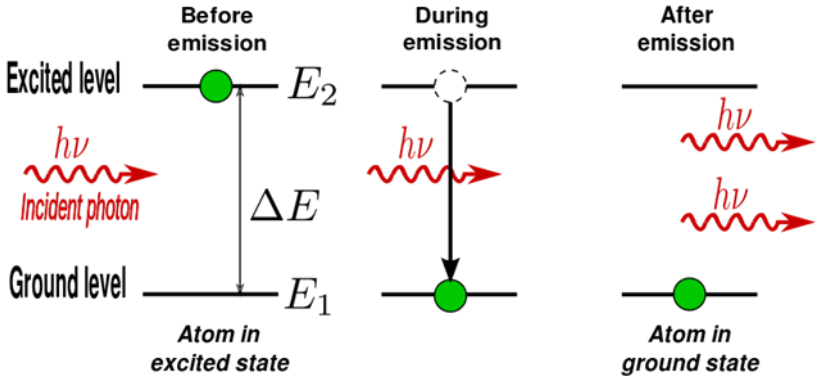
PHY 110 Engineering Physics

Lecture 4

UNIT 2 – laser

Lasers and applications:

- Fundamentals of laser- energy levels in atoms
- Radiation matter interaction
- Absorption of light
- Spontaneous emission of light
- Stimulated emission of light
- Population of energy levels
- Einstein A and B coefficients
- Metastable state
- Population inversion,
- Resonant cavity
- Excitation mechanisms
- **Nd – YAG**
- **He-Ne Laser**
- **Semiconductor Laser**
- lasing action
- Properties of laser
- Applications of laser: holography



$$E_2 - E_1 = \Delta E = h\nu$$

$$R_1 = \frac{R_{st}}{R_{sp}}$$:

Ratio of stimulated emission rate to spontaneous emission rate

Ratio of stimulated emission rate to induced absorption rate

$$R_2 = \frac{R_{st}}{R_{abs}}$$

Will give us an Idea about what we need to realize LASER

To have LASER action dominant Stimulated emission is required and for that we have to have high R_1 and R_2

$$R_2 = \frac{N_2}{N_1}$$

1. Population inversion

2. High photon density

$$R_1 = \frac{B_{21}}{A_{21}}\rho(\nu)$$

3. Increase the life time

1. POPULATION INVERSION by Pumping

2. LARGE PHOTON DENSITY (ρ) using Optical resonant cavity

3. LONG LIFE TIME IN THE EXCITED STATE: by introducing Metastable state

Which scientist first came up with the idea of stimulated emission ?

a) Alexander Graham Bell
b) Isaac Newton
c) Arthur Schalow
d) Albert Einstein

Ansr: D

Einstein coefficient B_{12} for the absorption transition is equal to B_{21} of the stimulated transition .. Means?

a) When atoms are placed in a radiation field probability upward transition is more
b) When atoms are placed in a radiation field probability downward transition is more
c) Probability for downward and upward transition are equal
d) None of the above

Ansr: C

SOLID STATE LASER

In a solid state laser, active material/active medium is solid material …either crystalline or amorphous (glassy)

1. Ruby laser.
    i. First laser invented in 1960 by Theodore Maiman
    ii. Three level laser
    iii. Ruby crystal (Al_2O_3) with 0.05% Cr active centers
    https://www.youtube.com/watch?v=yQ0lMSNuj_o

2. **Nd-YAG Laser**
    i. Most popular type of solid state laser
    ii. Four level Laser
    iii. Nd- YAl_5O_{12}

