Final

- Final: Tuesday, June 10 12-3
- 1 two sided 8.5 x 11” crib sheet
- Material:
  - Kasip, chapters 1-6
  - Lecture notes
- Problems:
  - Photodetectors+ Photovoltaics
  - VCSEL
  - Lasers
  - Optical fibers

- Why do most transmitters bias the off level of the laser close to threshold instead of zero bias?

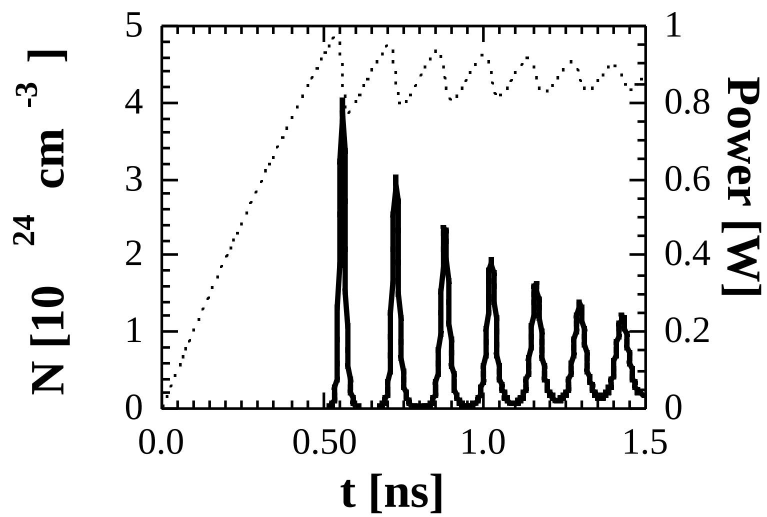
Large Signal Modulation
Step Response

Turn-on delay:

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

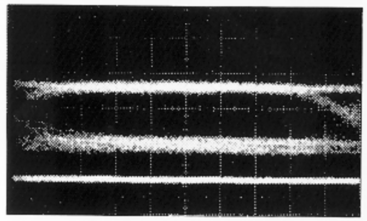
Oscillation frequency:

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

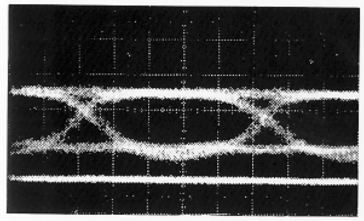


- What does NRZ mean?
  What does RZ mean?
  What is an eye diagram?

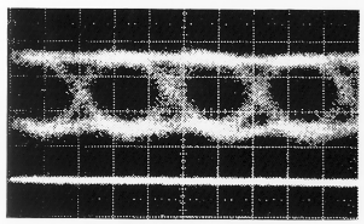
DIGITAL MODULATION OF A CONSTRICTED MESA LASER (50 ps/div, 100 mA DC BIAS)



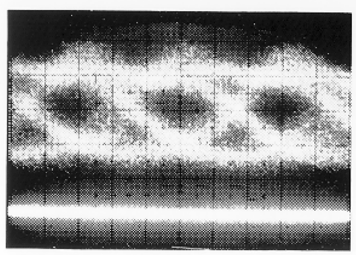
2 Gbit/s NRZ



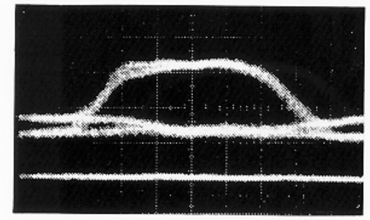
4 Gbit/s NRZ



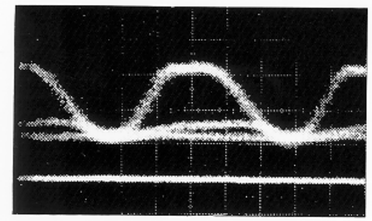
8 Gbit/s NRZ



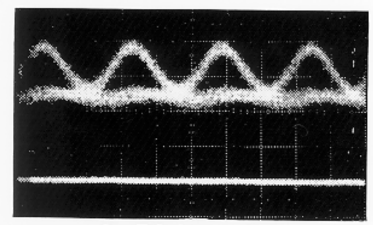
16 Gbit/s NRZ (20 ps/div)



2 Gbit/s RZ



4 Gbit/s RZ

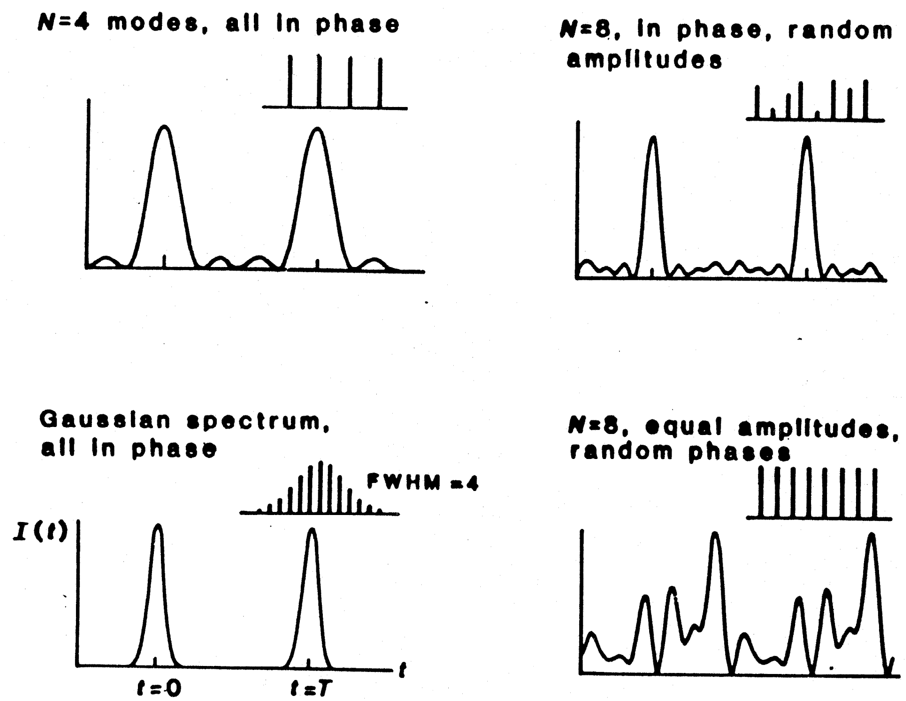


8 Gbit/s RZ

- What is mode locking?
- What is gain switching?

