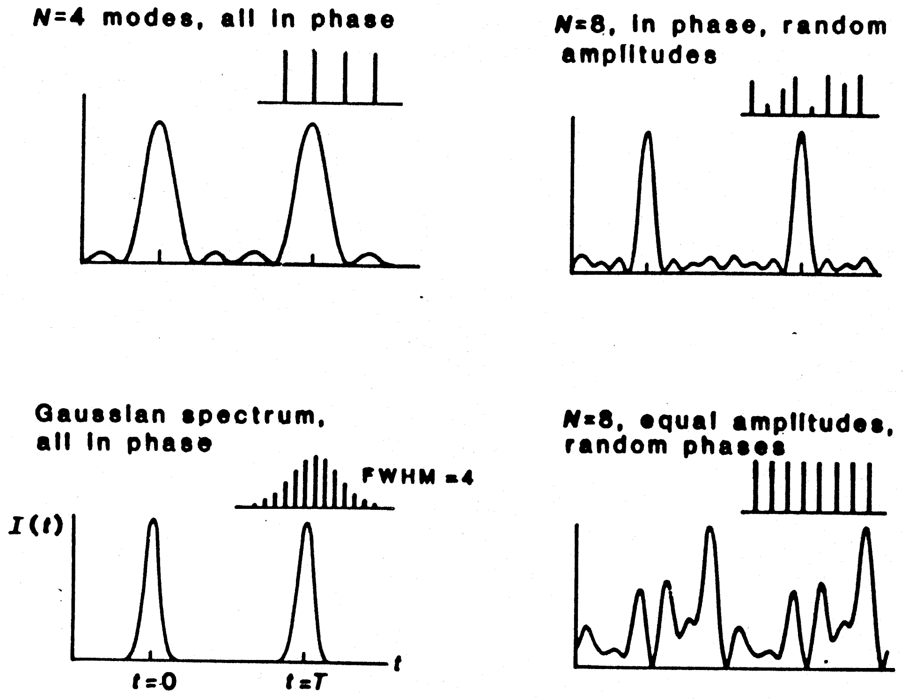
Oscillation frequency:

$$f_r = \sqrt{\frac{1 + \Gamma v_g a N_{tr} \tau_p}{\tau_p \tau_n}\left(\frac{I - I_{th}}{I_{th}}\right)}$$



Pulse Generation : Mode-Locking

- Modulation at cavity frequency phase locks modes
- More modes and better phase lock gives shorter pulses
- Pulse repetition rate determined by cavity length - does not depend on bias conditions

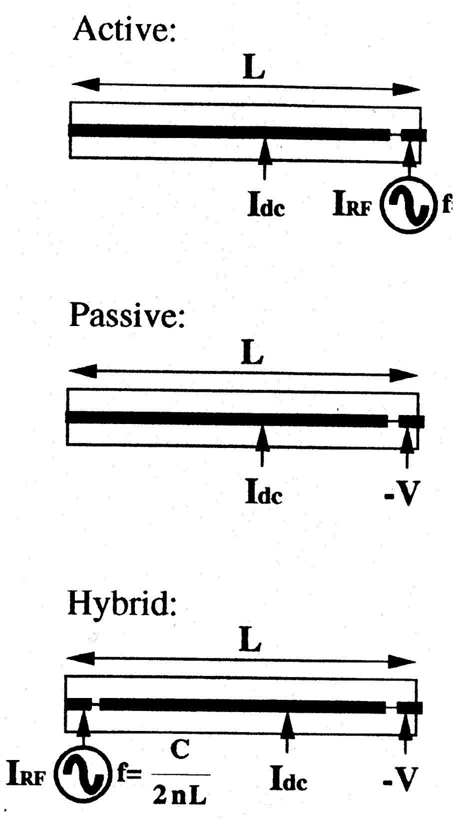


A.E. Siegman, “Lasers”, University Press, 1987

Pulse Generation : Mode-Locking

Resonant modulation of roundtrip gain or phase at the cavity frequency

- Active mode-locking
  - modulation signal applied externally
- Passive mode-locking
  - Non-linear element in cavity provide modulation
- Hybrid mode-locking



