APPLIED PHYSICS -II

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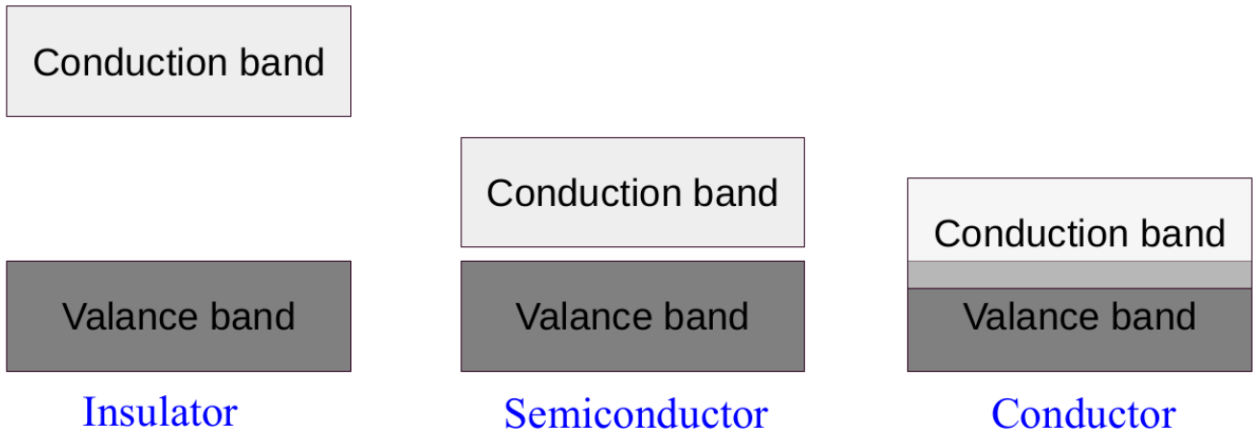
UNIT-IV MODERN PHYSICS

1) What are semiconductors

Semiconductors are materials with electrical conductivity (or resistivity) in between good insulators and good conductors. Semiconductors have a narrow bandgap.

2) Distinguish between conductors, semiconductors and insulators based on their bandgap?



Insulator

In an insulator the valance band is completely filled, and the forbidden energy band gap between the valance band and conduction band is very large. Hence there is no electrons in the conduction band for electrical conduction.

Semiconductor

In a semiconductor the forbidden energy gap between conduction band and valance band (band gap) is small. At absolute zero (T= 0 K) the valance band of semiconductor is completely filled, and the conduction band is empty, so that it behaves like an insulator. But at room temperature, some of the electrons acquire enough thermal energy and get excited

to conduction band, where they can participate in conduction of electricity under applied electric field.

Conductor

In a conductor or a metal the valance band overlaps with the conduction band, so that there is a large number of electrons available in the conduction band. These electrons can easily acquire energy from an electric field to participate in electrical conduction. Resulting in high conductivity or low resistance to conduction.

3) At absolute zero the semiconductors may behave as insulators why?

In a semiconductor the forbidden energy gap between conduction band and valance band (band gap) is small. At absolute zero (T= 0 K) the valance band of semiconductor is completely filled, and the conduction band is empty, so that at absolute zero there is no electrons available in conduction band for electrical conduction and the semiconductor behaves like an insulator.

4) Distinguish between intrinsic and extrinsic semiconductors

Semiconductors can be generally classified as intrinsic semiconductors and extrinsic semiconductors.

Intrinsic semiconductors

Extremely pure semiconductors without any impurities are known as intrinsic semiconductors. At 0 K, intrinsic semiconductors have completely filled valence band and empty conduction band. In an intrinsic semiconductor, the number of electrons is equal to the number of holes. Example for intrinsic semiconductors are Germanium (Ge) and Silicon (Si)

Extrinsic semiconductors

The conduction properties of a semiconductor can be controlled by diffusing a small amount of impurity in it. The addition of impurities to the intrinsic one is called doping. Intrinsic semiconductors with suitable amount of impurities are called extrinsic semiconductors.

