MODULE 2: Materials for memory and display systems (8hr)

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).

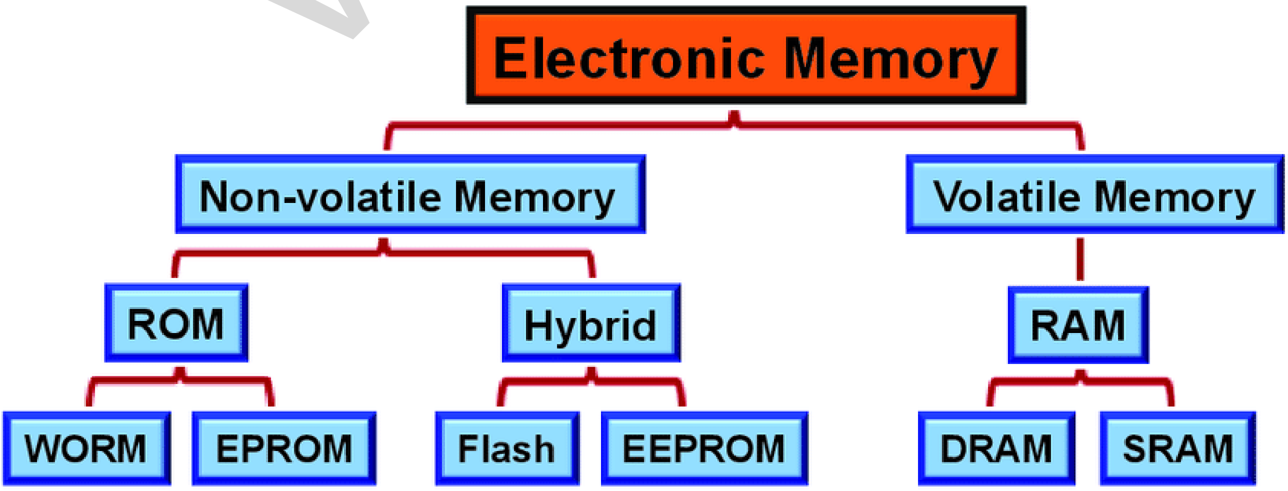
Display Systems: Photoactive and electro active materials, Nanomaterials and organic materials used in optoelectronic devices. Liquid crystals (LC's) - Introduction, classification, properties and application in Liquid Crystal Displays (LCD's). Properties and application of Organic Light Emitting Diodes (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), Aluminium(Al), and Brominated flame retardants in computers.

Memory Devices

Introduction, Basic concepts of electronic memory

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", as one of the core functions (primary storage) of modern computers. An electronic memory device is a form of semiconductor storage which is fast in response and compact in size, and can be read and written when coupled with a central processing unit (CPU, a processor). In conventional silicon-based electronic memory, data are stored based on the amount of charge stored in the memory cells. Organic/polymer electronic memory stores data in an entirely different way, for instance, based on different electrical conductivity states (ON and OFF states) in response to an applied electric field. Organic/polymer electronic memory is likely to be an alternative or at least a supplementary technology to conventional semiconductor electronic memory. According to the storage type of the device, electronic memory can be divided into two primary categories: volatile and non-volatile memory.



1. **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. ROM (WORM, EPROM) and Hybrid (Flash, EEPROM) memories are non-volatile memories.
2. **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.

1.a. 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 and EPROM are ROM based memories.

i. 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

ii. 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 microcontrollers.

1.b. Hybrid memories

Hybrid memories 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 and EEPROM are the two types.

i. Flash

- Flash 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.

ii. 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.

2.a. 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.

i. 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.

ii. 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)

Classification of Electrical Memory Devices

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

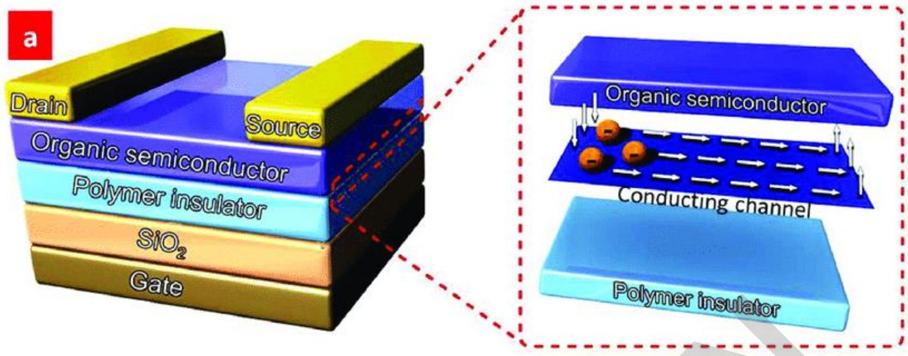
1. Transistor-Type Electronic Memory

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. The main components are-

(a) source
(b) drain
(c) gate
(d) dielectric layer of inorganic and polymer insulator
(e) active semiconducting layer made of conjugated molecule or polymer
(f) electrodes: Au for polymer-based FETs
(g) Substrate: glass, wafer or plastic

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.

