Semiconductor Lasers

ECE 162C
Lecture #8
Prof. John Bowers

Read Kasip, Chapters 3,4
Midterm: May 5. Chapters 1-4

Lasing threshold

r_1 is the amplitude reflection coefficient.

R_1 is the power reflection coefficient

R is the average power reflection coefficient

$$R_1 = r_1^{\,2}$$

$$R = \sqrt{R_1 R_2} = r_1 r_2$$

$$R_1 R_2 e^{(\Gamma g_{th} - \alpha_i)2L} = 1$$

$$\Gamma g_{th} = \alpha_i + \frac{1}{2L} \ln \frac{1}{R_1 R_2}$$

$$\Gamma g_{th} = \alpha_i + \alpha_m = \alpha_T$$

$$\alpha_m = \frac{1}{2L} \ln \frac{1}{R_1 R_2} = \frac{1}{L} \ln \frac{1}{R}$$

$R = 0.32$ (typical for InGaAsP or GaAs Lasers)

Round trip phase

- Round trip phase must be a multiple of pi.
- The round trip cavity length must be a multiple of the wavelength

$$m\lambda = 2nL$$

- The spacing between modes is

$$\Delta\lambda = \frac{\lambda^2}{2n_g L}$$

Solve Wave Equation for Symmetric Guide

$$e(x,y,z,t) = \mathrm{Re}[E(x,y,z)e^{i\omega t}]$$

$$\nabla^2\vec{E} + \omega^2\mu\varepsilon\vec{E} = 0$$

$$\boxed{\nabla^2\vec{E} + k^2\vec{E} = 0}$$

where

$$k = \omega\sqrt{\mu\varepsilon} = \omega n / c$$

$$c = 1/\sqrt{\mu_0\varepsilon_0}$$

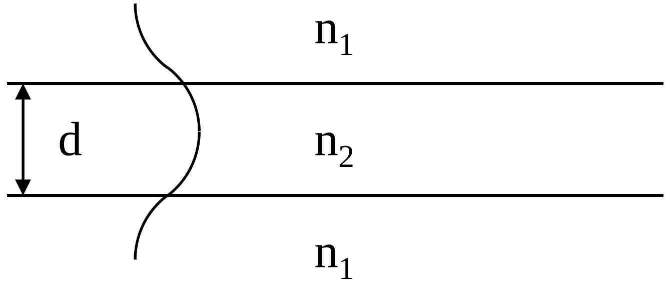
$$n = \sqrt{\frac{\mu\varepsilon}{\mu_0\varepsilon_0}}$$

Symmetric 3 Layer Guide

- Solve wave equation
  - Sinusoidal solutions and exponential solution
  - Match boundary conditions at interface
  - Apply boundary condition at infinity

