Materials for Memory and Display Systems

An electronic 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).

For a material to show memory effect in main requirements are;

1. The individual memory cells must possess at least two stable states. In Silicon-based memory devices, data is stored on the base of the amount of charge stored in the memory cells. Memory cells exhibit two charge states which are coded as “0” & “1”.
2. These States must be stable for a period for the data storage.

New organic/polymeric materials exhibit two electrical stable states known as electrical bistability. The shift from one state (ON state) to another state (OFF state) when an external electric field is applied. Therefore, these chemical materials store information in the form of change in their properties under applied electric fields.

Classification of electronic memory devices

1. Transistor:

➔ A transistor-type semiconducting electronic memory device contains a fine electronic circuit, including a complementary metal oxide semiconductor and capacitor (C).

➔ In this electronic circuit, 0 and 1 correspond to the “discharged” and “charged” states of the C respectively.

➔ In comparison to the semiconductor memory device, an organic resistive memory device stores data based on 2 conductivity states. The “low conductivity state” and “high conductivity state” are assigned 0 and 1 respectively.

2. Capacitor:

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

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

➔ Bistable state of a capacitor is based on the amount of charge stored in the cell.

3. Resistor:

➔ This type of memory device uses switchable resistive materials to store data.

➔ It is based on the change of the electrical resistivity of materials in response to an applied voltage.

➔ Electrical bistability arises in these materials due to different electrical resistivity which are assigned ON and OFF States.

4. Charge transfer:

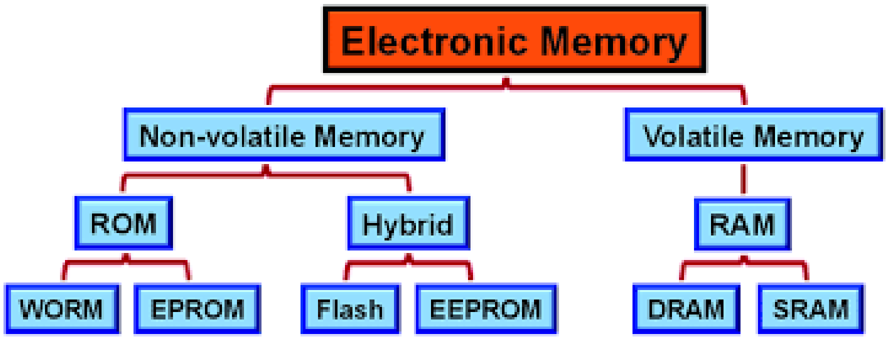
➔ This type of memory device is based on the charge transfer effects of a charge transfer complex.

➔ A charge transfer complex consists of two parts, one electron donor and other an electron acceptor, it is also called donor-acceptor (D-A) complex.

➔ In this complex, a partial transfer of charges occurs from the donor part to the accepter part. This results in a difference in conductivity.

➔ It exhibits bistable states due to differences in conductivity. This behavior is used to design molecular electronic devices.

Classification of electronic memories:



1. Volatile memory: Loses the stored information unless it is provided with a constant power supply.

a. RAM: Stored information to be periodically read and rewritten, otherwise the data will be lost.

- ❖ Dynamic RAM: Stores each bit of data in a separate capacitor within an integrated circuit.
- ❖ Static RAM: It exhibits data remanence, but still stored data is eventually lost when the memory remains in the power-off state.

2. Non-volatile memory: Retain its data when its power supply is switched off.

a. ROM: Data is physically and coded in the circuit and cannot be programmed after fabrication.

- ❖ WORM: Write once, read many times. Example: CD, DVD
- ❖ EPROM: Erasable programmable read only memory.

b. Hybrid: It allows data to be read and re-written at any time.

- ❖ Flash: Its stored data can be reprogrammed and it has the ability to write, read, erase and retain the stored data.
- ❖ EEPROM: Electrical erasable Programmable ROM.