Device Structure

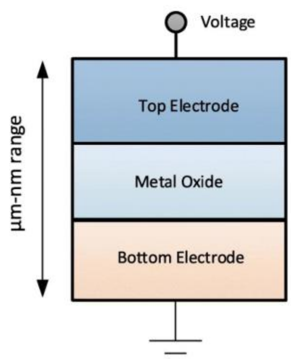


OFET structure　　　　Conducting channel in OFET

2. Capacitor-Type Electronic Memory

Capacitors can store charges on two parallel plate electrodes under an applied electric field. Based on the amount of charge stored in the cell, the bit level (either “0” or “1”) can be encoded accordingly. 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.

3. Resistor-type Electronic Memory



Device Structure

Memory devices containing resistive materials are generically classified as resistor-type memory, or resistive random access memory (RRAM). Unlike transistor and capacitor memory devices, resistor-type memory does not require a specific cell structure (e.g. FET) or to be integrated with the CMOS (complementary metal-oxide-semiconductor) technology. Resistor-type memory devices store data in an entirely different form, for instance, based on different electrical conductivity states (ON and OFF states). 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. Resistor-type memory is based on the change of the electrical conductivity of materials in response to an applied voltage (electric field). The structure comprises of an insulating layer sandwiched between the two metal 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". The top and bottom electrodes can be either symmetric or asymmetric, with aluminium, gold, copper, p- or n-doped silicon, and ITO being the most widely used electrode materials. Various mechanisms have been proposed to explain electrical conductance switching in organic/polymer memory devices. Among them, the most widely reported mechanisms include filament conduction, space charges and traps, charge transfer effects, and conformational changes.

4. Charge-transfer 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. If the donor is characterized by small size and low ionization potential, a strongly ionic salt forms and a complete transfer of charge (or with the CT degree value, $\delta > 0.7$) occurs from the donor to the acceptor, making the ionic salt insulating. When the donor is very large and has a high ionization potential, a neutral molecular solid ($\delta < 0.4$) forms, which is also insulating. If the donor has intermediate size and ionization potential, it tends to form a weakly ionic salt with the acceptor, which possesses incomplete CT ($0.4 < \delta < 0.7$) and thus is potentially conductive. The formation of a conductive CT complex can be employed to design molecular electronic devices. Many organic CT systems, including organometallic complexes, carbon allotrope (fullerene, carbon nanotubes and graphene)-based polymer complexes, gold nanoparticle–polymer complexes, and single polymers with intra-molecular D–A structures.

Organic-Based Electrical Memory Devices/Organic semiconductors

If organic molecular material used to store the data is called organic –based memory device. Organic semiconductors are π-conjugated polycyclic and heterocyclic systems which have a certain degree of electrical conductivity. Organic electronic memory device stores data based on different electrical conductivity states (ON and OFF states) in response to an applied electric field.

The advantages of organic and polymer electronic memory over traditional silicon-based memory include-

- good processability
- molecular design through chemical synthesis
- simple device structure: use of low cost substrate like plastic and paper

- miniaturized dimensions
- low-cost
- low-power operation
- multiple state properties
- large capacity for data storage
- lighter
- more flexible

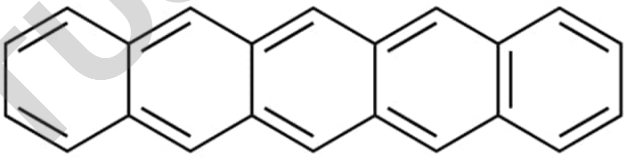
Based on materials used Organic memory devices (OMDs) broadly classified as:

a) resistive switch and 'write once, read many times' (WORM) devices,
b) molecular memory devices, and
c) polymer memory devices (PMDs)

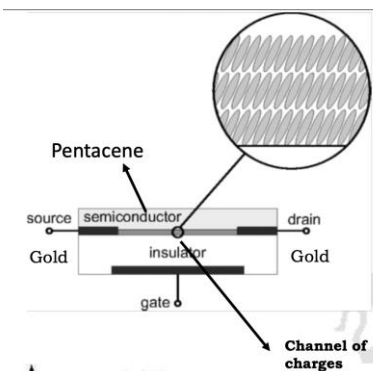
There are two major classes of organic semiconductors: -low molecular weight materials and polymers. Organic semiconductors can be divided according to the character of charge carriers into **p-type** (a positive charge or hole as the major carrier), **n-type** (a negative charge or electron as the major carrier) or Ambipolar organic semiconductors (both electrons and holes are involved as charge carriers)

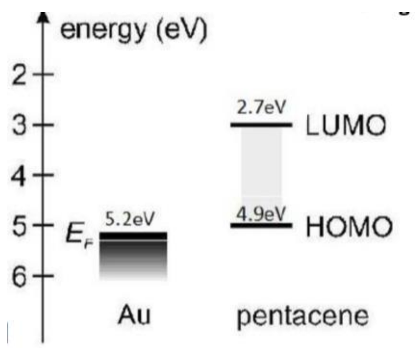
a. The p-Type Organic Semiconductor Material "Pentacene ($C_{22}H_{14}$)"

An Organic molecule with π conjugated system and possess holes as major charge carrier is called p-type semiconductor. Example: Pentacene. Pentacene is a polycyclic, linear aromatic hydrocarbon formed by the fusion of five benzene rings. The extended π-system allows the continuous delocalization of π-electrons and there is a lateral overlapping of pi-electrons between the molecules.



