MODULE II: Materials for Electronic Applications

1.1 Nanomaterials

The materials which are created from blocks of nanoparticles or they are defined as" a set of substance where at least one dimension is less than approximately100nanometres" Nanomaterials are defined as materials with at least one dimension in the size range from approximately 1 - 100 nanometers.

Nanomaterials are of interest because at this scale unique optical, magnetic, electrical and other properties emerge. these emergent properties have the potential of great impacts in electronics, medicine and other fields. Nano carbon such as fullerenes and carbon nanotubes are excellent examples of Nano-materials. The properties of Nanomaterials are entirely different from bulk materials. The reasons for this are Increased relative surface area and Quantum effects.

1.1.1 Classification

I.Classification based on dimension Classification of the nanostructured materials and Systems essentially depends on the number of dimensions which lie within the nanometric range (1-100 nm)

(a) Zero dimension(0-D): Here all the three dimensions are in the Nanometric range. Example: -Quantum dots

(b) One dimension(1-D): Here one of the dimensions is outside the nanometric range and the other two are within the range. Example: -Nanowires, nanotubes, nanofibers.

(c) Two dimension(2-D): Here two of the dimensions are outside the nanometric range and one is within the range. Example: -Nanofilm, Nanolayers, Nanocoating

(c) Three dimension(3-D): Here all the dimensions are outside the nanometric range. Example: -Bundles of nanowires and nano tubes

II. Classification based on materials

(a) Carbon based Nanomaterials: -These are defined as materials in which the nano component is pure carbon. Example: -carbon nanotubes (CNT), wires, fullerenes.

(b) Metal based Nanomaterials: -Metal based Nanomaterials are made of metallic nanoparticles like gold, silver, metal oxides etc.

Example: -TiO_2, SiO_2, *nanogold.*

(c)Nanocomposites: −Composite Nanomaterials contain a mixture of simple nanoparticle

or compounds such as nanosized clay with in a bulk material. Nanoparticle will give better physical, mechanical and chemical properties to the initial bulk material.

(d) Nano polymers or Dendrimers: - Dendrimers a nanosized polymers built from branch units. these are tree like molecules with defined cavities. They can be functionalized at the surface and can hide molecules in their cavities. A direct application of dendrimers is for drug delivery.

(e) Biological Nanomaterials: - These Nanomaterials are of biological origin and are used for nanotechnological applications. The important features of these particles are i) self-assembly properties and ii) specific molecular recognition. Example of DNA nanoparticle, nanostructured peptides. Various self-assembled peptides can be designed to release compounds under specific conditions and are used in drug delivery Systems.

1.1.2 Synthesis of nanoparticles Chemical methods

1. Hydrolysis: Nanoparticles of metal oxides can be prepared by the hydrolysis of their alkoxide solutions under controlled conditions .Example:- silica (SiO_2),Titania(TiO_2),alumina (Al_2O_3) are prepared by this method.

$$Ti\,(OR)_4 + 2H_2O \rightarrow TiO_2 + 4ROH$$

This method can be divided into two; -

(a) Hydrothermal synthesis the process involves heating a solution taken in a steel Bomb to a temperature between 100^0C and 1000^0C.On heating high pressure from 1 atm to 1000 atm is generated inside the bomb depending on temperature and solvent used. The solvent vapours under high pressure and temperature facilitates the interaction of precursors during synthesis. If water is used as the solvent, the method is called hydrothermal synthesis.

The process can be used to prepare Nanoparticles of various geometry including thin films, bulk powders, single crystals and nano crystals. The morphology of the crystals (3D,2D, or 1D) Of the crystals formed is controlled by manipulating the solvent and temperature. For example, MgO nanoparticles can be prepared by the hydrolysis of $MgCl_2$solution by hydrothermal method.

$$MgCl_2 + H_2O \longrightarrow MgO + 2HCl$$

(b) Sol-gel method: The sol-gel method is based on the phase transformation of a sol in to a gel. A sol is a colloidal system of Nano solid particles dispersed in a liquid. A gel is a colloidal system in which liquid droplets are dispersed in solid nanoparticles. Hydrolysis of metallic alkoxides can give a sol at a suitable temperature and pH. The sol contains many other impurities. In order to remove impurities sol is transformed in to a gel by changing the pH or other factors. The gel can be purified by filtration and washing with suitable solvents. The purified gel on drying give solid nanoparticles. For example: - Al_2O_3 nanoparticles are obtained by hydrolysis of aluminium oxide by sol-gel technique.