History of Organic/Polymer Electronic Memory Devices:

- ☐ During 1968-70, bistable electrical conductivity and resistivity phenomenon was observed in pb/polydivinyl benzene, tetracene, phthalocyanines and polystyrene polymer materials. all these materials showed bistable switching and memory switching effects. But, the performance was not satisfactory for practical application.
- ☐ During the same period, controlled polymer chain ordering and disordering with respect to electric field was discovered in polymethylmethacrylate, polystyrene, polymethyl methacrylate and poly butyl methacrylate polymer films.
- ☐ In 1980's, two stable ferroelectric polymerization states were discovered in polymers. Thin films of ferroelectric polymer materials can be repeatedly switched between two stables and are capable of exhibiting non-volatile memory effects. but they required a very high operating voltage of 30V.
- ☐ In 1995, ferroelectric polymer films as thin as 1 nm were fabricated. These required just 1V to switch between two states. Since then, polymer ferroelectric random access memory(FeRAM) was developed as a promising memory technology.
- ☐ In 2001, an organic field-effect transistor (OFETs) memory device was demonstrated using an oligomer as conductor and ferroelectric organic polymer material as a gate insulator.
- ☐ In 2003, a WORM type memory device was developed consisting of a thin film p-i-n silicon diode and a mixture of two conductive polymers poly(ethylene dioxythiophene) and polystyrene sulfonic acid.
- ☐ In 2004, ultra thin film organic materials were discovered with multilevel conductivity states.
- ☐ In 2005, multilevel conductance switching films with a continuum of conductance states was reported in TTO device

Types of organic memory devices

There are three classes of materials which can exhibit bistable states and are used in organic memory devices.

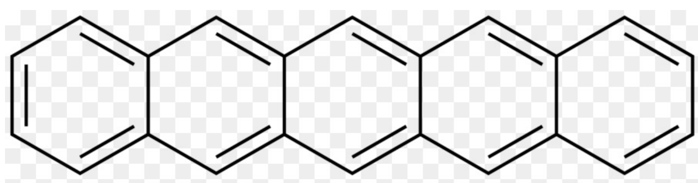
1. Organic molecules
2. Polymeric materials
3. Organic inorganic hybrid materials

1. **Organic molecules**: These are different categories of organic molecules which show bistable and multistable states when an external field is applied. When a threshold voltage is applied they undergo a transition from the “OFF" state to the “ON” state and vice versa. All these materials can be used in organic memory devices.

   a. ***Acene derivatives:*** Acene are the polycyclic aromatic compounds consisting of linearly fused benzene rings. They have high charge carrier mobility.

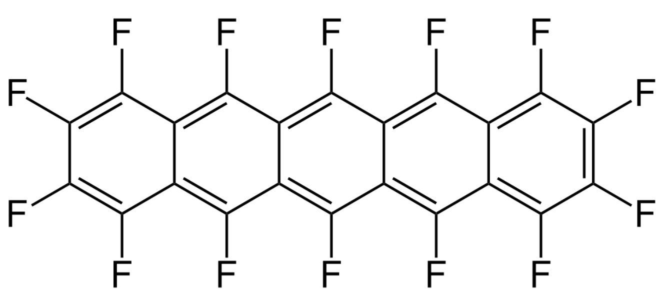
   Examples for acenes are pentacene, perfluoropentane, naphthalene, anthracene, tetracene etc.

   ★ Pentacene is a linearly fused aromatic compound with five benzene rings. It can be obtained in crystal and thin film form. It exhibits a very good hole mobility and hence it behaves as a *p-type semiconductor.*



Pentacene

   ★ When all the hydrogen atoms of pentacene are replaced by fluorine atoms the resulting molecule is perfluoropentane. Strong electron withdrawing nature of fluorine atoms converts this molecule into *n-type semiconductor*.



