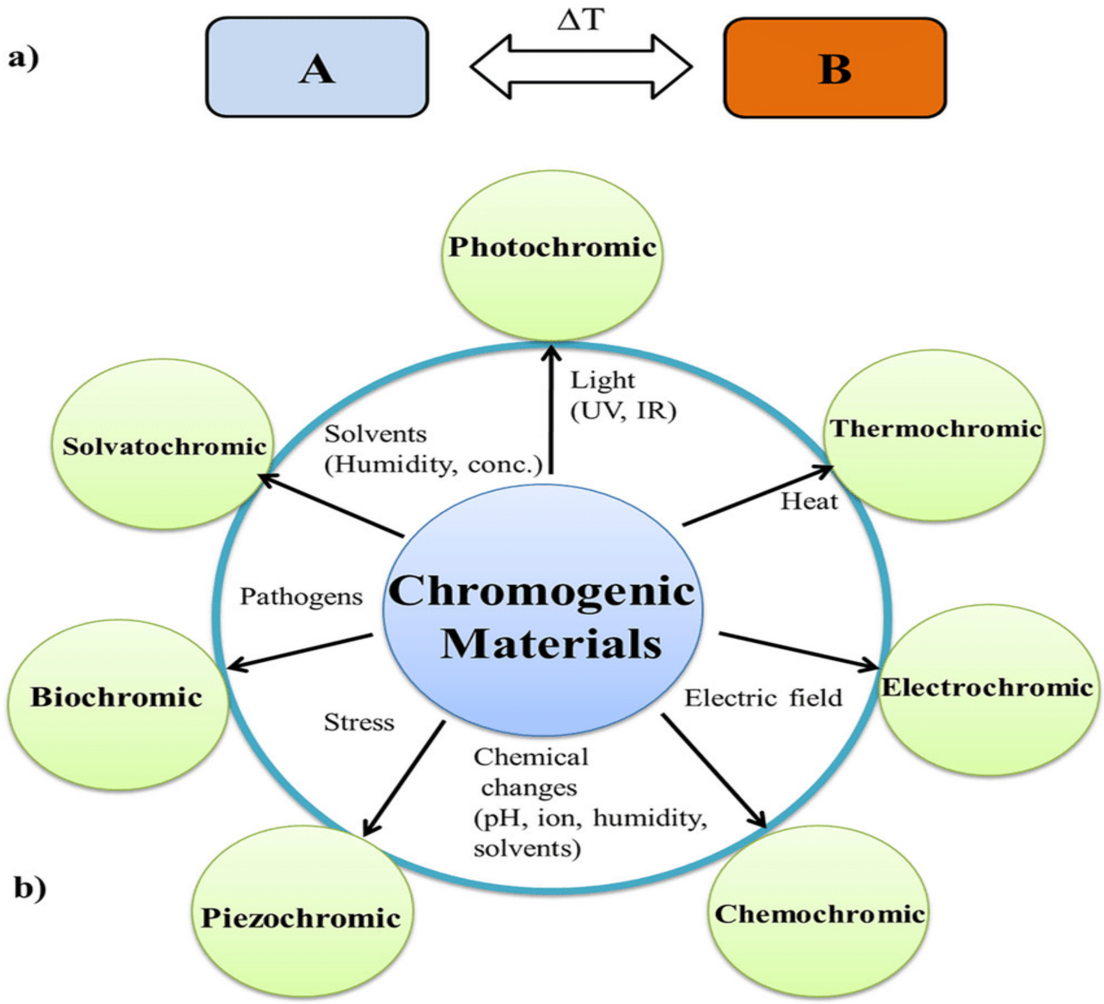
Unit -4 Advanced Electronic Materials and E-waste

Materials, mechanism, examples and applications of photochromic, thermochromic, electrochromic, electrostrictive, magnetostrictive, RFID, MEMS and NEMS, e-skin, e-nose devices. E-waste - Types, environmental risks, recycle management.



