BVRIT HYDERABAD
College of Engineering for Women
Approved by AICTE and Affiliated to JNTUH, Hyderabad
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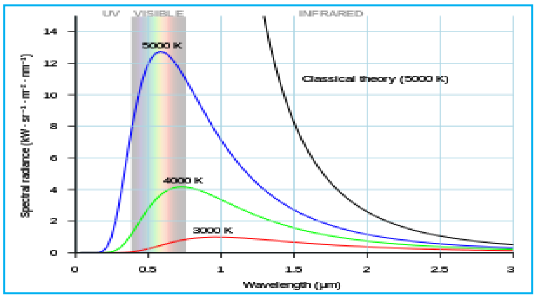
Course Hand Out

UNIT-I: QUANTUM PHYSICS AND SOLIDS

Introduction: Quantum mechanics is the science of microscopic world. It explains the behavior of matter and its interactions with energy on the scale of atomsand subatomic particles.

Black body Radiation

- A blackbody is an idealized object which absorbs and emits all frequencies.
- Black-body radiation has a characteristic, continuous frequency spectrum that depends only on the body's temperature.
- The spectrum is peaked at a characteristic frequency that shifts to higher frequencies with increasing temperature.



Stephan Boltzmann law: The total energy emitted at all wavelengths by a black body is proportional to the fourth power of its absolute temperature.

$$\mathbf{E \alpha T^4}$$

$$\mathbf{E=\sigma T^4}$$

whereE is the total energy emitted, σ is the proportionality constant ($5.67 \times 10^{-8} Wm^{-2}K^{-4}$), and T the absolute temperature (K).

Wein's displacement law: Weins law gives a relationship between the temperature of the black body and its peak spectral wavelength. The objects of different temperatures emit spectra that peak at different wavelengths and the product of the peak wavelength and the temperature is found to be a constant.

$$\mathbf{\lambda_m T=b}$$

Here b is the Wien's displacement constant = 2.8977*10^3m.K, and T is the temperature in kelvins.

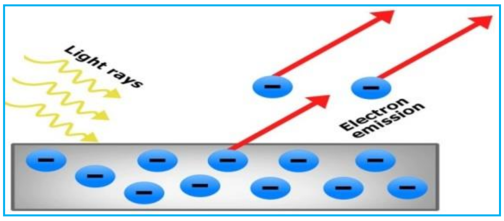
Planck's law

- Planck's law describes the spectral density of electromagnetic radiation emitted by a black body in thermal equilibrium at a given temperature T.
- Planck's law for the energy E_λ radiated per unit volume by a cavity of a blackbody in the wavelength interval λ to λ + Δλ

$$E_\lambda = \frac{8\pi hc}{\lambda^5} \frac{1}{\exp\left(\frac{hc}{\lambda kT}\right) - 1}$$

Photoelectric Effect

- The emission of electrons by a metal surface when it is irradiated by light or more-energetic photons.
- The kinetic energy of the emitted electrons depends on the frequency ν of the radiation, not on its intensity.
- For a given metal, there is a thresholdfrequency ν_0 below which no electrons are emitted.



Einstein equation: $E = E_0 + KE$ where E= total energy; E_0=work function

De-Broglie's hypothesis

- Every moving particle is associated with a wave and that is called *Matter Wave*. As it is conceived by de Broglie, it is also called as *de Broglie wave*.
- *The wave length formula in different forms*

$$\lambda = \frac{h}{p} ==> \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2meV}}$$

Davisson-Germer experiment

- The *Davisson-Germer experiment* demonstrated the wave nature of the electron, confirming the earlier hypothesis of deBroglie.

Heisenberg Uncertainity Principle

- Heisenberg proposed a very interesting principle, which is a direct consequence of the dual nature of matter, Known as uncertainty principle.
- According to Heisenberg uncertainty principle, " it is impossible to measure both the position and momentum of a particle simultaneously to any desired degree of accuracy.

Born's interpretation of the wave function

- Square of the modulus of the wave function is a measure of the probability of finding the particle at that position.
- $\Psi\Psi^*$ represents probability density of locating the particle
- Normalization Condition $\int_{-\infty}^{\infty} \Psi\Psi^* \mathrm{dxdydz} = 1$.

Schrödinger Equation

Schrödinger expressed de Broglie's hypothesis concerning the wave behavior of matter in a mathematical form

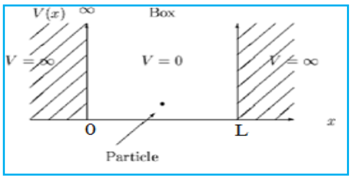
$$\nabla^2\psi + \frac{2m}{\hbar^2}(E - V)\psi = 0$$

Particle in 1 D Box

The boundary conditions in 1D box are $V(x)=0$; $0<x<L$ *and* $V(x)=\infty$; $L \le x \le 0$

Energies of the particle are quantized ($E_n \alpha\ n^2$) $E_n = \frac{n^2h^2}{8mL^2}$

$$\text{wave function } \Psi_n(x) = \sqrt{\frac{2}{L}} \sin\frac{n\pi x}{L}$$



Symmetry in solids, in crystallography, fundamental property of the orderly arrangements of atoms found in crystalline solids. Each arrangement of atoms has a certain number of elements of symmetry; i.e., changes in the orientation of the arrangement of atoms seem to leave the atoms unmoved.

Free electron Theory

In solids, electrons in outer most orbits of atoms determine its electrical properties. Electron theory is applicable to all solids, both metals and non-metals. In addition, it explains the electrical, thermal and magnetic properties of solids. The structure and properties of solids are explained employing their electronic structure by the electron theory of solids. It has been developed in three main stages:

1. Classical free electron theory 2. Quantum Free Electron Theory. 3. Zone Theory.

Fermi-Dirac distribution function

It used to describe the probability with which a half-integral spin (electron, proton, neutron etc.,) particle can occupy a particular energy level.

Importance: In fields like electronics, one particular factor which is of prime importance is the conductivity of materials. This characteristic of the material is brought about the number of electrons which are free within the material to conduct electricity.

Periodic potential- Bloch's theorem

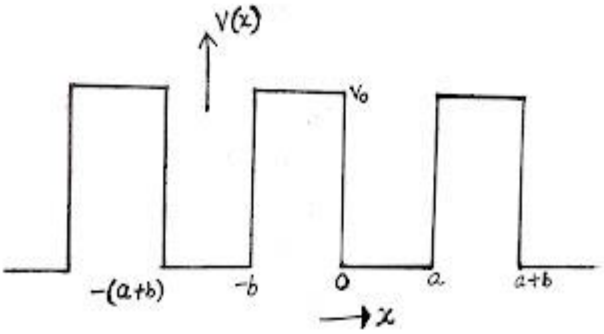
According to Quantum free Theory of methods a conduction in a metalexperience constant (or zero) potential and free to move within the crystal but will not comeout the metal. This theory successfully explains electrical conductivity, specific heat etc butfails to explain many other physical properties, for example (I) Difference betweenconductors, insulators and semiconductors.To overcome the above problems, the periodic potentials due to +ve ions in a metal havebeen considered.

$$V(x+a) = V(x)$$

Bloch theorem states that, the solutions of Schrodinger wave equation for an electron moving in a periodic potential are the plane waves modulated by a function having the same periodicity as that of the lattice.