$$Al(OR)_3 + 3H_2O \longrightarrow Al(OH)_3 + 3ROH$$

2. **Reduction**: Nanoparticles of gold and silver can be prepared by the reduction of their respective solutions using reducing agents. $Ag^+ + 1e^- \longrightarrow Ag$

(a) Reduction using reducing agents: Silver nanoparticles can be prepared by this method.60ml of 1mM $AgNO_3$ solution is taken in a beaker, covered with a watch glass and heated in a hot plate with magnetic stirrer. On boiling the solution 60ml of 1mM of trisodium citrate is added dropwise, about one drop per second. The beaker is then closed and kept for some time till the colour of the solution changed to a light golden colour. Then it is allowed to cool. The solvent can be removed by freeze-drying.

(b) Electro reduction Copper nanoparticles have been prepared by electro reduction process using copper plating bath containing homogeneously acidified $CuSO_4$solution. The nanoparticles are formed as spongy black coloured layers of ball structures at the cathode. The spongy layers of copper can be easily separated to give fine particles.

1.1.3 Applications

1. Magnetic nanocomposites are used as ferrofluids for high density information storage and magnetic refrigeration.
2. Nanostructured metal oxide thin films are use as gas sensors

   (CO, CO_2, CH_4 and aromatic hydrocarbons).
3. Carbon nanotube-based transistors are used for miniaturizing electronic devices.
4. A mixture of carbon nanotubes and fullerenes issued for making solar cells.
5. Nanoparticles can be used as catalysts.
6. Nano-cadmium-telluride exhibit different colour depending upon its size. It can be used for dyeing fabrics which never fades.
7. Nanomaterials are used as targeted delivery,genetherapy,photoimaging, antioxidant activity etc.
8. nanoparticles are used in water treatment like removal of toxic pollutants, heavy metals, oil droplets, pesticides, insecticides etc.

1.2 Graphene

Graphene is an allotrope of carbon consisting of mono layer of carbon atoms arranged in two-dimensional honey comb lattice . It can be visualized as a single layer extracted from the layered structure of graphite. Graphite is three-dimensional whereas graphene is two dimensional with one atom thickness. Graphene is defined as "the two-dimensional mono layer of carbon atoms, which is the basic building block of graphitic materials (i.e. fullerene, nanotube, graphite)"

It is considered to the lightest, thinnest, strongest material that conducts heat and electricity. It is stronger than diamond and ten times more conducting than copper**.** In graphene the carbon atoms are *sp*^{2}-hybridised and are arranged in a hexagonal fashion. Graphene is worlds thinnest material.it is only one atom thick, one million thinner than human hair. However it is very stronger than steel and diamond.

Synthesis of graphene

1.Mechanical exfoliation method (such as Scotch tape method): Encompasses the repeated peeling off layers of graphite using adhesive tape. This was the method employed by Geim and Novoselov**.**

2. Chemical vapor deposition: Involves the deposition of carbon atoms onto a substrate (like copper) in the presence of a carbon-containing precursor gas such as methane.

3. Thermal decomposition on SiC: Silicon carbide substrate is heated under ultra-high vacuum which results in the sublimation of silicon atoms and deposition of carbon atoms t form graphene layers on the SiC surface.

4. Graphene oxide reduction method: Graphite oxide, obtained from graphite, is chemically treated to exfoliate into graphene oxide (GO), which is then reduced to graphene.

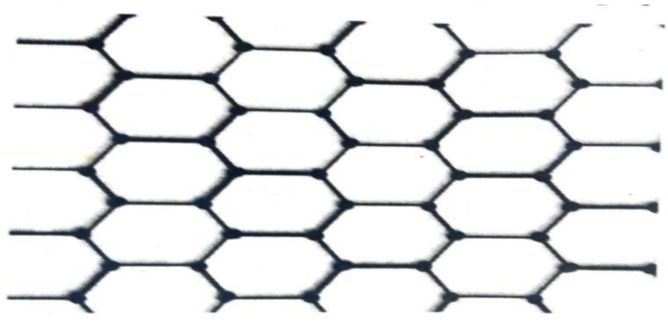


Figure 2.1: Honey comb lattice of graphene

Properties and Applications.

- High Electrical Conductivity:
- Large Surface area.
- High Strength and lightweight
- Excellent Thermal Conductivity

Applications of Graphene

1. Smaller size transistors can be developed using graphene which shows better performance.

2.Graphene incorporated lithium-ion batteries have longer life span, faster charging time and higher capacity.

3.Grahene is used in supercapacitors to provide high energy density.

