MODULE-2 Materials for Memory and Display Systems

1 What are Memory Devices? Explain the Classification of electronic memory devices with examples

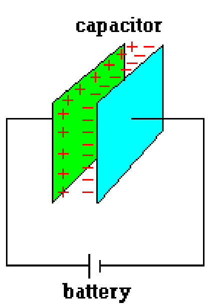
A memory device is a piece of hardware made of semiconducting materials used to store data.
Example: CD, DVD, USB and external hard disc.
Classification of Memory Devices:

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

1. Transistor-Type Electronic Memory:

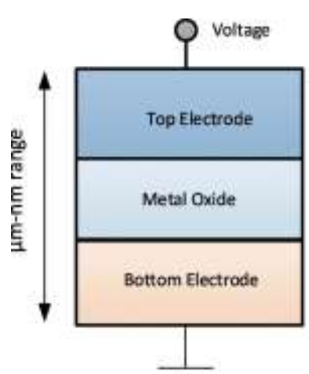
A transistor is a miniature electronic component that can work either as an amplifier or a switch. A computer memory chip consists of billions of transistors, each transistor is working as a switch, which can be switched ON or OFF. Each transistor can be in two different states and store two different 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.

2. Capacitor-Type Electronic Memory



A capacitor consists of two metal plates which are capable of storing an electric charge. 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.**

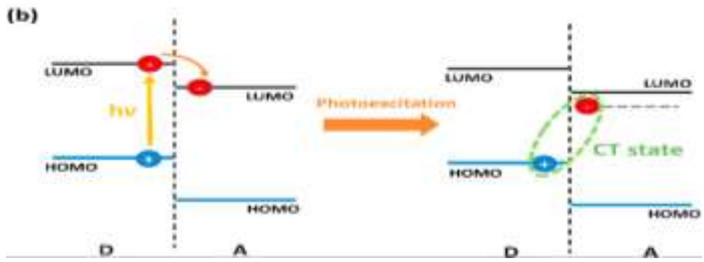
3. Resistor-Type Electronic Memory



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".

4. Charge Transfer Effects

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 has intermediate size and ionization potential, it tends to form a weakly ionic salt with the acceptor, which possesses incomplete CT (0.4 < δ < 0.7) and thus is potentially conductive.

2. Explain the types of organic memory devices by taking p- type and n-type semiconducting materials.

Organic electronic memory device uses organic semiconductors and stores data based on different electrical conductivity states (ON and OFF states) in response to an applied electric field.

The p-Type Organic Semiconductor Material "Pentacene"

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

Example: Pentacene

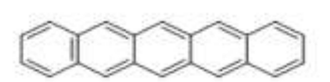
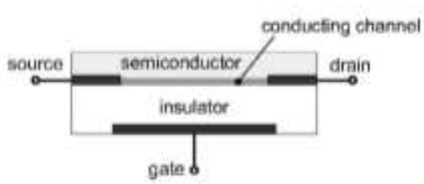
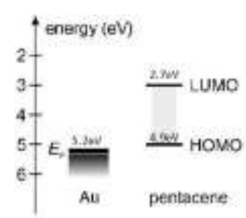


Fig: 2.6 Pentacene





When a positive voltage was applied between gate and source, it was found no flow of electrons to drain due to higher energy gap between the Fermi level of gold (source) and LUMO of Pentacene. On the other hand, when a negative voltage is applied between the drain and source, **holes** are induced at source. This permits a channel of charges (holes) to drain through semiconductor and insulator interface when a secondary voltage is applied. Therefore it called as P-type semiconductor

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.

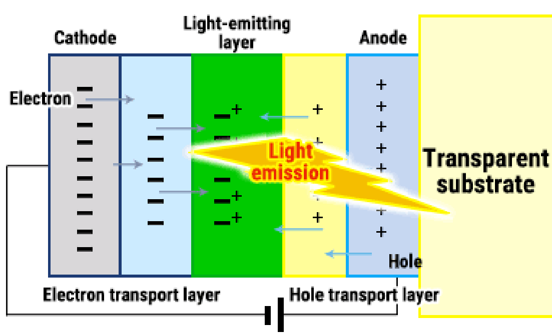
In Pentacene, when hydrogen atoms are substituted by highly electronegative fluorine atoms, it is called Perfluoropentacene and acts as N-type of semiconductor. When a positive voltage is applied between source and drain, **electrons** are induced in the source (gold).This permits the channel of charges to drain through semiconductor-insulator interface as the bandgap between Fermi level of gold (source) LUMO energy of Perfluoropentacene is 1.95ev which is lesser than LUMO energy of Pentacene. Therefore, it is n-type semiconductor.

3 Define photoactive and electroactive materials and write their working principle in display system.

Photoactive and electro active organic materials are the semiconductors composed of of π-electron systems which are used in electronic and optoelectronic devices.