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



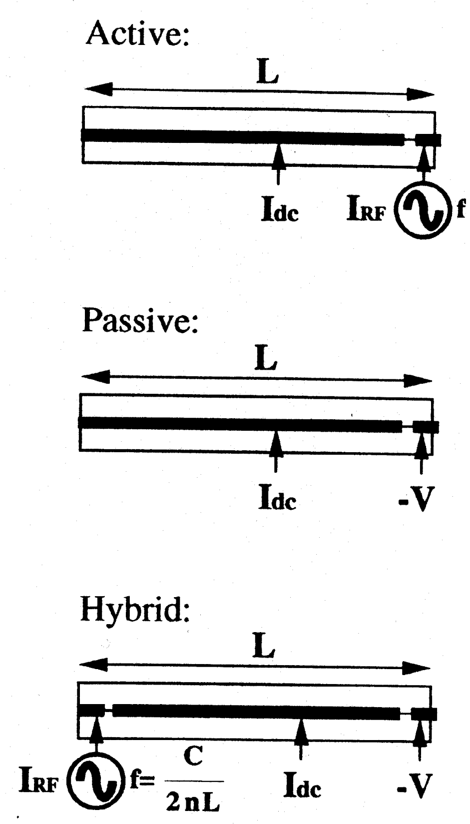
A.E. Siegman, “Lasers”, University Press, 1987

- How does active mode locking work?
- How does passive mode locking work?

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



- What is the linewidth enhancement factor?
- What is a typical value?

Chirp

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

$$\alpha = \frac{4\pi \frac{dn}{dN}}{\lambda \frac{dg}{dN}}$$

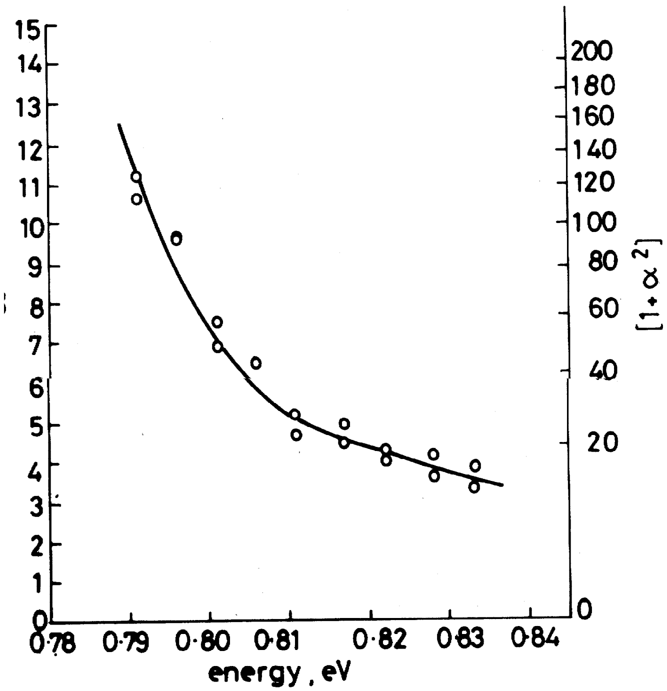
The Chirping is

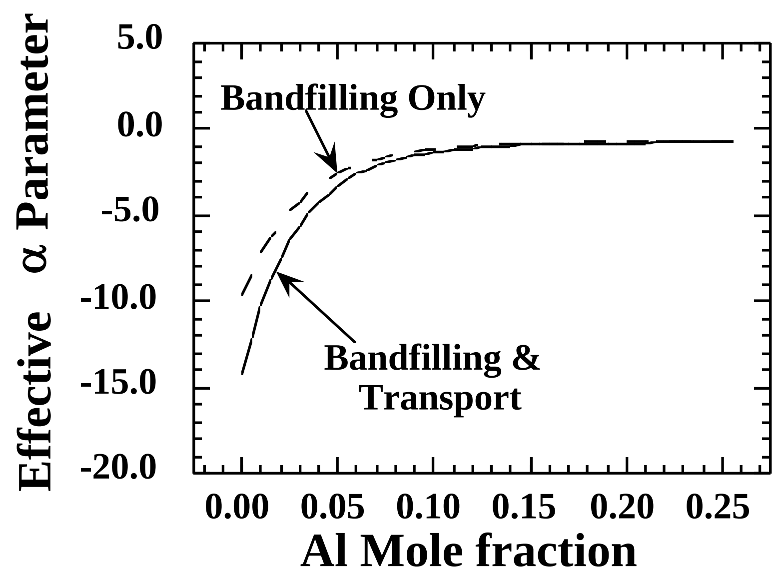
$$\Delta\nu(t) = -\frac{\alpha}{4\pi}\frac{1}{P}\frac{dP}{dT} + 2\frac{\Gamma\varepsilon}{V\eta h\nu}P$$

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





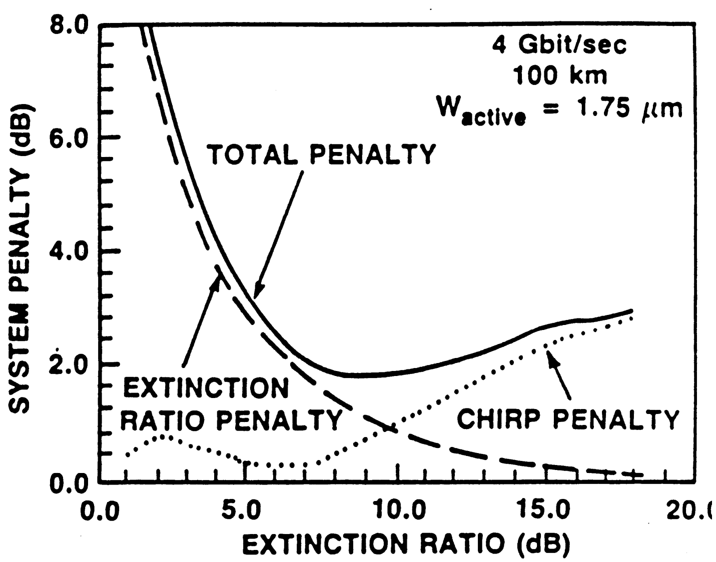
L.D. Westbrook, Electron. Lett., vol. 21, no. 22, 1018 (1984)

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

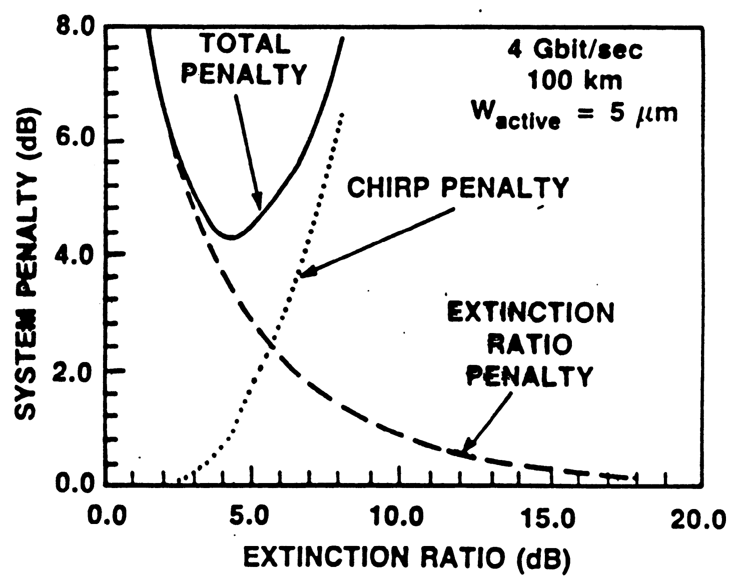
- What is the extinction ratio penalty?
- What is the chirp penalty?