4.Graphene-based biosensors are highly sensitive when detecting DNA, ATP, dopamine etc.

Carbon Quantum Dots (CQDs)

carbon quantum dots are zero-dimensional small carbon nano particle.it consists of ultra-fine, distributed, quasi-spherical carbon nanoparticles with size less than 10 nm. Recently they have attained much attention due to their good solubility and strong luminescence properties. CODs are found to be much more superior than traditional semiconductor quantum dots, due to its lower molecular weight, reduced toxicity, case of surface functionalization, costeffectiveness, exceptional fluorescence stability, tunable emission wavelengths, strong bio compalibility etc. It can be synthesized using two man methods: ”top-down’ and ’bottom-up”. The top-down approach involves breaking down large carbon structures into small CQDs using techniques like chemical oxidation, laser ablation, arc discharge, and electrochemical synthesis. The bottom-up method involves building CODs from small carbon molecules through processes like hydrothermal synthesis, microwaveassisted synthesis, and pyrolysis, which allows control over their size and shape.

Properties

- They exhibit strong fluorescence, photoluminescence and chemiluminescence which makes them useful in imaging and sensing applications.
- CQDs show excellent photostability and bio compatible with less toxicity

Applications

1. They are used in drug delivery systems.
2. CQD-based hybrids have been identified as excellent materials for supercapacitors. CQD-RuO_2, hybrid show remarkable electrochemical performance.
3. Lighting: Due to their stable light emitting, low cost and eco-friendliness they

are used as LED materials. Switchable electroluminescence behaviour makes it useful for developing colourful LEDs.

1.3 Carbon Nanotube (CNT)

CNTs were discovered in1991 by the Japanese electron microscopist Sumio lijima who was studying the material deposited on the cathode during the arc-evaporation synthesis of fullerenes.

Carbon Nanotubes are allotropes of carbon having hollow cylindrical structure. They have a diameter of a few nanometers (as low as 1nm) made up of lattices of carbon atoms. Carbon atoms are linked by covalent bonds. Because of

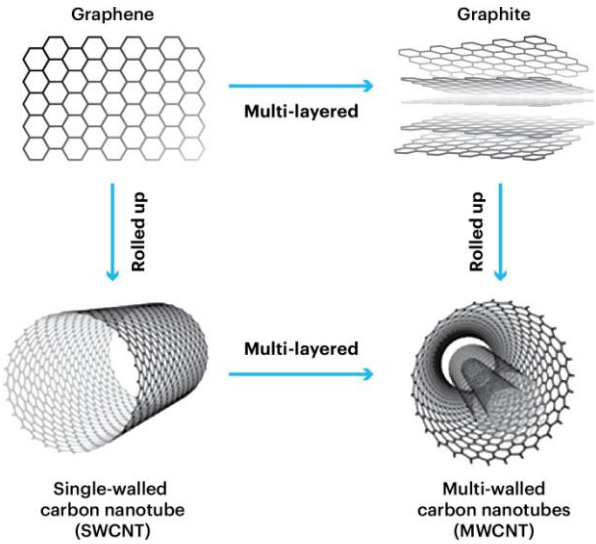
SP^2 hybridisation, they have unique strength and noval properties. There are two types of CNTs. Single walled carbon nanotubes and Multi walled carbon nanotube.

Single walled carbon nanotubes (SWCNT): It is a one atom thick sheet of graphite rolled up in to a cylindrical form. They have a few nanometers in diameter and several centimeters length.

Multi walled carbon nanotubes (MWCNT): It consist of multiple layers of graphite. The distance between the layers is approximately $3.4A^0$.

Properties

- High tensile strength.
- Exhibit high modulus.
- CNTs are extremely lightweight.
- They show unique stiffness and strength
- Chemicaliy inert and difficult to oxidise



Applications

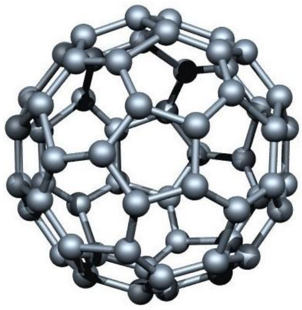
- They can be used in transistors, computers, and other electronic devices.
- used in batteries, solar panels, and fuel cells.
- They can be used to deliver drugs, treat diseases, and create artificial organs.
- They can be used to clean up pollution and filter water.
- They can be used in many other areas, such as sports equipment, clothing, and cosmetics.

