Opto-Electronics and Photonics

Lecture 22 : Lasers

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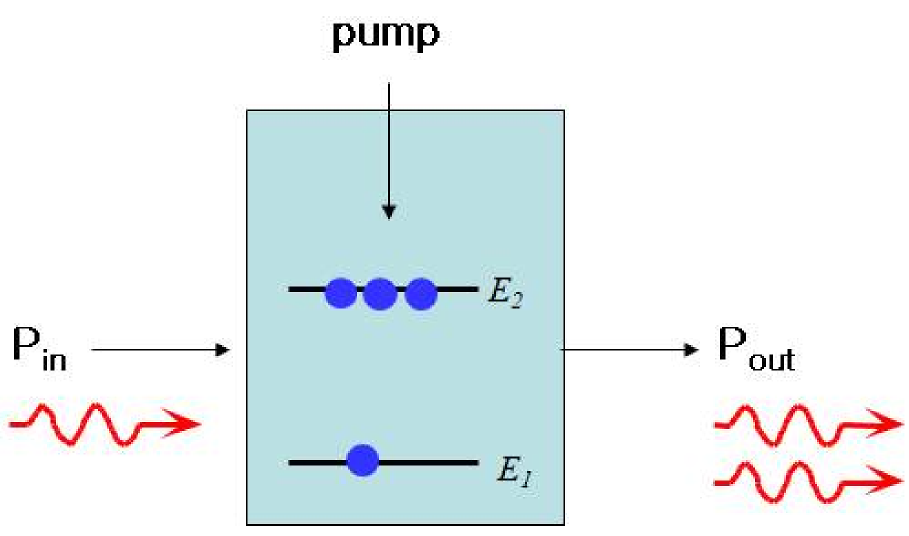
Lecture 22: Lasers

Optical Amplifier



Light source based on stimulated emission?

Laser (Light Amplification by Stimulated Emission of Radiation)

➔ Optical oscillator

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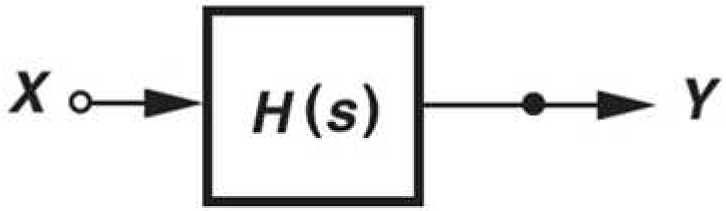
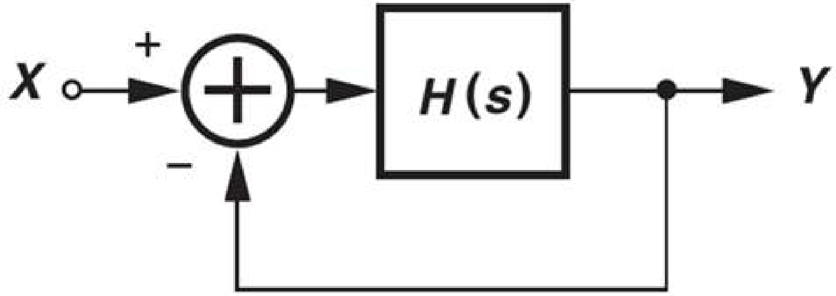
In Electronic circuits

Amplifier



With Feedback



$$Y = (X - Y)H(s)$$

$$Y\left(1 + H(s)\right) = XH(s)$$

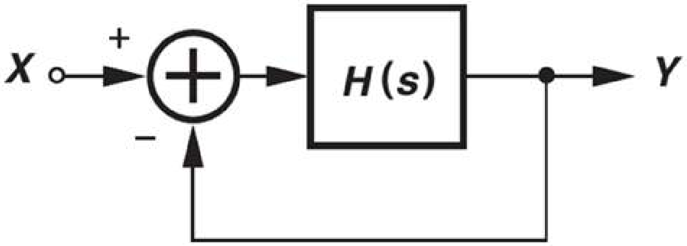
$$\frac{Y}{X} = \frac{H(s)}{1 + H(s)}$$

If $H(s) = -1$, Output without input

➔ Oscillation

$|H(j\omega)| = 1$ and $\angle H(j\omega) = 180^\circ$

(Barkhausen oscillation condition)



