

MODULE 4

NANOMATERIALS AND DISPLAY SYSTEMS

Definition: Nanotechnology can be defined as the manipulation of atoms and molecules (one billionth) scale (1-100 nm) to produce devices, structures, or systems with at least one novel or superior property. Materials having at least one dimension in the nanoscale are called **nanomaterials**.

Size dependent properties of nanomaterial's

Materials in the nanometer scale exhibit physical properties distinctively different from that of the bulk material

1. Surface area
2. Electrical properties
3. Optical properties
4. Catalytic properties
5. Thermal properties

Surface Area

1. When a bulk material is subdivided into individual nanomaterials, the total volume remains the same, but the collective surface area is enormously increased.
2. Nanomaterial's have a large proportion of atoms existing at the surface.
3. Properties like catalytic activity gas adsorption and chemical reactivity depend on the surface area.
4. Therefore nanomaterial's can show specific surface related properties that are not observed in bulk materials.

Example: Bulk gold is catalytically inactive, but gold nanoparticles are catalytically very active for selective redox reaction.

Electrical properties

1. Some metals which are good conductor in bulk become semiconductor or insulator as their size is decreased to nano level.
2. The reason is that the electronic bands in bulk material are continuous due to overlapping of orbitals of billions of atoms.
3. Nanomaterial's very few atoms or molecules are present and so the electronic bonds become separate and separation between different electronic states varies with the size of nanomaterial

Optical properties

1. The nanomaterial's of different size can scatter radiation of different wavelengths.

Example: Color of few colloidal solutions are due to this scattering effect.

2. Nano particles of metals exhibit unique optical property called as surface 'Plasmon resonance'.

3. When lights hit the surface of metals particle, electron present on the surface (Surface plasmon) starts oscillating back and forth in a synchronized way in a small space and the effect is known as surface plasmon resonance.

4. Depending on the frequency of oscillation resonating electrons capture radiation of different wavelength.

Catalytic properties

1. The catalytic property of materials depends on particle size.

2. If the size of the particles reduces from bulk to Nano scale, surface to volume increases drastically, that leads to very high catalytic activity of same material.

Example: Catalytic properties of gold nanoparticles. Although bulk gold samples are practically inert, nanometer sized gold particles have been proven to be highly active for several reactions, including

- ☐ Low- temperature oxidation of CO
- ☐ Partial oxidation of hydrocarbons.
- ☐ The water-gas shift reaction.
- ☐ Reduction of nitrogen oxides when dispersed over certain oxides and carbides.

Thermal properties (Melting point)

1. Melting point is defined as the temperature at which the atoms, ions or molecules in a substance have enough energy to overcome the intermolecular forces that hold the them in a fixed position in a solid.

2. As the size of the material decreases to Nano scale, their melting point decreases. Because surface atoms are in contact with only fewer atoms in nanomaterial's and require lesser energy to overcome inter-molecular forces.

Synthesis of nanomaterial's:

There are two approaches to the synthesis of nanomaterials

1. Bottom up synthesis
2. Top-down synthesis

In the bottom-up approach, molecular components arrange themselves into more complex assemblies' atom-by-atom, molecule-by-molecule, cluster-by-cluster from the bottom.

Example: Growth of a crystal

In the top-down approach, Nano scale devices are created by using larger externally controlled devices to direct their assembly. The top-down approach often uses the traditional workshop or micro-fabrication methods in which externally controlled tools are used to cut, mill, shape and order. Attrition and milling for making nanoparticles are typical top-down processes.

Bottom-up approaches, in contrast arrange molecular components themselves into some useful conformation using concept of molecular self -assembly. The bottom -up approach has been well known to the chemists for a long time. This approach plays a very important role in preparing nanomaterials having very small size where the top-down process cannot deal with the very tiny objects.

The bottom-up approach generally produces nanostructure with fewer defects as compared to the nanostructures produced by the top-down approach. The main driving force behind the bottom-up approach is the reduction in Gibbs free energy. Therefore, the materials produced are close to their equilibrium state.

In top-down techniques, significant crystallographic defects can be introduced to the processed patterns.

Example Nanowires made by lithography are not smooth and can contain a lot of impurities and structural defects on its surface.

In spite of the defects, the top-down approach plays an important role in the synthesis and fabrication of nanomaterials. The present state of nanoscience can be viewed as an amalgamation of bottom-up chemistry and top-down engineering techniques.

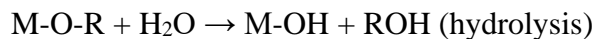
Synthesis by Sol-Gel method

Sol-gel method of synthesizing nanomaterials is very popular amongst chemists and is widely employed to prepare metal oxide nanomaterial.

The sol-gel process can be characterized by a series of distinct steps.

1. Preparation of sol

A stable colloidal solution called sol is prepared. (The sol is a liquid suspension of solid particles ranging in size from 1nm to 1 micron). It is prepared by hydrolysis and partial condensation of precursors such as metal alkoxide.



Metal alkoxide

2. Conversion of Sol to Gel

Further condensation of sol into a three-dimensional network produces a gel material (The gel is a diphasic material in which the solids encapsulate the solvent)



Metal alkoxide

3. Aging of the Gel

The polycondensation reaction continues until the gel transforms into a solid mass accompanied by contraction of the gel networks and expulsion of solvent from gel pores. The aging process of gels can exceed 7 days.

