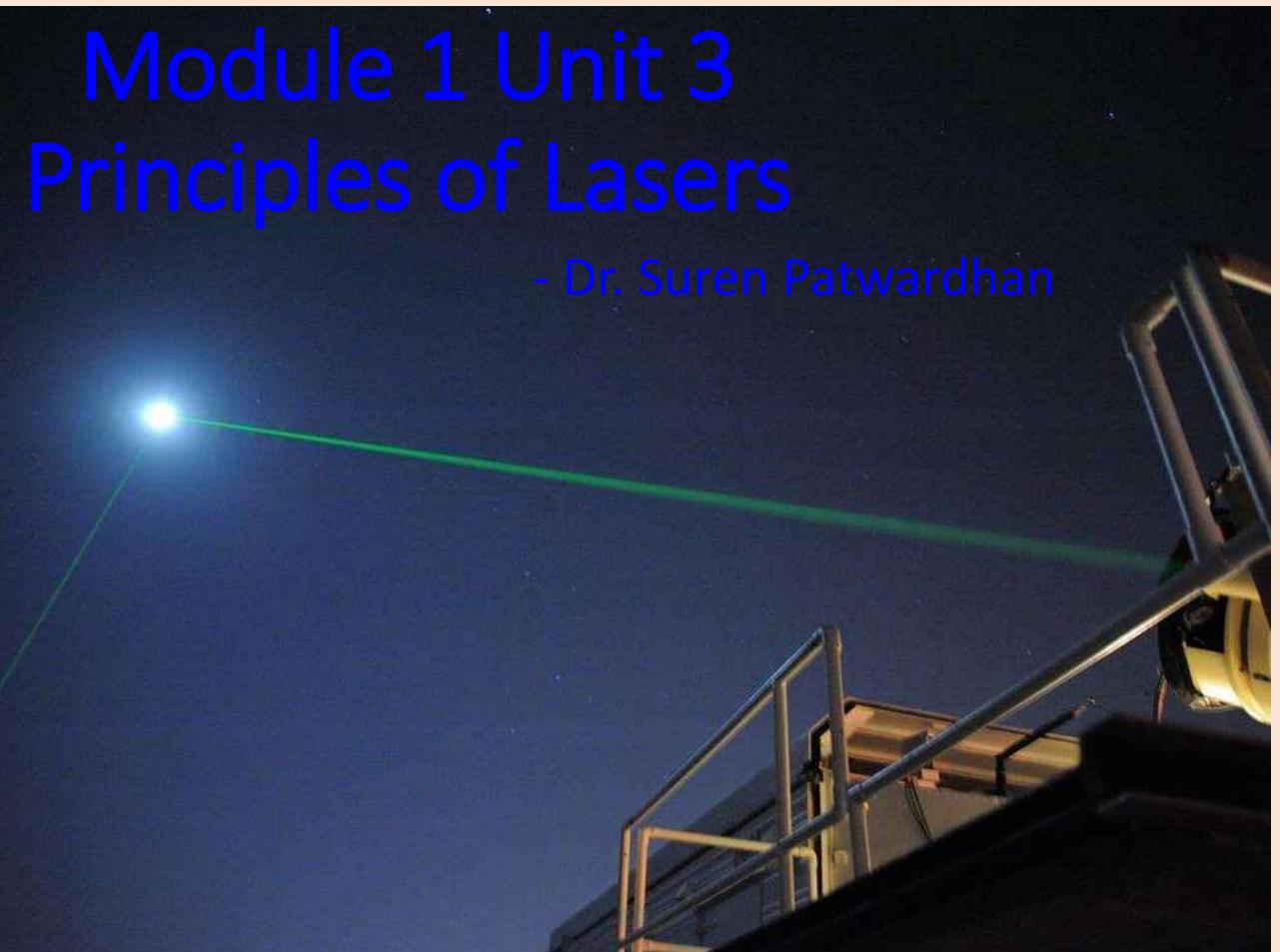


# Module 1 Unit 3

## Principles of Lasers

- Dr. Suren Patwardhan



The Moon

Geophysical and Astronomical Observatory at NASA's Goddard Space Flight Center in Greenbelt, Md., USA

Image Courtesy: <https://www.nasa.gov/multimedia/imagegallery>

Dr. Suren Patwardhan

# Properties of LASER

**Light Amplification by Stimulated Emission of Radiation**

- Monochromatic
    - Unique wavelength
  - Coherent
    - All waves are In phase
  - Directional
    - Light emitted along same path
  - Focused
    - Low divergence/ Low spreading
  - Bright
    - High intensity/ High power
  - Polarized (optional)
    - E-M vibrations in same plane
- 
- Most of the lasers are in the IR to Green range
  - Difficult to get Violet-Ultraviolet lasers  
(Nitride-based semiconductors have made it possible)
  - May not be possible to get X-ray lasers (at least on Earth)

# Some Popular Laser Sources

Name of laser source	Emission wavelength	Applications
He-Ne laser	Red, green	Mainly laboratory purpose
Ar laser	Blue-green	Eye surgery
Nd:YAG laser	Invisible (IR)	Machining
Ruby laser	Extreme Red	High speed photography
GaAs/GaN lasers	Red to Blue	Fibre optic communications
CO <sub>2</sub> laser	Invisible (IR)	Dermatology