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.



When electrons move from cathode, anode allows movement of holes towards light emitting layer under an applied field. Electron-hole pairs are created at the Light-Emitting-Layer and energy is released due to recombination. This energy is sufficient to excite an electron from HOMO to LUMO in the light emitting layer made of photoactive and electroactive materials. There is a re-emission of light while electron is returning to HOMO level. This light is extracted by a transparent substrate placed adjacent to either of the electrode.

4 What are nanomaterials? Explain any four properties and applications of Polythiophenes (P3HT) suitable for optoelectronic devices.

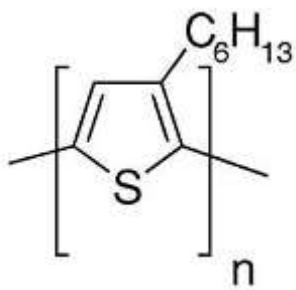
Any substance in which at least one dimension is less than 100nm is called nanomaterials.

The properties of nanomaterials are different from bulk materials due to:

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

Polythiophenes are 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).

Structure of P3HT



The improved electronic properties yielded for nanostructured P3HT suitable for optoelectronic devices are listed as follows:

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) have 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 2.14 eV.
5. Fundamental bandgap of P3HT is 490nm visible region, corresponding to $\pi \rightarrow \pi^*$ transition, giving electron-hole pair.

Applications:

1. P3HT-ITO forms a p-n junction permit 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.
6. Used in the fabrication new types of memory devices.

5 **What is QLED? Mention any four properties and applications of QLED.**

Quantum dot light emitting diodes are a form of light emitting devices consisting of nano-scale crystals that can convert light energy into electrical energy or vice-versa.

Properties of QLED

1. QLEDs are capable of producing highly accurate and vibrant colors due to their use of quantum dots.
2. QLEDs are more energy-efficient than traditional LCD displays because they do not require as much backlighting.
3. QLED displays have high contrast ratios and produce more detailed and lifelike images.
4. 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.

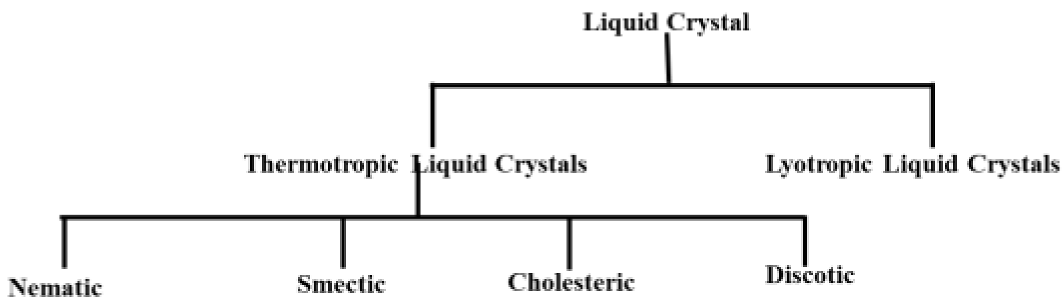
Applications of QLED

1. QLED displays are commonly used in televisions, monitors, smartphones, and other electronic devices.
2. QLEDs can also be used as a source of lighting in various applications, including automotive lighting, street lighting, and architectural lighting.
3. QLEDs can be used in medical imaging applications, such as in MRI machines, to produce high-resolution and accurate images.

4. QLED displays can be used in advertising displays, such as digital billboards and signage, to produce high-quality and eye-catching visuals.

6 Explain the classification of liquid crystals. Mention any four properties and applications of liquid crystals.

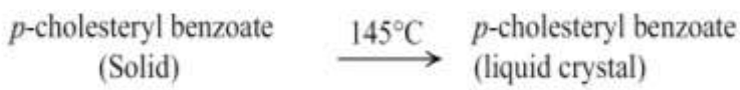
The liquid crystals are a unique state of matter between solid (crystalline) and liquid (isotropic) phases.



i) **Thermo tropic liquid crystal**

A liquid crystal is said to be thermo tropic if molecular orientation is dependent on the temperature.

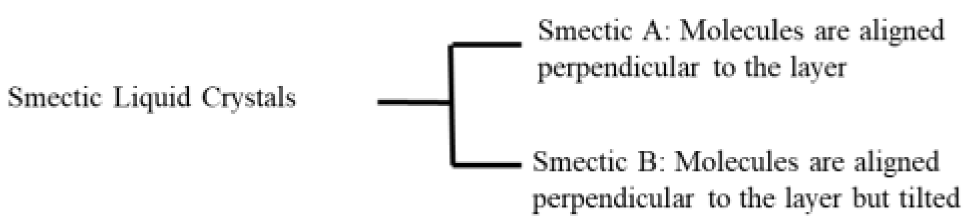
Example:



a) **Nematic (or thread-like liquid crystals)** : The molecules move either sideways or up and down. Increase in temperature decreases the degree of orientation.