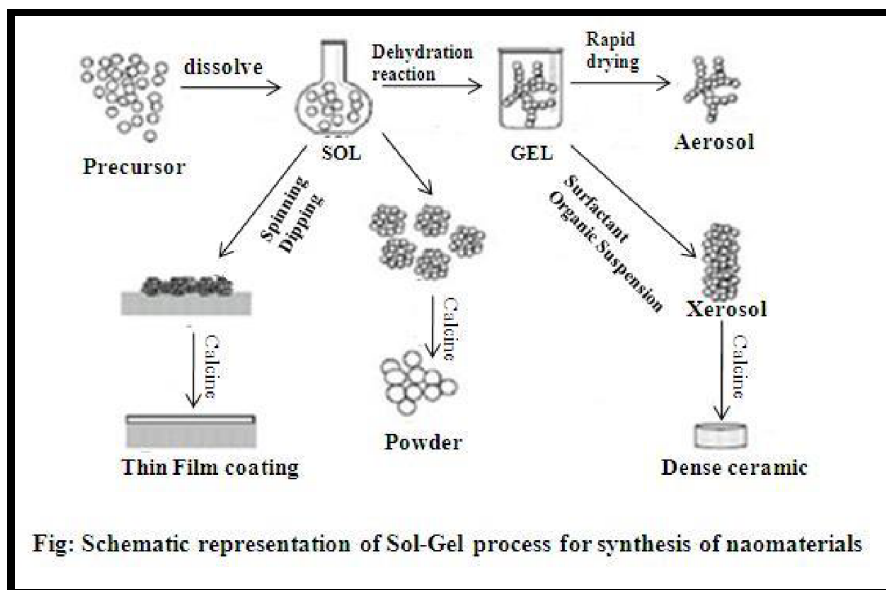
4. Drying of Gel

Water and other volatile liquid are removed from the gel network. If isolated by thermal evaporation, the resulting monolith is termed a Xerogel. If the solvent (such as water) is extracted under critical or near supercritical conditions, the product is an aerogel.

5. Dehydration

To stabilize the gel against any rehydration the surface-bound M-OH groups are removed by calcining(heating) the monolith at a temperature of up to 800°C. The typical steps that are involved in sol-gel processing are shown in the

schematic diagram below.



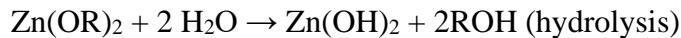
Advantages Sol-gel method

- ☐ Low-temperature route (below 200°C)
- ☐ Uniform particle size distribution
- ☐ Can easily shape materials into complex geometries in gel state

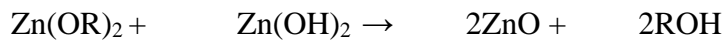
- A simple, effective method to produce high-quality coatings

Example: Synthesis of ZnO NPs by sol-gel method

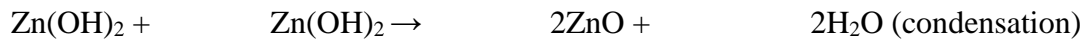
Initially, a stoichiometric amount of Zinc alkoxide ($\text{Zn}(\text{OC}_2\text{H}_5)_2$) was taken as a precursor to prepare the ZnO NPs. In the first step, Zinc alkoxide undergoes the hydrolysis process in presence of water resulting in the formation of zinc hydroxides. Later these zinc hydroxides undergo condensation and polycondensation followed by filtration, number of washings, drying and calcination to obtain zinc oxide nanoparticles.



Zinc alkoxide



Zinc alkoxide Zinc hydroxide Zinc oxide NPs

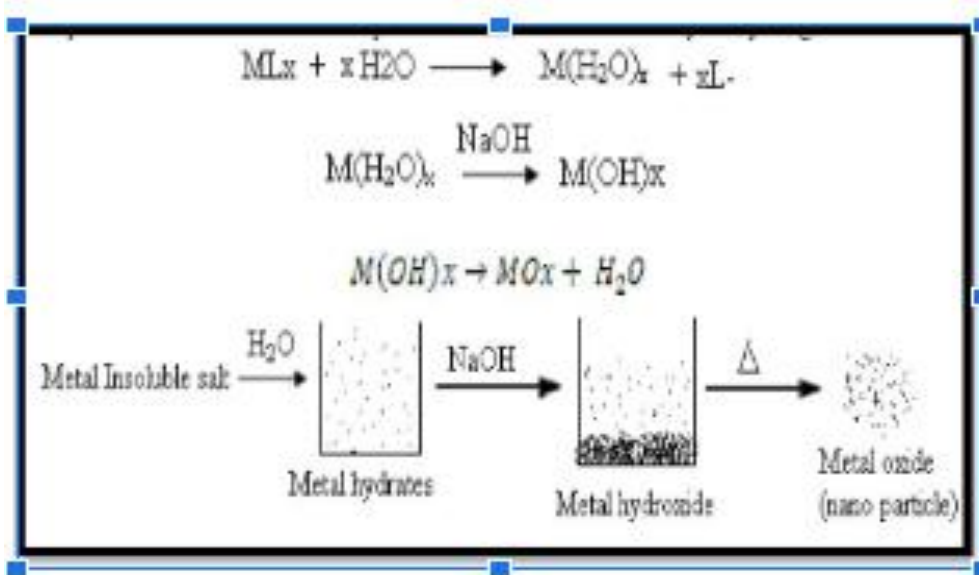


Zinc hydroxide Zinc hydroxide Zinc oxide NPs

2. Co-precipitation method:

- The other commonly used solution method for the synthesis of single or multi-component oxides is the co-precipitation method, which produces a “mixed” precipitate comprising two or more insoluble species that are simultaneously removed from the solution.
- The precursors used in this method are mostly inorganic salts (nitrate, chloride, sulfate, etc.) that are dissolved in water or any other suitable medium to form a homogeneous solution with clusters of ions.
- The solution is then subjected to pH adjustment or evaporation to force those salts to precipitate as hydroxides, hydrous oxides, or oxalates.
- The crystal growth and their aggregation are influenced by the concentration of salt, temperature, the actual pH, and the rate of pH change.
- After precipitation, the solid mass is collected, washed, and gradually dried by heating to the boiling point of the medium.

- The washing and drying procedures applied for co-precipitated hydroxides affect the degree of agglomeration in the final powder and must be considered when nanosized powders are the intended product.
- Generally, a calcination step is necessary to transform the hydroxide into crystalline oxides. In most of the binary, ternary, and quaternary systems, a crystallization step is necessary, which is generally achieved by calcination or, more elegantly, by a hydrothermal procedure in high-pressure autoclaves.