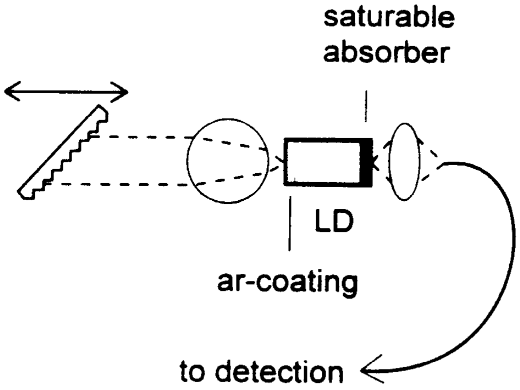
Pulse Generation : Mode-Locking

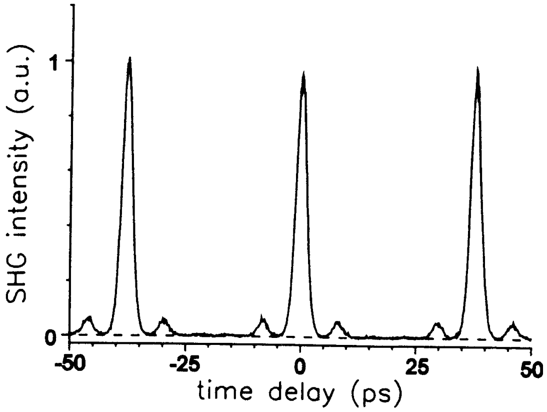
Limits to minimum pulsewidth

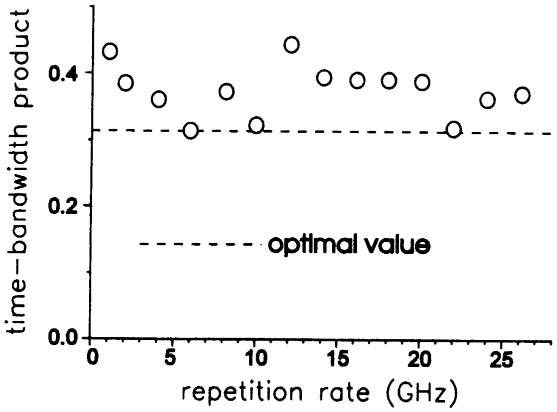
- Gain bandwidth
  - Very wide, potential for pulses <100fs
- Self Phase Modulation
    - refractive index depends on carrier density
  - Spectral width larger than transform limit
  - Generation of chirped pulses
- Dispersion
  - Causes broadening of chirped pulses

