UNIT V

NANO-TECHNOLOGY

Introduction:

Nanotechnology is defined as the study and use of structures between 1 nanometer and 100 nanometers in size. Nanotechnology is the engineering of functional systems at the molecular scale. This covers both current work and concepts that are more advanced. In its original sense, nanotechnology refers to the projected ability to construct items from the bottom up, using techniques and tools being developed today to make complete, high performance products.

Nanoscience: It deals with the study of properties of materials at nanoscales where properties differ significantly than those at larger scale. The applications of nanoscience emerged as nanotechnology.

Nano science deals with the synthesis, manipulation and the characterization of materials at atomic and molecular level and to study the various properties like electrical, magnetic, optical, mechanical and chemical etc.

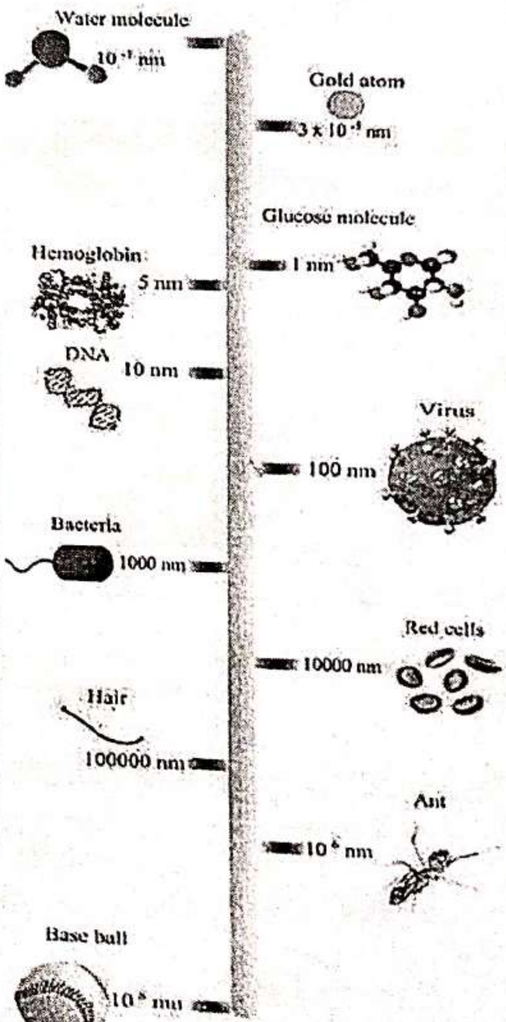
Nanoscale:

$1nm = 10^{-9}m = 10^{-7}cm$

Nano means 10^{-9}m i.e. a billionth part of a meter. Atoms are extremely small & the diameter of a single atom can vary from 0.1 to 0.5nm depending on the type of the element.

Dimensions of few nanomaterials

Carbon atom	0.15 in diameter
Water molecule	0.3nm
Red blood cell	7,000nm
Human hair	80,000nm wide
White blood cell	10,000nm
Virus	100nm
Hydrogen atom	0.1nm
Bacteria range	1,000 to 10,000nm
Proteins	5 to 50nm
DNA	2nm Width
Quantum dots	8nm



Nanotechnology: It deals with the design, characterization, production and application of nanostructures, nano-devices and nano-systems.

Nanomaterials:

The materials in which the atoms are arranged in the order of 1 to 100nm in any one of the dimension and these atoms will not move away from each other, called as nano materials. (All materials are composed of grains, which in turn comprise many atoms. The visibility of these grains depends on their size. The materials possessing grains of size ranging from 1 to 100nm, known as nonmaterial's, can be produced with different dimensionalities)
Ex: C, Zno, Cu – Fe alloys, Ni, Pd, Pt etc.

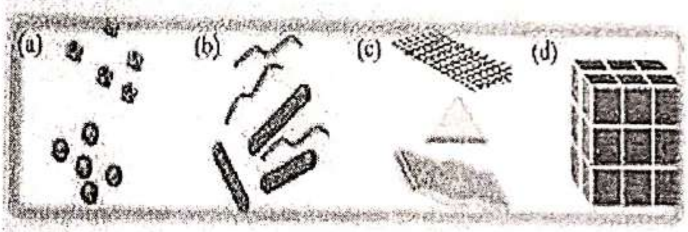
Zero-dimensional nanomaterials: Materials wherein all the dimensions are measured within the nanoscale (no dimensions, or 0-D, are larger than 100 nm). The most common representation of zero-dimensional nanomaterials are nanoparticles.

One dimensional nanomaterial: Materials that are nanoscale in one dimension called as one dimensional nano materials (nano layers). Examples: Nano tubes and nano wires.

Two dimensional nanomaterials: Materials having two of its dimension in nano scale is called two dimensional nano materials. Examples: Nano thin films, nano plates

Three dimensional nanomaterials: Materials having three of its dimension in nano scale is called three dimensional nano materials.

Examples: 3D particles of precipitates, Colloids, quantum dots, tiny particles of semi-conductor materials.

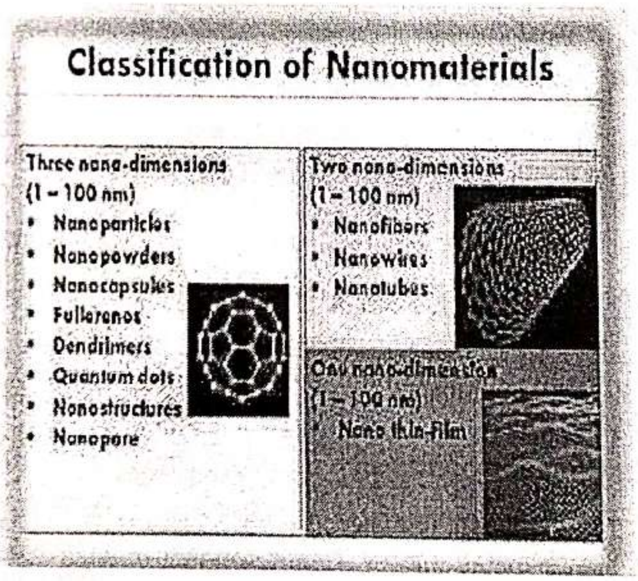


(a) 0D spheres and clusters,

(b) 1D nanofibers, wires, and rods,

(c) 2D films, plates, and networks,

(d) 3D nanomaterials.



Basic principles /properties of Nanomaterials:

When the material size of the object is reduced to nanoscale, then it exhibits different properties than the same material in bulk form. The factors that differentiates the nanomaterials form bulk material is

They are

(i) Increase in surface area to volume ratio

(ii) Quantum confinement

Increase in surface area to volume ratio: Nano materials have a large surface area to volume ratio when compared to bulk material and it is a great measure for efficiency of nanotechnology.

