Unit-II
Lasers and Applications

1)Types of Lasers

2) Pumping Mechanisms

3) Ruby Laser

4) Nd-YAG Laser

5) He-Ne Laser

6) Semiconductor Laser

7) Applications of Lasers

Types of Laser

Based on the mode of operation

(i) Pulsed Laser systems:

(iii) Continuous wave Laser systems:

Based on the mechanism in which Population Inversion is achieved

(i) Three level lasers

(ii) Four level lasers

Based on state of active medium used

(i) Solid state Laser: Ruby laser, Nd-YAG laser

(ii) Gas Laser: He-Ne laser, CO_2 laser, Argon laser

(iii) Liquid Laser: sodium fluorescein, rhodamine B and rhodamine 6G

Important Prefixes/Symbol/Multiplying Factor (Useful for numericals)

Prefixes	Symbol	Multiplying factor
yotta	Y	$1\ 000\ 000\ 000\ 000\ 000\ 000\ 000\ 000 = 10^{24}$
zetta	Z	$1\ 000\ 000\ 000\ 000\ 000\ 000\ 000 = 10^{21}$
exa	E	$1\ 000\ 000\ 000\ 000\ 000\ 000 = 10^{18}$
peta	P	$1\ 000\ 000\ 000\ 000\ 000 = 10^{15}$
tera	T	$1\ 000\ 000\ 000\ 000 = 10^{12}$
giga	G	$1\ 000\ 000\ 000 = 10^{9}$
mega	M	$1\ 000\ 000 = 10^{6}$
kilo	k	$1\ 000 = 10^{3}$
hecto	h	$100 = 10^{2}$
deka	da	$10 = 10^{1}$
deci	d	$0{,}1 = 10^{-1}$
centi	c	$0{,}01 = 10^{-2}$
milli	m	$0{,}001 = 10^{-3}$
mikro	μ	$0{,}000\ 001 = 10^{-6}$
nano	n	$0{,}000\ 000\ 001 = 10^{-9}$
piko	p	$0{,}000\ 000\ 000\ 001 = 10^{-12}$
femto	f	$0{,}000\ 000\ 000\ 000\ 001 = 10^{-15}$
atto	a	$0{,}000\ 000\ 000\ 000\ 000\ 001 = 10^{-18}$
zepto	z	$0{,}000\ 000\ 000\ 000\ 000\ 000\ 001 = 10^{-21}$
yocto	y	$0{,}000\ 000\ 000\ 000\ 000\ 000\ 000\ 001 = 10^{-24}$

Pumping Mechanism

Pumping is the process to achieve population inversion. The pumping mechanism maintains a higher population of atoms in the upper energy level relative to that in the lower level

The most commonly used pumping methods are

1) Optical Pumping: Solid state lasers use this method. Generally for optical pumping Xenon flash lamps are used. (Used in ruby, Nd: YAG Laser)

2) Electrical Discharge Pumping: Gas lasers use this method. The electric discharge acts as the pump source. A high voltage electric discharge is passed through the laser medium or gas. After that the high electric field speeds up the electrons to high speeds. Resulting in collision with neutral atoms in the gas. Thus electrons gain energy and get excited. (Used in He-Ne laser, CO_2 laser)

3) Injection Current Pumping : In case of semiconductors, injection of current through the junction also results in population inversion among the minority charge carriers. (Used in GaAs and InP)

4) Inelastic Atom-Atom Collisions Pumping: In addition to electric discharge method Here also a high voltage electric discharge acts as a pump source. However in this method, a combination of two types of gases X and Y are used. Both X and Y gases are having the same excited states (X^+ and Y^+). (Used in Helium-Neon (He-Ne)).

RUBY LASER

Ruby Crystal

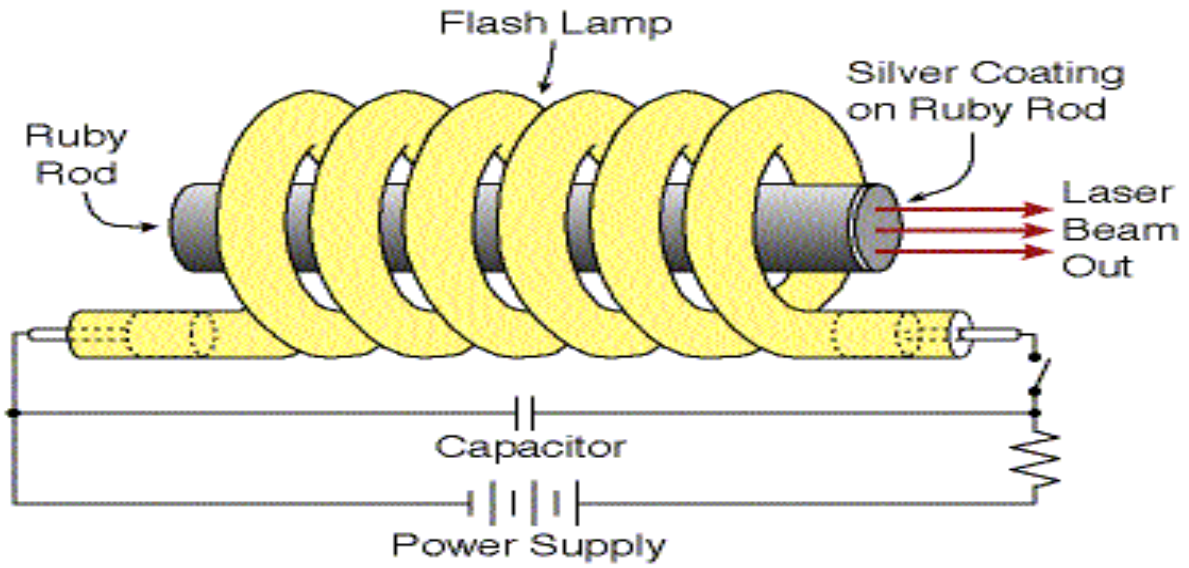
- First laser = operated successfully in 1960 by Maiman.
- Lasing medium: Aluminum oxide doped with chromium ions

