# Engineering Optics

## Lecture 22

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*by*

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# Problem

$P_1 = 0.25, P_2 = 0.5, P_3 = 0.75$ are the probability of occurrence per second of three different atoms. Which wave will be having more life time at excited state.

# Answer:

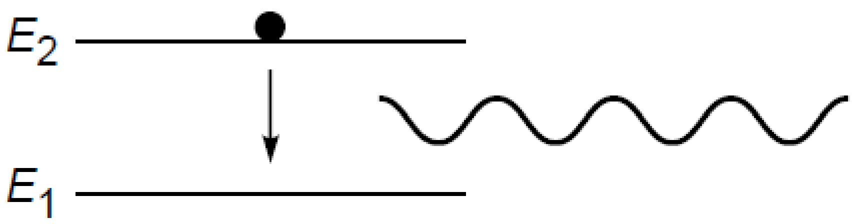
$$P \propto \frac{1}{\tau} \qquad\qquad \tau \propto \frac{1}{P}$$

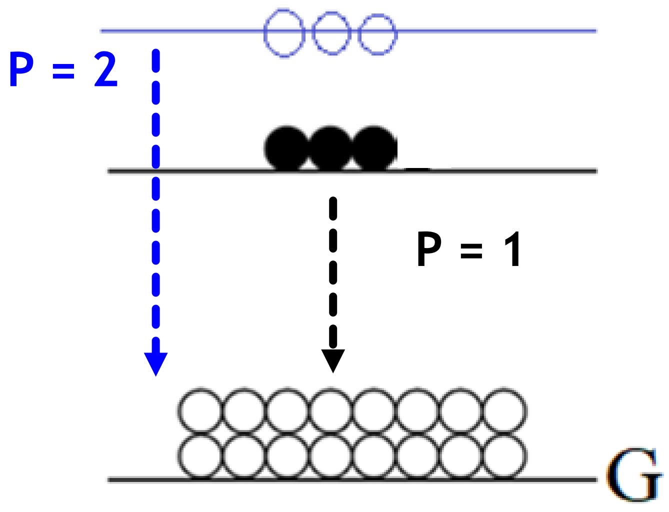
$$P_1 = 0.25, P_2 = 0.5, P_3 = 0.75$$

$\Rightarrow$ 1$^{ST}$ atom will be having more life time

# Probability and life time of a state

Keep in mind that the transition rate, the number of atoms making transitions per second, divided by the number of atoms, is the probability of a transition occurring per second, $\mathscr{P}$. Consequently, the probability per second of spontaneous emission is $\mathscr{P}_{sp} = A_{ji}$.