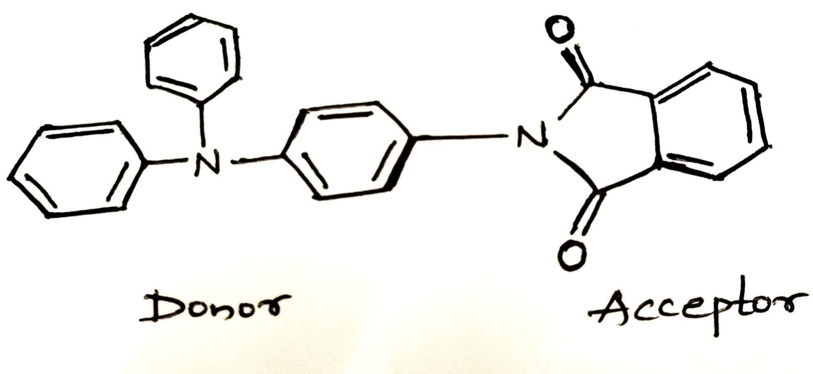
Perfluoropentacene

   ★ Both the molecules exhibit same structure as well as crystal packing but former behaves as p-type semiconductor and latter has an n-type semiconductor. Therefore, these molecules together exhibit charge-transfer processes that are useful for memory applications.

2. Polymer molecules: There are polymers which exhibit memory affect and are used in electronic memory devices.

- ★ *Polyimides (PIs):* PIs are one of the most commonly used polymeric materials for organic electrical memory applications. They have high thermal ability and mechanical strength and can be easily processed from solution.

  In functional PIs, phthalimide acts as the electron acceptor and triphenylamine acts as an electron donor to form a Donor-Acceptor structure. They exhibit two stable charge states under the applied electric field. These states arise due to transfer of electrons from donor to acceptor. This bistability is used to store data in memory devices.



3. Organic inorganic hybrid materials

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).

- ★ organic-carbon allotrope hybrid materials: Polymers containing electron donors such as thiophene, fluorine, carbazole and aniline derivatives can be combined with fullerene to obtain a charge transfer hybrid material with donor-acceptor ability and electrical bistable states. Fullerenes exhibit high electron-withdrawing ability and can capture upto 6 electrons. So they are used in WORM memory effect devices.
- ★ Organic-Inorganic Nanocomposites: These are the hybrid electronic memory device in which organic polymers with functional groups are clubbed with metal nanoparticles, QDs.

  Example: Composite of 8-hydroxyquinoline containing polymers with gold nanoparticles 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-hydroxyquinoline.

Photoactive and electro active organic materials:

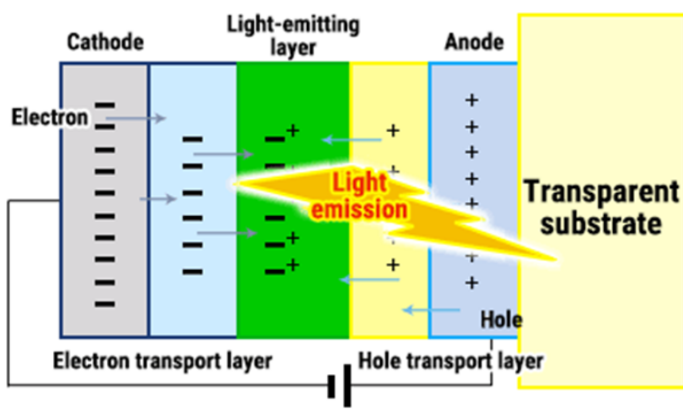
Organic semiconductors used in electronic and optoelectronic devices are called electro active and Photoactive materials. Photoactive and electro active organic materials are the semiconductors composed of π-electron systems.

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 absorbs light and allows an electron to jump from HOMO of a Donor to LUMO of an Acceptor. This phenomenon generates and transports charge carriers.

In an OLED device, the light-emitting layer is excited by the combination 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

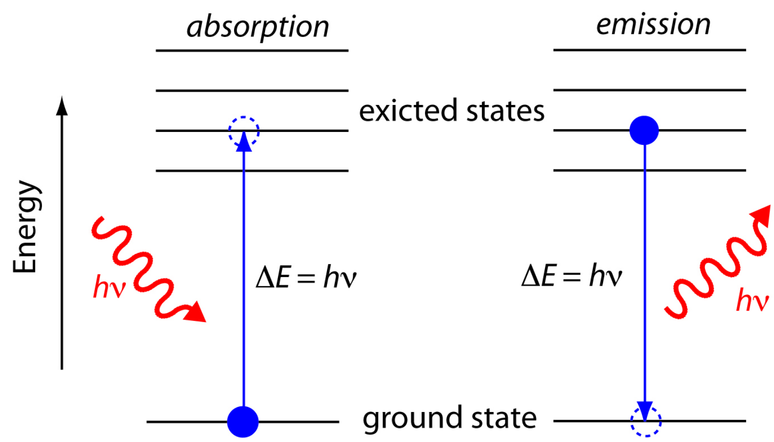
Optoelectronics is the communication between optics and electronics which includes the study, design and manufacture of a hardware device that converts electrical energy into light and light into energy through semiconductors.