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)

Explain this figure

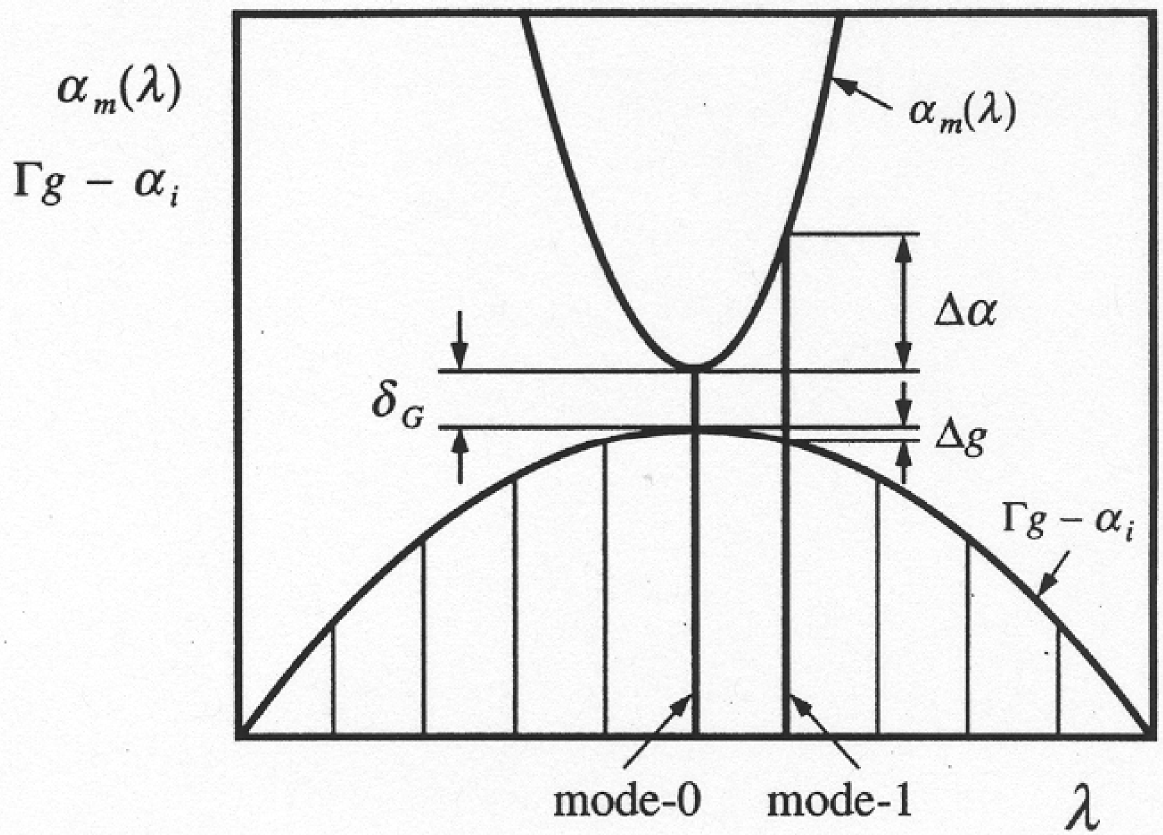
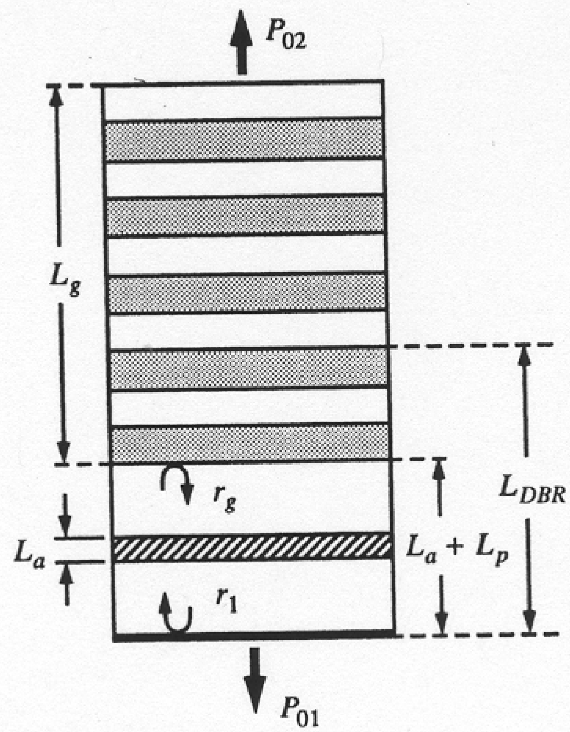


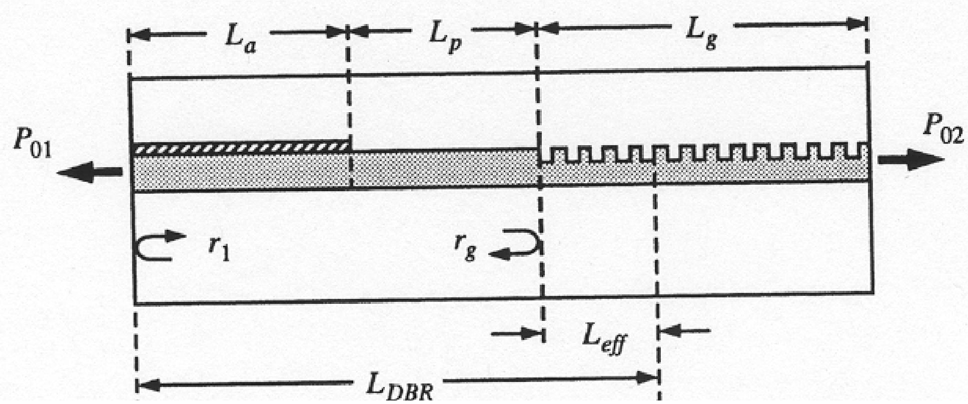
FIGURE 3.20 Definition of gain and loss margins for use in MSR calculations.