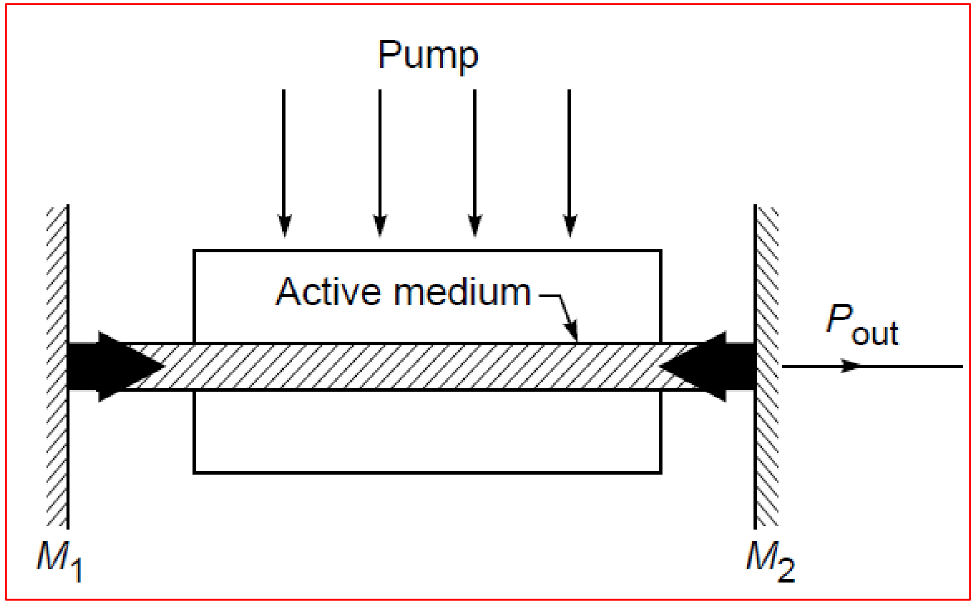

**Q: most preferred state?**

For a single excited atom making a spontaneous transition to a lower state, the inverse of the transition probability per second is the **mean life** or **lifetime** of the excited state $\tau$. Thus (operating under conditions that exclude any other mechanism but spontaneous emission), if $N$ atoms are in that excited state, the total rate of transitions, that is, the number of emitted photons per second, is $N\mathscr{P}_{sp} = NA_{ji} = N/\tau$. A low-transition probability means a long lifetime.

Optics, Hecht

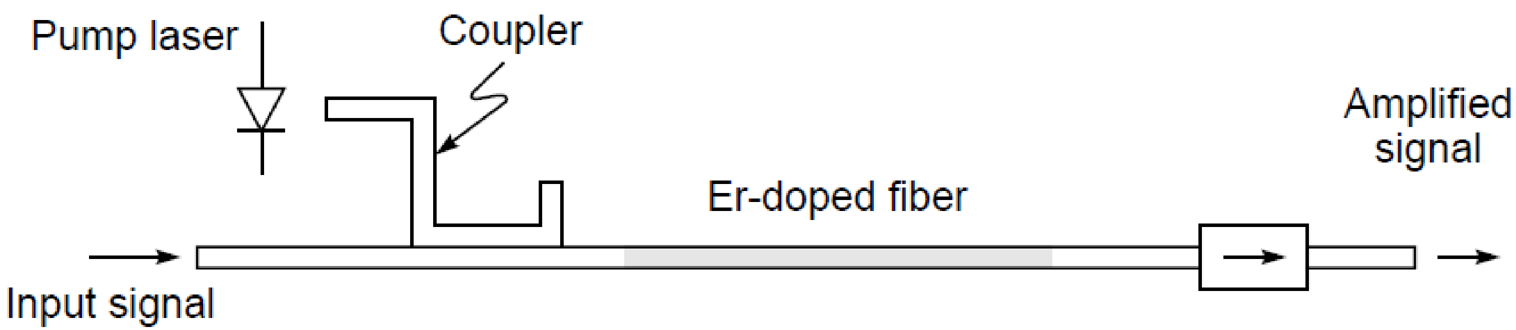
# Main Components of the Laser

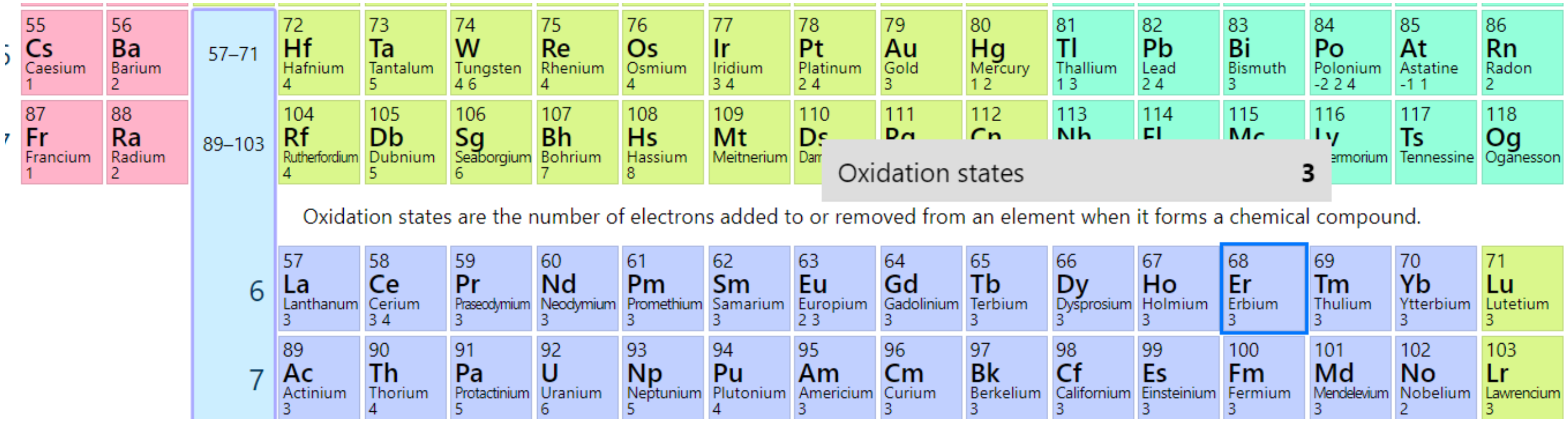
- 1. Active medium
- 2. Pumping source
- 3. Optical resonator

