MODULE 2: MATERIALS FOR MEMORY AND DISPLAY SYSTEM

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 system: Photo active and electro active 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), Aluminum (Al) and Brominated flame retardants in computers.

MEMORY MATERIALS

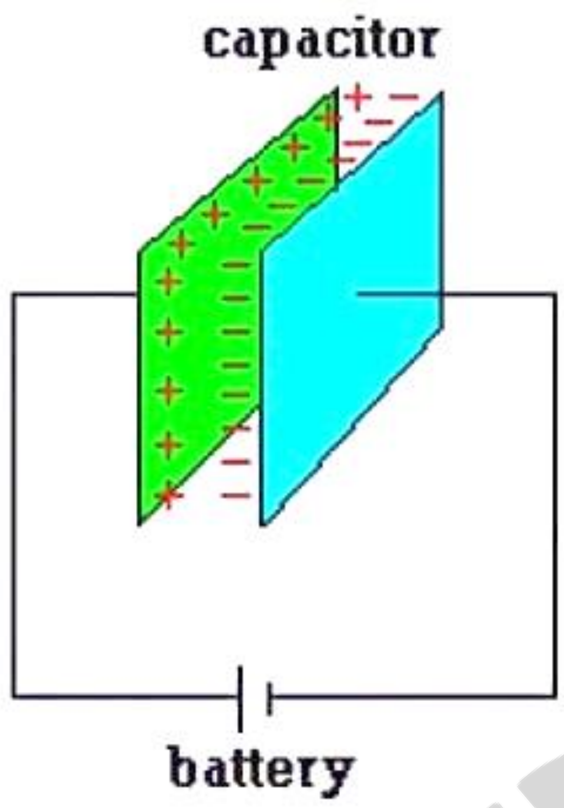
Definition of memory device:
A memory device is a piece of hardware used to store data. Most electronic devices such as computers, mobile phones, tablets, etc. All have a storage device that stores data and/or programs.

Basic Concepts of Electronic Memory
An electronic memory device is a form of semiconductors to rage which is fast in response and compact in size. A semiconductor storage system which can be read and written when coupled with a central processing unit (CPU, processor). The basic goal of a memory device is to provide a means for storing and accessing binary digital data sequences of "1's" and "0's".
Electronic memory device consists of
1. Two electrodes
2. Switching layer between two electrodes
The layer is operated from High Resistance State (HRS) to Low Resistance State (LRS) under an external electric voltage. The HRS can be regarded as "0" bit in data storage (OFF). The switching from HRS to the Low Resistance State (LRS) is equivalent to"0" to "1" binary conversion (ON). If a single material (used in making memory device) provides more than two resistance states (bistable), the storage capacity of a single memory increases exponentially.

Classification of Electrical (electronic) Memory Devices: Electronic memory devices can be divided into 4 types depending the type of material it is made of.
1. Transistor-Type Electronic Memory Devices
2. Capacitor-Type Electronic Memory Devices
3. Resistor-Type Electronic Memory Devices
4. Charge Transfer Type Electronic Memory Devices

Transistor-Type Electronic Memory
Transistors are made from silicon, a semiconductor. It is converted to p-type and n-type semiconductor by doping trivalent and pentavalent impurities. Transistors are made using p-type and n type semiconductor. A transistor is a miniature electronic component that can work either as an amplifier or a switch. A computer memory chip consists of billions of transistors; each transistor is working as a switch, which can be switched ON or OFF. Each transistor can be in two different states and store two different numbers, ZERO and ONE. Since chip is made of billions of such transistors and can store billions of Zeros and ones, and almost every number and letter can be stored.