5) What is doping

Doping is the process of adding impurities into an intrinsic semiconductor. Doping is used for controlling the conduction properties of a semiconductor.

6) Explain n type and p type semiconductor

There are two types of extrinsic semiconductor: n-type semiconductor and p-type semiconductor

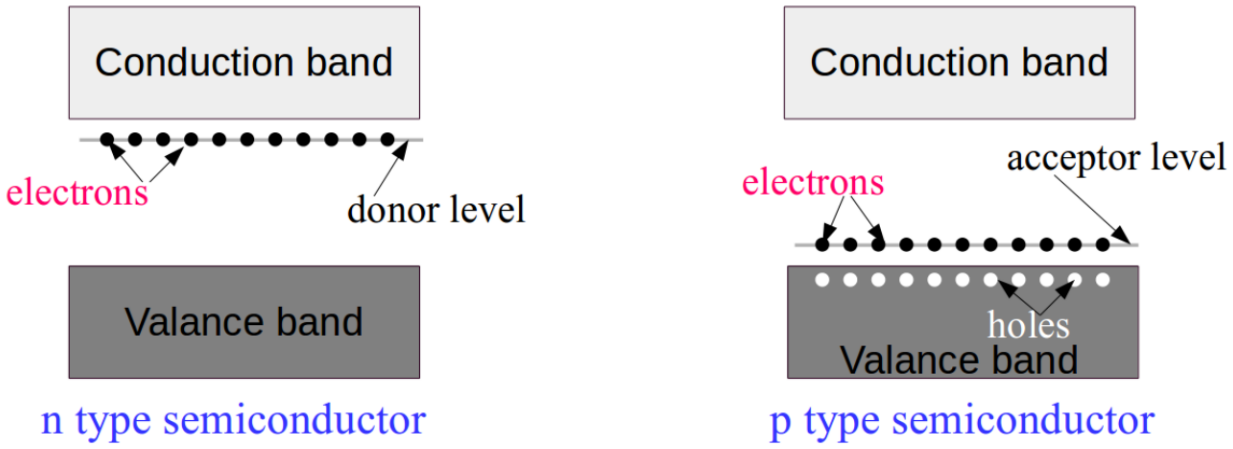
n type semiconductor

The extrinsic semiconductor in which the impurity is a donor is called n type semiconductor. A donor impurity atom provides the crystal with one or more additional electrons than the original atom, and they creates an impurity level in the forbidden gap called donor level just below the conduction band. In n-type semiconductor, electrons are the majority carriers and holes are the minority carriers. For making n type semiconductor doping is done with

pentavalent atoms such as arsenic (As), phosphorus (P), bismuth (Bi), and antimony (Sb).

p type semiconductor

The extrinsic semiconductor in which the impurity is an acceptor is called p type semiconductor. An acceptor impurity atom provides the crystal with less number of electrons than the original atom, and they creates an impurity level in the forbidden gap called acceptor level just above the valance band. In p-type semiconductor, holes are the majority carriers and electrons are the minority carriers. For making p type semiconductor doping is done with trivalent atoms such as boron (B), indium (In), and gallium (Ga).