Example: p-azoxyphenetole

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.



c) **Cholesteric liquid crystals:** Molecules in successive layers are slightly twisted and form helical pattern.

d) **Discotic liquid crystal:** Molecules are arranged in a column arranged with disc like structure.

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. At low concentrations, molecules are randomly arranged and higher concentration produces a definite pattern heads out and tail in. Soaps and detergents form Lyotropic crystals when they combine with water

Properties of liquid crystals

1. They exhibit optical anisotropy which is defined as the difference between refractive index parallel to the director and refractive index perpendicular to the director.
2. The intermolecular forces are rather weak and can be perturbed by an applied electric field.
3. They interact with an electric field, which causes them to change their orientation slightly.
4. Liquid Crystal can flow like a liquid, due to loss of positional order.

Applications of liquid crystals

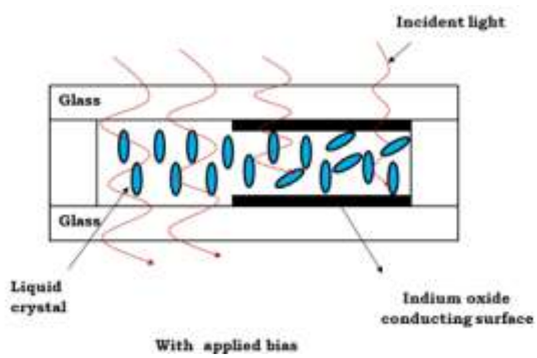
1. The liquid crystal layer in LCDs allows for the display of images and text through the use of electrical currents that control the orientation of the crystals.
2. Liquid crystal sensors are used in various applications such as temperature sensing, humidity sensing, and chemical sensing.
3. Liquid crystals are used in various optical devices such as variable optical attenuators, phase shifters, and tunable filters. These devices are used in optical communication systems, spectroscopy, and imaging.
4. 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.

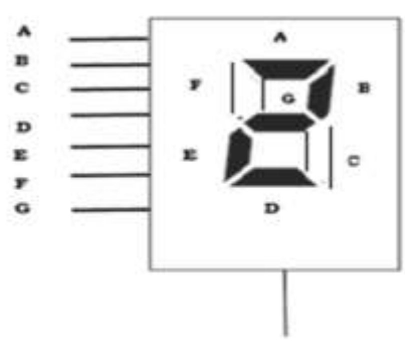
7 Discuss the working of Liquid Crystal Display.

Liquid-crystal displays (LCDs) consist of multiple layers. Light produced by a light-emitting diode passes through polarizing filters, color filters, and a liquid-crystal layer to produce an image.

The basic working principle of LCD is blocking of light. When the external light passes from one polarizer to the next polarizer, external supply is given to the liquid crystal, the polarized light aligns itself so that the image is produced in the screen.

The indium oxide conducting surface is a transparent layer which is placed on both the sides of the sealed thick layer of liquid crystal. When no external bias is applied the molecular arrangement is not disturbed.





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.

The LCD can display images in colour by using filters that absorb different colours of light. First, a white light-emitting diode shines light toward the front of the display, generating each pixel. The pixels actually consist of three sub pixels, one for each color—red, blue, and green. These sub pixels are made up of a liquid-crystal layer and the appropriate color filter sandwiched between two polarizing light filters. Transistor arrays switch the structural states of the liquid crystals to control whether or not a sub pixel gets lit up, which in turn produces all the colors in an image.

8 Explain any four properties and applications of Light emitting materials - Poly[9-vinylcarbazole] (PVK)] suitable for optoelectronic devices.

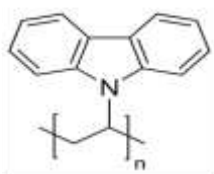


Fig: 2.13 Poly[9-vinylcarbazole] (PVK)]

Poly (N-vinyl carbazole) (PVK) is a polymers and an efficient hole transport material to prepare highly efficient and stable planar heterojunction perovskite solar cells.

Properties of PVK

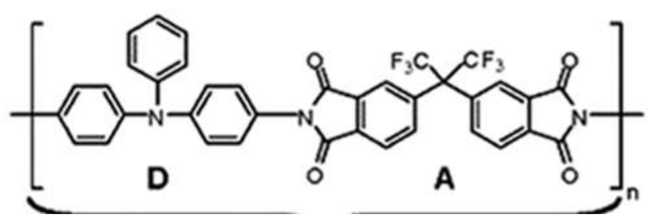
1. It is a semiconducting polymer and an electron acceptor converts ultra-violet (UV) light into electricity.
2. PVK has a band gap of 3.4 eV, optical absorption edge stating at 350 nm capable of absorbing Ultra-Violet light.
3. The PVK film is hydrophobic, thermally stable with a relatively high glass transition temperature (T_g) of 200 °C
4. The PVK solution also showed good wettability, and provide uniform thin films on glass/ITO substrates.

