Unit III: Materials for memory and display technology

3.1 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 or programs.

3.2 Basic concepts of electronic memory:

- 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.

3.3 Classification of electronic memory devices

According to the device structure, electronic memory devices can be divided into four primary categories: transistor-type, capacitor-type, and resistor-type and charge transfer-type.

(1) Transistor-type electronic memory device

A transistor is a miniature electronic component that can work either as an amplifier or a switch.

- It is converted to p-type and n- type semiconductor by doping trivalent and pentavalent impurities.
- 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 device

Capacitors have two parallel plate electrodes and charges are stored in these electrodes under an applied electric field.

- Data can be stored in these devices based on different charge stored in the cell. Charges stored in the cell maintain electric polarization that can be switched between two stable states by an external electric field.

- Organic and polymeric ferroelectric materials can be used in capacitor- type electronic memory device.

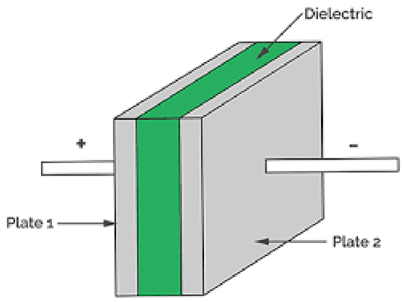


Fig 4.1: Capacitor

One common example of a transistor-type and capacitor type electronic memory device is Dynamic Random Access Memory (DRAM). DRAM is widely used as the main memory (RAM) in computers and electronic devices.

Basic structure of DRAM: DRAM consists of a grid of memory cells, where each cell is made up of a capacitor and a transistor. The **capacitor** stores a charge, representing the binary state (0 or 1), and the **transistor** acts as a switch that controls the flow of charge in and out of the capacitor.

Storage Mechanism of DRAM: The information in DRAM is stored in the form of electrical charges in the capacitors. When a charge is present in the capacitor, it represents a binary '1,' and when there is no charge, it represents a binary '0.' The transistor is used to read and write data by controlling the flow of charge.

(3) Resistor-type electronic memory device

Resistor-type memory devices are a type of electronic memory that uses resistors to store information.

- The memory cell consists of a resistor-type material that can change its resistance when an electric field is applied. The resistance can be set to high or low states, representing binary values (0 or 1).
- The resistors are arranged in a particular pattern to store the information.
- Unlike transistor and capacitor memory devices, resistor-type memory does not require a specific cell structure (e.g. Field Effecting Transistor) or to be integrated with the CMOS (complementary metal-oxide-semiconductor) technology.

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”

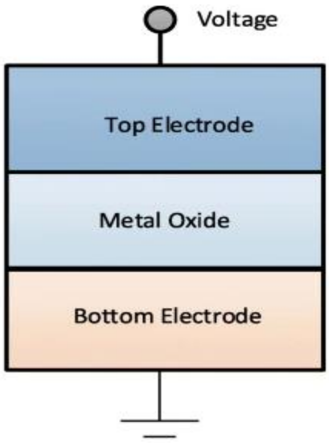


Fig 4.2: Resistor

(4) Charge transfer type electronic memory device

Charge-transfer type electronic memory devices typically involve the movement of charge carriers (usually electrons) within the device to store and retrieve data.

- This type of electronic device is based on the Charge Transfer Effects of a charge transfer complex. A charge transfer (CT) complex consists of two parts, one electron donor and other an electron acceptor.
- It is also called as a donor–acceptor (D– A) complex. The conductivity of a CT complex is dependent on the ionic binding between the D–A components. In CT complex, a partial transfer of charges occurs from donor part to the acceptor part.
- This results in difference in conductivity. CT complexes exhibit bistable states due to difference in conductivity. This behavior is used to design molecular electronic devices.

3.4 Types of organic memory materials

There are three classes of materials which can exhibit bistable states and are used inorganic memory devices. They are:

i) Organic molecules, ii) Polymeric materials and iii) Organic- inorganic hybrid materials.

Under each category, lots of different types of molecules exhibiting memory effect are available. Few of them are described here:

3.4.1 Organic molecules used for memory device

Small organic molecules containing both an electron donor and an electron acceptor are an important type of material for organic electronic memory devices.

Examples: Pentacene, Perfluoropentacene, etc

3.4.2 Criteria for organic molecules/polymers used as semiconductor materials

The selection of organic molecules/polymers as semiconductor materials for electronic devices is based on various criteria, taking into account the specific requirements of the application. Here are some key criteria for choosing organic molecules/polymers as semiconductor materials:

a) Conjugation and π-Electron System: Molecules with extended conjugation and a well-defined π-electron system tend to exhibit semiconducting properties. This allows for efficient charge carrier transport within the material.

b) Bandgap Energy: The bandgap of the material is crucial. The bandgap determines the energy difference between the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO). The bandgap influences the type and efficiency of charge carriers (holes or electrons) in the semiconductor.

c) Chemical Stability: The organic semiconductor should be chemically stable under the operating conditions of the device. Stability is crucial for the long-term performance and reliability of electronic devices.

d) Substituent Effects: The introduction of specific functional groups or substituents can influence the electronic properties, molecular packing, and stability of organic semiconductors. This allows for the tailoring of properties to meet specific device requirements.

e) Environmental Stability: Some organic semiconductors may be sensitive to environmental factors such as moisture and oxygen. It's important to consider the environmental stability of the material, especially for applications where devices may be exposed to varying conditions.

f) Cost and Scalability: The cost of production and the scalability of manufacturing processes are critical considerations. Organic semiconductors are often favored for their potential for low-cost and large-area fabrication.