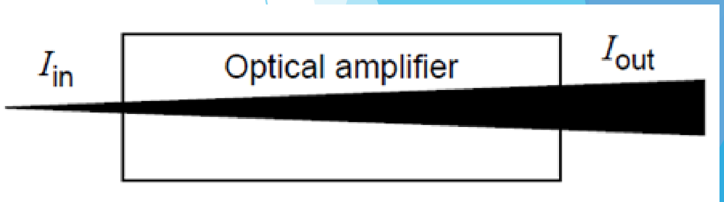



***Points to note:*** *Some of the energy is coupled back to the system → oscillator.*

# Understanding Optical Amplification



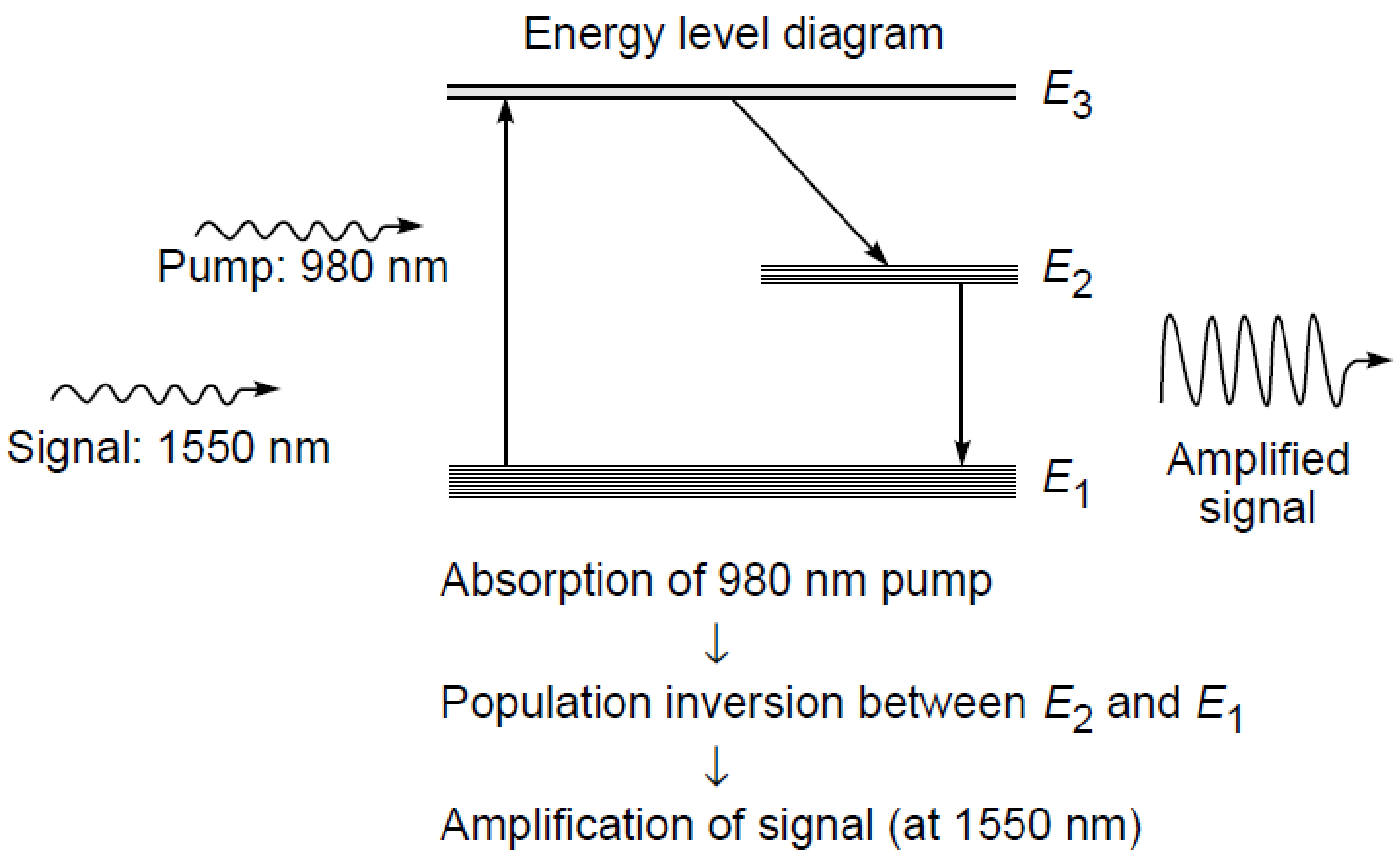




- understand optical amplification → EDFA
- **Erbium doped fiber amplifier**
- The EDFA: consists of a silica optical fiber the core doped with erbium oxide ($Er_2O_3$)
- light is guided through the optical fiber
- three discrete energy levels of $Er^{3+}$ ion in silica host glass.

Optics, Ghatak

# EDFA




$Er^{3+}$ concentration $\approx 7 \times 10^{24}$ ions m$^{-3}$ pump power $\approx$ 5 mW

and, the optimum length of the erbium doped fiber $\approx$ 7m.

- $E_3$ - $E_1$ = 1.3 eV → 980 nm
- $E_2$ – $E_1$ = 0.81 eV → 1550 nm
- When a trigger of 980 nm is fed → Er atoms jump to $E_3$ → *pump*
- Atoms in $E_3$ jumps to $E_2$ → *heating*
- State $E_2$ is ***metastable*** → long lifetime (few milliseconds).
- large lifetime of state $E_2$ than $E_3$ → the population of the erbium atoms in state $E_2$ grows with time
- Population inversion can be achieved
- $N_2 > N_1$
- Send a signal beam (1550 nm) → it gets amplified
- Why? → stimulated emission of radiation