Example: Let us consider a sphere of radius 'r'

Its surface area = $4\pi r^2$

Its volume (atom)= $4/3\ \pi r^3$

Surface area (S.A.) to volume ratio = $\frac{4\pi r^2}{\frac{4}{3}\pi r^3} = \frac{3}{r}$

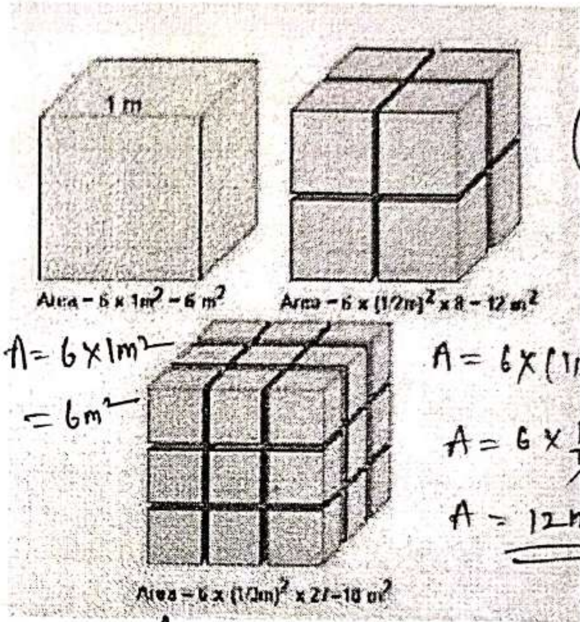
Therefore when the radius of the sphere decreases, its surface area to volume ratio increases.

Example: Let us consider a cubic volume shown in figure.

If a given sample its surface area is $6m^2$. When it is divided into 8 pieces its surface area becomes $12m^2$. When the volume is divided into 27 pieces its surface area becomes $18m^2$.

Thus, when the given volume is divided into smaller pieces. the surface area increases.

Due to increase in surface area, more number of atoms will appear at the surface. This makes nano materials more chemically reactive. Reducing the dimensions of material affects reactivity, optical properties, electrical properties, magnetic properties.



$A = a^2$

$6rs$

$A = 6 \times 1m^2 = 6m^2$

$A = 6 \times (1/2\,m)^2 \times 8$

$A = 6 \times \frac{1}{4} m^2 \times 8$

$A = 12m^2$

$A = 6 \times (1/3\,m)^2 \times 27 = 18\,m^2$

(ii) Quantum Confinement: The properties of materials can be studied based on the energy levels. When atoms are isolated, their energy levels are discrete. When very large no of atoms are closely packed to form a solid, the energy levels split & form bands. Nano materials represent intermediate stage. As a result, the energy levels change.

When we apply the problems of particles in a potential well as well as in a potential box. The dimensions of such wells or boxes are of the order of deBroglie wavelength of electrons, energy levels of electrons change. This effect is called Quantum confinement.

This affects the optical, electrical, magnetic properties of nanomaterials.

When the electrons are confined, the particles will have more oscillations and this will result in colour change of the materials. For examples, nano gold colloids are dispersed in ruby glass, the ruby glass exhibits red hue.

Synthesis (or) Fabrication of nanomaterials:

The production of nano materials or nano crystalline materials requires precise methods. There are various techniques that are capable of creating nano structures. In general there are two approaches that are classified as

1) Top-down approach (or) technique

2) Bottom-up approach (or) technique

Top–down approach: Top down techniques involves starting with a block of individual material, etching (removing the surface by dissolution) or convert it down to the desired size. The challenge here is to produce smaller and smaller structures.Nano material particle can be made through this method.

In this method, the nanomaterials are synthesized by assembling or arranging the bulk materials into nanosizes.

Top –down processing has been and will be the dominant process in semiconductor manufacturing.

Examples: (i) Sol-gel method.

(ii) Ball-milling method.

(iii) ~~Lithography~~.

(iv)~~Mechanical grinding~~.

Bottom-up approach: Bottom-up technique involves the assembly of smaller sub unit (atoms or molecules) to make larger structure.

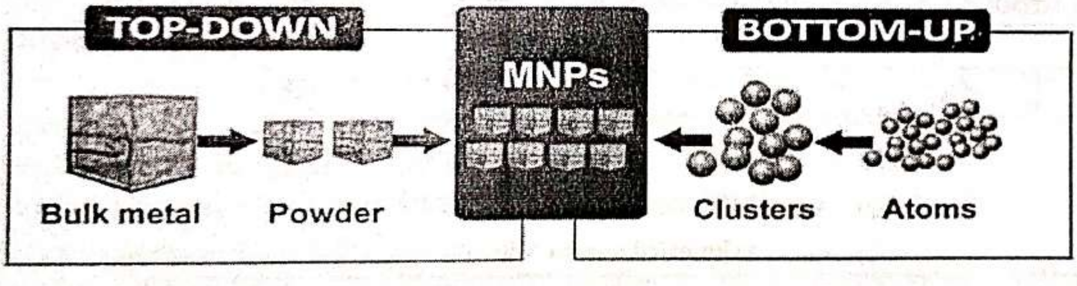
In this method, the nano materials are synthesized by assembling (or) arranging the atoms or molecules together to form the nano materials.

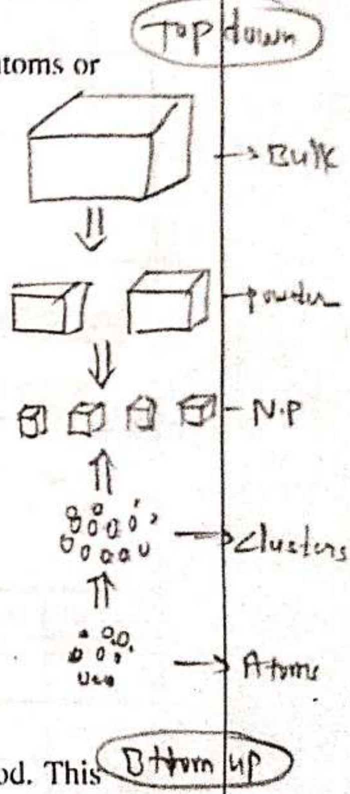
Examples: (i) physical vapour deposition method

(ii) Chemical vapour deposition method

(iii) ~~Plasma arcing and~~

(iv) ~~Electro deposition~~





Sol-Gel Method:

The sol-gel method is a wet chemical method or chemical solution deposition method. This technique is used to generate nanoparticles & nanopowders.