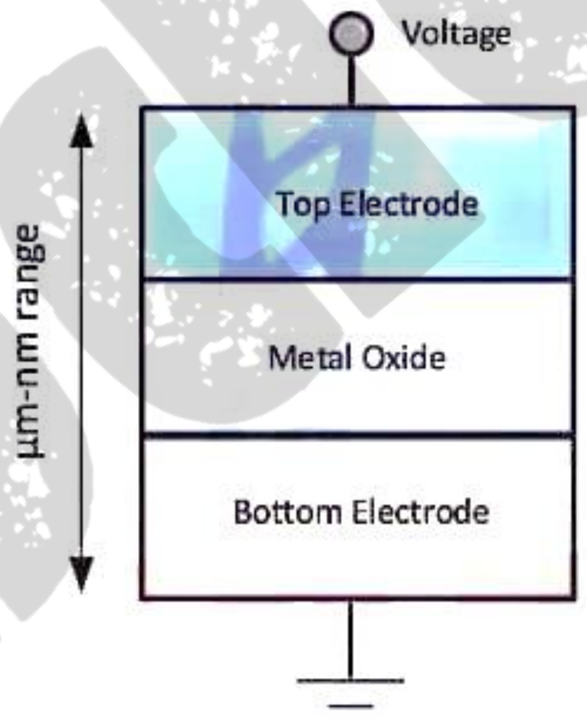
Capacitor-Type Electronic Memory



A capacitor 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 holds "0" when the cell is discharged.

If the parallel plates of a capacitor are separated by dielectric layer, charges dissipate slowly and memory would be volatile. On the other hand, if the medium between the electrodes is ferroelectric in nature, can maintain permanent electric polarization that can be repeatedly switched between two stable states (bistable) by an external electric field. Thus, memory based on ferroelectric capacitors (FeRAM) is non-volatile memory.

Resistor-Type Electronic Memory



Memory devices containing switchable resistive materials are classified as resistor-type memory, or resistive random access memory (RRAM). Resistor-type electronic memory usually has a simple structure, having a metal-insulator-metal structure generally referred to as MIM structure. The structure comprises of an insulating layer (I) sandwiched between the two metal (M) electrodes and supported on a substrate (glass, silicon wafer, plastic or metal foil). Initially, the device is under high resistance state or "OFF" and logically "0"state, when resistance changed or under external applied field changes to low resistance state or "ON" logical value "1".

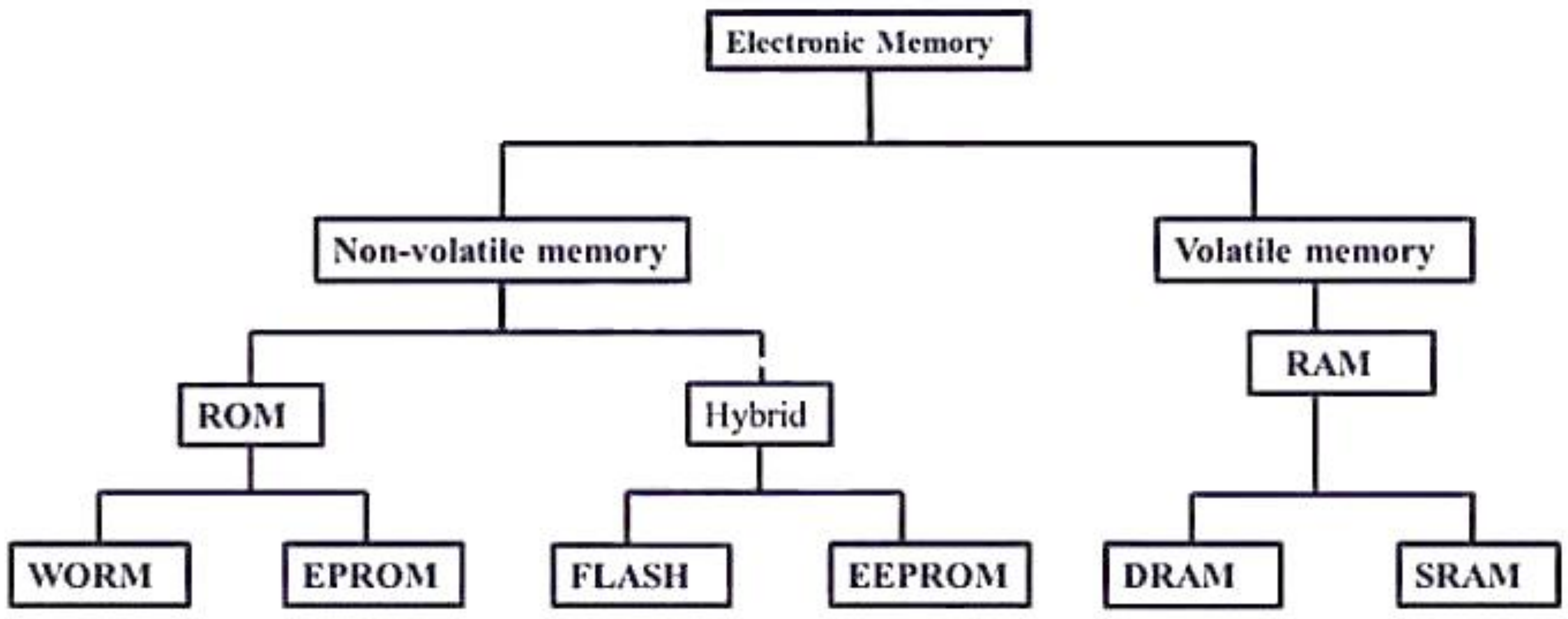
Charge Transfer Effects Type Electronic Memory

