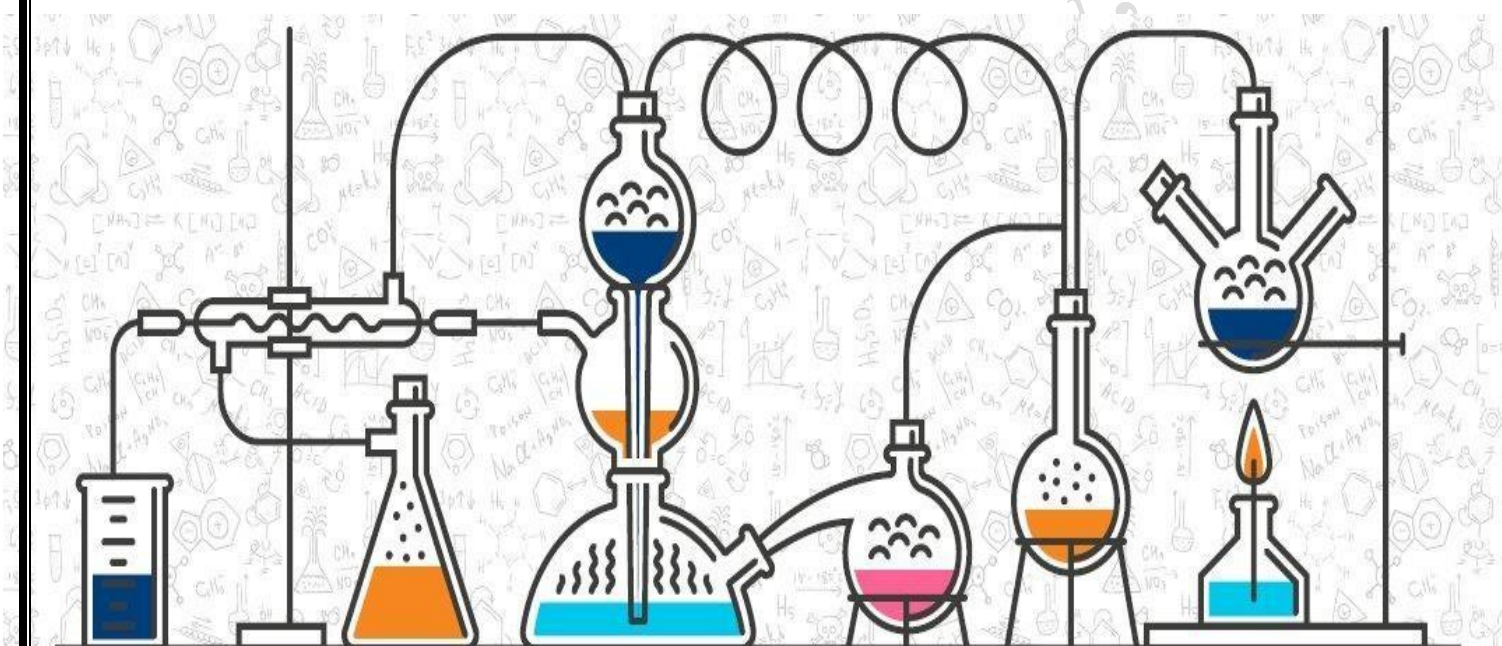
APPLIED CHEMISTRY- CS Stream

I / II SEMESTER (22CHES12/22)

Materials for Memory and Display Systems



DAYANANDA SAGAR COLLEGE OF ENGINEERING

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MODULE- 5
Materials for Memory and Display Systems

Introduction to Memory Devices:
Definition: 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 general, data storage technologies consists of ferroelectric random access memory (FeRAM), magnetoresistive random access memory (MRAM), phase change memory (PCM), and organic/polymer memory have appeared on the scene of the information technology industry.