$$4Al + 3O_2 = 2Al_2O_3.$$

Then Al ions are replaced with Cr

- Energy levels of the chromium atoms take part in lasing action
- A three level laser system.
- It is a pulsed Laser.

Typical set up:

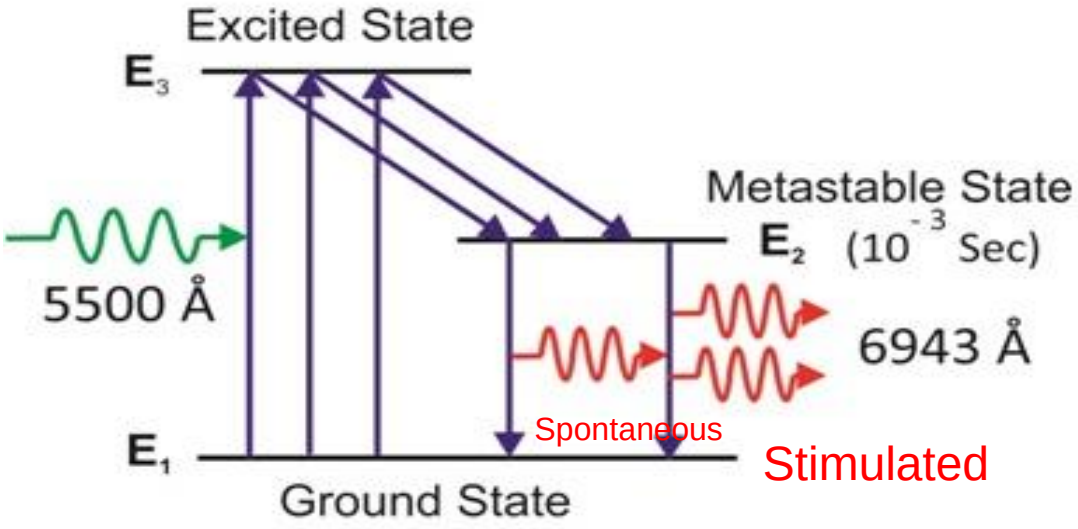


Working:

Ruby is pumped optically with the help of intense Xenon flash lamp. This causes Chromium ions to be excited by absorption of Radiation around 550nm.

Internal Processes in Ruby Laser

- Chromium ions are excited to levels E(3) levels.
- Excited ions decay non-radiatively to the level E(2) lasing level
- E(2) metastable level has a lifetime of ~ 3ms and atoms from E(1) is excited due to optical pumping which produces population inversion.
- Laser emission occurs between level Metastable and ground state G at an output wavelength of 0.6943 μm



Energy Level Diagram of Ruby LASER

Nd-YAG laser:


YAG Rod

➢Neodymium Yttrium Aluminum Garnet is Solid state lasers and same as Ruby laser (Ruby Rode replaced by YAG **($Y_3Al_5O_{12}$**)Rod) And was first demonstrated by J. E. Geusic in 1964.