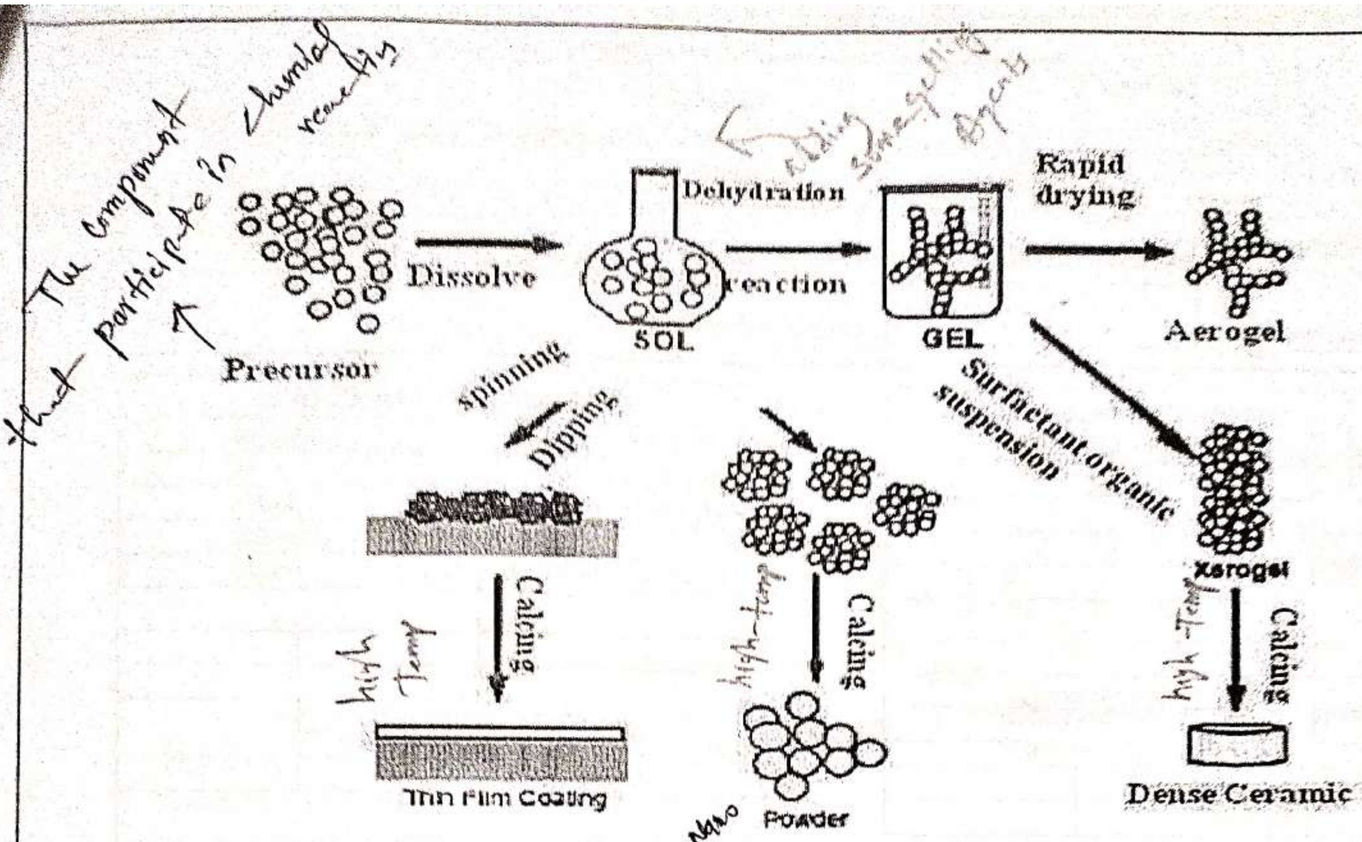
A given material converted into colloids & dissolved in water or in acids, then forms a solution (Sol). A colloid suspended in a liquid is called as "Sol". A suspension that keeps its shape is called Gelatin or "Gel". The sol-gel formation occurs in different stages. They are

1) Hydrolysis of precursors.

2) Condensation and polymerization of monomers to form particles.

3) Growth of particles and development of particles. (Agglomeration)

The schematic representation of the synthesis of nano particles using the Sol-Gel method is shown in fig.



This method takes place in following steps.

(i) Take a material & convert it into liquid precursors (inorganic salts or organic species such as

metal –alkoxide) & dissolved in water or in other solvents. It forms colloidal suspensions known as "Sol".

(ii)This solution is kept at a suitable temperature and some amounts of gelling agents are added to it. This will produce a gel.(By dehydration reaction with Sol forms Gel)

(iii) Rapid drying of the gel, under super critical conditions an aero-gel.

(iv) Drying of the "Gel" i.e. water & other liquids are removed from the gel forms a Xerogel. By calcination xerogel forms ceramics.

(V) The solution further proceed through spinning & finally by calcination forms thin films & nanopowder respectively.

Advantages:

(i) This method is used to prepare thin films, nanopowder, glasses, glass ceramics etc at very low temperatures.

(ii) To prepare mono-sized nanoparticles.

(iii)Very high purity in synthesized materials can be obtained.

Disadvantages:

(i) The raw materials are very costly.

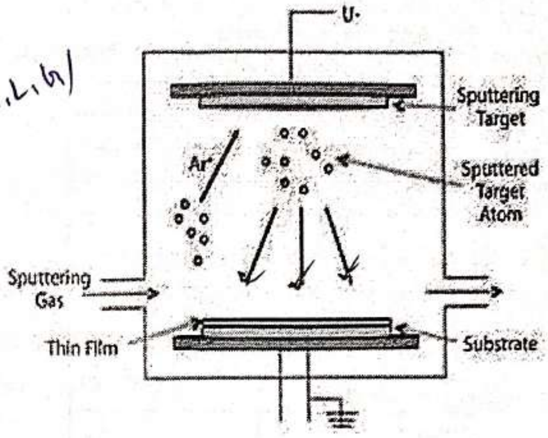
(ii) The synthesis reaction requires relatively longer time.

(iii) Organic solvents used are harmful to the environment.

PVD(Physical vapour deposition technique):

Physical Vapour Deposition (PVD) is a collective set of processes used to deposit thin layers of material, typically in the range of few nanometers to several micrometers. PVD processes are environmentally friendly vacuum deposition techniques consisting of three fundamental steps :

- Vaporization of the material from a solid source assisted by high temperature vacuum or gaseous plasma. (S, L, G)
- Transportation of the vapor in vacuum or partial vacuum to the substrate surface.
- Condensation onto the substrate to generate thin films.