Basic Concepts of Electronic Memory
- In conventional silicon-based electronic memory, data are stored based on the amount of charge stored in the memory cells. ROM consists of Metal-oxide semiconductor (MOS) and and bipolar transistors.
- RAM – is a volatile memory, which can be a Static (SRAM), Dymanic (DRAM), or Resitive (RRAM),
    - RAM- static RAM (SRAM), which uses several transistors per memory cell, and dynamic RAM (DRAM), which uses a transistor and a capacitor per cell. Transistor modulates the signal and the capacitor stores the memory which is a volatile memory.
    - RRAM- resistive RAM consists of only resistor type device which works by changing the resistance across a dielectric solid-state material. These have electrical bistability based on the ON and OFF states.
- 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. This electrical bistability of materials arising from changes in certain intrinsic properties, such as magnetism, polarity, phase, conformation and conductivity, in response to the applied electric field.
- The advantages of organic and polymer electronic memory include good processability, molecular design through chemical synthesis, simplicity of device structure, miniaturized dimensions, good scalability, low-cost potential, low-power operation, multiple state properties, 3D stacking capability and large capacity for data storage.

Classification of Electronic memory device- Based on storage type

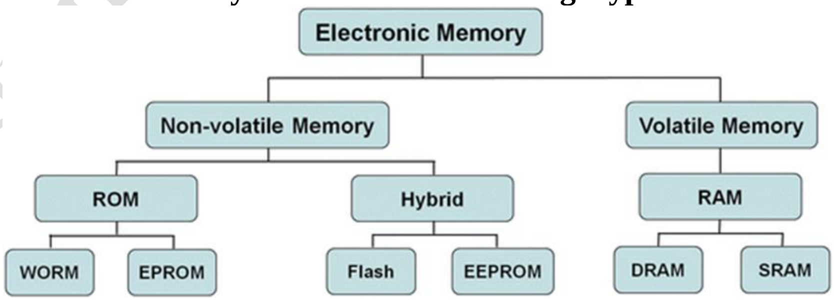


Fig. Classification of electronic memory devices based on storage type.

- According to the storage type of the device, electronic memory can be divided into two primary categories: volatile and non-volatile memory.
- Electronic memory can be further divided into sub-categories, as read only memory (ROM), hybrid memory, and random access memory (RAM).
- ROM is factory programmable only; data is physically encoded in the circuit and cannot be programmed after fabrication.
- RAM- Volatile memory eventually loses the stored information unless it is provided with a

constant power supply or refreshed periodically with a pulse. RAM requires the stored information to be periodically read and re-written, or refreshed, otherwise the data will be lost.

- Hybrid memory allows data to be read and re-written at any time.
- Among these types of electronic memory,
  (a) write-once read-many-times (WORM) memory,
  (b) erasable programmable read only memory (EPROM),
  (c) electrically erasable programmable read only memory (EEPROM)
  (b) hybrid non-volatile and rewritable (flash) memory,
  (c) static random access memory (SRAM) and
  (d) Dynamic random access memory (DRAM) are the most widely reported polymer memory devices.

Classification of electronic memory devices- Based on Device structure

According to the device structure, electronic memory devices can be divided into three primary categories: transistors, capacitors and resistors. With their respective ability to amplify electronic signals, to store charges, and to produce proportional electric currents, electronic memory devices can be constructed from transistors, capacitors and resistors.

1. Transistor – type electronic memory device

- Transistor-type memory devices are a type of electronic memory that uses transistors to store information.
- It is composed of three main components: source, drain and gate electrodes, a dielectric insulator layer and an active semiconductor layer for amplification of electronic signal
- Organic (including polymer) transistors are also of great potential for memory applications Organic field-effect transistor (OFET)
- In a transistor-type memory device, each transistor represents one bit of information, which is a 0 or a 1. When a transistor is turned on, it represents a 1, and when it's turned off, it represents a 0.
- One popular type of transistor-type memory is Dynamic Random Access Memory or DRAM

2. Capacitor - type electronic memory device

- Capacitors can store charges on two parallel plate electrodes under an applied electric field.
- In a capacitor-type memory device, each capacitor represents one bit of information, which is a 0 or a 1.
- When a capacitor is charged, it represents a 1, and when it's discharged, it represents a 0.
- One popular type of capacitor-type memory is Ferroelectric Random Access Memory or FeRAM which is used in some specialized applications.