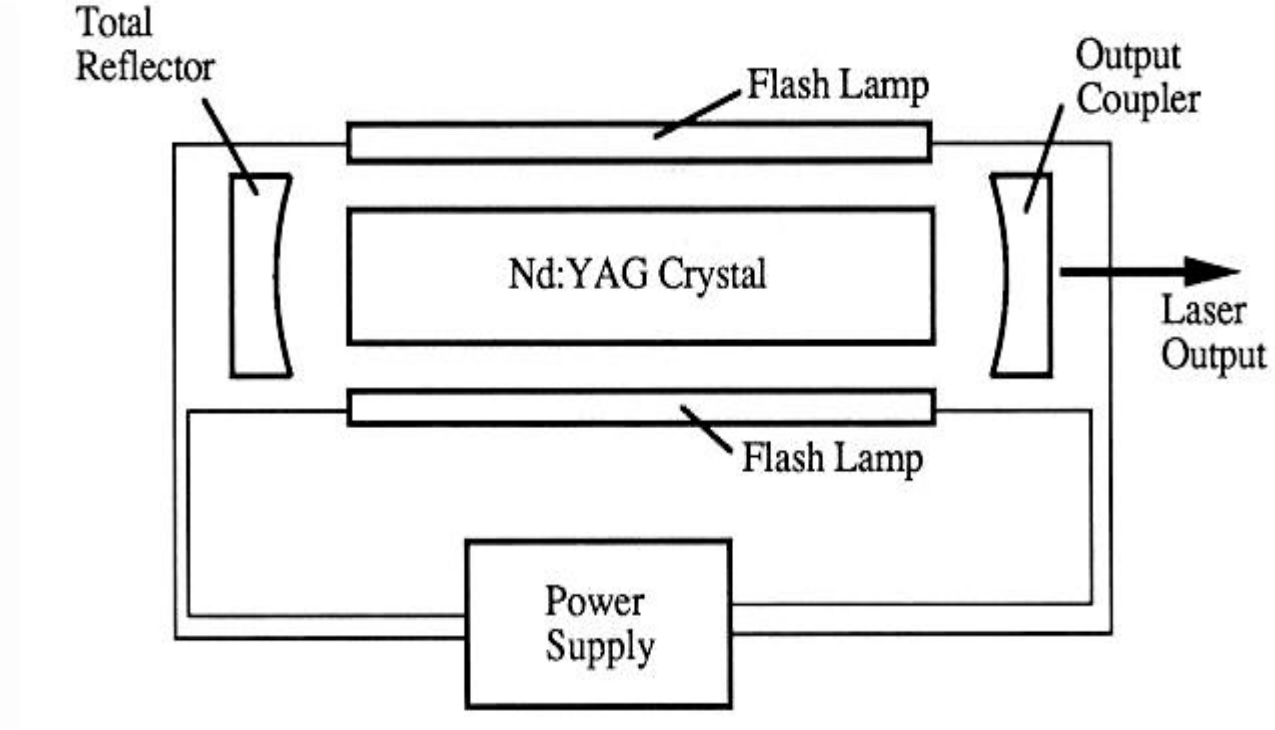
➢Energy levels of the Neodymium (**Nd_3**) ion takes place in lasing action

➢ Neodymium replaces 1% of Yttrium.

➢4 level laser systems

➢Nd:YAG lasers typically emit light with a wavelength of 1064 nm, in the infrared.

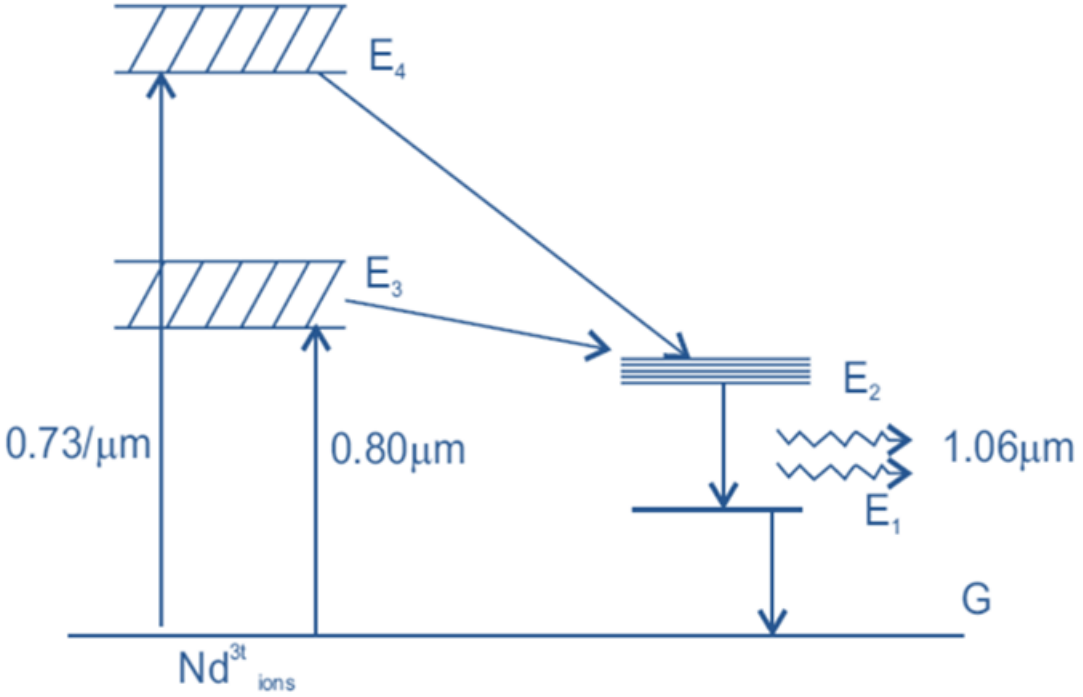
Typical set up:



- Pump band for excitation are 0.81 μm and 0.73 μm

Internal Processes in Nd YAG Laser

- Nd ions are excited to levels E(4) levels by optically pumping.
- Excited ions decay non-radiatively to the level E(3) lasing level
- E(3) metastable level has a lifetime of ~ 3ms and atoms from E(1) is excited due to optical pumping which produces population inversion.
- Laser emission occurs between level E(3) and ground state E(2) at an output wavelength of 1.06 µm
- Ions comes back to E(1)



He-Ne laser (Gas laser)

- It is continuous laser found by A. Javan et.al. in 1961.