Passive Mode-Locking in External Cavity

- Pulsewidth : 1-2 ps
- Repetition rate 1-26 GHz
- Transform limited pulses



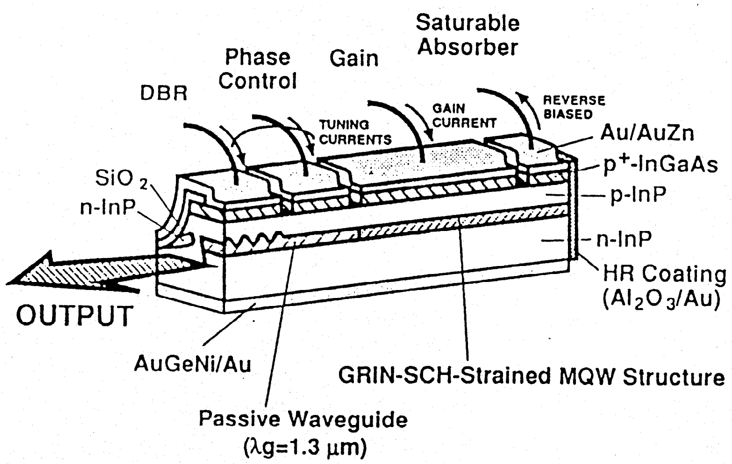


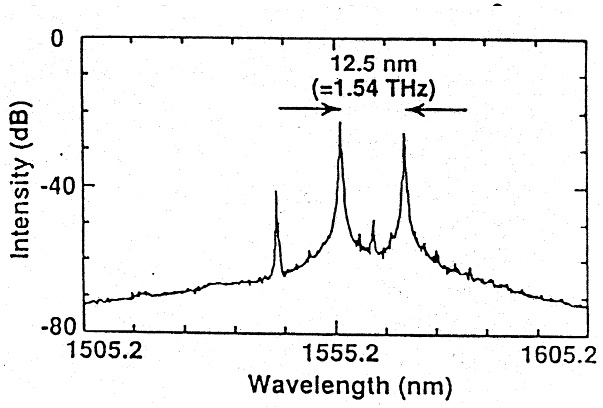


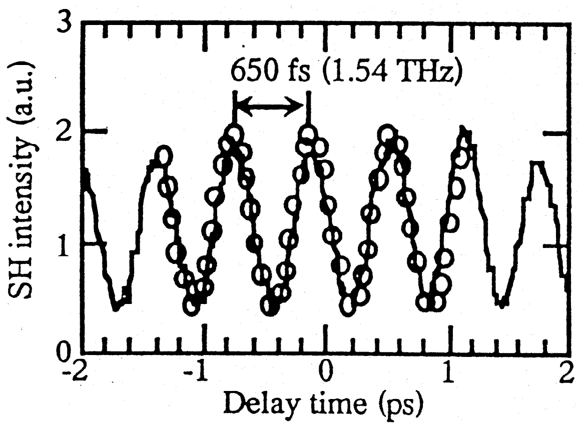
J. Yu et al., IEEE Photon. Technol. Lett., vol. 7, no. 5, 467 (1995)

Passive Mode-Locking
Monolithic Cavity

- Mode-locking at 1.54 THz
- Monolithic integrated DBR laser
- Total cavity length 1.1mm (cavity resosnace: 40GHz)
- .55µm
- , 400, THz.







S. Arahira et al., Optics Letters, vol.19, (no.11):834-6 (1994)
Y. Ogawa, International Workshop on Femtosecond Technology FST’95

Chirp

Modulation of injection current causes not only intensity modulation, but also frequency modulation. The linewidth enhancement factor α quantifies this