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



If the photon has an energy larger than the energy 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 the valence band, extra photon energy is emitted in the form of a light. This principle is used in Optoelectronic devices.

<u>Nano materials (Silicon Nanocrystals) for Optoelectronic devices</u>

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

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

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

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

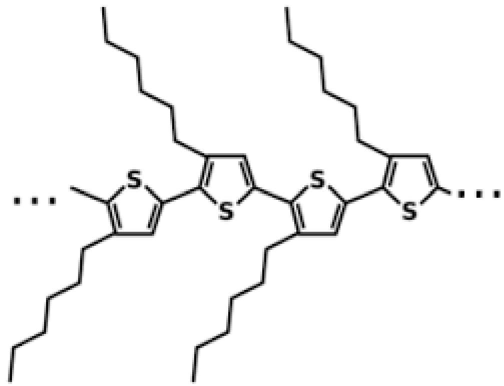
Special properties of Silicon Nanocrystals for optoelectronics

1. Silicon Nanocrystal has wider band gap energy due to quantum confinement.
2. SiNCs shows higher light emission property(Photoluminescence)
3. SiNCs exhibit a quantum yield of more than 60%.
4. Si-NCs exhibit tunable electronic structure
5. Larger surface area - volume ratio

Applications:

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

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



Polythiophenes are an important class of conjugated polymers, environmentally and thermally stable material.

Chemical structure of P3HT (Poly(3-hexylthiophene)) is a polymer with chemical formula $\mathbf{(C_{10}H_{14}S)_n}$.

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 0.33nm) fully extended chains which are oriented perpendicular to the substrate.

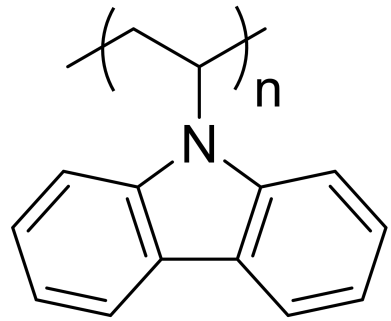
Properties:

1. P3HT is a semiconducting polymer with high stability and exhibits conductivity due to holes therefore considered as p-type semiconductor.
2. P3HT has great capability as light-absorbing materials in organic electronic devices.
3. P3HT has a crystalline structure and good charge-transport properties required for Optoelectronics.
4. P3HT has a direct-allowed optical transition with a fundamental energy gap of 2.14eV.
5. P3HT indicates that an increase in the conductivity is associated with an increase in the degree of crystallinity.

Applications:

- ☐ P3HT 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 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 and stable planar hetero junction Perovskite solar cells.

Applications

- ☐ PVK has been commonly used in OLEDs, light harvesting applications, photo refractive polymer composites and memory devices
- ☐ Used in the fabrication of light- emitting diodes and laser printers.
- ☐ Used in the fabrication of organic solar cells.
- ☐ 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

Definition:

Liquid crystals are distinct states of matter in which the degrees of molecular ordering lie intermediate between the observed crystalline solid state and the completely disordered liquid. The liquid crystal state is also referred to as mesophase.

Liquid crystals are classified into two main categories;

1. Thermotropic liquid crystals
2. Lyotropic liquid crystals

1. Thermotropic liquid crystals: These are compounds which exhibit crystalline behavior on variation of temperature.

The temperature range at which some liquid crystals are stable:

cholesteryl benzoate	145.5^0C to 178.5^0C
p-azoxy phenetole	137^0C to 167^0C
p-azoxyanisole	116^0C to 135^0C

Thermotropic liquid crystals may be further classified as:

a. **Nematic liquid crystals:** Liquid crystals are formed by compounds that are optically inactive. The molecules have elongated shape and are approximately parallel to one another.