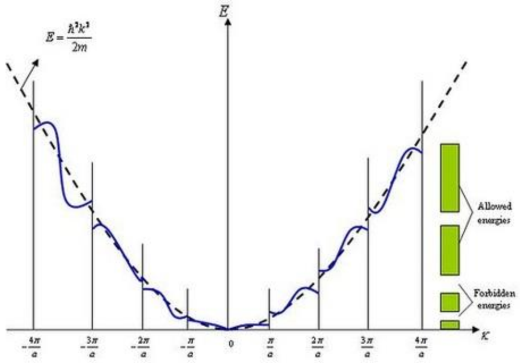
Kronig-Penny Model

Kronig and Penney examined the behavior of electrons in a periodic potential by considering a relatively simple and one-dimensional model. It is assumed that the potential energy of an electron has the shape of a square well as shown in fig. The period of potential is (a+b).



$$V = \begin{cases} 0 \ for & 0 < x < a \\ V_0 \ for & -b < x < 0 \end{cases}$$

E-K Diagram



An E-k diagram shows characteristics of a particular semiconductor material. It shows the relationship between the energy and momentum of available quantum mechanical states for electrons in the material.

Effective mass of electron

The mass of an electron in the periodic potentials of a crystal is different from the free electron mass and is usually referred to as the effective mass.

Origin of energy bands-Classification of solids

When two identical atoms are brought closer, then outer most orbits of these atoms overlap and interact. The energy levels corresponding to these two splits into two energy levels. Similarly, for a solid of 'n' number of atoms, each energy level splits into 'n' energy levels. These levels are so close to each other such that they form an almost continuous band.

- The band corresponding to the outer most orbit is called Conduction band. It may be empty or partially filled.
- The band filled with valance electrons is called Valance band.
- The gap between these two allowed bands is called Forbidden gap.
- Basing on the width of the gap between the bands, solids can be classified into three groups they are Conductors, Semiconductors and Insulators.

UNIT - II: SEMICONDUCTORS AND DEVICES

Introduction:

A semiconductor is a material whose electrical conductivity (and even resistivity) lies between that of conductors and insulators. For example: silicon, Germanium. The conductivity of a semiconductor increases with increase in the temperature. The conductivity of a semiconductor can be easily modified by controlled addition of impurities or by some other means. In this way, a semiconductor actually can be a good conductor or even a good insulator.

Types of Semiconductors

Semiconductors can be classified in two main types as

(i) Intrinsic Semiconductor
(ii) Extrinsic Semiconductor

Intrinsic Semiconductor

An extremely pure semiconductor is called Intrinsic Semiconductor. On the basis of the energy band phenomenon, an intrinsic semiconductor at absolute zero temperature is shown in Figure (a):

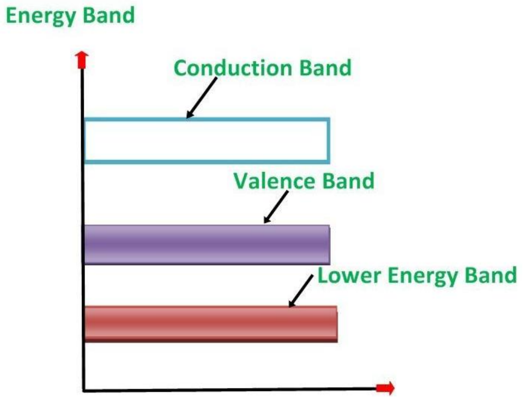


Fig. (a)

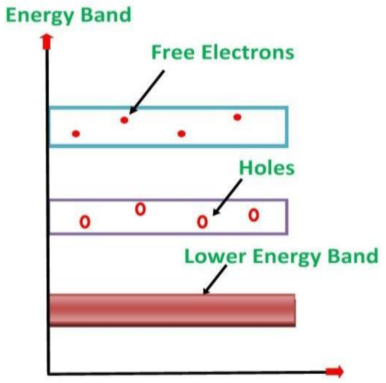


Fig. (b)

- Its valence band is completely filled and the conduction band is completely empty. When the temperature is raised and some heat energy is supplied to it, some of the valence electrons are lifted to conduction band leaving behind holes in the valence band as shown in Figure (b).

Extrinsic Semiconductor

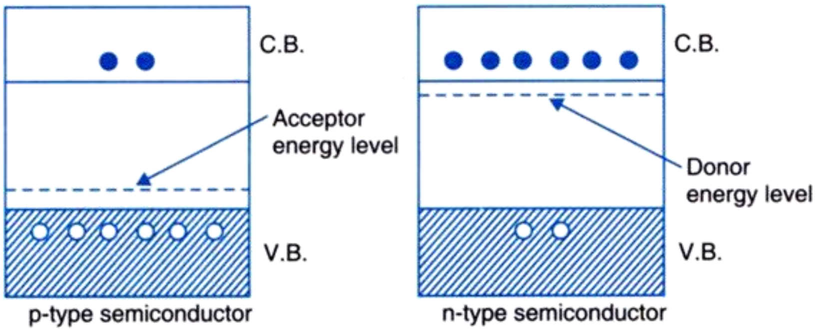
- Semiconductor to which an impurity at controlled rate is added to make it conductive is known as an extrinsic Semiconductor.
- Depending upon the type of impurity added the extrinsic semiconductor may be classified as n type semiconductor and p type semiconductor.

n-type Doped Semiconductors

- These have small amounts of group V impurities e.g., P, As
- Bonds with neighbouring atoms 4 go to form bonds with neighbouring Si atoms 5th electron is unpaired and weakly bound to As
- The addition of Pentavalent impurity results in a large number of free electrons.

P-type Doped Semiconductors

- Small amounts of Group III impurities e.g., B, Al
- B has 3 available electrons to form with neighbouring atoms
- B adopts tetrahedral bonding but with broken bond. [In fact, broken bond shared between all 4 bonds to neighbouring Si’s]



Energy level diagram of P-type and N-type Semiconductor

Hall Effect

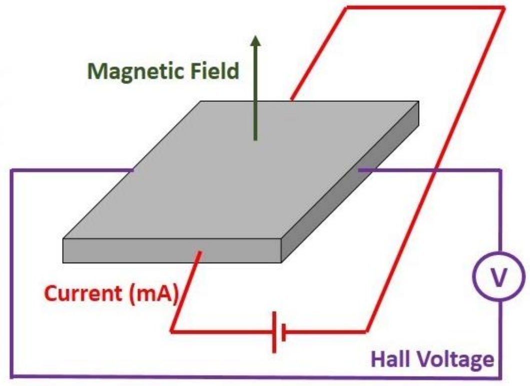
Definition:

When a magnetic field is applied to a current carrying conductor in a direction perpendicular to that of the flow of current, a potential difference or transverse electric field is created across a conductor. This phenomenon is known as Hall Effect.

Hall Effect was discovered by Edwin Hall in 1879. The voltage or electric field produced due to the application of magnetic field is also referred to as Hall voltage or Hall field.