$$\text{Gain (dB)} = 10 \log \frac{P_{output}}{P_{input}}$$

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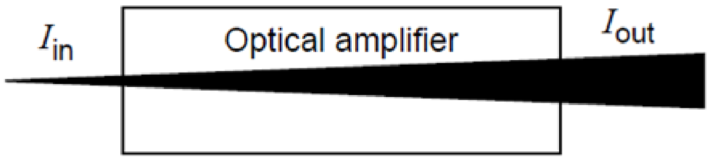
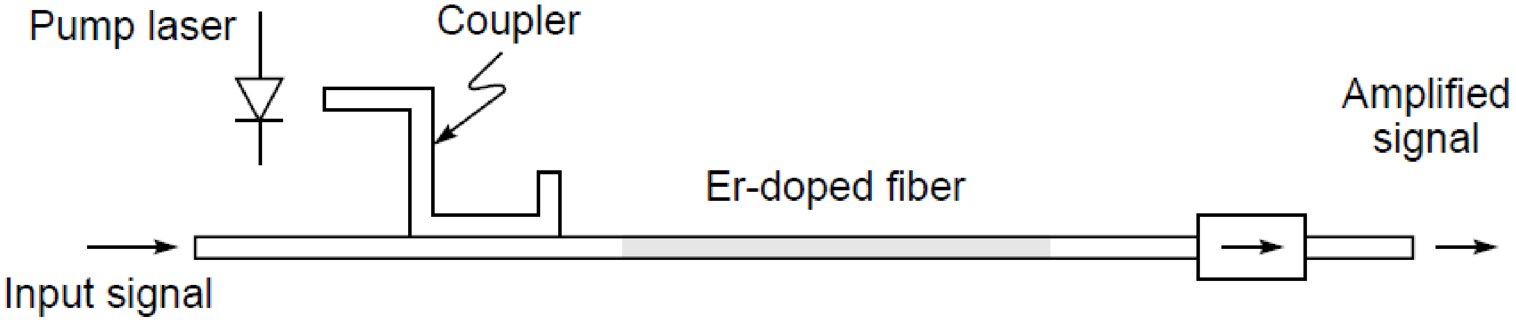
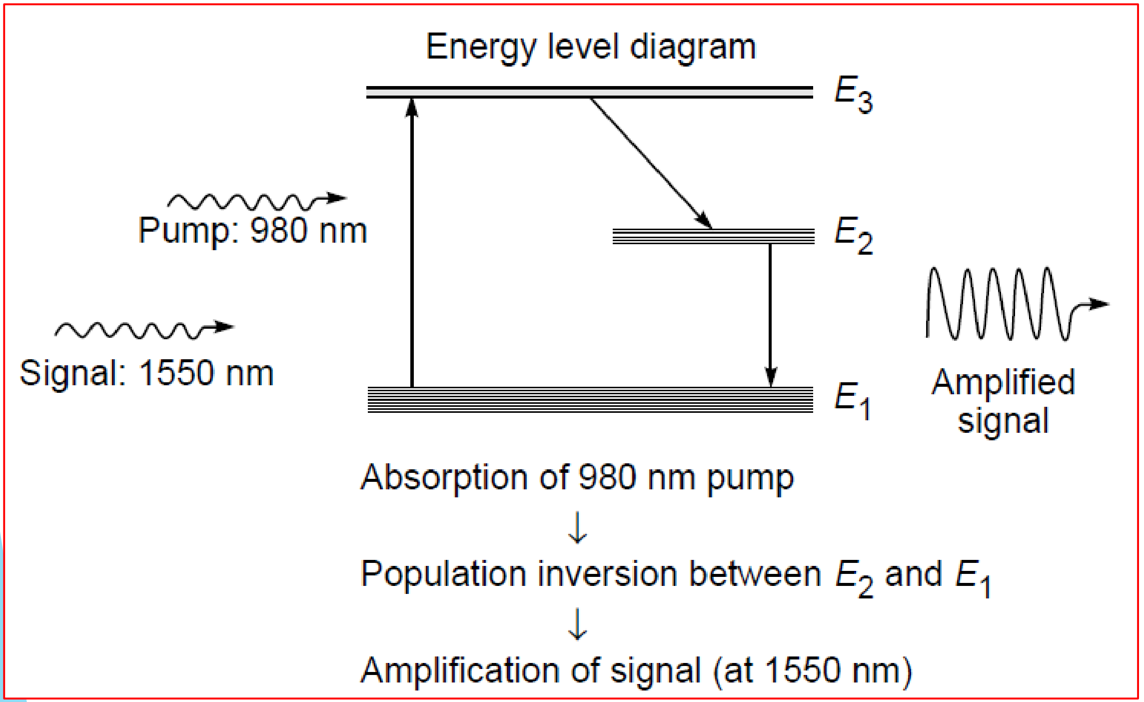
# Understanding Optical Amplification through EDFA




Loss: scattering from the laser medium, absorption at the mirrors