- Laser medium is mixture of Helium and Neon gases in the ratio 10:1 at pressure 0.1mm of mercury.

Note-: Without helium, the neon atoms would be excited mostly to lower excited states responsible for non-laser lines. A neon laser with no helium can be constructed but it is much more difficult without this means of energy coupling.

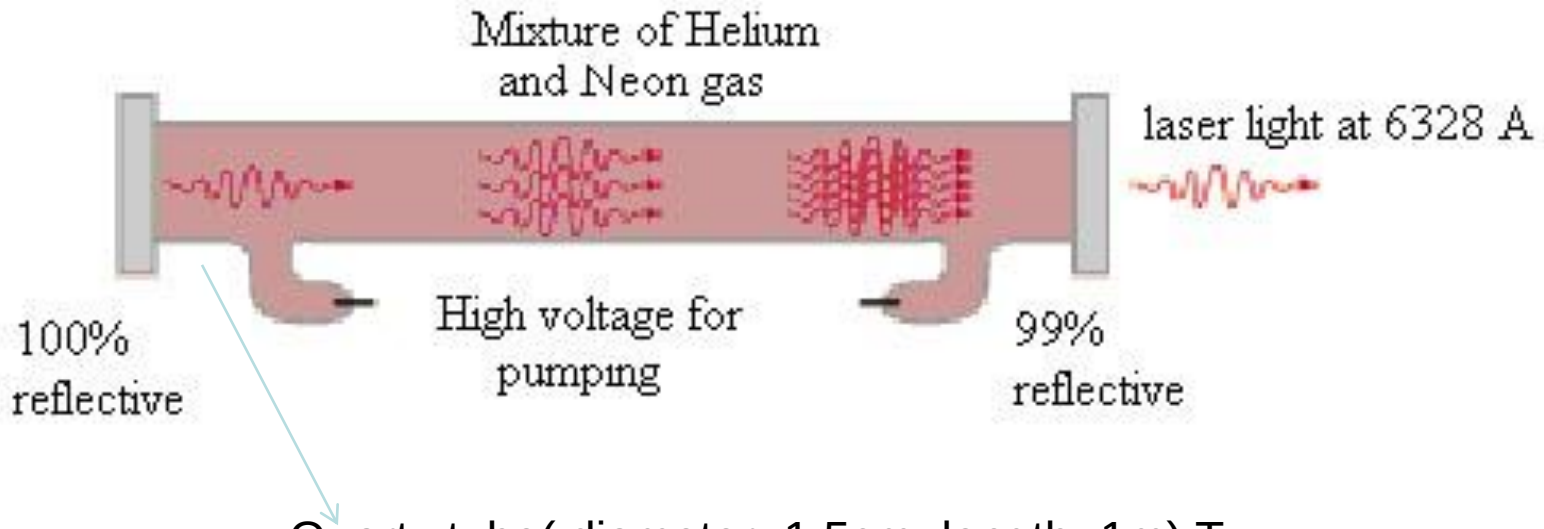
Typical set up

The helium-neon laser consists of three essential components:

•Pump source (high voltage power supply)

•Gain medium (laser glass tube or discharge glass tube)