Chromic group	Stimuli type
Photochromic	Absorbing Electromagnetic light
Thermochromic	Changing of temperature
Electrochromic	Appling electric Field
Magnetochromic	Appling magnetic field
Piezochromic	Mechanical Loading
Solvatechromic	Contact with some liquid
Carsolchromic	Bombarding with electron beam

Photochromic materials:

Photochromic materials are those that show a reversible change in optical properties (color) through the action of light, i.e., electromagnetic radiation. They are transparent materials which exhibit increased light absorption when they are exposed to light. They can be optical glasses or plastic materials, or sometimes delivered as a powder.

The photochromic properties usually result from the addition of a photochromic substance to a transparent material. Photochromic materials and systems have several important uses depending on the rates of the optical transformations. For example, very slow transformations are useful for optical data storage media, whereas fast transformations are required for optical switches.

- Photochromic compounds such as diarylethene (DE), dithienylethene (DT), and furylfulgide (FF) derivatives are thermally stable and resistant to photochemical side reactions, were mainly used in optical information storage.
- Photochromic molecules such as spirooxazines (SO) and spiropyrans (SP) have been embedded into sol–gel glasses to produce optical switches

Working Principle:

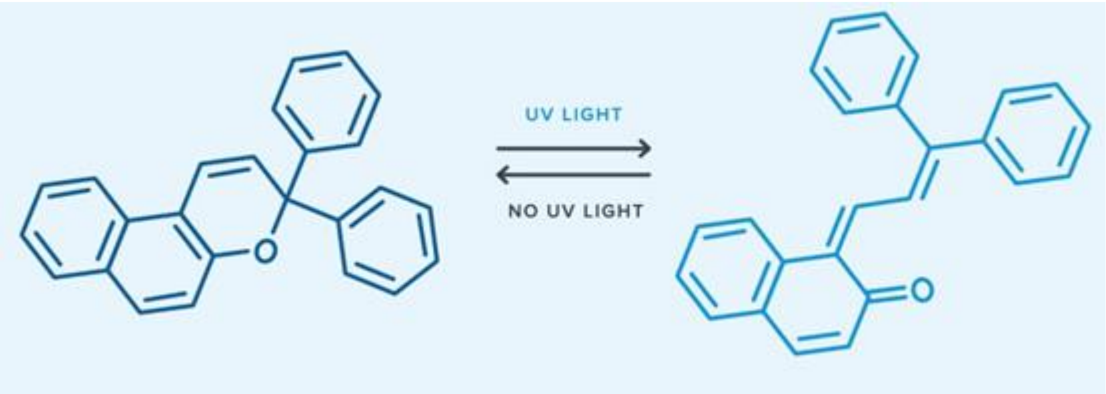
The working of photochromic materials is based on the reversible photochemical reaction that occurs when the material is exposed to light. The photochromic material absorbs light energy and undergoes a reversible chemical reaction that changes its molecular structure and color. When the light source is removed, the material returns to its original state.

The light-sensitive molecules inside photochromic lenses shift their structure when they're bathed in UV rays, allowing them to absorb more light and give the lenses a darkened appearance. Once the UV light goes away, the process reverses and the lenses become clear again. These photochromic molecules are sensitive to both the presence and amount of UV light. They'll change their structure more quickly when exposed to a lot of it, and more slowly if there's only a little bit. That's why you might notice your photochromic lenses darkening a bit less in the shade than out in the sun.

Photochromic lenses: Structure and Mechanism

Photochromic lenses are transparent in indoors, but darken when exposed to ultraviolet light from the sun. Essentially, they provide the benefits of glasses and sunglasses in a single frame. Plastic photochromic lenses have carbon-based compounds within them that change their structure in the presence of UV light. These organic compounds are also known as photochromic dyes.

Glass photochromic lenses have minute amounts of silver halide crystals (most commonly silver chloride) distributed inside them. When ultraviolet light hits these chemical compounds, the silver gains an electron and becomes elemental silver—the silver metal with which you’re probably familiar. The lenses appear darker as more and more silver molecules “appear” and absorb visible light.



In the above structure, napthopyran molecule exposed to UV light, their structure changes reversibly, the ultraviolet light powers a restructuring of the molecule on the left, which is cleaved between the carbon and the oxygen atom.