VCSEL



P_{02}
L_g
L_{DBR}
r_g
L_a
$L_a + L_p$
r_1
P_{01}
VCSEL
(a)

DBR



L_a
L_p
L_g
P_{01}
P_{02}
r_1
r_g
L_{eff}
L_{DBR}

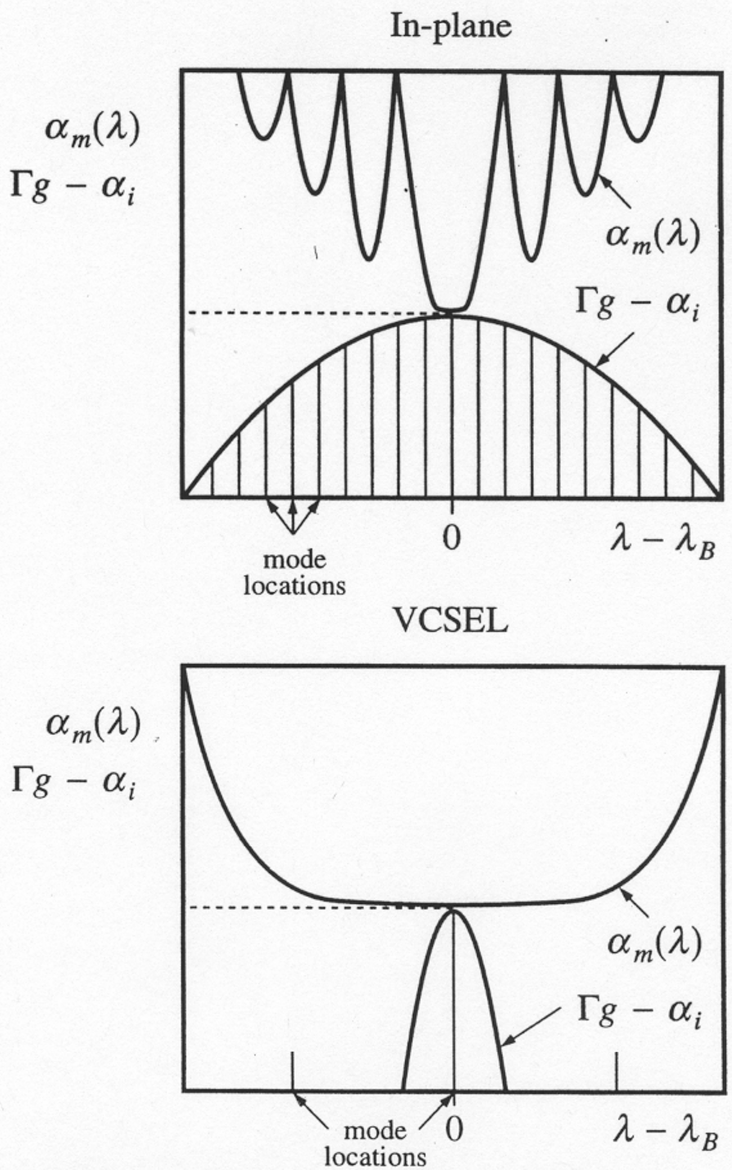


FIGURE 3.15 Schematic illustration of how a single axial mode is selected in an in-plane

- What is the difference between a DFB and DBR laser?

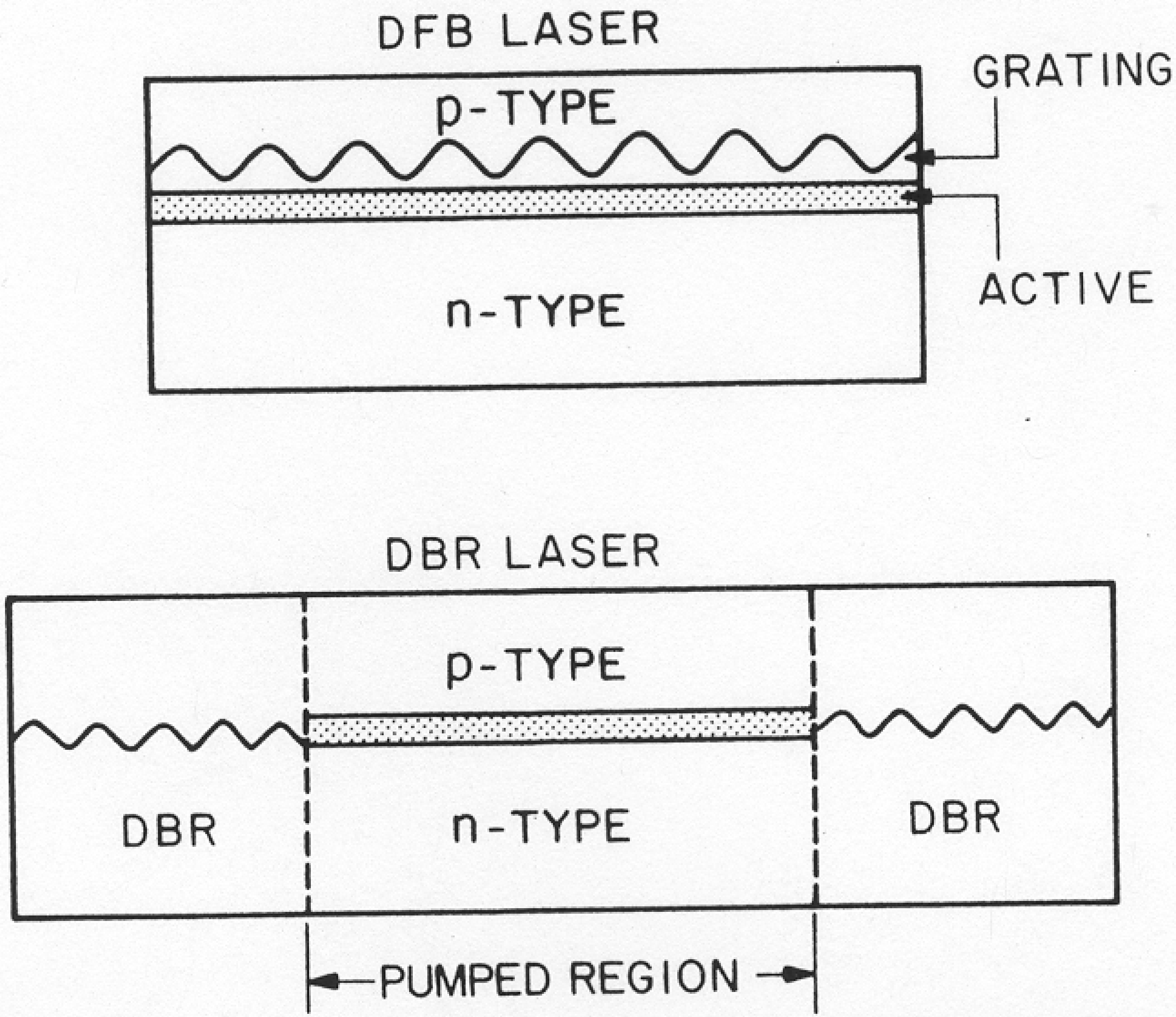
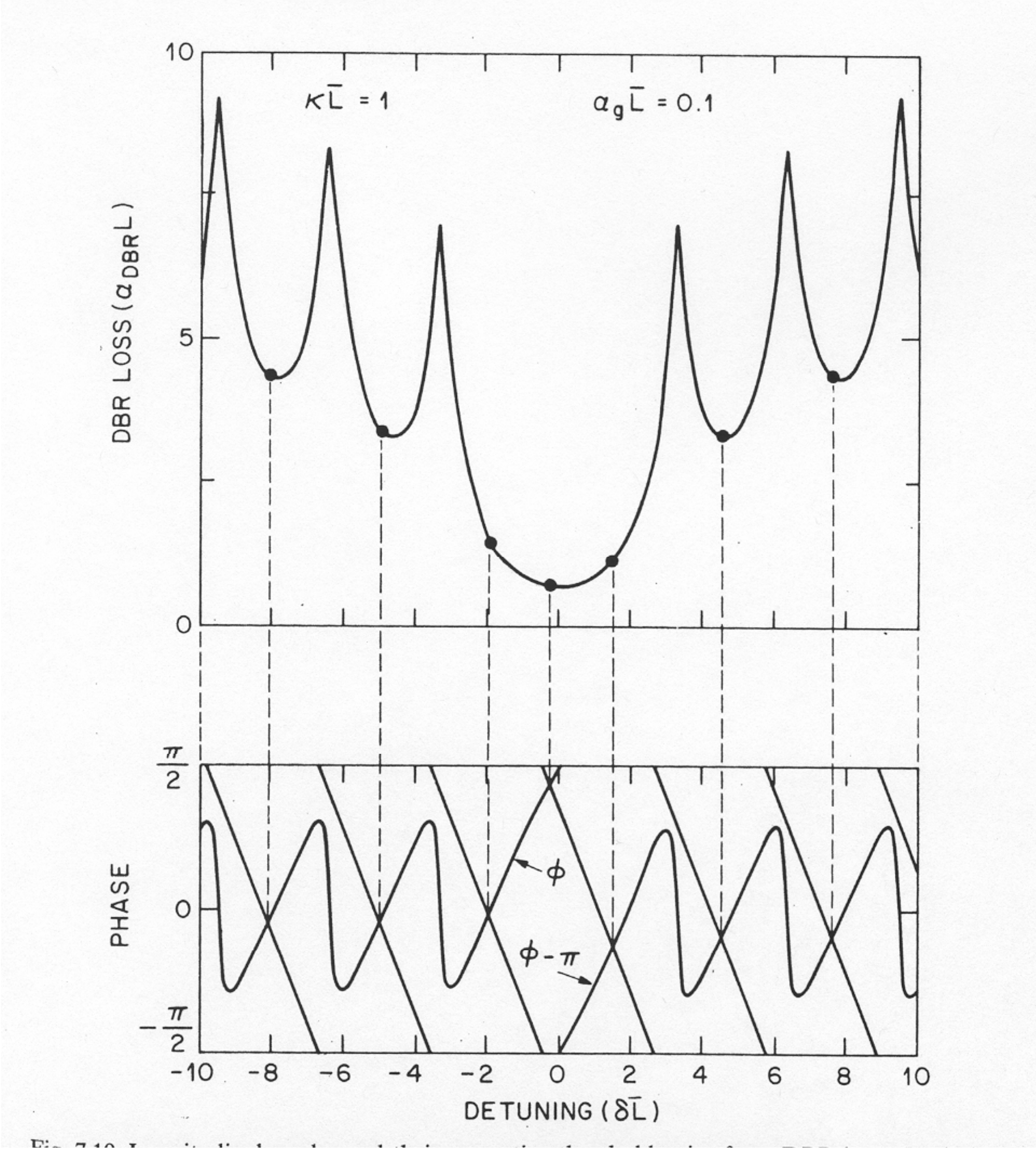