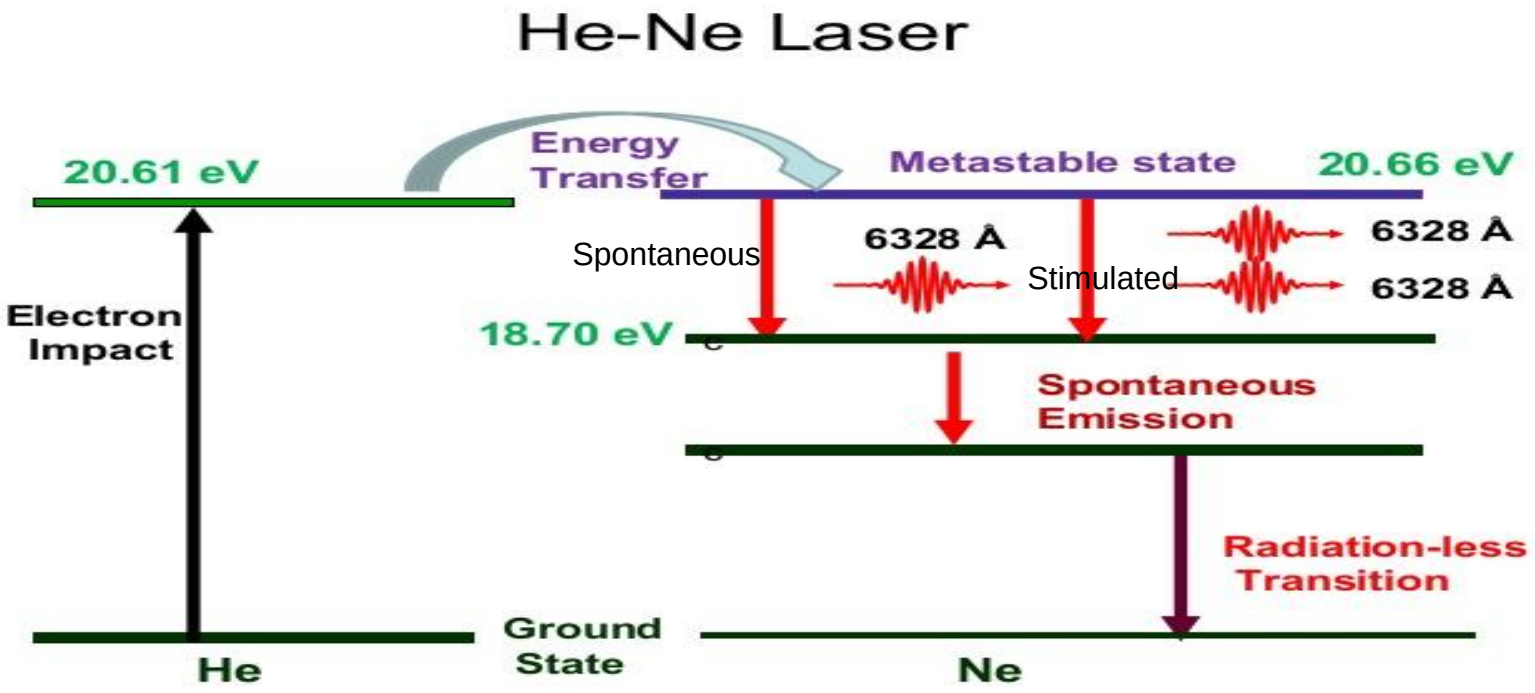
•Resonating cavity



Pumping action:

Electric discharge is passed through the gas. Electrons are accelerated, collide with He and He atoms and excite them to higher energy levels and population inversion is achieved.

- Medium excited by large electric discharge by 20.61eV, which is very close to a level in Ne at 20.66eV.
- The He atoms transfer energy to neon by inelastic collision and energy is transfer from He to Ne atoms and population inversion is achieved.
- Actual lasing atoms are the Neon atoms & produces 632.8nm (RED), when transistion took place fromm 20.66eV to 18.70eV.



Semiconductor Laser

Semiconductors

Semiconductors are materials which have a conductivity between conductors (generally metals) and nonconductors or insulators (such as most ceramics). Semiconductors can be pure elements, such as silicon or germanium, or compounds such as gallium arsenide (GaAs) or cadmium selenide (CdSe).

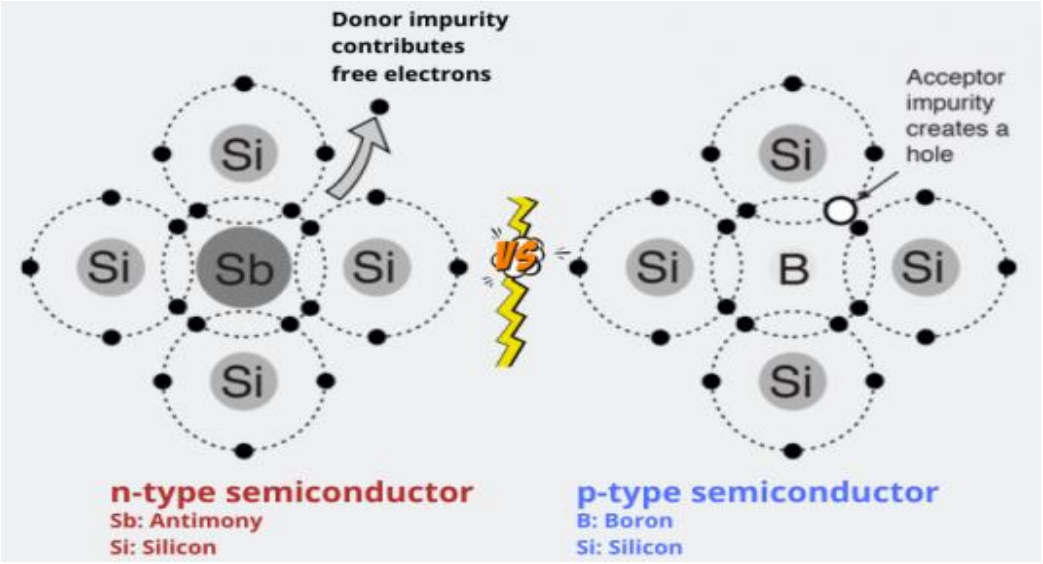
- In a process called doping, small amounts of impurities are added to pure semiconductors causing large changes in the conductivity of the material.