Advantages and disadvantages of Co-precipitation method.

- ☐ Simple and rapid preparation and easy control of particle size and composition
- ☐ Various possibilities to modify the particle surface state and all homogeneity.
- ☐ Low- temperature, Energy efficient, Do not involve use of organic solvent.

Disadvantages

- ☐ Not applicable to unchanged species.
- ☐ Trace impurities may also get precipitated with the product and time consuming.

Example: Synthesis of the magnetite nanoparticles (Co-precipitation method)

Materials required

□ Ferrous chloride tetrahydrate and ferric chloride anhydrous were used as the precursors, Ammonium hydroxide (25 wt. % NH_3 in water) was used as the precipitating agent, Oleic acid and hexanoic acid were used as the coating agents and ethanol was used to remove the excessive coating agent.

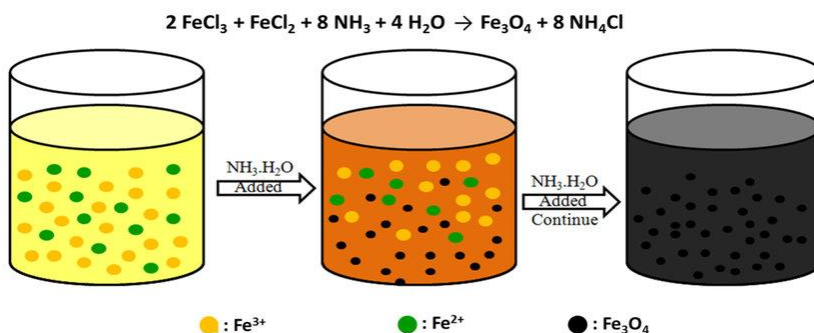
Synthesis of the magnetite nanoparticles

(a) The magnetite nanoparticles were prepared via the chemical co-precipitation method by the following 1.5 g of $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$ and 3.0 g of FeCl_3 , with the molar ratio of ferric ion to ferrous ion in the solution of 2.45, were dissolved in 100 ml of deionized water under a nitrogen gas flow with vigorous stirring at various temperatures (0–90 °C).

(b) A 10 ml of 25 wt% NH_4OH (excess base concentration) and various concentrations of the coating agents (oleic acid or hexanoic acid at concentrations between 0.2 and 1.0%, v/v) were added to the solution, then the solution color changed from orange to black rapidly.

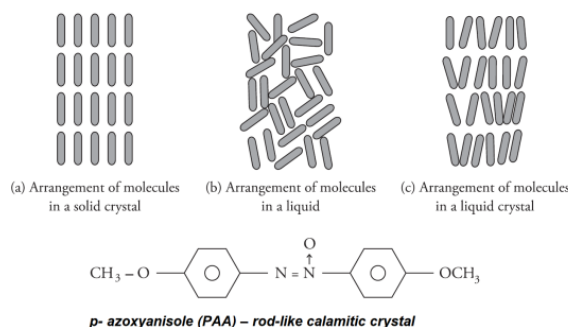
(c) The coated magnetite nanoparticles were filtered and thoroughly washed with deionized water to remove chloride ions and then washed with ethanol several times to remove excess coating agent, and finally dried in a vacuum at 80 °C for 24 h.

(d) The bare magnetite nanoparticles were prepared by the same procedure except without the coating agent and ethanol.



Liquid crystals:

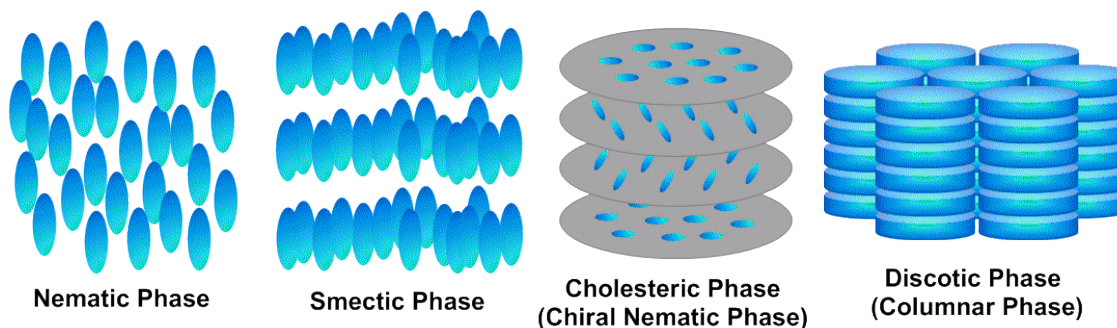
Liquid crystals are a unique phase of matter that exhibit properties of both liquids and solids. They are made up of rod-shaped or disk-shaped molecules that have a high degree of orientation but are still able to flow like a liquid. The orientation of the molecules can be manipulated by external stimuli such as electric or magnetic fields, temperature, or pressure, allowing for control over their optical properties.



Ex: Cholesteryl benzoate behaves like a liquid crystal in the temperature range of 145 °C to 178 °C and less than 145 °C behaves as a pure solid and beyond 178 °C behaves as a pure liquid. Similarly, between 116 °C and 135 °C *p*-azoxyanisole behaves as liquid crystal

Classification:

Liquid crystals can be classified into different types based on their molecular structure, orientation, and properties. Here are some common classifications of liquid crystals:



- **Nematic Liquid Crystals:** Nematic liquid crystals are the most common type of liquid crystal. They have a long, slender, rod-like molecular structure, and their *molecules are oriented in a parallel fashion, but without any positional order*. Nematic liquid crystals exhibit a characteristic birefringence or double refraction of light.
- **Smectic Liquid Crystals:** Smectic liquid crystals have a layered structure in which the *molecules are arranged in parallel layers with slight positional order* and have their natural degree of orientation. They exhibit a variety of subphases based on the degree of order and orientation such as smectic A, B and C.
- **Cholesteric Liquid Crystals:** Cholesteric liquid crystals are a type of chiral nematic liquid crystal. They have a twisted structure in which the *orientation of the molecules rotates in a helical pattern*. This rotation of orientation leads to a selective reflection of light that gives these liquid crystals their characteristic iridescence.
- **Discotic Liquid Crystals:** Discotic liquid crystals have a *disk-like molecular structure and are similar to smectic liquid crystals* in terms of their layered structure. These liquid crystals show electrical conductivity due to the delocalization of electrons in their molecular structure.