Fig. 7.1 Schematic illustration of distributed-feedback (DFB) and distributed Bragg reflector (DBR) semiconductor lasers. Different refractive indices on opposite sides of the grating result in a periodic index perturbation that is responsible for the distributed feedback. Shaded area shows the active region of the device.

Explain this figure. What are the dots?



- Why do you quarter wave phase shift a DFB?

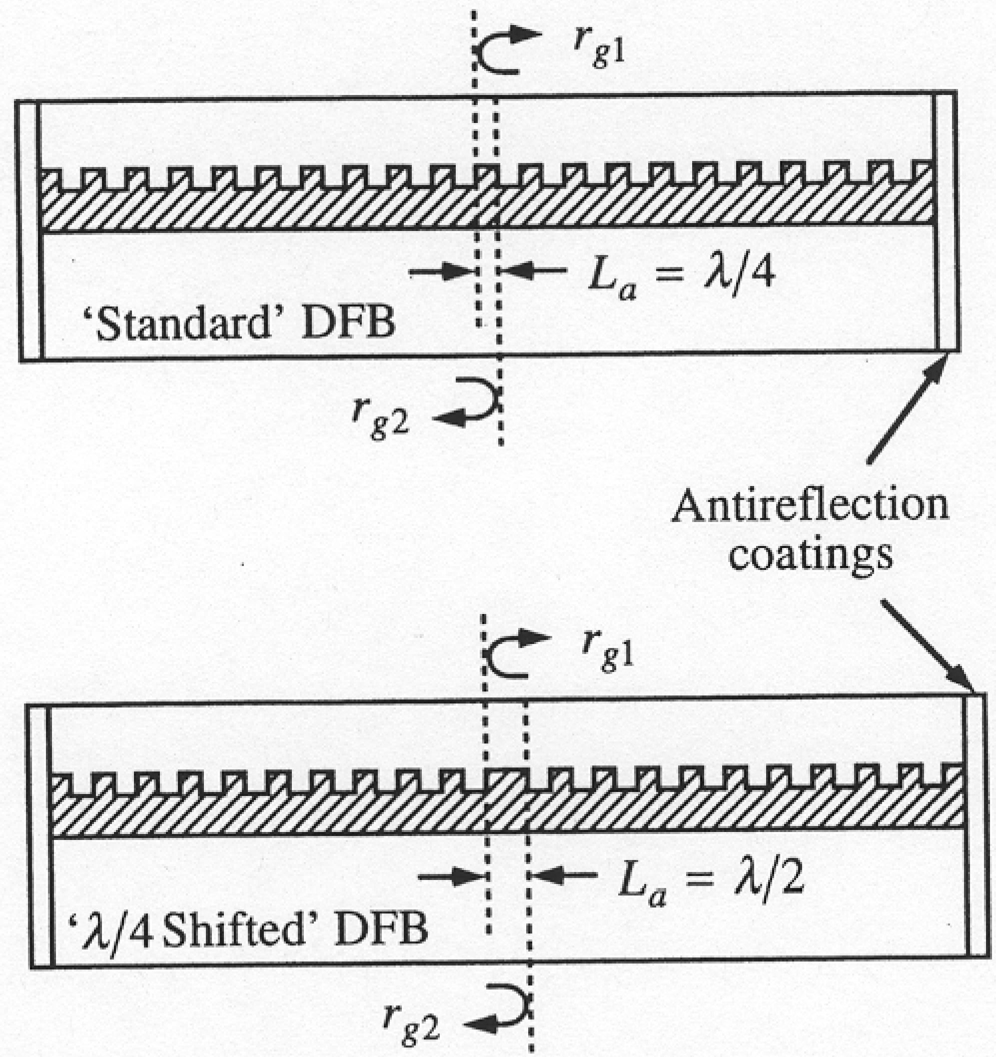
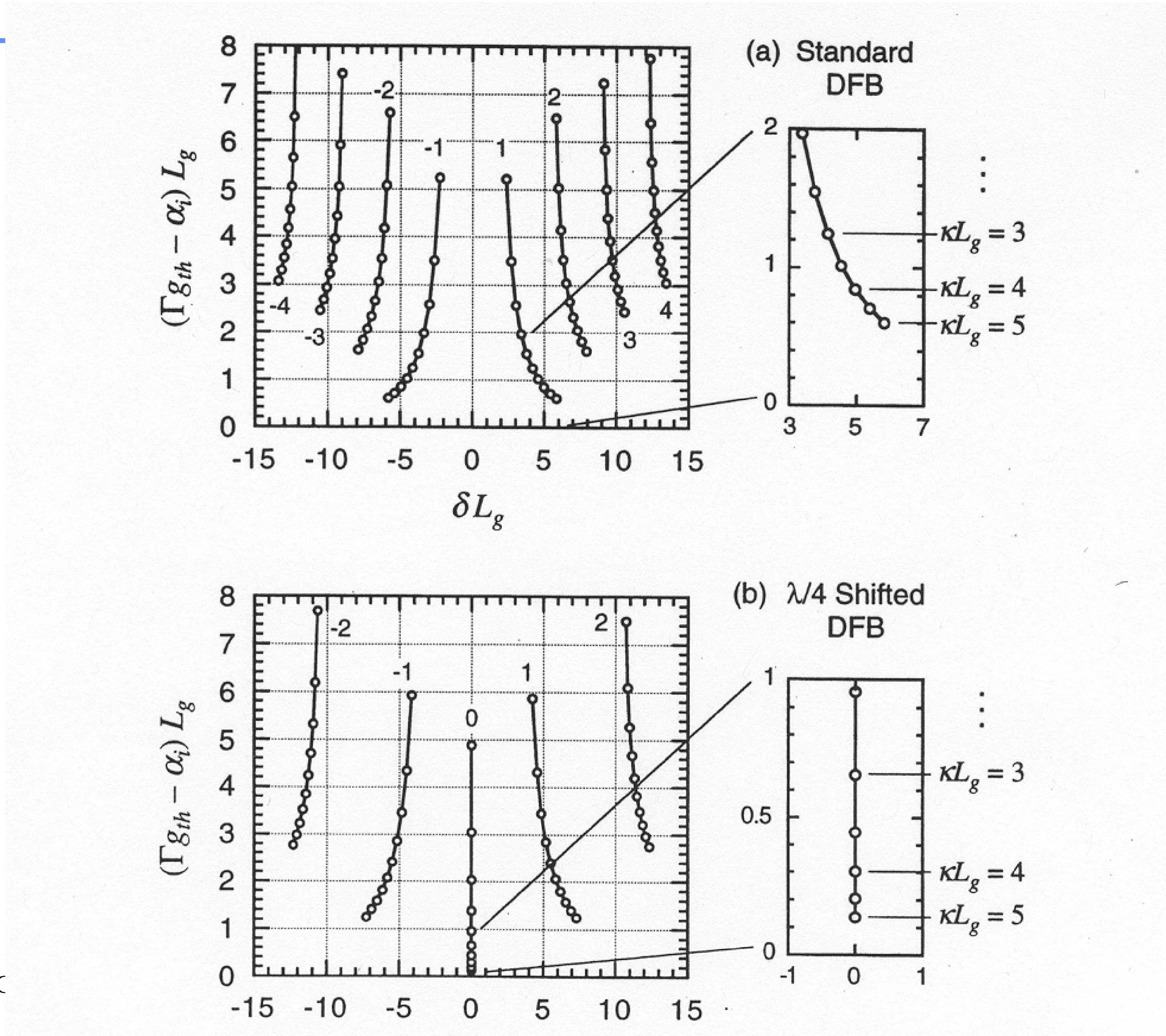
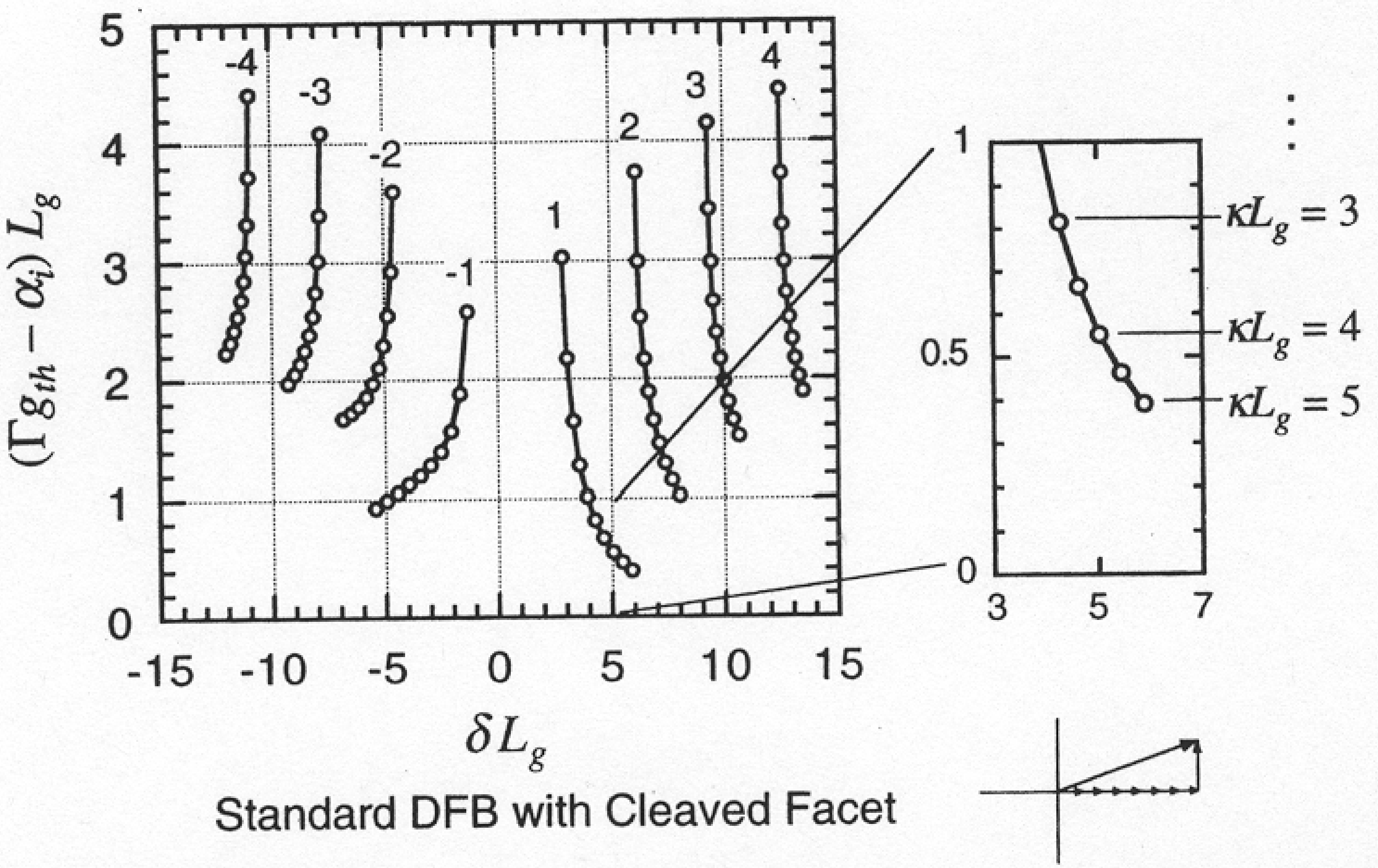


FIGURE 3.17 Standard and quarter-wave shifted DFB lasers. The entire length is filled with active material embossed with a grating.