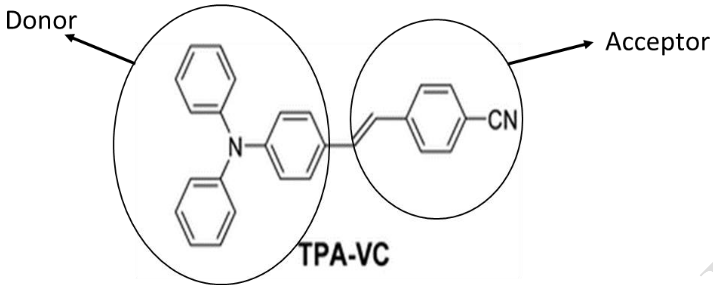
3. Resistor - type electronic memory device

- Resistor-type memory devices are a type of electronic memory that uses resistors to store information.
- In a resistor-type memory device, each resistor represents one bit of information, which is a 0 or a 1.
- The resistors are arranged in a particular pattern to store the information.
- Resistor-type memory devices store data in an entirely different form, for instance, based on different electrical conductivity states (ON and OFF states). Electrical bistability usually arises from changes in the intrinsic properties of materials.
- Unlike transistor and capacitor memory devices, resistor-type memory does not require a specific cell structure.
- One popular type of resistor-type memory is Programmable Read-Only Memory or PROM

Types of Organic-Based Electronic Memory Devices

Organic Molecules:

- Organic electronic memory devices based on organic molecules were first reported in several acene derivatives including naphthalene, anthracene, tetracene, pentacene, perylene kind of molecules. The molecule for the memory device should consist of a Donor- Acceptor in the structure which will help in charge transfer (CT) process electronic switching properties. Eg: D–A structures of triphenylamine as donor and nitril group as acceptor.



- Device consists of organic molecule embedded between ITO and Ag electrodes.
- The device exhibited reproducible electrically switched between the ON state and the OFF state.

Polymeric Materials:

- Polymeric materials have advantage over the small organic molecules due its good solution processability, high thermal stability and mechanical strength.
- The molecular structure of polymeric materials can be tailored using electron donors and acceptors of different strengths, spacer moieties and functional group to induce different switching behaviors for electronic memory applications.
- In D–A structured polymer of phthalimide as the electron acceptor, and triphenylamine as electron donors can be used as electrical memory applications. These materials have better charge transfer (CT) complex.
- The Al/polymer/ITO device exhibits dynamic random access memory (DRAM) behaviour with an ON/OFF current

Organic–Inorganic Hybrid Materials

- Generally, organic–inorganic hybrid materials are composed of organic layers containing fullerenes, carbon nanotubes, graphene, metal nanoparticles, semiconductor nanoparticles or inorganic quantum dots (QDs).
- Organic–Carbon Allotrope Hybrid Materials: Fullerene and its derivatives possess high electron-withdrawing ability, and are able to capture up to six electrons. For organic electronic memory applications, they have been widely used as electron acceptors to form CT complexes with polymer-containing electron donors, such as thiophene, fluorene, carbazole and aniline derivatives. CNT, single-walled carbon nanotubes (SWNTs), Graphene oxide (GO) nanosheets also used as acceptor materials.

Display system

Definition: Display System means a system for the use of Display Materials. The display systems consists of Photoactive and electroactive materials as the active materials which convert the electrical energy into to light emission.

Photoactive material: materials that changes its properties when exposed to light, often in the ultraviolet or visible region of the electromagnetic spectrum. Example: conducting polymers such as polythiophene, polypyrole and nanomaterials such as TiO_2, ZnS etc.

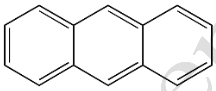
Electroactive materials: An electroactive material exhibits a change in size or shape when stimulated by an electric field. Example: polyacetylene, Barium Titanate, Potassium Niobate etc.