P-type semiconductor

- Electron minority carriers
- Holes Majority carriers

N-type semiconductor

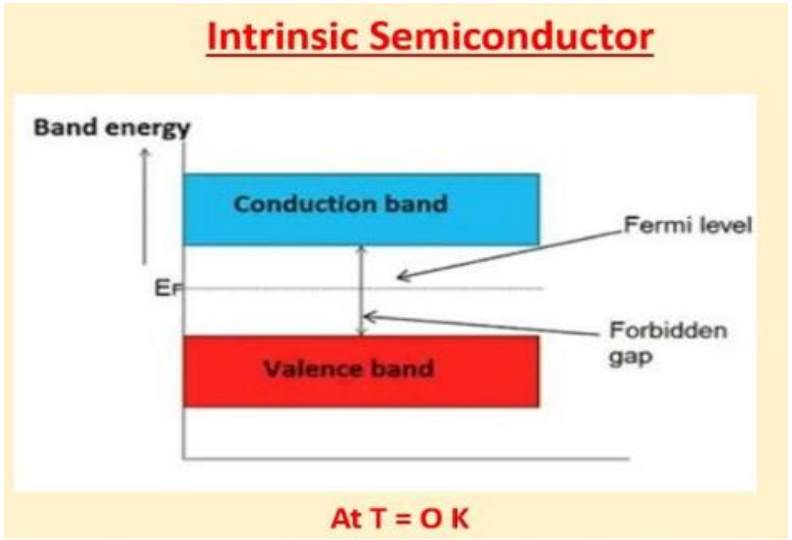
- Electron majority carriers
- Holes minority carriers

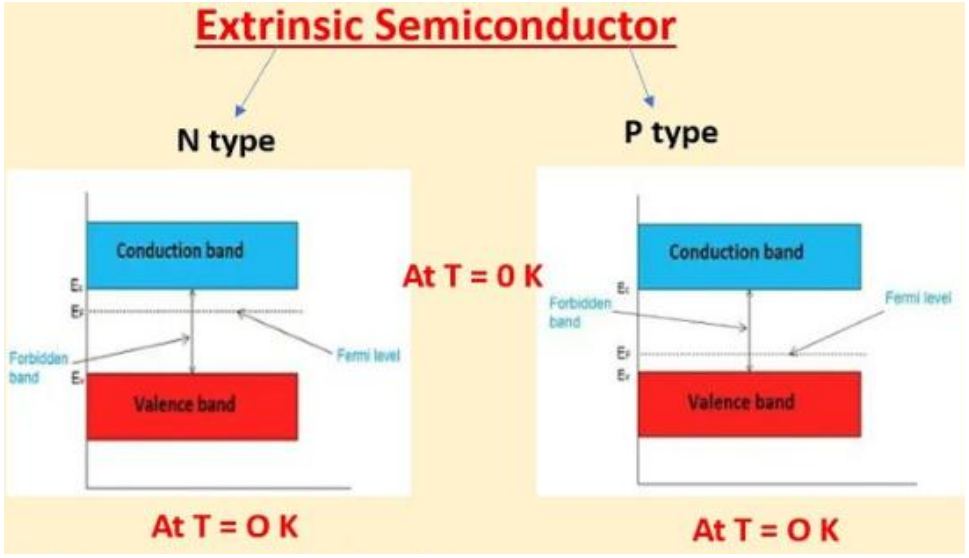


Extrinsic semiconductors

The doping of the semiconductors increases its conductivity. The process of deliberately adding a desirable impurity is known as doping and the impurity atoms are called dopants. Extrinsic semiconductors are further classified into two types - N-Type semiconductors and P-type semiconductors.

Fermi Level: **The highest energy level that an electron can occupy at the absolute zero temperature** is known as the Fermi Level. The Fermi level lies between the valence band and conduction band because at absolute zero temperature the electrons are all in the lowest energy state.