Different PVD technologies utilize the same three fundamental steps but differ in the methods used to generate and deposit material.

The two most common PVD processes are **thermal evaporation** and **sputtering.**

Thermal evaporation is a deposition technique that relies on vaporization of source material by heating the material using appropriate methods in vacuum.

Sputtering is a plasma-assisted technique that creates a vapor from the source target through bombardment with accelerated gaseous ions (typically Argon).

In both evaporation and sputtering, the resulting vapor phase is subsequently deposited onto the desired substrate through a condensation mechanism to give nanofilms(thin-films).

Applications:

PVD is used in a variety of applications. & used in

(i) including fabrication of microelectronic devices,
(ii) interconnects, battery and fuel cell electrodes,
(iii) diffusion barriers,
(iv) optical and conductive coatings,
(v) surface modifications.

Advantages:

(i)This method consists good strength and durability

(ii)It is environment friendly vapor deposition technique.

Disadvantages:

(i) Cooling systems are required, to get nanomaterials.

(ii) Mostly high temperature and vaccum control needs skill and experience.

Characterization of Nano-particles:

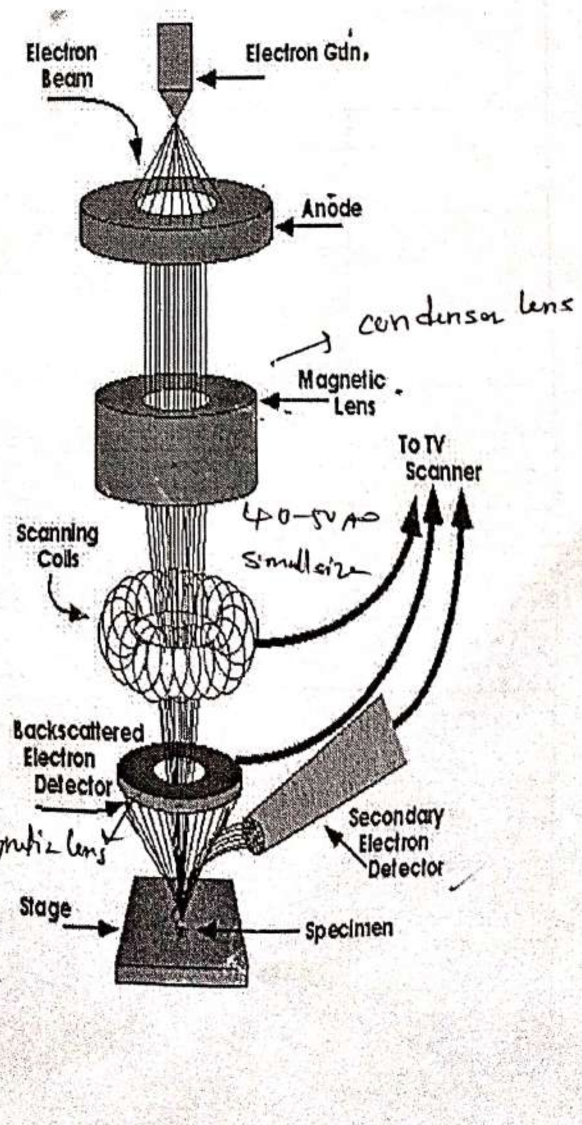
Characterization refers to the study of material features such as its composition, structure and its properties like physical. electrical, magnetic etc.

For characterization of nano particles both X-ray diffraction (XRD) & electron microscope are the most widely used techniques. They are

1. XRD
2. Electron microscope.

2) Electron microscope: It is an instrument by using we can study & analysis of small particles & crystal structures. It's magnification is high i.e. 10^6 times greater than the size of given particle (or) object. In electron microscopes, current carrying coils produce magnetic fields that act as lenses to focus an electron beam on a specimen.
They are two types of electron microscope
(1)SEM (Scanning electron microscope)
(2)TEM (Transmission electron microscope)

SEM (Scanning electron microscope):



Scanning electron microscope is an electron microscope that images the sample surface by it with a high energy beam of electrons.

Principle: The surface of a sample is scanned using a high energy beam of electrons.
This gives rise to secondary electrons, back scattered electrons, and characteristic X-rays. Conventional light microscopes use a series of glass lenses to bend light waves and create a magnified image. while the SEM Creates magnified images by using electrons instead of Light waves.
SEM consists of

1. Electron gun.
2. Anode.
3. Magnetic lens (consists of two condensed lens)
4. Scanning coils.
5. TV scanner.
6. Detectors.
7. Specimen stage.

Construction and working:

1. The virtual source at the top represents the electron-gun which produces a stream of high energy monochromatic electrons.
2. Electrons are attracted and travel through anode there by attains directionality.
3. Two magnetic lenses are used as condenser lenses to convert the diverging electron beam into a fine pencil beam and condenser lens eliminated the high angled electrons from the beam so electron –beam becomes thin and coherent.
4. A scanning coil is used to deflect the electron beam to scan the sample.
5. The objective lens is used to focus the scanning beam on a desired spot on the sample.
6. When the high energy electron beam strikes the sample, some electrons scattered due to elastic scattering (due to back scattering) called back scattered electrons, some electrons are knocked off from the surface called secondary electrons and some electrons penetrate deep into the inner shells of the sample atoms to knockoff inner shell electrons due to which X-rays (wavelength matches)are produced.
7. The intensities of secondary electrons, back scattered electrons and X-rays recorded using detectors and the signals are amplified and the images are then displayed on a TV scanner (monitor).
8. This process is repeated several times.i.e.30 times/sec to get accurate results.

Applications:

1. Topography: To study the surface features of an object and its texture.
2. Morphology: To study the shape, size, arrangement of particles.
3. Composition: To study the elements and compound ratio in a sample.
4. Crystallography: Arrangement of atoms, and their order in the crystal.
5. SEM shows very detailed 3D images at much high magnifications as compared to light microscopes.
6. The surface structure of polymer nano composites, fracture surfaces, nano fibres, nano particles and nano coating can be imaged through SEM with great clarity.