SOLID STATE LASER

ND:YAG LASER

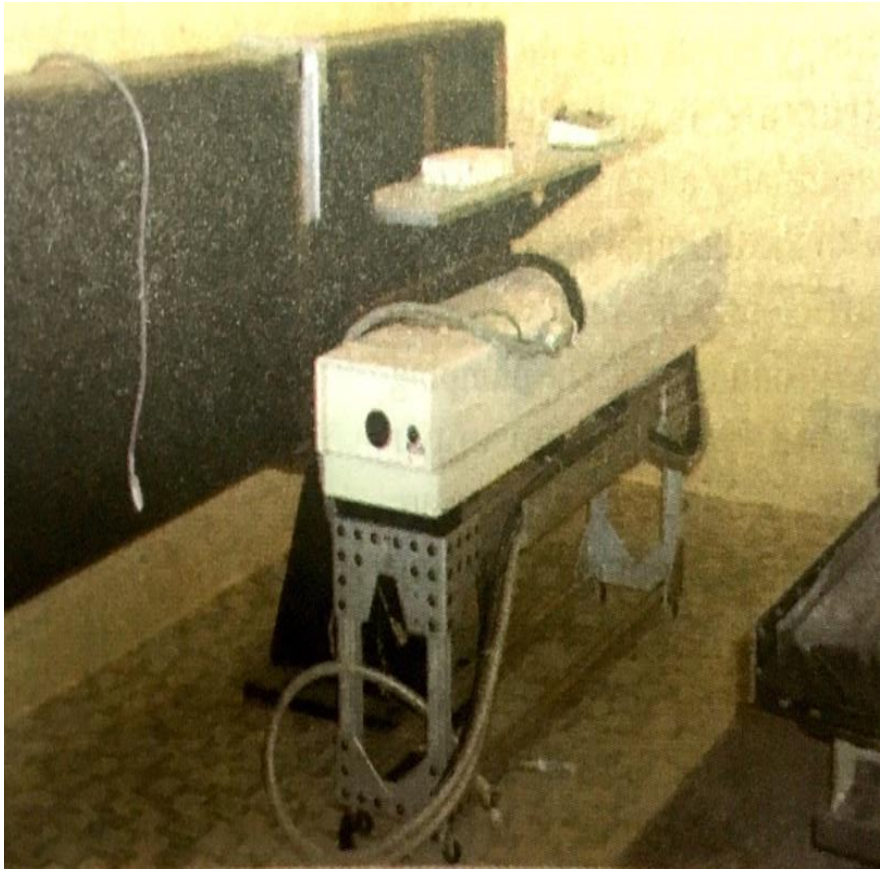
Operates in the IR region at a wavelength of about 1060 nm. Many industrial application such as welding, drilling , in surgery etc..

Yttrium aluminum garnet (YAG)– Host material YAl_5O_{12}

Neodymium (Nd).. Active centers..

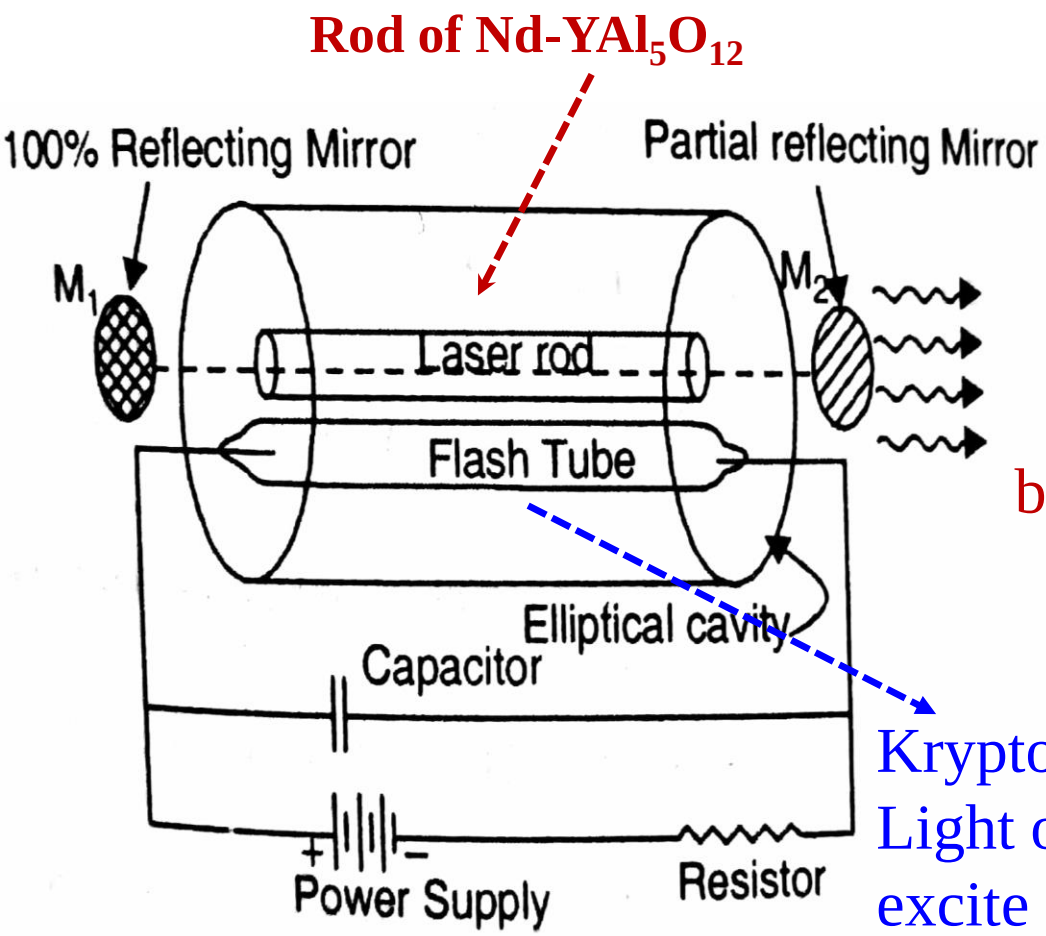
Nd^{3+} replace some Al^{3+} (0.725% by wt)