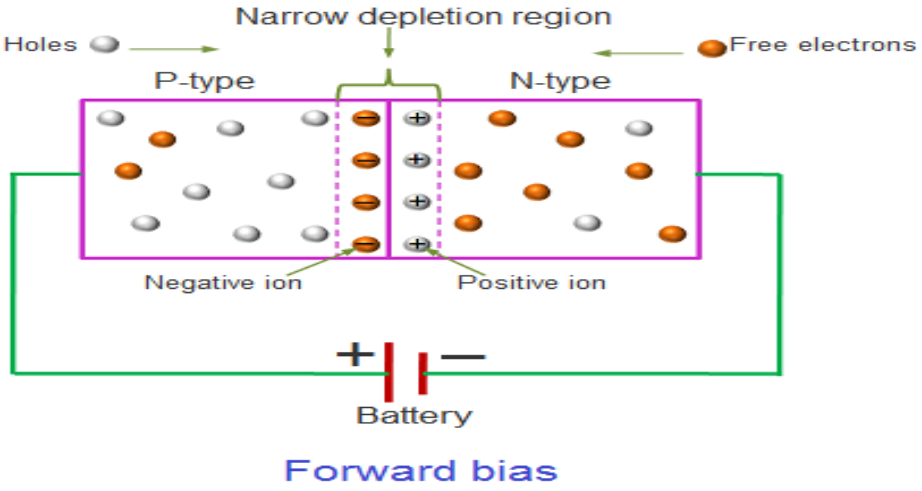




P-N Junction Diode

A p-n junction diode is two-terminal or two-electrode semiconductor device, which allows the electric current in only one direction while blocks the electric current in opposite or reverse direction.

Biasing of PN junction: Means connection to the external circuit

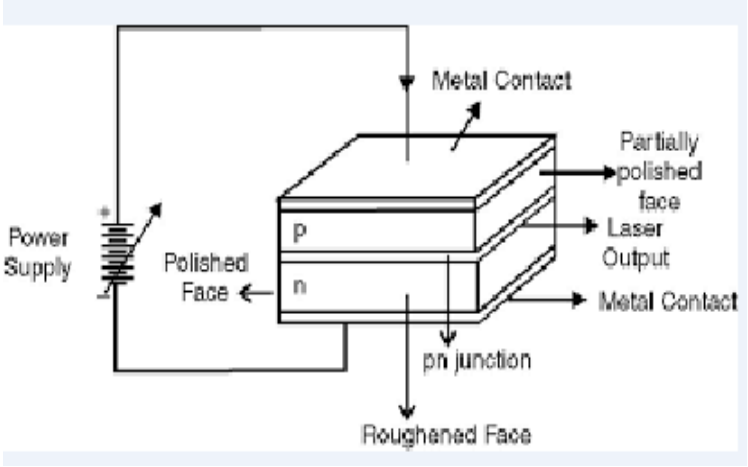


Forward Bias– The voltage potential is connected positively to the P-type terminal and negatively to the N-type terminal of the Diode.

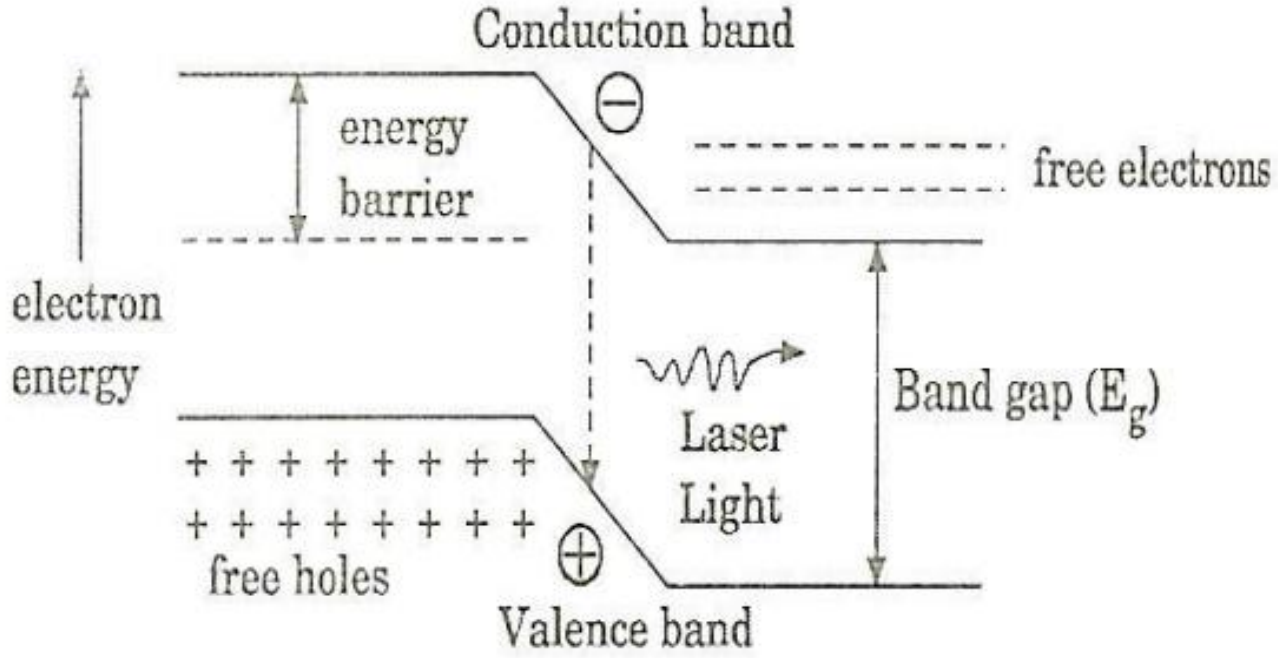
Reverse Bias– The voltage potential is connected negatively to the P-type terminal and positively to the N-type terminal of the Diode.