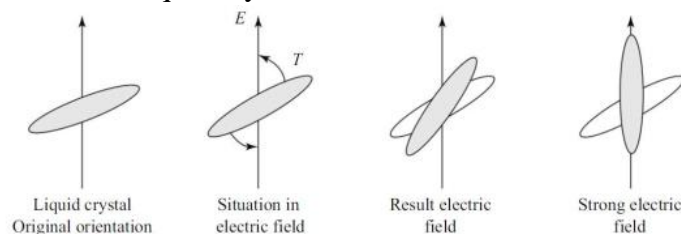
- **Ferroelectric Liquid Crystals:** Ferroelectric liquid crystals have an *electric dipole moment* and exhibit *spontaneous polarization*, which can be switched by applying an electric field. They find applications in display technologies, including liquid crystal displays (LCDs).
- **Polymer Liquid Crystals:** Polymer liquid crystals are formed by the *combination of liquid crystal molecules and polymers*. These materials exhibit improved mechanical properties and processability and find applications in optoelectronic devices.

There are also many other subtypes and variations of liquid crystals, including *antiferroelectric*, *bent-core*, and *blue phases*, which have different structures and properties.

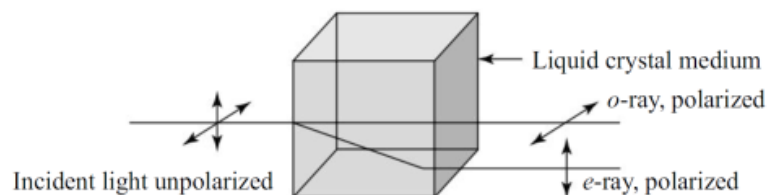
Properties:

Liquid crystals have unique physical and optical properties that make them useful in various applications. Here are some of the key properties of liquid crystals:

- **Anisotropy:** Liquid crystals exhibit anisotropic properties, meaning they have different physical and optical properties in different directions. This anisotropy is due to the molecular orientation of the liquid crystal molecules.



- **Birefringence:** Liquid crystals have birefringent properties, meaning they can split a single light beam into two beams with different polarizations. This property is used in optical applications, including polarizers and liquid crystal displays (LCDs).



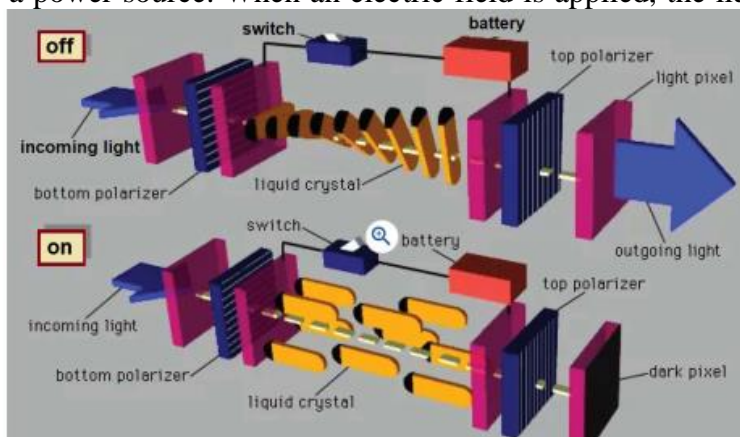
- **Viscosity:** Liquid crystals have a high viscosity, which means they flow slowly like a liquid but have some properties of a solid, such as resistance to deformation.
- **Optical Activity:** Chiral liquid crystals can exhibit optical activity, which means they rotate the plane of polarized light as it passes through the material. This property is used in applications such as cholesteric liquid crystal displays.
- **Electric Field Response:** Some types of liquid crystals, such as ferroelectric and twisted nematic liquid crystals, exhibit an electric field response, meaning they can be switched between different orientations by applying an electric field.
- **Temperature Sensitivity:** Liquid crystals can exhibit temperature sensitivity, with their physical and optical properties changing as the temperature changes. This property is used in applications such as thermometers and thermostats.

Application in Liquid Crystal Displays (LCD's)

Liquid crystal displays (LCDs) are widely used in electronic devices such as televisions, computer monitors, and mobile phones. The technology relies on the optical properties of liquid crystals to selectively control the transmission of light through a display.

In an LCD, a thin layer of liquid crystals is sandwiched between two transparent electrodes, and the electrodes are connected to a power source. When an electric field is applied, the liquid crystal molecules align themselves along the direction of the electric field, changing the orientation of their polarization, and this in turn modifies the optical properties of the liquid crystal.

A backlight behind the LCD panel shines light through it. The liquid crystal layer selectively blocks or transmits the light, depending on the orientation of the liquid crystal molecules. The blocked or transmitted light when it reaches to color filter at different areas result in the LCD can appear either light or dark, creating images and text. Color filters or LCD are made up of millions of pixels and a pixel is made up of three subpixels; red, blue and green—commonly called RGB. When the subpixels in a pixel change color combination, a different color can be produced. With all the pixels on a display working together, the display can make millions of different colors. When the pixels are rapidly switched on and off, a picture is created.