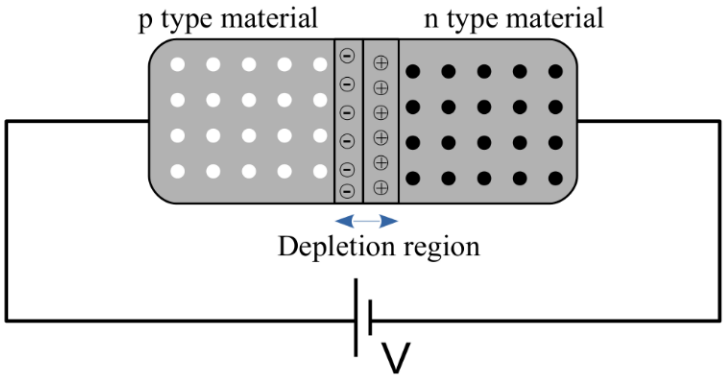


7) What is a p n junction

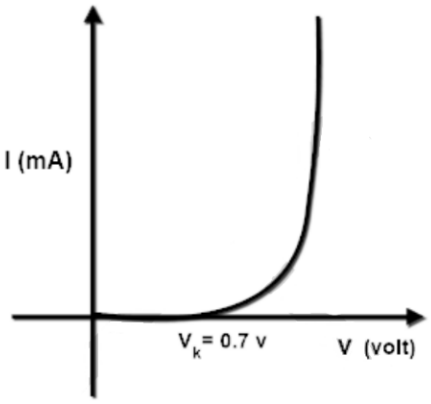
A p n junction is formed when there is a physical contact between a p type semiconductor and an n type semiconductor. p n junctions are made by selectively doping one end of a semiconductor n type and the other end p type.

8) Describe the forward bias connection of a p-n junction?

A p n junction is formed when there is a physical contact between a p type semiconductor and an n type semiconductor. In forward bias the positive terminal of the battery is connected to the p-side and the negative terminal to the n-side of the p n junction. During forward bias the potential barrier at the junction and the width of the depletion region decreases. This increases the charge carrier diffusion across the junction and the current through the junction. Hence under the action of forward potential difference, the junction offers a very low resistance. The current increases slowly till the forward bias voltage reaches 0.3 V for Ge and 0.7 V for Si p-n junction. These voltages are called knee voltage (V_k). After knee voltage, there is an exponential rise in the forward current.



Forward biased p n junction



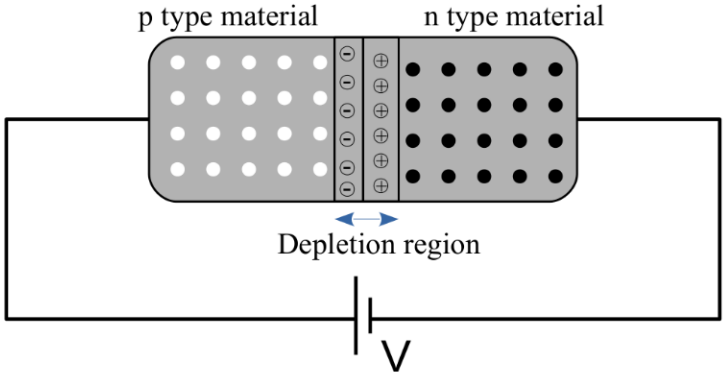
V-I characteristics of a forward biased p-n junction

9) Why there are no mobile charge carriers at the depletion region of a p-n junction?

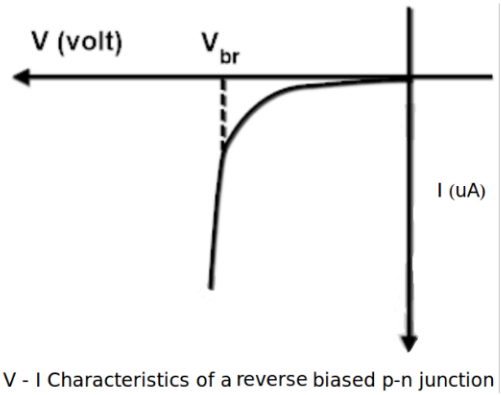
When a p n junction is formed, the electrons in the n region and the holes in the p region crosses the junction. When these electrons and holes combines they become electrically neutral, and leave behind an electrically neutral region with no mobile charge carriers. This region is called as depletion region

10) Describe the reverse bias connection of a p-n junction

If the p-side of the junction is connected to the negative terminal and the n-side to the positive terminal of a battery, the junction is said to be reverse-biased. In this case, the potential barrier or depletion region get widened. Therefore, the charge carrier diffusion becomes more difficult and hence the diffusion current decreases. Thus, during reverse bias, only a small current is allowed by the junction. That is the junction offers a large resistance when reverse biased.



Forward biased p n junction



V - I Characteristics of a reverse biased p-n junction

11) Distinguish between drift and diffusion of carriers in p-n junction

Diffusion of charge carriers

Diffusion of charge carriers happens because of the difference in concentration of charge

carriers. In a p-n junction, holes try to diffuse from the p-side to the n-side and electrons diffuse from the n- side to p-side.