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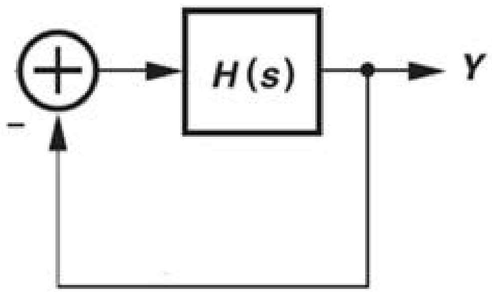

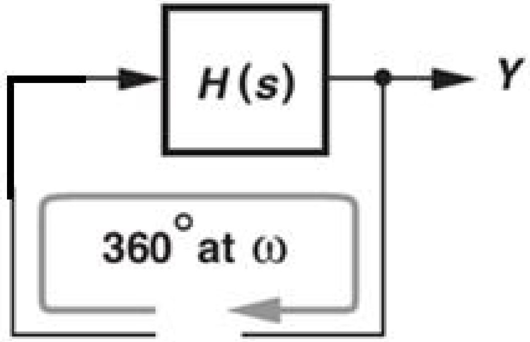

Oscillator: Amplifier with feedback

In-phase and the same magnitude after one round trip

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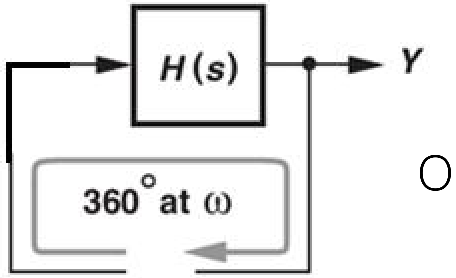
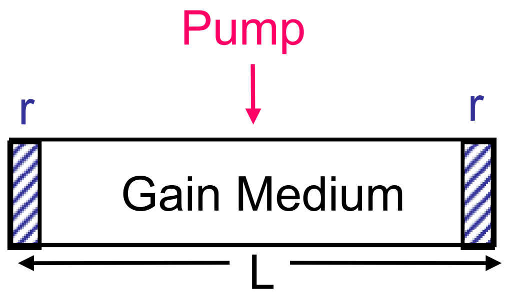


LASER:

Optical Amplifier + Mirrors



In gain medium: $$k = nk_0 + j\frac{g}{2}$$

Initially E_0

After one round trip $E_0 \cdot e^{-jkL} \cdot r \cdot e^{-jkL} \cdot r = E_0$

$$r^2 \cdot e^{-j2kL} = 1 \qquad e^{-j2kL} = \frac{1}{r^2} = \frac{1}{R} \qquad e^{-j2nk_0L} e^{gL} = \frac{1}{R}$$

$\therefore\ e^{gL} = \frac{1}{R}$ $\quad e^{-j2nk_0L} = 1$ What provides initial E_0 ? Spontaneous emission (Noise)

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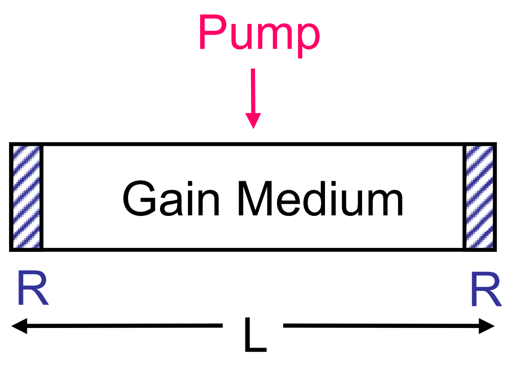

$$e^{gL} = \frac{1}{R} \quad \text{and} \quad e^{-j2nk_0L} = 1$$

$$g = \frac{1}{L}\ln\frac{1}{R}$$ (Threshold gain, g_{th})

➔ Minimum gain required for lasing (mirror loss compensation)

