Module-V

1.What do you mean by Density of states?

The density of states function describes the number of energy states that are available in a system and is essential for determine the carrier concentrations and energy distributions of carriers within a semiconductor.

In semiconductors, the free motion of carriers is limited to two, one and zero spatial dimensions. When applying semiconductor statistics to systems of these dimensions, the density of states in quantum well (2D), quantum wires (1D) and quantum dots (0D) must be known.

2

2.What are low dimensional systems?

A low-dimensional system is one where the motion of microscopic degrees-of-freedom, such as electrons, phonons or photons, is restricted from exploring the full three dimensions of the present world.

In the low dimensional quantum systems such as Quantum well, Quantum wire and Quantum dot, the charge carriers are free to move in two, one and zero dimensions respectively.

This high confinement brings out new effects of great technological potential applications. Quantum mechanics plays a major role as the semiconductor size approaches the nanoscale.

The main advantages of these low dimensional semiconductor systems are in the realizations of important devices, like the double heterostructure lasers with low threshold at room temperature, high effective LEDs, bipolar transistors, p-n-p-n switching devices, high electron mobility transistors (HEMT) and many other optoelectronic devices.

3.Brief the DOS in low dimensional systems?

Three-dimensional electron or hole obtained by doping semiconductors are not ideal for studying quantum effects for two reasons: (i) they are strongly disordered owing to the background of ionized impurities and (ii) the most quantum effects are more pronounced in lower-dimensional systems than those of bulk constituents.

Therefore, reduction in the dimensionality of a physical system has profound consequences on its profile and new types of electronic and photonic devices can be designed. These devices make use of electron motion through potentials that change rapidly on a length scale comparable to the wavelength associated with the electron and they operate on the rules of quantum mechanics.

The low dimensional semiconductor systems play a critical role in determining the properties of materials due to the different ways that electrons interact in two-dimensional, one-dimensional and zero-dimensional structures.

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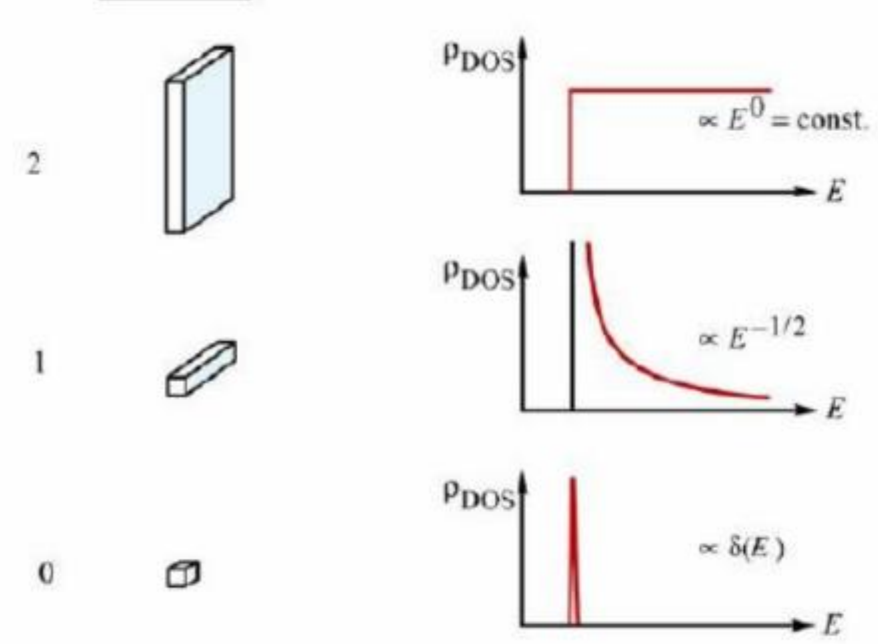
4.Compare the DOS in OD,1D and 2D systems.



