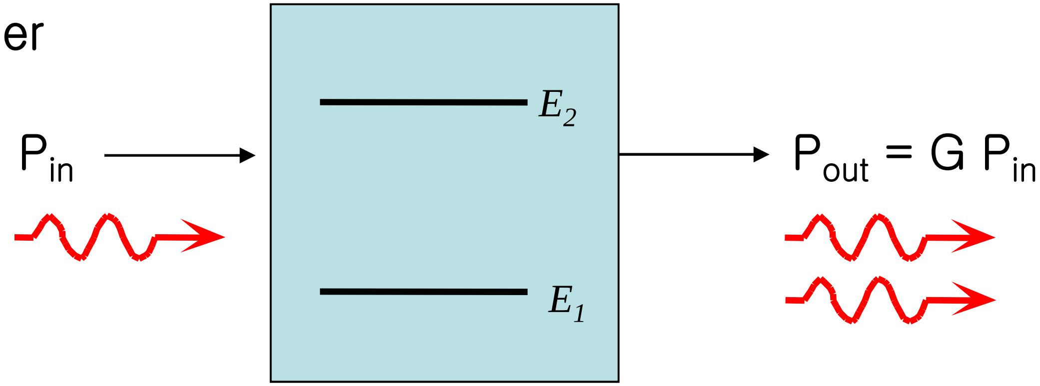
Lect. 20: Laser

Optical Amplifier



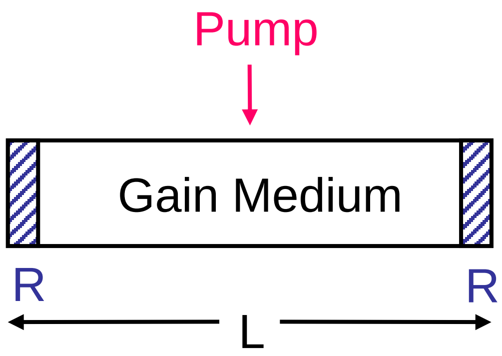
Light source based on stimulated emission?

- Use photons produced by spontaneous emission as initial seed
- Recycle output photons as seeds for further stimulated emission
- Use mirror for recycling output photons

➔ LASER: Light Amplification by Stimulated Emission Radiation

Lect. 20: Laser

LASER: Optical Amplifier + Mirror



Optical property of gain medium: n, g

$$k = nk_0 + j\frac{g}{2}$$

g depends on λ and the amount of pumping

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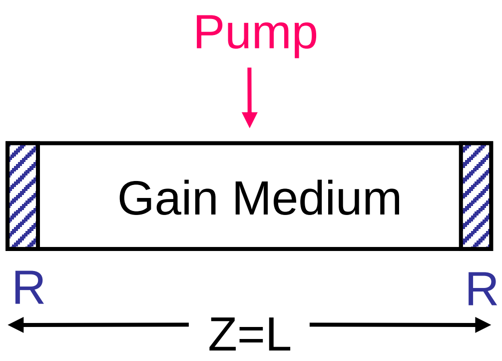


$$k = nk_0 + j\frac{g}{2}$$

Assume there is an initial photon moving in z-direction inside gain medium.

What is the condition that this photon is sustained?

➔ No loss after one round trip.

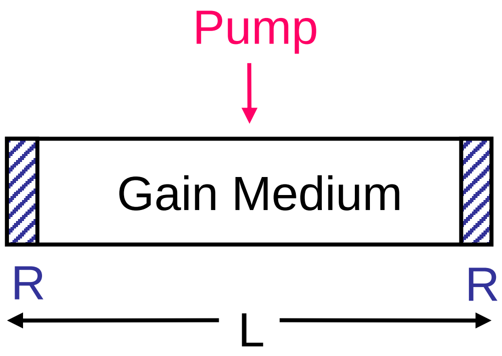
$$E_0 \cdot e^{-jkL} \cdot r \cdot e^{-jkL} \cdot r = E_0$$

$$r^2 \cdot e^{-j2kL} = 1 \qquad e^{-j2kL} = \frac{1}{r^2} = \frac{1}{R}$$

$$e^{-j2nk_0L} e^{gL} = \frac{1}{R} \qquad \therefore\ e^{gL} = \frac{1}{R} \text{ and } e^{-j2nk_0L} = 1$$