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

Cavity length should be integer multiples of half wavelength ➔ lasing mode

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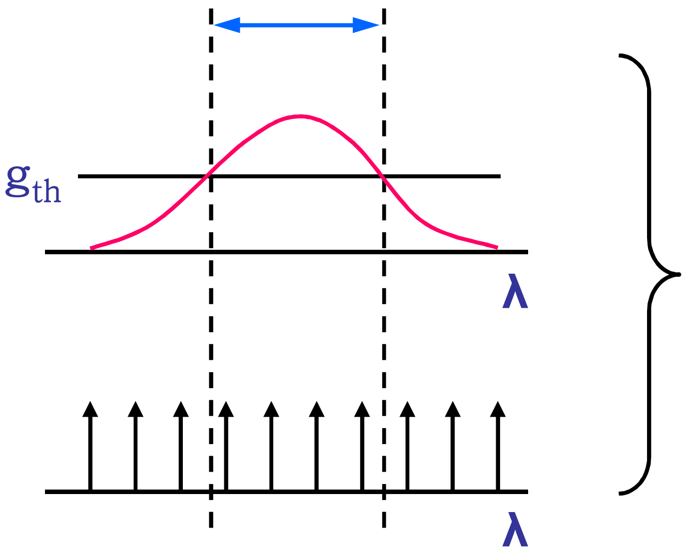
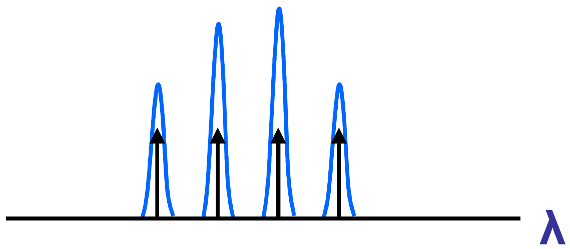
Two conditions for lasing: (1) $g_{th} = \frac{1}{L}\ln\frac{1}{R}$ and (2) $\frac{\lambda}{n} = \frac{2L}{m}$

Gain is function of pumping and λ





Lasing spectrum

Lasing modes has non-zero linewidth due to various linewidth-broadening effects

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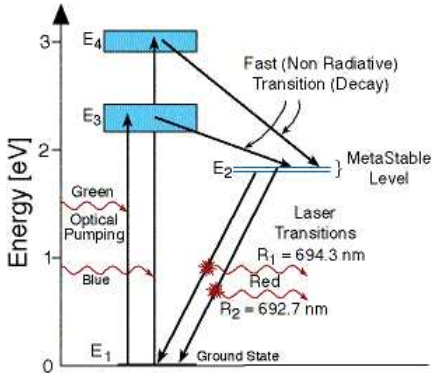
Any optical gain material with mirrors can be a laser

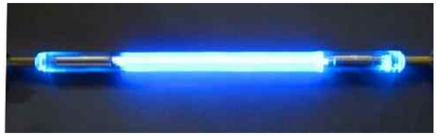
First laser demonstrated by Maiman in 1960 at Hughes Aircraft Company

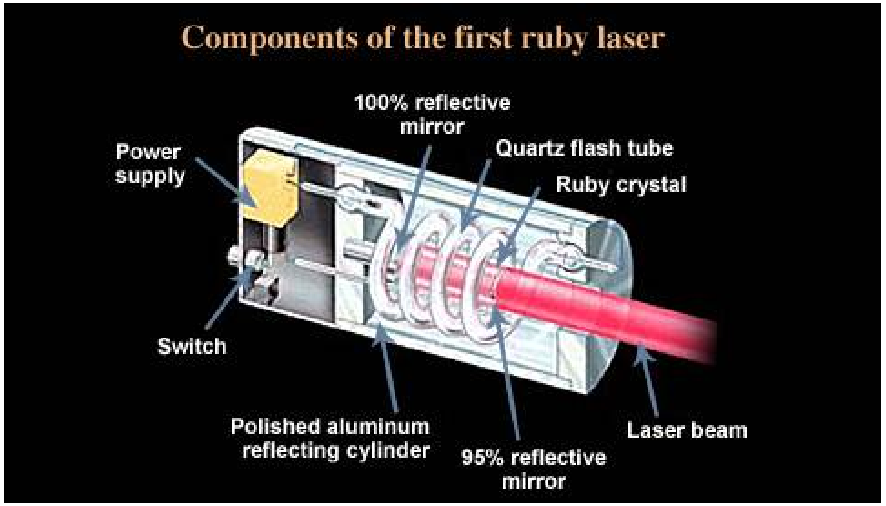
Ted Maiman (1927-2007)

Optical Gain Material: Cr in Al_2O_3



Pump: Xenon flash lamp





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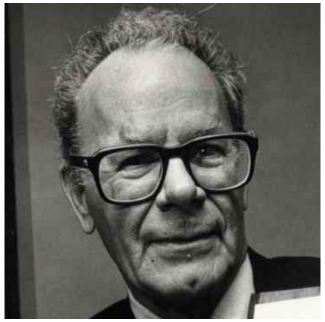
1964 Nobel Prize in Physics for invention of laser