$$k_x^2 = k_0^2 n_2^2 - \beta^2$$

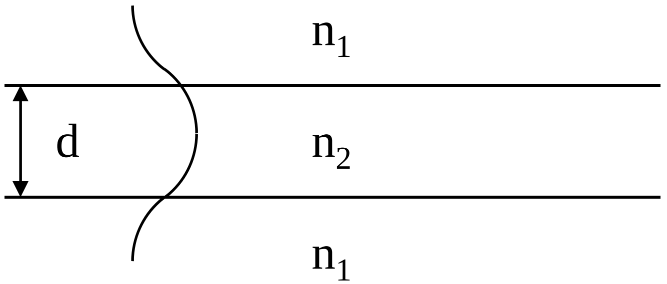
$$\gamma^2 = \beta^2 - k_0^2 n_1^2$$



$$k_x \tan \frac{k_x d}{2} = \gamma$$

Symmetric 3 Layer Guide

- Plot graphically



$$k_x^2 = k_0^2 n_2^2 - \beta^2$$

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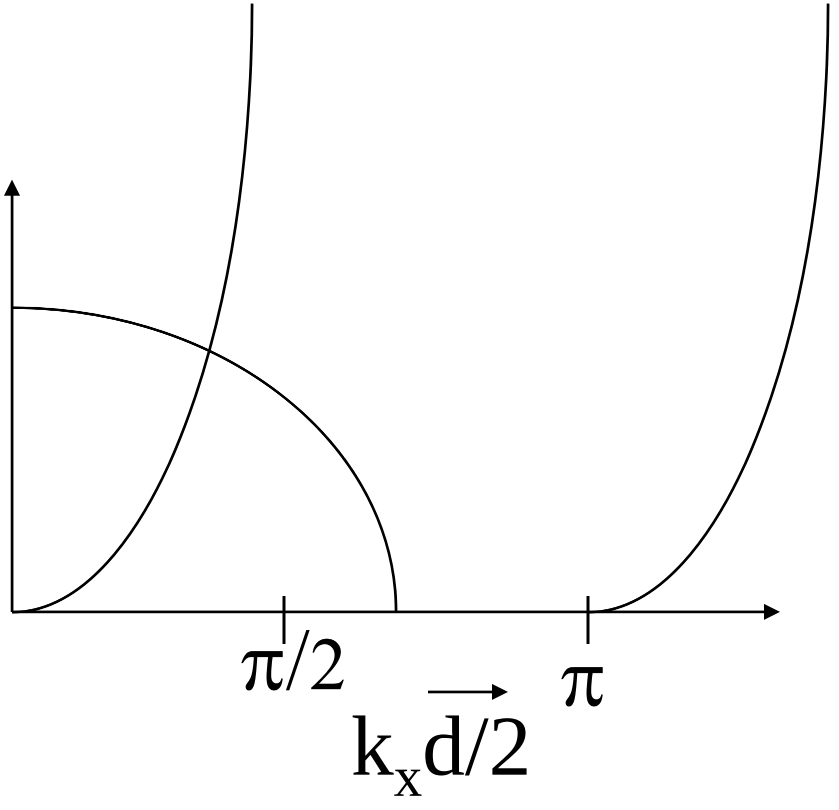
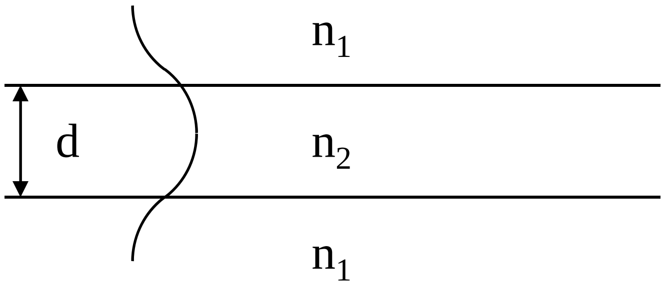
$$k_x \tan \frac{k_x d}{2} = \gamma$$