3.4.3 The p -type organic semiconductor material “Pentacene”

Pentacene is a polycyclic aromatic hydrocarbon consisting of five linearly fused benzene rings.

- It is an organic semiconductor that generates excitons upon absorption of ultra-violet or visible light, making it very sensitive to oxidation.
- The extended π-system allows the continuous delocalization of π- electrons and there is a lateral over lapping of pi-electrons between the molecules.

In the context of organic electronics, pentacene is often used as a semiconductor in organic thin-film transistors (OTFTs) and other electronic devices.

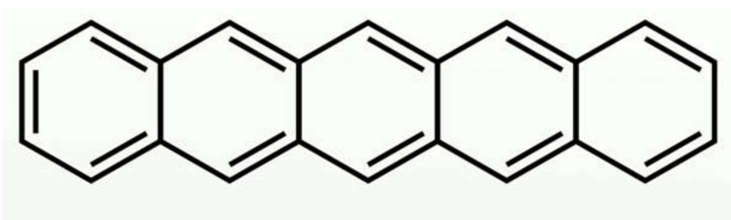


Fig 4.3: Pentacene structure

3.4.4 The n -type organic semiconductor material "Perfluoropentacene"

Perfluoropentacene is a derivative of pentacene where all hydrogen atoms in the pentacene structure are replaced by fluorine atoms. It is used in molecular thin-film devices such as OLEDs.

- The introduction of fluorine atoms can affect the electronic structure and improve certain performance aspects.
- Fluorine substitution is known to enhance stability and alter the molecular packing in films, potentially leading to improved charge transport properties.

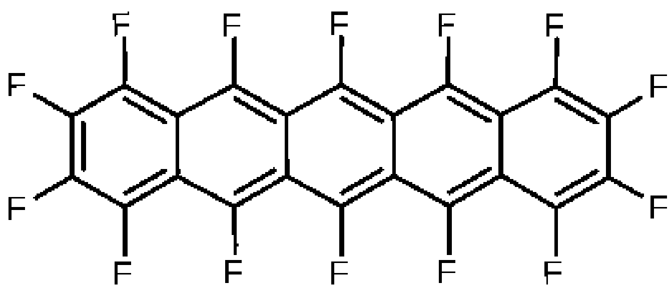


Fig 4.4: Perfluoropentacene

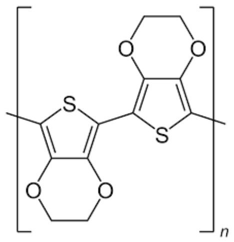
3.5 Polymeric material for Organic memory device

Polymeric materials are commonly used in organic memory devices due to their unique properties, such as flexibility, processability, and the ability to tailor their electronic properties.

Poly(3,4-ethylenedioxythiophene): Polystyrene Sulfonate (PEDOT:PSS):

Example (1) PEDOT: PSS is a conductive polymer blend commonly used in organic electronic devices. It has been investigated for use in organic memory devices due to its good electrical conductivity and stability. Modifications and optimizations of PEDOT:PSS have been explored to enhance its memory performance.

Example (2) Poly(N-vinylcarbazole) (PVK): PVK is a widely studied polymer in organic electronics. It has been employed as a host material in organic light-emitting diodes (OLEDs) and as a charge transport layer in organic solar cells. PVK and its derivatives have also been investigated for their potential in organic memory devices.



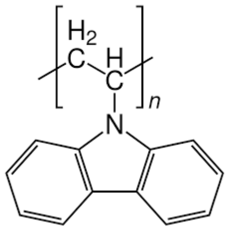


Fig 4.5: (PEDOT:PSS):

PVK

Some more examples as polymers used organic semiconductors

(3) Polythiophenes: Poly(3-hexylthiophene) (P3HT)

(4) Polyfluorenes: Poly(9,9-dioctylfluorene) (PFO)

3.6 Organic-inorganic hybrid materials

Organic-inorganic hybrid materials combine the unique properties of both organic and inorganic components, offering a versatile platform for various applications, including memory devices. These hybrid materials often leverage the organic component for flexibility and processability, while the inorganic component provides enhanced electronic or optical properties.

Generally, organic-inorganic hybrid materials are composed of organic layers containing inorganic materials. Inorganic materials used are allotropes of carbon like fullerenes, carbon nanotubes, graphene and metal nanoparticles, semiconductor nanoparticles and inorganic quantum dots (QDs).