The expression for Hall coefficient (R_H) and Density of Charge carriers (n) are given by

$$\boxed{R_H = \frac{z \times V_H}{I \times B}} \qquad \boxed{n = \frac{1}{R_H e}}$$

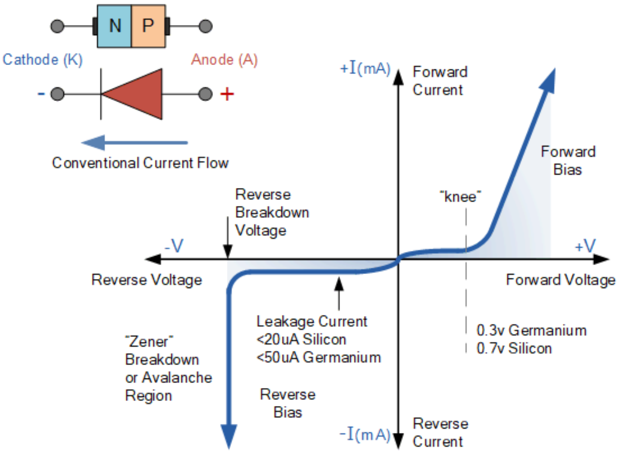


Hall Effect Schematic Diagram

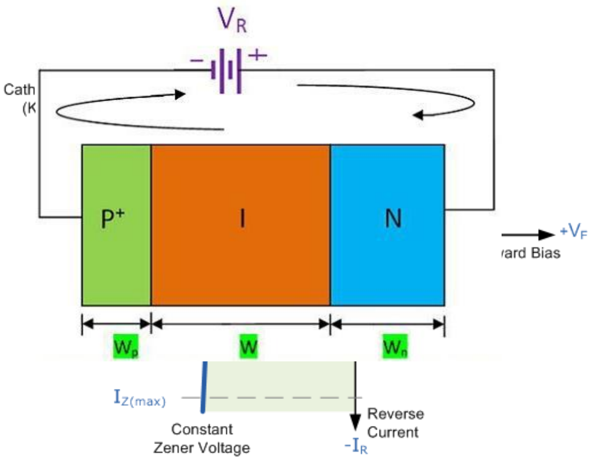
P-N junction diode The p-region has many holes (majority carriers).

- The n-region has many free electrons (majority carriers).
- Free electrons from the n-region recombine with the holes in the p-region, generating the depletion region (area without free charges).
- For every e- from the n-region that recombines with a hole in the p-region, a positively charged atom (ion) is left in the n-region. Similarly, a negatively charged ion is left in the p-region.

Zener diode and their V-I Characteristics



- A Zener diode is a special type of P-N diode designed to operate in the Zener breakdown region.
- The breakdown voltage of a Zener diode is carefully set by controlling the doping level during manufacture.
- Zener diode has very thin depletion. Therefore, Zener diodes allow more electric current than the normal p-n junction diodes.



Breakdown in Zener diode

- There are two types of reverse breakdown regions in a Zener diode: avalanche breakdown and Zener breakdown.
  - Avalanche breakdown
- The avalanche breakdown occurs in both normal diodes and Zener diodes at high reverse voltage.

Bipolar Junction Transistor (BJT)

- The Bipolar Junction Transistor is a semiconductor device which can be used for switching or amplification.
- Junction transistors are classified into two types
- 1.n-p-n transistor (p type region is sandwiched between two n type regions).
- 2.p-n-p transistor (n type region may be placed in between two p type regions).

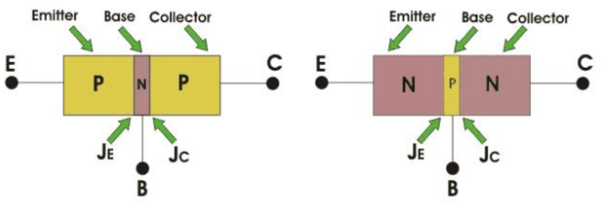
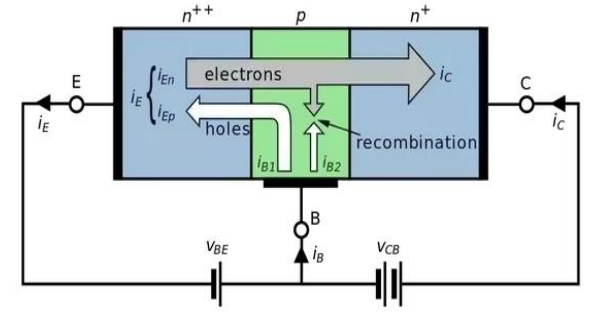


Fig.1. Bipolar Junction Transistor (BJT)

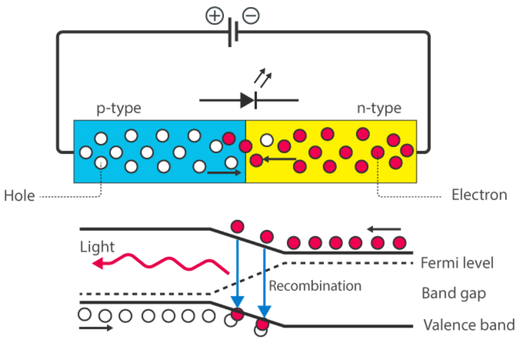


Terminals of BJT

- BJT has three terminals a) **Emitter** b) **base** c) **collector** analogous to cathode gate and anode in vacuum tube. Emitter is heavily doped; collector is moderately doped and base is lightly doped

Light Emitting Diode (LED)

- A Light Emitting Diode (LED) is a semiconductor P-N junction diode which emits light when it is in forward biased.
- The principle behind LED is electroluminescence.
- The process of injecting electrons and holes into the n-type and p-type materials is known as injection electroluminescence.



PIN Photo diode

PIN photodiodeis a kind of photo detector, it can convert optical signals into electrical signals. This technology was invented in the latest of 1950's. There are three regions in this type of diode.

There is a p-region an intrinsic region and an n-region. The p-region and n-region are comparatively heavily doped than the p-region and n-region of usual p-n diodes. The width of the intrinsic region should be larger than the space charge width of a normal pn junction.

Avalanche Photo Diode (APD)

Definition: Avalanche photodiode is a photodetector in which more electron-hole pairs are generated due to impact ionization.

It is like P-N photodiode or PIN photodiode where electron-hole pairs are generated due to absorption of photons but in addition to this avalanche photodiode uses the impact ionization principle for increasing magnitude of photocurrent.

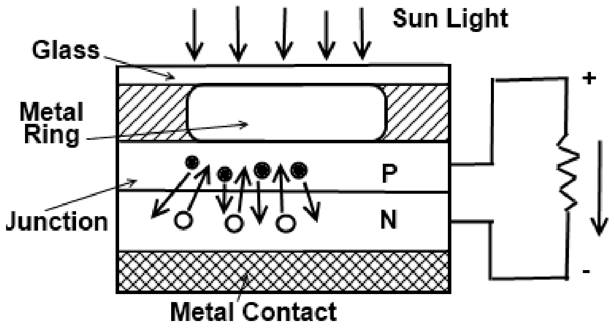
Principle: Impact ionization

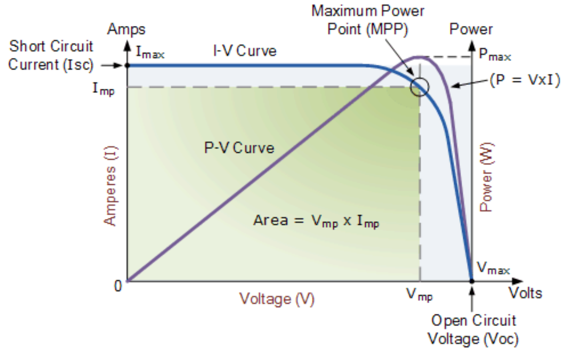
Impact ionization is the process in which one energy carrier with sufficient high kinetic energy strikes bounded energy carrier and imparts its energy to it so that the bounded energy carrier can move freely. This leads to higher concentration of energy carriers and thus higher magnitude of current.

Solar Cells

A solar cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon.

It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Solar cells are the building blocks of photovoltaic modules, otherwise known as solar panels.





UNIT - III: DIELECTRIC, MAGNETIC AND ENERGY MATERIALS

Dielectric Materials

Introduction

Dielectrics are insulating materials. In dielectrics, all the electrons are bound to their parent molecules and there are no free charges. Even with normal voltage or thermal energy electrons are not released. Dielectrics are non-metallic materials of high specific resistance and have negative temperature coefficient of resistance.