# LOSER Changed to LASER

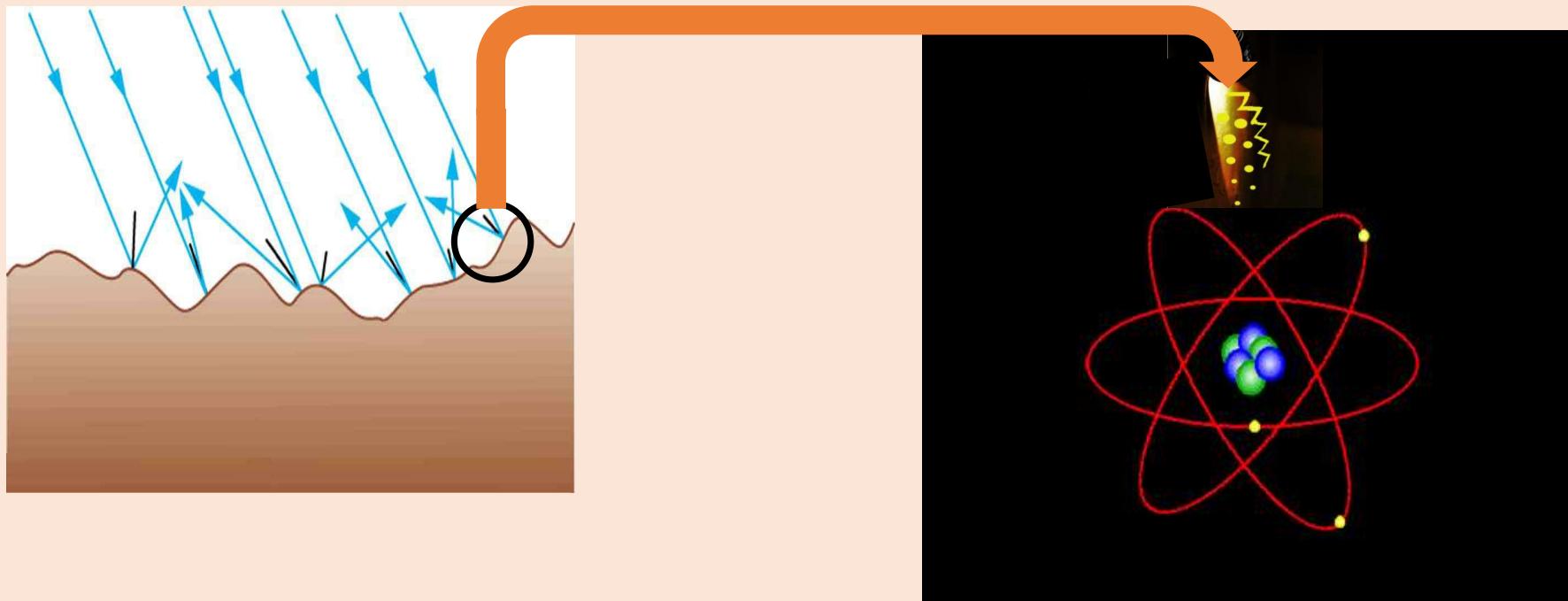
Oscillations

Amplification

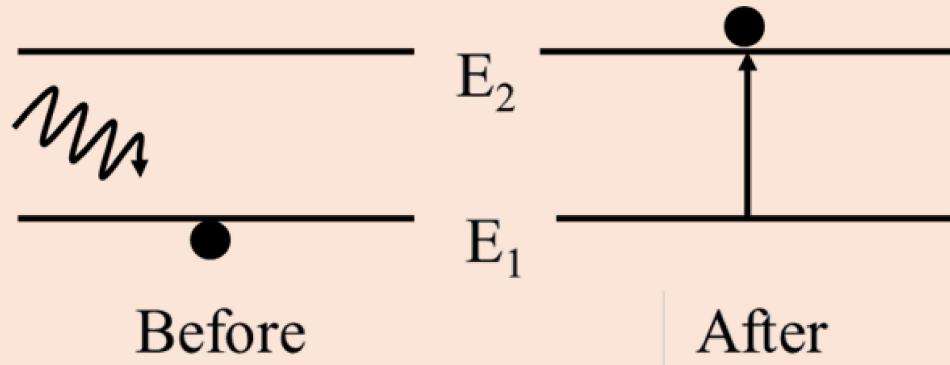
- First discovered by Maiman 1960 (kind of MASER – M for Microwaves)
- Once teased as discovery in search of applications, today has hundreds of applications
  - CO<sub>2</sub> laser used in cosmetics
  - Nd:YAG laser used in machining and surgery
  - Ar laser used in surgery
  - Diode laser used in communications
  - Dye lasers used in spectroscopy
  - Nd:Glass laser used in nuclear fusion
  - He-Ne laser used laboratory experimentation

# Interaction of Radiation with Matter

1. Absorption - Energy supplied
2. Spontaneous emission - Energy emitted
3. Stimulated emission - Energy emitted



# Absorption i.e. Stimulated Absorption



Rate of transition

$$\frac{dN}{dt} \Big|_{ab} = B_{12} N_1 Q$$

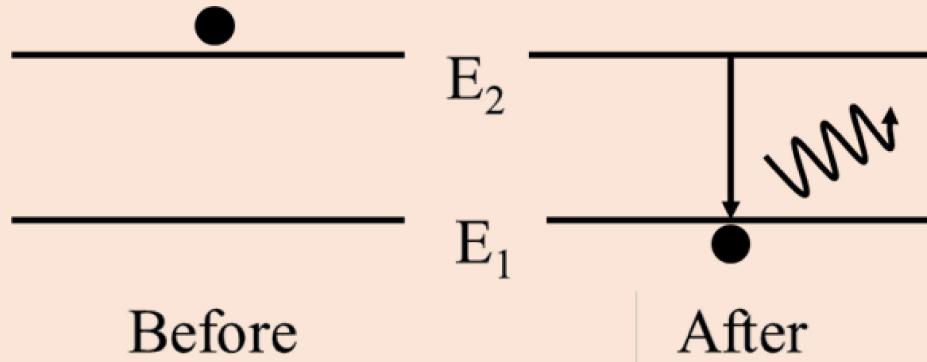
Where,

$B_{12}$ : probability of absorption process

$N_1$ : number of atoms in lower energy level  $E_1$

$Q$ : energy density of incident radiation per unit frequency ( $J\cdot s/m^3$ )