TEM (Transmission electron microscope):

TEM is a powerful tool to investigate the lattice structure and defects on materials directly. The first TEM invented by Ruska in April 1932 could hardly compete with optical microscope with only 14.4 (3.6 × 4.8) magnification the basic components in TEM are:

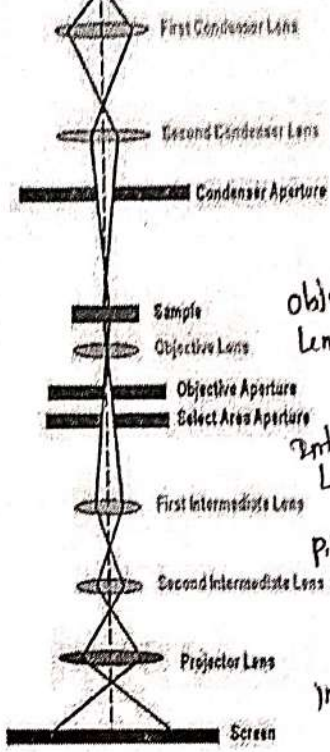
- Electron gun
- Condenser system
- Objective lens (most important lens in TEM which determines the final resolution)
- Diffraction lens → (Image producing system)
- Projective lens (all lens are inside the equipment column, between apertures)
- Image recording system (used to be negative films, now is CCD cameras)

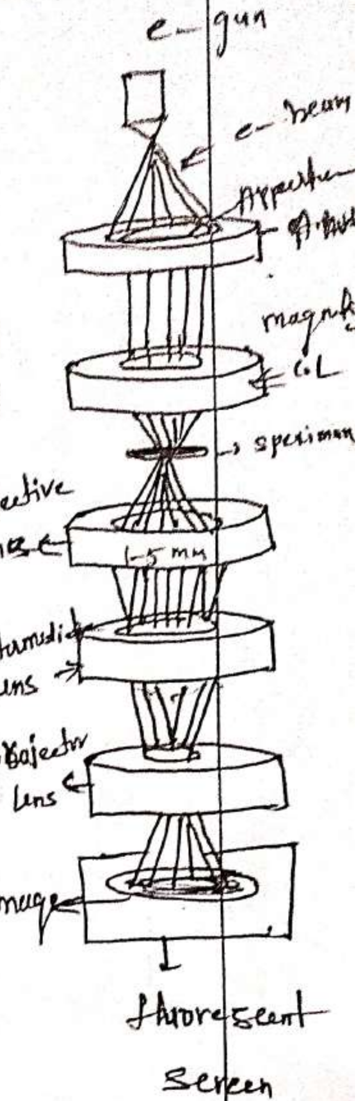
→ The image – recording system

- Vacuum system

Working:

1. The virtual source at the top represents the electron gun which produces of high energy monochromatic electron beam.
2. The beam strikes the ultra thin specimen(usually thinner than 10 nm) and parts of it are transmitted.
3. The image formed from the interaction of the electrons with the sample is magnified and focused onto an imaging device, such as photographic film, a fluorescent screen, or detected by CCD camera.
4. The darker areas of the image represents those areas of the sample that fewer electrons were transmitted through (they are thicker or denser).
5. The lighter areas of the image represents those areas of the sample that more electrons were transmitted through(they are thinner or less dense).





Applications: TEM gives the following useful information:

1. **Morphology:** The size, shape and arrangement of particles as well as their relationship to one another on the scale of atomic diameters.

2. **Crystallographic information:** The arrangement of atoms in the specimen and their degree of order, detection of atomic-scale defects a few nanometers in diameter.

3. **Composition:** To study the elements & compound ratio in a sample.

Applications of Nano materials or Nano technology:

Nano materials are 'small materials with big future' because of their extremely small size, they have many applications and advantages.

1. Material technology:

- Nano materials used in cutting tools made up of nano crystalline materials which are much harder, much more wear-resistant and last longer.
- Nano materials used as sensors.
- They are used as smoke detectors, ice-detectors on air craft wings.

2. Information-technology:

- Nanoparticles are used for information storage.
- Nan photonic crystals are used in chemical/l computers.
- Nano thickness –controlled coating are used in optoelectronic devices.
- Nanoscale-fabricated magnetic materials are used in data storage.
- Used in opto electronic devices, mobiles and laptops etc.

3. Electronic industry:
Nano materials used in

- Glass fibres.
- Used to prepare laser diodes.
- Optical switches
- data memory

4. Medical field:

- Nano materials used in drug delivery systems.
- Used as agents in cancer therapy.
- Used as active agents.
- Used to reproduce or repair damaged tissues.

Quantum dot :- if three dimensions are reduced to nanosize
While structure formed in this case is call quantum dots.

Quantum Well :- if one of The dimension is reduced to The nano-range While other two dimenssions remains same then, structure is called quantum Well.

Quantum Wire :- if two dimension are reduced to nano size While one dimension remains same, structure so formed is called quantum w

Fig3.2 Schematic of Chemical Vapour Deposition

3.8 Characterization of Nanomaterials

The characterization technique that is employed for the characterization of Nanomaterial depends on the type and application of the nanomaterial. For all Nanomaterials, particle size determination is essential and this can be done using X-ray diffraction and Electron microscopy.

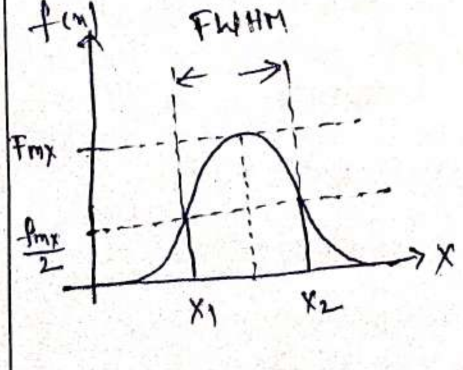
3.8.1. X-ray Diffraction Method

- Phase identification using X-ray diffraction lies mainly on the position of the peaks in the diffraction profile and to some extent on the relative intensities of these peaks.
- The shape, particularly the width of the peak is a measure of the amplitude of thermal vibrations of the atoms at their regular lattice sites.
- It can also be a measure of any deviations from the normal structure.

  Ex: Plastic deformation, impurity doping, second phase addition to the host phase. When X-ray powder pattern is taken on poly crystalline powders, the crystallite size causes peak broadening. The crystallite size is easily calculated as a function of peak width, specified as Full Width at Half Maximum (FWHM), peak position and wavelength. The average crystallite size 'L' is given by,

  $$\langle L \rangle_{\mathrm{Vol}} = \frac{K\lambda}{B_{1/2} \cos\theta_B}$$

  Where, θ_B is the Bragg's angle $B_{1/2}$ is FWHM of the diffraction peak; K is a constant and λ is the wavelength of X-rays used.