Lect. 20: Laser

$$e^{gL} = \frac{1}{R} \quad \text{and} \quad e^{-j2nk_0L} = 1$$



From $e^{gL} = \frac{1}{R}$, $g_{\text{th}} = \frac{1}{L}\ln\frac{1}{R}$

==> Sufficient gain to compensate mirror loss

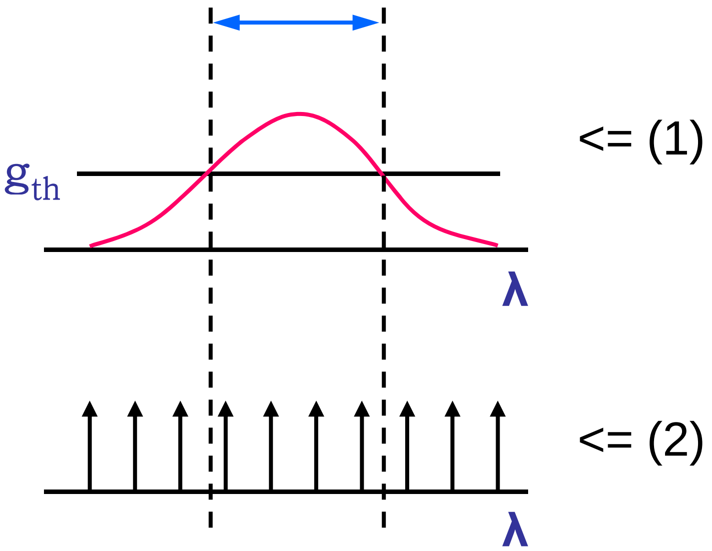
From $e^{-j2nk_0L} = 1$, $2nk_0L = 2m\pi \Rightarrow \frac{\lambda}{n} = \frac{2L}{m}$ or $L = m\frac{\lambda}{2n}$

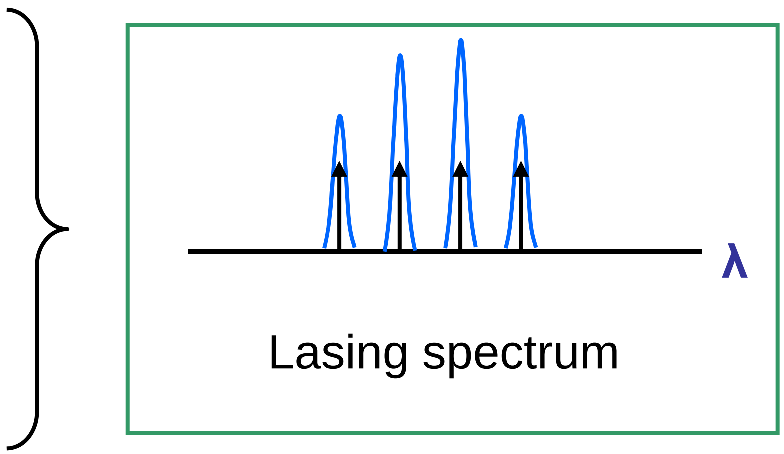
cavity length should be multiples of half wavelength

➔ Identical photons are continuously produced at two outputs

Lect. 20: Laser

Two conditions for lasing: (1) $g_{th} = \frac{1}{L}\ln\frac{1}{R}$ and (2) $\frac{\lambda}{n} = \frac{2L}{m}$





Lasing peaks (modes) has non-zero linewidth

W.-Y. Choi

Lect. 20: Laser

Various LASERs
Any optical gain material with mirrors can form a laser

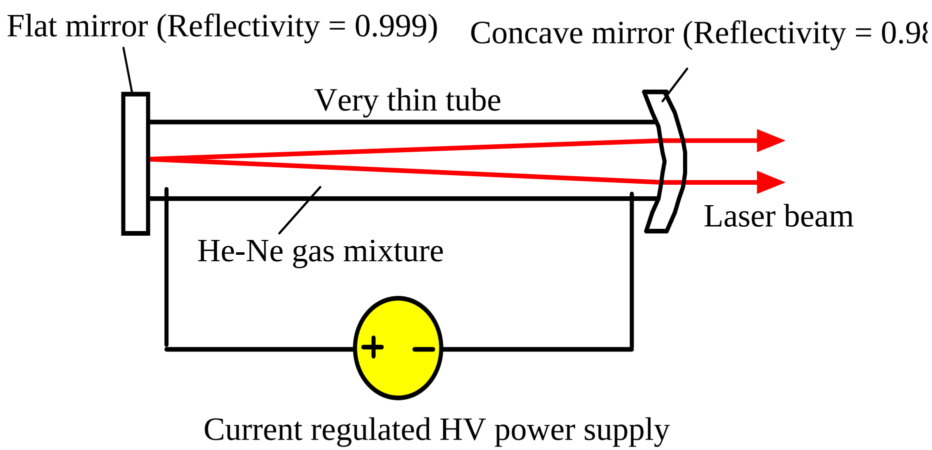
First Laser:
Ruby doped with Cr ($Al_2O_3:Cr^{3+}$)