## Spontaneous i.e. Natural Emission



Rate of transition

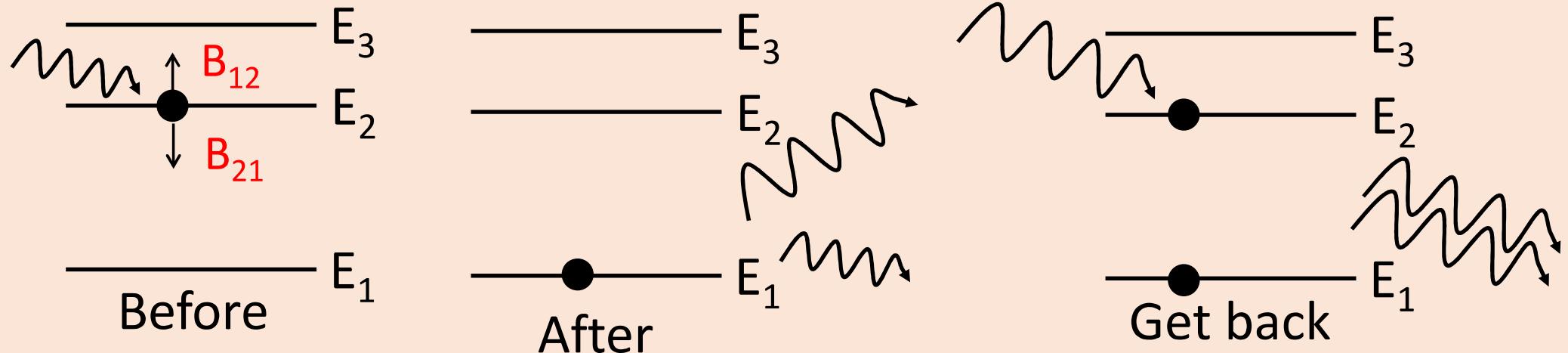
$$\left. \frac{dN}{dt} \right|_{sp} = A_{21} N_2$$

Where,

$A_{21}$ : probability of spontaneous emission process

$N_2$ : number of atoms in higher energy level

## Stimulated i.e. triggered emission



Einstein showed  $B_{12} = B_{21}$

$$\text{Rate of transition } \frac{dN}{dt}_{st} = B_{21} N_2 Q$$

Where,

$B_{21}$ : probability of stimulated emission process

$N_2$ : number of atoms in higher energy level  $E_2$

$Q$ : energy density of incident radiation per unit frequency

### Advantages

Emitted radiation has same  
Wavelength

Direction of propagation  
Phase

# Lasing Condition

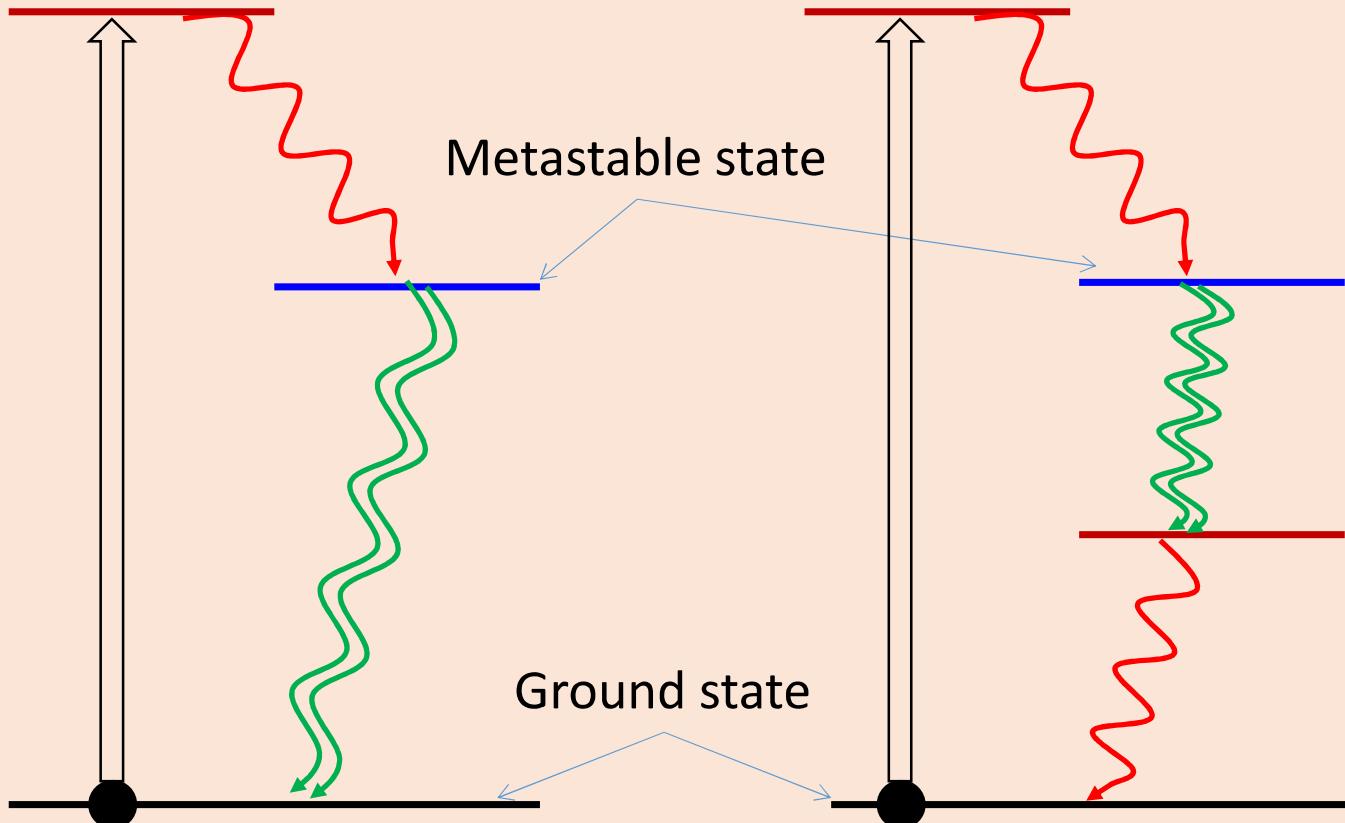
- At equilibrium,  $N_1 \gg N_2$
- Lower states  $E_1$  are far more “populated” than upper states  $E_2$
- For laser emission we need everything उलटा
  1.  $N_2 > N_1$  i.e. “population inversion”
  2. Non-equilibrium, against natural distribution of atoms
  3. More gain than losses