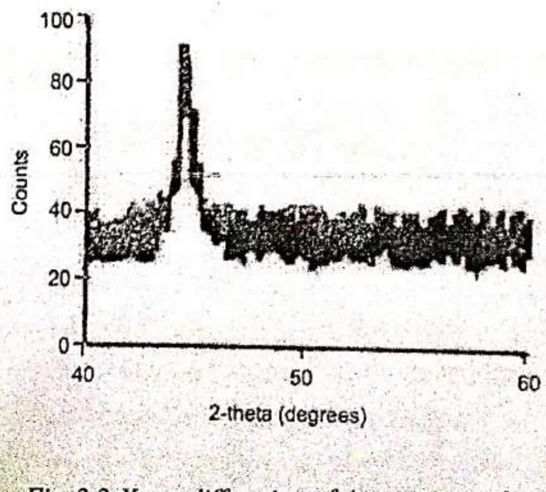


Fig. 3.3 X-ray diffraction of Ag nanoparticles

3.6 Properties of Nanomaterials

3.6.1 Physical Properties

At the macro scale, the physical and chemical properties are not dependent on the size of the material, but at the nanoscale, everything, including colour, melting point and chemical properties will change, compared to what they exhibit on a macro scale. The various physical properties are explained below.

(i)Geometric structure

- Large nanoparticles have the same crystal structure as that of the bulk material, but different lattice parameters.
- In nanomaterials, the surface area to volume ratio increases. Similarly, the interatomic distance decreases by reducing the size of nanoparticles.

(ii) Optical properties

- Different sized nanoparticles scatter different wavelengths of light incident on it and hence, they appear with different colours.

For ex., nanoscale gold particles can be orange, purple, red or greenish in colour, depending on their grain size. The bulk copper is opaque whereas nanoparticle copper is transparent. Porous silicon exhibits red photoluminescence, but bulk silicon does not show this effect.

(iii)Thermal properties

- The melting point of nanogold decreases from 1200k to 800k as the size of the particles decreases from 300A^{o} to 200A^{o}.
- The Debye temperature and ferro electric phase transition temperature are lower *for Nano materials.*
- Super plasticity of nanomaterial occurs at lower temperatures by reducing the grain size.
- Stable Aluminium becomes combustible in nano phase. Solid Gold changes to liquid as it goes from bulk to nanomaterial at room temperature.

(iv) Magnetic properties

The magnetic properties of nanomaterials are different from that of bulk materials.

- In nanomaterials single domains are used, unlike large no of domains in bulk materials. The co-ercivity of single domain is very large.
- Fe, Co, Ni and Gd are ferro magnetic in bulk but they exhibit super paramagnetism in the nanophase. Na, K and Rh are Paramagnetic in bulk but in nanophase, they are ferromagnetic.

- Small clusters (containing less than 80 atoms) of non-magnetic substances show spontaneous magnetic moment where as in the case of magnetic nanoparticles, the magnetic moment is reduced.
- Clusters of non-magnetic element, supported on metal substrates also show magnetism. This shows that small particles possess more magnetism than the bulk material. Nanoparticles of even non-magnetic solids are found to be magnetic.

(v)Electronic properties

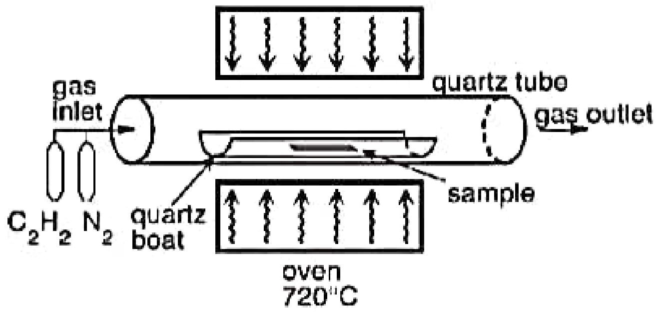
- The electrical conductivity and energy band width of some materials change when they pass from bulk phase to nanoparticle phase. **For Ex.,** bulk silicon is an insulator; it becomes a conductor in the nano phase. Nanomaterial semi-conductors such as Ge and Si do not show semi-conducting property.
- In nanoceramics and in nanomagnetic composites, electrical conductivity increases with reducing particle size. In metals, electrical conductivity decreases with reducing particle size.
- By reducing the size of metal particles from bulk top nano, the energy bands become narrower and hence the ionization potential energy increases.

(vi)Mechanical properties

- Mechanical properties such as hardness, toughness, elastic modulus, scratch resistance, fatigue strength, crack initiation and propagation are significantly different for nanostructures than bulk materials.
- In metals and alloys, the hardness and toughness are increased by reducing the size of nanoparticles. In ceramics, the ductility and super plasticity are increased on reducing particle size. Hardness increases 4 to 6 times as one goes from coarse grain Cu to nanocrystalline Cu and it is 7 to 8 times for Ni. The hardness increases 2 to 7 times by decreasing the size of nanocrystalline metals from $1\mu m$ to 10 μm.
- Materials with smaller grain size are stronger because crack propagation can be delayed or reduced in nanostructures than in bulk materials. Brittle materials (ceramics, inter metallic) can become ductile by reducing their grain size.
- The transition from bulk to nano phase reduces elastic strength and increases plastic behavior. Creep involves atomic transport along grain boundaries. This leads to super plasticity. The creep rate can be increased by 6 to 8 times by reducing the grain size from microns to nanometers.

3.7.3 Chemical Vapour Deposition (CVD)

- In this method, the material is heated to gaseous phase and allowed to condense on a solid surface in vacuum.
- Nanomaterials of metallic oxides or metallic carbides can be formed by heating metal and carbon or metal and oxygen, in a vacuum chamber to gaseous phase, and allowed to deposit on the surface of a solid.
- Pure metal powders (nanoparticles) are formed by this method. The metal is melted, excited with microwave frequency and vaporized to produce plasma at 1500^{0}c. By cooling this plasma with water in a reaction column, nanoparticles are produced.
- The grain size of the nanoparticles depends on the concentration of the metal vapour, its rate of flow in the reaction column and temperature. This method can also be used to grow surfaces.