Density of states in 2D

To find dk/dE, we know that

Therefore, $\frac{dE}{dk} = \frac{\hbar^2 k}{m} \Rightarrow \frac{dk}{dE} = \frac{m}{\hbar^2 k}$

Then DOS in 2D systems = $\frac{1}{\cancel{L^2}} \times \frac{\cancel{L^2} \cancel{k}}{\pi} \times \frac{m}{\hbar^2 \cancel{k}} = \frac{m}{\hbar^2 \pi}$

$= \frac{4\pi^{\cancel{2}} m}{h^2 \cancel{\pi}} = \boxed{\frac{4\pi m}{h^2}}$ where $\left[\because \hbar^2 = \frac{h^2}{4\pi^2}\right]$

DOS in 2D systems = $\frac{4\pi m}{h^2}$

Density of states in 1D

From 2D systems we know $\frac{dk}{dE} = \frac{m}{\hbar^2 k}$ where $k = \frac{\sqrt{2mE}}{\hbar}$

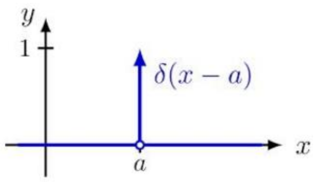
Then Density of states in 1D system $= \frac{1}{L} \times \frac{2L}{\pi} \times \frac{m}{\hbar^{\cancel{2}} \left[\frac{\sqrt{2mE}}{\cancel{\hbar}}\right]}$

$= \frac{1}{\cancel{L}} \times \frac{2\cancel{L}}{\cancel{\pi}} \times \frac{m \times 2\cancel{\pi}}{h\sqrt{2mE}}$

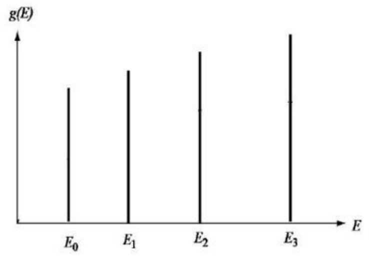
Density of states in 1D system $= \boxed{\frac{2\sqrt{2}\,(m)^{1/2}\,(E)^{-1/2}}{h}}$

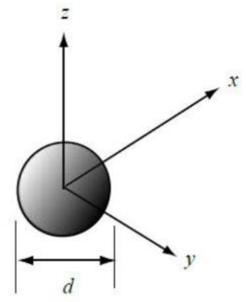
Density of states in 0D

- Therefore DOS of 0D can be expressed as a delta function



$$\boxed{g(E)_{0D} = 2\delta(E - E_c)}$$





5.Discuss about quantum well, quantum wire and quantum dot.

Quantum well, Quantum wire and Quantum dots

- When the size or dimension of a material is continuously reduced from a large or macroscopic size, such a metre or centimetre, to a very small size, the properties remain the same at first, then small changes begin to occur, until finally when the size drops below100 nm, dramatic changes in properties can occur.
- If one dimension is reduced to the nanorange while the other dimensions remain large, them we obtain a structure known as **quantum well**.
- If two dimensions are so reduced and one remains large, the resulting structure is referred to as a **quantum wire**.
- The extreme case of this process of size reduction in which all three dimensions reach the low nanometer range is called a **quantum dot**.

The conduction electrons are confined in a narrow dimension and such a configuration is referred as *quantum well*.
A *quantum wire* is a structure such as a copper wire that is long in one dimension, but has a nanometer size as its diameter. In this case, the electrons move freely along the wire but are confined in the transverse directions.
The *quantum dot* may have the shape of a tiny cube, a short cylinder or a sphere with low nanometre dimensions.

6.What are the different allotropes of carbon?

7.Write the properties of CNT.

CNT exhibits extraordinary mechanical properties:

- The Young's modulus is over 1 Tera Pascal. It is stiff as diamond.
- The estimated tensile strength is 200 GPa. These properties are ideal for reinforced composites, Nano electromechanical systems (NEMS)