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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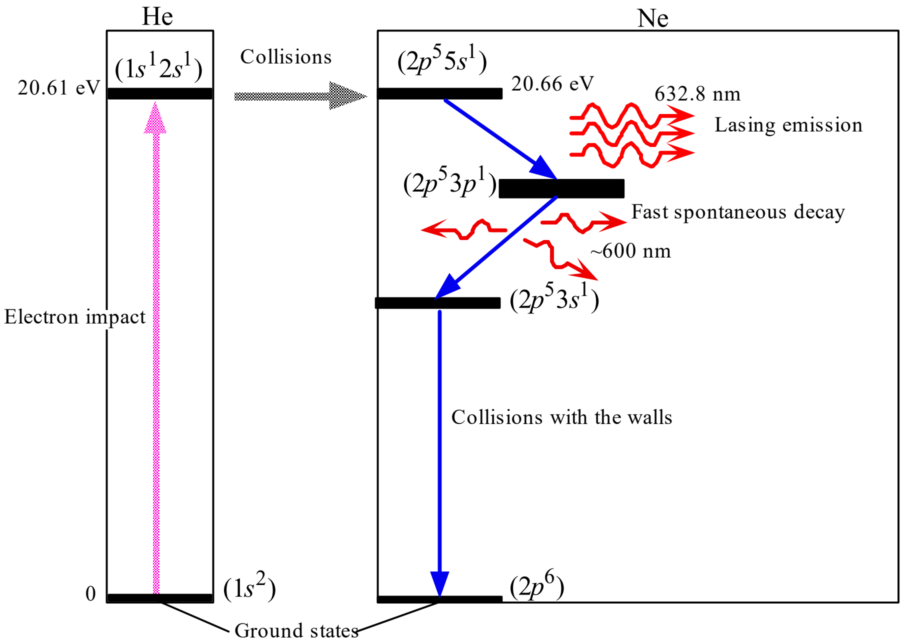
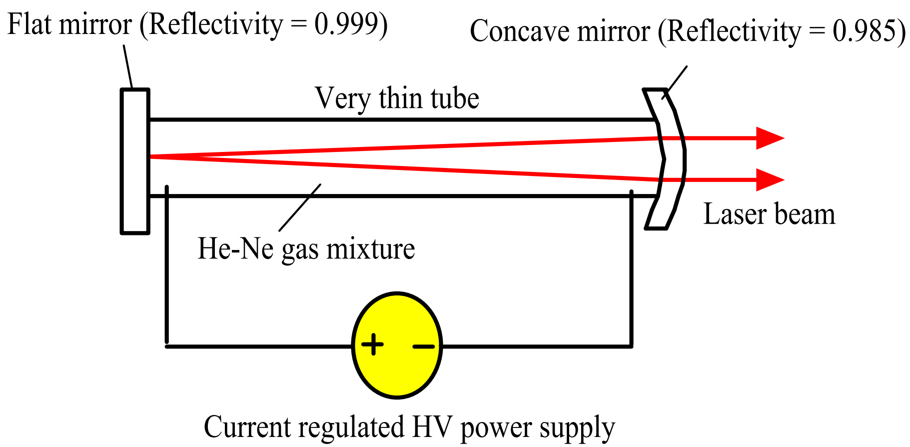
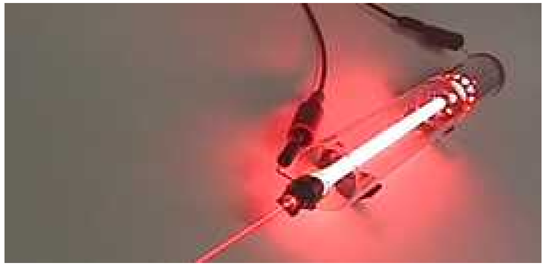
Gas Laser (HeNe)