Maiman with first laser in 1960.

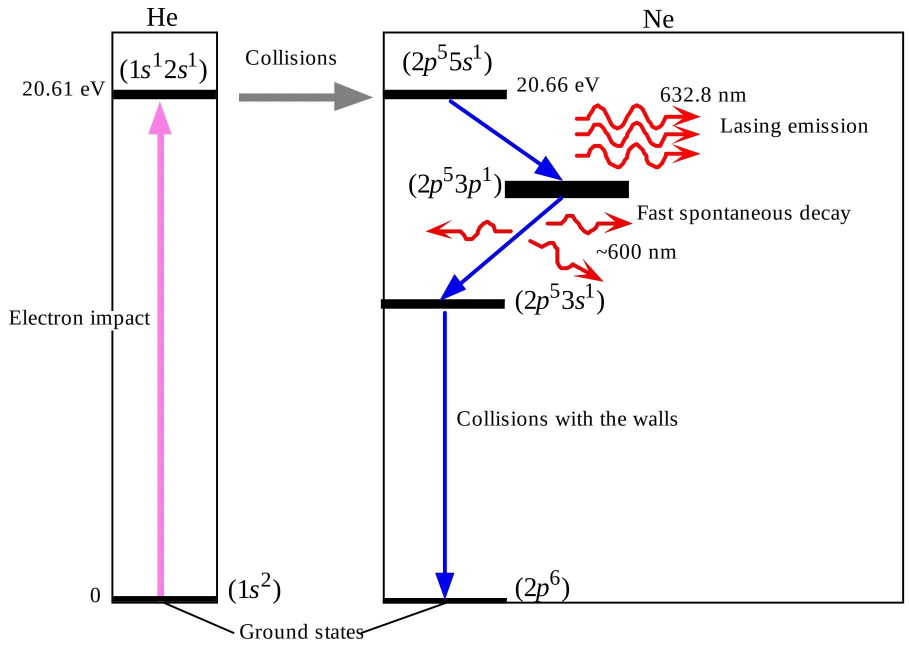
Optical Gain: Cr in Al_2O_3
Pump: Flash Lamp

Lect. 20: Laser

Gas Laser (HeNe)