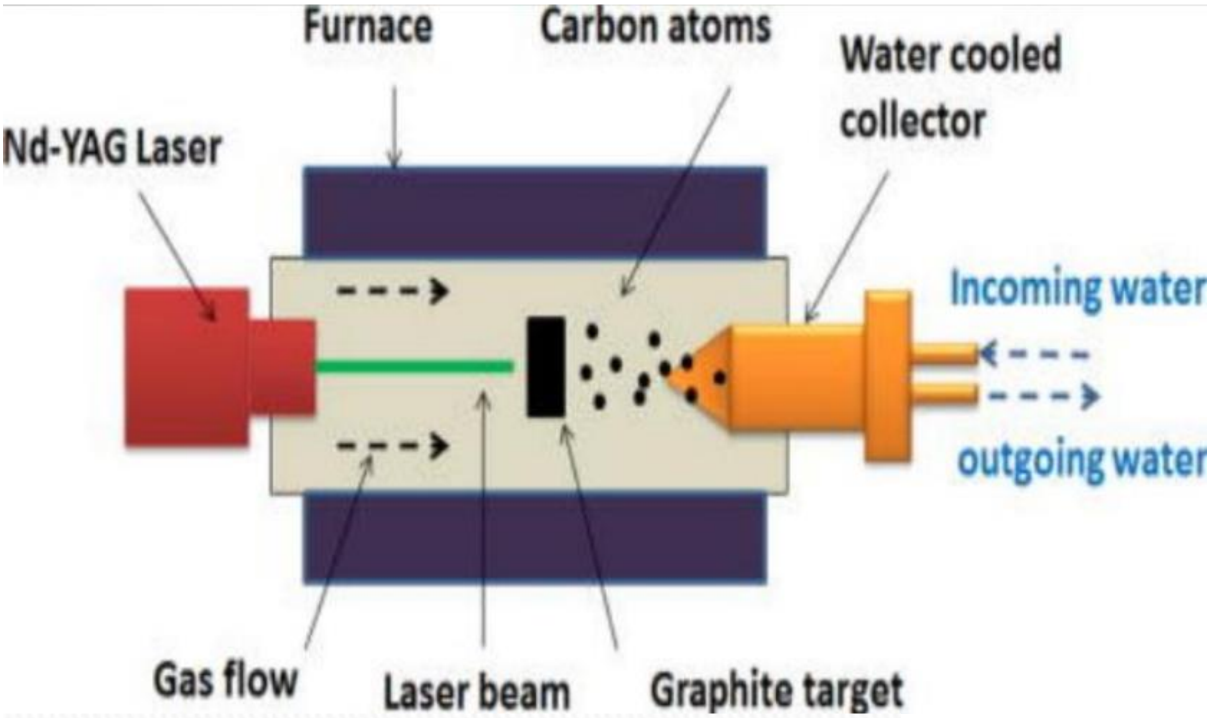
- The dimensions of CNT are variable (down to 0.4 nm in diameter)
- Apart from remarkable tensile strength, CNT nanotubes exhibit varying electrical properties (depending on the way the graphite structure spirals around the tube, and other factors, such as doping), and can be superconducting, insulating, semiconducting or conducting (metallic)

- CNT Nanotubes can be either electrically conductive or semi conductive, depending on their helicity (shape), leading to nanoscale wires and electrical components.
- These one-dimensional CNT fibers exhibit
  - Electrical conductivity as high as copper,
  - Thermal conductivity as high as diamond,
  - Strength 100 times greater than steel at one sixth the weight, and high strain to failure

- **Chemical reactivity.**

- The chemical reactivity of a CNT is very high as compared with a graphene sheet because of its curved surface.
- A Nanotube with smaller diameter results in increased reactivity.

8.How will you synthesize CNT by Laser ablation?



Laser Ablation Method

- Discovered in 1995 at Rice University
- Vaporizes graphite at 1200 °C
- Helium or argon gas
- A hot vapor plume forms and expands and cools rapidly
- Carbon molecules condense to form large clusters
- Similar to arc discharge
- Yield of up to 70%

9.Give any 3 Applications of CNT.

- Carbon Nanotube can be used as a **conducting channel** in Field emission Transistor
- CNT conducting channel result the device with low power consumption

Nanoprobes and sensors

- Because of their flexibility, nanotubes can also be used in scanning probe instruments.
- Since MWNT tips are conducting, they can be used in STM and AFM instruments.
- Advantages are the improved resolution in comparison with conventional Si or metal tips and the tips do not suffer from crashes with the surfaces because of their high elasticity.
- However, Nanotube vibration, due to their large length, will remain an important issue until shorter nanotubes can be grown controllably.
- Nanotube tips can be modified chemically by attachment of functional groups.

