Module: 2

Materials for Memory and Display Systems

Syllabus
Memory Devices: Introduction, Basic concepts of electronic memory, History of organic/polymer electronic memory devices, Classification of electronic memory devices types of organic memory devices (organic molecules, polymeric materials, organic inorganic hybrid materials). **Display Systems:** Photoactive and electroactive materials, Nanomaterials and organic materials used in optoelectronic devices. Liquid crystals (LC's) - Introduction, classification, properties and application in Liquid Crystal Displays (LCD's). Properties and application of Organic Light Emitting Diodes (OLED's) and Quantum Light Emitting Diodes (QLED's), Light emitting electrochemical cells. **Self-learning:** Properties and functions of Silicon (Si), Germanium (Ge), Copper (Cu), Aluminium (Al), and Brominated flame retardants in computers.
Course Outcomes
CO1: Identify the terms and processes involved in scientific and engineering applications
CO2: Explain the phenomena of chemistry to describe the methods of engineering processes
CO3: Solve for the problems in chemistry that are pertinent in engineering applications
CO4: Apply the basic concepts of chemistry to explain the chemical properties and processes
CO5: Analyze properties and processes associated with chemical substances in multidisciplinary situations

DISPLAY SYSTEMS:

Liquid Crystals: -

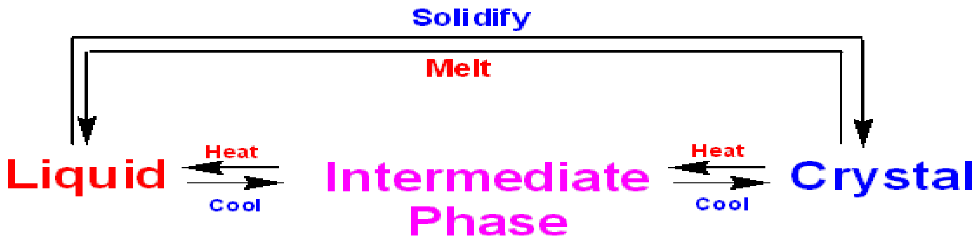
A liquid Crystals is a Phase between Solid and Liquid States.

Ex: - Cholerteryl Benzoate (145.5° to 178.5°C)

P – Azoxyphenetole (137° to 167°C)

P – Azoxyanisole (116° to 135°C)

Anisaldazine (165° to 185°C)



Classification of Liquid Crystals

1. **Thermotropic Liquid Crystals**
2. **Lyotropic Liquid Crystals**

1. Thermo tropic Liquid Crystals: -

liquid crystal is said to be thermo tropic if molecular orientation is dependent on the temperature.
Ex: - Cholerteryl Benzoate (145.5° to 178.5°C)
P – Azoxyphenetole (137° to 167°C)
P – Azoxyanisole (116° to 135°C),
Anisaldazine (165° to 185°C)

Base on the Transition, The Thermotropic LC's again classified into Four types.

a. **Nematic LC's: -**
The molecules move either sideways or up and down. Increase in temperature decreases the degree of orientation.
Ex: P–Azoxyanisole (118° – 135°C)

b. **Chiral Nematic LC's: -**
   These LC's are formed from optically active compounds having Chiral centers.
   Ex: - Cholesteryl Benzoate, Cholesteryl Myristate, Cholesteryl Formate, etc.,
c. **Smectic LC's: -**
   The molecules in smectic crystals are oriented parallel to each other as in the nematic phase but in layers.
   Ex: - (4-(trans-4-n-hexylcyclohexyl).
d. **Discotic LC's: -**
   These are the LC's shown by molecules which have disc like structure.
   Ex: - Benzene hexan-alkonotes, etc.,

2. Lyotropic Liquid Crystals: -

These are the liquid crystals obtained, when an appropriate concentration of a material is dissolved in some solvents. **Ex: -** Soap Mixture, Phospholipids, etc.