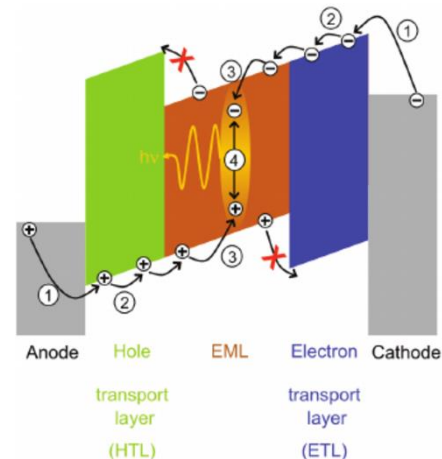
There are different types of LCDs, including twisted nematic (TN) and in-plane switching (IPS) displays. TN displays use a nematic liquid crystal and depend on the degree of twist of the liquid crystal molecules to control the polarization of the transmitted light. IPS displays use a smectic liquid crystal and rely on a more complex switching mechanism to control the polarization.

Organic Light Emitting Diodes

Organic light-emitting diodes (OLEDs) are a type of display technology that uses thin organic films to emit light in response to an electric current. OLEDs are used in a variety of applications, including televisions, mobile devices, and lighting.

The basic structure of an OLED consists of a stack of organic layers sandwiched between two electrodes, an anode and a cathode. The organic layers include a hole transport layer, an emissive layer, and an electron transport layer. The layers are very thin, usually, only a few nanometers thick, and are deposited on a glass or plastic substrate.

When a voltage is applied across the electrodes, an electric current flow through the organic layers, causing the electrons and holes to combine in the emissive layer. This process creates an excited state, and the excess energy is released in the form of light.



Properties:

Organic light-emitting diodes (OLEDs) have a number of properties that make them attractive for a variety of applications, including displays and lighting. Here are some key properties of OLEDs:

- **High contrast:** OLEDs have a very high contrast ratio, meaning that they can produce very dark blacks and very bright whites in the same image, resulting in excellent image quality and clarity.
- **Wide viewing angles:** OLEDs can be viewed from almost any angle without significant color distortion or loss of contrast, making them ideal for large displays and signs.
- **Flexible and thin:** OLEDs can be made on thin and flexible substrates, allowing for new design possibilities and form factors.
- **Low power consumption:** OLEDs consume less power than other display technologies, resulting in longer battery life for portable devices and lower electricity usage for lighting applications.
- **Fast response time:** OLEDs have a very fast response time, meaning that they can display rapidly changing images without blurring or ghosting.
- **High color accuracy:** OLEDs are capable of producing very accurate colors, making them ideal for applications such as photo and video editing, medical imaging, and color-critical industrial applications.
- **Scalable:** OLEDs can be fabricated using a variety of techniques and can be scaled to large areas, making them suitable for use in large displays and lighting applications.

Application of OLEDs:

Organic light emitting diodes (OLEDs) are a type of display technology that is becoming increasingly popular in various applications. Here are some of the main areas where OLEDs are being used:

- **Display panels:** OLED displays are used in various devices, such as smartphones, TVs, and computer monitors. These displays offer high contrast, vibrant colors, and excellent viewing angles.
- **Lighting:** OLEDs are also being used as a lighting source in both commercial and residential settings. OLED lighting panels are thin, lightweight, and highly energy-efficient.
- **Automotive:** OLEDs are used in the automotive industry for both interior and exterior lighting. They provide an innovative and modern look to cars and offer better visibility and safety.
- **Wearable technology:** OLEDs are used in wearable devices such as smartwatches and fitness trackers. They offer brighter and more energy-efficient displays, making them ideal for small devices with limited battery life.
- **Medical devices:** OLEDs are also used in medical devices, such as pulse oximeters and blood glucose monitors. They offer high brightness and low power consumption, making them ideal for portable devices.

Advantages:

- OLEDs is that they can emit light over a wide range of colors, depending on the materials used in the organic layers.
- High contrast, wide viewing angles, and fast response times.
- Very thin and flexible, allowing for a variety of form factors and design possibilities.

Limitation:

- Short lifespan compared to some other technologies.
- Susceptibility to water and oxygen damage.

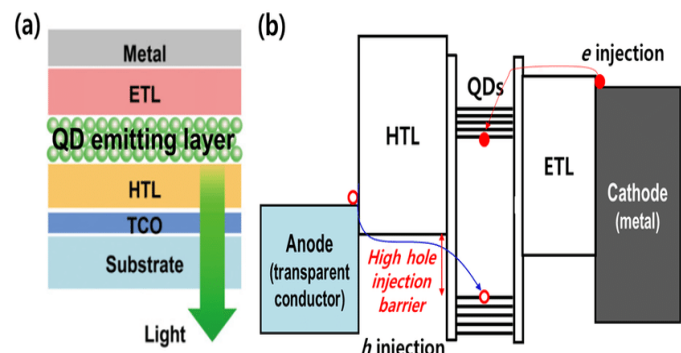
Quantum Light Emitting Diodes (QLEDs):

Quantum light emitting diodes (QLEDs) are a relatively new type of light-emitting diode (LED) that use quantum dots as the emitting layer. Quantum dots are tiny semiconductor particles that have unique optical and electronic properties.

Quantum Light Emitting Diodes (QLEDs) work on the principle of electroluminescence, which is the process of converting electrical energy into light. However, unlike conventional LEDs, QLEDs use quantum dots (QDs) as the emissive layer, which are nanoscale semiconductor crystals that can emit light at specific wavelengths.

Properties:

Quantum light-emitting diodes (QLEDs) have a number of unique properties that make them attractive for various applications. Some of the main properties of QLEDs include:



- **High color purity:** QLEDs can produce pure and vibrant colors because quantum dots can be precisely tuned to emit light at very specific wavelengths. This high color purity makes QLEDs attractive for use in displays and lighting applications.
- **High brightness:** Quantum dots are very efficient light emitters, which means that QLEDs can produce high brightness with low power consumption. This makes QLEDs ideal for use in high-performance displays and lighting systems.
- **Narrow emission spectra:** Quantum dots have a narrow emission spectrum, which means they can produce light at a very specific wavelength. This can be useful for applications such as fluorescence microscopy, where precise control of the emitted light is important.
- **High color tunability:** The color of QLEDs can be easily tuned by changing the size and composition of the quantum dots used. This allows for a wide range of colors to be produced, making QLEDs highly versatile.
- **Long lifetimes:** QLEDs can have long lifetimes, with some devices showing little to no degradation in performance over thousands of hours of operation. This can make them attractive for use in applications where long-term reliability is important.