Here are some examples of organic-inorganic hybrid materials used in memory devices:

a) Metal-Organic Frameworks (MOFs):

Example: MOFs incorporating organic ligands and metal ions or clusters.

b) Hybrid Organic Ferroelectric Materials:

Example: Organic ferroelectric polymers combined with inorganic ferroelectric materials.

c) Organic-Inorganic Nanocomposites

These are the hybrid electronic memory devices in which organic polymer with appropriate functional group is clubbed with metal nanoparticles, quantum dots and metal oxide nanoparticles.

An example is a composite of 8-hydroxyquinoline- containing polymer with gold nanoparticle sandwiched between two metal electrodes. Bistable electronic transition states are observed when an electric field is applied due to charge transfer between the Au nanoparticles and 8-hydroxy- quinoline.

3.7 Bio-composite based memory devices

Bio-composite-based memory devices represent a fascinating and emerging area of research at the intersection of materials science, biology, and electronics. These devices leverage bio-inspired or bio-compatible materials to create memory storage components.

a) DNA-Based Memory Devices:

Material: DNA (deoxyribonucleic acid)

Application: DNA has been investigated for use in non-volatile memory devices. DNA strands can be used to store information through sequence variations or by exploiting the inherent charge and structural characteristics of DNA.

Properties: DNA is known for its information-carrying capacity and ability to self-assemble. Researchers are exploring its potential for data storage.

b) Protein-Based Memory Devices:

Material: Proteins, such as bacteriorhodopsin

Application: Bacteriorhodopsin, found in the membranes of certain bacteria, has been explored for use in optical memory devices. It can undergo reversible photochemical reactions, making it suitable for information storage.

Properties: Bacteriorhodopsin exhibits light-sensitive properties, allowing for the creation of bio-composite-based memory devices with potential applications in optical storage.

c) Peptide-Based Memory Devices:

Material: Peptides

Application: Peptide-based materials are being investigated for their potential in resistive switching memory devices. These devices use changes in resistance to store information.

Properties: Peptides offer a wide range of structural and functional diversity, making them attractive for designing novel memory devices.

d) Cellulose-Based Memory Devices:

Material: Cellulose and cellulose derivatives

Application: Cellulose, a natural polymer found in plant cell walls, has been explored for use in flexible and biodegradable memory devices.

Properties: Cellulose-based materials are abundant, renewable, and environmentally friendly. They have potential applications in sustainable and biocompatible memory devices.

3.8 Manufacturing of semiconductor chips

A semiconductor chip is an electric circuit with many components such as transistors and wiring formed on a semiconductor wafer. An electronic device comprising numerous these components is called "integrated circuit". The layout of the components is patterned on a photomask (reticle) by computer and projected onto a semiconductor wafer in the manufacturing processes described below. Entire manufacturing process takes time, from start to packaged chips ready for shipment, at least six to eight weeks.

Fabrication Steps: It is a multiple-step sequence of photolithographic and chemical processing steps (such as surface passivation, thermal oxidation, planar diffusion and junction isolation) during which electronic circuits are gradually created on a wafer made of pure semiconducting material.

Entire manufacturing process can be divided into 8 steps.

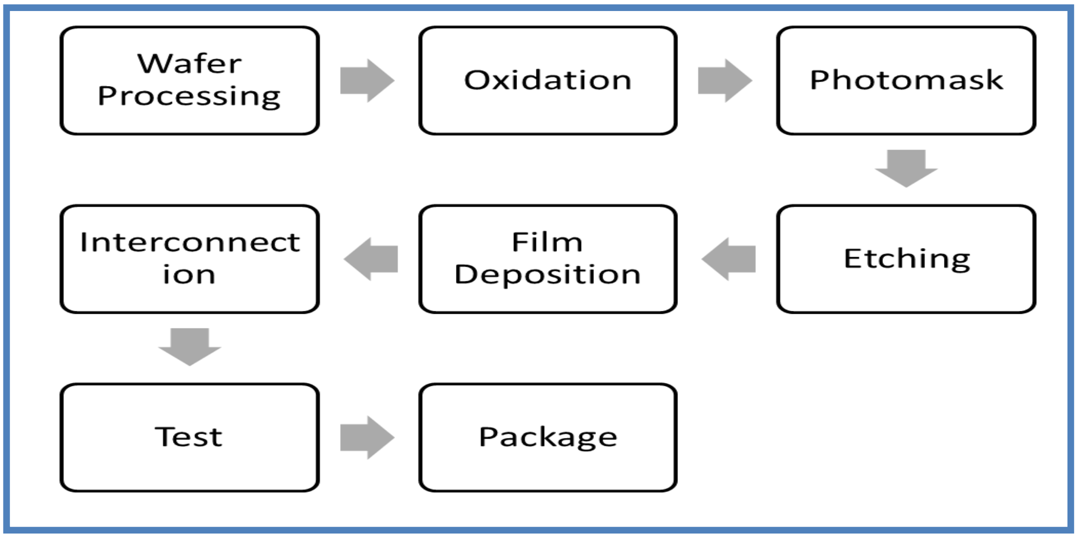
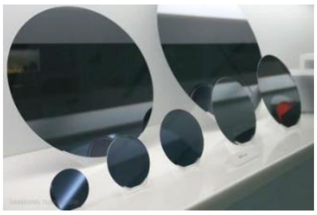


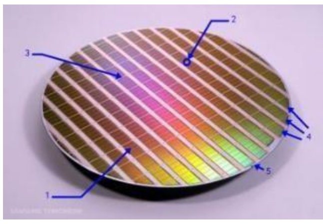
Fig 4.6: Overview of fabrication steps of semiconductor chip

(i) Wafer Processing: A wafer, also called a disc, is a thin round glossy slice of a silicon rod (or Germanium) that is cut using specific diameters for the fabrication of integrated circuits. Most wafers are madeof silicon extracted from sand.