Properties of Liquid Crystals: -

- Light weight and compact
- Low power consumption
- High resolution
- Wide viewing angle
- Easy to manufacture

Applications of Liquid Crystals:

- Used in Consumer Electronics like TV, Computer Monitor, Mobile Phones, etc.,
- Used in Medical Equipment's like X-ray and Patient monitoring systems, etc.,
- Used in Automotive Industry.
  Ex: - GPS System, Electronic Displays in car etc.,
- Used in Gaming Display devices.
- Used in Analytical instruments like Colorimeter, pH meter, Potentiometer, Conductometer, etc.,
- Used in Traffic Signals, Thermometers, Petrol Pump indicators etc.,

Organic Light Emitting Diodes (OLED's)

"OLEDs are thin film devices consisting of a stack of organic layers sandwiched between two electrodes. OLEDs operate by converting electrical current into light via an organic emitter".

Properties of OLED's:

- Thin and Flexible.
- High Contrast ratio.
- Produce more accurate color.
- Very thin and Light Weight.
- Low Power Consumption.
- Fast response time.
- Very high efficiency.
- Self-emissive.
- Long life span.

Applications of OLED's

- Used in Consumer Electronics like TV, Computer Monitor, Mobile Phones, etc.,
- Used in Automotive Industry.
  Ex:- Dashboard Displays, Lighting Systems, Electronic Displays in car, etc.,
- Used in Wearable devices like Smart Watches, Fitness Trackers, etc.,
- Used in Medical instruments like Surgical lights, Diagnostic Equipment's, etc.,

Quantum Light emitting diodes (QLED's)

These are the type of light emitting diode, that uses Quantum dots to emit light. They produce high quality image with excellent color accuracy and brightness.

Properties of QLED's

- High color accuracy.
- High Brightness.
- Produce more color accurately.
- Low Power Consumption.
- Long life Span and High efficiency.
- More flexibility.

Applications of QLED's

- Used in TV Screens, Digital Cameras, Mobile Phones, etc.,
- Used in Personal gaming Equipment's.
- Used to filter light from LED's.
- Used in Digital Signal Displays.
- Used in electronic Displays in Car and other Vehicle's.

Light Emitting Electrochemical Cells

These are type of electrochemical devices that can generate light, when a voltage is applied.

Properties of LEEC's:

- High efficiency.
- Low Voltage operation.
- Thin and Flexible.
- Wide color range.
- Having Simple Structure.

Applications of LEEC's:

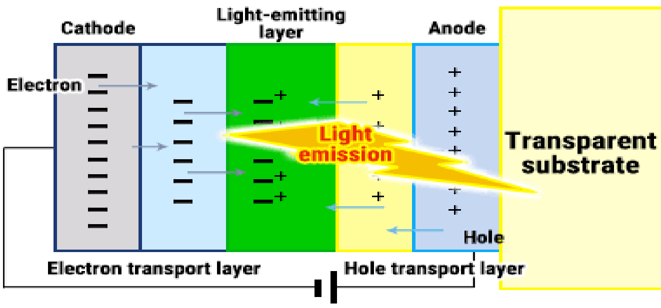
- Used in Lighting like outdoor and indoor lighting.
- Used in Displays like Flexible and Transparent displays.
- Used in Digital Signal Displays.
- Used in Wearable devices like Smart watches, Fitness Trackers, etc.,
- Used in Medical Devices like light therapy, Surgical lighting, etc.,

Photoactive and electroactive materials

Organic semiconductors used in electronic and optoelectronic devices are called as electroactive and Photoactive materials.

Ex: - Pentacene, Anthracene, Rubrene, Silicon, Gallium arsenide, etc.,

<u>Working Principle</u>: -



- Photoactive and electroactive material absorb and emit light in the UV to IR region.
- Display system (OLED) consisting of photoactive and electroactive material absorb light and allows an electron to jump from HOMO of a Donor to LUMO of an Acceptor.
- This phenomenon generates and transport charge carriers.
- In an OLED device, the light-emitting layer is excited by their combination energy of electrons from the cathode and holes from the anode, and then the light-emitting layer emits light when returning to the ground state. One of the electrodes consists of transparent material in order to extract light from the light emitting layer.

Optoelectronic devices:

A hard ware device that converts electrical energy in to light and light in to electrical energy through semiconductors.