Dielectrics are the materials having electric dipole moment permanently.

- **Dipole:** A dipole is an entity in which equal positive and negative charges are separated by a small distance.
- **Dipole moment (μ_{ele}):** The product of magnitude of either of the charges and separation distance between them is called Dipole moment.

Different types of Electric Polarization

Polarization occurs due to several microscopic mechanisms. Particularly in the d.c. electric fields, the macroscopic polarization vector P is created by four types of microscopic polarization mechanisms:

1. Electronic Polarization
2. Ionic Polarization
3. Orientational Polarization
4. Space charge Polarization

Ferroelectric Materials

Ferro electricity refers to the creation of large induced dipole moment in a weak electric field as well as the existence of electric polarization even in the absence of an applied electric field.

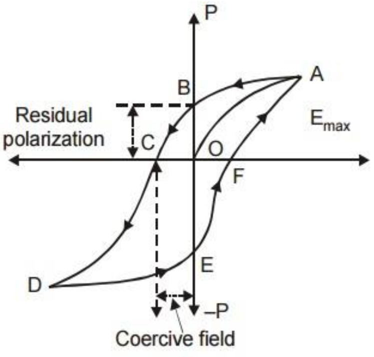
Examples:

- Barium Titanate ($BaTiO_3$)
- Potassium Dihydrogen Phosphate (KDP)
- Ammonium Dihydrogen Phosphate ($NH_4H_2PO_4$)
- Lithium Niobate (LiN_6O_3)

Hysteresis of Ferroelectric Materials

The ferro electrics are known as non –linear dielectrics. Such materials exhibit hysteresis curve similar to that of ferro magnetic materials.

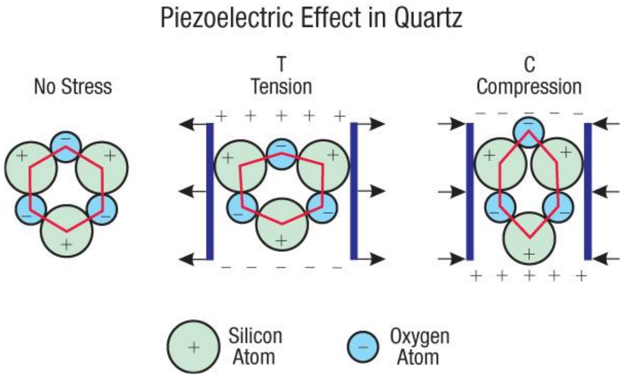
The lagging of polarization ‘P’ behind the applied electric field E is called dielectric hysteresis.



Piezoelectric Materials

Piezoelectricity is the process of using crystals to convert mechanical energy into electrical energy, or vice versa.Regular crystals are defined by their organized and repeating structure of atoms that are held together by bonds; this is called a unit cell. Most crystals, such as iron have a symmetrical unit cell, which makes them useless for piezoelectric purposes.

There are other crystals that get lumped together as piezoelectric materials. The structure in these crystals isn’t symmetrical but they still exist in an electrically neutral balance. However, if you apply mechanical pressure to a piezoelectric crystal, the structure deforms, atoms get pushed around, and suddenly you have a crystal that can conduct an electrical current. If you take the same piezoelectric crystal and apply an electric current to it, the crystal will expand and contract, converting electrical energy into mechanical energy.



Pyroelectric materials

Definition: When some polar crystals are heated, they produce a small electric potential. The electric potential thus produced is known as pyroelectricity. This phenomenon is termed as pyroelectric effect.

Pyroelectricity is a property of certain crystals which are naturally electrically polarized and as a result contain large electric fields. Pyroelectricity can be described as the ability of certain materials to generate a temporary voltage when they are heated or cooled. The change in temperature modifies the positions of the atoms slightly within the crystal structure, such that the polarization of the material changes. This polarization change gives rise to a voltage across the crystal. If the temperature stays constant at its new value, the pyroelectric voltage gradually disappears due to leakage current. The leakage can be due to electrons moving through the crystal, ions moving through the air, or current leaking through a voltmeter attached across the crystal.

Applications

liquid crystal displays (LCD)

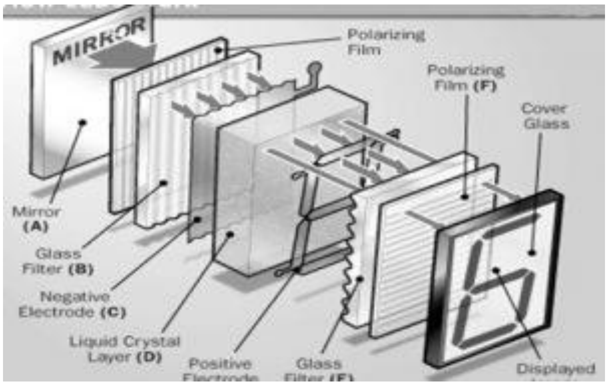
What is an LCD (Liquid Crystal Display)?

A liquid crystal display or LCD draws its definition from its name itself. It is a combination of two states of matter, the solid and the liquid. LCD uses a liquid crystal to produce a visible image. Liquid crystal displays are super-thin technology display screens that are generally used in laptop computer screens, TVs, cell phones, and portable video games. LCD's technologies allow displays to be much thinner when compared to a cathode ray tube (CRT) technology.

How LCDs are Constructed?

Simple facts that should be considered while making an LCD:

1. The basic structure of the LCD should be controlled by changing the applied current.
2. We must use polarized light.
3. The liquid crystal should able be to control both of the operations to transmit or can also able to change the polarized light.



Crystal Oscillators

In RC and LC oscillators the values of resistance, capacitance and inductance vary with temperature and hence the frequency gets affected. In order to avoid this problem, the piezo electric crystals are being used in oscillators.

The use of piezo electric crystals in parallel resonant circuits provide high frequency stability in oscillators. Such oscillators are called as**Crystal Oscillators**.

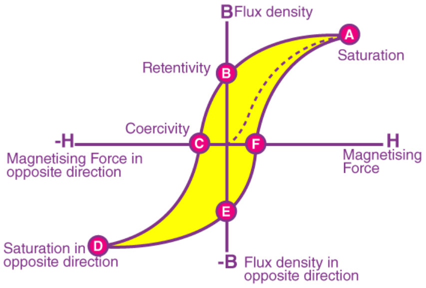
The principle of crystal oscillators depends upon the Piezo electric effect. The natural shape of a crystal is hexagonal. When a crystal wafer is cur perpendicular to X-axis, it is called as X-cut and when it is cut along Y-axis, it is called as Y-cut.The crystal used in crystal oscillator exhibits a property called as Piezo electric property.

Magnetic Materials

Hysteresis

Definition: The meaning of hysteresis is 'lagging'. Hysteresis is characterized as a lag of magnetic flux density (B) behind the magnetic field strength (H).

When a ferromagnetic material is magnetized in one direction, it will not relax back to zero magnetization when the imposed magnetizing field is removed. It must be driven back to zero by a field in the opposite direction. If an alternating magnetic field is applied to the material, its magnetization will trace out a loop called a hysteresis loop.