$$\alpha = \frac{\dfrac{dn}{dN}}{\dfrac{dg}{dN}}$$

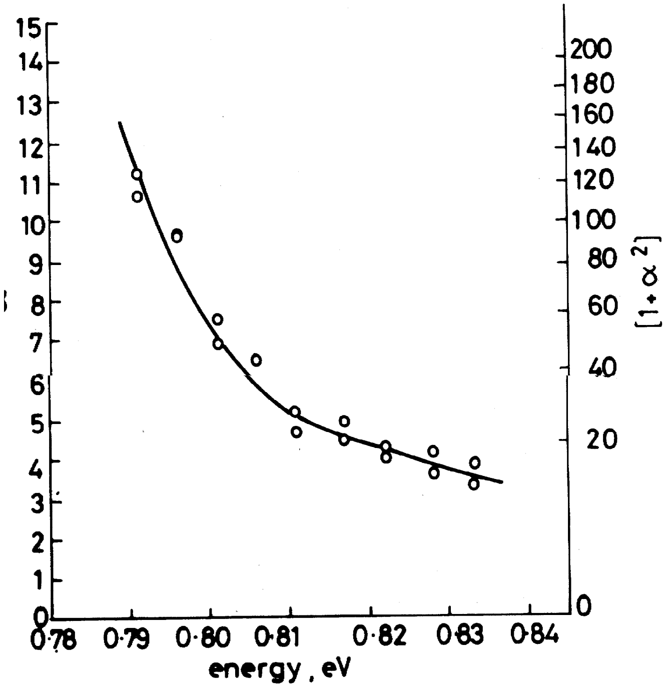
The Chirping is

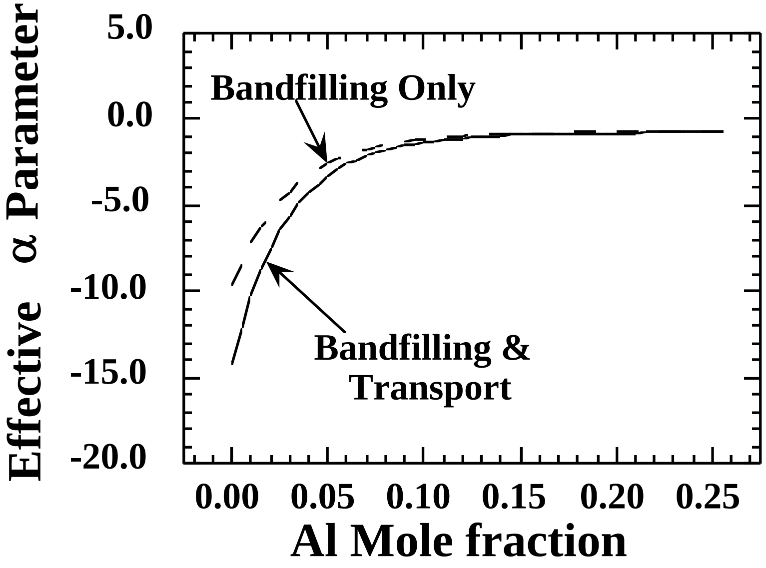
$$\Delta\nu(t) = -\frac{\alpha}{4\pi}\frac{1}{P}\frac{dP}{dT} + 2\frac{\Gamma\varepsilon}{V\eta h\nu}P$$

T. Koch et al., Elec. Lett., vol. 20, no. 25, 1038 (1984)
T. Koch et al., Appl. Phys. Lett., vol. 48., no. 10, 613 (1986)

Chirp

The linewidth enhancement factor changes with wavelength, and can also depend on the structure



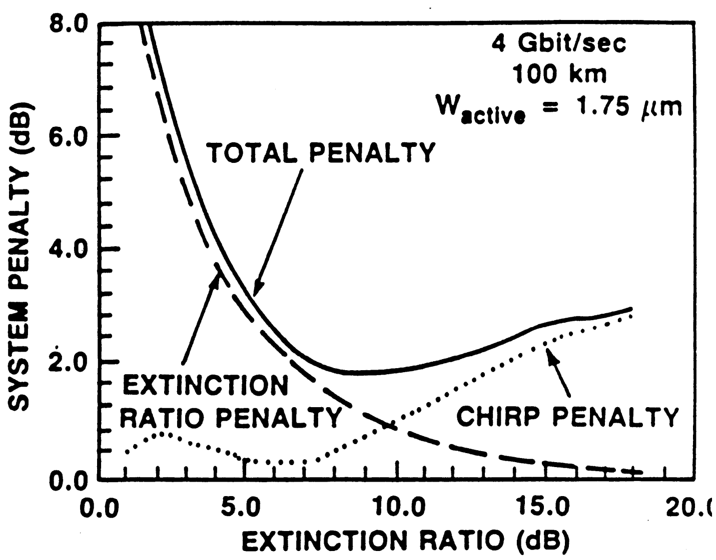


L.D. Westbrook, Electron. Lett., vol. 21, no. 22, 1018 (1984)