Ex: - LED's, Photodetectors, OLED's, QLED's, etc.,

Optoelectronic devices are primarily transducers i.e. they can convert one energy form to another.

They can also detect light and transform light signals to electrical signals for processing by a computer.

Working Principle: -

- Optoelectronic devices are special types of semiconductor devices that are able to convert light energy to electrical energy or electrical energy to light energy.
- If the photon has an energy larger than the energy a gap, the photon will be absorbed by the semiconductor, exciting an electron from the valence band into the conduction band, where it is free to move. A free hole is left behind in the valence band.
- When the excited electron is returning to valence band, extra photon energy is emitted in the form a light.
- This principle is used in Optoelectronic devices.

Nanomaterials and Organic materials for Optoelectronic devices:

Nanomaterials: -

Any materials in which at least one dimension is less than 100nm is called nanomaterials.

Ex: - Silicon Nanocrystals

Properties of Silicon nanocrystals:

- Silicon Nanocrystal has wider band gap energy due to quantum confinement.
- Si NCs shows higher light emission property (Photoluminescence).
- Si NCs exhibit quantum yield of more than 60%.
- Si-NCs exhibit tunable electronic structure.
- Larger surface area-volume ration.

Organic materials for Optoelectronic devices [Light absorbing materials –Polythiophenes] (P_3HT): -

Polythiophenes are an important class of conjugated polymers, environmentally and thermally stable material.

Chemical structure of P_3HT [Poly(3-hexylthiophene)] is a polymer with chemical formula $(C_{10}H_{14}S)n$.

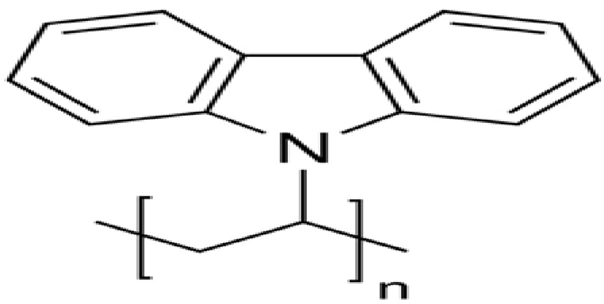
It is a polythiophene with a short alkyl group on each repeat unit.

Properties of Polythiophene:

- P3HT is a semiconducting polymer with high stability and exhibits conductivity due to holes therefore considered as p-type semiconductor.
- Poly-3-hexylthiophene (P3HT) have great capability as light-absorbing materials in organic electronic devices.
- P3HT has a crystalline structure and good charge-transport properties required for Optoelectronics.
- P3HT has a direct-allowed optical transition with a fundamental energy gap of 2.14eV.
- Fundamental band gap of P3HT is 490nm visible region, corresponding to $\pi\rightarrow\pi^*$ transition, giving electron-hole pair.
- P3HT indicate that an increase in the conductivity is associated with an increase in the degree of Crystallinity.

Light emitting material – Poly [9-vinyl carbazole] (PVC)]:-

Poly(N-vinyl carbazole) (PVK) is one of the highly process able polymers as hole conducting material and there fore used as an efficient hole transport material to prepare highly efficient and stable planar hetero junction perovskite solar cells.



Properties:-

- High optical transparency.
- High charge carrier mobility.
- Good film-forming properties.
- High thermal stability.
- Good solubility.
- Good photoconductive property.

Memory Devices:

It is an electronic component or piece of hard ware used to store data.

There are two type of memory devices,

1. **Internal Memory**
2. **External Memory**

1. Internal Memory: It is the computer's working memory that is used to store and retrieve data that the CPU is actively processing.

Ex: RAM, Cache memory etc.,

2. Secondary Memory: It is a computer memory that is non-volatile and is not directly accessed by a computer. It is used for long term storage of data, even when the power is turned off.