Certain silver halides can also be used much the same way to make photographic film: exposure to light causes the image to darken and develop. However, unlike photos, glass photochromic lenses are able to revert back to their original clear appearance. In the absence of ultraviolet light, a second compound (typically copper chloride) that's also embedded within the glass takes the transferred electron back from the silver metal. The process reverses, and the lenses become transparent once more.

Advantages of Photochromic Lenses

- The two main purposes of photochromic lenses are to protect your eyes from UV light and to eliminate the need for a separate pair of prescription sunglasses.
- The lenses provide complete protection from UVA and UVB rays at all times

Disadvantages of Photochromic Lenses

.

- Photochromic lenses get darken when coming in contact with the sunlight, blocking your windshields. Therefore, they are risky to wear while driving.
- Some photochromic lenses are not polarized, leading to harsh glares of sunlight.

Applications of photochromic materials:

- Supramolecular chemistry: Photochromic units can be used to create molecules that can switch their shape, function or interactions with light.
- Data storage: Photochromic compounds can be used to store information in optical media, such as CDs or DVDs, by changing their reflectivity or fluorescence with light.
- Solar energy storage: Photochromic materials can be used to store solar energy by converting light into heat or electricity, and then releasing it when needed
- Smart textiles : Photochromic dyes can be used to make fabrics that change color with light, such as for fashion, art or medical purposes.

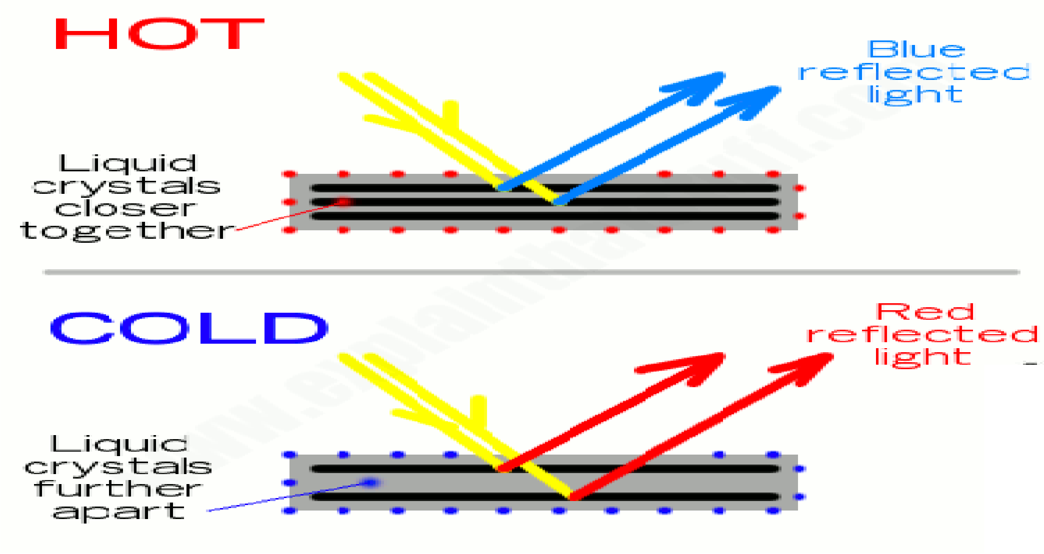
Thermochromic materials are materials that change color due to a change in temperature. They can be used for various applications, such as temperature indicators, mood rings, baby bottles, kettles, battery testers and coffee cups. There are two common types of thermochromic materials: liquid crystals and leuco dyes.