Ball milling Method :-

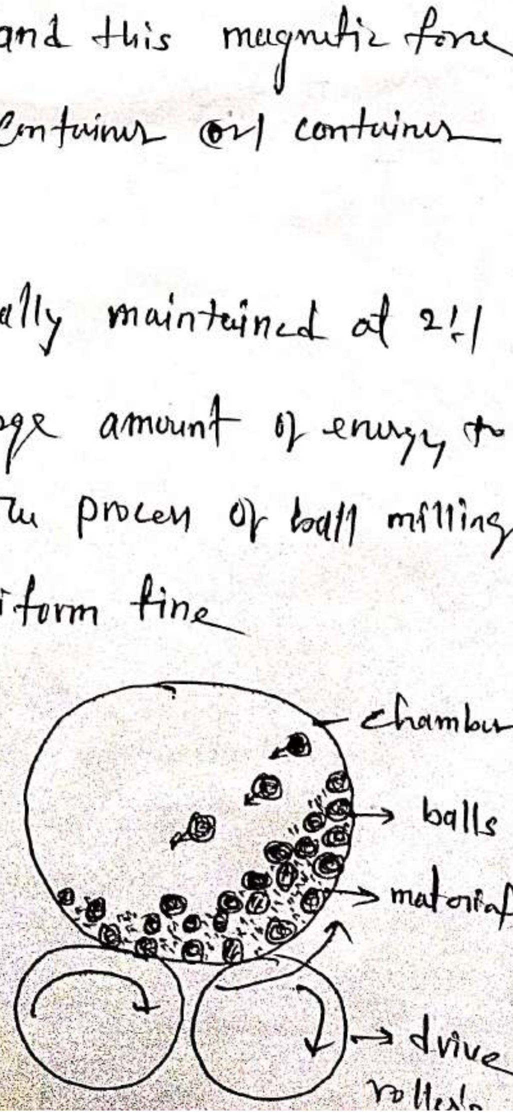
→ The ball milling method consists of balls and mill chamber. A ball mill contains a stainless steel container and many small ball made up of iron, hardness, steel, tungusten carbide or silicon carbide which are allowed to rotate inside a mill.

⇒ The powder of a material is taken inside the steel container and is converted into nanosize using the ball milling technique. The ball mill is a process of producing ultrafine particles by a top down process. ~~Severe plastic deformation of coarse grains can result in the desired product~~ A magnet is placed outside the container to provide the pulling force to the material and this magnetic force increases the milling energy when milling container or container rotates the metal balls.

→ The ball the material mass ratio is normally maintained at 2:1

→ The silicon carbide balls provide very large amount of energy to the powder and the powder get crushed. The process of ball milling is done approximately 4-6 days to get uniform fine

→ Ball milling is a mechanical process and they all the structural and chemical changes are produced by mechanical energy



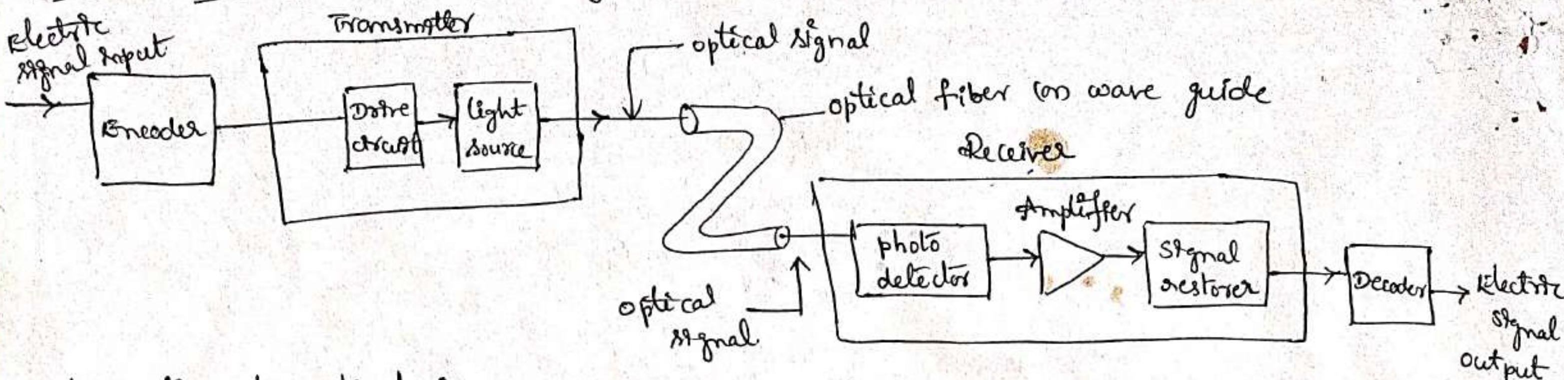
Advantages :-

→ Nanopowders of 2 to 20nm is size can be produced. The size of nano powder also depends upon the speed of the rotation of the balls

→ It is an inexpensive and easy process

Disadvantages :-

→ The shapes of the nano material is irregular optical fibers in communicating systems:— (not in present syllabus) ✗.



An efficient optical fiber communication system requires high information capacity, fast operating speeds over long distances. An optical fiber mainly consists of following parts.

Encoder, Transmitter, waveguide, Receiver & decoder.

(Modulator)
Encoder:— It is an electronic system that converts the analog information like voice figures, objects etc. into binary data. this data contains electrical pulses.

Transmitter:—

It consists of two parts, they are drive circuit and light source. Drive circuit supplies electric signals to the light source from the encoder in the required form. In the place of light source, either an LED or a diode laser can be used which converts electric signals into optical signals.

wave guide:—

In an optical fiber which carries information in the form of optical signals over long distances with the help of repeaters. with the help of specially made connector optical signals will be received by the receiver from the waveguide.

Receiver:—

It consists of 3 parts they are photodetector, amplifier and signal restorer the photodetector converts the optical signals into the equivalent electric signals and supply them to amplifier. The amplifier amplifies the electric signals. the signal restorer keeps all the electric signals in a sequential form and supplies to decoder in the suitable way.

Decoder:— (Demodulator).

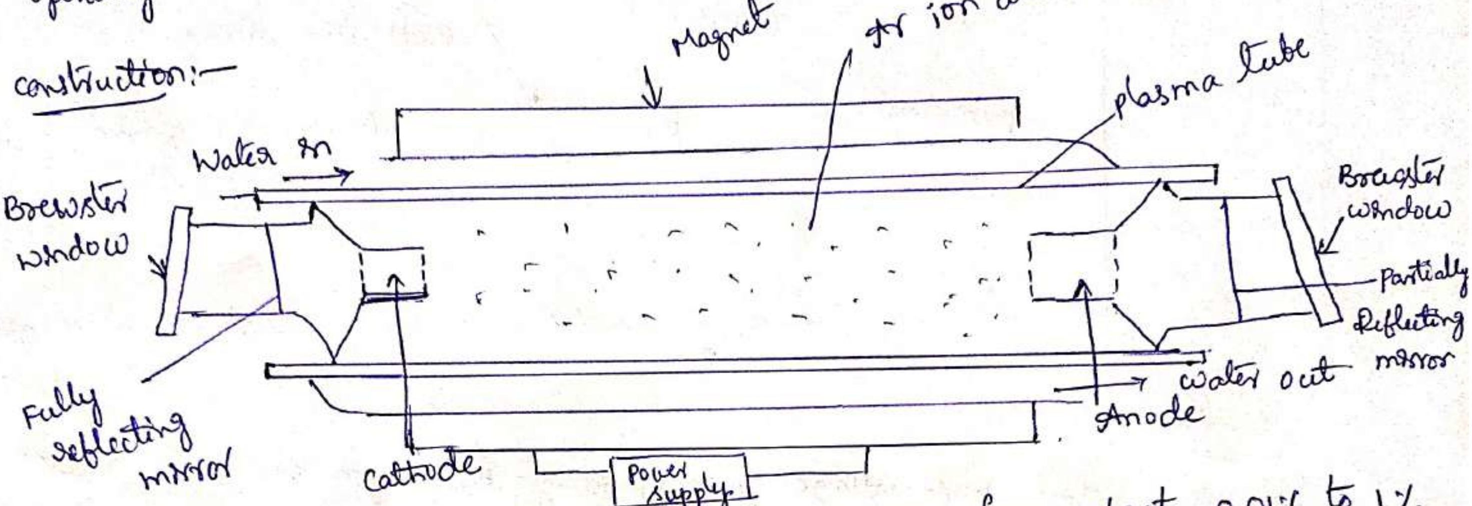
It converts the received electrical signals into the analog information.