Fullerene

The discovery of fullerenes in 1985 by Curl, Kroto, and Smalley culminated in their Nobel Prize in 1996. Fullerenes, or Buckminister fullerenes, are named after Buckminister fuller the architect and designer of the geodesic dome and are sometimes called bucky balls.

Fullerenes are allotrope of carbon having cagelike structure. The most well-known fullerene is buckminsterfullerene (C60), which has a spherical structure with 60 carbon atoms arranged in 20 hexagons and 12 pentagons. The geometry is same as that of soccer football.

A six membered ring is fused with six or five membered rings but a five membered ring can only fuse with six membered rings.Each carbon atom is bonded to three others and is SP^2 hybridised.Other fullerenes include C70 and C80.



Properties

- Fullerenes are spirangly soluble in many solvents.
- Harder than steel and diamond.
- Higher fullerenes have variety of colours.
- They are electrical insulators

Applications

- Exhibit photochromic effect
- They are powerful antioxidant
- can be used as fillers
- used as drug delivery tools
- it inhibit HIV virus
- act as catalyst in organic reactions and water purifications.

Fire Retardant Polymers

Fire retardant polymers are materials designed to resist or suppress combustion. They are widely used in various industries, including electronics, construction, and textiles, to enhance safety and minimize fire damage. There are two main categories of fire retardant polymers: halogenated and non-halogenated.

Halogenated Fire Retardant Polymers: Halogenated polymers contain elements such as chlorine, bromine, or fluorine. These elements can interfere with the combustion process by:

- Absorbing heat: Halogens can absorb heat from a flame, slowing down the combustion process.
- Diluting the fuel: Halogens can dilute the fuel vapor, making it more difficult to ignite.
- Generating free radicals: Halogens can generate free radicals that can terminate the combustion chain reaction.

Common examples of halogenated fire-retardant polymers include polyvinyl chloride (PVC), brominated flame retardants (BFRs), and chlorinated flame retardants (CFRs).

Non-Halogenated Fire-Retardant Polymers: Non-halogenated fire-retardant polymers do not contain halogens. They employ different mechanisms to achieve fire resistance, such as:

- Some polymers generate a carbonaceous char that acts as a barrier between the flame and the underlying material.
- Endothermic reactions: Certain polymers undergo endothermic reactions that absorb heat from the flame, slowing down the combustion process.

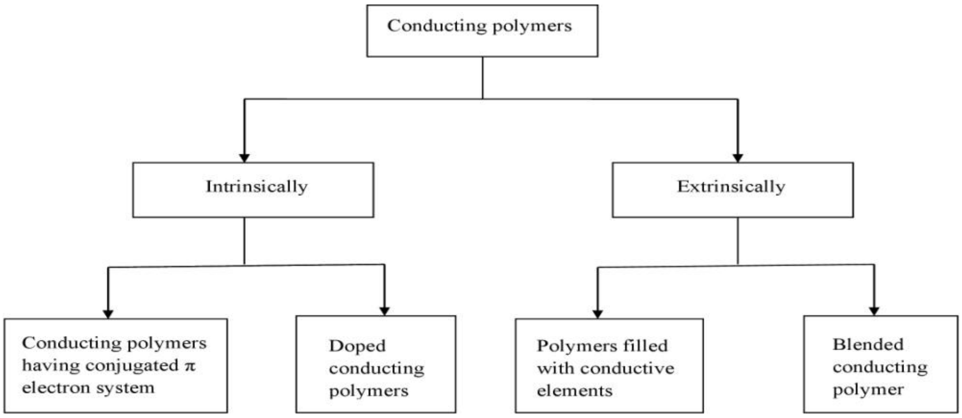
Examples of non-halogenated fire retardant polymers include intumescent coatings, mineral-filled polymers, and phosphorus-containing polymer. Nitrogen based polymers such as melamine-formaldehyde, inorganic polymers such as silicone polymers etc comes under the category of fire-retardant polymers. Phenolic polymers such as novolac, bakelite etc are intrinsically fire-resistant polymers

Inorganic additives such as aluminium hydroxide, magnesium hydroxide, ammonium polyphosphate etc. and organophosphorus compounds (such as DMMP, BDP) can be incorporated into polymers to enhance their fire resistance.

1.4 Conducting polymers

In general polymers are insulators. Organic polymers which can conduct electricity are called conducting polymers. Most conducting polymers are polyacetylene, polyaniline and polypyrrole. The conductance is due to two facts.