A schematic illustration of the He-Ne laser



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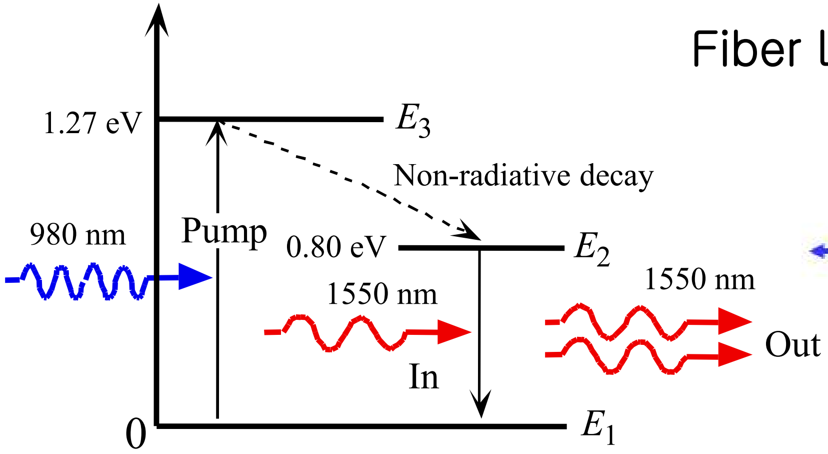
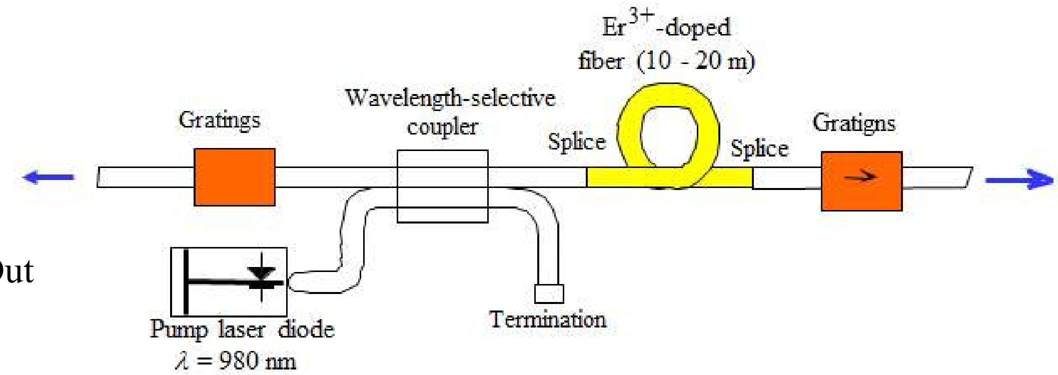


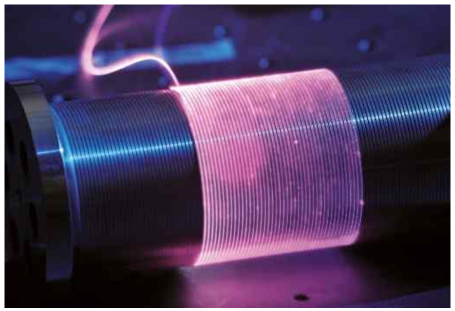
Fiber Laser with EDF

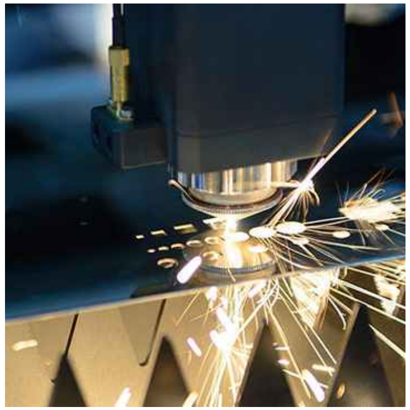


Various fiber lasers

Tm (Thulium, atomic No. 69):
1750~2100nm

Yb (Ytterbium, atomic No. 70):
1030~1100nm





Most popular laser material: semiconductors

Lecture 22: Lasers

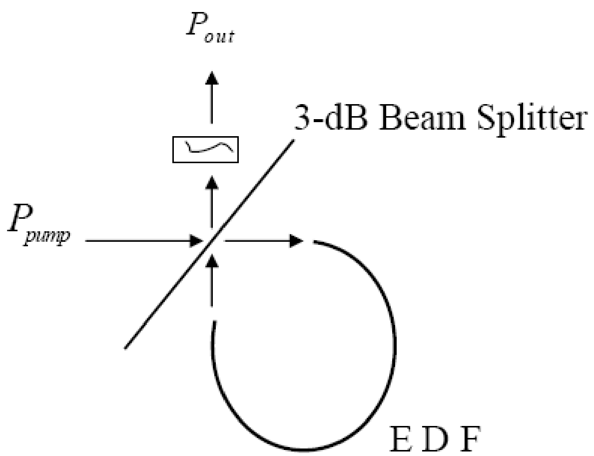
Homework (Due on 11/30)

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.

l (EDF length): 1m

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

$n_{eff}(at\ 1.55\mu m) = 1.55$



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

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