Principle and working of a semiconductor laser (GaAs)

- When a p-n junction diode is forward biased, the electrons from n – region and the holes from the p- region cross the junction and recombine with each other.
- During the recombination process in depletion region (in order of few microns), the light radiation (photons) is released from a certain specified direct band gap semiconductors like **Ga-As**. This light radiation is known as recombination radiation.
- The photon emitted during recombination stimulates other electrons and holes to recombine. As a result, stimulated emission takes place which produces laser.
- If the population density is high, a condition of population inversion is achieved. The electrons and holes recombine with each other and this recombination's produce radiation in the form of light.



Note : Laser Cavity called as Fabry-Parot cavity



- When the forward – biased voltage is increased, more and more light photons are emitted and the light production instantly becomes stronger. These photons will trigger a chain of stimulated recombination resulting in the release of photons in phase.
- The photons moving at the plane of the junction travels back and forth by reflection between two sides placed parallel and opposite to each other and grow in strength.

- After gaining enough strength, it gives out the laser beam of wavelength 8400 angstrom . The wavelength of laser light is given by

$$E_g = h\nu = h\frac{c}{\lambda}$$

$$\lambda = \frac{hc}{E_g}$$

Where Eg is the band gap energy in joule.

Coherence of Light

Coherence describes the properties of the interrelation between physical quantities of a single wave or between several waves. Two waves are coherent when they they have zero or constant phase difference and the same frequency.

Types of Coherence: 1) Temporal Coherence 2) Spatial Coherence:

1) Temporal (longitudinal,spectral) Coherence: means a strong correlation between the electric fields at different locations across the beam profile.

2) Spatial (transverse) Coherence: means a strong correlation between the electric fields at one location but different times.

Principles of bar code reading

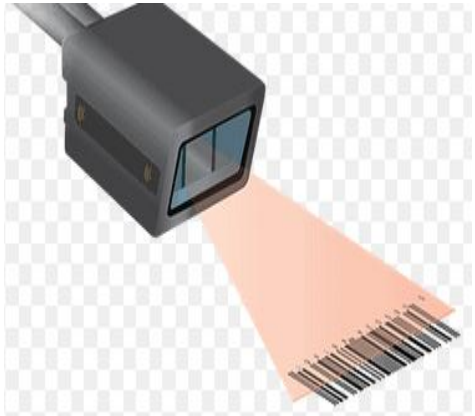
- A bar code consists of white and black bars. Data retrieval is achieved when bar code scanners shine a light at a bar code, capture the reflected light and replace the black and white bars with binary digital signals.
- Reflections are strong in white areas and weak in black areas. A sensor receives reflections to obtain analog waveforms
- The analog signal is converted into a digital signal via an A/D converter. (Binarization)
- Data retrieval is achieved when a code system is determined from the digital signal obtained. (Decoding process)

Types of bar code scanners

Laser method: Laser light is shone on the label surface and its reflection is captured by a sensor (laser photo detector) to read a bar code.
A laser beam is reflected off a mirror and swept left and right to read a bar code Using laser allows reading of distant and wide bar code labels.

Pen method: This method only has a LED light source and a sensor to capture its reflection. Since a person moves a scanner to read a bar code, practice is required for operation. The mechanism is simple, making this method inexpensive.

CCD method: This method uses a semiconductor device called CCD(Charge Coupled Device), which converts light signals into electric signals.



The CCD method bar code scanner has a built-in light. A scanner shines this light at a bar code and its reflection is captured via CCD for reading.
A bar code is captured once, allowing fast reading. There are no movable parts and impact resistance is excellent.

Laser pointer

It is a small pen-like handheld device that uses a power source (usually batteries) and diode laser to produce a coherent beam of monochromatic light. Laser pointers are used mainly for highlighting a point of interest by using a strongly colored beam of light. Typical low-end laser pointers that come with key chains are nothing more than strong LEDs to ensure safety

Original laser pointers have some safety hazards, as they can be very dangerous if pointed towards skin or eye, causing serious damage, and are to be used with great care. Laser pointers were introduced to make use of low powered laser tool for everyday use.

Laser pointers are most commonly used

1) In business/educational presentations

2) Higher power are also used in astronomy to point out celestial objects.

3) On weapons for targeting accuracy etc.

Holography

holography, means of creating a unique photographic image without the use of a lens. The photographic recording of the image is called a hologram, which appears to be an unrecognizable pattern of stripes and circles but which—when illuminated by coherent light, as by a laser beam—organizes the light into a three-dimensional representation of the original object.

- Holography was discovered in 1948 by Denis Gabor who proposed to use this technique to improve the resolution.
- Denis Gabor received the Nobel Prize for this work in 1971.

Photography vs Holography

Photography: 1) 2D image 2) Gives information of light intensity 3) Any light source is used

Holography: 1) 3D Images 2) Gives inentsity and phase information 3) Monochromatic and coherent light is used

Thank you….