Drift of charge carriers

In an electric field electrons move towards the positive side and holes move towards the negative side. This motion of charge carries in the presence of an electric field is called as drift.

12) What is reverse breakdown voltage or avalanche breakdown voltage in a p-n junction?

If the reverse-bias voltage across a p-n junction diode is increased, at a particular voltage the reverse current suddenly increases to a large value. This phenomenon is called breakdown of the diode and the voltage at which it occurs is called the breakdown voltage or avalanche breakdown voltage (V_{br}).

13) List the applications of p-n junction diodes?

a) Diode as rectifier: The p-n junction offers very low resistance in the forward bias and very high resistance in the reverse bias. So, if an alternating voltage is applied across a p-n junction the current flows only in that part of the cycle when the diode is forward biased. This property is used to rectify alternating voltages and the circuit used for this purpose is called a rectifier.

b) Diode as a voltage regulator (Zener diode): A diode meant to operate in the breakdown region is called an avalanche diode or a Zener diode. Once the breakdown occurs, the potential difference across the diode does not increase even if the applied potential is increased. Such diodes are used to obtain constant voltage output.

c) Photo diodes used for detecting optical signal (photo detectors): A Photodiode is a special purpose p-n junction, where electron-hole pairs are generated up on illumination. Hence the magnitude of the photo current depends on the intensity of incident light

d) Light emitting diodes (LED): It is a heavily doped p-n junction which under forward bias emits spontaneous radiation.

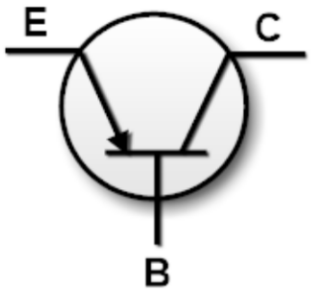
e) Photovoltaic devices (or solar cell): It a device which convert optical radiation into electricity .A solar cell is basically a p-n junction which generates emf when solar radiation falls on the p-n junction.

14) Differentiate the emitter, base and collector based on their size and doping?

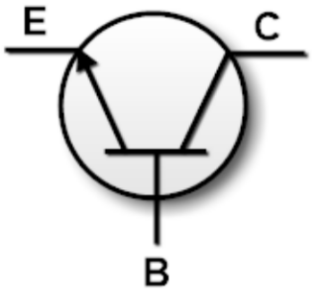
Emitter: It is one of the outer regions with moderate size and heavily doped. Emitter supplies a large number of majority carriers for the current flow through the transistor. **Base:** This is the central narrow region. Base is very thin and lightly doped.

Collector: collector is moderately doped and larger in size as compared to the emitter. This region collects a major portion of the majority carriers supplied by the emitter.

15) Draw thy symbols for n-p-n and p-n-p transistor. Also Interpret the direction of arrow mark



Symbol for pnp transistor



Symbol for npn transistor

The arrowhead in the diagram says the direction of electric current (direction opposite to the flow of electrons).

In the n-p-n transistor, there are a large number of conduction electrons in the emitter and a large number of holes in the base. If the junction is forward-biased, the electrons will diffuse from the emitter to the base and holes will diffuse from the base to the emitter. The direction of electric current at this junction is, therefore, from the base to the emitter.

Similarly, In the p-n-p transistor, there are a large number of holes in the emitter and a large number of electrons in the base. If the junction is forward-biased, the hole will diffuse from the emitter to the base and electrons will diffuse from the base to the emitter. The direction of electric current at this junction is, therefore, from the emitter to base.