To show that Pentacene is a p-Type semiconductor





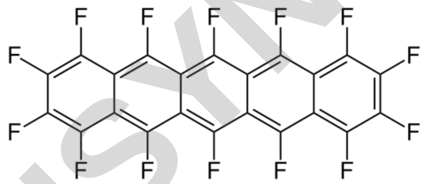
Consider OTFT (Optical Thin Film Transistor) as shown above. Source and drain was made of gold and semiconductor was Pentacene. When a Positive voltage is applied to the gate negative charges are induced at the source electrode (Au). Since, Fermi level of gold is away from LUMO of Pentacene, electron flow cannot takes place. When a negative voltage is applied to the gate holes are injected from source to semiconductor because Fermi level energy of gold is close to energy of HOMO of Pentacene. A conducting channel is formed at the insulator and semiconductor interface and allows the movement of charge carriers holes from source to drain when secondary voltage is applied. Hence pentacene is a p-type semiconductor

Note:

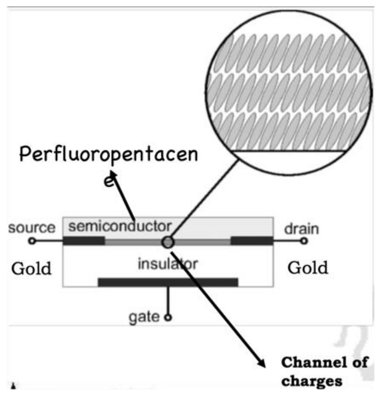
- Source is the terminal through which the majority charge carriers are entered in a transistor. Drain: Drain is the terminal through which the majority charge carriers exit in a transistor
- The highest energy level that an electron can occupy at the absolute zero temperature is known as the Fermi Level.

b. The n-type organic semiconducting material Perfluoropentacene

An Organic molecule with π conjugated system with electron withdrawing substituent groups and possess electrons as major charge carrier is called n- type semiconductor. When a p-type semiconductor Pentacene is modified with electronegative fluorine atoms to lower the Lowest Unoccupied Molecular Orbital (LUMO) energy levels of materials for electron injection and transport. The HOMO-LUMO gaps of perfluorinated pentacene are smaller than those of the corresponding Pentacene.



To show that Perfluropentacene is a n-Type semiconductor

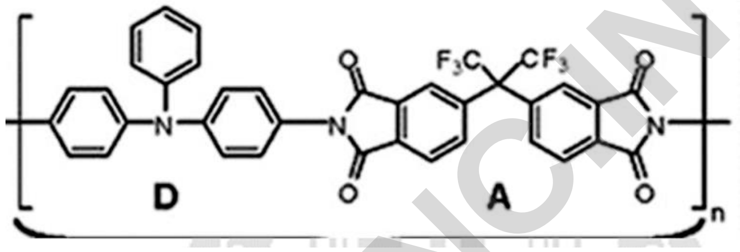


Consider OTFT(Optical Thin Film Transistor) as shown above. Source and drain was made of gold and semiconductor was Perfluropentacene. The HOMO-LUMO gaps are 2.07 eV for pentacene and 1.95eV for perfluoropentacene. When a Positive voltage is applied to the gate negative charges are induced at the source electrode (Au). The source and drain electrodes inject electrons in its LUMO level. This charge forms a conducting channel at the insulator and semiconductor interface and allows the charge carriers electron from source to drain. Hence, Perfluropentacene is considered as a n-Type semiconductor.

Polymeric material for Organic memory device

A volatile memory is a type of memory which cannot sustain the two distinct electronic states without an external electronic power supply, that is, the written data will disappear. A non-volatile memory can sustain the two distinct states without the power supply, that is, the written data will not disappear when an external electronic power supply is removed.

Understanding the relationship between the chemical structure and memory properties is a subject of utmost importance in the development of polymer memory materials. One such polymer used for organic memory device is Polyimide with Donor- Triphenylamine and Acceptor- phthalimide. Donor: Triphenyl Amine group (TPA) Acceptor: Phthalimide group. Hexafluoroisopropylidene (6F): Increases the solubility of PI.



The donors and acceptors of PIs contribute to the electronic transition based on an induced charge transfer (CT) effect under an applied electric field. When an electric field more than threshold energy is applied, the electrons of the HOMO (TPA unit) is excited to LUMO. The energy of LUMO of donor and acceptor are similar and therefore, after excitation the electron transferred to LUMO(acceptor), generating a CT state. This permits the generation of holes in the HOMO, which produces the open channel for the charge carriers to migrate through. Therefore, Field-induced charge transfer from triphenylamine to phthalimide exhibit the switching behaviour (bistable states ON/OFF). This device exhibits dynamic random access memory (DRAM) behaviour with an ON/OFF current ratio of up to 10^5.

Display System

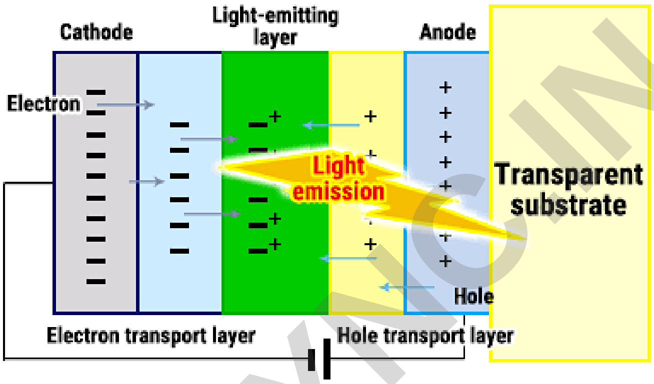
Display: Display is an output device used to present visual information.