This is achieved by two important concepts:

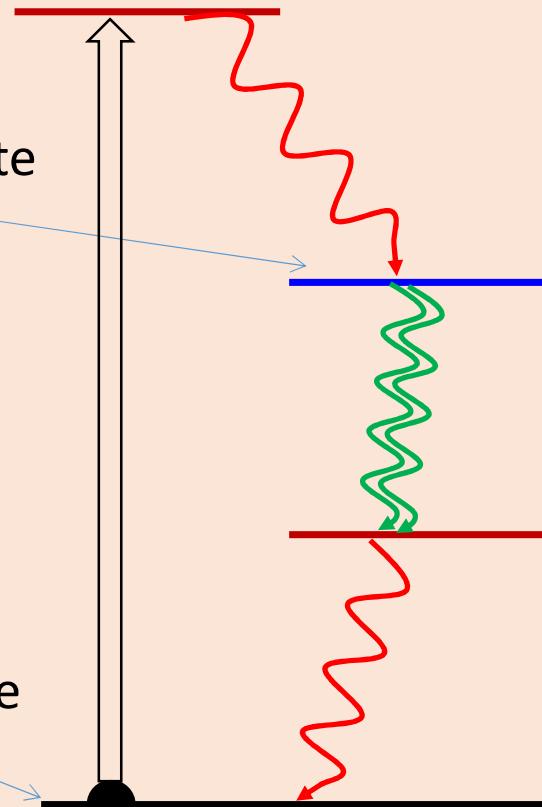
1. Metastable states – ensures stimulated emission
2. Optical Resonator – ensures light amplification