16) Describe the applications of transistors

a) Transistor as a switch: For a transistor to operate there should be a minimum bias voltage across the emitter base junction. In other words we can switch the output voltage of a transistor by changing the input (or base current)

b)Transistor as an amplifier: In a transistor the collector (output) current (I_C) is directly proportional to the base (input) current (I_B) and the transistor act as a current amplifier. This condition can be written as:

$$I_C \propto I_B$$
$$or \qquad I_C = \beta I_B$$

the quantity β is called the current gain.

c) Transistor as an Oscillator: An oscillator is a circuit which produce self self-sustained signal. In a transistor circuit, by giving a portion of the output power to the input in phase with the starting power (positive feedback) we can convert it in to an oscillator

17) Describe the photoelectric effect in metals

When light of sufficient wavelength is incident on some metal surface, electrons are ejected from the metal. This phenomenon is called the photoelectric effect. The electrons ejected from the metal are called photoelectrons. The experimental observations on photoelectric effects are

1) The photoelectric effect is frequency dependent, 2) The photoelectric current is intensity dependent, 3) Photoelectric effect is an instantaneous process,

18) Give Einsteins explanation to photoelectric effect?

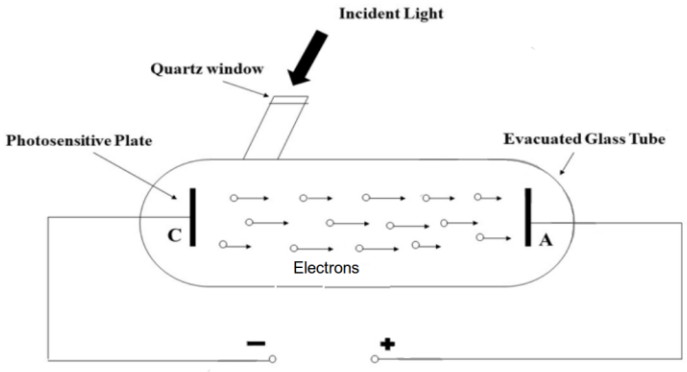
Einstein explained photoelectric effect with the help of Quantum theory of light. According to quantum theory light is not continues flow energy rather it is emitted or absorbed as discrete packets of energy called as Quanta. The quantum of light energy is called as photon. The energy of a photon depends on the frequency of the light.

Einstein proposed that the incident energy of light is used for removal of electrons from the atom in the surface and the remaining energy is given as the kinetic energy of the emitted photo electron from the metal surface.This can be summarized by an expression called Einsteins Photoelectric Effect equation and is given by;

$$\begin{aligned}\text{Incident photon energy} &= \text{Energy needed to remove an electron from the atom} \\ &\quad + \text{Kinetic energy acquired by the photoelectron} \\ h\nu &= h\nu_0 + \frac{1}{2}mv^2\end{aligned}$$

where h is the Plank's constant.

19)Explain the principle behind photocells.



Photocell is a common nomenclature used for light sensitive semiconductor electronic devices such as cadmium sulphide cells, LDR (Light Dependent Resistors), photoresistors etc., They are sensors used to detect the light or intensity of light. The working principle of Photocells is photoelectric effect.

the main parts of the photocell are an evacuated glass tube, which contains two electrodes namely a cathode and an anode. The cathode is coated with a photosensitive material. When light falls on the cathode, photoelectrons are emitted which are collected by the anode, and an electric current is generated.

20) Describe the different laws of Photoelectric effect

The three laws of photoelectric effect are:

1) The photoelectric effect is frequency dependent: It is experimentally observed that photoelectric effect is not observed for radiation of all frequencies. There is a particular frequency above which the photoemission of electrons happens. This frequency is called as **threshold frequency**.

2) The photoelectric current is intensity dependent: The number of photoelectrons generated determines the photocurrent. If the incident wave frequency is higher than or equal to the threshold frequency the photocurrent generated is proportional to the intensity of radiation.

3) Photoelectric effect is an instantaneous process: There is no time lag between the incidence of radiation and emission of photoelectrons

21) What is a solar cell? Explain the working of a solar cell?

Solar cells are devices that use the photovoltaic effect to convert the energy of light directly into electricity. The energy conversion consists of absorption of light (photon) energy, producing electronhole pairs and charge carrier separation. A pn junction is used for charge carrier separation. When light of suitable frequency incident on the Solar cell, the photon energy is absorbed by the atoms and produces electron hole pair at the depletion region. At the depletion region the electron hole pair get split, and the electron moves to the n region and hole move to the p region due to the existing electric potential between the depletion region. And a photovoltage is developed. If the ends are connected to a load, these charge carriers flow through the conducting wire to the load and create a current.