Magnetostriction

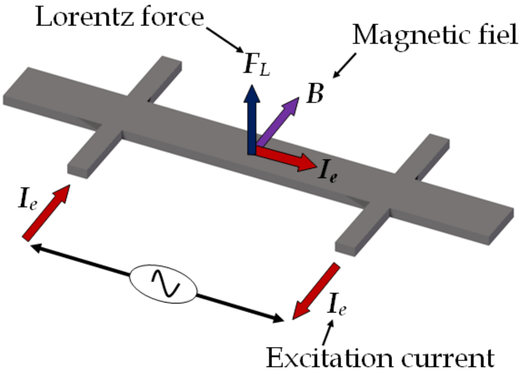
Magnetostriction is a property of ferromagnetic materials which causes them to expand or contract in response to a magnetic field. This effect allows magnetostrictive materials to convert electromagnetic energy into mechanical energy. As a magnetic field is applied to the material, its molecular dipoles and magnetic field boundaries rotate to align with the field. This causes the material to strain and elongate.

Magnetostrictive materials can convert magnetic energy into kinetic energy, or the reverse, and are used to build actuators and sensors. The property can be quantified by the magnetostrictive coefficient, λ, which may be positive or negative and is defined as the fractional change in length as the magnetization of the material increases from zero to the saturation value. The effect is responsible for the familiar "electric hum" which can be heard near transformers and high-power electrical devices.

Magnetoresistance

Resistance is caused by collisions between charge carriers (like electrons) and other carriers or atoms. An electron moving through a perfect crystal of metal at a temperature of absolute zero will experience no collisions, so the crystal would have zero resistance. Imperfections, however, do exist, and temperatures above absolute zero cause the atoms to vibrate out of their lattice locations. These vibrations and imperfections cause collisions, increasing the resistance of the crystal.

Applying a magnetic field can also increase the resistance of a material, since the magnetic force on the moving charges will tend to increase the number of collisions between charges. This dependence of resistance on magnetic field is **called magnetoresistance**. Magnetoresistance is proportional to the strength of the magnetic field, with a larger field producing a higher resistance. This property is used in computers to read magnetic data.



Applications

Bubble Memory Devices

Bubble memory is a type of non-volatile memory that makes use of a thin layer of magnetic material that holds small magnetized areas known as bubbles or domains, which are able to store one bit of data each. The magnetic material is arranged into parallel tracks where the bubbles can move along through the action of an external magnetic field. Bubble memory was a promising technology in the 1980s, offering similar density to hard disk drives and similar performance to core memory, but major advancements in both hard disk and semiconductor memory chips pushed bubble memory into the shadows. Bubble memory is also known as magnetic bubble memory.

Magnetic field sensors

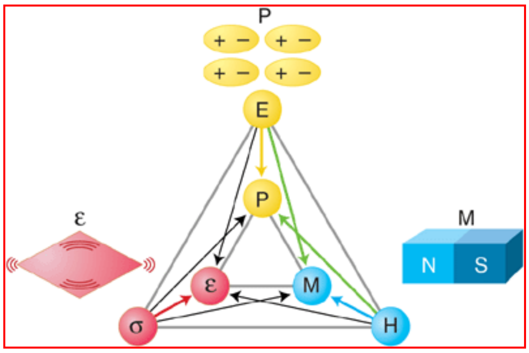
Magnetic field sensors are used to measure magnetic flux and/or the strength and direction of a magnetic field. They are used mainly in scientific measurement, navigation, and industrial applications.

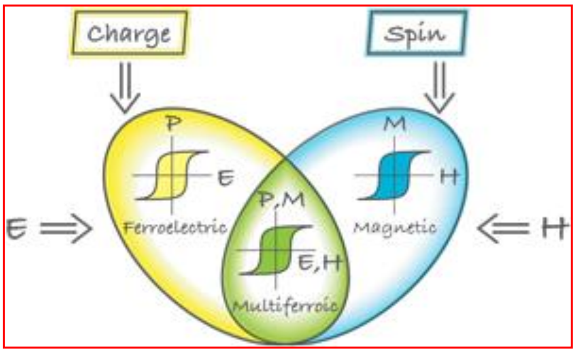
Types of Magnetic Field Sensors: Magnetoresistivesensors, Flux gate or coilsensors, Hall Effectsensors, Magnetoinductivesensors, Proton precessionsensors, Optically-pumpedsensors, SQUIDsensors

Multiferroics

Multiferroicsare defined as materials that exhibit more than one of the primary ferroic properties in the same phase:

- ferromagnetism – a magnetisation that is switchable by an applied magnetic field
- ferroelectricity – an electric polarisation that is switchable by an applied electric field
- ferroelasticity – a deformation that is switchable by an applied stress





Energy Materials

Conductivity of liquid and solid electrolytes

Most ofthe battery systems have solid electrodes separated by liquid electrolytes. Conductivity of liquid electrolyte is always better than any other electrolyte. Major advantage of liquid electrolyte is that it reduces problems from volume changes. Volume changes may occur because of changes in composition of electrode materials as they are charged and discharged.
Liquid electrolytes = Lithium Salt + Organic solvent

A solid compound in which ions migrate through vacancies or interstices within the lattice which leads to ionic conductivity. Solids are fast ion conductors with high mobile ions.

Superionic conductors

In materials science,fast ion conductorsaresolidconductorswith highly mobileions. These materials are important in the area of solid state ionics, and are also known assolid electrolytes and superionic conductors. These materials are useful in batteries and various sensors. Fast ion conductors are used primarily in solid oxide fuel cells. As solid electrolytes they allow the movement of ions without the need for a liquid or soft membrane separating the electrodes. The phenomenon relies on the hopping of ions through an otherwise rigid crystal structure.

Materials and Electrolytes for Supercapacitors

There are various electrode material and electrolytes used for making supercapacitors.
The most commonly used electrode material for supercapacitors is carbon in various manifestations such as activated carbon (AC), carbon fibre-cloth (AFC), carbide-derived carbon (CDC), carbon aerogel, graphite (graphene), graphene and carbon nanotubes (CNTs).

Electrolyte plays a critical role in supercapacitor performance. A good electrolyte offers a wide voltage window, high electrochemical stability, high ionic concentration and conductivity, low viscosity, and low toxicity. Common electrolytes can be classified into three types: aqueous, organic liquid, and ionic liquid. Aqueous electrolytes, such as H_2SO_4 and KOH, dissolve in water, have high ionic conductivity, and low internal resistance. The maximum working voltage of aqueous electrolyte is limited to 1.23 V. Organic electrolyte and ionic electrolyte can provide broader working voltage windows (for example, higher than 2 V) but they are often accompanied with higher internal resistance.

Rechargeable ion batteries

Rechargeable batteries (also known as secondary cells) are batteries that potentially consist of reversible cell reactions that allow them to recharge, or regain their cell potential, through the work done by passing currents of electricity. As opposed to primary cells (not reversible), rechargeable batteries can charge and discharge numerous times.

Solid fuel cells

A solid oxide fuel cell (or SOFC) is an electrochemical conversion device that produces electricity directly from oxidizing a fuel. Fuel cells are characterized by their electrolyte material; the SOFC has a solid oxide or ceramic electrolyte.

Advantages of this class of fuel cells include high combined heat and power efficiency, long-term stability, fuel flexibility, low emissions, and relatively low cost. The largest disadvantage is the high operating temperature which results in longer start-up times and mechanical and chemical compatibility issues.

UNIT-IV NANOTECHNOLOGY

Introduction

- Nanotechnology is an emerging area of research which has a potential in replacement ofconventional micron technologies and gives size dependent properties of the functionalmaterials.
- The interest in nanoscience (science of low dimensional systems) is a realization of a famous statement by Feynman that "There's a Plenty of Room at the Bottom".
- Based on Feynman’s idea, K. E. Drexler advanced the idea of “molecularnanotechnology” in 1986 in the book Engines of Creation, where he postulated theconcept of using nanoscale molecular structures to act in a machine like manner to guideand activate the synthesis of larger molecules.
- When the dimension of a material is reduced from a large size, the properties remain thesame at first, then small changes occur, until finally, when the size drops below 100 nm,dramatic changes in properties can occur.
- If only one dimension of a three-dimensional nanostructure is of nanoscale, the structureis referred to as a quantum well; if two dimensions are of nanometer scale, the structure isreferred to as a quantum wire; and if all three dimensions are of nanometer scale, thestructure is referred to as a quantum dot.Hence a quantum dot has all three dimensions inthe nanorange and is the ultimate example of nanomaterials.The word quantum is associated with these three types of nanostructures because changesin properties arise from the physics of quantum-mechanics.