A charge transfer (CT) complex is defined as an electron donor– acceptor (D–A) complex, characterized by an electronic transition to an excited state in which a partial transfer of charge occurs from the donor moiety to the acceptor moiety. The conductivity of a CT complex is dependent on the ionic binding between the D–A components.

Classification of electronic memory based on storage type of the device:
Electronic memory can be divided into two primary categories: volatile and non-volatile memory.
Non-volatile memory: Non-volatile memory (NVM) or non-volatile storage is **a type of memory that can retain stored information even after power is removed**.
Volatile Memory: Volatile memory is **a type of memory that maintains its data only while the device is powered**. If the power is interrupted for any reason, the data is lost.

Further it is divided as shown below:

ROM: Read Only Memory
- ✓ ROM is a non-volatile memory.
- ✓ Information stored in ROM is permanent.
- ✓ Information and programs stored on it, we can only read.
- ✓ Information and programs are stored on ROM in binary format.
- ✓ It is used in the start-up process of the computer.



WORM (Write Once Read Many times)
Describes a data storage device in which information once written, cannot be modified. This write protection affords the assurance that the data cannot be tampered with once it is written to the device, excluding the possibility of data loss from human error, computer bugs, or malware.

EPROM (Erasable programmable read-only memory)
EPROM also called EROM is a type of PROM but it can be reprogrammed. The data stored in EPROM can be erased and reprogrammed again by ultraviolet light. Reprogrammed of it is limited. Before the era of EEPROM and flash memory, EPROM was used in micro controllers.

HYBRID MEMORIES
These can be read and written as desired, like RAM, but maintain their contents without electrical power, just like ROM. It is a Non-Volatile memory.

FLASH
It is an electronic non-volatile computer memory storage medium that can be electrically erased and reprogrammed. Flash memory is a non-volatile memory chip used for storage and for transferring data between a personal computer (PC) and digital devices.

EEPROM (Electrically Erasable Programmable Read-Only Memory)
Electronically erasable programmable read only memory, is a standalone memory storage device such as a USB drive. It is a type of data memory device using an electronic device to erase or write digital data.

RAM: (Random Access Memory)
It is a computer's short-term memory. It can be read and changed in any order, typically used to store working data and machine code.
RAMs consist of ferromagnetic particles embedded in a polymer matrix having a high dielectric constant. One of the most common RAMs is called iron ball paint, which contains tiny metal-coated spheres suspended in an epoxy-based paint. The spheres are coated with ferrite or carbonyl iron.

DRAM (Dynamic Random Access Memory)
It is a type of semiconductor memory that is typically used for the data or program code needed by a computer processor to function. All DRAM chips manufactured to date use capacitors containing electrodes made of doped silicon or polysilicon and dielectric films of silicon dioxide and/or silicon nitride.

SRAM (Static Random Access Memory)
It is a type of RAM that holds data in a static form, that is, as long as the memory has power.
SRAM: It is made up of metal-oxide-semiconductor field-effect transistors (MOSFETs).

Types of organic memory devices

Organic memory device stores data based on different electrical conductivity states (ON and OFF states) in response to an applied electric field.
There are three types of organic memory devices

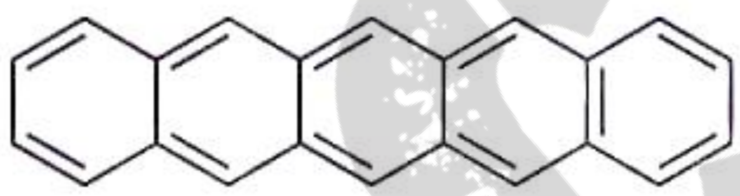
1. Organic molecular memory devices
2. Polymeric molecules
3. Organic-Inorganic hybrid materials

Molecular memory devices: If organic molecular material used to store the data is called organic–based memory device. Organic electronic memory devices based on organic molecules were first reported in several acene derivatives including naphthalene, anthracene, tetracene, pentacene, perylene, p-quarterphenyl and p-quinquephenyl.