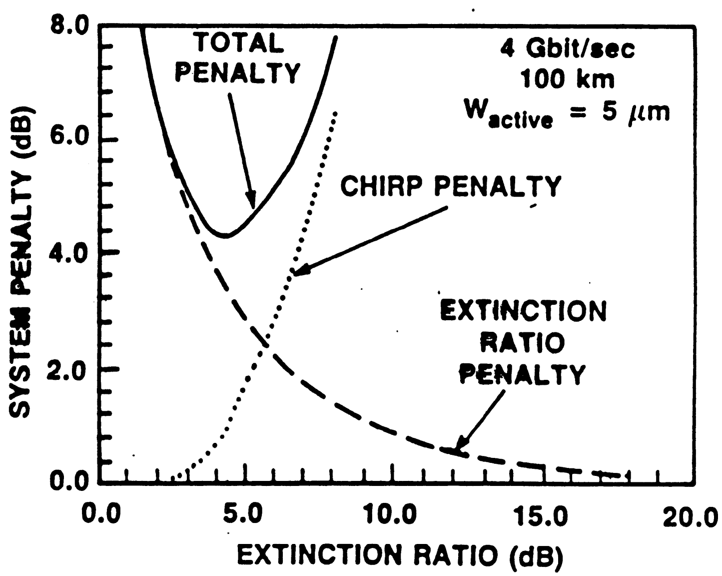
R. Nagarajan, J. Quantum Electronics, vol. 29, no. 6, 1601 (1993)

Chirp

Low chirp laser is a requirement to achieve the full potential of an optical communication system



DCPBH Laser



Ridge Waveguide Laser

P.J. Corvini et al., J. Lightwave Technol., vol. LT-5, 1591 (1987)

Single Longitudinal Mode Lasers

- A technique is needed to filter the gain or loss so only one mode reaches threshold.
- Possibilities:
  - Short cavity lasers
  - Coupled cavity lasers (3 or 4 mirror cavities)
  - Grating feedback
    - Distributed feedback (DFB)
    - Distributed Bragg Reflector (DBR)
    - Bulk grating (external cavity)

Single Longitudinal Mode Lasers

- A technique is needed to filter the gain or loss so only one mode reaches threshold.
- Possibilities:
  - Short cavity lasers
  - Coupled cavity lasers (3 or 4 mirror cavities)
  - Grating feedback
    - Distributed feedback (DFB)
    - Distributed Bragg Reflector (DBR)
    - Bulk grating (external cavity)
    - Vertical Cavity Surface Emitting Laser (VCSEL)