Quantum confinement effect

The quantum confinement effect is observed when the size of the particle is too small to be comparable to the wavelength of the electron. To understand this effect, we break the words like quantum and confinement, the word confinement means to confine the motion of randomly moving electron to restrict its motion in specific energy levels(discreteness) and quantum reflects the atomic realm of particles. So as the size of a particle decrease till we a reach a nano scale the decrease in confining dimension makes the energy levels discrete and this increases or widens up the band gap and ultimately the band gap energy also increases.

Surface to Volume Ratio

Surface area to volume ratio in nanoparticles have a significant effect on the nanoparticle's properties. Firstly, nanoparticles have a relative larger surface area when compared to the same volume of the material.

Due to its high surface to volume ratio nature of nanostructures, its chemical properties completely different as compare to the bulk materials.

For example, let us consider a sphere of radius r

The surface area of the sphere will be $4\pi r^2$

The volume of the sphere = $4/3(\pi r^3)$

Therefore, the surface area to the volume ratio will be $4\pi r^2/\{4/3(\pi r^3)\} = 3/r$

It means that the surface area to volume ration increases with the decrease in radius of the sphere and vice versa.

Bottom-Up fabrication

The bottom-up approach is based on the principle of molecular self-assembly. Bottom-up fabrication uses chemical and physical forces at a nanoscale level to assemble simple units into larger structures.The fabrication of nanomaterials of tailored properties involves the control of Size, shape, structure, composition and purity of their constituents. In this connection several methods were introduced to prepare the nanomaterials such as sol-gel, coprecipitation, Hydrothermal etc.

The fabrication and process are the key issues in nanoscience and nanotechnology toexplore the novel properties and phenomena of nanomaterials to realize their potential applications in science and technology. Many technological approaches/methods have beenexplored to fabricate nanomaterials.

Followings are the key issues or challenges in the fabrication of nanostructured materialsusing any process or technique:

Can you Control the particle size?
Can you control the shape of nanoparticles?
Can you control the structure either crystalline or amorphous?
Particle size distribution (monodespersive: all particles are of same size).

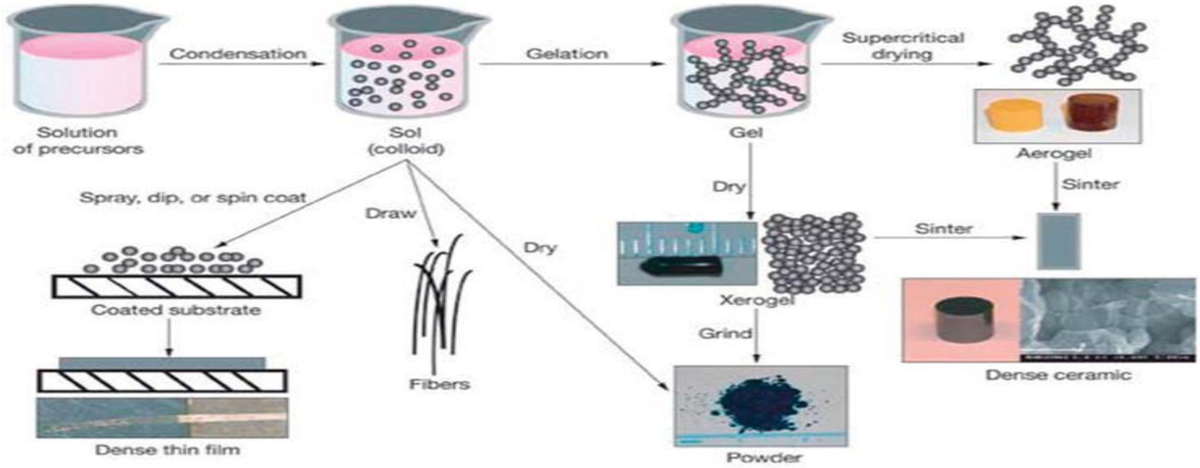
Sol-gel preparation method

The sol–gel process is a wet chemical technique also known as chemical solution deposition, and involves several steps, in the following chronological order: hydrolysis and polycondensation, gelation, aging, drying, densification, and crystallization.

Sol-gel process provides a new approach to the preparation of new materials. This process allows a better control of the whole reactions involved during the synthesis of solids.

Homogenous multi-component systems can be easily obtained, particularly homogenous mixed oxides can be prepared by mixing the molecular precursors solution.

Sol-gel method can also be described as: “Formation of an oxide network through polycondensation reactions of a molecular precursor in a liquid”. In general, in this process, several stages are identified, starting with a silicate solution and then forming a sol, which will then be transformed into a gel, and finally, a dry gel is obtained which is generally formed by a three-dimensional network of silica, with numerous pores of various sizes interconnected. The below figure represents an outline of the routes of this mechanism.

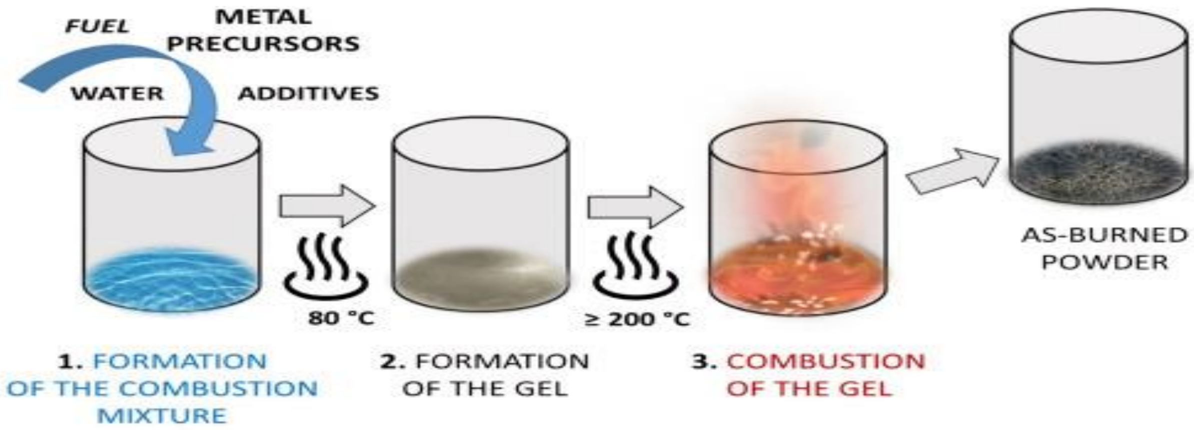


Precipitation method

Precipitation is a simple and low-cost method for synthesizing nanostructures with enhanced properties but is influenced by multiple process factors.Coprecipitation is a process in which a solid is precipitated from a solution containing other ions.

Combustion methods

Combustion synthesis (CS), or self-propagating high-temperature synthesis (SHS), is an effective, low-cost method for production of various oxide materials. Solution combustion synthesis (SCS) is a versatile process that allows the successful synthesis of a wide range of nano-sized ceramic materials. A diagrammatic depiction of the same (SCS) is as shown in the below figure.