Pumping source: Flash tube …light



SOLID STATE LASER

Nd:YAG LASER- Design



Design of Nd-YAG Laser

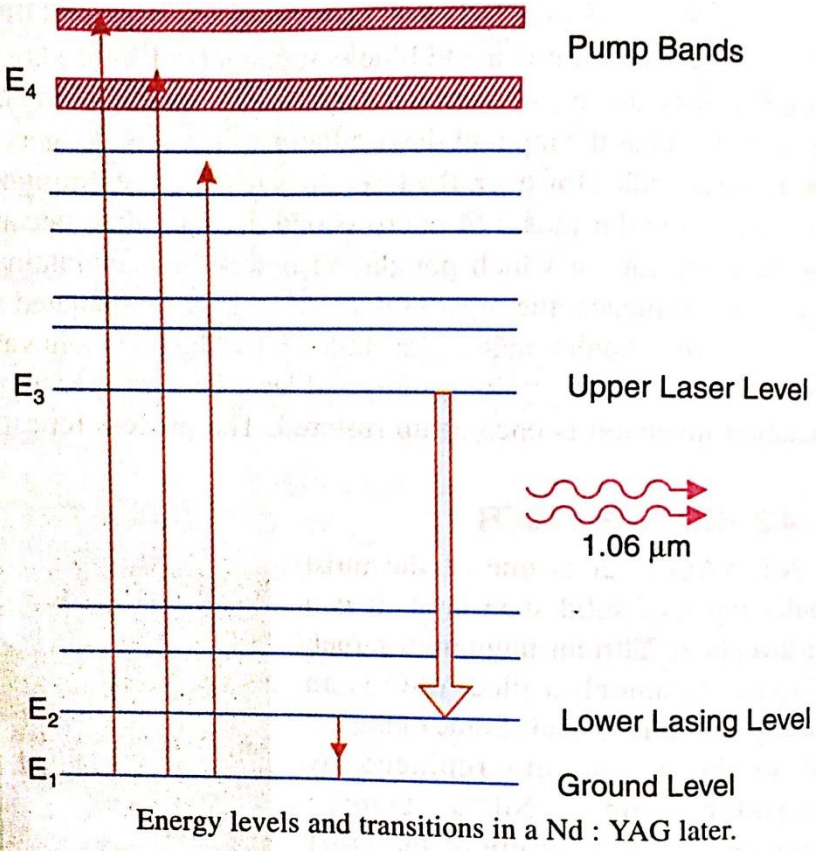
a. Light from the flash tube reflected and fall entirely on the Nd-YAG rod.. That realize excitation by optical pumping and population inversion

b. Two mirrors constitute the optical resonator..

Krypton Arc Lamp
Light of wavelength 500 to 800 nm excite Nd^{3+} into higher levels

SOLID STATE LASER

Nd:YAG LASER



Energy levels and transitions in a Nd : YAG later.