- Liquid crystals are organic compounds that can reflect different colors at different temperatures, depending on their molecular structure and spacing. Examples of liquid crystals are cholesteryl esters, cholesteryl ethers, cholesteryl benzoates and cholesteryl oleyl carbonates. They are often used in thermometers, thermal cards, mood rings and other devices that require precise temperature measurements.
- Leuco dyes are organic molecules that can change from colored to colorless or vice versa when they interact with other chemicals at certain temperatures. Examples of leuco dyes are crystal violet lactone, malachite green lactone, phenolphthalein and fluoran. They are often used in papers, polymers, inks and other materials that require a wide range of colors.
- In addition to organic materials, some inorganic materials also exhibit thermochromic properties. These include metal oxides such as vanadium dioxide (VO_2), titanium dioxide (TiO_2), zinc oxide (ZnO), niobium dioxide (NbO_2), iron silicide ($FeSi_2$) and titanium sesquioxide ($Ti2O_3$). These materials change their optical properties due to a change in their crystal structure or electronic configuration at certain temperatures.

Liquid crystal thermochromic materials-Working and Mechanism:

Liquid crystal thermochromic materials are materials that change their reflected color as a function of temperature when illuminated by white light. They have chiral (twisted) molecular structures and are optically-active mixtures of organic chemicals. They can reflect different wavelengths of light depending on the temperature and the orientation of the molecules. The principle of working in liquid crystal thermochromic materials is based on the phenomenon of selective reflection of certain wavelengths by the crystalline structure of the material, as it changes between the low-temperature crystalline phase, through anisotropic chiral or twisted nematic phase, to the high-temperature isotropic liquid phase. Only the nematic mesophase has thermochromic properties; this restricts the effective temperature range of the material.

Liquid crystals change their molecular orientation and spacing when they undergo phase transitions from solid to liquid or from one liquid phase to another. This changes their selective reflection of certain wavelengths of light and produces different colors.



Top (Hot): Incoming light rays hit the layers of liquid crystals (black lines) and reflect back out again, with outgoing rays interfering to produce light of a particular color—in this case, blue. The color of the reflected light depends on how closely the crystal layers are together. Bottom (Cold): In this made-up example, cooling the liquid crystals makes them move further apart, changing the way the outgoing light waves interfere and making the reflected light redder than before.

Applications:

- Thermochromic materials are mainly used as temperature indicators in many industrial sectors, to determine the temperature variation and reaction heat in chemical reactions.
- Thermometers for room, refrigerator, aquarium, and medical use, which display different colors at different temperatures.
- Indicators of level of propane in tanks, which change color depending on the temperature and pressure of the gas.
- Heat transfer mapping devices, which visualize the temperature distribution and convection patterns on a surface.
- Artistic and educational materials, such as mood rings, thermal cards, stickers, and toys, which change color with body heat or ambient temperature.

Electrochromic materials are materials that can change their color or opacity when an electric field is applied to them. They are different from photochromic materials, which change color with light. Electrochromic materials can be used to make smart windows, mirrors, sunglasses and other devices that can control the amount of light and heat passing through them.

Some examples of electrochromic materials are:

Metal oxides: Inorganic compounds that can change their color by accepting or releasing ions and electrons. For example, tungsten oxide (WO_3) can change from transparent to blue when a voltage is applied.

Conducting polymers: Organic compounds that can change their color by changing their oxidation state. For example, polyaniline can change from green to blue when a voltage is applied.

Organic dyes: These are organic compounds that can change their color by changing their molecular structure. For example, viologen can change from colorless to blue or red when a voltage is applied.

Among the metal oxides, tungsten oxide (WO_3) is the most extensively studied and well-known electrochromic material. Others include molybdenum, titanium and niobium oxides, although these are less effective optically.

Principle:

The principle of electrochromic materials is based on the reversible change in their optical properties caused by redox reactions. When an electrochromic material is placed on the surface of an electrode, an electric field can induce the redox reactions and change the color or opacity of the material. The color change can be between a transparent state and a colored state, or between two colored states. The color change can also be controlled by the magnitude of the applied voltage.

Some electrochromic materials can show several colors, and they are called polyelectrochromic. Electrochromic materials can be organic or inorganic, and they can be used to make smart devices that can adjust the amount of light and heat passing through them.