   Ex: p-azoxyanisole (PAA) 118^0C-135^0C

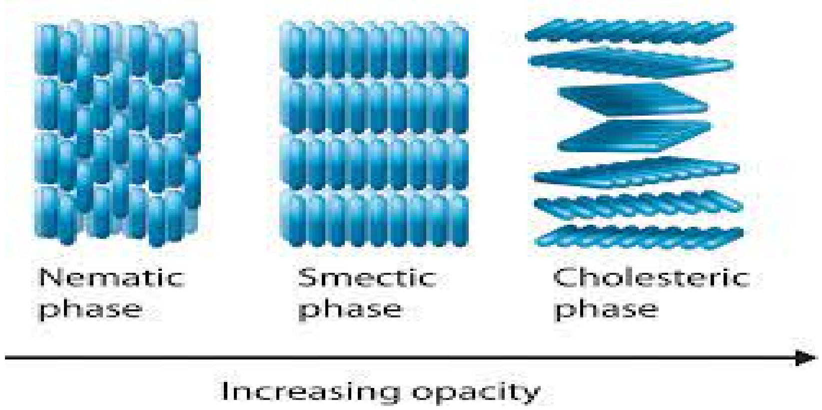
b. **Chiral nematic phase (twisted):** These are formed from optically active compounds having chiral centers. All the molecules are approximately parallel to one another in chiral nematic phase, the molecules arrange themselves so as to form a helical structure.

   Ex: Cholesteryl benzoate

c. **Smectic liquid crystal:** These consist of flat layers of cigar-shaped molecules with their long axes oriented perpendicularly to the plane of the layer.

2. Lyotropic liquid crystals: These are obtained by mixing the compound in a solvent and increasing the concentration of compound till liquid crystal phase is observed.

Ex: Soap (Soap-water mixture) molecules, Phospholipids

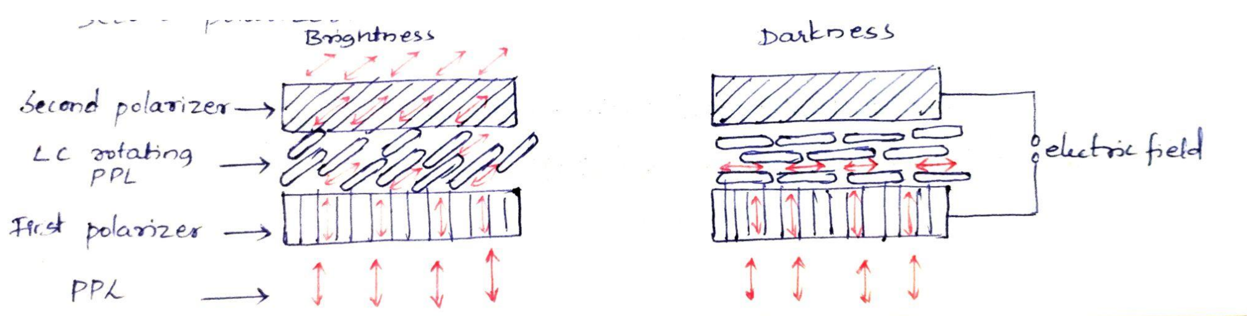


Properties of liquid crystals

1. **Electro-optic effects in liquid crystals:**

Nematic liquid crystals have rod-like molecular structure and align themselves spontaneously along the director. Nematic materials have two dielectric constants- one is parallel and another is perpendicular to the director. Difference between these two dielectric constants is called Dielectric anisotropy. Similarly Nematic materials have two refractive indices- one is parallel and another is perpendicular to the director. This difference is called optical anisotropy.