Composite materials

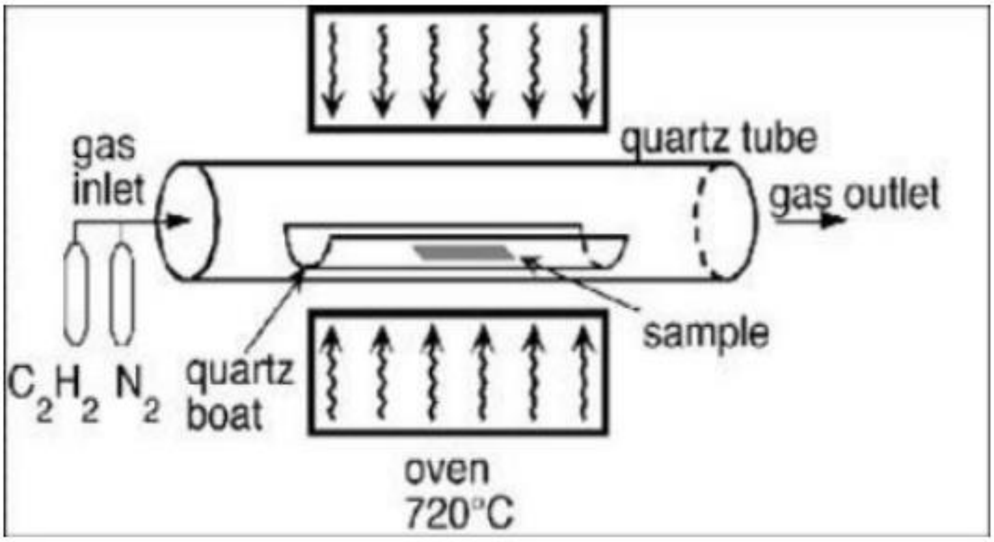
- Because of the stiffness of carbon nanotubes, they are ideal candidates for structural applications.
- For example, they may be used as reinforcements in high strength, low weight, and high performance composites.
- Theoretically, SWNTs could have a Young's Modulus of 1 TPa.
- MWNTs are weaker because the individual cylinders slide with respect to each other.
- Ropes of SWNTs are also less strong.
- The individual tubes can pull out by shearing and at last the whole rope will break.

Templates

- Because of the small channels, strong capillary forces exist in nanotubes.
- These forces are strong enough to hold gases and fluids in nanotubes.
- In this way, it may be possible to fill the cavities of the nanotubes to create nanowires.

10.Brief on the working of CVD

Chemical vapour Deposition



A basic CVD process consists of the following steps:

- A predefined mix of reactant gases and diluent inert gases are introduced at a specified flow rate into the reaction chamber;
- The gas species move to the substrate;
- The reactants get adsorbed on the surface of the substrate;
- The reactants undergo chemical reactions with the substrate to form the film; and
- The gaseous by-products of the reactions are desorbed and evacuated from the reaction chamber.

- During the process of chemical vapor deposition, the reactant gases not only react with the substrate material at the wafer surface (or very close to it), but also in gas phase in the reactor's atmosphere.
- Reactions that take place at the substrate surface are known as heterogeneous reactions, and are selectively occurring on the heated surface of the wafer where they create good-quality films.
- Reactions that take place in the gas phase are known as homogeneous reactions.
- Homogeneous reactions form gas phase aggregates of the depositing material, which adhere to the surface poorly and at the same time form low-density films with lots of defects.
- In short, heterogeneous reactions are much more desirable than homogeneous reactions during chemical vapor deposition.

11.Differentiate heterogenous and homogenous reactions in CVD

Homogeneous reactions form gas phase aggregates of the depositing material, which adhere to the surface poorly and at the same time form low-density films with lots of defects.

In short, heterogeneous reactions are much more desirable than homogeneous reactions during chemical vapor deposition.