(a) Standard DFB
$(\Gamma g_{th} - \alpha_i) L_g$
δL_g
$\kappa L_g = 3$
$\kappa L_g = 4$
$\kappa L_g = 5$
(b) λ/4 Shifted DFB
$(\Gamma g_{th} - \alpha_i) L_g$
$\kappa L_g = 3$
$\kappa L_g = 4$
$\kappa L_g = 5$



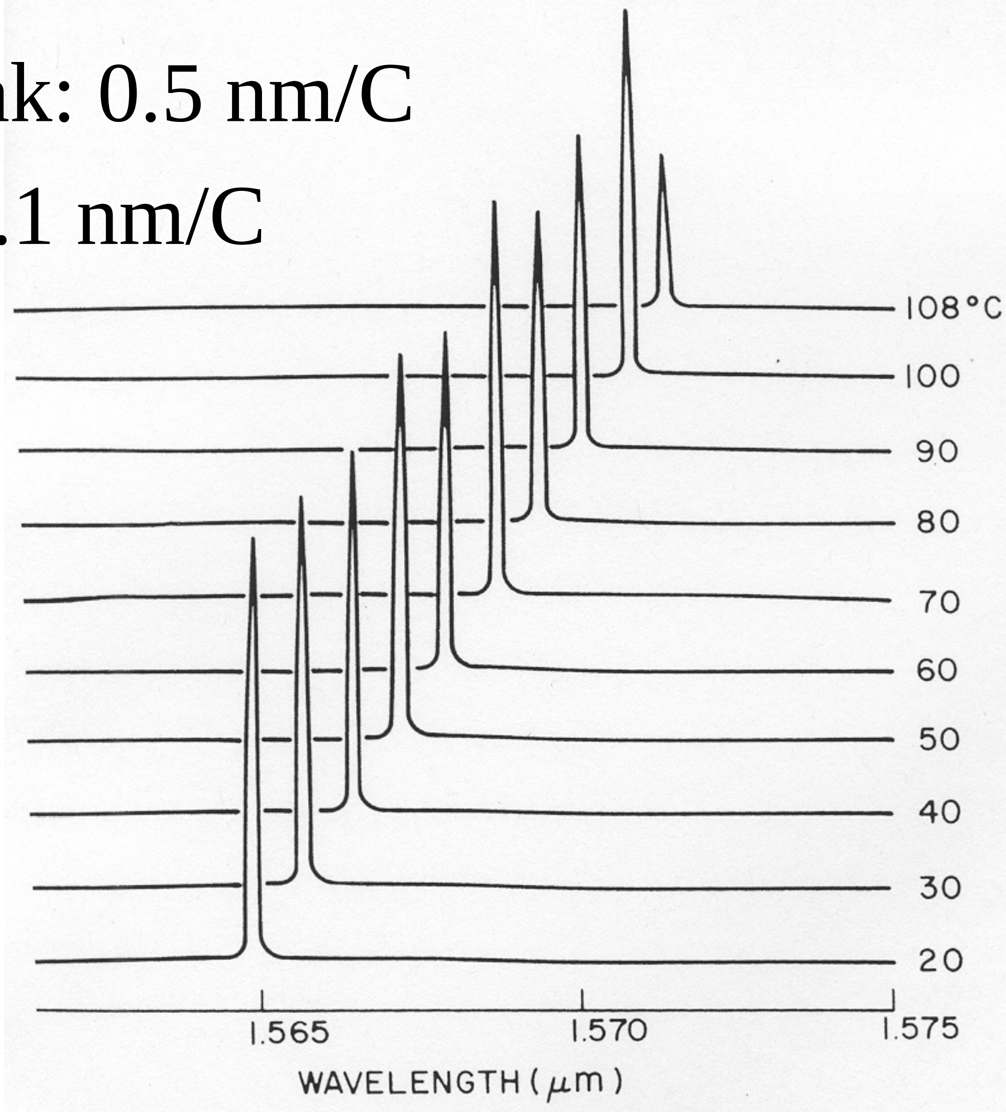
IGURE 3.19 Normalized plot of threshold modal gain and threshold wavelength for ifferent modes of a standard DFB laser with κL_g ($\equiv 2mr$) ranging from 5 to 0.5 in 0.5 icrements. One end of the laser is AR coated and the other end is cleaved such that he facet reflection (with a field magnitude of 0.565) is 90° out of phase with the small rating reflections (as illustrated in the lower right corner). Here $\delta = \beta - \beta_0$, where β ; the average propagation constant of the grating.

- The center wavelength of a laser shifts from 1.50 μm to 1.55 μm when the laser is heated from room temperature to 120 C. Is it a DFB laser?