Ex: Hard disk drives, Solid state drives, optical disks (Cd & DVD's) etc.,

Basic Concepts of Electronic Memory:

- An electronic memory device is a form of semiconductor storage which is fast in response and compact in size.
- It is an integral part of modern computing.
- A semiconductor storage system which can be read and written, when coupled with a CPU.
- Electronic memory stores data in the form of bits. (they have two states 0 & 1)
- Byte is a basic unit of measurement in electronic memory.
- Electronic memory can be read or written to. Reading refers to retrieving data from the memory, while writing refers to storing data in the memory.

History of organic / Polymeric Memory Devices: -

- During 1968-70, bistable electrical conductivity and resistivity phenomenon was observed in Polydivinyl benzene and Polystyrene polymer materials. But the performance was not satisfactory for practical applications.
- In 1980's two stable ferroelectric polarization sates was discovered in polymers. But they required very high operating voltage of 30V.
- In 1995, ferroelectric polymer films as thin as 1nm were fabricated, which requires 1V to switch between two states.
- In 2001, an organic field effect transistors memory devices was demonstrated using a thiophene oligomer as the conductor and a ferroelectric organic polymer as gate insulator.
- In 2000, a WORM type memory device was developed consisting of a thin film P-n silicon diode.
- In 2004, ultrathin film organic materials were discovered with multilevel conductivity states.
- The international technology Roadmap for semiconductors has identified polymer memory as an emerging memory technology since the year 2005.

Classification of electronic memory devices: -

1. Transistor Type Electronic Memory.
2. Capacitor Type Electronic Memory.
3. Resistor Type Electronic Memory.
4. Charge Transfer Effects Electronic Memory.

1. Transistor Type Electronic Memory:

These type of devices contains a five electronic circuit, including a complementary metal oxide semiconductor, transistor and capacitor. In this electronic circuit "0" and "1" corresponds to the discharged and charged states of the capacitors.

Ex: DRAM (Dynamic Random Access Memory),
SRAM (Static Random Access Memory)

Some key materials used in these devices are Silicon, Metal oxides like Silicon Dioxide, Hafnium Oxide, Polysilicon, Metals like Al, CU, etc.,

2. Capacitor Type Electronic Memory:

A capacitor type consists of two metal plates which are capable of storing an electric charge. It is used to store data. It is like a battery that holds data based on energy.

If the capacitor is charged, it holds the binary numeral "1" and hold "0" when the cell is discharged.

Ex: - Dynamic Random Access Memory

Organic and Polymeric ferroelectric materials are used in these type of memory devices.

3. Resistor Type Electronic Memory:

This type of memory device uses switchable resistive materials to store data.
Initially, the device is under high resistance state or OFF and logical value 0 state.
When resistance changed or under external applied field changes to low resistance sate or ON logical value "1".

Ex: Resistive Random Access Memory (RRAM)

Some key materials used are Metal oxides like TiO2, HfO2, Metals like Pt, Ag, Dielectrics like SiO_2, etc.,

4. Charge Transfer Effects Electronic Memory:

This type of electronic device is based on the charge transfer effects of a charge transfer complex.

A charge transfer complex consists of two parts, one electron donor and other an electron acceptor. It is called as a donor-acceptor complex.

The conductivity of CT complex is dependent on the ionic binding between the D-A components.

Ex: Ferroelectric Random Access Memory (FeRAM)

Types of Organic Memory Devices / Materials

These are three class of materials, which can exhibit bistable states and are used in organic memory devices are called organic memory materials.
Organic electronic memory device stores data based on different electrical conductivity states (ON and OFF states) in response to an applied electric field.

1. Organic Molecules.
2. Polymeric Materials.
3. Organic – inorganic Hybrid Materials.

Organic Molecules:

These are different category of organic molecules, which show bistable or multiscale states, when external field is applied.

