4061- Lecture Six

Outline

Mirrorless Laser

Optical Feedback
    $\gamma_{threshold}$ for cavity

Population inversion density requirements for lasing
    $\gamma \geq \gamma_{threshold}$

Requirements for Laser
    Good Cavity/Fabry-Perot

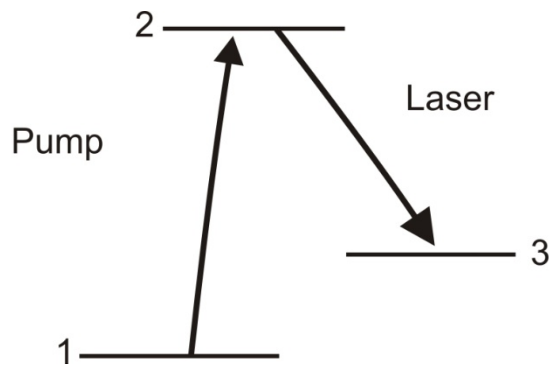
Optically pumped gas laser
    He-Ne Laser

Recall

$$I = I_o e^{\gamma z}$$
$$\gamma = \Delta n \sigma = \Delta n\, A_{21}\, (\lambda^2/8\pi)\, g(\nu_L)$$

- Independent of intensity
- "small signal gain"
- What is the amplification if $\gamma > 0$

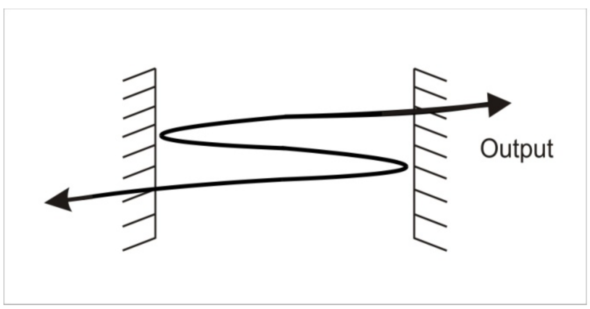
Mirrorless Laser



- Pulsed excitation to transfer population from 1 to 2 in cylindrical column
- Photons emitted (due to spontaneous emission) on the 2→ 3 transition along long axis are amplified
- Direction of output and beam size are related to sample size and shape

Example
$\gamma = 1 \times 10^{-2}$ /cm = 1 /m
L =1 m
$e^{\gamma L} = e^{(1)(1)} = 2.7$

- Incident intensity (I_o) is amplified by a factor of 2.7



Feedback

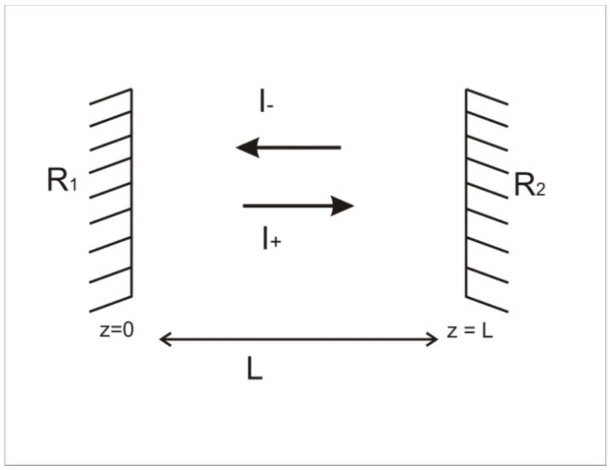
- To increase amplification, use optical feedback with mirrors

In Practice

- Amplification must overcome losses due to
  - Diffraction
  - Mirror absorption/mirror scattering
  - Coupling losses

So let us assume that medium absorption and medium scattering is small

Cavity Threshold to Sustain Laser Oscillation



- Incident Light – I
- Reflected Light – RI
- Transmitted Light – TI

$$R = r^2$$
$$T = t^2$$

- R and T are Reflection and Transmission coefficients for intensity
- r are the reflection and transmission coefficients for E field

$$E_{ref} = r\, E_{incident}$$
$$E_{trans} = t\, E_{incident}$$

Conservation of Energy

$R + T = 1$
$R + T + S = 1$

- S is scattering loss/mirror absorption

Near Threshold → Consider Roundtrip of EM wave

$$dI^+/dz = \gamma I^+ \rightarrow I^+(z) = I^+(z{=}0)e^{\gamma z}$$
$$dI^- /dz = -\gamma I^- \rightarrow I^-(z) = I^-(z{=}L)e^{\gamma(L-z)}$$

z = L

$I^+(L) = I^+(0)e^{\gamma z}$ (1)

z = 0

$I^-(0) = I^-(L)e^{\gamma z}$ (2)

Boundary Condition

$I^+(0) = I^-(0)R_1$ (3)

Using (2) gives

$I^+(0) = R_1[e^{\gamma L} I^-(L)]$ (4)

Boundary Condition

$I^-(L) = I^+(L)R_2$ (5)

Using (4) and (5) gives

$I^+(0) = R_1 e^{\gamma L} [I^+(L)R_2] = R_1 R_2 e^{\gamma L}[I^+(0)e^{\gamma z}] = R_1 R_2 e^{2\gamma L} I^+(0)$

Using (1) under the condition that $I^+(0)$ is unchanged in 1 Roundtrip

$R_1 R_2 e^{2\gamma L} = 1$

This is the Condition for sustaining laser oscillation in cavity

$I^+(0) \neq 0$

Include Medium/Mirror Losses

$R_1R_2e^{2(\gamma-\alpha)L} \geq 1$

$2(\gamma-\alpha)L = \ln(1/R_1R_2)$

- Cavity threshold gain $\gamma_{th} = \alpha + (1/2L)(\ln(1/R_1R_2))$
- Large R → small γ_{th}
- In practice we need $\gamma >> \gamma_{th}$ ie. Atomic gain should overcome cavity gain

$\Delta n A_{21}(\lambda^2/8\pi)\ g(\nu) >> \gamma_{th}$

$\Delta n \geq 8\pi\ \gamma_{th}/\ A_{21}\lambda^2 g(\nu)$

This is the inversion density required for lasing

Δn should be small since large Δn means more pump power

Substitute value for $g(\nu_o) = g_{max} = 2/\pi\Delta\nu$

$\Delta n \geq 8\pi\ \gamma_{th}\ \pi\Delta\nu/\ 2A_{21}\lambda^2$

Requirements for Reducing Δn

Need low α_{cavity}

High R_1R_2 → small γ_{th}

Long cavity → small γ_{th}

Narrow gain linewidth

Large A_{21}