Display System: Display system is 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 electro active and Photoactive materials. Photoactive and electro active organic materials are the semiconductors composed of π-electron systems.

Working Principle



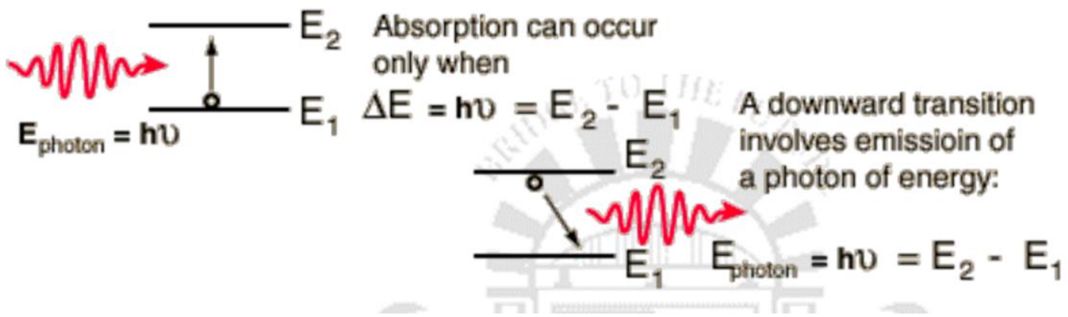
Photoactive and electroactive material absorb and emit light in the UV to IR region. Display system (OLED) consisting of photoactive and electroactive material absorb light and allows an electron to jump from HOMO of a Donor to LUMO of an Acceptor. This phenomenon generate and transport charge carriers. In an OLED device, the light-emitting layer is excited by the recombination 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.

Optoelectronics

Optoelectronics is the communication between optics and electronics which includes the study, design and manufacture of a hardware device that converts electrical energy into light and light into energy through semiconductors. Optoelectronic devices: A hardware device that converts electrical energy into light and light into energy through semiconductors. 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 (Silicon Nanocrystals: Si NC) for Optoelectronic devices

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

Properties of Silicon Nanocrystals for optoelectronics:

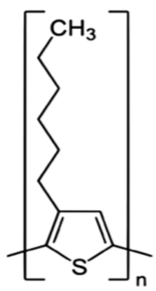
- Silicon Nano crystal has wider bandgap energy due to quantum confinement.
- Si NCs shows higher light emission property (Photoluminescence)
- Si NCs exhibit quantum yield of more than 60%.
- Si-NCs exhibit tuneable electronic structure.
- Larger surface area-volume ratio

Applications:

- Si NCs are used in neuromorphic computing and down-shifting in photovoltaics
- Si NCs are used in the construction of novel solar cells, photodetectors 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 polythiophene with a short alkyl group on each repeat unit. Highly ordered (P3HT) are composed of closely packed, p–p stacked (p–p distance of 0.33 nm) fully extended chains which are oriented perpendicular to the substrate.



Properties:

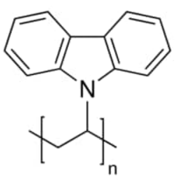
- P3HT is a semiconducting polymer with high stability and exhibits conductivity due to holes therefore considered as p-type semiconductor.
- Poly-3-hexylthiophene (P3HT) have great capability as light-absorbing materials in organic electronic devices.
- P3HT has a crystalline structure and good charge-transport properties required for Optoelectronics.
- P3HT has a direct-allowed optical transition with a fundamental energy gap of 2.14 eV.
- Fundamental bandgap 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.

Applications:

- P3HT-ITO forms a p-n junction permit the charge carriers to move in opposite direction and hence, used in Photovoltaic devices.
- It can be used as a positive electrode in Lithium batteries.
- Used in the construction of Organic Solar Cells.
- Manufacture of smart windows .
- 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 processable polymers as hole conducting material and therefore used as an efficient hole transport material to prepare highly efficient stable planar heterojunction perovskite solar cells.

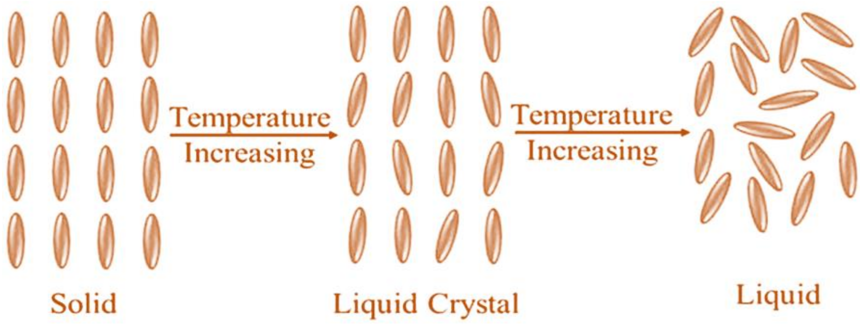


Structure of poly(9-vinylcarbazole) (PVK)

Applications

- PVK has been commonly used in OLEDs , light harvesting applications , photorefractive polymer composites and memory devices
- Used in the fabrication of light-emitting diodes and laser printers.
- Used in the fabrication of organic solar cells when combined with TIO on glass substrate.
- Used in the fabrication of solar cells when combined with Perovskite materials.
- PVK-Perovskite junction is used in Light-Emitting Diodes with Enhanced Efficiency and Stability