When the laser oscillates in steady state, the losses are exactly compensated for by the gain provided by the medium

→ wave coming out of the laser can be represented as a continuous wave

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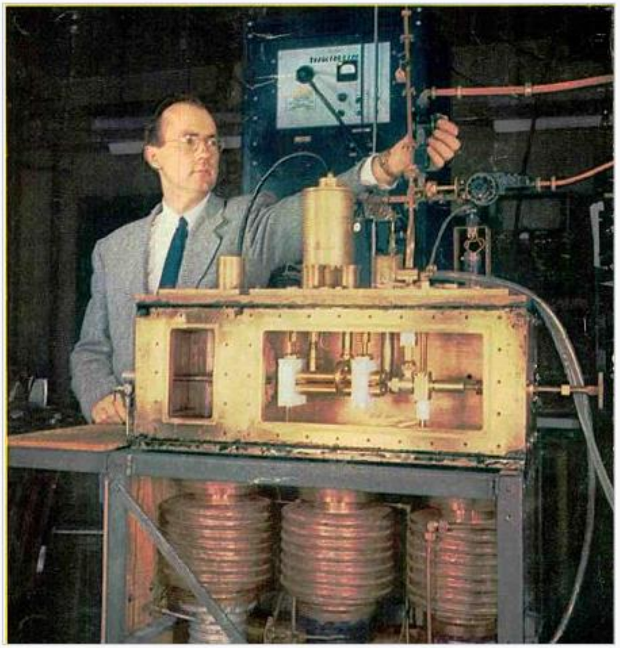
# Do you know?