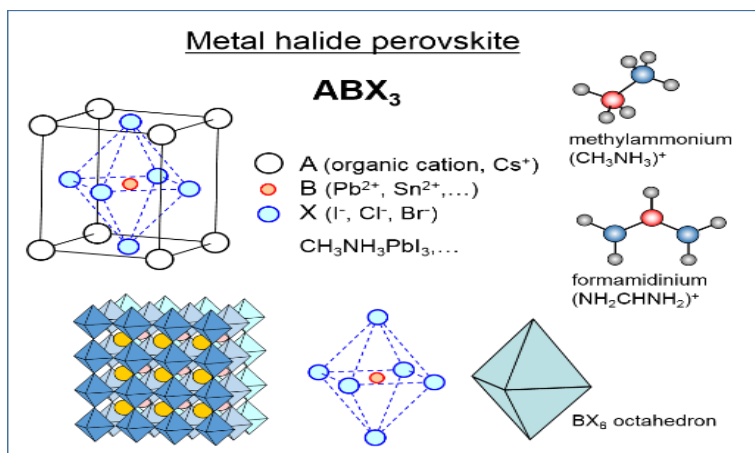
Application of QLEDs:

QLEDs offer several advantages over traditional LEDs, including higher efficiency, better color purity, and the ability to emit light at specific wavelengths. Here are some of the potential applications of QLEDs:

- **Display technology:** QLEDs have the potential to revolutionize display technology by providing brighter, more vibrant colors and higher resolution than current LCD or OLED displays. Samsung has already introduced QLED displays in their high-end TVs.
- **Lighting:** QLEDs can be used to create highly efficient lighting solutions that offer superior color rendering compared to traditional LEDs. They can also be used to create smart lighting systems that can be controlled remotely.
- **Medical imaging:** QLEDs can be used in medical imaging applications such as fluorescence imaging, where they can be used to tag specific cells or molecules and emit light when activated by a specific wavelength of light.
- **Sensing:** QLEDs can be used as sensors for various applications such as temperature, pressure, and chemical detection. The sensitivity and selectivity of QLED-based sensors can be tuned by changing the size, shape, and composition of the QDs.
- **Quantum computing:** QLEDs can be used as a source of single photons for quantum computing applications, where they can be used to transfer information between qubits.
- **Photovoltaics:** QLEDs can also be used in photovoltaic cells, where they can be used to harvest light and convert it into electricity. QLED-based solar cells have the potential to be more efficient and less expensive than traditional silicon-based solar cells.

Perovskite materials- Introduction, properties and applications in optoelectronic devices.

Perovskites are materials that have the same crystal structure as the mineral perovskite, which is composed of calcium titanate (CaTiO_3). Perovskite materials have a general formula of ABX_3 , where A and B are cations and X is an anion.



The classification of perovskites can be done based on the type of cation present in the A and B sites. Here are some examples:

Classification of Perovskite materials

1. A-site perovskites: These are perovskite materials where the A-site is occupied by an alkali or alkaline earth metal cation. Examples include CsSnI_3 and $\text{CH}_3\text{NH}_3\text{PbI}_3$.
2. B-site perovskites: These are perovskite materials where the B-site is occupied by a transition metal cation. Examples include LaCoO_3 and LaNiO_3 .
3. Double perovskites: These are perovskite materials where both the A and B sites are occupied by cations. Examples include $\text{Sr}_2\text{FeMoO}_6$ and $\text{Ba}_2\text{BiReO}_6$.
4. Ruddlesden-Popper perovskites: These are perovskite materials with a layered structure, where the A-site is partially occupied by a larger cation and the B-site is occupied by a transition metal cation. Examples include Sr_2IrO_4 and $\text{Ca}_{2-x}\text{Sr}_x\text{CuO}_3$.
5. Hybrid perovskites: These are perovskite materials where the A-site is occupied by an organic cation, such as methylammonium (MA) or formamidinium (FA). Examples include $\text{CH}_3\text{NH}_3\text{PbI}_3$ and $\text{HC}(\text{NH}_2)_2\text{PbI}_3$.

6. **Inverse perovskites:** These are perovskite materials where the anion occupies the A-site and the cation occupies the B-site. Examples include $\text{Cs}_2\text{AgBiBr}_6$ and $\text{Cs}_2\text{AgBiCl}_6$.

Properties of perovskites:

Perovskites have a wide range of properties that make them interesting for various technological applications. Some of the important properties of perovskites are:

1. **Tunable bandgap:** The bandgap of perovskites can be easily tuned by changing the composition of the A and B sites. This makes them promising candidates for solar cells and light-emitting diodes.
2. **High carrier mobility:** Perovskites have high carrier mobility, which is important for efficient charge transport in electronic devices.
3. **High absorption coefficient:** Perovskites have a high absorption coefficient, which means that they can absorb light over a wide range of wavelengths. This is important for solar cells, as it allows them to capture a larger fraction of the solar spectrum.
4. **Easy synthesis:** Perovskites can be synthesized using a variety of methods, including solution-based methods, which are relatively simple and inexpensive.
5. **High defect tolerance:** Perovskites have a high defect tolerance, which means that they can tolerate defects and impurities without significantly degrading their performance. This is important for practical applications, as it allows for the production of high-quality materials at large scales.
6. **Strong electron-phonon coupling:** Perovskites have a strong electron-phonon coupling, which results in efficient heat dissipation and low thermal conductivity. This makes them promising candidates for thermoelectric applications.
7. **Magnetic and superconducting properties:** Some perovskites exhibit magnetic and superconducting properties, which are important for spintronic and quantum computing applications.