1. Conjugated double bonds.
2. Doping



Classification of conducting polymers

Intrinsically conducting polymers: **-**They have continuous conjugation in the polymer backbone. it can be divided into two. They are

1. **Conducting polymers having conjugated π electron system**-They have conjugated double bonds along the polymer back bone. The P orbital of the conjugated π electrons overlap over the entire polymer back bone. As result valence and conductance bands are formed over the entire poly- mer molecule. These bands are separated by a large band gap. So conduction will occur only when electrons from valance band are excited to conduction band thermally or photolytically. Example: Poly-aniline,Poly-acetylene.
2. **Doped Conducting polymers -** Conducting polymers with conjugated π electrons in their back bone can be easily oxidised or reduced. Their conductivities can be increased by creating positive or negative charge on the polymer backbone by oxidation or reduction. This process is called "doping".
3. **P-doping:** This is done by oxidation. Some electrons from the conjugated double bonds are removed. The holes so created can move along the polymer chain and it becomes conductive. Oxidation is done by Lewis acid like $FeCl_3$.
   n-doping: This is done by reduction Some electrons are added into the polymer chain having conjugated double bonds. The negative charge is created can move along the polymer chain and it becomes conductive. Reduction is done by Lewis bases.

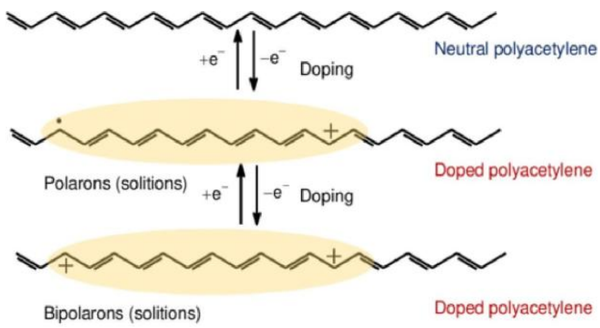


Figure : p-doping and n-doping of polyanilene

Extrinsically conducting polymers: Conductivity is due to externally added ingredients.

1. **Conductive Element filled Polymer:** The polymers are filled with conducting elements like carbon black metallic fibres. Polymer act as a binder to hold the conducting elements. Hey have low cost, light weight, durability and strength. Can be made into desired shape.
2. **Blended conducting polymers:** They are made by blending conductive polymers with ordinary polymers. Good mechanical, physical and chemical properties.

1.4.1 POLYANILINE(PANI)

Formed by the condensation polymerization of aniline under acidic condition.it is known as Aniline black. High conductivity of polyaniline was discovered in 1980.

Chemical synthesis:-Aqueous solution of ammonium per sulphate is added slowly to a solution of Aniline in dilute HCl at 50C with stirring. After one hour a precipitate is formed.it is separated by filtration. The polymer is washed with ammonia and dried.

Electrochemical oxidation: -platinum foil electrodes are dipped in to acidified aqueous solution of Aniline. A potential of 0.7V is applied. A thin film of polyaniline is formed on the surface of the positive electrode.

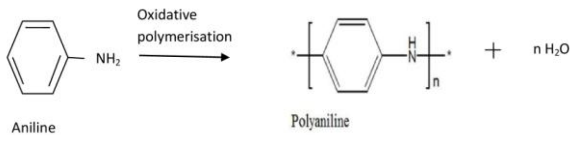


Figure : Polyaniline

Properties

- Appearance: PANI can be white, clear, or colorless.
- Solubility: PANI is insoluble in water, acetone, and ethanol, but soluble in dimethylformamide and dimethyl sulfoxide.
- Environmental stability: PANI is highly environmentally stable.
- Synthesis: PANI is easy to synthesize.
- Cost: PANI is low cost.
- Thermal stability: PANI has high thermal stability.
- Doping: PANI is easily doped by different acids and dopants.
- Mechanical properties: PANI prepared from solutions is more rigid and has better mechanical properties.

Application Polyaniline (PANI) is a conductive polymer with a wide range of applications due to its unique properties. Here are some key applications:

1. Electronics: Used in antistatic coatings, conductive inks, and organic electronics such as light- emitting diodes (OLEDs) and organic photovoltaics.
2. Sensors: Employed in gas sensors, biosensors, and chemical sensors due to its sensitivity to environmental changes.
3. Energy Storage: Utilized in supercapacitors and batteries, enhancing conductivity and charge storage.
4. Corrosion Protection: Acts as a protective coating for metals, helping to prevent corrosion.
5. Textiles: Integrated into fabrics for antistatic and conductive properties, useful in wearable technology.

6. Electrochromic Devices: Used in smart windows and displays, where its conductivity can be altered by applying a voltage.
7. Biomedical Applications: Explored for drug delivery systems and tissue engineering.