$$k_x \tan \frac{k_x d}{2} = \sqrt{k_0^2 (n_2^2 - n_1^2) - k_x^2}$$



Symmetric 3 Layer Guide

- Asymmetric solutions



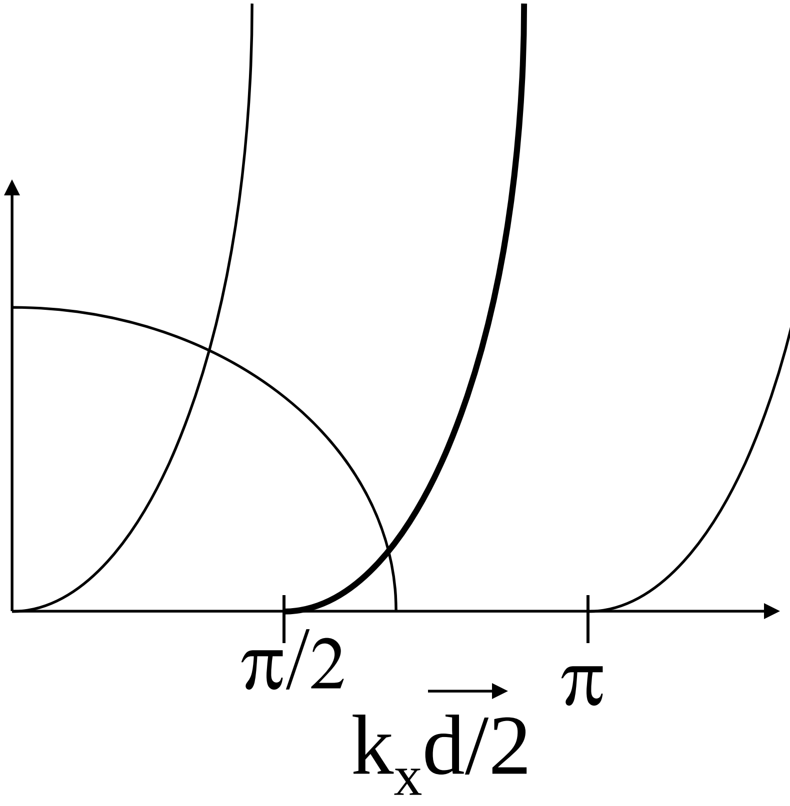
$$k_x^2 = k_0^2 n_2^2 - \beta^2$$

$$\gamma^2 = \beta^2 - k_0^2 n_1^2$$

$$k_x \cot\frac{k_x d}{2} = -\gamma$$

$$k_x \cot\frac{k_x d}{2} = \sqrt{k_0^2(n_2^2 - n_1^2) - k_x^2}$$

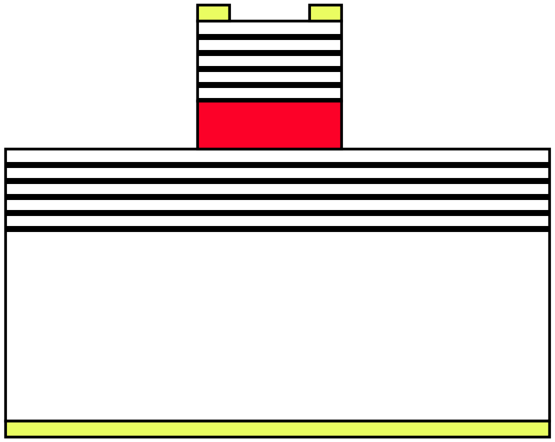
$$d < \frac{\pi}{k_0^2\sqrt{(n_2^2 - n_1^2)}}$$



Single mode condition

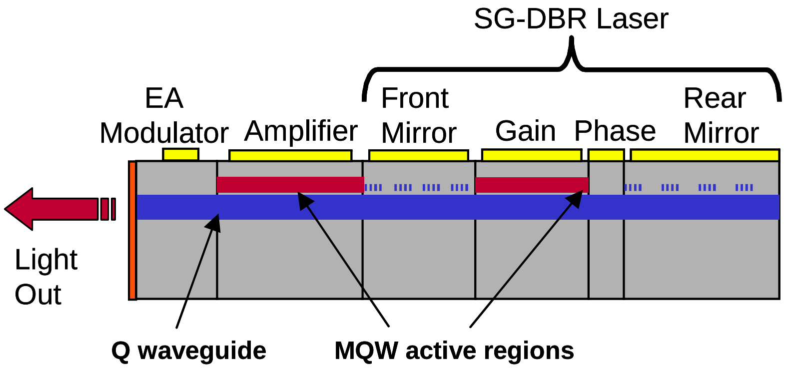
Semiconductor Lasers

- In-plane lasers
  - CD lasers, most telecom lasers
  - Simple, low cost die
  - divergence angle is large, coupling to fiber difficult
  - Requires cleaving for lasing



- Vertical Cavity Laser
  - Simple to make arrays
  - Single frequency (for small aperature)
  - Short gain section
  - Requires high reflectivity mirrors
  - Most datacom (850 nm transceivers)

Semiconductor Lasers



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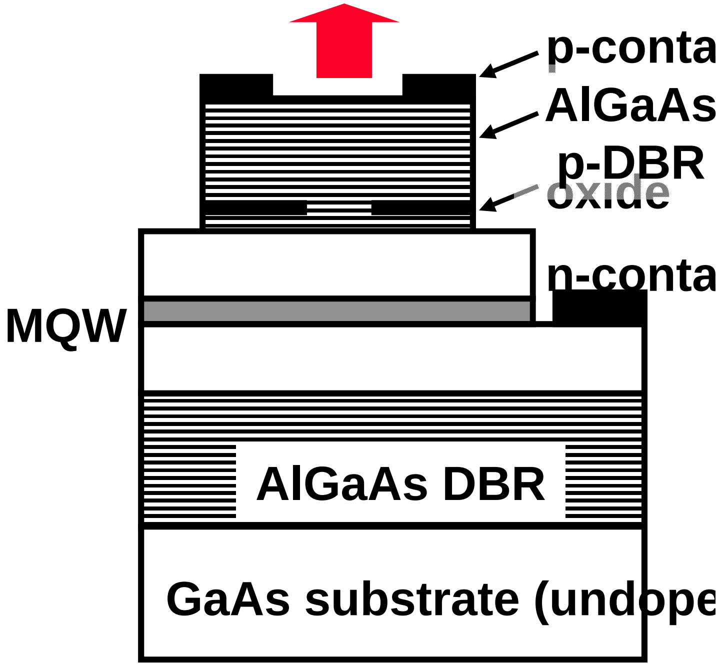

Laser Requirements

- Confinement of the optical mode
  - Transverse
  - Lateral (rib, strip, gain guided)
  - Longitudinal (cleaved facets, rings, DFB, DBR,…)
- Confinement of carriers
  - Heterojunction, etched, no confinement (implanted, diffused,…)
- Confinement of current
  - Oxide
  - Homojunction
  - PN junction
  - Semi-insulating