1. Nd^{3+} will be excited to E_4 levels from E_1 ground levels
2. E_3 is the metastable level and is the upper laser level.
3. E_3 will be rapidly populated by the optical pumping
4. E_2 is the lower laser level and almost empty. Population inversion between E_3 and E_2.
5. Laser emission occurs in the Infrared region (1060 nm)
6. Used in welding, drilling and in surgery.
7. Used in range finders and target designators in military

GAS LASER

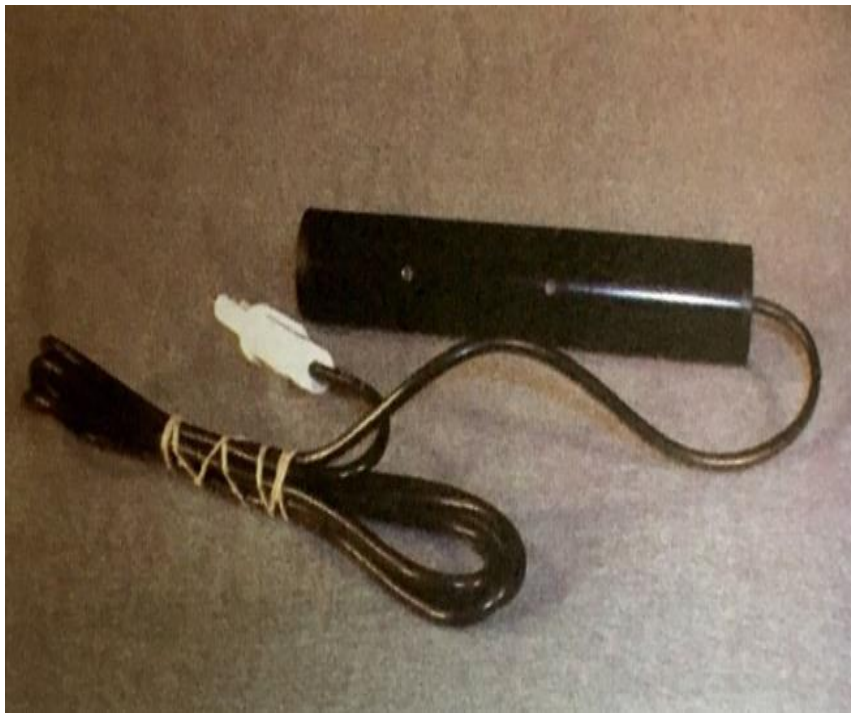
Gas Lasers are the most widely used lasers

Optical pumping is not used, but electric discharge used to excite atoms

Gas have narrow band and hence selection of optical source is difficult

Helium-Neon LASER

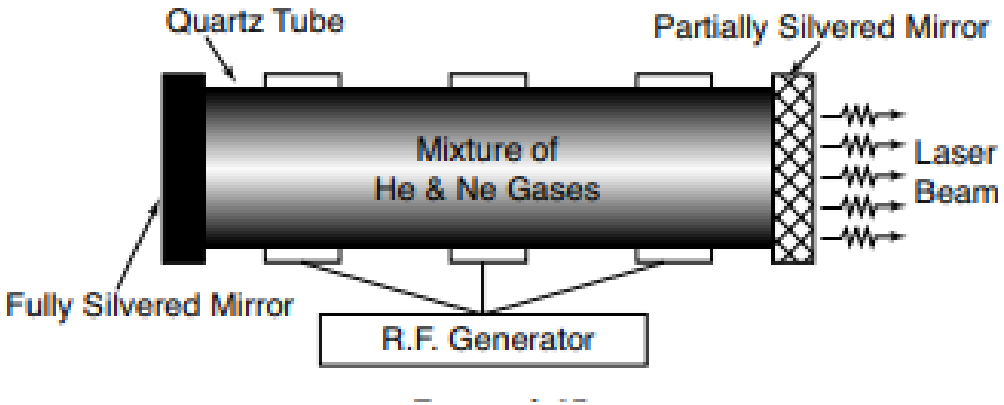
- Operates in the visible region at a wavelength of about 632.8 nm. Operates in the CW mode widely used as monochromatic source in laboratories , in laser printing and bar-code reading..
- Invented in 1961 by Ali Javan, W.R. Bennet and D.R. Herriot



