Lecture 7

Material and Homework

Read:
Chapter 5 Section 5.4, 5.6 Yariv and Yeh
Chapter 6 Sections 6.1-6.5 Yariv and Yeh
Chapter 3 Section 3.0-3.2 Yariv and Yeh
Chapter 15 Yariv and Yeh
Appendices 1 and 2 in Coldren (on reserve)

Homework #3
Due Tuesday, May 2, 2006

a. Derive equation 5.4-1 in Yariv starting with equation 5.3-8
b. Problem 5.1 Yariv
c. Problem 5.6 Yariv

Absorption and Amplification

- For a plane wave of frequency ν and intensity I_0 propagating in a medium with N_2 atoms in state 2 and N_1 atoms in state 1, the net power generated per unit volume is

$$\frac{P}{Volume} = (N_2 - N_1) W_i h\nu$$

- Using the previous result for Wi, we can write the incremental change in the intensity per unit length as

$$\frac{dI_0}{dz} = (N_2 - N_1) \frac{c^3 g(\nu)}{8\pi n^2 \nu^2 t_{spont}} I_0$$

- Which has solution for evolution of the intensity $I_0(z)$ defined by the gain coefficient $\gamma(\nu)$

$$I_0(z) = I_0(0) e^{\gamma(\nu) z}$$

$$\gamma(\nu) = (N_2 - N_1) \frac{c^3}{8\pi n^2 \nu^2 t_{spont}} g(\nu)$$

Note gain increases exponentially with linear increase in N_2-N_1

Note absorption as N_2-N_1<0

Absorption and Amplification

- The absorption and amplification can also be described using the electric susceptibility and this description must be consistent with the prior description using the induced transition rate $W_i(\nu)$

$$\frac{P}{Volume} = (N_2 - N_1)W_i(\nu)h\nu = \frac{\omega\varepsilon_0\chi''(\nu)}{2}|E|^2$$

- Which leads to a solution for χ'' assuming a Lorentzian lineshape for $g(\nu)$

$$\chi''(\nu) = (N_2 - N_1)\frac{\lambda^3}{16\pi^2 n t_{spont}} g(\nu)$$

$$= (N_2 - N_1)\frac{\lambda^3}{16\pi^2 n t_{spont}} \frac{1}{\Delta\nu\left[1 + \left(\frac{2(\nu - \nu_0)}{\Delta\nu}\right)^2\right]}$$

- Comparing the equation for χ'' above and $\gamma(\nu)$ on the previous slide, we can write

$$\gamma(\nu) = -\frac{2\pi}{\lambda n}\chi'' = -\frac{k}{n^2}\chi''$$

Laser Oscillation Frequency

- Now, back to Chapter 6, Section 6.2 in Yariv.
- Since the phase part of the Fabry-Perot cavity is satisfied for an infinite number of frequencies, the laser oscillation will occur at those frequencies where both the gain condition and the phase condition occur (where $\nu_m = mc/2nl$)

$$kl\left(1+\frac{\chi'(\nu)}{2n^2}\right) = m\pi = \frac{\pi 2nl}{c}\nu_m$$

- Using our prior derivation of χ' and χ'' to relate the two, which we also expect from Kramers-Kronig