22) Distinguish between spontaneous and stimulated emission?.

Spontaneous emission

An atom in the excited state return to the ground state by emitting photon by itself is called spontaneous emission. Here only two energy levels included, namely ground state level and excited state levels of energy. The direction and phase of the spontaneously emitted photons are random. So that it will not have a collective emission nature. So, it cannot produce lasing action.

Stimulated emission

A photon striking an excited atom can induce the atom to return to the ground state by emitting an identical photon (same frequency, direction, phase, and polarization as the incident photon,). This process is called stimulated emission. Stimulated emission is used in lasers

23) Describe the term population inversion?

Population inversion is a necessary condition to achieve lasing action. In order to produce lasing action from a medium, the number of atoms in the excited state should be more than the number of atoms in the lower state. This state is known as population inversion.

24) Describe the different methods to produce population inversion?

There are several methods for producing the population inversion, some of the most commonly used are :-

1) Optical pumping or photon excitation:- In the case of optical pumping, an external light source is employed to produce a high population of some particular energy level in the laser medium by selective optical absorption. This method is used in solid state laser. Example ruby laser

2)Electron excitation: Here direct electron excitation by gaseous discharge is used to produce the population inversion. This method is used in some of the gaseous ion lasers such as argon laser.

3) Inelastic atom-atom collisions: Here the collision between the atoms leads to the population inversion. In this method a suitable combination of gases is employed such that both have some excited states that coincide or nearly coincide. In helium- neon laser population inversion is produced by this method.

4) Chemical pumping: Here chemical reaction produce the population inversion. Chemical lasers use chemical pumping. Example hydrogen fluoride laser

25) What are the characteristics of LASER?

The characteristices of LASER are :-

a) **Laser light is monochromatic:** The laser radiation is having a single color, or the radiation is having only one wavelength.

b) **Laser light is highly coherent:** The individual waves in the laser radiation are in same phase.

c) **Laser light is highly intense:**

d) **Laser light is highly directional:** Unlike normal light laser light spreads less. Or laser light has low divergence

26) List the applications of LASER?

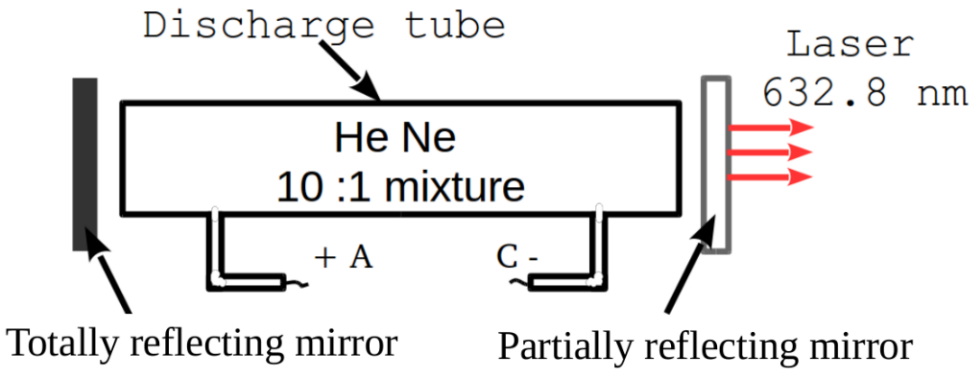
Some of the applications of LASER are :-

1. Laser is used as tool for surgery (Ophthalmic surgery).
2. Laser is used for precision cutting, drilling, and welding.

3. Laser beam can be used as a carrier of information (telephone signal through optical fiber cables).
4. Laser is used for range finding (measurement of distance of faraway objects).
5. Laser is used in Holography or 3D imaging.
6. Laser is used to read and write data in CD/DVD systems.
7. Laser is used in printing technology (Laser printer).
8. Laser is used to initiate fusion reaction.
9. Laser based methods are used to guide missiles and pilot-less fighter planes.