Applications of Photoactive and electroactive materials: Photoactive and electroactive materials belong to the huge field of photonics, where materials that actively interact with light are tuned and optimized to achieve effects such as;

- Convert electrical signal to light- light emission (LEDs and lasers, just to name the most common ones)
- Light detection, with related signal amplification (e.g., in photomultipliers) and processing operations.
- Alternatively, they can be used to develop light-sensitive circuits and switches (such as with photoresistors),
- Convert light into an electrical signal (photodiodes – PV Cells)

<u>**Nano-materials and organic materials used in optoelectronic devices**</u>

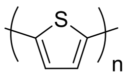
1. **Organic materials as optoelectronic devices:** Organic molecules used as optoelectronic devices: Small molecules and conjugated polymers, the two main types of organic materials used for optoelectronic and photonic devices, can be used in a number of applications including organic light-emitting diodes, photovoltaic devices, etc. Organic molecules having alternative conjugation with planar sp^2 carbon in the backbone structure are basically used for optoelectronic application. These conjugated materials hence, behave as semiconductor materials. Anthracene is one such molecule known for almost a century (1910) possesses alternative conjugation and planar structure.



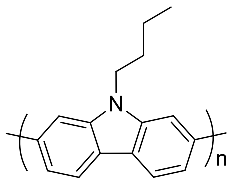
Anthracene

Organic semiconductor materials in general can be separated into two classes: conjugated polymers and small molecules.

Polymers have high molecular weights that result good mechanical and thermal stability, and hence, polymers are advantageous for large-area device fabrications. Example: polythiophene, polycarbazole

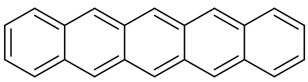


Polythiophene

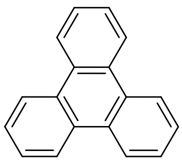


Polycarbazole

Small molecules have advantages in good batch-to-batch repeatability, high crystallinity, and excellent charge carrier mobilities due to strong intermolecular π-π stacking. Example: pentacene, triphelylene



pentacene

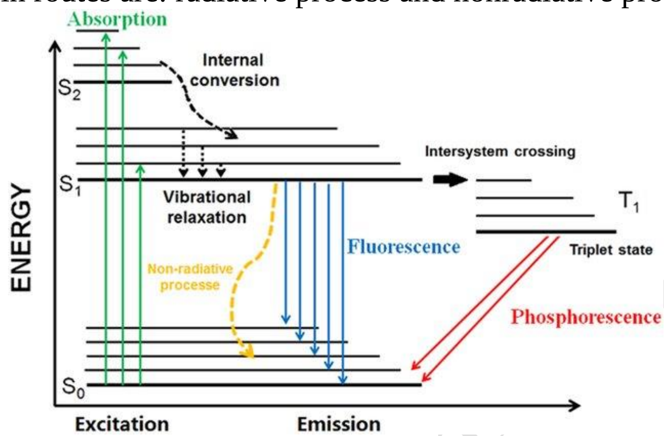


triphenylene

2. **Nano materials as optoelectronic devices**
   - Optical properties such as absorption, transmission, reflection, and light emission are exhibited by nanomaterial.
   - Intrinsic characteristics of nanoparticles such as size, shape, and surface properties determines its applications.

- At a specific wavelength (frequency) of light, the collective oscillation of electrons on the metal nanoparticle surface causes a phenomenon called surface plasmon resonance, which results in a strong extinction of light which makes nanomaterial as materials for optical and optoelectronics applications.
- Metal oxides such as TiO_2 and ZnO and quantum dots such as CdSeS and ZnS are used for optoelectronic applications.

Jablonski diagram: Jablonski diagram is a diagram that illustrates the electronic states and often the vibrational levels of a molecule, and also the transitions between them. Once a molecule has absorbed energy in the form of electromagnetic radiation, there are a number of routes by which it can return to ground state. The two main routes are: radiative process and nonradiative process



Radiative process: It involves the emission of the absorbed energy as radiation or photon.

- Fluorescence: If the photon emission occurs between states of the same spin state (e.g. $S_1 \rightarrow S_0$) this is termed fluorescence. Since the transition is between similar state, it is allowed transition and lifetimes of fluorescent states are very short (1 x 10^{-5} to 10^{-8} seconds).
- Phosphorescence: If the spin state of the initial and final energy levels are different (e.g. $T_1 \rightarrow S_0$), the emission (loss of energy) is called phosphorescence. This a forbidden transition and hence, fluorescence is statistically much more likely than phosphorescence for most molecules. Phosphorescence somewhat longer (1 x 10^{-4} seconds to minutes or even hours; think about glow-in-the-dark flying disks).