12.Differentiate Hot wall reactor and cold wall reactor in CVD

Types of chemical vapor deposition

- A number of forms of CVD are in wide use.
- These processes differ in the means by which chemical reactions are initiated (e.g., activation process) and process conditions.
- For instance, a reactor is said to be 'hot-wall' if it uses a heating system that heats up not only the wafer, but the walls of the reactor itself, an example of which is radiant heating from resistance-heated coils.
- 'Cold-wall' reactors use heating systems that minimize the heating up of the reactor walls while the wafer is being heated up, an example of which is heating via IR lamps inside the reactor.
- In hot-wall reactors, films are deposited on the walls in much the same way as they are deposited on wafers.
- so this type of reactor requires frequent wall cleaning.

13.Classify CVD based on the operating pressure

Another way of classifying CVD reactors is by basing it on the range of their operating pressure.

Atmospheric pressure CVD (APCVD) reactors operate at atmospheric pressure, and are therefore the simplest in design.

Low-pressure CVD (LPCVD) reactors operate at medium vacuum (30-250 Pa) and higher temperature than APCVD reactors.

Plasma Enhanced CVD (PECVD) reactors also operate under low pressure, but do not depend completely on thermal energy to accelerate the reaction processes.

They also transfer energy to the reactant gases by using an RF-induced glow discharge.

CVD Process	Advantages	Disadvantages	Applications
APCVD	Simple, Fast Deposition, Low Temperature	Poor Step Coverage, Contamination	Low-temperature Oxides
LPCVD	Excellent Purity, Excellent Uniformity, Good Step Coverage, Large Wafer Capacity	High Temperature, Slow Deposition	High-temperature Oxides, Silicon Nitride, Poly-Si, W, WSi_2
PECVD	Low Temperature, Good Step Coverage	Chemical and Particle Contamination	Low-temperature Insulators over Metals, Nitride Passivation

14.Brief on the working of PVD

Physical Vapour Deposition(PVD)

Introduction

1.Physical vapour deposition (PVD) is fundamentally a vaporisation coating technique, involving transfer of material on an atomic level. It is an alternative process to electroplating
2.The process is similar to chemical vapour deposition (CVD) except that the raw materials/precursors, i.e. the material that is going to be deposited starts out in solid form, whereas in CVD, the precursors are introduced to the reaction chamber in the gaseous state.

Working Concept

PVD processes are carried out under vacuum conditions. The process involved four steps:

1.Evaporation
2.Transportation
3.Reaction
4.Deposition

Evaporation

During this stage, a target, consisting of the material to be deposited is bombarded by a high energy source such as a beam of electrons or ions. This dislodges atoms from the surface of the target, 'vaporising' them.

Transport

This process simply consists of the movement of 'vaporised' atoms from the target to the substrate to be coated and will generally be a straight line affair.

Reaction

- In some cases coatings will consist of metal oxides, nitrides, carbides and other such materials.
- In these cases, the target will consist of the metal.
- The atoms of metal will then react with the appropriate gas during the transport stage.
- For the above examples, the reactive gases may be oxygen, nitrogen and methane.

In instances where the coating consists of the target material alone, this step would not be part of the process.

Deposition

This is the process of coating build up on the substrate surface.

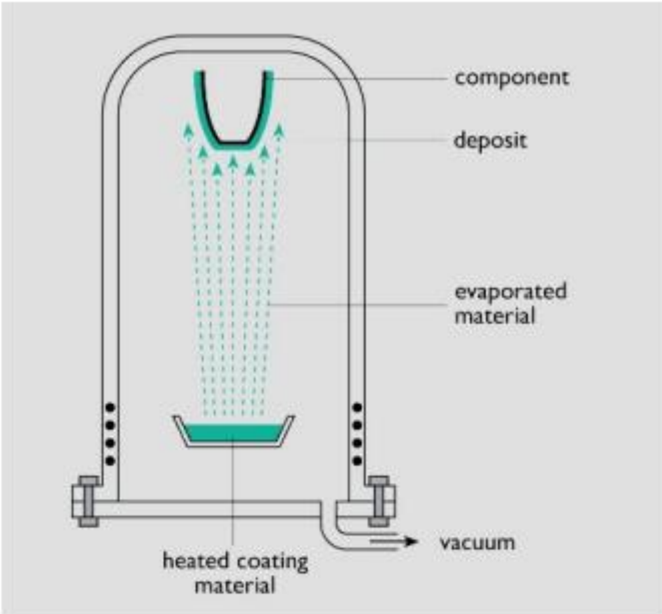
Depending on the actual process, some reactions between target materials and the reactive gases may also take place at the substrate surface simultaneously with the deposition process.