POLYPYRROLE(PPy) It is an intrinsic conducting polymer with conjugated double bonds and multifunctional applications. Made by two methods:

1. **Chemical oxidative polymerization: -** It is carried out in a beaker by mixing 0.1M aqueous solution of Pyrrole and 0.1M Ammonium sulphate in 1:1 ratio for three hours. The polymer is precipitated.
2. **Electrochemical method: -** By the electrolysis of pyrrole in aqueous solution of acetonitrile using platinum electrodes. A supporting electrolyte is also used. The polymer is deposited on the anode as a blue-black film.

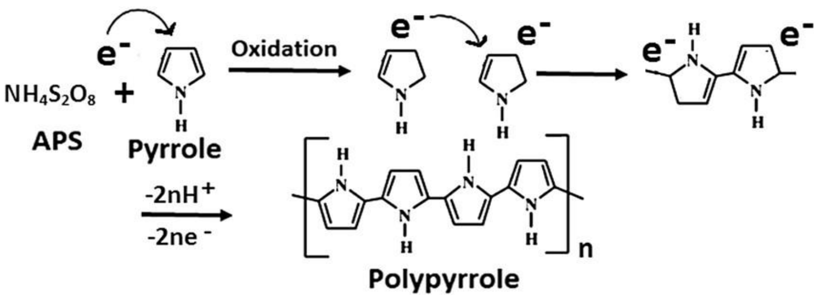


Figure : Synthesis of polypyrrole

Properties

- Electrical conductivity- PPy has high electrical conductivity, with bulk and thin-film materials having conductivity of approximately 105 S/cm and even greater than 380 S/cm.
- Environmental stability- PPy is stable in air and water, making it a good choice for biomedical applications.
- Bio-compatibility- PPy is bio-compatible, which makes it a good candidate for biomedical applications.
- Synthesis- PPy can be synthesized using a variety of methods, including chemical oxidation and electrochemical synthesis.

Applications

- Energy storage- PPy is used in batteries and supercapacitors because of its high surface area, good electrical conductivity, and electrochemical performance.
- Sensors- PPy is used in electrochemical biosensors to detect blood biomarkers for cancer screening.
- Tissue engineering- PPy is used in tissue engineering scaffolds because of its bio-compatibility, electrical conductivity, and ease of modification. PPy can also be used to direct electrical stimulation to cells, which can help with tissue regeneration.
- Drug delivery- PPy can be used to release small-molecule drugs and growth factors in a controlled, pulsatile manner.
- Antistatic coatings- PPy is used in antistatic coatings.
- Actuators- PPy is used in actuators for robots, memory chips, and micro-electromechanical systems (MES).

General applications of conducting polymers

- Small size rechargeable batteries
- Used in electrochromic displays
- Used in electroluminescence displays like TV, Mobile etc.
- Analytical sensors for pH, glucose, O_2, NO_2etc
- Photovoltaic devices
- In electronics like LEDs and electron beam Lithography

1.5 Organic Light Emitting Diode (OLED)

They are thin film semiconductor devices which use electroluminescent organic polymeric materials. (Electroluminescence is an optical and electrical phenomenon in which a material emits light in response to the passage of electric current) A typical OLED structure consists of the following five parts: -

1. Substrate – Transparent glass or plastic which support the OLED
2. Anode (+ve) - made of indium Tin Oxide (ITO), which adds holes or remove electrons when current flows through the device.
3. Conducting layer – made of polyaniline. Which transport holes from anode. This layer is also known as Hole transport layer (HTL)
4. Emissive layer –made of polyfluorene (an electroluminescent polymer).It act as Electron Transport Layer(ETL)
5. Cathode – made of Al, Ca or Ag. It injects electrons when current flows through the device.

Working:

When a voltage is applied across the electrode, the cathode receives electrons from the power source and anode loses electrons. The added electrons make the emissive layer negatively charged (similarly to the n-type layer in a p-n junction diode). Simultaneously the conductive layer becomes positively charged (similar to the p-type layer in a p-n junction diode). The holes are much more mobile than the electrons. So, they jump across the boundary (junction) from the conductive layer to the emissive layer. When a hole meets an electron, the charges cancel out and release a brief burst of energy in the form of a quantum of light or a photon. This process is called recombination. As long as current flows through the device, OLED produces continuous emission of light, because the recombination process occurs many times in second.