2. **Effect of electric field:** The director in a liquid crystal is free to point any direction. But when a film of liquid crystal is placed between two plates and an electric field is applied across them, then the director is forced to point along a particular direction. The deformity begins at a threshold value of the applied field and increases with increase in the strength of the field. So it changes in the optical characteristics of the liquid crystal.
3. **Effect of light:** When the plane polarized light passes through 2 crossed polarizers by placing a twisted nematic liquid crystal in between two polarizers. Here, the optically active liquid crystal makes the light pass through 2 inclined polarizers. If an electric field is applied between two polarizers, liquid crystal molecules align themselves in a particular direction. The rotation angle of plane polarized light is also changed and hence light radiation cannot pass through the second polariser.



Thus, the display appears bright in the absence of an electric field and appears dark in the presence of an electric field. This combination of optical and electrical properties of liquid crystals used in LCD.

Advantages

- ➢ It is thin and compact
- ➢ Lower power consumption
- ➢ Less heat is emitted during operation
- ➢ Low cost

Application

- ★ Used in digital wrist watch
- ★ Display images in digital cameras display
- ★ Screen in calculators
- ★ Mainly used in TV
- ★ Used in mobile screens
- ★ Used in video players
- ★ Used in image sensing circuits

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."

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 the ground state, they release energy in the form of photons.

Properties:

1. **Thickness and flexibility**: OLEDs are very thin and flexible, which makes them suitable for use.
2. **High contrast:** OLEDs have a high contract ratio, which means that they can produce deep black and bright white, resulting in images with vivid and rich colors.
3. **Fast responsive time:** OLEDs have fast responsive time, which means that they can switch ON and OFF quickly, resulting in smooth and seamless motion in video content.
4. **Wide weaving angle:** OLEDS have a wide viewing angle, which means that the image quality is maintained even when viewed from different angles.
5. **Energy Efficiency:** OLEDs are energy efficient, as they do not require a backlight like LCD displays resulting in lower power consumption.
6. **Self-emissive**: OLEDs are self emissive, which means that they do not require a separate light source, resulting in a thinner display.
7. **Long lifespan**: As they do not contain a backlight that can degrade over time, resulting in a longer-lasting display.

Applications

1. **TV and displays:** Used in TV, monitors, smartphone etc.
2. **Lighting:** Used as a source of lighting such as street light, automotive lighting and architectural lighting.
3. **Wearable devices:** Suitable for use in wearable devices, such as smartwatches and fitness trackers.
4. **Automotive**: Such as dashboard displays, interior lighting and tail lights.
5. **Medical:** Used in surgical lighting and medical imaging.

Quantum Light Emitting Diodes (QLEDs)

"QLEDs 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

1. Accurate and vibrant colors: QLEDs are capable of producing highly accurate and vibrant colors due to their use of quantum dots, which emit light of a specific color when they are excited by a light source or an electrical current.
2. Energy efficient : QLEDs are more-energy efficient because they do not require as much back lighting.
3. High contrast: QLEDs 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.
4. Fast responsive time: which means that they can display fast moving images without motion blur or ghosting.
5. Flexibility: QLEDs can be made on flexible substrate, which allows for the creation of flexible displays.
6. Long lifespan: QLEDs have a longer lifespan because they don't suffer from the same issues of backlight or color fading over time.

Applications

1. **TV and displays:** Used in TV, monitors, smartphone etc.
2. **Lighting:** Used as a source of lighting such as street light, automotive lighting and architectural lighting.
3. **Virtual and augmented reality**
4. **Advertising display**
5. **Automotive**: Such as dashboard displays, interior lighting and tail lights.
6. **Medical:** Used in surgical lighting and medical imaging.

LIGHT EMITTING ELECTROCHEMICAL CELLS

A light-emitting electrochemical cell (LEC) is an organic molecule containing device which emits light when an electric current is applied across it. Light emission in these devices is due to movement of ions as a result of electrochemical redox reactions.

Properties

1. LEC is a simple single layer device. It can emit light from just a single active layer.
2. Light emission in these devices is due to movement of ions as a result of electrochemical redox reaction under applied external fields.
3. The light emitter in an LEC is immobile and has indirect contact with both electrodes.
4. LEC can be printed as a thin film using graphene and carbon nanotube electrodes.

Application

1. They are mainly used as lighting devices.
2. They can be used in display devices.