Applications

1. PVK is used in OLEDs for light harvesting applications.
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.
5. PVK-Perovskite junction is used in Light-Emitting Diodes with Enhanced Efficiency and Stability.

9 **Discuss the use of Polyimide Polymeric material for Organic memory device.**

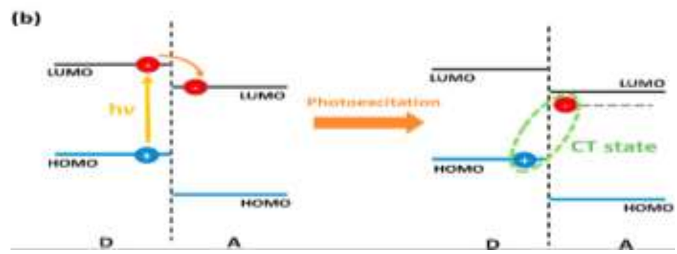
Organic polymer used for polymer used for organic memory device is Polyimide with Donor-Triphenylamine and Acceptor- phthalimide.



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.

1. When an electric field more than threshold energy is applied, the electrons of the HOMO (TPA unit) is excited to LUMO.
2. The energy of LUMO of donor and acceptor are similar and therefore, after excitation the electron transferred to LUMO (acceptor), generating a CT state.

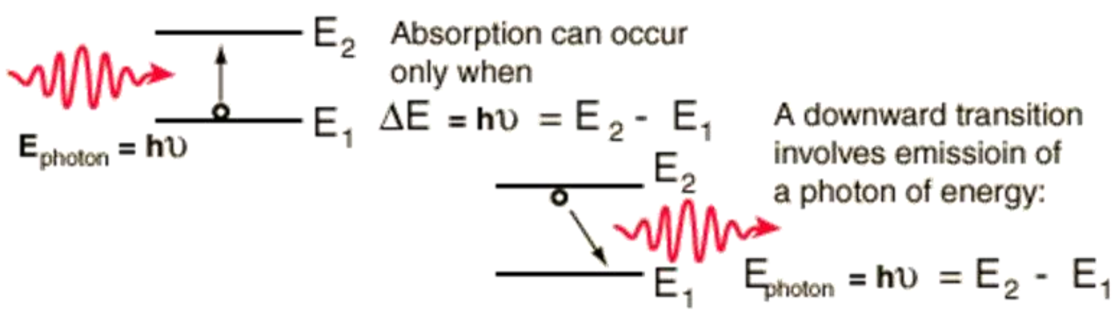


3. This permits the generation of holes in the HOMO, which produces the open channel for the charge carriers to migrate through.
4. Therefore, Field-induced charge transfer from Triphenylamine to Phthalimide exhibit the switching behavior (bistable states ON/OFF).

10 Define Optoelectronic device. Explain the working principle of Optoelectronic device.

A hardware device that converts electrical energy into light and light into energy through semiconductors is called Optoelectronic device. Optoelectronic devices are primarily transducers i.e. they can convert one energy form to another.

Working principle



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.

11 Write the properties and applications of Silicon Nano Crystals for Optoelectronic devices

Properties of Silicon Nanocrystals for optoelectronics

1. Silicon Nano crystal has wider bandgap energy due to quantum confinement.
2. Si NCs shows higher light emission property (Photoluminescence)
3. Si NCs exhibit quantum yield of more than 60%.
4. Si-NCs exhibit tunable electronic structure

Applications:

1. Si NCs are used in neuromorphic computing and down-shifting in photovoltaics
2. Si NCs are used in the construction of novel solar cells, photodetectors and optoelectronic synaptic devices.

12 **What is OLED? Mention any four properties and applications of OLED.**

"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

1. OLEDs are very thin and flexible, which makes them suitable for use in curved or flexible displays.
2. OLEDs have a high contrast ratio, and produce images with vivid and rich colours.
3. OLEDs have a fast response time, resulting in smooth and seamless motion in video content.
4. OLEDs have a wide viewing angle, and image quality is maintained even when viewed from different angles.
5. OLEDs are energy efficient, as they do not require a backlight like traditional LCD displays.

Applications of QLED

5. QLED displays are commonly used in televisions, monitors, smartphones, and other electronic devices.
6. QLEDs can also be used as a source of lighting in various applications, including automotive lighting, street lighting, and architectural lighting.
7. QLEDs can be used in medical imaging applications, such as in MRI machines, to produce high-resolution and accurate images.

QLED displays can be used in advertising displays, such as digital billboards and signage, to produce high-quality and eye-catching visuals.