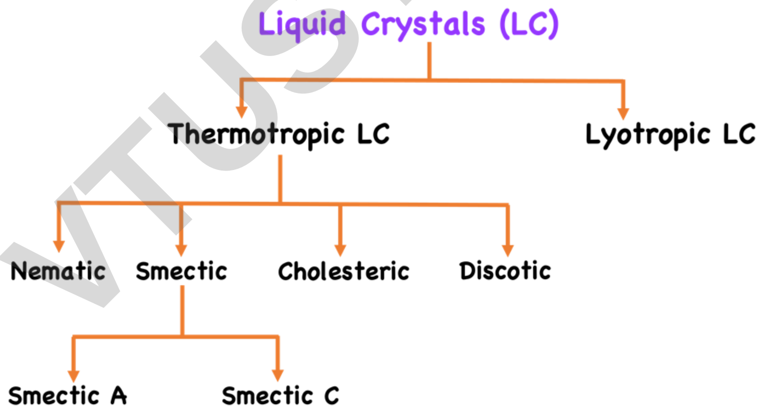
Liquid Crystals



The liquid crystals are a unique state of matter between solid (crystalline) and liquid (isotropic) phases. Liquid crystal is a material which flows like a liquid and shows some properties of solid. The molecular structure of liquid crystal is in between solid crystal and liquid isotropic. Liquid Crystal Display (LCD) is an flat display screen used in electronic devices such as laptop, computer, TV, cell phones and portable video games. These LCD are very thin displays and it consumes less power than LEDs. In Liquid crystal display (LCD) nematic type of liquid crystal molecular arrangement is used in which molecules are oriented in some degree of alignment. For example when we increase the temperature the ice cube melts and liquid crystal is like the state in between ice cube and water.

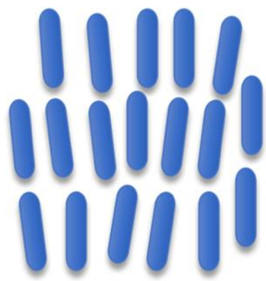
LC are classified as follows

1. Thermotropic liquid crystals
2. Lyotropic liquid crystals



1. Thermotropic liquid crystal

A liquid crystal is said to be thermotropic if molecules orientation is dependent on the temperature. By increasing the temperature, the increase in energy and thereby movement of constituent molecules, will induce phase changes. Eg:

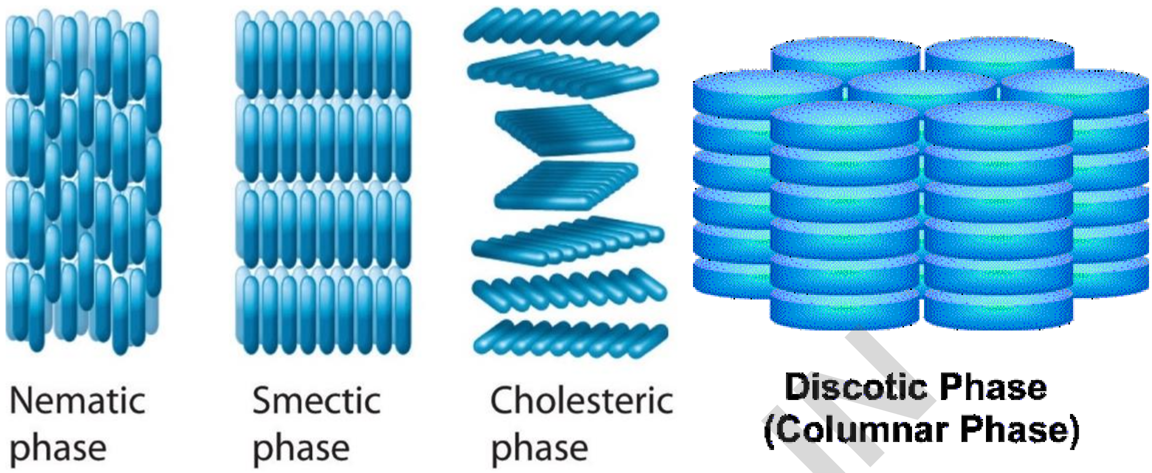


Ethyl-*p*-azoxycinnamate (Solid) $\xrightarrow{140°C}$ Ethyl-*p*-azoxycinnamate (liquid crystal)

p-cholesteryl benzoate (Solid) $\xrightarrow{145°C}$ *p*-cholesteryl benzoate (liquid crystal)

Thermotropic liquid crystals have been classified into the following types:

(a) Nematic liquid crystals
(b) Smectic liquid crystals
(c) Cholesteric liquid crystals
(d) Discotic liquid crystals



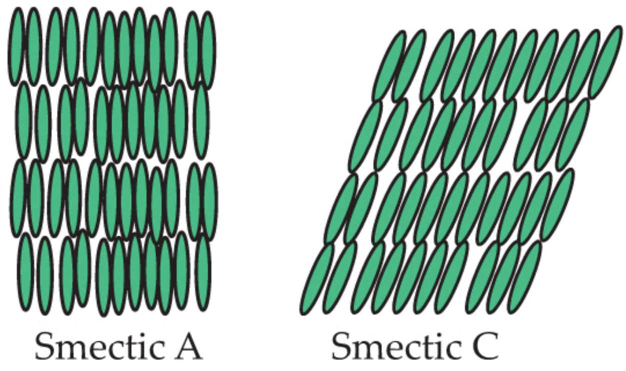
(a) Nematic (or thread-like liquid crystals)

The molecules move either sideways or up and down. Each molecule can also twist or rotate around its axis giving rise to a twisted nematic. Since the molecules are oriented in one direction, they exhibit anisotropy. In this case, the molecules are readily aligned in the same direction in the presence of electric and magnetic fields. The alignment of molecules is temperature sensitive – as the temperature is increased, the degree of orientation of the nematic crystals decreases and they change into isotropic liquids. Examples: p-azoxyphenetole, anisaldazine.