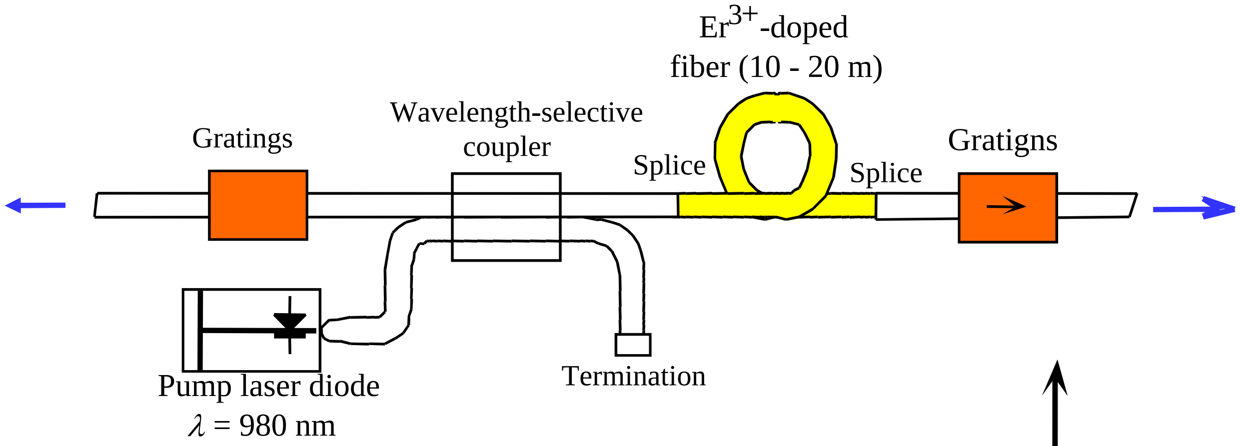


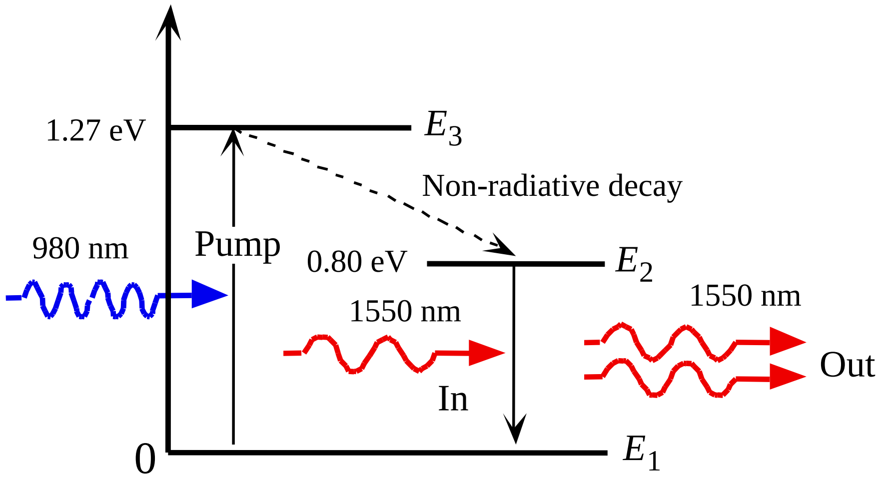
A schematic illustration of the He-Ne laser



Lect. 20: Laser

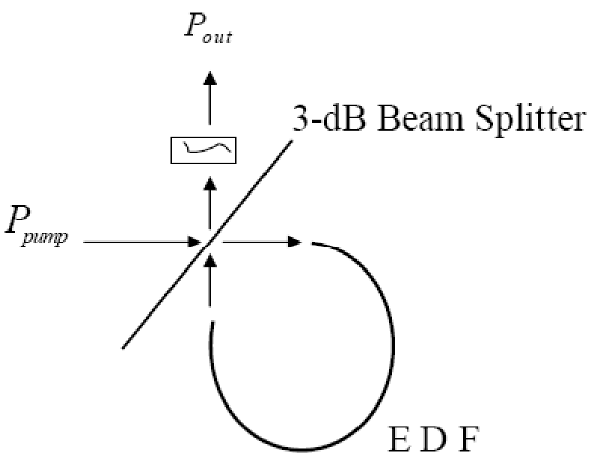
Fiber Laser





Homework (Due on Nov. 22): Prob.1 in 2003 TEST 3

A fiber ring laser lasing around 1.55μm is realized with a piece of Er-doped fiber (EDF) and a 3-dB beam splitter as shown below. The 3-dB beam splitter divides the input power into two equal output powers. Assume all the pump power transmitted by the beam splitter is absorbed by EDF and the resulting excited carriers are uniformly distributed within EDF. Also assume the reflected pump power is filtered out by an optical filter so that only the laser output is present at the output. Values of parameters that are needed to solve this problem are given below.



Γ(EDF confinement factor): 0.1

l (EDF length): 1m

g (gain in EDF) = $a(N - N_0)$

where a=10^{-24}m^{-2}, N_0=10^{25}m^{-3}

η_i (internal quantum efficiency in EDF): 1

α_{int} (internal loss in EDF): 0

τ (carrier lifetime in EDF): 1 msec

$V = 10 - 10$m3

λ_{pump} = 0.98 μm

Lect. 20: Laser

Homework (Due on Nov. 22): Prob.1 in 2003 TEST 3

(a) What is the threshold gain of the laser in 1/m?

(b) What is the excited carrier density at the threshold in $1/m^3$?

(c) What is the threshold pump power (P_{pump}) required for lasing in mW?

(d) The laser produces multi-mode lasing spectrum. What is the mode separation in wavelength at around 1.55μm?