First prototype ammonia maser and inventor Charles H. Townes. The ammonia nozzle is at left in the box, the four brass rods at center are the quadrupole state selector, and the resonant cavity is at right. The 24 GHz microwaves exit through the vertical waveguide Townes is adjusting. At bottom are the vacuum pumps. wikipedia

## The Nobel Prize in Physics 1964

Photo from the Nobel Foundation archive.

Charles Hard Townes

Prize share: 1/2

Photo from the Nobel Foundation archive.

Nicolay Gennadiyevich Basov

Prize share: 1/4

Photo from the Nobel Foundation archive.

Aleksandr Mikhailovich Prokhorov

Prize share: 1/4

Maiman with his laser in July 1960.

https://www.aps.org/publications/apsnews/201005/physicshistory.cfm


World's first laser

wikipedia

The Nobel Prize in Physics 1964 was divided, one half awarded to Charles Hard Townes, the other half jointly to Nicolay Gennadiyevich Basov and Aleksandr Mikhailovich Prokhorov "for fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle."

https://www.nobelprize.org/prizes/physics/1964/summary/

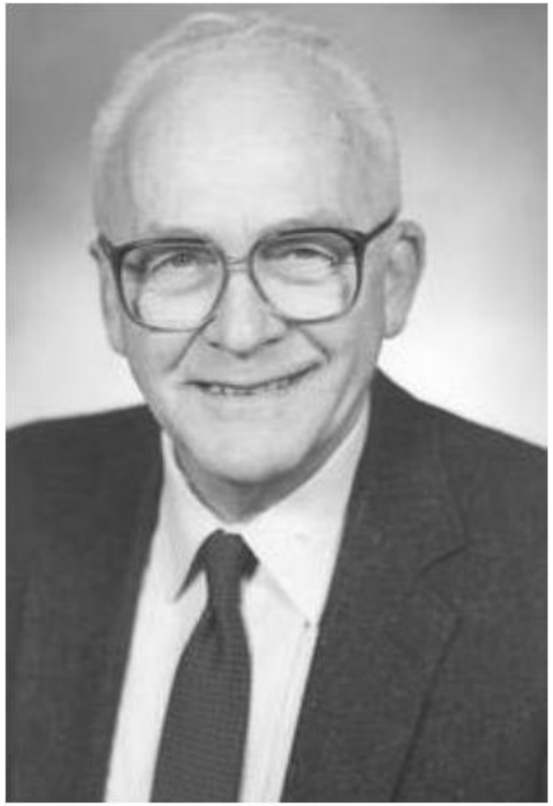
# THE FIBER LASER

- put the doped fiber between two mirrors (resonator), + appropriate pump → fiber laser
- 1960: Maiman's demonstration of the first ever laser
- 1961: Elias Snitzer wrapped a flash lamp around a glass fiber (having a 300 mm core doped with $Nd^{3+}$ ions clad in a lower-index glass) and when suitable feedback was applied, the first fiber laser was born.
- *Contribution in EDFA*
- *commercially available in the market*
- Applications: widespread → in welding, cutting, drilling, and in medical surgery.

Oxidation states are the number of electrons added to or removed from an element when it forms a chemical compound.

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 57 La Lanthanum 3 | 58 Ce Cerium 3 4 | 59 Pr Praseodymium 3 | 60 Nd Neodymium 3 | 61 Pm Promethium 3 | 62 Sm Samarium 3 | 63 Eu Europium 2 3 | 64 Gd Gadolinium 3 | 65 Tb Terbium 3 | 66 Dy Dysprosium 3 | 67 Ho Holmium 3 | 68 Er Erbium 3 | 69 Tm Thulium 3 | 70 Yb Ytterbium 3 | 71 Lu Lutetium 3 |
| 89 Ac Actinium 3 | 90 Th Thorium 4 | 91 Pa Protactinium 5 | 92 U Uranium 6 | 93 Np Neptunium 5 | 94 Pu Plutonium 4 | 95 Am Americium 3 | 96 Cm Curium 3 | 97 Bk Berkelium 3 | 98 Cf Californium 3 | 99 Es Einsteinium 3 | 100 Fm Fermium 3 | 101 Md Mendelevium 3 | 102 No Nobelium 2 | 103 Lr Lawrencium 3 |