# Pumping Schemes and Metastable States

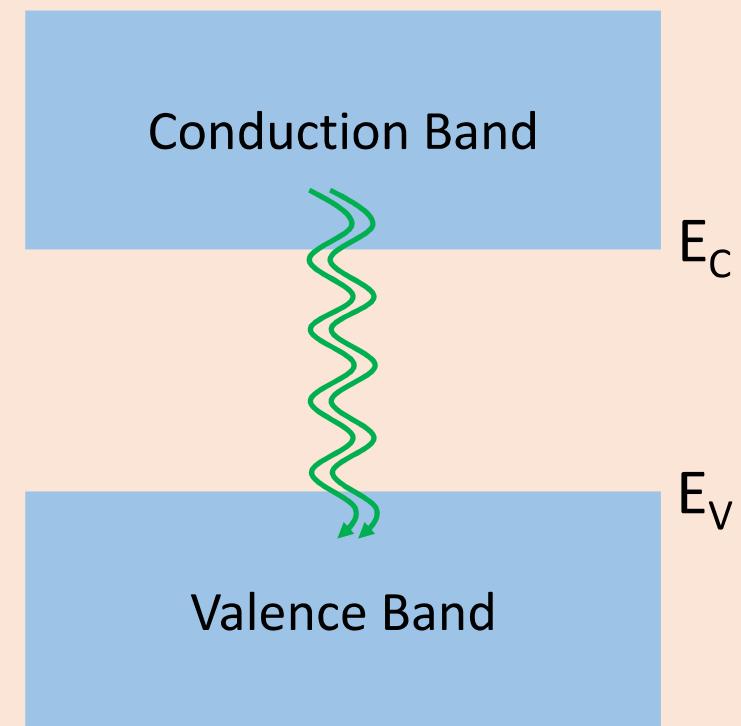
Three-Level



Four-Level



Two-Level/Band to Band



# Pumping and its Types

**Pumping:** *Process of supplying trigger/input energy to achieve population inversion*

- **Optical pumping**

A broad and bright source of light (photons) is used to supply energy

Example: Xenon flash lamp in Ruby laser, Nd:YAG laser, Dye lasers

- **Electrical Pumping**

High electric field is set up by a pair of electrodes

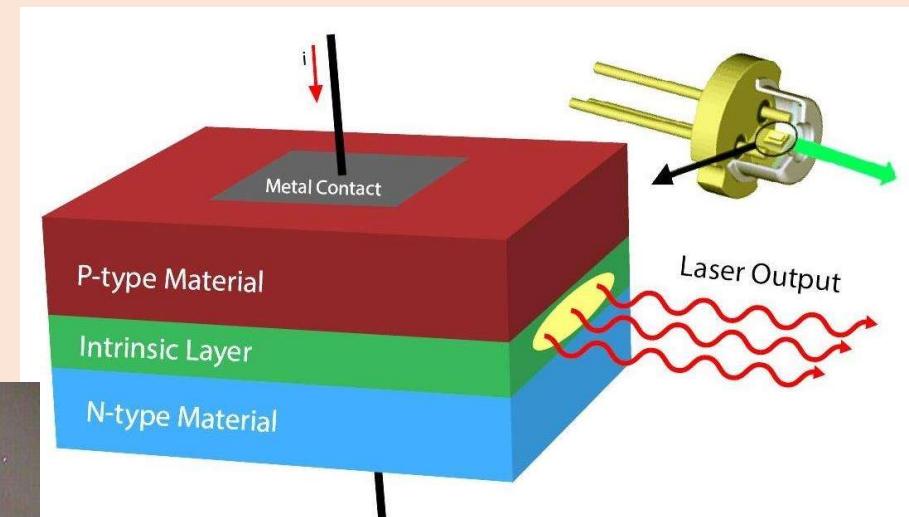
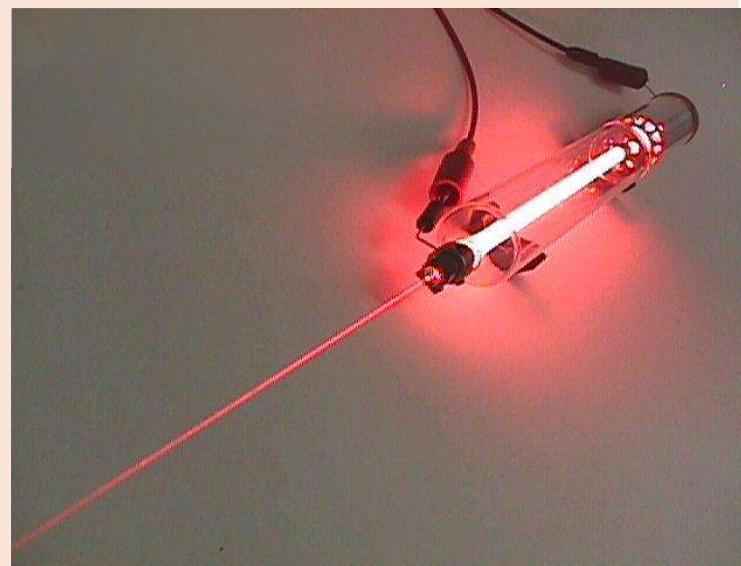
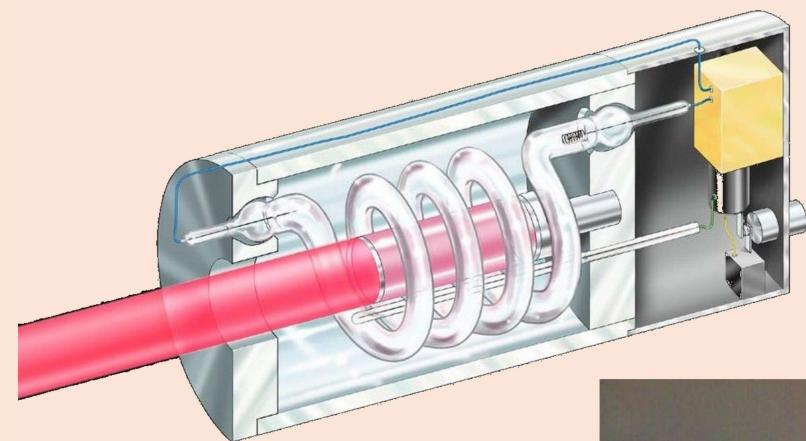
Example: He-Ne laser, CO<sub>2</sub> laser, Ar laser