(b) Smectic (or soap-like liquid crystals)

The molecules in smectic crystals are oriented parallel to each other as in the nematic phase but in layers. These layers can slide pass each other because the force between the layers is weak. They are denoted by alphabet letter A, B, C, etc. Some common types of smectic liquid crystals are given below.

i. **Smectic A**: In smectic A, the molecules are aligned perpendicular to the layer planes.
ii. **Smectic C**: The arrangement of molecules is similar to smectic A except that the molecules are slightly tilted. They have high viscosity and are not suitable for devices.



(c) Cholesteric liquid crystals

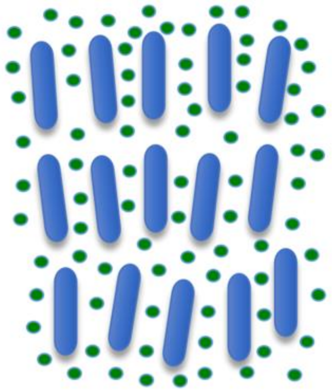
This type of mesophase is formed by derivatives of cholesterol such as cholesteryl esters. Like the nematic phase, the molecules in this type of crystal are also parallel to each other but arranged in layers. The molecules in successive layers are slightly twisted or rotated with respect to the layers above and below so as to form a continuous helical or spiral pattern. Cholesteryl benzoate, the first known liquid crystal, is of cholesteric type. Its transition temperature is 146 °C and melting point is 178.5 °C.

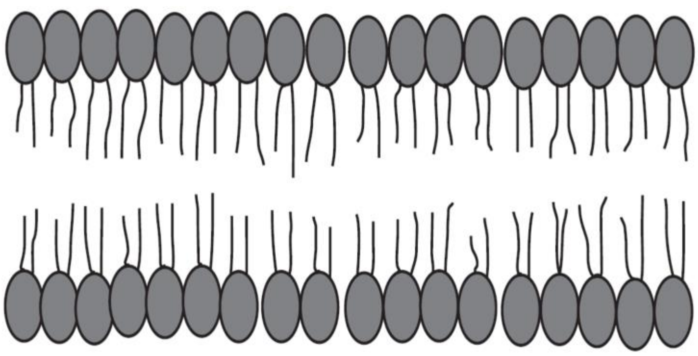
(d) Discotic liquid crystals

Molecules are arranged in a column arrangement with disc like structure. These are referred to as columnar phases. Applications are: in photovoltaic devices, organic light emitting diodes (OLED), and molecular wires.

2. Lyotropic liquid crystals

The orientational behaviour of lyotropic crystals is a function of concentration and solvent. These molecules are amphiphilic – they have both hydrophilic and hydrophobic ends in their molecules. The hydrophilic end is attracted towards water, whereas the hydrophobic end is water repellent and attracted towards non-polar solvents. At low concentrations, these molecules are randomly oriented but as the concentration increases, the molecules start arranging themselves. Cell membranes and cell walls are examples of lyotropic liquid crystals. Soaps and detergents form lyotropic crystals when they combine with water.





Properties of liquid crystals

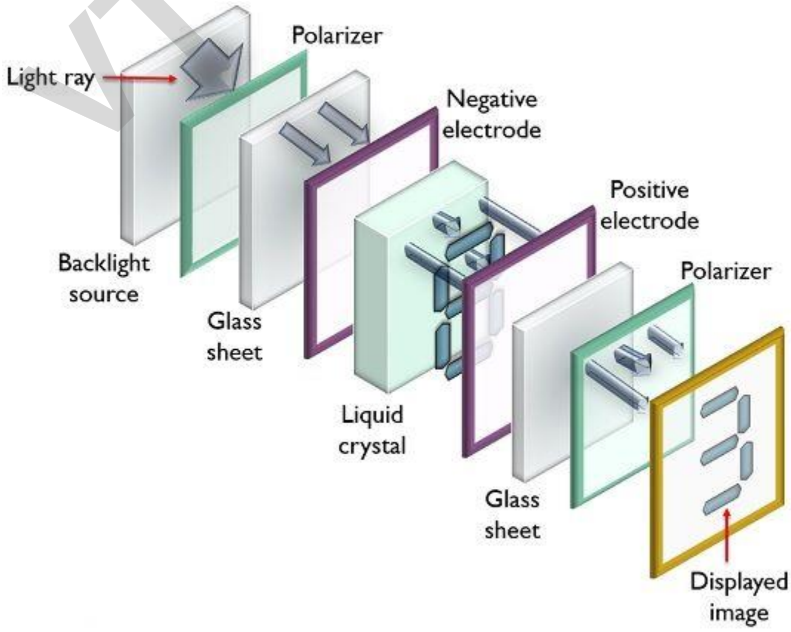
- They exhibit optical anisotropy which is defined as the difference between refractive index parallel to the director and refractive index perpendicular to the director. These two properties are important for the electro-optic effects in liquid crystals.
- The intermolecular forces are rather weak and can be perturbed by an applied electric field.
- Because the molecules are polar, they interact with an electric field, which causes them to change their orientation slightly.
- Liquid Crystal can flow like a liquid, due to loss of positional order.
- Liquid crystal is optically birefringent, due to its orientation order.
- Liquid crystals, like all other kinds of matter, exhibits thermal expansion (Thermal Imaging).