## Elias Snitzer



OSA Awards & Distinctions

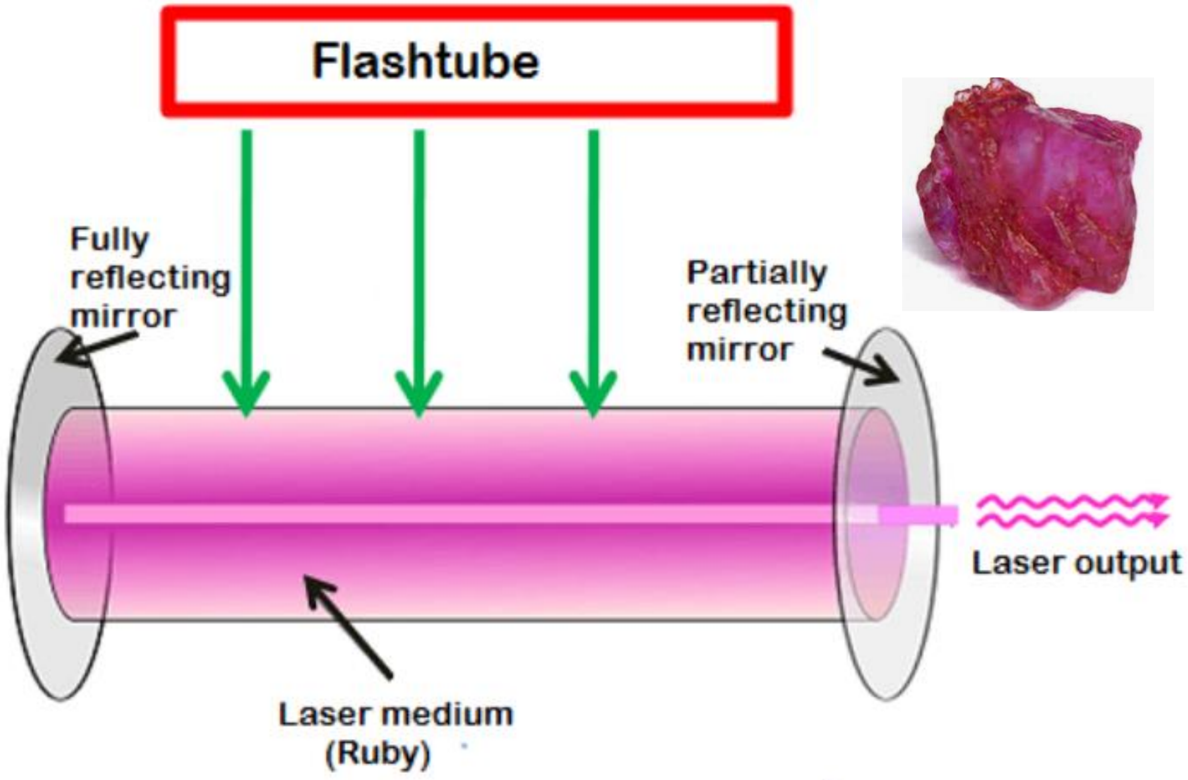
- John Tyndall Award
- Charles Hard Townes Medal
- Fellow

https://www.osa.org/en-us/history/biographies/bios/elias_snitzer/

https://www.photonics.com/Articles/Fiber_Laser_Pioneer_Honored_with_IEEE_Milestone/a52186

Optics, Ghatak

# The Ruby LASER






Maiman's original device → the first operative laser

Active medium → a small, cylindrical, synthetic, pink ruby rod

What is Ruby? $Al_2O_3$ crystal containing about 0.05 percent (by weight) of $Cr_2O_3$.

Helical discharge tube (flashtube) → pump

The rod's end faces were polished flat, parallel and normal to the axis. Then both were silvered to form the **resonator**

Maiman with his laser in July 1960.