$$\chi'(\nu) = \frac{2(\nu_0-\nu)}{\Delta\nu}\chi''(\nu)$$

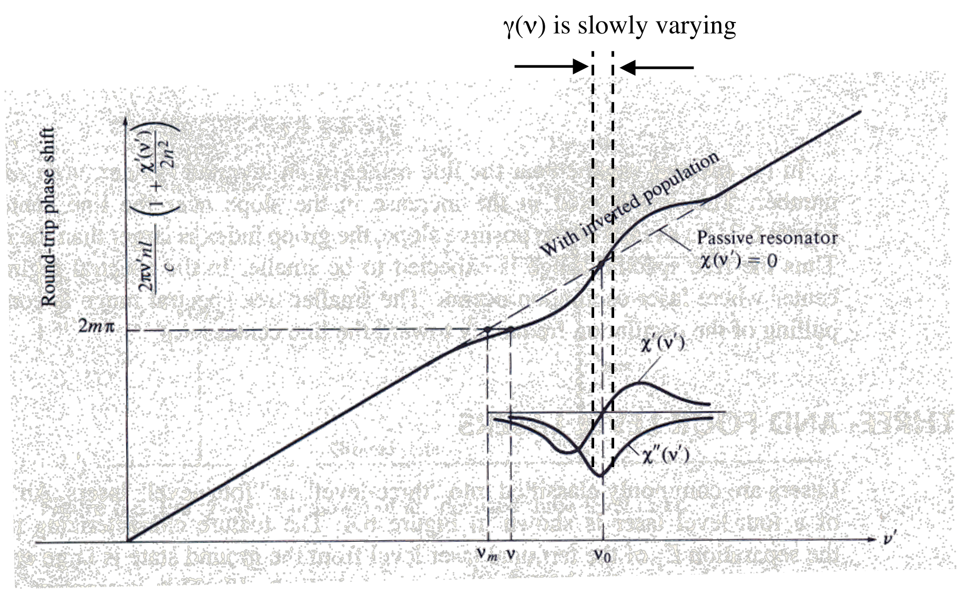
- Combining this the relation with the one on prior slide that relates $\gamma(\nu)$ and $\chi''(\nu)$ the oscillation frequency of the laser is

$$\nu\left[1-\left(\frac{\nu_0-\nu}{\Delta\nu}\right)\frac{\gamma(\nu)}{k}\right] = \nu_m$$

Laser Oscillation Frequency

- How can we understand the laser oscillation condition?
- Assume the resonator length is adjusted so that ν_m is very close to the atomic resonance peak ν_0.
- Also assume that $\gamma(\nu)$ is slowly varying when $\nu \sim \nu_0$
- Then can replace $\gamma(\nu) \Rightarrow \gamma(\nu_m)$ and $(\nu - \nu_0) \Rightarrow (\nu - \nu_m)$ and the oscillation frequency is given by

$$\nu = \nu_m - (\nu_m - \nu_0)\frac{\gamma(\nu_m)c}{2\pi n \Delta\nu}$$

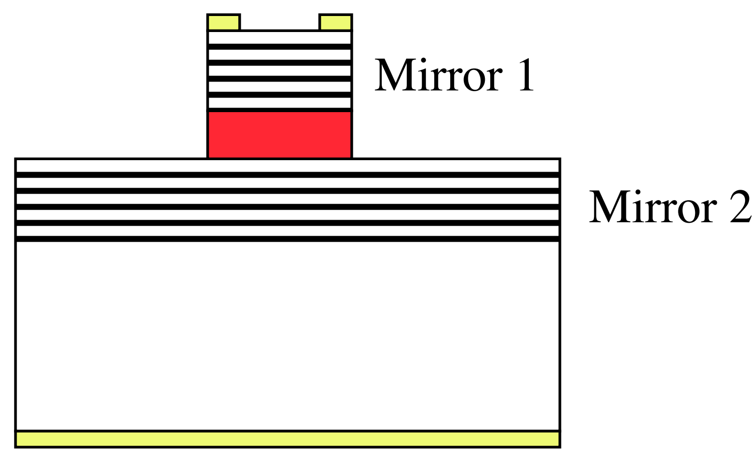


Yariv and Yeh, Photonics

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)



Guiding

- Gain guided
  - simple
  - far field not stable, poor for fiber coupling
  - higher loss
- Index guided
  - smaller mode, lower threshold
  - stable modes (mode determined by index difference, not by carrier levels

Polarization

- Transverse electric (TE) or Transverse magnetic (TM) are possible.
- Most lasers are TE.
  - The difference in confinement factor (i.e. lower modal gain for TM) and the difference in reflectivity tend to select TE operation.