Applications of liquid crystals

Liquid crystals have a wide range of applications in various fields, including electronics, optics, displays, sensors, and medicine. Some of the major applications of liquid crystals are:

- Liquid Crystal Displays (LCDs): The liquid crystal layer in LCDs allows for the display of images and text through the use of electrical currents that control the orientation of the crystals.
- Sensors: Liquid crystal sensors are used in various applications such as temperature sensing, humidity sensing, and chemical sensing.
- Optical Devices: Liquid crystals are used in various optical devices such as variable optical attenuators, phase shifters, and tuneable filters. These devices are used in optical communication systems, spectroscopy, and imaging.
- Medicine: Liquid crystals have been used in drug delivery systems, where the drug is encapsulated in the liquid crystal matrix and delivered to specific target cells.

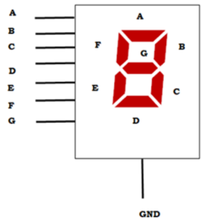
Application in Liquid Crystal Displays (LCD's)



A liquid crystal display (LCD) is a flat panel display technology that uses liquid crystals to produce images. LCDs are commonly used in electronic devices such as televisions, computer monitors, and mobile phones. LCD consists of two polarized glass pieces. Two electrodes, one is positive and the other one is negative. External potential is applied to LCD through this electrodes and it is made up of indium-tin-oxide. Liquid crystal layer of about 10µm- 20µm is placed between two glass sheets. The light is passed or blocked by changing the polarization.

Working principles of LCD

- The working principle of an LCD is based on the optical properties of liquid crystals.
- An LCD consists of a layer of liquid crystal material sandwiched between two transparent electrodes.
- When an electric field is applied to the liquid crystal, it twists the orientation of the liquid crystal molecules, which changes the polarization of the light passing through the liquid crystal.
- Polarizing filter is placed in front of and behind the liquid crystal layer to control the orientation of the light passing through it.
- The LCD also has a backlight, which shines light through the liquid crystal layer to produce an image.
- The LCD can display images in colour by using filters that absorb different colours of light. Each pixel of an LCD contains three sub-pixels that can produce red, green, and blue colours. By adjusting the voltage applied to each sub-pixel, the LCD can create millions of different colours.
- Overall, the working principle of an LCD is based on the manipulation of light using liquid crystals and polarizing filters to create images.
- When the external bias is applied the molecular arrangement is disturbed and that area looks dark and the other area looks clear.
- In the segment arrangement the conducting segment looks dark and the other segment looks clear. To display number 2 the segments A, B, G, E, D are energized.



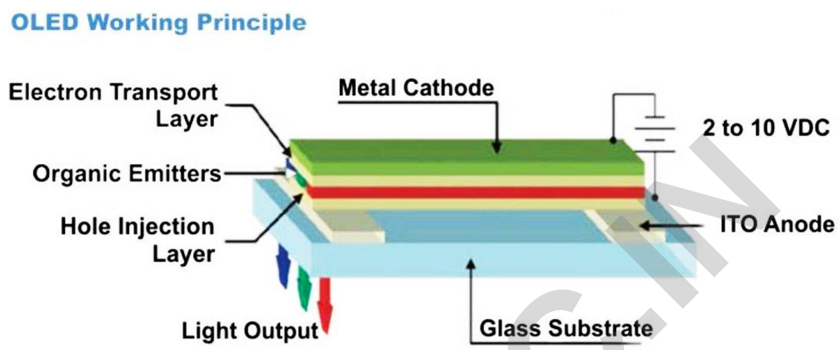
Organic Light Emitting Diodes (OLED's)

"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". The basic OLED cell structure consists of a stack of thin organic layers sandwiched between a conducting anode and a conducting cathode.

Working principle of OLED: The components of OLED are-

- Substrate (can be plastic, glass, or metal foil) – Foundation of the OLED
- Anode (may or may not be transparent depending on the type of OLED) – Positively charged to injects holes (absence of electrons) into the organic layers that make up the OLED device
- Hole Injection Layer (HIL) – Deposited on top of the anode this layer receives holes from the anode and injects them deeper into the device

- Hole Transport Layer (HTL) – This layer supports the transport of holes across it so they can reach the emissive layer
- Emissive Layer – The heart of the device and where light is made, the emissive layer consists of a colour defining emitter doped into a host. This is the layer where the electrical energy is directly converted into light.
- Blocking layer (BL) – Commonly used to improve OLED technology by confining electrons (charge carriers) to the emissive layer
- Electron Transport Layer (ETL) – Supports the transport of electrons across it so they can reach the emissive layer.
- Cathode (may or may not be transparent depending on the type of OLED) – Negatively charged to inject electrons into the organic layers that make up the OLED device.