Device Structure:

The basic structure of electrochromic device (ECD) consists of two EC layers separated by an electrolytic layer. The ECD works on an external voltage, for which the conducting electrodes are used on the either side of both EC layers. In the below representation there are three principally different kinds of layered materials in the ECD: The EC layer and ion-storage layer conduct ions and electrons and belong to the class of mixed conductors. The electrolyte is a pure ion conductor and separates the two EC layers. The transparent conductors are pure electron conductors. Optical absorption occurs when electrons move into the EC layers from the transparent conductors along with charge balancing ions entering from the electrolyte. Optical absorption occurs when electrons move into the EC layers from the transparent conductors along with charge balancing ions entering from the electrolyte.

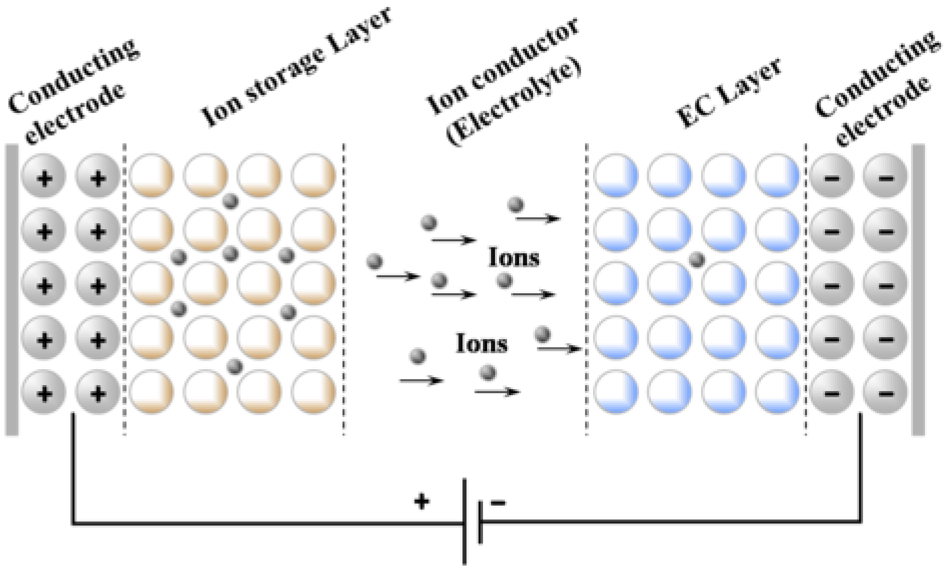
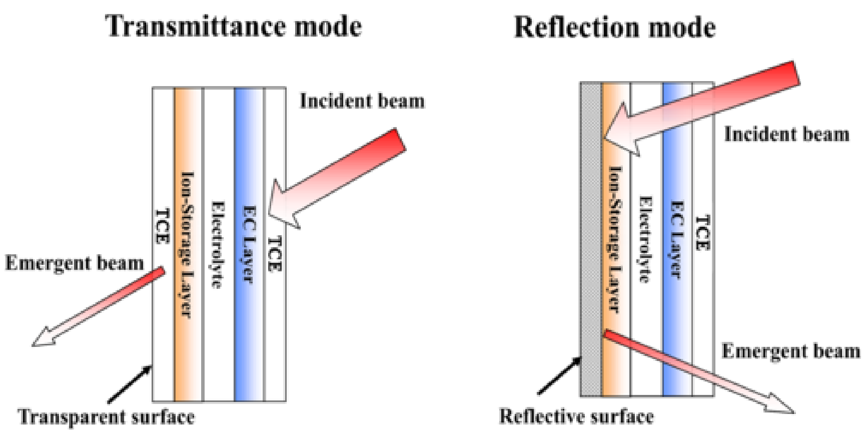