Once silicon is extracted from sand, it needs to be purified before it can be put to use. First, it is heated until it melts into a high-purity liquid then solidified into a silicon rod, or ingot, using common growing methods like the Czochralski (chokh-RAL-skee) process or the Floating Zone process. In these process, a cylindrical ingot of high purity monocrystalline semiconductor, such as silicon or germanium, called a boule, is formed by pulling a seed crystal from a melt. These ingots are then sliced into wafers about 0.75 mm thick. The thin slice obtained through cutting process is called "die" that is an unprocessed "raw wafer". The die surface is uneven and polished to remove surface defects through grinding and chemical etching processes then to smooth surface trough polishing to obtain mirror-smooth finish.The flawless surface allows the circuit patterns to print better on the wafer surface during the lithography process.

Once the wafers are prepared, many process steps are necessary to produce the desired semiconductor integrated circuit. Donor impurity atoms, such as boron, phosphorus, arsenic, or antimony in the case of silicon, can be added to the molten intrinsic material in precise amounts in order to dope the crystal, thus changing it into an extrinsic semiconductor of n- type or p-type.





b) **finished wafer**

Fig 4.7 a) Si wafer

(ii) Oxidation: The role of oxidation process is to form a protective film on the surface of wafer. It can protect the wafer from chemical impurities; prevent leakage current from entering circuit, diffusion during ion implantation and the wafer from slipping off during etching.

(iii) Photomask: A photomask is basically a “master template” of an IC design. Photomask is the use of light to print circuit patterns onto wafer. A photomask is an opaque plate with holes or transparencies that allow light to shine through in a defined pattern. (Previously, photomasksused to be produced manually by using rubylith and mylar).

The wafer is then covered with a light-sensitive coating called 'photoresist'. There are two types of resist: positive and negative. The main difference between positive and negative resist is the chemical structure of the material and the way that the resist reacts with light. With positive resist, the areas exposed to ultraviolet light change their structure and are made more soluble – ready for etching and deposition. The opposite is true for negative resist, where areas hit by light polymerize, meaning they become stronger and more difficult to dissolve. Positive resist is most used in semiconductor manufacturing because its higher resolution capability makes it the better choice for the lithography stage.

(iv) Etching: The next step is to remove the degraded resist to reveal the intended pattern. During 'etch', the wafer is baked and developed, and some of the resist is washed away to reveal a 3D pattern of open channels. Etch processes must precisely and consistently form increasingly conductive features without impacting the overall integrity and stability of the chip structure.

Removal is any process that removes material from the wafer; examples include etch processes (either wet or dry) and chemical-mechanical planarization (CMP).

Wet etching uses chemicals solutions to remove oxide films. In wet etching, the exposed thin film on the surface layer is dissolved using chemicals, such as hydrofluoric acid or phosphoric acid, and removed. This forms the pattern. Advantages are low cost, fast etching speed and high productivity. Wet etching is not suitable for fine circuit diagrams. There is also a dry etching method in which the wafer surface is bombarded with ionized atoms to remove the film layer. Now dry etching **has been widely used for fine circuit diagrams.**

Dry etching has three different types:

Chemical etching -which uses gas (Hydrogen fluoride), physical sputtering-ions in the plasma are used to strike and removethe excess oxide layer **and** Reactive ion etching

(v) Film deposition: To create the micro devices inside the chip, deposit layers of thin films and remove excess parts by etching and add some materials to separate the different devices. Thin film layers of silicon oxide, aluminum and other metals that will become the circuit materials are formed on the wafer. Thin films of conducting, isolating or semiconducting materials – depending on the type of the structure being made are deposited on the wafer to enable the first layer to be printed on it. This important step is commonly known as 'deposition'.

Implantation of Impurities: Once patterns are etched in the wafer, the wafer may be bombarded with positive or negative ions to tune the electrical conducting properties of part of the pattern.

Raw silicon – the material the wafer is made of is not a perfect insulator or a perfect conductor. Silicon electrical properties are somewhere in between. In order to give the silicon substrate semiconducting properties, impurities, such as phosphor or boron ions, are implanted in the wafers.

(vii)Test: The main goal of the test is to check whether the quality of the semiconductor chip meets a certain standard, thereby eliminating the defective products and improving the reliability of the chip. Electronic Die sorting (EDS) is a testing method for wafers.