Fig. shows a schematic diagram of the principles behind one common PVD method.

The component that is to be coated is placed in a vacuum chamber. The coating material is evaporated by intense heat from, for example, a tungsten filament.

An alternative method is to evaporate the coating material by a complex ion bombardment technique.

The coating is then formed by atoms of the coating material being deposited onto the surface of the component being treated.



The vacuum evaporation PVD process

15.What are the four 4 processes in PVD?

Working Concept

PVD processes are carried out under vacuum conditions. The process involved four steps:

1.Evaporation
2.Transportation
3.Reaction
4.Deposition

16.State Bragg's law

The structures of crystals and molecules are often being identified using x-ray diffraction studies, which are explained by Bragg's Law. The law explains the relationship between an x-ray light shooting into and its reflection off from the crystal surface.

$$n\lambda = 2d\sin\theta$$

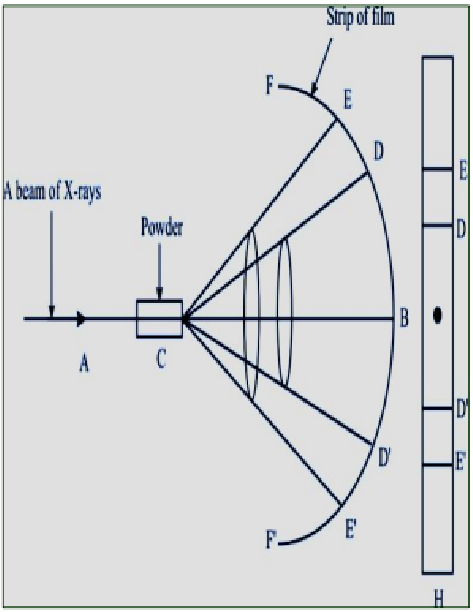
where:

- λ is the wavelength of the x-ray,
- d is the spacing of the crystal layers (path difference),
- θ is the incident angle (the angle between incident ray and the scatter plane), and
- n is an integer

17.What is the method of Powder XRD?

***The powder method*:**

- A narrow beam of monochromatic X-rays fall on the finely powdered specimen to be examined, and the diffracted rays are passed on to a strip of film which almost completely surrounds the specimen.
- The random orientation of crystals produces diffraction rings.
- This method is commonly used for identification purposes by comparing the data with the standard files available.
- For a cubic crystal the identification of lines in the powder photograph is simple compared to other types.



18.What is the principle of SEM?

Scanning Electron Microscope (SEM)

Working Concept

- **SEM** allows surfaces of objects to be seen in their natural state without staining.
- The specimen is put into the vacuum chamber and covered with a thin coating of gold to increase electrical conductivity and thus forms a less blurred image.
- The electron beam then sweeps across the object building an image line by line as in a TV Camera.
- As electrons strike the object, they knock loose showers of electrons that are captured by a detector to form the image.

When the high energy electron beam strikes the sample,

- some electrons are scattered due to elastic scattering (the back-scattered electrons),
- some electrons are knocked off from the surface (secondary electrons) and
- some electrons penetrate deep into the inner shells of the sample atoms to knock off inner shell electrons due to which characteristic X-rays are produced.

19.How are backscattered, secondary and Auger electrons utilised in SEM?

• The production of backscattered electrons varies directly with the specimen's atomic number.
• This differing production rates causes higher atomic number elements to appear brighter than lower atomic number elements.
• This interaction is utilized to differentiate parts of the specimen that have different average atomic number.