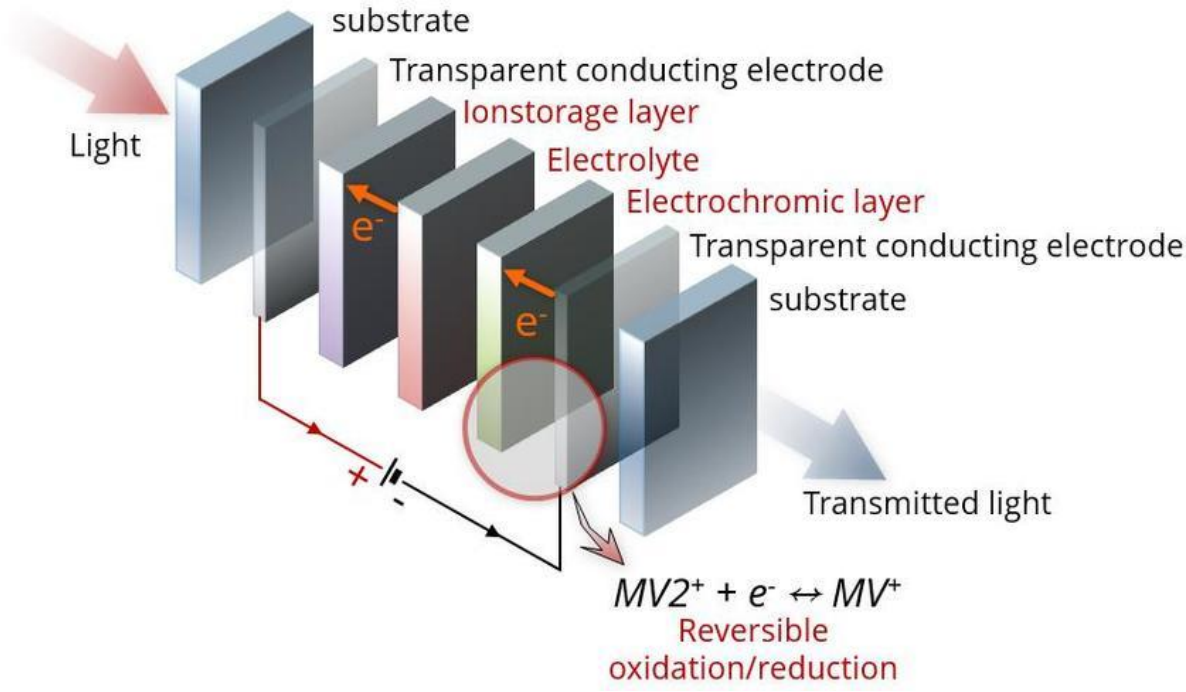
Diagram showing the layers of a typical laminated electrochromic device

ECD are of two types depending on the modes of device operation, namely the transmission mode and reflectance mode. In the transmission mode, the conducting electrodes are transparent and control the light intensity passing through them; this mode is used in smart-window applications. In the reflectance mode, one of the transparent conducting electrodes (TCE) is replaced with a reflective surface like aluminium, gold or silver, which controls the reflective light intensity; this mode is useful in rear-view mirrors of cars and EC display devices.



Applications:

- Auto-dimming rear view mirrors can reduce glare from other vehicles.
- Smart sunglasses or goggles that can adapt to different lighting conditions.
- Electrochromic displays that can show information with low power consumption.
- Military camouflage gear that can change color to match the environment.
- Sensors, optical shutters or optical modulators which controls the transmission or reflection of light.
- PEDOT:PSS-(poly(3,4-ethylenedioxythiophene) polystyrene sulfonate) is a polymer mixture of two ionomers based smart electrochromic materials shows fast, real-time and efficient reversible color change due to redox process under influence of electric field. The color changes can directly carry readable visual information by the naked human eyes, showing promising applications in smart display, health monitoring, and energy storage.



Electrostrictive materials are materials that exhibit a quadratic relationship between mechanical stress and the square of the electric polarization. Electrostriction can occur in any material, but some engineered ceramics, known as **relaxor ferroelectrics**, have extraordinarily high electrostrictive constants. Typical electrostrictive materials include such compounds as lead manganese niobate lead titanate (PMN PT) and lead lanthanium zirconate titanate (PLZT).

Principle:

The principle of electrostrictive materials is that they change their shape under the application of an electric field. This is caused by the displacement of ions in the crystal lattice of the material, which results in a compressive force. The induced strain has a quadratic dependence on the applied field and is independent of its polarity.