Once the front-end process has been completed, the semiconductor devices or chips are subjected to a variety of electrical tests to determine if they function properly. The percent of devices on the wafer found to perform properly is referred to as the yield.

(viii) Package: Single wafers are cut into individual chips by cutting. The entire packaging system is divided into five steps. Namely wafer sawing, single wafer attachment, interconnection, molding and packaging.

The entire process of creating a silicon wafer with working chips consists of thousands of steps and can take more than three months from design to production. To get the chips out of the wafer, it is sliced and diced with a diamond saw into individual chips. Cut from a 300- mm wafer, the size most often used in semiconductor manufacturing, these so-called 'dies' differ in size for various chips. Some wafers can contain thousands of chips, while otherscontain just a few dozen.

The chip die is then placed onto a 'substrate'. This is a type of baseboard for the microchip die that uses metal foils to direct the input and output signals of a chip to other parts of a system. And to close the lid, a 'heat spreader' is placed on top. This heat spreader is a small, flat metal protective container holding a cooling solution that ensures the microchip stays cool during operation.

3.9 Display Systems: Photoactive and electro active materials

Photoactive materials, also known as photosensitive or photosensitive materials, are substances that exhibit a change in their properties when exposed to light.
Photoactive materials belong to the huge field of photonics, where materials that actively interact with light are tuned and optimized to achieve effects such as;

- light emission (LEDs and lasers, just to name the most common ones)
- light detection, with related signal amplification (e.g., in photomultipliers) andprocessing operations.
- Alternatively, they can be used to develop light-sensitive circuits and switches (suchas with photoresistors)

Electroactive materials are substances that can undergo reversible changes in their electrical properties when subjected to an external electrical stimulus, such as an electric field or voltage. These materials find applications in various technologies, including sensors, actuators, batteries, and capacitor.

3.10 Materials for display technology

3.10.1 Liquid crystals

Introduction:

Liquid crystals are state of matter which has properties between those of conventional liquids and those of solid crystals. There are many different types of liquid –crystal phases, which can be distinguished by their different optical properties (such as textures).

Liquid crystal (LC) phases represent a unique state of matter characterized by both mobility and order on a molecular and at the supramolecular levels. This behaviour appears under given conditions, when phases with a characteristic order intermediate to that of a three dimensionally ordered solid and a completely disordered liquid are formed. Molecules in the crystalline state possess orientational and three dimensional positional orders. That is the constituent molecules of highly structured solids occupy specific sites in a three dimensional lattice and points their axes in fixed directions as illustrated in Fig.

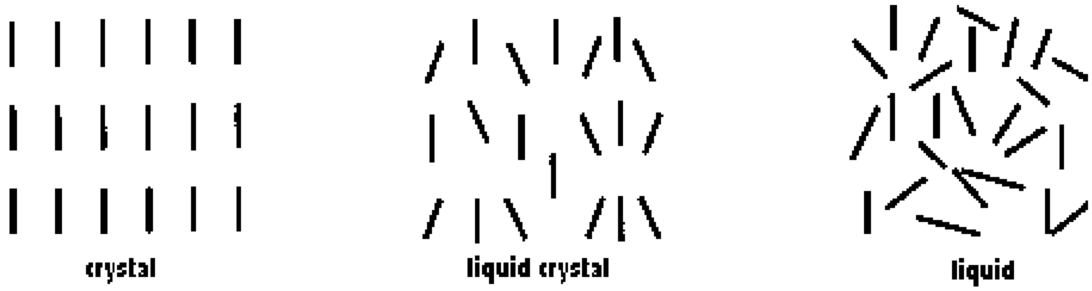


Fig 4.8: Schematic representation of molecular packing in the a) Crystals, b) & c) liquid crystalsand d) liquid state

Liquid crystals are another class of matter in which the extent of molecular ordering is in between highly ordered solid and completely disordered liquid state.

Hence liquid crystals show anisotropy.

Liquid crystal refers to the intermediate status of a substance between solid (crystal) and liquid. When crystals with a high level of order in molecular sequence are melted, they generally turn liquid, which has fluidity but no such order at all. However, thin bar-shaped organic molecules, when they are melted, keep their order in a molecular direction although they lose it in molecular positions. In the state in which molecules are in a uniform direction, they also have refractive indices, dielectric constants and other physical characteristics similar to those of crystals, depending on their direction, even though they are liquid. This is why they are called liquid crystal.