Applications in optoelectronic devices

1. **Solar cells:** Perovskites have been widely investigated as light-absorbing materials in solar cells. Perovskite solar cells have achieved power conversion efficiencies of over 25%, making them competitive with traditional silicon-based solar cells. The high efficiency of perovskite solar cells is due to their high absorption coefficient, long carrier diffusion length, and low recombination rate.
2. **Light-emitting diodes (LEDs):** Perovskites have also been used in LEDs due to their high quantum efficiency and tunable emission wavelength. Perovskite LEDs have shown promising results in terms of efficiency, color purity, and stability.
3. **Photodetectors:** Perovskites have been used in photodetectors due to their high sensitivity, fast response time, and low noise. Perovskite photodetectors have demonstrated excellent performance in terms of responsivity, detectivity, and stability.

4. **Lasers:** Perovskites have shown potential in laser applications due to their high photoluminescence quantum yield, narrow emission linewidth, and tunable emission wavelength. Perovskite lasers have been demonstrated in various configurations, including vertical cavity surface emitting lasers, waveguide lasers, and random lasers.
5. **Optical sensors:** Perovskites have been used in optical sensors due to their high sensitivity to light, good stability, and low cost. Perovskite-based sensors have been developed for various applications, such as chemical sensing, biosensing, and environmental monitoring.

Nanofibers

Nanofibers are extremely thin fibers with diameters in the nanometer range (typically between 1 and 1000 nm). They can be made from a variety of materials, including polymers, metals, ceramics, and composites. Nanofibers can be produced using a variety of methods, including electrospinning, melt-blowing, phase separation, template synthesis, and self-assembly. Among these methods, electrospinning is the most commonly used technique for the production of polymer nanofibers.

Nanofibers have unique properties that make them attractive for various applications. Some of the properties of nanofibers include:

1. **High surface area-to-volume ratio:** Nanofibers have a high surface area-to-volume ratio due to their small size and high aspect ratio. This property makes them attractive for applications that require high surface area, such as catalysis, sensors, and tissue engineering.
2. **High porosity:** Nanofibers can have a high porosity due to the small size of their pores. This property makes them attractive for applications that require high permeability, such as filtration, drug delivery, and tissue engineering.
3. **Small pore size:** Nanofibers can have a small pore size due to their small diameter. This property makes them attractive for applications that require high selectivity, such as filtration and sensors.
4. **High mechanical strength:** Nanofibers can have high mechanical strength due to their high aspect ratio and crystallinity. This property makes them attractive for applications that require high strength, such as tissue engineering and structural composites.
5. **Flexibility:** Nanofibers can be flexible and bendable due to their small size and high aspect ratio. This property makes them attractive for applications that require flexibility, such as wearable electronics and smart textiles.

6. **Optical properties:** Nanofibers can exhibit unique optical properties, such as strong light scattering and fluorescence, due to their small size and surface chemistry. This property makes them attractive for applications in optics and photonics.

Nanofibers have a wide range of potential applications due to their unique properties. Some of the applications of nanofibers include:

1. **Tissue engineering:** Nanofibers can be used as scaffolds to guide the growth of cells and tissues. The high surface area and porosity of nanofibers make them attractive for tissue engineering applications, such as bone, cartilage, and nerve regeneration.
2. **Drug delivery:** Nanofibers can be used to encapsulate drugs and control their release rate. The high surface area and porosity of nanofibers allow for high drug loading and efficient drug release, making them attractive for drug delivery applications.
3. **Filtration:** Nanofibers can be used to create highly efficient filters for air and water purification. The small pore size and high porosity of nanofibers allow for high filtration efficiency and low pressure drop.
4. **Energy storage:** Nanofibers can be used as electrodes in energy storage devices, such as batteries and supercapacitors. The high surface area and mechanical strength of nanofibers allow for high energy and power density.
5. **Sensors:** Nanofibers can be used to create highly sensitive and selective sensors for various analytes. The small pore size and high surface area of nanofibers allow for high sensitivity and selectivity.
6. **Textiles:** Nanofibers can be used to create smart textiles with various functionalities, such as sensing, actuation, and energy storage. The flexibility and high aspect ratio of nanofibers allow for seamless integration into textiles.

Nanosensors

Sensors are devices that can detect and sense certain signals. The signals can be biomedical, optical, electronic, electrical, physical or mechanical. A sensor can be defined as a transducer that converts a measurement into a signal that carries information while nanosensors are tiny sensors reduced in size from a few nanometers to 10 to 100 nanometers. They make use of the unique properties of nanomaterials and nanoparticles to detect and measure materials and components on the nanoscale.

Types of Nanosensors

The different nanosensor types are given below based on the detection of signals.

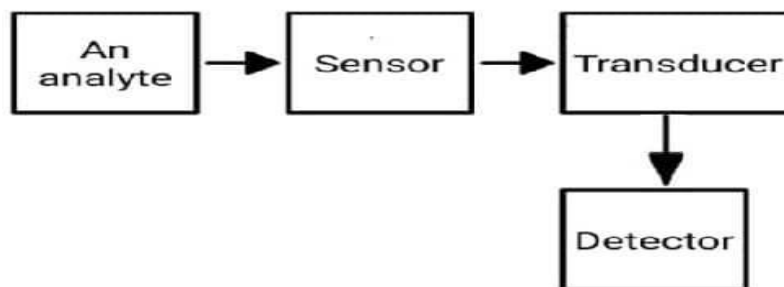
Optical Nanosensors: These types of sensors are used for analytical purposes, to monitor and detect biological or chemical processes and convert the information into signals for important data. These are further divided into 2 types, are Proximity Nanosensors, Ambient Light Nanosensors

Biological Nanosensors: These are used for bio-molecular processes like interactions of DNA, antigen or antibodies, enzymatic or for communication of cellular processes. These are further divided into 3 types. They are, Enzymatic interaction nanosensors, Antibody or antigen interaction nanosensors and DNS interaction nanosensor.

