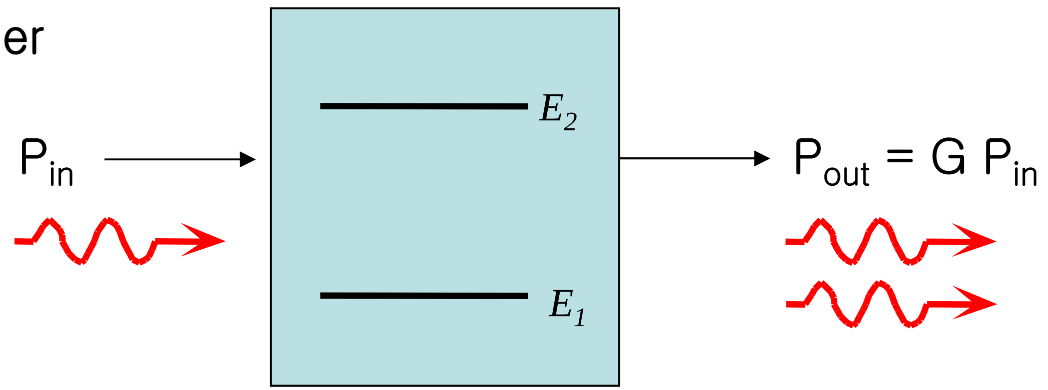
Lect. 20: Lasers

Optical Amplifier



Light source based on stimulated emission?

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

➔ LASER: Light Amplification by Stimulated Emission Radiation

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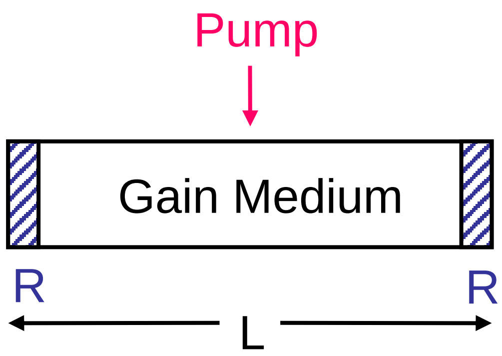
LASER: Optical Amplifier + Mirror



Optical property of gain medium: n, g

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

Imaginary part for *k* ?

g is due to absorption and stimulated emission

g depends on material property, λ, amount of pumping

factor of 2 because *g* is often defined for power

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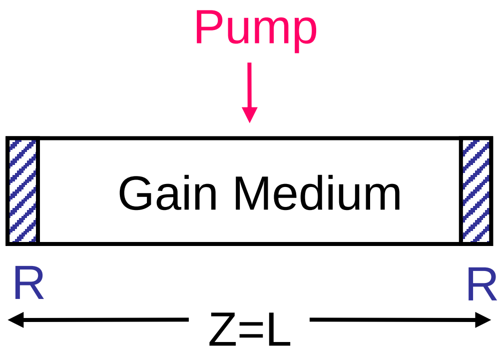

$$k = nk_0 + j\frac{g}{2}$$

Assume initially there is one photon moving in z-direction inside gain medium

What is the condition that this this photon can be maintained within?

➔ No loss after one round trip.

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

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

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

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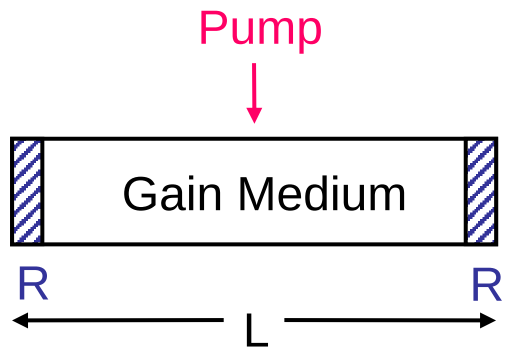
$$e^{gL} = \frac{1}{R} \quad \text{and} \quad e^{-j2nk_0L} = 1$$