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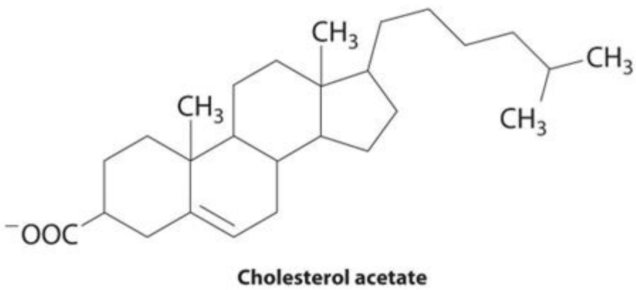
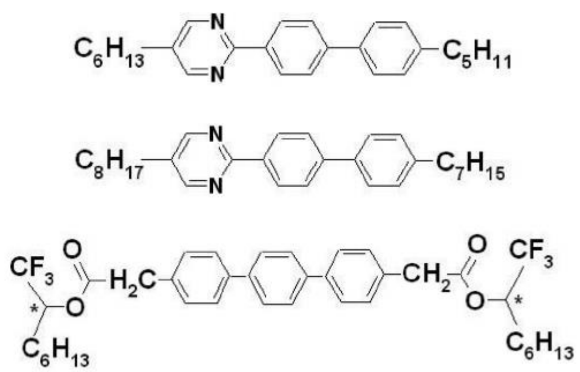


Fig 4.9: An example of liquid crystal molecule

Basic requirements of a liquid crystal

	• Each molecule be elongated in shape and has rigid central part in it. • Each molecule have flexible end

3.10.2 Types of Liquid crystals:

Liquid crystals can be divided into

1) Thermotropic, 2) Lyotropic and 3) Metallotropic.

Thermotropic and lyotropic liquid crystals consist mostly of organic molecules, although a few minerals are also known. Thermotropic LCs exhibit a phase transition into the LC phase as temperature changes.

Lyotropic liquid crystals exhibit phase transitions as a function of both temperature and concentration of molecules in a solvent (typically water).

Metallotropic liquid crystals are composed of both organic and inorganic molecules; their LC transition additionally depends on the inorganic-organic composition ratio.

3.10.3 Application of Liquid crystals in display: Liquid Crystal Display (LCD)

Liquid crystals find wide use in liquid crystal displays, which rely on the optical properties of certain liquid crystalline substances in the presence or absence of an electric field. This field has grown into a multi-billion dollar industry, and many significant scientific and engineering discoveries have been made.

Principle of liquid crystal display

A liquid crystal display (LCD) has liquid crystal material sandwiched between two sheets of glass. Without any voltage applied between transparent electrodes, liquid crystal molecules are aligned in parallel with the glass surface. When voltage is applied, they change their direction and they turn vertical to the glass surface. They vary in optical characteristics, depending on their orientation. Therefore, the quantity of light transmission can be controlled by combining the motion of liquid crystal molecules and the direction of polarization of two polarizing plates attached to the both outer sides of the glass sheets. LCDs utilize these characteristics to display images.

Working principle of an LCD

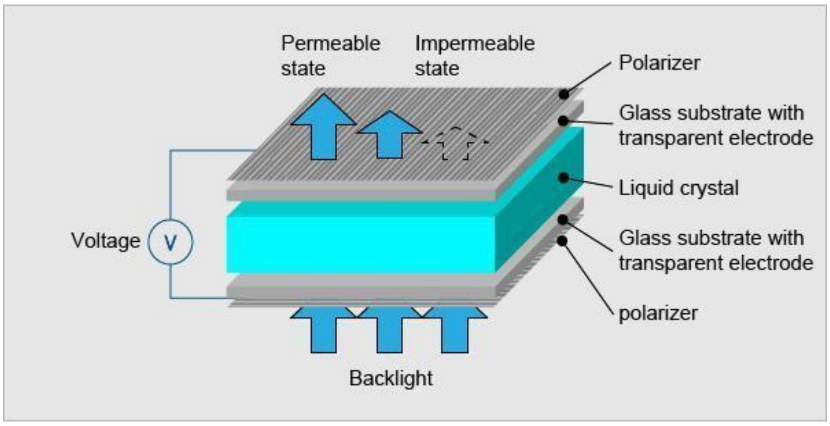


Fig.4.10: Schematic representation of LCD

The working principle of a LCD is based on the optical properties of liquid crystals.

a) LCD consists of a layer of liquid crystal material sandwiched between two transparent electrodes.
b) 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.
c) Polarizing filter is placed in front of and behind the liquid crystal layer to control the orientation of the light passing through it.
d) The LCD also has a backlight, which shines light through the liquid crystal layer to produce an image. The LCD can display images in color by using filters that absorb different colors of light.
e) Each pixel of an LCD contains three sub-pixels that can **produce red, green, and blue colors**. By adjusting the voltage applied to each sub-pixel, the LCD can create millions of different colors.
f) Overall, the working principle of an LCD is based on the manipulation of light using liquid crystals and polarizing filters to create images.
g) The LCD can display images in color by using filters that absorb different colors of light.
h) Each pixel of an LCD contains three sub-pixels that can **produce red, green, and blue colors**. By adjusting the voltage applied to each sub-pixel, the LCD can create millions of different colors.
i) Overall, the working principle of an LCD is based on the manipulation of light using liquid crystals and polarizing filters to create images.