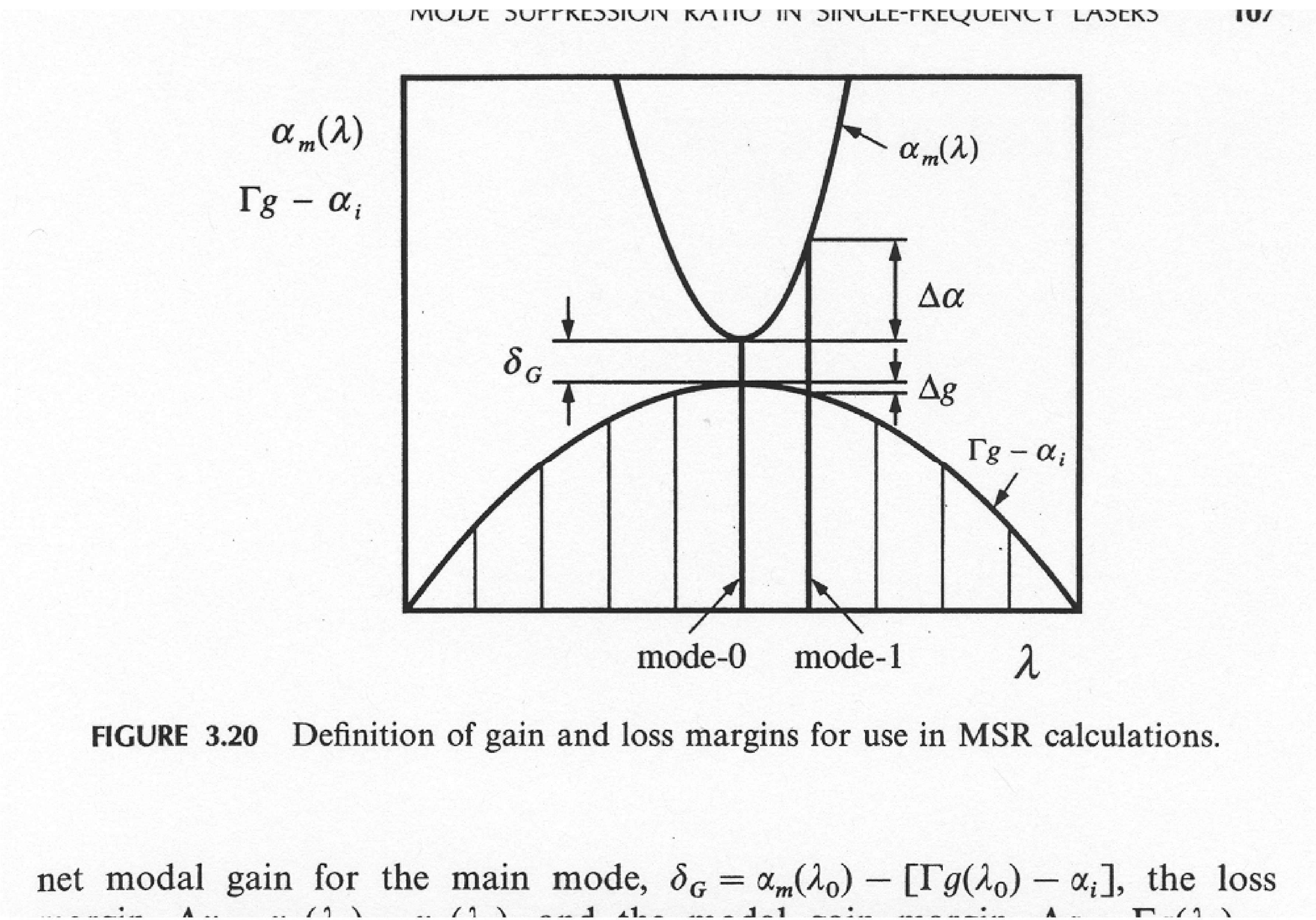
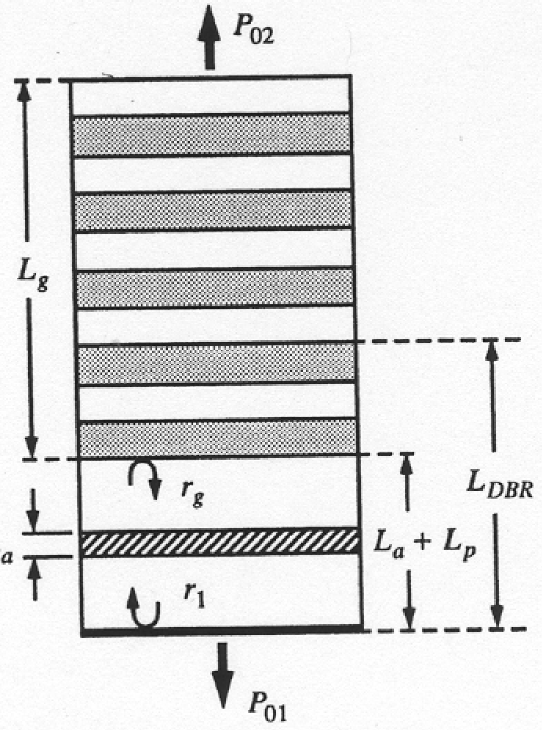


FIGURE 3.20 Definition of gain and loss margins for use in MSR calculations.