Nonradiative process: Three nonradiative deactivation processes,

- Internal conversion (IC): Internal conversion is the radiationless transition between energy states of the same spin state (compare with fluorescence-a radiative process).
- Intersystem crossing (ISC): Intersystem crossing is a radiationless transition between different spin states (compare to phosphorescence).
- Vibrational relaxation: Vibrational relaxation, the most common of the three--for most molecules, occurs very quickly (<1 x 10^{-12} seconds) and is enhanced by physical contact of an excited molecule with other particles with which energy, in the form of vibrations and rotations, can be transferred through collisions. This means that most excited state molecules never emit any energy because in liquid samples the solvent or, in gas phase samples, other gas phase molecules that are present "steal" the energy before other deactivation processes can occur.

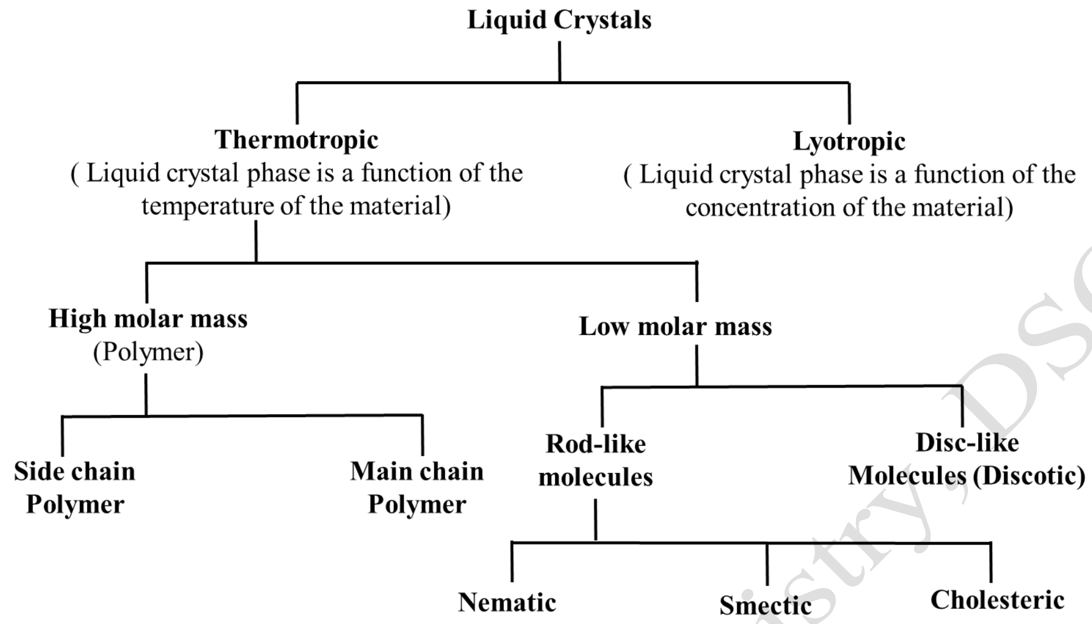
Liquid crystals

Introduction

- LCs are a unique state of matter, between solid (crystalline) and liquid (isotropic) phases some compounds form a distinct, different intermediate phase, sometimes referred to as the “fourth state of matter” or “mesophase”.
- Possess properties characteristics of both crystalline solids and liquids.

- Also possess properties characteristics not found in either solids or liquids.
- May response to external perturbation and some changes colour with temperature

<u>Classification of LC's</u>



Nematic Liquid Crystals: The nematic phase has calamitic or rod-shaped organic molecules that have no positional order. But these molecules tend to self-align in order to have long-range directional order having long axes that are roughly parallel to each other. The molecules of the nematic phase show fluidity that is similar to the fluidity in an ordinary isotropic liquid. However, we can easily align the molecules in this phase through the application of an external magnetic or electric field. When these molecules are aligned into an order, the nematic phase shows optical properties of uniaxial crystals, and therefore, these phases are very useful in liquid crystal displays.