Organic molecules

The p-Type Organic Semiconductor Material "Pentacene"

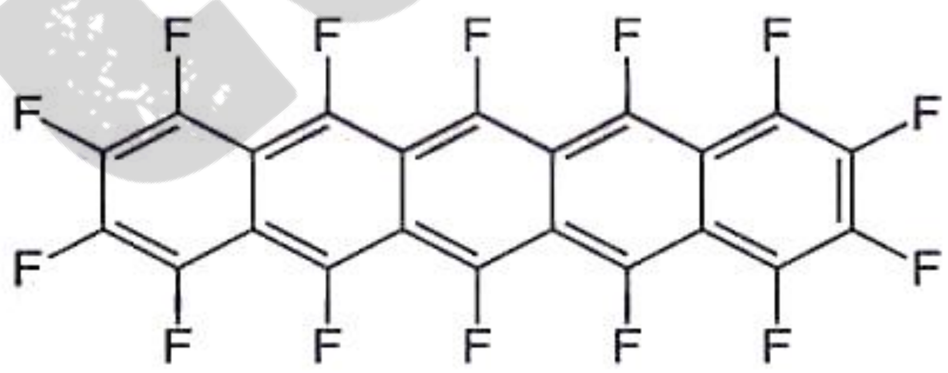
An Organic molecule with π conjugated system and possesses holes as major charge carrier is called p-type semiconductor.
Ex: Pentacene
These molecules show bistable states when external field is applied i.e. ON and OFF state.
It is linearly fused aromatic compound with five benzene rings.
It can be obtained in crystal and thin film form.
It shows good hole mobility, hence it behaves as a p-type semiconductor.



Pentacene

The n-type organic semiconducting material Perfluoropentacene

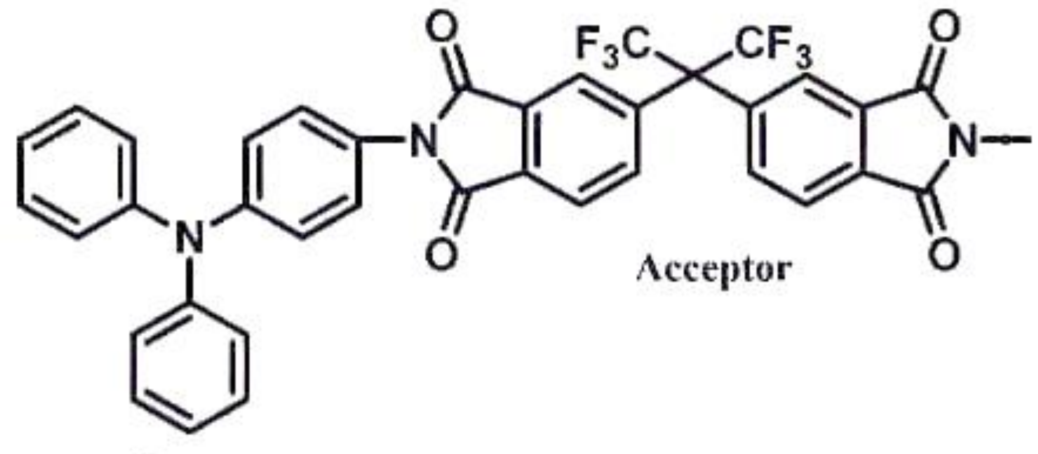
When all the hydrogen atom of pentacene is replaced by Fluorine atoms, it formed Perfluoropentacene. Basically Fluorine is electron withdrawing nature. Hence it convers this molecules into n-type semiconductor.



Perfluoropentacene

Polymeric Molecules

Polymer used for organic memory device is Polyimide (PI) with Donor-Triphenylamine and Acceptor- phthalimide.
This polymer has high thermal stability and mechanical strength. The donors and acceptors of PIs contribute to the electronic transition based on an induced charge transfer (CT) effect under an applied electric field.



DISPLAY SYSTEM

A system through which information is conveyed to people through visual means.

Photoactive and electro active organic materials

Organic semiconductors used in electronic and optoelectronic devices are called as electroactive and Photoactive materials. Photoactive and electroactive organic materials are the semiconductors composed of π-electron systems.