- **Direct conversion**

By passing an electric current

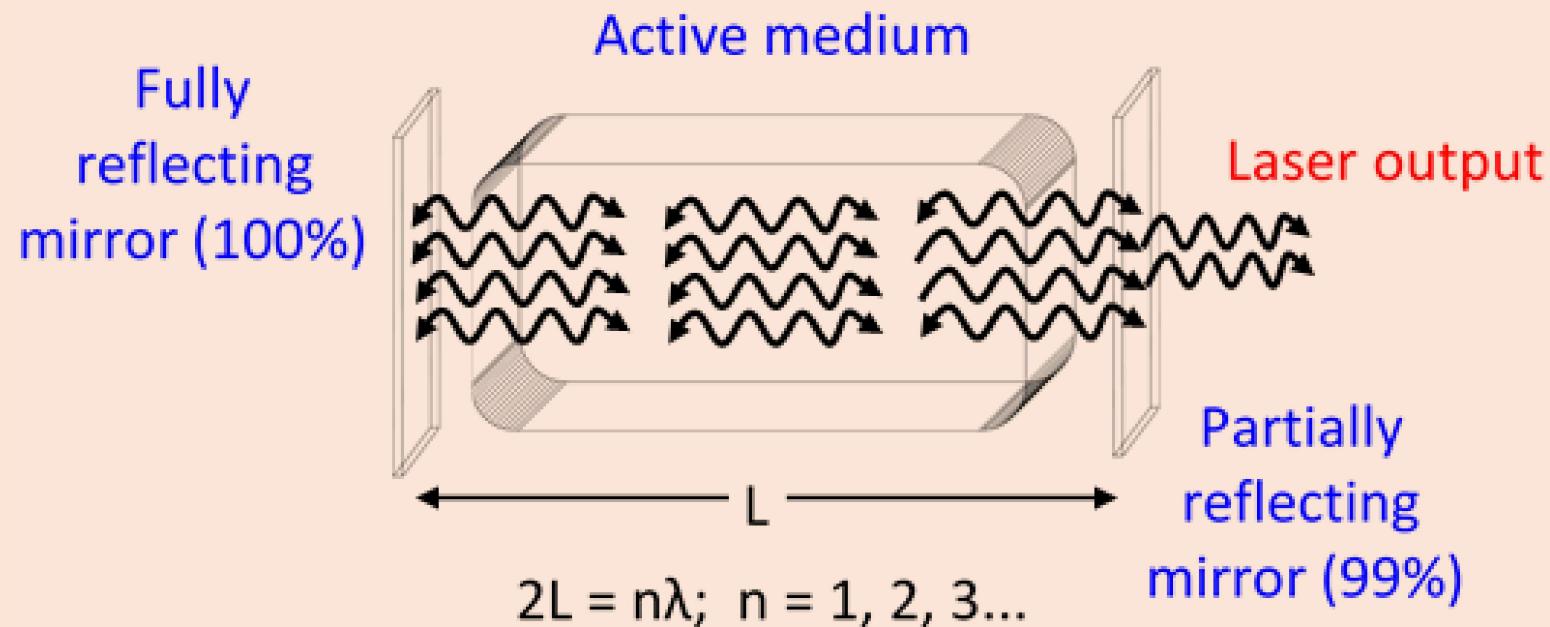
Example: Semiconductor diode lasers

# Types of Pumping - Schematics

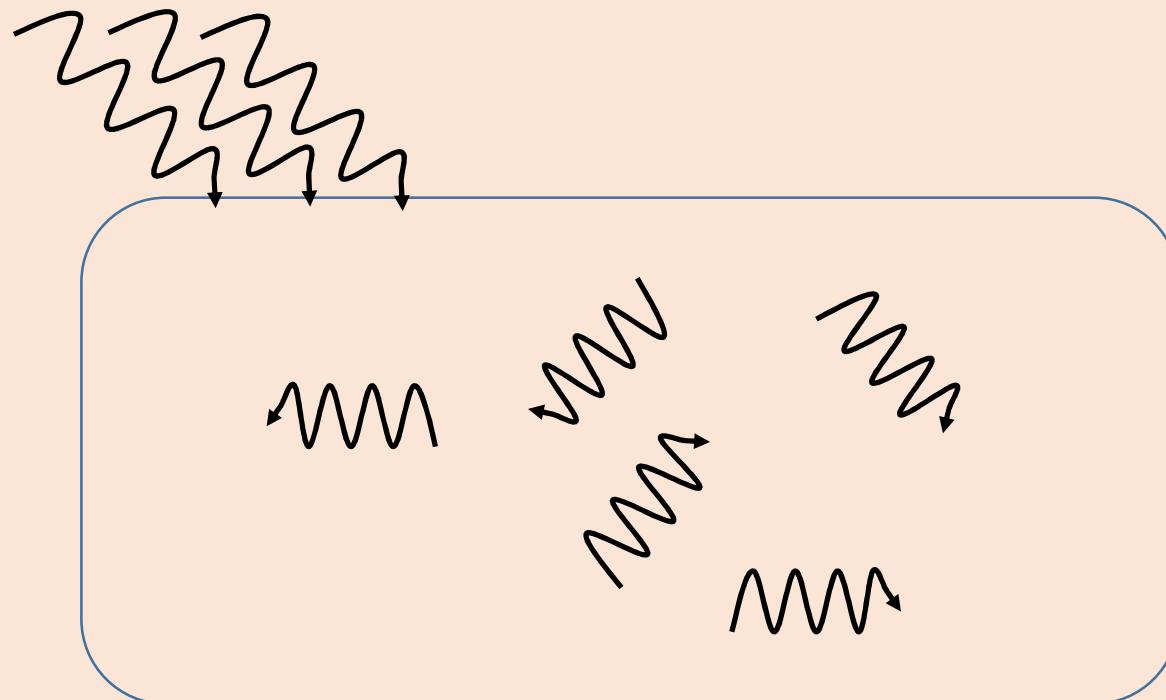


# Optical Resonator/Active Medium

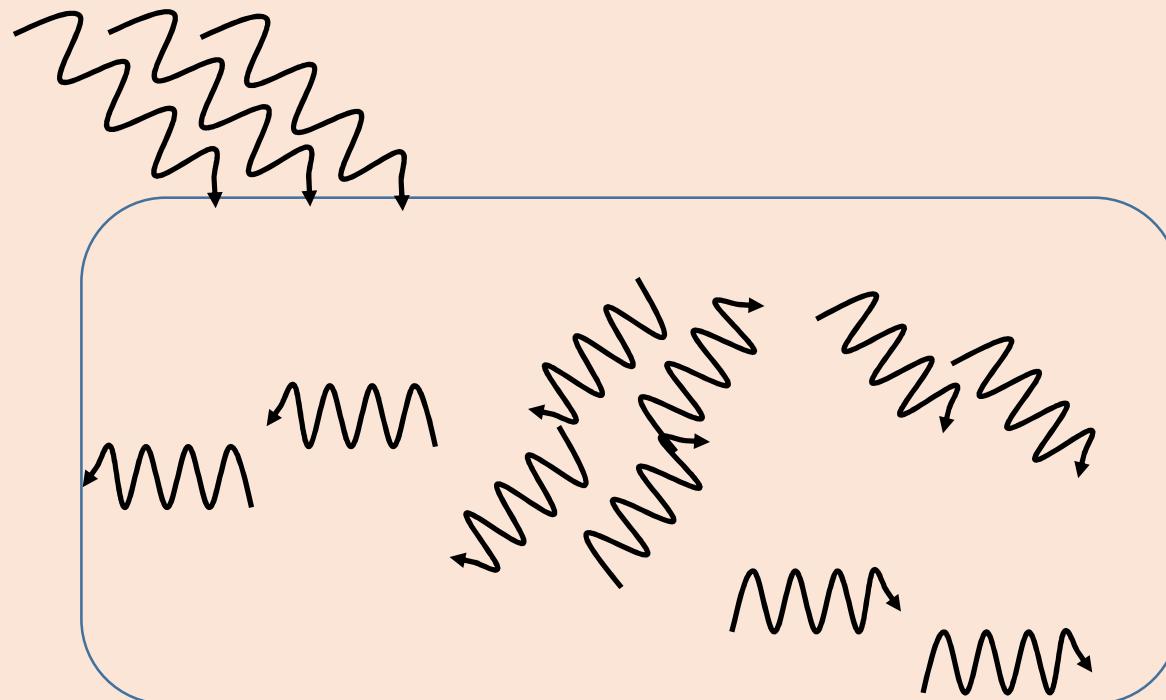
Active medium: *Region of the laser source where population inversion is achieved*