- Production of secondary electrons is very topography related.
- Due to their low energy, 5eV, only secondaries that are very near the surface (<10nm,) can exit the sample and be examined.
- Any changes in topography in the sample that are larger than this sampling depth will change the yield of secondaries due to collection efficiencies.
- Collection of these electrons is aided by using a "collector" in conjunction with the secondary electron detector.
- The collector is a grid or mesh with a +100V potential applied to it which is placed in front of the detector, attracting the negatively charged secondary electrons to it which then pass through the grid-holes and into the detector to be counted.

- Auger Electrons have a characteristic energy, unique to each element from which it was emitted from.
- These electrons are collected and sorted according to energy to give compositional information about the specimen

20.What is the principle of TEM?

The working principle of the Transmission Electron Microscope (TEM) is similar to the light microscope. The major difference is that light microscopes use light rays to focus and produce an image while the TEM uses a beam of electrons to focus on the specimen, to produce an image. Electrons have a shorter wavelength in comparison to light which has a long wavelength. The mechanism of a light microscope is that an increase in resolution power decreases the wavelength of the light, but in the TEM, when the electron illuminates the specimen, the resolution power increases, increasing the wavelength of the electron transmission. The wavelength of the electrons is about 0.005nm which is 100,000X shorter than that of light, hence TEM has better resolution than that of the light microscope, of about 1000 times.

This can accurately be stated that the TEM can be used to detail the internal structures of the smallest particles like a virion particle

21.How does unscattered, elastically scattered and inelastically scattered electrons provide information in TEM?

Unscattered electrons:
Incident electrons which gets transmitted through the specimen without interacting with the sample
Utilization:
Thicker sample- fewer transmitted electrons-appear darker
Thinner sample- more transmission- appear brighter

Elastically scattered electrons:
Incident electrons which gets scattrered by the atoms in the sample elastically (no loss of energy). Then they are transmitted
Utilization:
All electrons follow Braggs condition for scattering

Inelastically Scattered Electrons :
Incident electrons interact with the sample inelastically (loss of energy) and gets transmitted into the specimen

22.What is the principle of AFM?

Vander Waal's forces, electrostatic forces, magnetic forces and the other forces which arise due to the physical interaction between the surface atoms, cause the cantilever tip to deflect.

The AFM principle is based on the cantilever/tip assembly that interacts with the sample; this assembly is also commonly referred to as the probe. The AFM probe interacts with the substrate through a raster scanning motion. The up/down and side to side motion of the AFM tip as it scans along the surface is monitored through a laser beam reflected off the cantilever. This reflected laser beam is tracked by a position-sensitive photo-detector (PSPD) that picks up the vertical and lateral motion of the probe. The deflection sensitivity of these detectors must be calibrated in terms of how many nanometers of motion correspond to a unit of voltage measured on the detector.

23lComment on the working concept of AFM

In an atomic force microscope(AFM) a sharp probe is mechanically scanned across a surface and the motion of the probe is captured with a computer. The probe's motion is then used to create a three dimensional image of the surface. In the AFM either the probe can be scanned over a stationary surface(tip scanning AFM), or the sample can be scanned under a stationary probe(sample scanning AFM). The primary components in an AFM are illustrated in Figure 1.

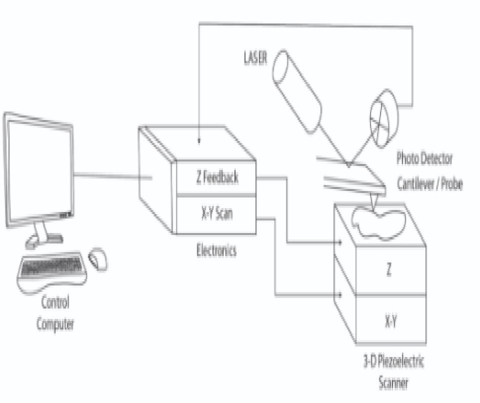


Figure 1

This figure illustrates the primary components of a sample scanning atomic force microscope: a) Control Computer b) Z Feedback Electronics c) XY Scan Electronics d) Light lever force sensor with a laser, cantilever and photodetector e) 3-D piezoelectric scanner.