Chemical Nanosensors: These are used to determine the identity or concentration of a chemical substance. These are further divided into 2 types. They are, Molecular concentration nanosensors and Chemical composition type nanosensors.

Physical/Mechanical Nanosensors: These are used to monitor and measure the properties of material like force, pressure, displacement, temperature, pressure, and mass. These are further divided into 4 types. They are, Pressure type nanosensors, Mass-type nanosensors, Displacement type nanosensors, Force type nanosensors, Temperature nanosensors, Flow nanosensors.

Working Mechanism: Nanosensors can detect and monitor electrical, optical, biomedical, and mechanical signals. The basic components of nanosensors are an analyte, sensor, transducer, detector, and the feedback path from the detector to the sensor block (if necessary). These sensors operate by monitoring the electrical changes in the sensor material and are capable of measuring single molecule levels.



Nanosensors have a number of unique properties that make them useful for detecting and measuring physical, chemical, and biological signals at the nanoscale. Some of the properties of nanosensors include:

1. **High sensitivity:** Nanosensors can detect very small changes in the environment due to their small size and high surface-to-volume ratio. This property allows for highly sensitive detection of physical, chemical, and biological signals.
2. **Specificity:** Nanosensors can be designed to detect specific targets by functionalizing their surfaces with specific molecules or materials. This property allows for highly specific detection of target molecules, such as biomolecules or pollutants.
3. **Selectivity:** Nanosensors can be designed to selectively detect one target molecule or signal while ignoring other molecules or signals present in the environment. This property allows for highly selective detection of target molecules or signals.
4. **Rapid response time:** Nanosensors can respond quickly to changes in the environment due to their small size and high surface-to-volume ratio. This property allows for real-time monitoring of changes in the environment.
5. **Miniaturization:** Nanosensors can be made very small, allowing for integration into small devices or systems. This property allows for the development of portable, wearable, or implantable sensors.
6. **Low power consumption:** Nanosensors can be designed to operate with low power consumption, making them suitable for battery-powered or energy-harvesting applications.

Applications:

1. **Medical diagnosis and monitoring:** Nanosensors can be used for the early detection of diseases, monitoring of drug delivery, and real-time monitoring of physiological parameters. For example, nanosensors can be used to detect cancer biomarkers or to monitor glucose levels in diabetic patients.
2. **Environmental monitoring:** Nanosensors can be used to detect pollutants and toxins in water and air. For example, nanosensors can be used to detect heavy metals or pesticides in water, or to monitor air quality for pollutants such as carbon monoxide or ozone.

3. **Food safety:** Nanosensors can be used to detect contaminants and pathogens in food. For example, nanosensors can be used to detect bacterial toxins or allergens in food or to monitor food spoilage.
4. **Security:** Nanosensors can be used for the detection of explosives and hazardous materials. For example, nanosensors can be used to detect trace amounts of explosive materials in luggage or vehicles.
5. **Industrial process monitoring:** Nanosensors can be used to monitor and control industrial processes, such as chemical reactions or manufacturing processes. For example, nanosensors can be used to monitor temperature, pressure, or gas concentration in industrial reactors or pipelines.
6. **Wearable and implantable sensors:** Nanosensors can be integrated into wearable or implantable devices for continuous monitoring of physiological parameters or drug delivery. For example, nanosensors can be used to monitor heart rate, blood pressure, or glucose levels in real-time.

Nanophotonics

Nanophotonics is a branch of science and technology that deals with the study and manipulation of light at the nanoscale level. It combines the principles of nanotechnology and photonics, which is the study of light and its properties. Nanophotonics involves the use of materials and structures that are smaller than the wavelength of light to control and manipulate the behavior of light. This allows for the creation of devices and systems that can process information using light instead of electricity.

properties of nanophotonic materials are:

1. **Size-dependent optical properties:** The optical properties of nanophotonic materials are strongly influenced by their size and shape. As the size of the material decreases, the optical properties shift towards the blue end of the spectrum.
2. **Strong light-matter interactions:** Nanophotonic materials have a high surface area to volume ratio, which results in strong interactions between light and matter. This property can be used to enhance the sensitivity of sensors or to create efficient photovoltaic devices.
3. **Plasmonic properties:** Many nanophotonic materials exhibit plasmonic properties, which arise from the collective oscillation of electrons on the surface of the material. Plasmonic

materials can confine light to very small volumes and can be used to enhance the intensity of light in a small area.

4. **Tunable properties:** Nanophotonic materials can be engineered to have specific optical properties by controlling their size, shape, and composition. This property allows for the creation of materials with unique optical properties for specific applications.
5. **Quantum confinement:** In some nanophotonic materials, quantum confinement can occur due to the confinement of electrons and holes in a small volume. This property can be used to create materials with tailored electronic and optical properties.

Applications of nanophotonics:

1. **Optical communications:** Nanophotonics can be used to develop faster and more efficient optical communication systems. This includes the development of optical fibers and components that can manipulate and process light signals.
2. **Sensing and imaging:** Nanophotonic materials can be used to create highly sensitive sensors that can detect very small changes in the environment. Nanophotonic imaging systems can also be used to create high-resolution images of biological tissues or to identify individual molecules.
3. **Solar energy conversion:** Nanophotonic materials can be used to create more efficient solar cells that can convert sunlight into electricity. This includes the development of materials that can capture light from a wider range of the spectrum.
4. **Lighting:** Nanophotonic materials can be used to create more efficient and durable light sources such as LEDs, which are widely used in lighting applications.
5. **Medical applications:** Nanophotonics can be used in medical applications such as drug delivery, imaging, and diagnostics. For example, nanoparticles made from nanophotonic materials can be used to deliver drugs to specific areas of the body or to create high-resolution images of biological tissues.
6. **Data storage:** Nanophotonic materials can be used to develop more efficient data storage devices that use light instead of electricity. This includes the development of materials that can store information in a more compact and durable form.