Argon Ion Laser:-

William Bridges first invented the Argon Laser. It is a four level laser which operates in visible region over a wavelength range from 3510 A°, 5200 A°.

The argon ion laser is the most powerful continuous wave laser operating in visible region.

Construction:-



The over all efficiency of argon laser varies from about 0.01% to 1%. with average efficiency about 0.02 %.

Construction:-

→ In argon lasers, the active medium is argon gas and the active centres are ionised argon atoms. The typical design of the discharge is shown in figure.

→ It consists of a narrow water - cooled ceramic tube in which an arc discharge takes place.

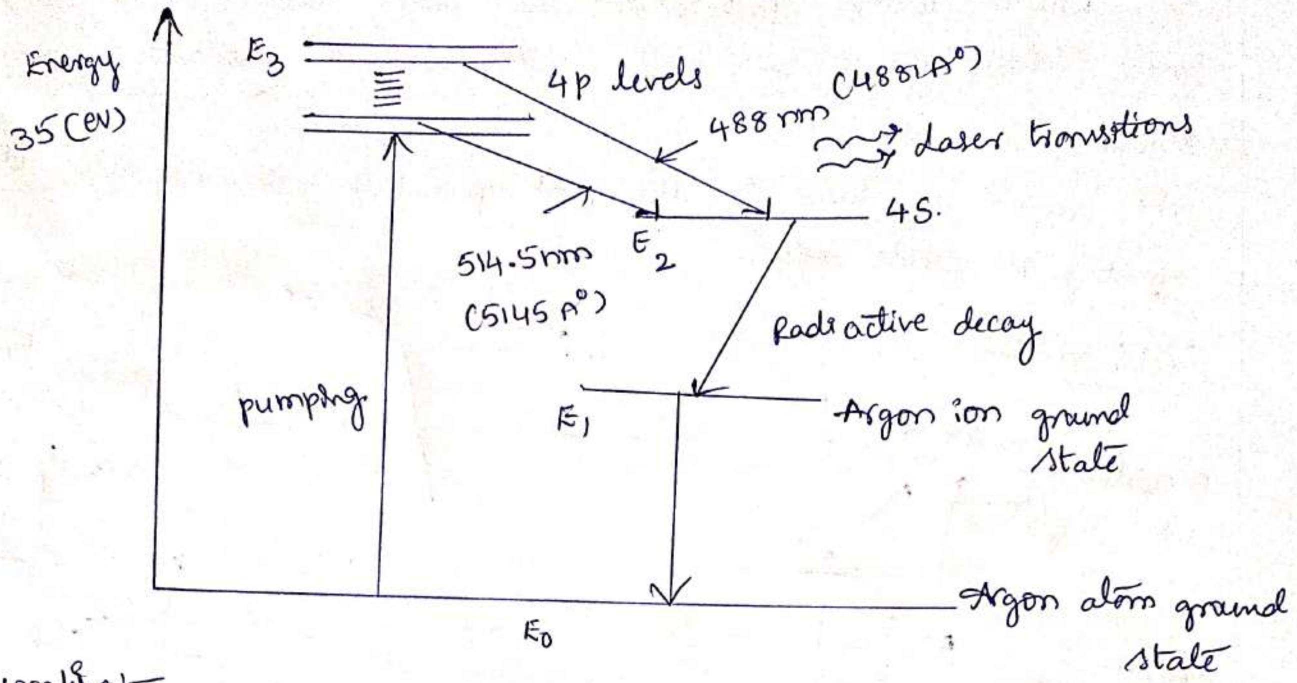
→ The electrodes are arranged at the ends of the capillary tubes.

→ In the discharge tube the gas is circulated between the anode and cathode spaces.

→ The discharge tube is surrounded by a magnet which narrows the discharge area and increases ion concentration along its axis.

→ As a result, the o/p power and efficiency increase

Working:—



Working:—

→ An initial high voltage pulse ionising the argon gas and raises the ion to a group of high energy levels, which are about 35 eV above the ground state of neutral argon atoms.

→ Different processes populate the meta stable upper laser level. three possible processes are.

(i) Electron collisions with Ar^+ ions in the ground state.

(ii) electron collisions with ions in meta stable states and

(iii) Radiative transitions from higher states.

→ The Ar ion laser is a 4 level laser. when electric discharge passes through the tube, the Ar atoms are pumped to E_3 by two-step of collision with electrons

→ In the first step, neutral argon atoms are ionized and raised to E_1. In the second step, the ion in the ground state is excited to energy level E_3.

→ The excited argon ion in E_3 falls back to E_2 either the spontaneous emission or by stimulated emission process. The ions in energy level E_2 decay spontaneously to the ground state of argon-ion emitting a photon of wavelength 720 A°.

→ In the Argon ion laser, the no. of photons of diff. wavelengths is emitted.

→ The transitions between upper & lower lasing levels and the most intense lines are 4881 A° (blue) and 5145 A° (green).

Advantages:-

→ The width of the spectrum of Argon ion laser is large. i.e it emits multiple wave lengths.

→ The argon laser is a high gain system.

→ The divgence of the Argon laser is very small

Disadvantages:-

→ The cost of an Argon laser is more than that of He-Ne laser

→ The efficiency of the Argon laser is very small

→ A large amount of power supply is needed to operate an argon laser.

Applications:-

→ Argon lasers are used to treat glaucoma and diabetic eye diseases.

→ They are used in holography

→ They are used in Raman Spectroscopy