Working:

Electrostrictive materials work by changing their shape when an electric field is applied to them. This is because the electric field causes the positive and negative ions in the material to move in opposite directions, creating a compressive force. The amount of deformation depends on the square of the electric polarization, which is the alignment of electric dipoles in the material. Electrostrictive materials do not change their shape when the electric field is reversed.

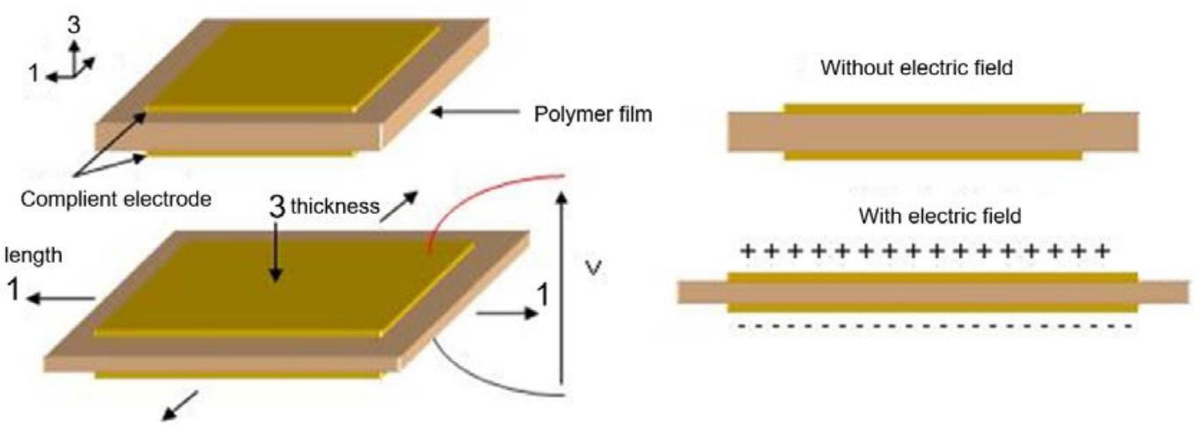


Figure 1. Illustrates the direction of the applied electric field as well as the deformation.

Applications:

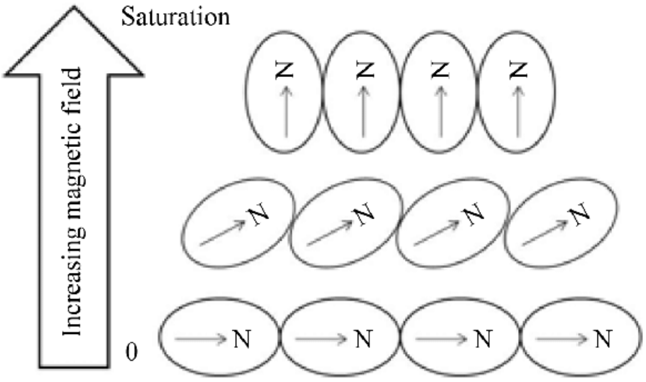
- Electrostrictive materials are used in actuator applications.
- Electrostrictive ceramics set aside a market in low dimensional application such as micro-pumps, positioning and micro-electromechanical systems (MEMS).
- Different types of actuators, such as hydraulic actuators, pneumatic, electrical, thermal, and mechanical actuators, are developed using electrostrictive material for various applications.

Magnetostrictive materials are a class of smart materials that can convert energy between the magnetic and elastic states. They have a property called magnetostriction, which causes them to change their shape or dimensions during the process of magnetization. Some examples of magnetostrictive materials are nickel, iron, cobalt, and some ferrites and rare earths.

Working:

- When a **magnetic field** is applied to a magnetostrictive material, the **molecular dipoles** and the **magnetic field boundaries** (also called **Bloch walls**) inside the material **rotate** to align with the applied field.
- The rotation of the dipoles and the boundaries changes the shape and dimensions of the material. This causes a **strain** or a **deformation** in the material.
- The amount of strain depends on the intensity of the magnetic field and the magnetic anisotropy of the material. The magnetic anisotropy is the tendency of the material to magnetize more easily in certain directions than others.
- The strain can be measured by various methods, such as using strain gauges, optical sensors, or piezoelectric devices.
- The inverse effect also occurs, that is, when a **stress** or a **force** is applied to a magnetostrictive material, it changes its magnetization. This can be used to create sensors that measure a magnetic field or detect a force.