Smectic Liquid Crystals: Smectic liquid crystals are a type of liquid crystals that have well-defined layers of molecules that are able to slide over one another. This behavior is similar to the sliding effects given by soap. Moreover, smectic liquid crystals occur at temperatures lower than that of the nematic liquid crystals. The term smectic originates from the Latin word "smectius" which means "cleaning"; in other words, it means the presence of soap-like properties. Therefore, the smectic phase is positioned in order along one direction.

Cholesteric Liquid Crystals: Cholesteric liquid crystals are a type of liquid crystals made only of chiral molecules. This type of phase shows chirality. Often, we call this phase a chiral phase or a twisted nematic phase due to its chirality. The term cholesteric comes from its first observation where this phase of matter first appeared in cholesterol derivatives. We can observe this type of phase exhibiting a twisting of the molecules, which are perpendicular to the director where the molecular axis is parallel to the director.

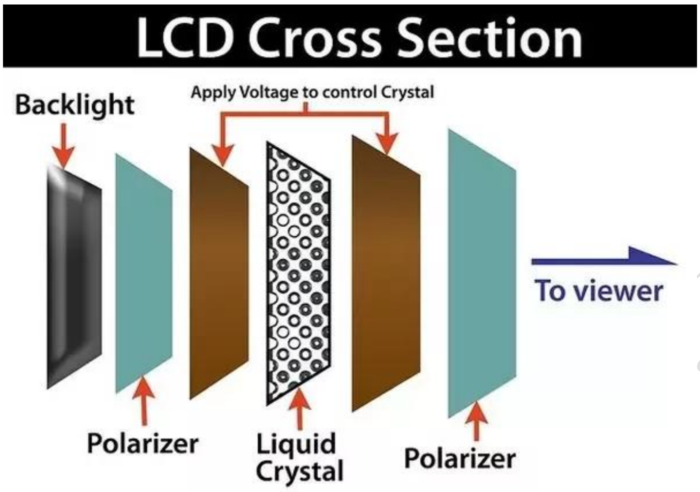
Properties of LC's:

- Liquid crystals can flow like a liquids, due to loss of positional order.
- Liquid crystals is optically birefringent, due to its orientational order
- The intermolecular forces are weak and can be altered by an applied electric field.
- The molecules are polar, they interact with an electric field, which causes them to change their orientation slightly.
- The properties of liquid crystals which make them suitable for use in displays are; their ability to affect the path of plane polarized light upon applied potential.

Applications of Liquid Crystals displays (LCDs.)

Liquid crystal technology has had a major effect many areas of science and engineering, as well as device technology. Example: Liquid Crystal Displays, the most common application of liquid crystal technology is liquid crystal displays (LCDs.)

Principle: The basic working principle of LCD is blocking of light. It does not produce light on its own. So external light source is used. Nematic phase is usually used for LCD.



Working:

- LCD uses background light (backlight) to display the image, and does not produces any independent illumination.
- 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.
- 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.
- A display is made up of millions of pixels. A pixel is made up of three subpixels; a red, blue and green—commonly called RGB. When the subpixels in a pixel change colour combinations, a different colour can be produced.
- With all the pixels on a display working together, the display can make millions of different colours. When the pixels are rapidly switched on and off, a picture is created.

Organic Light Emitting Diodes (OLED's): OLED (organic light-emitting diode), also known as organic LED is a light-emitting diode that emits light when an electric current is passed through its emissive layer. OLEDs use organic materials to emit light, rather than traditional backlighting used in LCD displays. Molecules commonly used in OLEDs include organometallic chelates, fluorescent and phosphorescent dyes and conjugated dendrimers.

The OLED contains three basic layers: the cathode, anode and organic layer. The organic layer consisted of an emissive layer and a conductive layer. When a current is passed through the material, electrons are generated at the cathode, and "holes" are generated at the anode which eventually combine to emit light through fluorescence or phosphorescence method.

Properties of OLED:

- **Self-emissive**: OLEDs are self-emissive, which means that they do not require a separate light source.
- **They are lightweight and flexible**: because they are made of organic materials that are much lighter than the materials used in traditional displays. OLEDs emit light themselves,

meaning that they do not need additional layers of materials to create a backlight. This allows for a thinner and lighter as well as curved display.