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

==> 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: mode

➔ Photons are in phase after one round trip

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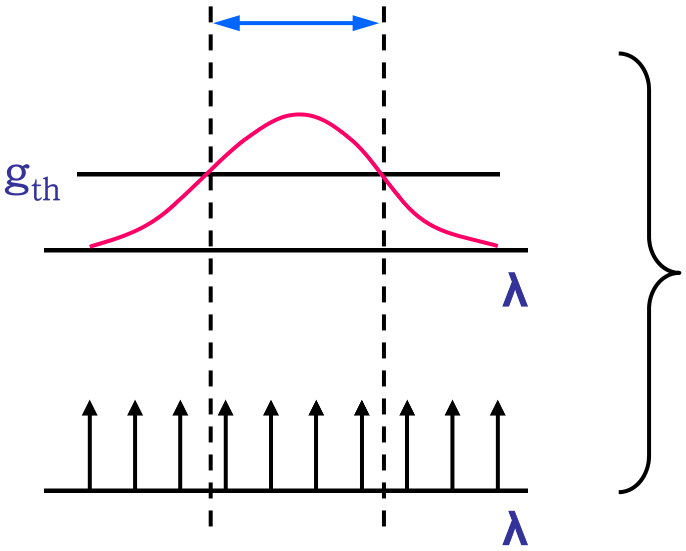
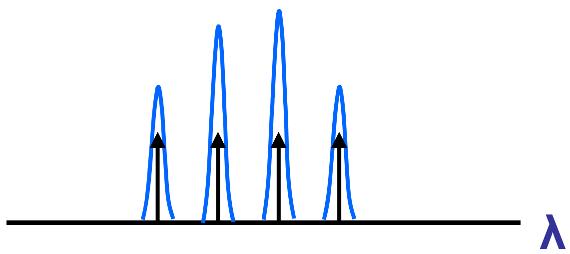
Two conditions for lasing: (1) $g_{th} = \frac{1}{L} \ln \frac{1}{R}$ and (2) $\frac{\lambda}{n} = \frac{2L}{m}$

In real lasers, gain is function of wavelength



Laser length determines mode wavelength



Lasing spectrum

Lasing modes has non-zero linewidth

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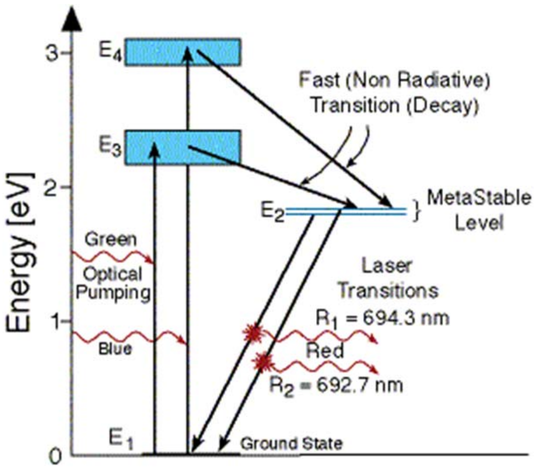
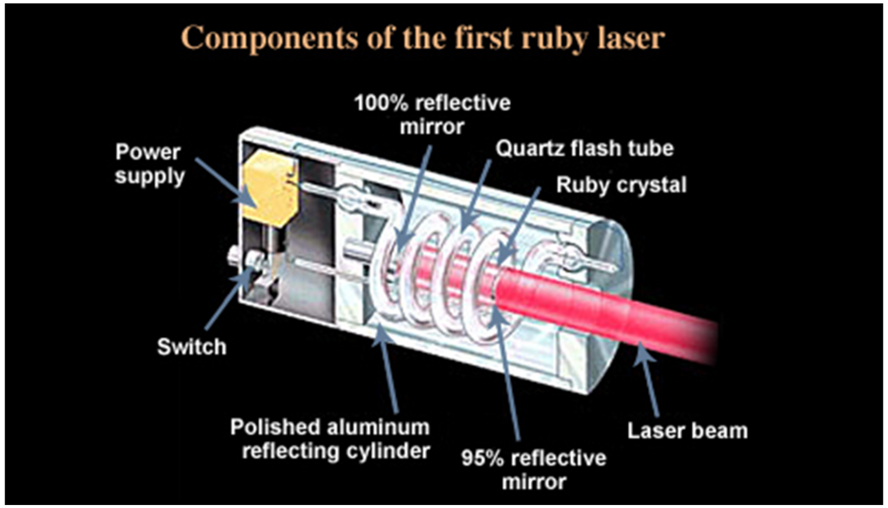
Any optical gain material with mirrors can form a laser

First working laser by Maiman in 1960
at Hughes Aircraft Company

Optical Gain Material: Cr in Al_2O_3
Pump: Xenon flash lamp

Ted Maiman
(1927-2007)