He-Ne gas laser is a low power laser.. Where as CO_2 gas laser is a high power laser used **for the industrial applications**

GAS LASER

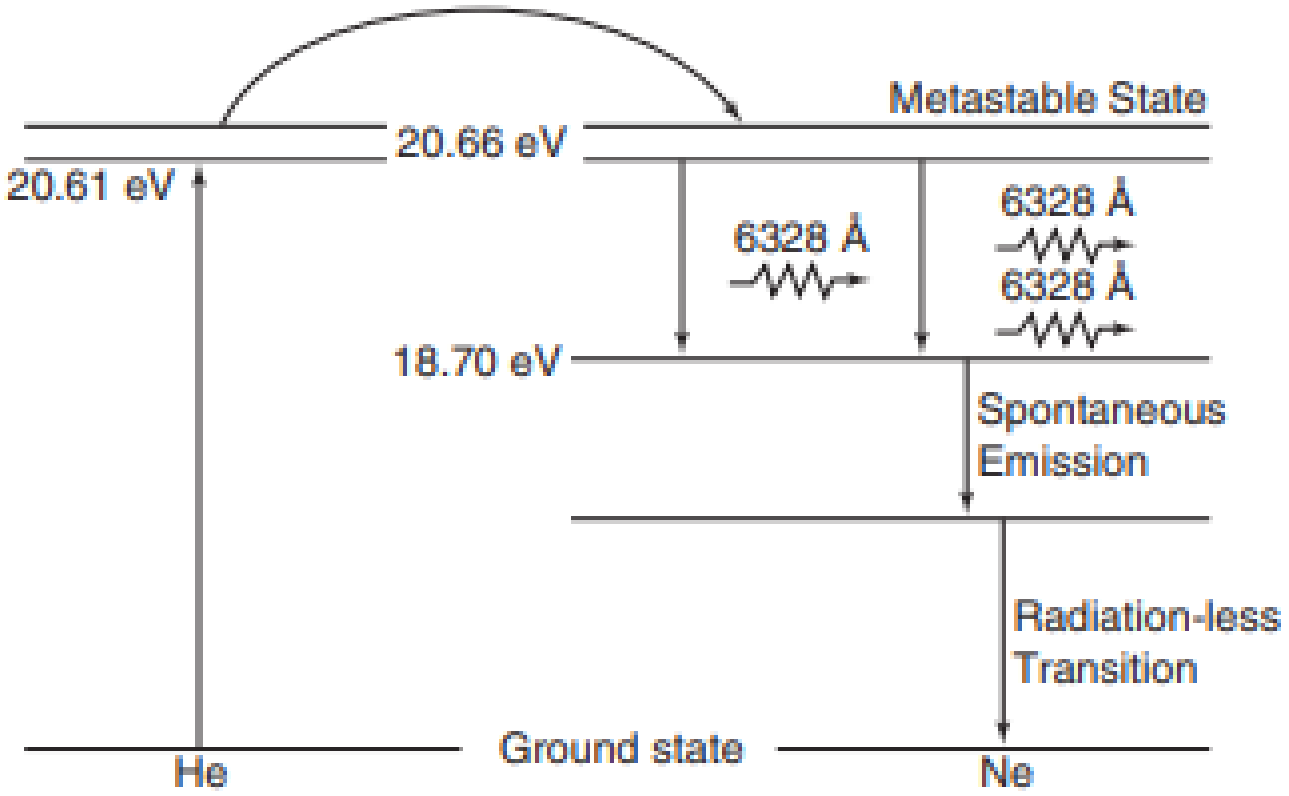
Design of Helium-Neon LASER



- ✓ He:Ne ratio is 10:1
- ✓ Neon atoms active centers
- ✓ He help to excite Ne atoms
- ✓ Pumping by electric discharge ~ 10 kV ionize gas:
- ✓ High energy electrons in the medium excite He atoms