- **OLEDs produce high contrast**: OLEDs have a high contrast ration, which means that they can produce deep blacks and bright whites.
- **Vibrant colors:** OLED displays can produce a wider range of colours than traditional displays; they can produce colours more accurately and with more intensity. hence colours appear more vibrant and lifelike, making the better viewing experience.
- **OLEDs are faster and more responsive**: OLEDs have a fast response time, which means that they can switch on and off quickly. They can respond more quickly to changes in the image being displayed. These results in less lag and produce smooth and seamless motion in video content (feel more lifelike and realistic).
- **Wide viewing angle:** OLEDs have a wide viewing angle (typically around 160-180 degrees), which means that the image quality is maintained even when viewed from different angles. As a result, multiple people can view the same display at the same time, even if they are sitting at different angles to the screen.
- **Energy efficiency**: OLEDs are energy efficient. This is because OLEDs are self emissive doesn't rely on a backlight like LCDs, resulting in lower power consumption.
- **Long life span**: OLEDs have a long lifespan, as they do not contain a back light that can degrade over time, resulting in a longer-lasting display

Applications of OLED

- **Televisions and displays**: OLED displays are used in televisions, monitors, smart phones, 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 smart watches 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.

Difference between LCD Vs. OLED:

LCD	OLED
It uses background light to display the image	It uses independent and separate illuminating pixels
LCD screen offers cleaner white colour because it has a strong backlight	The OLED has lower brightness than LCD but has better viewing angles
LCD screen requires the same amount of constant power as the type of image they display	OLED requires less power, their images did not display too much white colour
Not a flexible display system	It is a flexible display system
No Burn-in observed	OLEDs are prone to burn-in

Quantum Light emitting diodes (QLED's): The structure of a QLED is similar to the basic design of an OLED. The major difference is that the light emitting devices are quantum dots, such as cadmium selenide (CdSe) nanocrystals.

In this technology, a layer of quantum dots is placed between electron and hole-transporting layers, like sandwiched structure. Electrons and holes are accumulated in the quantum dot layer by an applied electric field. Then, they will recombine and emit narrow spectrum of photons.

Properties

- **Produces Accurate and vibrant colours**: QLEDs are capable of producing highly accurate and vibrant colours (even more compared to OLED's) 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.
- **High Energy-efficiency**: QLEDs are more energy-efficient than traditional LCD displays because they do not require as much backlighting as LCD's.
- **High contrast:** QLED displays have high contrast ratios, compared to LED's which means that the difference between the darkest and brightest areas of the display is greater, resulting in more detailed and lifelike images.
- **Long life span**: QLEDs have a longer lifespan than traditional LCD displaysbecause they do not suffer from the same issues of backlight burnout or color fading over time. They have longer lifespan even more than OLED's because organic materilas may degrade over a period of time.
- **Faster sponse times**: QLED displays have fast response times, compared to LED's which means that thethey can display fast-moving images without motion blur. 6. Flexibility: QLEDs can be made on flexible substrates, which allows for the creation of flexible displays that can be bent or curved.
- **Virtual and augmented reality and Gaming :** 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.
- **Economical:** QLED displays tend to be more affordable than OLED displays, making them a better choice for consumers who want high-quality displays at a lower cost.

Application of QLED

- **Televisions and displays**: QLED displays are commonly used in televisions, monitors, smart phones, 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.
- **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 and Gaming**: 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 to produce high-quality and eye-catching visuals.

Light emitting electrochemical cells (LEC) - A light-emitting electrochemical cell (LEC or LEEC) is a solid-state device that generates light due to electrochemical reaction. These are made up of light emitting organic molecule undergo either oxidation or reduction when an electric current is applied across it. This leads to the movement of ions leading to the emission of light by these molecules. Generally organic molecules with pi-conjugated systems are generally used in LEC

Properties

- LEC is a simple single layer device. It can emit light from just a single active layer.
- Light emission in these devices is due to movement of ions as a result of electrochemical Redox reaction under applied external field.
- The electrolyte acts as conducting medium as well as oxidiser or reducer. Hence low voltage is sufficient to produce light.

- Since it works by migration of ions than by electron transfer therefore it is cost effective.
- LEC can be printed as a thin film using graphene and carbon nano tube electrodes.

Application of LEC

- They are mainly used as lightning devices
- They can be used in display devices