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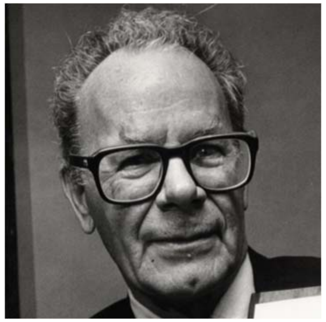
1964 Nobel Prize in Physics for invention of laser

Charles Townes
(1915-2015)
(1/2)

Nikolay Basov
(1922-2001)
(1/4)

Aleksandr Prokhorov
(1916-2002)
(1/4)



Gordon Gould
(1920-2005)

30 year battle
for laser patent

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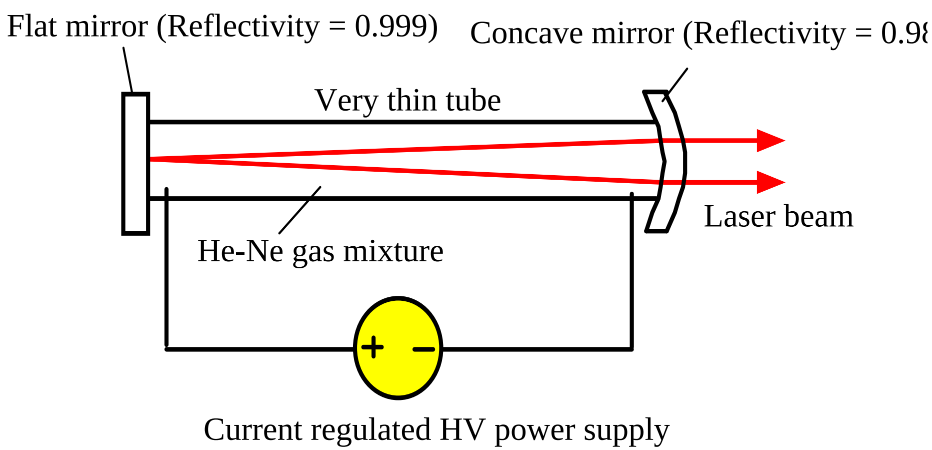
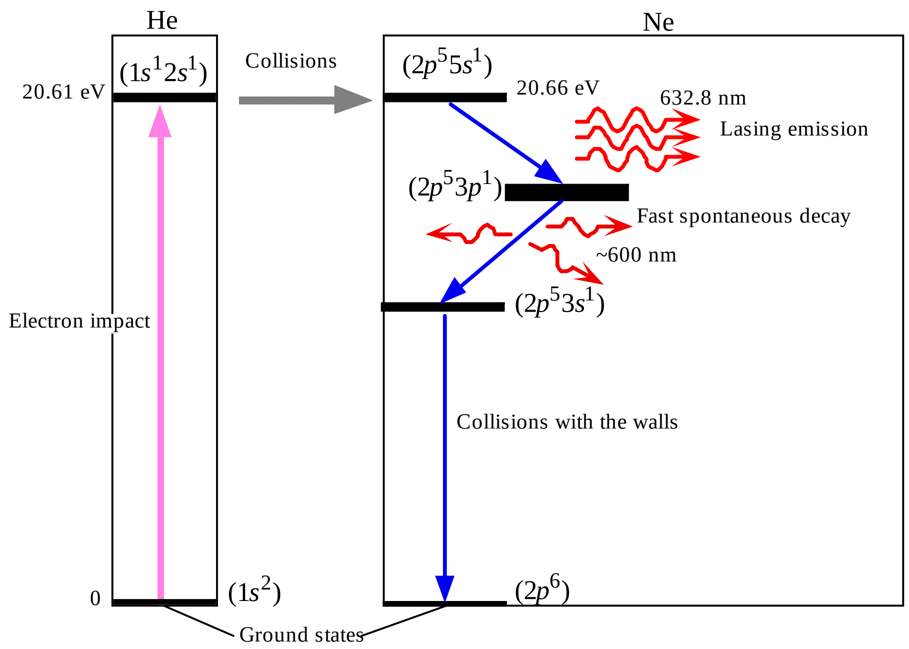
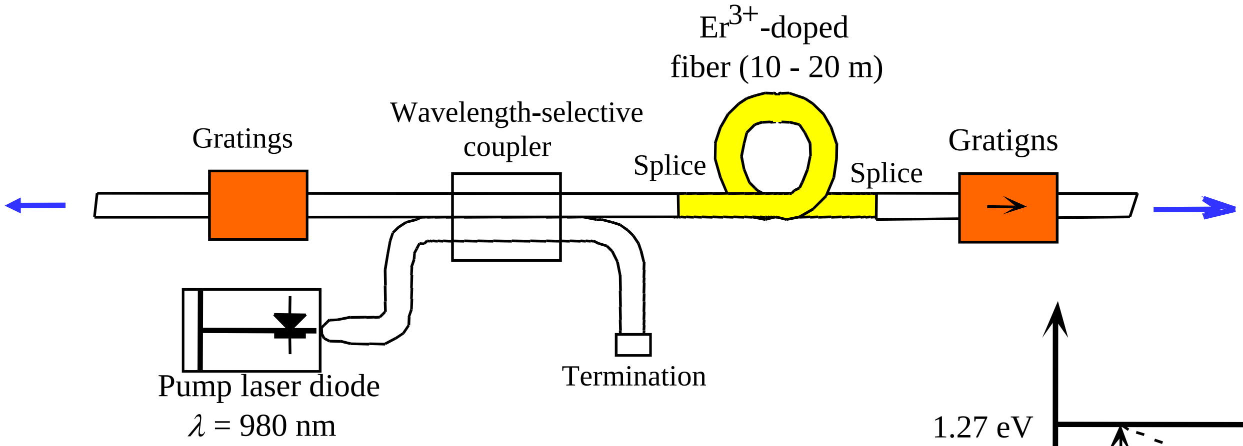
Gas Laser (HeNe)