TFT LCD

An LCD consists of many pixels. A pixel consists of three sub-pixels (Red/Green/Blue, RGB). In the case of Full-HD resolution, which is widely used for smartphones, there are more than six million (1,080 x 1,920 x 3 = 6,220,800) sub-pixels. To activate these millions of sub-pixels a TFT is required in each sub-pixel. TFT is an abbreviation for "Thin Film Transistor". A TFT is a kind of semiconductor device. It serves as a control valve to provide an appropriate voltage onto liquid crystals for individual sub-pixels. A TFT LCD has a liquid crystal layer between a glass substrate formed with TFTs and transparent pixel electrodes and another glass substrate with a color filter (RGB) and transparent counter electrodes. In addition, polarizers are placed on the outer side of each glass substrate and a backlight source on the back side. A change in voltage applied to liquid crystals changes the transmittance of the panel including the two polarizing plates, and thus changes the quantity of light that passes from the backlight to the front surface of the display. This principle allows the TFT LCD to produce full-color images.

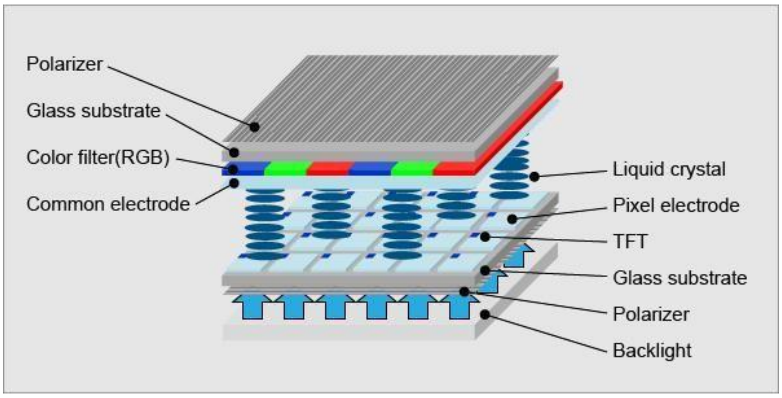


Fig.4.11: Structure of a TFT LCD

3.10.3 Light-emitting diodes (LEDs)

Light-emitting diodes (LEDs) are solid-state devices that use semiconductors and electroluminescence to create light. Essentially, LEDs convert electric energy directly into light, which differs from traditional incandescent lighting, which uses heat energy to generate light, which typically result in a significant waste of energy through heat loss. In comparison, LED technology is often referred to as "cold light technology‟, due to the lower heat output from LEDs, and the fact they don't waste energy in the form of non-light producing heat.

LED technology should not be confused with LCD (liquid crystal display) technology. LED screens are a completely different technology to LCD screens.

Advantages of LEDs:

1. Very low voltage and current are enough to drive the LED.
   Voltage range – 1 to 2 volts. Current – 5 to 20 milliamperes.
2. Total power output will be less than 150 milliwatts.
3. The response time is very less – only about 10 nanoseconds.
4. The device does not need any heating and warm up time.
5. Miniature in size and hence lightweight.
6. Have a rugged construction and hence can withstand shock and vibrations.
7. An LED has a lifespan of more than 20 years.

3.10.4 Organic light emitting diode (OLED)

Organic light emitting diode: Organic Light Emitting Diode popularly known as OLED is a solid-state device that consists of thin films of organic molecules that generate a bright light on the application of electric current. They are made by a series of organic thin films placed between two conductors.

Construction: The multilayer stack consists of a hole injection layer (HIL), a HTL, an electron-blocking layer (EBL), an emission layer (EML), a hole-blocking layer (HBL) andan electron transport layer (ETL). The various blocking and transport layers ensure effective injection of electrons and holes, as well as their subsequent transport to the EML, where they recombine radiatively. The iridium complex is a phosphorescence emitter that allows for highly efficient emissions by harvesting the energy of both singlet and triplet excitons.

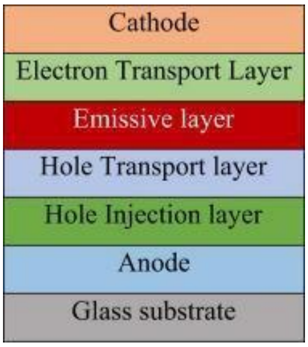


Fig.4.12: The general structure of a multilayer OLED

Working of OLED

(i) When a voltage is applied across the OLED, a current flow through the device and into the emissive layer.

(ii) As the current passes through the emissive layer, the organic molecules become excited and move to a higher energy state.

(iii) When they return to their original energy state, they release energy in the form of photons, which create the visible light that we see.

OLED technology advantages:

- **Flexible:** It is possible to make OLED displays flexible by using the right materials and processes.
- **Very thin:** OLED displays can be made very thin, making them very attractive for televisions and computer monitor applications.
- **Colour capability:** It is possible to fabricate OLED displays that can generate all colours.
- **Power consumption:** The power consumed by an OLED display is generally less than that of an LCD when including the backlight required. This is only true for backgrounds that are dark, or partially dark.
- **Bright images:** OLED displays can provide a higher contrast ratio than that obtainable with an LCD.