Advantages

1. Light weight and flexible
2. Easily synthesized by chemical method.
3. Production cost is less
4. Used in thin-film flexible devices
5. Properties can be fine-tuned by structure modification

Photoactive Process:

1. Absorption and emission of light radiation in the wavelength region from ultraviolet to near infrared.
2. Photogeneration of charge carriers (photons of light creates electron-hole pair in the semiconductor)
3. Transport of charge carriers (Charge carriers are particles or holes that freely move within a material and carry an electric charge)

Electroactive Process

Injection of charge carriers from the electrode (The process whereby light is emitted at the junction of N- and P-type semiconductors when an external electric source is applied to drive the electrons and the holes into the junction)
Transport of Charge carriers

Optoelectronic Process

1. Absorption and emission of light radiation in the wavelength region from ultraviolet to near infrared.
2. Photogeneration of charge carriers (photons of light creates electron-hole pair in the semiconductor).
3. Transport of Charge carriers (Charge carriers are particles or holes that freely move within a material and carry an electric charge).
4. Injection of charge carriers from the electrode (The process whereby light is emitted at the junction of N- and P-type semiconductors when an external electric source is applied to drive the electrons and the holes into the junction).
5. Exhibit excellent non-linear optical properties (originate from the interactions between the electrons in the molecule and the electric fields in light (electromagnetic radiation).

Organic materials used in optoelectronic devices

The organic compounds with conjugation and π – electron are capable of exhibiting the optoelectronic properties. Organic materials are broadly classified as 3 categories.

1. Small Molecules
2. Oligomers with well-defined structures
3. Polymers

Nanomaterials (Silicon Nanocrystals) for Optoelectronic devices

Any substance in which at least one dimensions is less than 100nm is called nanomaterials.
The properties of nanomaterials are different from bulk materials due to:

1. Quantum Confinement effect
2. Increased surface area to volume ratio

The improved electronic properties yielded for nanostructured silicon in comparison to its bulk, which led the use of Silicon Nanocrystals in electronics and optoelectronics fields.
Special properties of Silicon Nanocrystals for optoelectronics

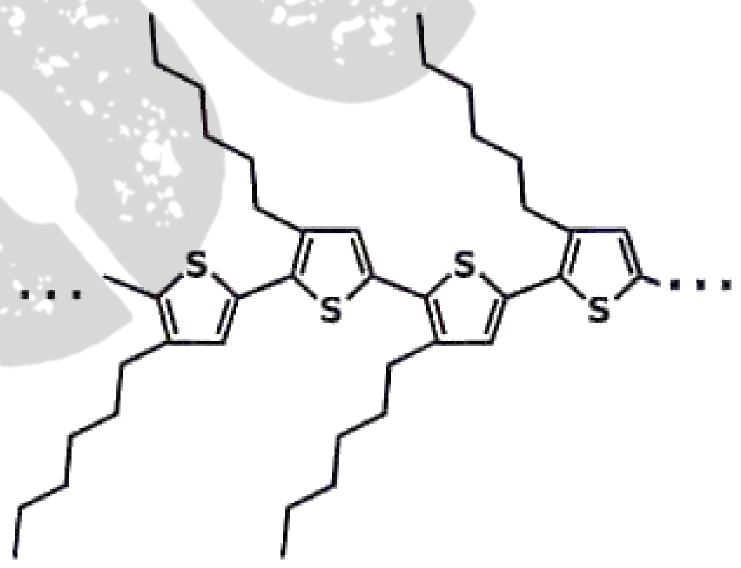
1. Silicon Nanocrystal has wider band gap energy due to quantum confinement.
2. SiNCs shows higher light emission property (Photoluminescence)
3. SiNCs exhibit quantum yield of more than 60%.
4. Si-NCsexhibittunableelectronicstructure

Applications:

1. SiNCs are used in neuromorphic computing and down-shifting in photovoltaics
2. SiNCs are used in the construction of novel solar cells, photo detectors and optoelectronic synaptic devices.

Organic materials for Optoelectronic devices [Light absorbing materials –Polythiophenes] (P3HT)

Polythiophenes are an important class of conjugated polymers, environmentally and thermally stable material. Chemical structure of P3HT Poly (3-hexylthiophene) is a polymer with chemical formula $(C_{10}H_{14}S)n$. It is a Polythiophenes with a short alkyl group on each repeat unit.
Highly ordered (P3HT) are composed of closely packed, p–p stacked (p–p distance of 0.33nm) fully extended chains which are oriented perpendicular to the substrate.