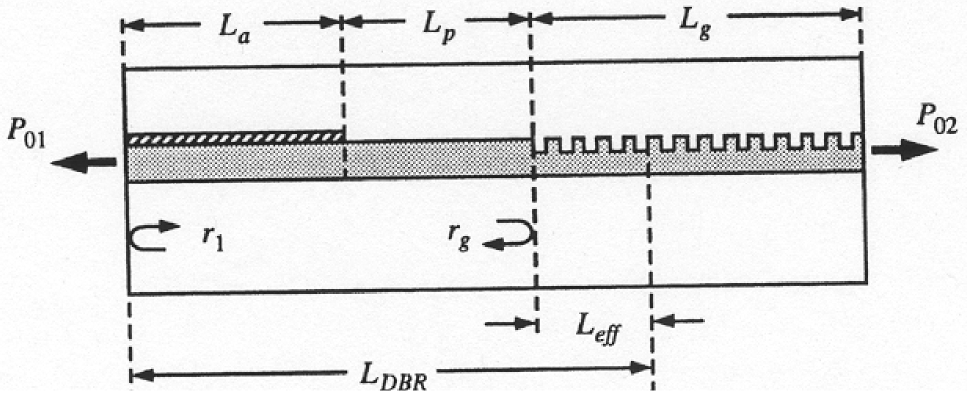
net modal gain for the main mode, $\delta_G = \alpha_m(\lambda_0) - [\Gamma g(\lambda_0) - \alpha_i]$, the loss

VCSEL



VCSEL
(a)

DBR



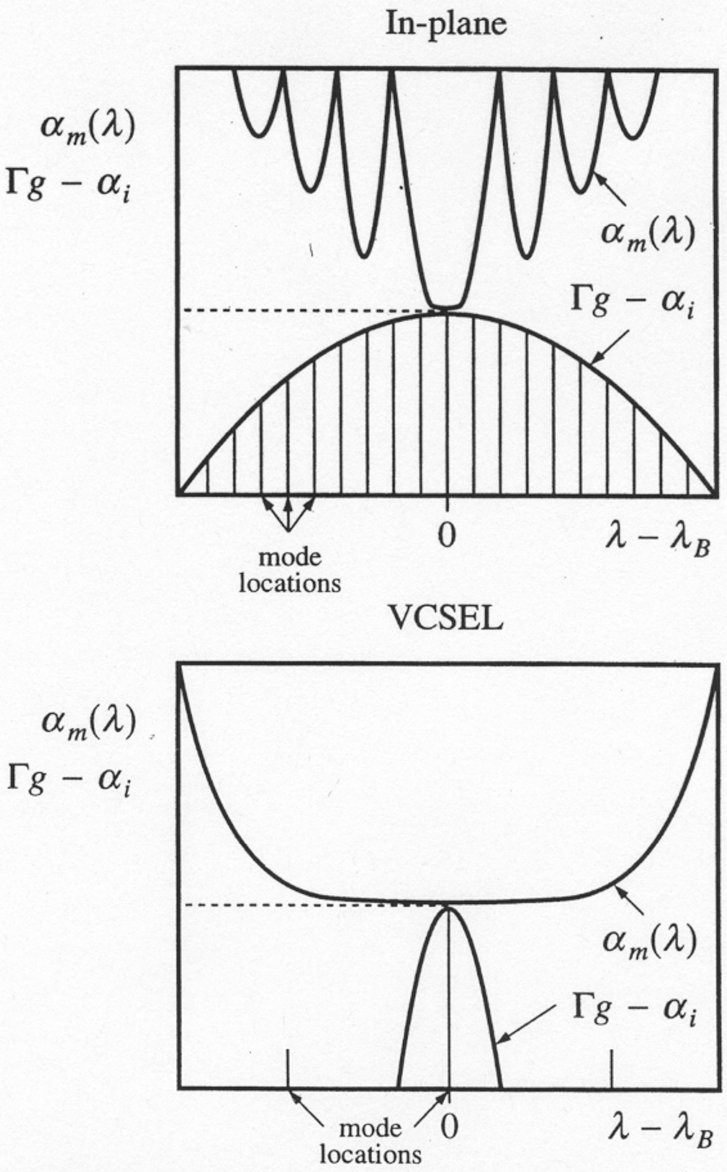


FIGURE 3.15 Schematic illustration of how a single axial mode is selected in an in-plane