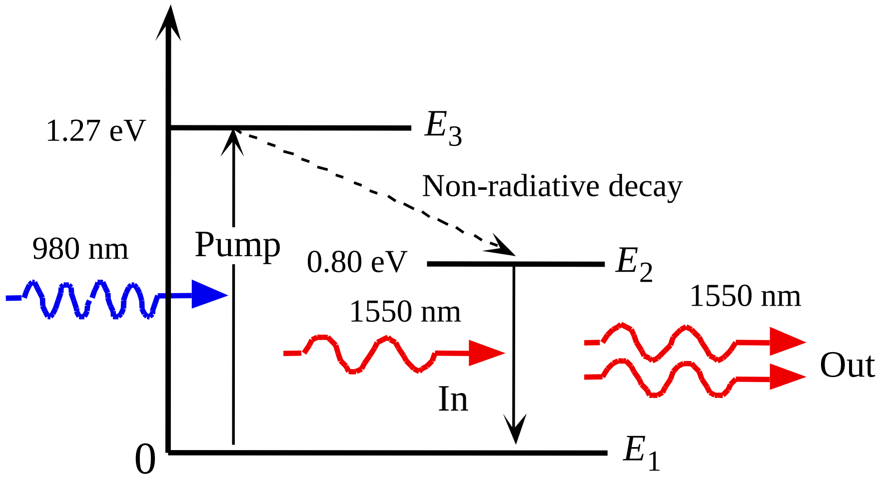


A schematic illustration of the He-Ne laser



Fiber Laser

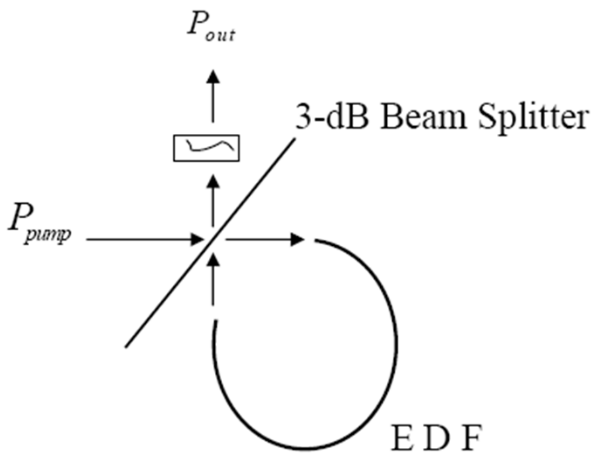




Another popular laser material: semiconductors

Homework

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 $a=10^{-24}\text{m}^{-2}$, $N_0=10^{25}\text{m}^{-3}$

$V = 10-10\text{m}3$

$\lambda_{pump} = 0.98\ \mu\text{m}$

Homework (Continued)

(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?