Modes

- Transverse (vertical)
  - Virtually all lasers have single transverse mode; simple to obtain, only requires ability to grow thin layers (0.2 micron—not all that thin)
- Lateral modes
  - Most laser waveguides sustain multiple lateral modes (1 to 2 micron is above the single mode limit)
  - Lasers of width below 1.5 micron tend to lase single mode because the lowest order mode has the lowest threshold; higher order modes don't reach threshold
  - Lasers of width above 2 micron tend to have multiple lateral modes; difficult to couple to single mode fiber efficiently
- Longitudinal modes
  - Fabry Perot lasers tend to lase in 5-10 modes
  - Something must be done to select 1 mode

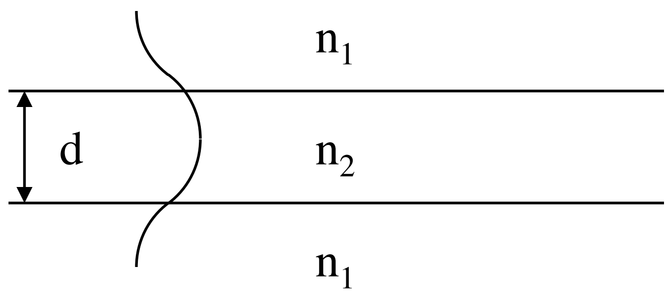
Symmetric 3 Layer Guide

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

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

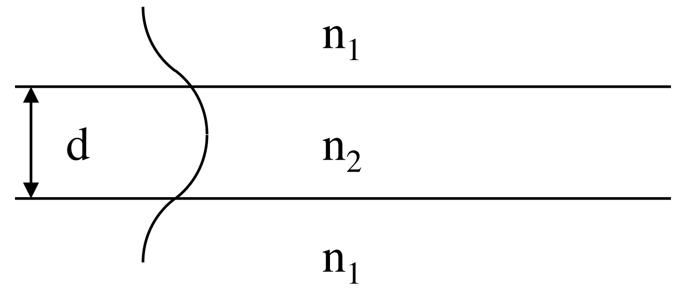
$$\gamma^2 = \beta^2 - k_0^2 n_1^2$$

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



Symmetric 3 Layer Guide

- Plot graphically

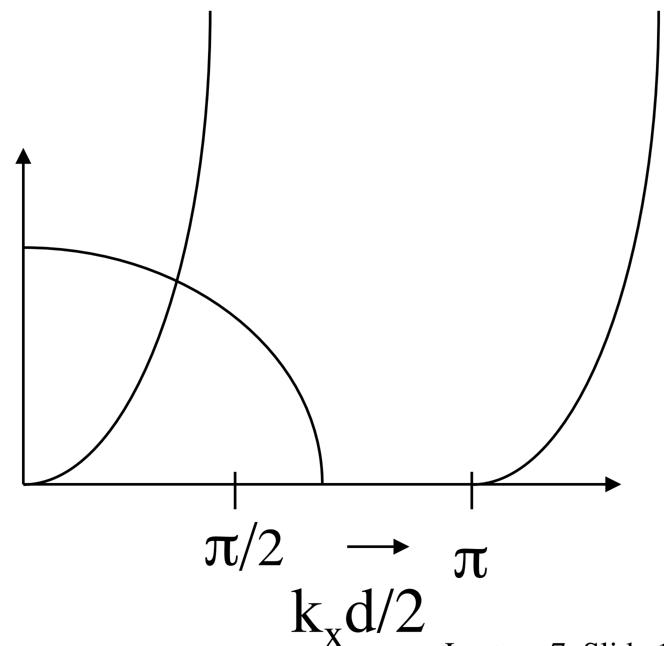


$$k_x^2 = k_0^2 n_2^2 - \beta^2$$

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

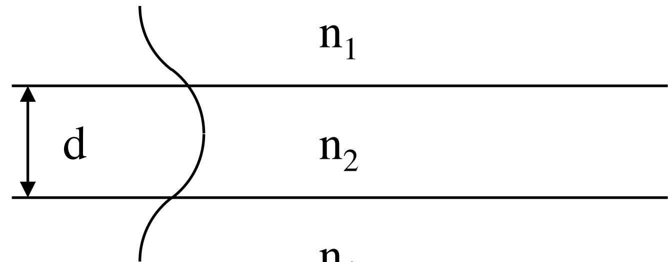
$$k_x \tan \frac{k_x d}{2} = \gamma$$

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



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