Structure of P3HT

Properties:

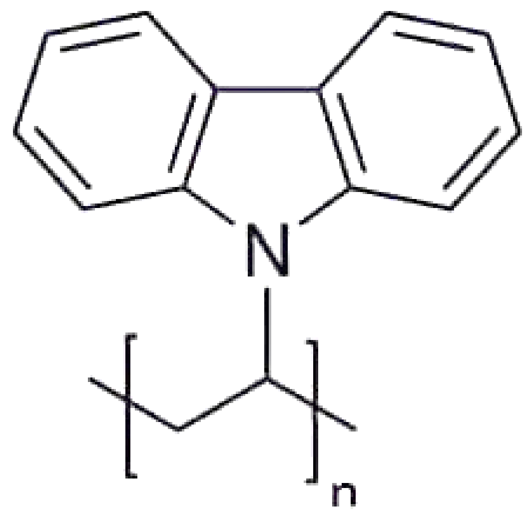
1. P3HT is a semiconducting polymer with high stability and exhibits conductivity due to holes therefore considered as p-type semiconductor.
2. Poly-3-hexylthiophene (P3HT) has great capability as light-absorbing materials in organic electronic devices.
3. P3HT has a crystalline structure and good charge-transport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

Applications:

1. P3HT-ITO forms a p-n junction permits the charge carriers to move in opposite direction and hence, used in Photovoltaic devices.
2. It can be used as a positive electrode in Lithium batteries.
3. Used in the construction of Organic Solar Cells.
4. Manufacture of smart windows.
5. Used in the fabrication new types of memory devices.

Light emitting material-Poly [9-vinylcarbazole] (PVK)]

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



Structure of poly (9-vinylcarbazole)

Applications:

1. PVK has been commonly used in OLEDs, light harvesting applications. Photorefractive polymer composites and memory devices.
2. Used in the fabrication of light-emitting diodes and laser printers.
3. Used in the fabrication of organic solar cells when combined with TIO on glass substrate.
4. Used in the fabrication of solar cells when combined with Perovskite materials.

LIQUID CRYSTALS

A distinct state of a matter in which degree of molecular ordering is intermediate between the ordered crystalline state and completely disordered liquid state.

Classification:

Liquid crystals are classified into two types
Thermotropic liquid crystals
Lyotropic liquid crystals

1) Thermotropic liquid crystals (TLC): The compounds which exhibit liquid crystal behavior with variation of temperature are called thermotropic liquid crystals.

Ex: 1) Cholesteryl Benzoate: (145.5°C & 178.5°C)
2) P-Azoxy Anisole: (118°C & 135°C)

2) Lyotropic Liquid Crystals: Some of the compounds transformed into liquid crystal phase when mixed with another substance or solvent by the variation of concentration of the compound are called lyotropic liquid crystals

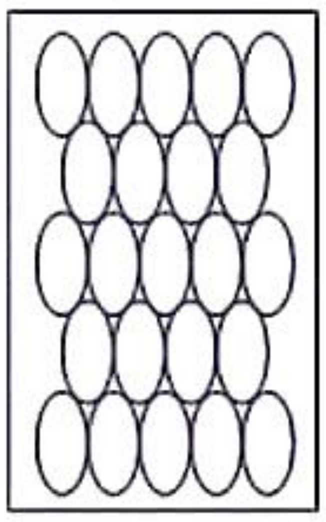
Ex: 1) Soap water mixture
2) Phospholipid water mixture

Types of Thermotropic liquid crystals:

There are four types of liquid crystals

1. Nematic Liquid Crystals (NLC)
2. Chiral Liquid Crystals or Cholesteric Liquid Crystals (CLC)
3. Smectic Liquid Crystals (SLC)
4. Columnar Liquid Crystals or Discotic Liquid Crystals (DLC)