Top-Down fabrication

Top-down approach involves the breaking down of the bulk material into nanosizedstructures or particles.Top-down synthesis techniques are extension of those that have been used for producing micronsized particles.

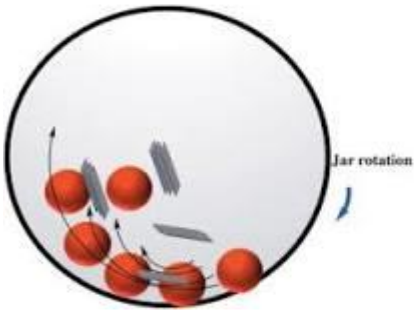
Top-down approaches are inherently simpler and depend either on removal or division of bulkmaterial or on miniaturization of bulk fabrication processes to produce the desired structure withappropriate properties.

The biggest problem with the top-down approach is the imperfection of surface structure.

For example, nanowires made by lithography are not smooth and may contain a lot of impuritiesand structural defects on its surface. Examples of such techniques are high-energy wet ballmilling, electron beam lithography, atomic force manipulation, gas-phasecondensation, aerosolspray, etc.

Ball milling

Ball milling is a grinding method that grinds nanotubes into extremely fine powders.During the ball milling process, the collision between the tiny rigid balls in a concealed container will generate localized high pressure. Usually, ceramic, flint pebbles and stainless steel are used.



Physical vapour deposition

Physical vapour deposition (PVD) is fundamentally a vaporization coating technique, involving transfer of material on an atomic level. It is an alternative process to electroplating.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.PVD processes are carried out under vacuum conditions. The process involved four steps:

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

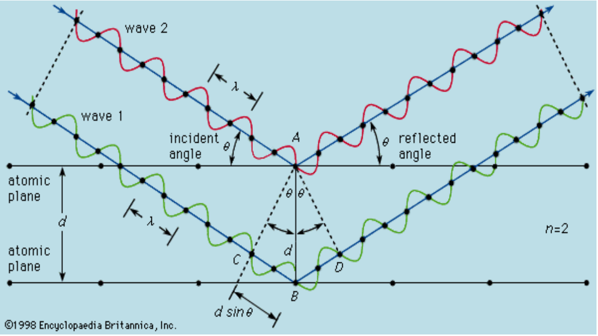
Chemical vapour deposition

Chemical vapor deposition is a vacuum deposition method used to produce high quality, and high-performance, solid materials. The process is often used in the semiconductor industry to produce thin films.In CVD, the wafer (substrate) is exposed to one or more volatile precursors, which react and/or decompose on the substrate surface to produce the desired deposit. Frequently, volatile by-products are also produced, which are removed by gas flow through the reaction chamber.

Characterization techniques

The characterization of nanoparticles is a branch of nanometrology concerned with the characterization, or measurement, of nanoparticles' physical and chemical properties. Nanoparticles are often engineered for their unique properties and have less than 100 nanometers in at least one of their external dimensions. Nanoparticles are characterized for a variety of purposes, including nanotoxicology studies and workplace exposure assessments to assess health and safety risks, as well as manufacturing process control. These properties can be measured using a variety of instruments, including microscopy, spectroscopy, and particle counters.

X-ray diffraction (XRD)

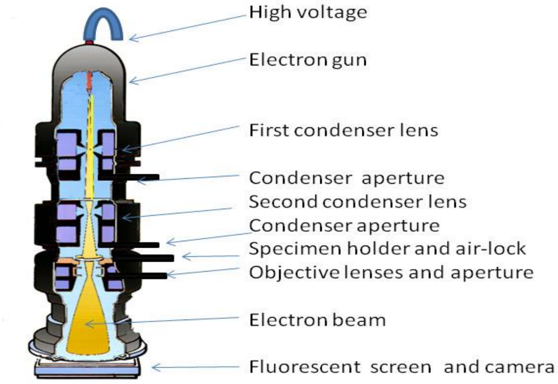


X-ray diffraction (XRD) is used for the primary characterization of material properties like crystal structure, crystallite size, and strain.X-ray diffraction, phenomenon in which the atoms of a crystal, by virtue of their uniform spacing, cause an interference pattern of the waves present in an incident beam of X-rays. The atomic planes of the crystal act on the X-rays in exactly the same manner as does a uniformly ruled diffraction grating on a beam of light. A beam of X-rays contacts a crystal with an angle of incidence θ. It is reflected off the atoms of the crystal with the same angle θ. The X-rays reflect off atomic planes in the crystal that are a distance d apart. The X-rays reflecting off two different planes must interfere constructively to form an interference pattern; otherwise, the X-rays would interfere destructively and form no pattern. To interfere constructively, the difference in path length between the beams reflecting off two atomic planes must be a whole number (n) of wavelengths (λ), or nλ. This leads to the Bragg law $n\lambda = 2d \sin\theta$. By observing the interference pattern, the internal structure of the crystal can be deduced.

Scanning electron microscopy (SEM)

The scanning electron microscope (SEM) generates a variety of signals at the surface of solid specimens by using a focused beam of high-energy electrons. The signals produced by electron-sample interactions reveal information about the sample such as its external morphology (texture), chemical composition, and the crystalline structure and orientation of the materials that comprise the sample. In most applications, data are collected over a specific area of the sample's surface, and a 2-dimensional image displaying spatial variations in these properties is generated.

Transmission electron microscope (TEM)



Transmission electron microscopes (TEM) are microscopes that use a particle beam of electrons to visualize specimens and generate a highly-magnified image. TEMs can magnify objects up to 2 million times.TEMs employ a high voltage electron beam in order to create an image. An electron gun at the top of a TEM emits electrons that travel through the microscope’s vacuum tube. Rather than having a glass lens focusing the light (as in the case of light microscopes), the TEM employs an electromagnetic lens which focuses the electrons into a very fine beam. This beam then passes through the specimen, which is very thin, and the electrons either scatter or hit a fluorescent screen at the bottom of the microscope. An image of the specimen with its assorted parts shown in different shades according to its density appears on the screen. This image can be then studied directly within the TEM or photographed.

Applications of nanomaterials

There are several important applications of nanomaterials such as aviation and space, chemical industry, optics, solar hydrogen, fuel cell, batteries, sensors, power generation, aeronautic industry, building/construction industry, automotive engineering, consumer electronics, thermoelectric devices, pharmaceuticals etc.,

UNIT-V: Lasers and Fiber Optics

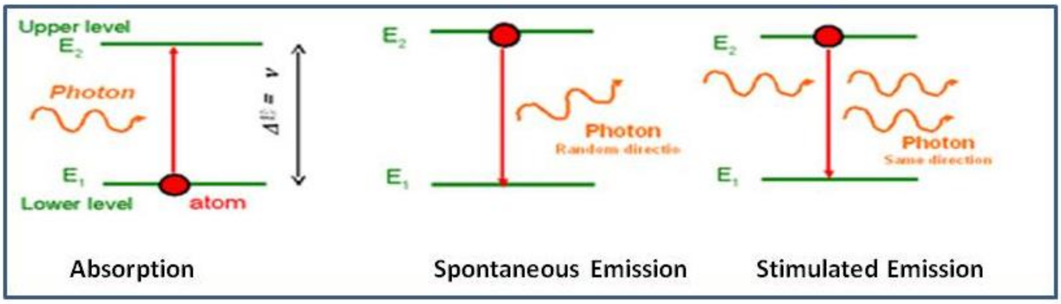
Introduction

A laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation. The term "laser" originated as an acronym for "light amplification by stimulated emission of radiation"