When a voltage is applied across the OLED, a current flows through the device and into the emissive layer. As the current passes through the emissive layer, the organic molecules become excited and move to a higher energy state. When they return to their original energy state, they release energy in the form of photons, which create the visible light that we see.

Properties of OLED

- Thinness and flexibility: OLEDs are very thin and flexible, which makes them suitable for use in curved or flexible displays.
- High contrast: OLEDs have a high contrast ratio, which means that they can produce deep blacks and bright ewhites, resulting in images with vivid and rich colours.
- 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.
- Wide viewing angle: OLEDs have a wide viewing angle, which means that the image quality is maintained even when viewed from different angles.
- Energy efficiency: OLEDs are energy efficient, as they do not require a backlight like traditional LCD displays, resulting in lower power consumption.
- Self-emissive: OLEDs are self-emissive, which means that they do not require a separate light source, resulting in a thinner display.
- Long lifespan: OLEDs have a long lifespan, as they do not contain a backlight that can degrade over time, resulting in a longer-lasting display.

Applications

Organic Light Emitting Diodes (OLEDs) have a wide range of applications due to their unique properties, including high contrast, energy efficiency, thinness, and flexibility. Like,

- Televisions and displays: OLED displays are used in televisions, monitors, smartphones, and other electronic devices.
- Lighting: OLEDs can also be used as a source of lighting in various applications, including automotive lighting, street lighting, and architectural lighting.
- Wearable devices: The thin and flexible nature of OLEDs makes them suitable for use in wearable devices, such as smartwatches and fitness trackers.
- Automotive: OLEDs can be used in automotive applications, such as dashboard displays, interior lighting, and taillights.
- Medical: OLEDs can be used in medical applications, such as in surgical lighting and medical imaging. They offer bright and highly accurate lighting options that can help improve medical procedures and diagnosis.

Quantum Light Emitting Diodes (QLED's)

Quantum dot light emitting diodes are a form of light emitting technology and consist of nano-scale crystals that can provide an alternative for applications such as display technology".

Properties of QLED

- 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.
- Energy-efficient: QLEDs are more energy-efficient than traditional LCD displays because they do not require as much backlighting.
- 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 lifelike images.
- Long lifespan: QLEDs have a longer lifespan than traditional LCD displays because they do not suffer from the same issues of backlight burnout or color fading over time.
- Fast response times: QLED displays have fast response times, which means that they can display fast-moving images without motion blur or ghosting.
- Flexibility: QLEDs can be made on flexible substrates, which allows for the creation of flexible displays that can be bent or curved.

Applications of QLED

- Televisions and displays: QLED displays are commonly used in televisions, monitors, smartphones, and other electronic devices. They offer superior image quality and color accuracy compared to traditional LCD displays.
- Lighting: QLEDs can also be used as a source of lighting in various applications, including automotive lighting, street lighting, and architectural lighting. They offer energy-efficient and highly customizable lighting options.

- Medical imaging: QLEDs can be used in medical imaging applications, such as in MRI machines, to produce high-resolution and accurate images.
- Virtual and augmented reality: QLED displays are suitable for use in virtual and augmented reality applications due to their ability to produce vibrant and accurate colours, which can enhance the immersive experience.
- Advertising displays: QLED displays can be used in advertising displays, such as digital billboards and signage, to produce high-quality and eye-catching visuals.

Light emitting electrochemical cells.

Organic semiconductors offer a series of advantages over their inorganic counterparts such as the possibility to fabricate light-weight and very thin devices, their processability on flexible and large-area substrates and the ease of tuning their electrical and optical properties. Efficient and stable state-of-the-art OLEDs are based on a multi-stack architecture of small molecular-weight components that make use of injection layers or reactive metals for an efficient injection of electrons. The multi-layer geometry is obtained by sequentially evaporating the active materials under high-vacuum conditions. These devices require rigorous encapsulation to prevent degradation of the air-sensitive materials supporting electron injection. As a result, production costs of OLEDs are considerable delaying their large-scale market entry for lighting applications. OLEDs require multiple layers, some of them processed by evaporation under high-vacuum conditions. Air-sensitive low work function metals or electron injecting layers are needed for efficient charge carrier injection. LECs can be prepared from just a single active layer. The movement of the ions in the layer under an applied bias allows for efficient charge carrier injection from air-stable electrodes. Taken from The properties of OLEDs can be drastically altered by mixing high concentrations of mobile ions with a conjugated polymer and a solid electrolyte. They described the injection of electronic charges from the metallic electrodes as electrochemical oxidation and reduction of the conjugated polymer, from which the name of the new devices (light- emitting electrochemical cells or LECs) was derived. An ionic transition-metal complex (iTMC) sandwiched in between two electrodes also leads to efficient electroluminescence .

Operation mechanism

- Two models have been proposed, the electrodynamic model (ED) and the electrochemical doping model (ECD) and measurement results have been interpreted in either of them.
- In the following, the current understanding of the functional principle of LECs is briefly reviewed.
- After applying an external bias, the first step in LEC operation involves a redistribution of the ions in the active layer.
- Driven by the electrical field, anions and cations migrate to the respective electrode interfaces to form thin sheets of uncompensated charge referred to as electric double layers. The external quantum efficiency (EQE) is determined by the fraction of electrons and holes that recombine to form excitons (b), the exciton-to- photon generation efficiency (φ) and the amount of photons that can escape the device or out coupling efficiency.