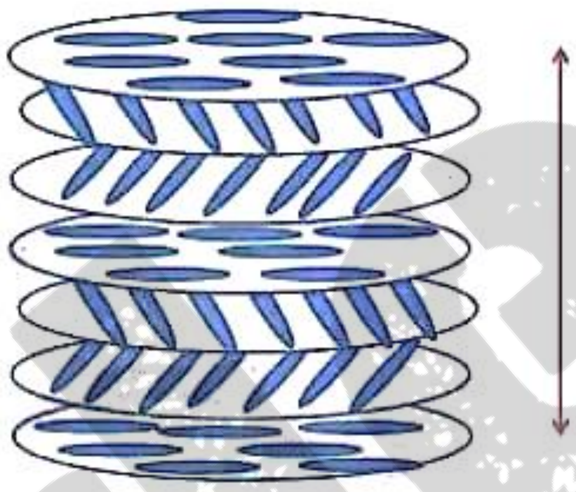
Nematic Liquid Crystals (NLC)



1. These are formed by the compounds that are optically inactive.
2. The molecules have elongated shape and are oriented parallel to the director.
3. These molecules possess intermolecular force of the attraction such that they stay parallel to one another to form nematic liquid crystals.

Ex: a) P-Azoxy Anisole (PAA)
b) P-Azoxy Phenetole

Chiral Liquid Crystals or Cholesteric Liquid Crystals

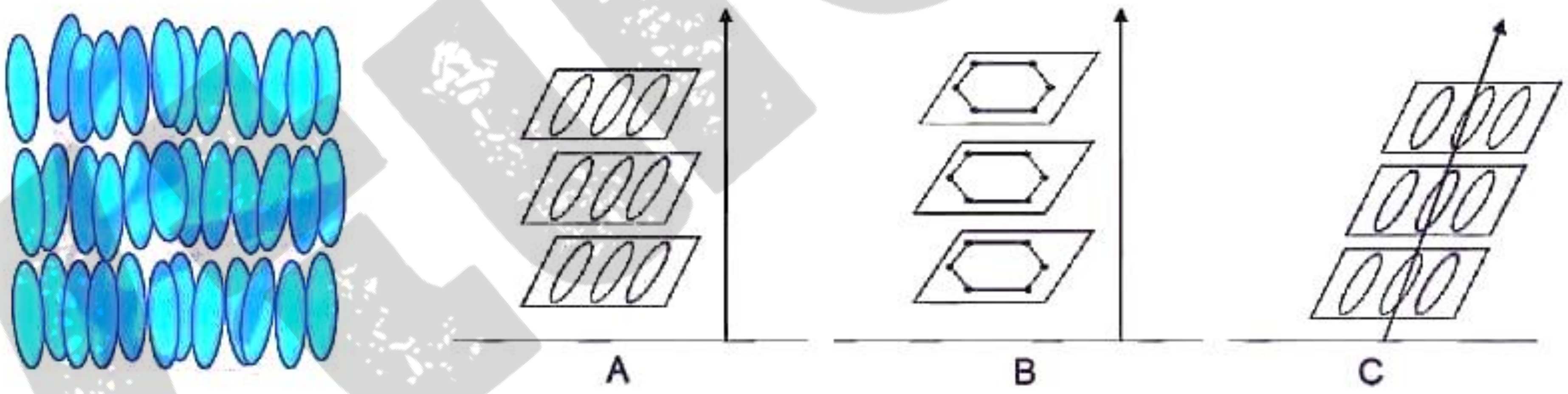


1. These are formed by optically active compounds having chiral center.
2. Hence molecules acquire spontaneous twist about an axis normal to molecular direction.
3. The twist may be right or left depending on molecular conformation.
4. Molecules are arranged themselves in such a way that group of molecules alike at different angles with respect to their adjacent groups.

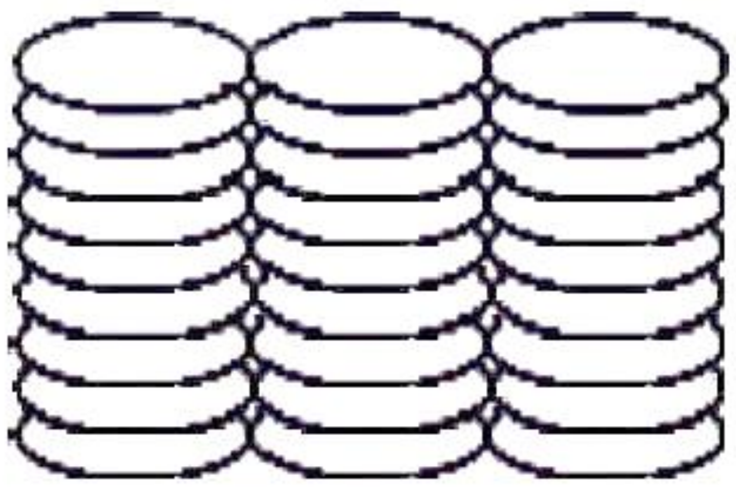
Ex: a) Cholesteryl benzoate
b) Cholesteryl formate etc.