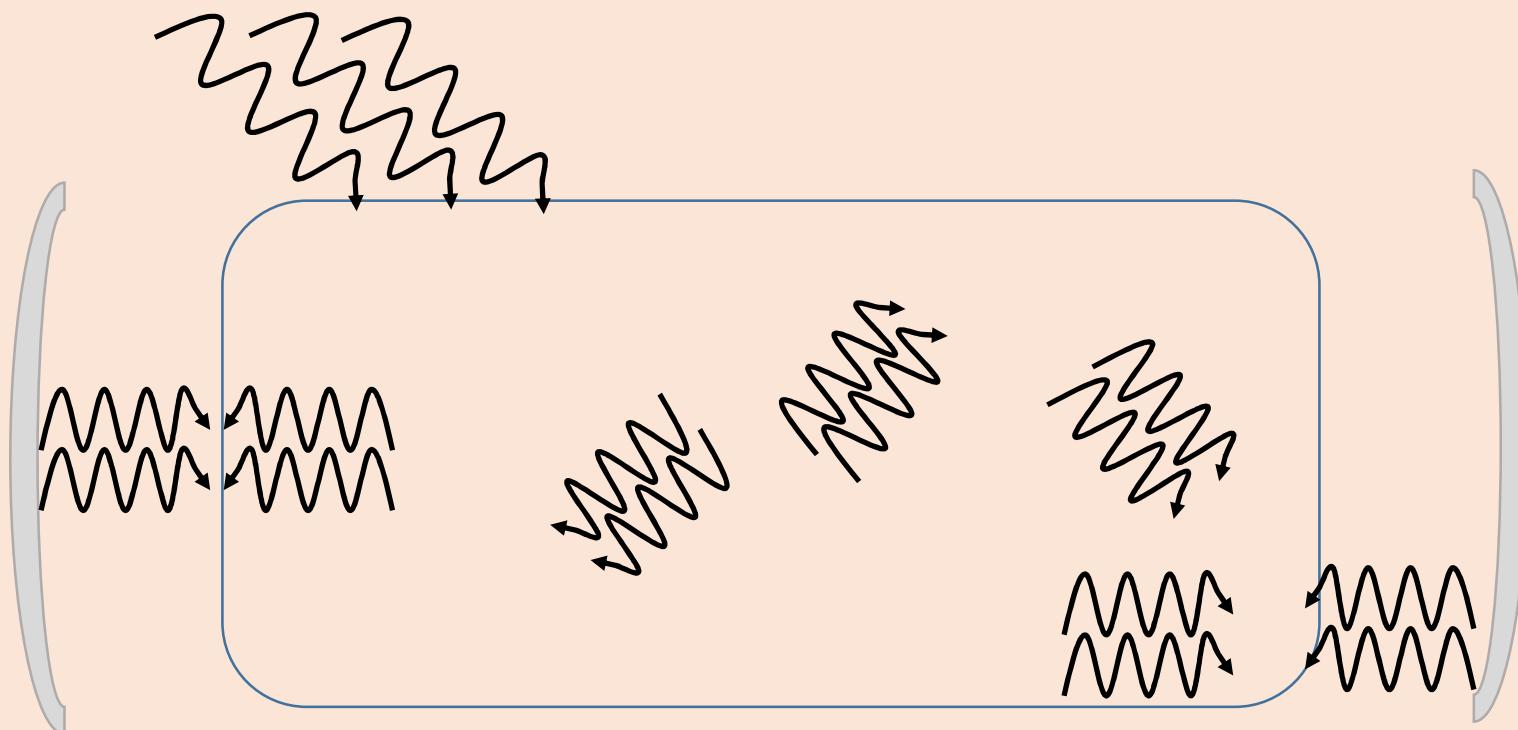
# Action of Optical Resonator



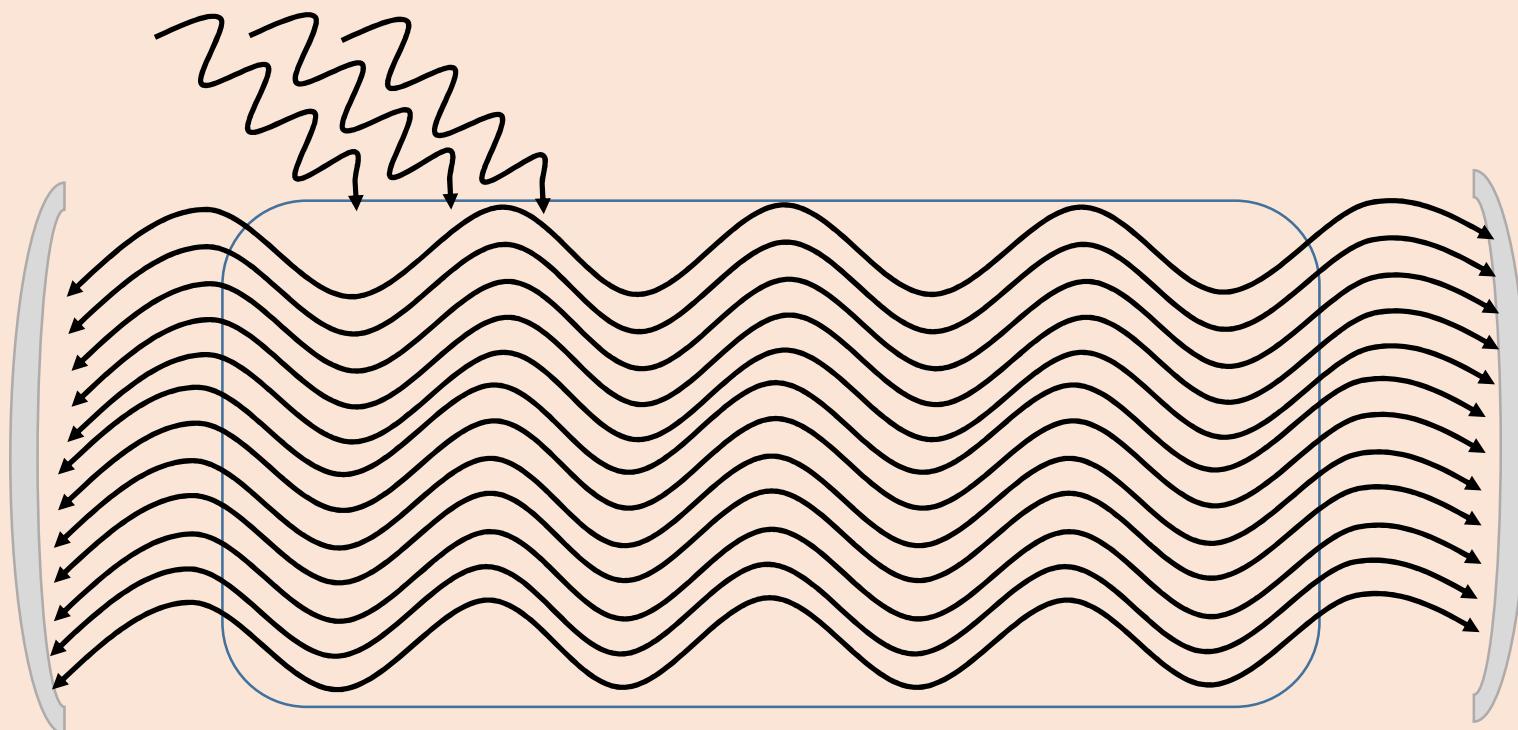
# Action of Optical Resonator



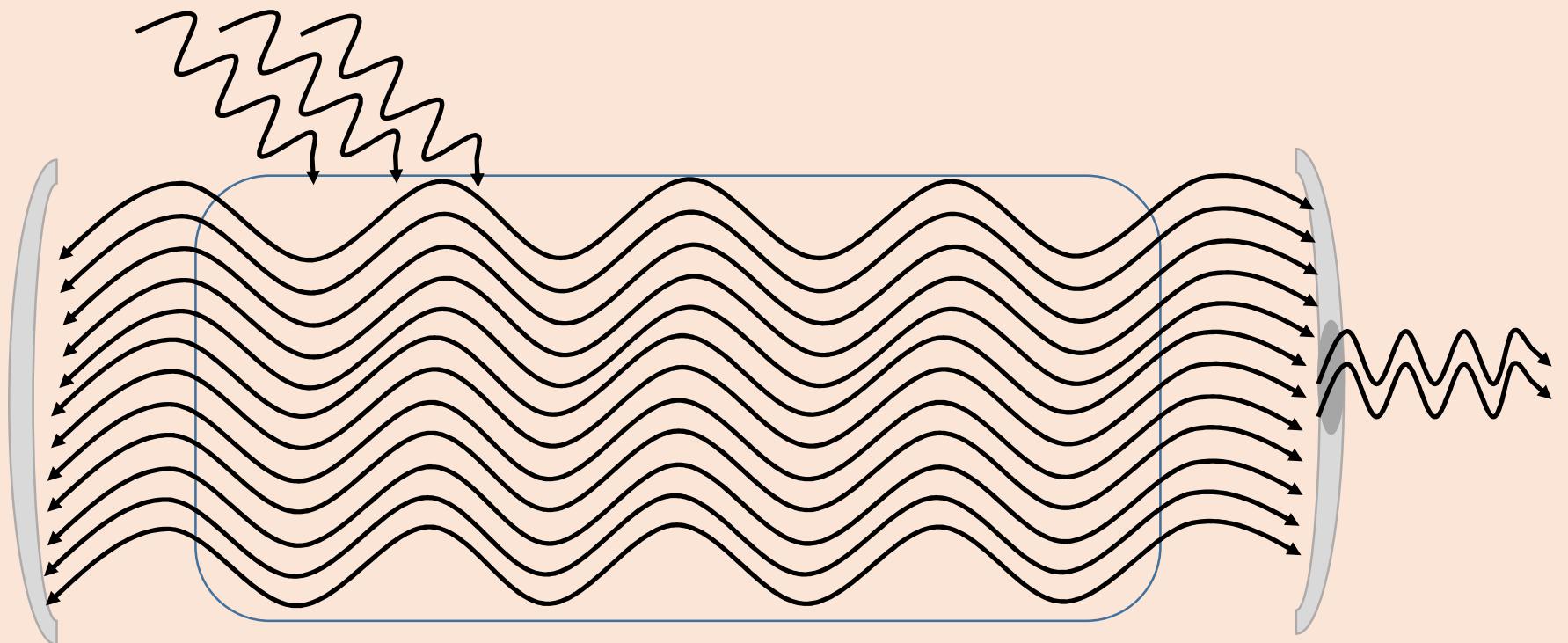
# Action of Optical Resonator



# Action of Optical Resonator



# Action of Optical Resonator



# Important Laser Physics Terms

- **Population**  
*The number of active atoms occupying a particular energy state*
- **Population Inversion**  
*Creating a non-equilibrium state with more atoms in excited states*
- **Pumping**  
*Process of supplying trigger/input energy to achieve population inversion*
- **Metastable State**  
*Special energy levels having unusually high lifetime than normal excited states*
- **Active medium**  
*Region of the laser source where population inversion is achieved*

# Thanks!

# Blackbody Radiation at Different Temperatures