3.10.5 Light-emitting electrochemical cell (LEC)

The light emitting electrochemical cell (LEC) is a newly invented illumination technology. The LEC was invented by Pei and co-workers in 1995. The LEC is a solid-state thin-film device, which comprises an active material sandwiched between a cathode and an anode (p-n junction doping structure) as its key constituent parts. Those large-area devices emit light when powered by a battery. LEC can be thin, flexible, and light-weight and be driven to essentially any emission color by the low voltage of a battery. It can also be extremely low cost, since it can be fabricated with low-cost printing and coating methods similar to how newspapers are fabricated.

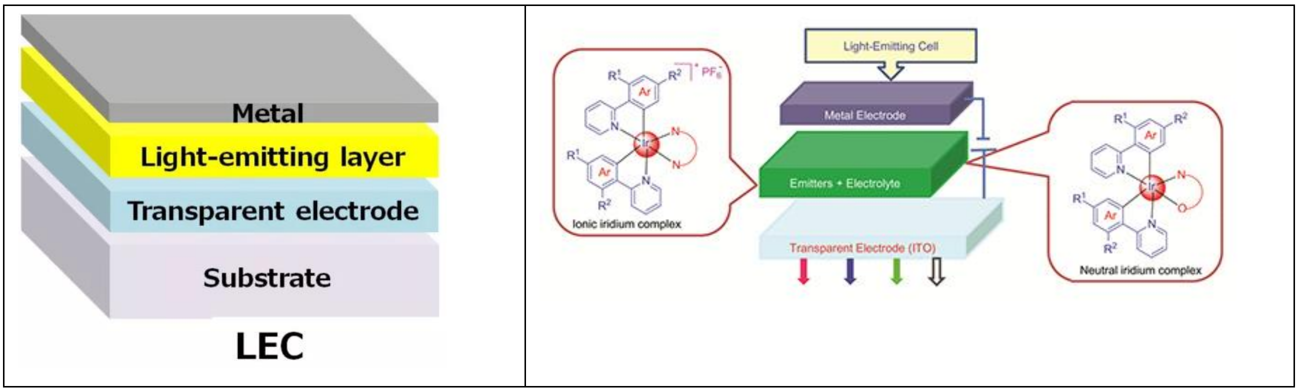


Fig.4.13: Structure of Light-emitting electrochemical cell

An active-material film sandwiched between two charge-injecting electrodes, one of which must be transparent in order to let the light generated in the active material escape the device structure, as schematically shown in Figure. The active material contains a mixture of a semiconducting and luminescent conjugated compound and mobile ions, and when a sufficiently large voltage is applied between the two electrodes, an electrochemical doping process is initiated in the active material. Eventually, light-emission is generated within a thin layer, the p-n junction zone, in the active material.

LECs contain ionic compounds in the light-emitting layer, have attracted considerable interest for their solid-state lighting and next generation display applications. Compared with conventional organic light-emitting diodes (OLEDs), LECs contain simple device architecture (generally only one light- emitting layer), and can use air-stable metals (e.g. Al, Ag and Au) as the cathodes directly. In particular, LECs based on ionic transition metal complexes (iTMCs) have received more attention because of their several advantages over conventional polymer-based LECs.

Solid-state light-emitting electrochemical cells (LECs) show the advantages of a simple fabrication process, low-voltage operation, and compatibility with inert electrodes. Employment of air-stabile materials for both electrodes and the use of a thick and uneven active material and hence cost-effective all-ambient solution-based fabrication of LEC devices.

The operation of a light-emitting electrochemical cell

The LEC differs from the OLED by the presence and action of mobile ions. These ions are intermixed with a luminescent organic semiconductor in the active material, which is sandwiched between an anode and a cathode. The organic semiconductor is characterized bya highest occupied molecular orbital (HOMO), a lowest unoccupied molecular orbital (LUMO), and an energy gap between the LUMO and HOMO. The energy gap defines the emission colour of the luminescent organic semiconductor.

When a voltage is applied between the cathode and anode, the mobile ions (being positive cations and/or negative anions) redistribute within the active material toward the electrode/active material interfaces (Figure). The cations and anions form electric double-layers (EDLs) at the cathodic and the anodic interfaces, respectively. These EDLs will screen the bulk of the active material from (most of) the external voltage and confine a large electric field within the EDLs. If the applied voltage is equal to, or larger than, the energy gap of the organic semiconductor, the high electric fields in the EDLs will facilitate for balancedelectron and hole injection into the LUMO and HOMO levels, respectively, of the organic semiconductor.

The initially injected electrons and holes are electrostatically compensated by a further redistribution of the mobile ions in order to preserve electroneutrality in the bulk of the active material. At the cathode, the electrons injected on the organic semiconductor will be compensated by cations and at the anode; the injected holes will be compensated by anions (Figure 4(a)). This process is termed electrochemical doping, specifically n-type doping at the cathode and p-type doping at the anode, and the organic semiconductor increases its conductivity significantly during the doping process. With time, the highly conducting p- andn-type doping regions grow in size and eventually make contact under the formation of a p-n junction. Subsequently injected electrons and holes can recombine at the p-n junction under the formation of electron-hole pairs (excitons), which can either decay radiatively (as light) or nonradiatively (as heat).