World's first laser

https://www.physics-and-radio-electronics.com/physics/laser/rubylaserdefinitionconstructionworking.html

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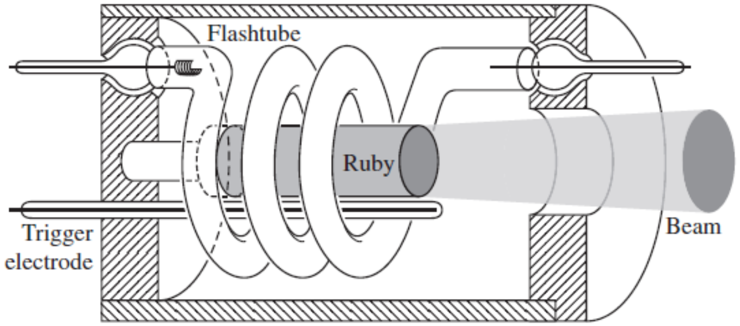
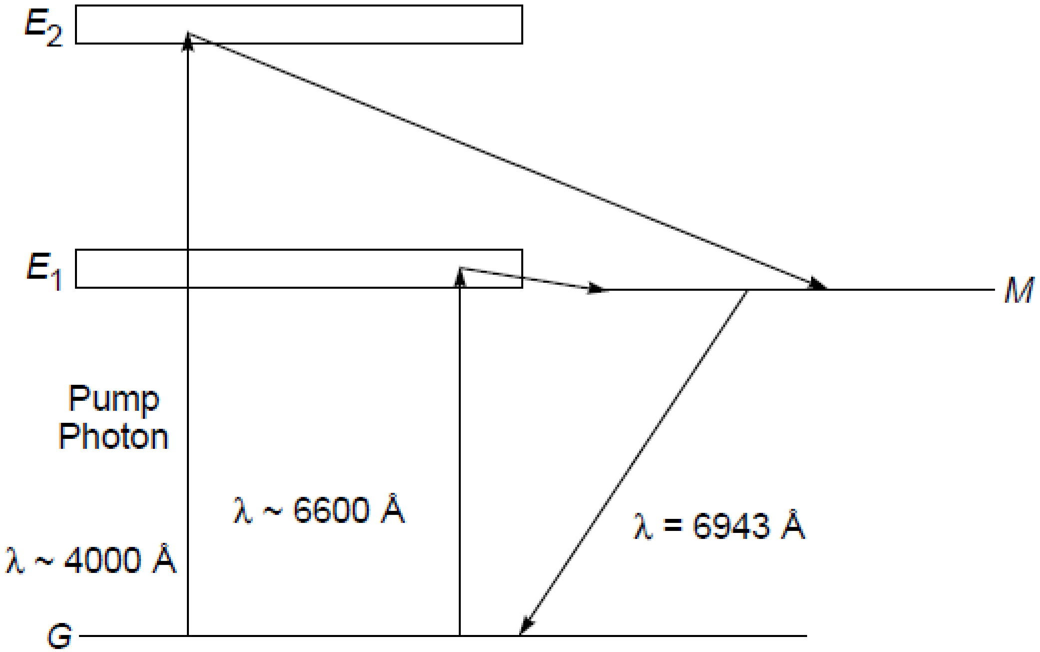
# Working principle




The energy levels of the chromium ion; $G$ and $M$ represent the ground and metastable states, respectively.

Optics, Ghatak; Hecht

1. photons are produced by the flash lamp
2. The chromium ion in its ground state can absorb a photon (~ 4000 Å) and make a transition to $E_2$ → by optical pumping OR to $E_1$ (6600 Å)
3. Once in $E_2$ or $E_1$ → it immediately makes a nonradiative transition (in a time ~ $10^{-8}$ s) to the metastable state *M* *(3 ms lifetime)*
4. the excess energy (transition from $E_2/E_1$ to M) is absorbed by the lattice and does not appear as EM radiation.
5. *M* has a very long life, the number of atoms in this state keeps increasing and one may achieve population inversion between states *M* and *G*.
6. Once population inversion is achieved, light amplification can take place, with two reflecting ends of the ruby rod forming a cavity.

- The ruby laser is an example of a three-level laser.
- Applications: medical and cosmetic procedures, holography

# Why is Ruby red?




- From blood red to pink → purple
- Reason? $Cr^{3+}$ concentration in $Al_2O_3$ ← white
- chromium atoms absorb certain wavelengths of light (blue, green) and reflect light in the red part of the visible light spectrum.
- This reflected red light is what your eyes see and gives rubies their distinctive red coloring.

https://en.wikipedia.org/wiki/Ruby

# Thank You