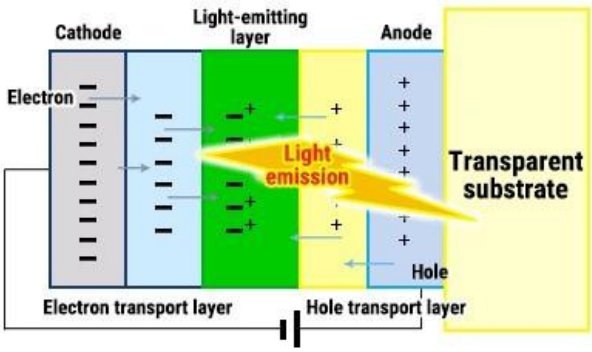


Figure: Schematic diagram for OLED

Advantages

- Response time less than LED
- Contrast ratio of OLED display is very high.
- OLED is small, thin and flexible, low power consumption and good colour.

Applications

OLED is used in Screens for smart phones, watches, laptops and TV • OLED gives readability in sunlight because of the high light output.

1.6 Dye-Sensitized Solar Cells (DSSCs)

A solar cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect. Conventional solar cells use crystalline silicon semiconductors. It work on the principle of photovoltaic cell. Here photons of light knock electrons from atoms within the semiconductor material, creating an electric current.

DSSCs were developed as an efficient and environmentally benign alternative to silicon based solar cells. A dye-sensitized solar cell (DSSCs) is a photoelectrochemical cell, which converts solar light absorbed by the dye to electric energy. It is a thin-film solar cell.

1.6.1 Construction of Dye-sensitized solar cells

A DSSC mainly consists of a substrate, transparent conductive oxide layer (TCO), semiconductor metal oxide nano particle, organic/inorganic dye, electrolyte and counter electrode.

Substrate is generally made up of glass or flexible transparent plastic, TCO is coated on the substrate

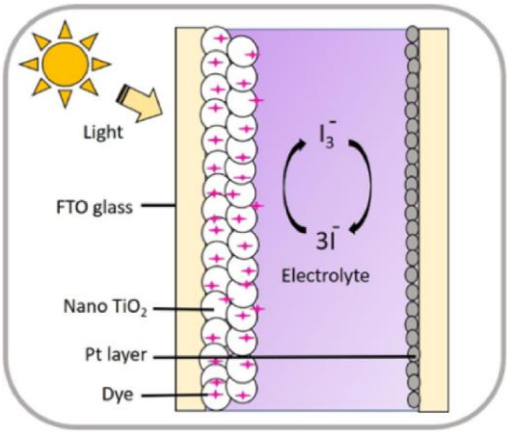
Transparent conductive oxide (TCO): Thin film of Indium Tin Oxide (ITO) or Fluorine doped Tin Oxide (FTO) acts as TCO.

Semiconductor metal oxide nano particles: Semiconducting metal oxides with high surface area and wide band gaps are used in DSSCs. TiO_2, is the commonly used metal oxide. Other metal oxide like ZnO and SnO_2, are also used.

Dye/photo sensitizer: Surface of the metal oxide particle is coated with dye molecules. These dye molecules are responsible for absorbing sunlight and inject the photoexcited electrons to the conduction band of the semiconductor. Dye-sensitized metal oxide semiconductor act as the anode. Ruthenium-based complexes and organic dyes are commonly used. Natural dyes extracted from plants can also be used as photo sensitizer.

Electrolyte: Redox couple iodide/triiodide solution is used as the electrolyte. Electrolyte should have good contact with the dye-sensitized metal oxide semiconductor and the counter electrode.

Counter electrode: Platinum or graphite-based materials are employed as the counter electrodes, which acts as the cathode. It facilitates the reduction of the oxidized dye molecules and completes the electrical circuit.



schematic representation of DSSC

1.6.2 Working of Dye-sensitized solar cells

Sunlight passes through the transparent conductive oxide layer and the dye molecules coated on the metal oxide semiconductor absorb the light. The electrons of the dye molecule then get excited and are injected into the conduction band of the metal oxide semiconductor. These electrons travel through metal oxide and move towards the external circuit to generate electric current. Electrons reach the counter electrode through the circuit and generate electricity. The oxidized dye molecules will get reduced by gaining electrons from the electrolyte and come back to their original form. The oxidised electrolyte species diffuse towards the counter electrode and get reduced. This process continues to produce the current.

Advantages

- DSSCs are cheaper to produce compared to traditional silicon-based solar cells.
- They have shown high efficiency rates, especially in low-light conditions.
- DSSCs are made from eco-friendly materials and produce no emissions.
- DSSCs have a simpler production process compared to traditional solar cells.
- DSSCs can be made flexible, making them suitable for various applications.