Smectic Liquid Crystals (SLC):

1. These liquid crystals have small amount of positional order and orientational order.
2. If the director is perpendicular to the plane, it is called *smectic A*. These are least ordered of the orthogonal smectic phases. The molecules are arranged in columns.
3. If the director is perpendicular to the plane and molecules are arranged in hexagonal order, it is called *smectic B*.
4. If the director makes an angle other than 90°, it is called *smectic C*.



Columnar Liquid Crystals or Discotic Liquid Crystals (DLC)



1. In these liquid crystals, there is an orientation order but no positional order.
2. There is a random motion of the molecules perpendicular to the plane.
3. The molecules orient themselves along the director.
4. The molecules tend to position themselves in columns.
5. The columns are arranged in hexagonal lattice.

Properties

- Liquid crystal can flow like a liquid, due to loss of positional order
- These are elongated and have some degree of rigidity

- They have less orientational order
- Transition from crystalline solids to liquid crystals caused by a change of temperature.

Applications of liquid crystals:

1) Liquid crystals are used in watches, calculators, mobile telephones, laptops, computers etc.
2) These are used in blood pressure instrument, digital thermometers and TV Chanel indicators.
3) These are used in potentiometer, conductometer, Colorimeter etc.

Application of Liquid Crystal in Display System (LCD):

Principle:

1) The display panel is composed of two polarizers and a mirrored surface.
2) A thin film of the liquid crystal is placed between two glass sheets. One of the glass sheet on one side is coated with electrically conducting material such as SnO_2.
3) In the absence of applied voltage, the liquid crystal molecules are precisely aligned.
4) The entire panel appears silvery because light passes through both the polarizers, reflects off the mirrored surface and then passes through both the polarizers.
5) When the voltage is applied the alignment of the LC molecules changes.
6) This results in the polarized light from the first polarizer not being rotated by 90°completely to align with second polarizer.
7) The second polarizer blocks the passing of light and causes the segment of the panel to appear black.

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 in to light via an organic emitter.
OLED is an electroluminescent device that uses organic molecules as a source of light emission. Light is emitted by organic material when an external field is applied across it.

Properties: Some of the key properties of Organic Light Emitting Diodes (OLEDs) include:

1. **Thinness and flexibility:** OLEDs are very thin and flexible, which makes them suitable for use in curved or flexible displays.
2. **High contrast:** OLEDs have a high contrast ratio, which means that they can produce deep blacks and bright whites, resulting in images with vivid and rich colours.
3. **Fast response time:** OLEDs have a fast response time, which means that they can switch on and off quickly, resulting in smooth and seamless motion in video content.
4. **Wide viewing angle:** OLEDs have a wide viewing angle, which means that the image quality is maintained even when viewed from different angles.
5. **Energy efficiency:** OLEDs are energy efficient as they do not require a back light like traditional LCD displays, resulting in lower power consumption.

Applications

1. Flat-panel TV screen
2. Digital cameras
3. Mobile phones

Quantum Light Emitting Diodes (QLED's)

QLED is an electroluminescent device that uses quantum dots (QD's) as a source of light emission.

Properties:

1. **Accurate and vibrant colours**: QLEDs are capable of producing highly accurate and vibrant colours due to their use of quantum dots, which emit light of a specific colour when they are excited by a light source or an electrical current.
2. **Energy-efficient**: QLEDs are more energy-efficient than traditional LCD displays because they do not require as much back lighting.
3. **High contrast**: QLED displays have high contrast ratios, which means that the difference between the darkest and brightest areas of the display is greater, resulting in more detailed and life like images.
4. **Long life span**: QLEDs have a longer life span than traditional LCD displays because they do not suffer from the same issue soft back light burnout or colour fading over time.
5. **Fast response times**: QLED displays have fast response times, which mean that they can display fast-moving images without motion blur or ghosting.
6. **Flexibility**: QLEDs can be made on flexible substrates, which allows for the creation of flexible displays that can be bent or curved.

Applications

1. Flat-panel TV screen
2. Digital cameras
3. Mobile phones