Ex: Pentacene, Perfluoropentacene, etc.,

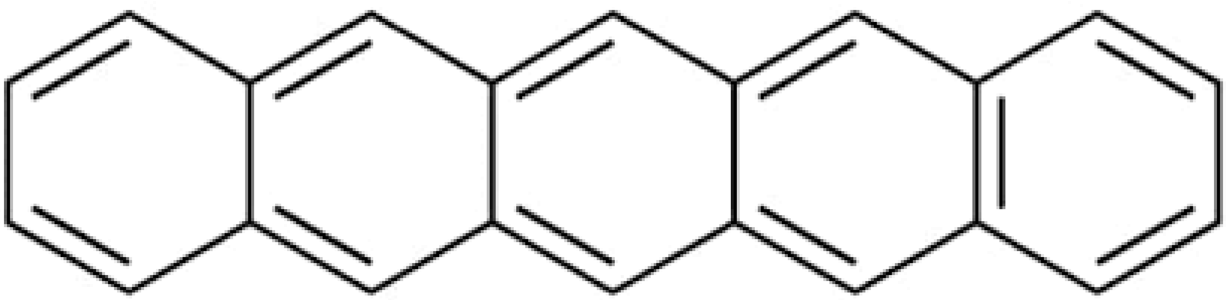
They are p-type and n-type organic semiconductor materials.

1. p-type organic semiconductor materials:

An organic molecule with π – conjugated system and possess holes as major charge carrier is called p-type organic semiconductor materials.

Ex: Pentacene.

It is a linear aromatic hydrocarbon formed by the fusion of five benzene rings. It obtained in crystal and thin film form and exhibits a very good hole mobility.

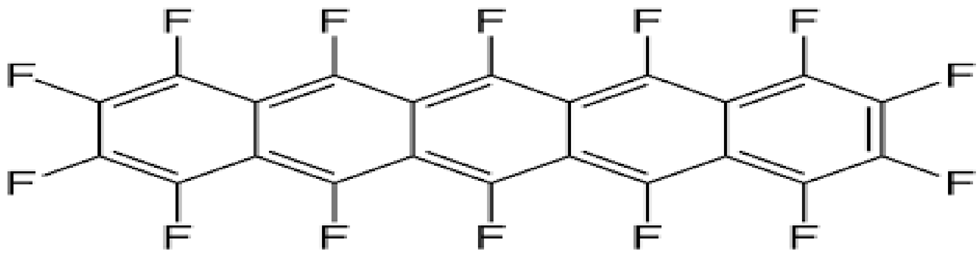


2. n-type organic semiconductor materials:

An organic molecule with π – conjugated system with electron withdrawing substituent groups and possess electrons as major charge carrier is called n-type organic semiconductor.

Ex: Perfluoropentacene.

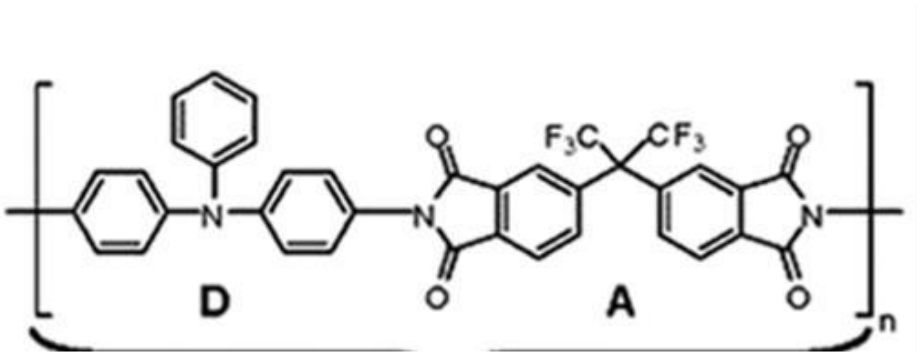
When all the hydrogen atoms of pentacene are replaced by fluorine atoms the resulting molecules is perfluoropentacene. It has strongly electron withdrawing nature of fluorine atoms, which exhibits strong electron mobility.



2. Polymeric Materials:

These are the class of polymers, which exhibit memory effect and used in electronic memory devices are called Polymeric materials.

- One such polymer used for organic memory device is Polyimide with Donor-Triphenyl amine and Acceptor-phthalimide to form Donor – acceptor structure.
- They exhibit two stable charge states under applied electric field. These sates arise due to transfer of electrons from donor to acceptor. This bistability is used to store data in memory device.



Donor (D): Triphenyl Amine group (TPA)

Acceptor (A): Phthalimide group