Applications

1. Building-Integrated Photovoltaics (BIPV)- Solar windows, Building facades,Roofs etc.
2. Mobile phone chargers, Laptop chargers, Power banksetc.
3. Wearable Electronics- Smart textiles, Fashion accessories (jewelry, hats),Medical devices (implantable sensors)
4. Solar Windows
5. Outdoor Furniture
6. Automotive Integrated Photovoltaics
7. Low-Light Environment Energy Harvesting

1.7 Spintronics

Spintronics or spin-electronics is an emerging field that exploits the spin of electrons, in addition to charge, to process information in new generation transistors, lasers and integra magnetic sensors. They act by storing information in electron spins, transmitting this information via mobile electrons and reading it at a terminal. Spin orientation lasts longer tha charge hased information, making them suitable for memory storage, magnetic sensors quantum computing.

A spin polarised current can be generated in a very simple way by passing the current through a ferroelectric material Spintronics materials should retain ferromagnetism. There are metal based, semiconductor based and graphene based spintronics. Metal oxides such as MgO, Al_2O_3, $SrTi0_3$ etc are examples of metal based spintronics materials. Ternary alloys such as InAs and GaAs alloyed with Mn, (Co, Fe, B), (Ga, Fe)N etc are used as semiconductor based spintronic materials due to their tunable magnetic and electronic properties. Graphenes are also used for development of spintronics due its efficient spin manipulation properties.

Materials in Quantum Computing Technologies

Quantum computing is an emerging computer technology that uses the principle of quantum theory for computation. Quantum computers harness the properties such as superposition (quantum particles as combination of all possible states), entanglement (ability of quantum particles to correlate their measurement results with each other) and quantum interference (behaviour of a qubit, arising from superposition, which influences the probability of the qubit collapsing to one state or another upon measurement) for computing.

Hexagonal boron nitride, a material consisting of just a few monolayers of atoms, can be stacked to serve as the insulating layer in the capacitors used in superconducting qubits.Diamonds with nitrogen- vacancy (NV) centers, nanowires, including semiconductor, superconducting, and topological nanowires are also used in quantum computing. Metals like Al, Nb are used in superconducting circuits. Quantum dots materials like Indium Arsenide (InAs) and Gallium Arsenide (GaAs) are employed to produce single photons, which are crucial for quantum communication applications. Quantum computing requires very low temperatures to avoid decoherance so that quibts remains in their quantum states and prevents error rates.

Supercapacitors

Supercapacitors or ultracapacitors are energy storage devices having high-capacity,with a capacitance value much higher than solid-state capacitors and batteries are energy storage devices. A capacitor contains two metal plates separated by a dielectric material whereas a super capacitor generally consists of electrodes,electrolyte,separator and collector.

Electrode: Materials with good conductivity and high stability like porous active carbon coating are generally used as the electrode material.Carbon based nanoparticles(eg:-carbon nanotubes,graphene,carbon quantum dots etc.)metal oxide nanoparticles,nanowires,quantum dots,conducting polymer-based composites etc.are used electrode materials in supercapacitors.Nanomaterials enhances the performance of the supercapacitors by increasing the capacitance,energy density and cycling stability of the supercapacitors.

Electrolyte: Capacity of the capacitor depends mainly on the dielectric constant of the electrolyte. Either solid or liquid can be used as the electrolyte. For commercial application solid electrolytes are preferred since they are leak-free and possess high ionic conductivity. Generally, a solvent mixed with conductive salts such as tetraalkylammonium or lithium salts act as the solid electrolyte. Sulphuric acid, KOH solution etc can act as the liquid electrolyte.

Separator: Electrolyte membranes will act as the separator. It prevents short-circuiting between the electrodes but allows the electrolyte ions to pass through. Polymer-based and paper-based are found to be durable and economical. **Collector:** Electrons are collected at the collector. Carbon fibre, metal like Al, Pt, Cu, Ni etc. are the commonly used collectors. Binders, such as polyvinylidene fluoride (PVDF) and polyacrylonitrile (PAN), act as adhesives to hold the active material and current collectors together.

Applications of supercapacitors

1. Used in hybrid buses in combination with the battery to increase battery life and decrease the size
2. used in implantable device and health monitoring device to supply power.
3. used in wind turbines to supply power to the pitch control of blade.
4. memory device in laptops, smartphones, tables etc., are developed using supercapacitors.
5. used in solar-powered road and framing devices, street light portable traffic light system, wireless security camera etc.