GAS LASER

Working of Helium-Neon LASER



- Four level laser
- Excited He atom transfer energy to Ne atom through collision,Such energy transfer can take place when the colliding atoms have identical states. Thus He help to achieve population inversion in Ne.
- An excited Ne atom passes spontaneously from the metastable state at 20.66 eV to the excited state at 18.70 eV byemitting a photon of wavelength 6328 Å. This photon travels through the gas mixture parallel to the axis of the tube and stimulates the surrounding Ne atoms present in the metastable state. This way we get other photons that are in the phase with the stimulating photons. These photons are reflected forth and back by the silvered ends and the number of photons gets amplified through stimulated emission every time. Finally, a portion of these intensified photons passes through the partially silvered end.

Semiconductor LASER

LASER Diode: Portable, need only low input power and operate in the IR to UV region. Widely used nowadays, in fiber optic communication, CD players, CR-ROM drives, high speed laser printing..

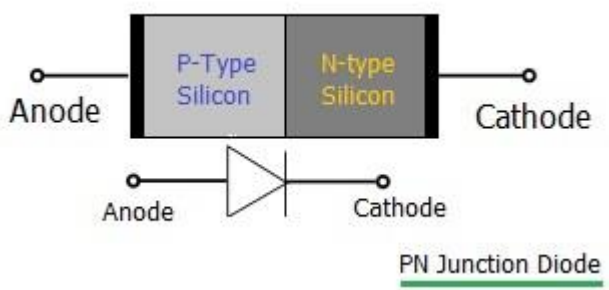
1962- low temperature diode laser with GaAs
1970-Room temperature diode laser in CW mode

- Bands of solid are involved not discrete energy levels of atoms
- Holes and electrons combines to produce photon
- Lasing action occur at junction..

- ✓ Basically a p-n junction diode
- ✓ Small in size 0.1 mm long and hence portable
- ✓ Forward biased condition used
- ✓ Direct bandgap semiconductors are used

Semiconductor LASER

P-n Junction diode



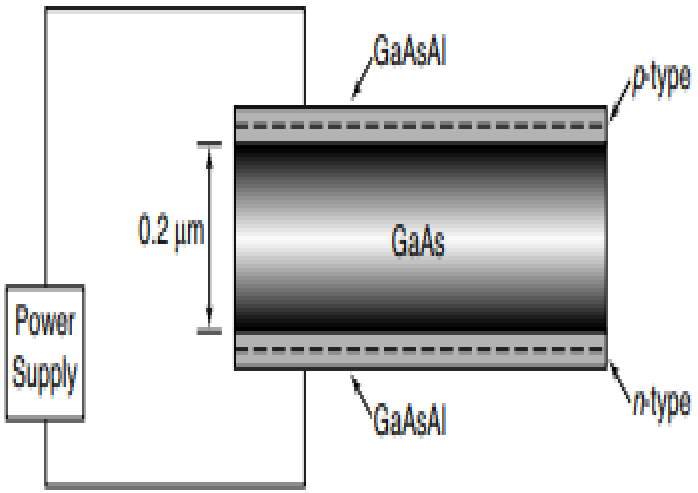
- Si is an indirect bandgap semiconductor..
  And hence can not be used for Laser diode

N-type, P-type, Fermi level
Band bending, Depletion region, junction????

Heavily doped?? We use this in laser diode..

Semiconductor LASER

Design of semiconductor Laser



- ✓ GaAs on both side of the junction- direct band gap semiconductor
- ✓ Top and bottom faces metallized
- ✓ left and right polished.. Reflect and form optical resonator
- ✓ Front and back are roughened to avoid lasing action in that direction
- ✓ Entire structure packaged in a metal case and that look like a discrete transistor

Remember

- Depletion region
- Charge injection to depletion region

- Direct band gap semiconductor (GaAs)
- Indirect band gap semiconductor (Si)

Gallium arsenide, indium phosphide, gallium antimonide and gallium nitride are all examples of compound semiconductor materials that can be used to create junction diodes that emit light

Si and Ge are indirect band gap material and hence not used

GaAS emit laser emit light 900 nm, IR region

In the following which is a four level laser system

a) CO_2 Laser
b) He-Ne Laser
c) Nd-YAG Laser
d) All of the above
e) None of the above