27) Describe the working of He-Ne gas LASER

Helium Neon laser is a gas laser. The essential parts of the laser are shown in the figure. The active medium of this laser is a mixture of helium (He) and neon (Ne) in the ratio 10:1. The gas mixture at low pressure is placed in a long discharge tube, typically 50 cm long and 0.5 cm diameter. The two mirrors at the ends provide the feedback, one of the mirror is highly reflecting while the other is partially reflecting.



Working:-

When electric discharge is maintained in the tube the electrons collide with the atoms in the tube. The helium atoms in the tube raised to the higher energy state by this collision of electrons. When excited helium atoms collide with the neon atoms, the excitation energy of helium is transferred to the neon atoms. In this way large number of neon atoms are raised to higher level. When population in the higher level happens to be more than that in the lower level, a spontaneously emitted photon can trigger laser action. The laser output from a helium neon laser has a wavelength 632.8nm

28) Describe the working of semiconductor LASER

A semiconductor diode laser consists of a p-n junction in a doped single crystal of a suitable semiconductor, such as gallium arsenide (GaAs). The junction layer is very thin of the order of micrometers in length. And the end faces of the crystal are made partially reflective by polishing to form an optical resonator. When a forward bias is applied to the diode, electrons are injected into the p side of the junction and holes are injected into the n side. The recombination of holes and electrons within the junction region result in the emission of light. If the junction current density is large enough, a population inversion can be obtained between the electron levels and hole levels. Stimulated emission can then occur and thereby lasing action.

29) What is nanoscience?

The study of objects and phenomena at a very small scale (1-100 nanometers) is called Nanoscience. In Nanometer scale the material properties are size and shape dependent.

30) What is nanotechnology?

Nanotechnology is the design, characterization, production and application of structures, devices and systems by controlling shape and size at Nano meter scale.

31) What do you understand by nanoparticles?

Nanoparticles are particles having size in the nanometer scale (1-100 nanometer). Nanoparticles have very different properties from that of the macroscopic material. Also the properties are size and shape dependent.

32 What are the factors responsible for change of properties of nanoscale material from that of the bulk material?

The factors responsible for the change of properties at nanoscale level are. 1) The large relative surface area of the nanoscale materials compared to that of the bulk material and 2) the changes in the electronic structure of the nanoscale material from the bulk material

33)Write few characteristics of Nanoscale materials

Some of the characteristics of nanoscale materials are;-

1. Nano fibers stronger than spider web
2. Nano metal is 100 times stronger than steel
3. Nano catalysts respond more quickly in reaction
4. Nano plastics that conduct electricity.
5. Nano coatings are frictionless
6. Nano materials that change colour and transparency

7. Nano scale powders better than metal for radiation protection.

34) Describe carbon nanotubes (CNT)

Carbon is tetravalent material so that it can form a sheet like structure. If the sheet of carbon atom network is folded like tube of nano scale diameter, it is called as carbon nanotube (CNT). There are two types of carbon nanotubes, namely single walled carbon nanotubes (SWCNTs) and Multi- walled carbon nanotubes (MWCNTs).

Single walled carbon nanotube is a two dimensional hexagonal lattice of carbon atoms rolled up as a hollow cylinder. Multi-walled carbon nanotubes (MWCNTs) consisting of nested single-wall carbon nanotubes which are weakly bound together by van der Waals interactions in a tree ring-like structure.

35) Describe some of the applications of carbon nanotubes (CNTs)

1. Medical Applications
   (a) Nanotubes can help with cancer treatment. They have been shown to be effective tumor killers in those with kidney or breast cancer.
   (b) The nanotubes show promise in treating cardiovascular disease.
   (c) They could play an important role in blood vessel cleanup.
   (d) Carbon nanotubes are used in tissue engineering and it can act as scaffolding for bone growth
2. CNTs are to make temperature resistant adhesive tape
3. CNTs are used in modern bicycle parts since they had better hardness with less weight
4. CNTs are used in a variety of sports gear such as skis, ice hockey sticks, baseball bats, hunting arrows, and surfboards.
5. CNTs are used in shuttle badminton rackets so that they are light weight and strong
6. CNTs can be applied to camera and telescope systems to decrease the amount of scattered light