DFB Temperature Dependence

Gain peak: 0.5 nm/C

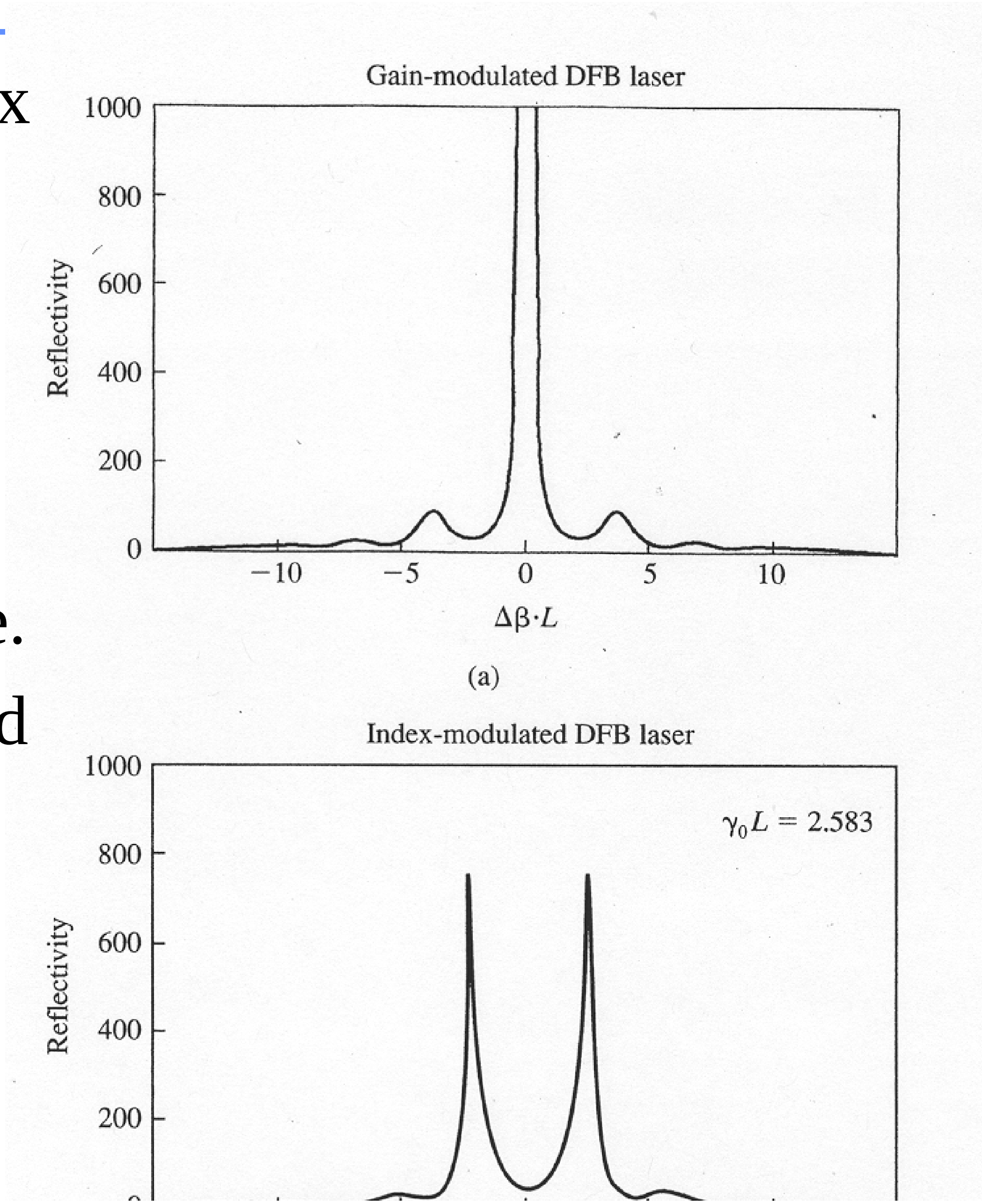
Mode: 0.1 nm/C



ɔngitudinal-mode spectra of the DCPBH DFB laser shown in Fig. 7.11 at several s. The laser maintains the same longitudinal mode while its wavelength shifts

- What is the difference between an index modulated DFB laser and a gain modulated DFB laser?
- Which is more common?

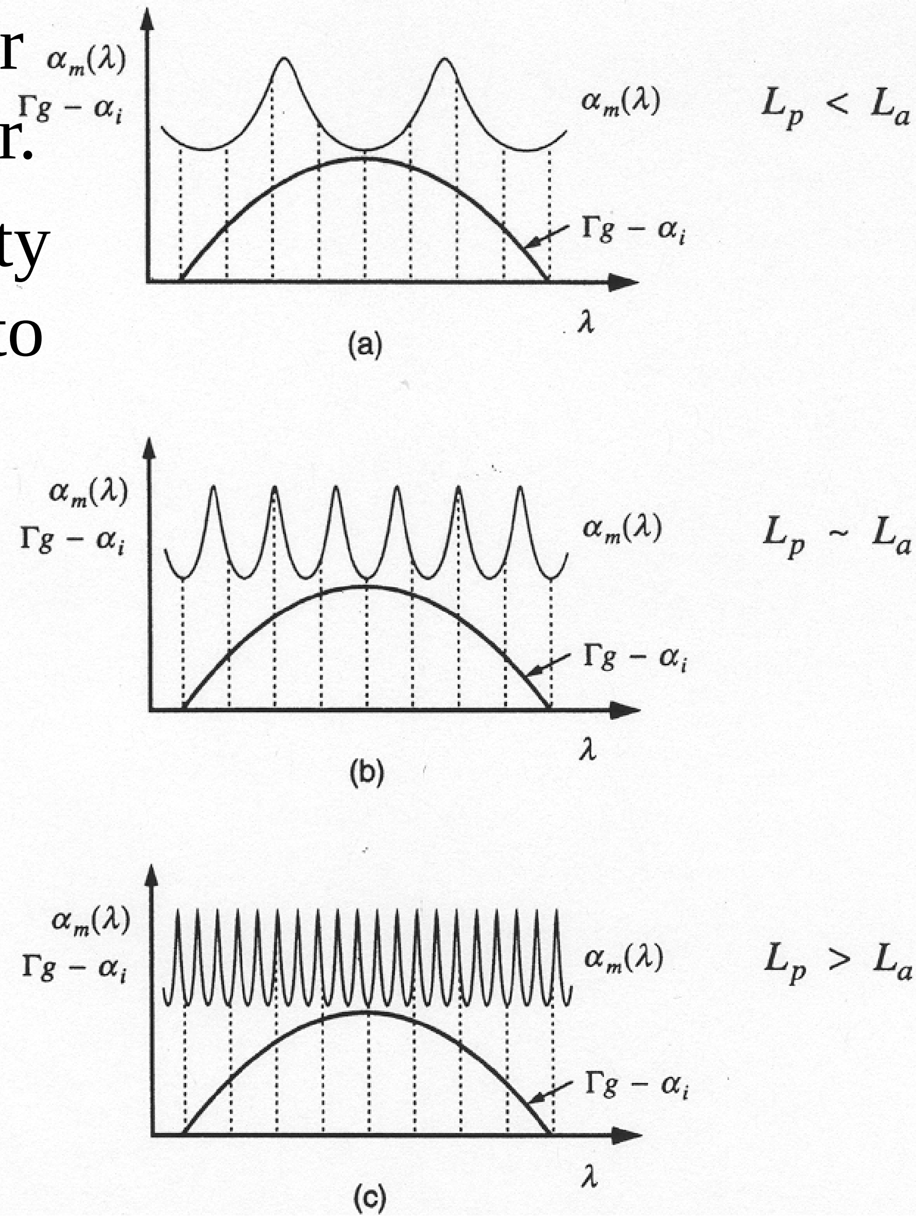
- Most DFB lasers are index modulated, formed by etching a grating in a waveguide region.
- The problem with index modulated DFBs is that two modes are degenerate.
- If the gain region is etched into a grating, then a gain modulated DFB results, which should lase in a single longitudinal mode.



What is a coupled cavity laser?

Coupled Cavity Lasers

- A coupled cavity laser is a 3 or 4 mirror laser.
- The ratios of the cavity lengths are designed to filter out just one mode.
- A C3 laser is a "cleaved coupled cavity" laser, and is formed by cleaving a laser in two.



- Explain dispersion
  - Material
  - Waveguide
  - Dispersion shifting
  - Dispersion management
  - PMD