Characteristics of a laser beam

Lasers have the following important characteristics over ordinary light source. They are:
Monochromaticity; Directionality; Coherence; Brightness/Intensity

Absorption and Emission



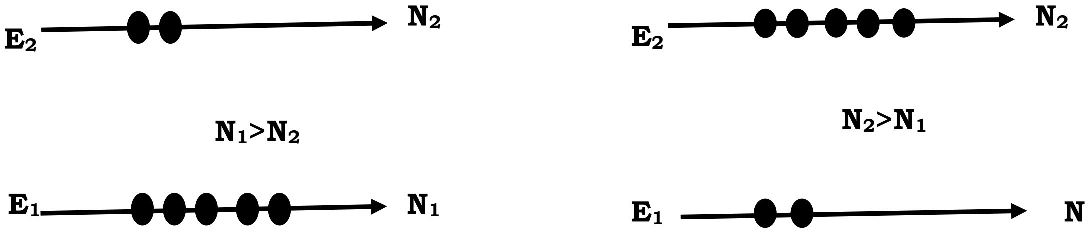
Einstein coefficients.

$$\frac{B_{12}}{B_{21}} = 1; \qquad \frac{A_{21}}{B_{21}} = \frac{8\pi h\vartheta^3}{c^3}$$

B_{12} is the probability of absorption per unit time.
B_{21} is the probability of absorption per unit time
A_{21} is the probability of absorption per unit time

Population Inversion

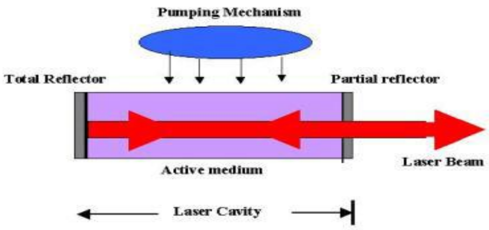
The process of creating more number of atoms in the higher state than the ground state is called population inversion.



Diagrammatic representation of (A) ordinary condition and (B) population inversion

Types of Pumping source in lasers

Depending upon the type of laser, the pumping methods are different. The most commonly used pumping methods are:
Optical pumping , Electric discharge, Chemical pumping, Heat pumping, Injection current



Requirements for laser action

1) Suitable active medium
2) Excited System (Creation of population inversion)
3) Optical feed back

❖ Solid state Laser/Ruby Laser

- The active medium is the Al_2O_3 crystal doped with Cr3+ ions at 0.05%
- Population inversion is achieved by optical pumping using xenon flash light.
- Optical feedback is provided by external mirror arrangement.
- Laser wave length is 694.3nm.

- The output of ruby laser is pulsed wave.

He-Ne laser

- Helium –Neon gas laser is a continuous four level gas laser.
- In this laser the He and Ne atoms in the ratio 10:1.
- Neon is the active material and Helium is used for creating population inversion.
- Population inversion is achieved by high current discharge through the gas.
- Laser wave length is 632.8nm

CO2 Laser

- It consists of a quartz tube 5 m long and 2.5 cm in the diameter.
- This discharge tube is filled with gaseous mixture of CO2 (active medium), helium and nitrogen with suitable partial pressures.
- The terminals of the discharge tubes are connected to a D.C power supply.

Argon Ion Laser

An **Argon ion laser** is a gas laser in which ionized Argon gas is used as the active or lasing medium.
The Argon ion Laser consists of a long and narrow discharge tube made of beryllium oxide filled with organ gas having two Windows at its ends inclined at **Brewster's angle**.

The narrow discharge tube act as an optical resonator or cavity as two Mirrors are placed at each end of the tube facing perpendicular to the length of the tube. One of the mirrors is partially reflecting mirror and the other is 100% reflecting mirror.

Advantages of Argon ion laser

- The width of the spectrum of Argon ion laser is large i.e. it emits multiple wavelengths.
- The output of the Argon laser is high as compared to the output of the He-Ne laser.
- The argon laser is a high-gain system.
- The divergence of the Argon laser is very small.

Nd:YAG laser

Neodymium-doped Yttrium Aluminum Garnet (Nd: YAG) laser is a solid state laser in which Nd: YAG is used as a laser medium.

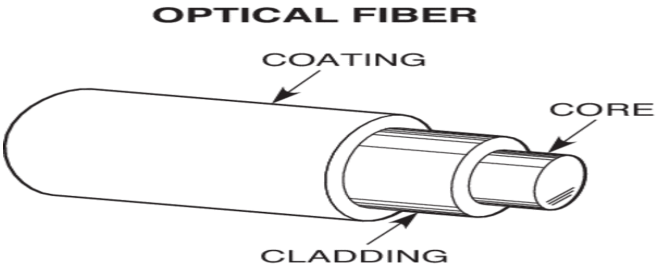
These lasers have many different applications in the medical and scientific field for processes such as Lasik surgery and laser spectroscopy.

Nd: YAG laser is a four-level laser system, which means that the four energy levels are involved in laser action. These lasers operate in both pulsed and continuous mode.

Nd: YAG laser generates laser light commonly in the near-infrared region of the spectrum at 1064 nanometers (nm). It also emits laser light at several different wavelengths including 1440 nm, 1320 nm, 1120 nm, and 940 nm.

FIBER OPTICS

Optical fiber is a very thin and flexible medium having cylindrical shape consisting of three sections, core, cladding and outer shield. The light launched at one end of the core propagates to the other end due to total internal reflection at the core and cladding interface.



Acceptance angle and acceptance cone

Acceptance angle is the maximum angle at which the light can be launched to an optical fiber cable such that it may undergo total internal reflection and propagate through the fiber. Acceptance Angle $\theta = \mathrm{Sin}^{-1}\sqrt{n_1^2 - n_2^2}$

Numerical aperture

The light accepting capacity of the fiber is expressed in terms of acceptance angle using the terminology numerical aperture. Sine of the maximum acceptance angle is called the numerical aperture 'NA' of the fiber.

Numerical Aperture N.A = $\mathrm{Sin}\,\theta$

N.A = $\sqrt{n_1^2 - n_2^2}$

N.A = $n_1\sqrt{2\Delta}$

Types of fibers

Optical fibers are classified based on the following concepts

1. Modes of propagation
2. Refractive index profile
3. Type of material used to fabricate the fiber cable such as glass or plastic

Modes of propagation

Single mode fiber- If the thickness of the fiber is so small that it can support only one mode of light Propagation

Multi mode fiber-If the fiber can support the propagation of a number of modes , it is called multimode Fiber

Refractive index profile

Based on Refractive index profile optical fibers are two types

- i) Step index fiber
- ii) Graded index fiber

Step index fiber

In these fibers the entire has a uniform refractive index n1 and the entire cladding has a uniform refractive index n2 slightly less than that of core. If Step index fiber fiber can support only one mode of propagation, it is called Single mode Step index fiber**.**

If Step index fiber can support the propagation of a number of modes, it is called multimode Step index fiber.

Graded index fiber

In a multimode graded index fiber the refractive index is maximum at the centre of the core and

gradually decreases radially.

If light signal pulse traveling through this fiber in two different paths, rays in both paths reaches other end simultaneously i.e. the problem of internal dispersion is overcome by using Graded index fiber

Attenuation in optical fiber

The intensity of the light at the receiving end of the fiber is always found to be less than the intensity at the input end. This is known as attenuation. The main causes of attenuation are given below.

- Scattering loses
- Absorption loses
- Bending loses.

Applications of Optical Fiber

- Medical Applications
- Defense/Government Applications
- Data Storage Applications
- Telecommunications Applications
- Networking Applications
- Industrial/Commercial Applications