  If a magnetic field is applied to the material at an angle to an easy axis of magnetization, the material will tend to rearrange its structure so that an easy axis is aligned with the field to minimize the free energy of the system. Since different crystal directions are associated with different lengths this effect induces a strain in the material.



Applications:

- Electronic article surveillance – using magnetostriction to prevent shoplifting
- Magnetostrictive delay lines - an earlier form of computer memory
- Magnetostrictive loudspeakers and headphones
- Magnetostrictive sensors and actuators - for measuring position, force, pressure, etc.
- Ultrasonic machining - using magnetostriction to generate high-frequency vibrations for cutting hard materials
- Audio-frequency oscillators- at sonic and ultrasonic frequencies
- Underwater projectors and sound detectors

RFID (radio frequency identification) is a form of wireless communication that incorporates the use of electromagnetic or electrostatic coupling in the radio frequency portion of the electromagnetic spectrum to uniquely identify an object, animal or person.

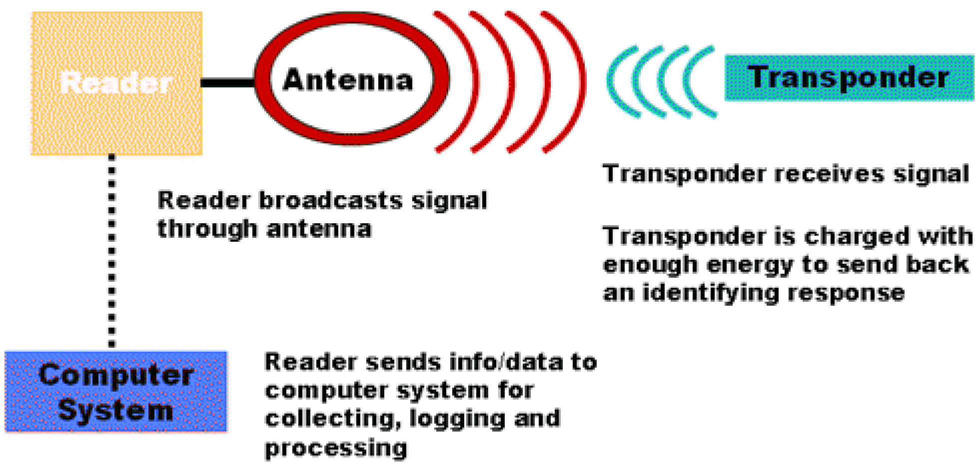
Materials:

The microchip in an RFID transponder is composed of **silicon**. The antenna can be made of etched copper, aluminum or conductive ink, while the chip and antenna are typically put on a substrate that is Polyethylene Terephthalate (PET).

Working:

RFID system consists of three components: a scanning antenna, a transceiver and a transponder. When the scanning antenna and transceiver are combined, they are referred to as an RFID reader or interrogator. There are two types of RFID readers -- fixed readers and mobile readers. The RFID reader is a network-connected device that can be portable or permanently attached. It uses radio waves to transmit signals that activate the tag. Once activated, the tag sends a wave back to the antenna, where it is translated into data.

The transponder is in the RFID tag itself. The read range for RFID tags varies based on factors including the type of tag, type of reader, RFID frequency and interference in the surrounding environment or from other RFID tags and readers. Tags that have a stronger power source also have a longer read range. RFID tags are made up of an integrated circuit (IC), an antenna and a substrate. The part of an RFID tag that encodes identifying information is called the RFID inlay.



There are two main types of RFID tags:

- **Active RFID.** An active RFID tag has its own power source, often a battery.
- **Passive RFID.** A passive RFID tag receives its power from the reading antenna, whose electromagnetic wave induces a current in the RFID tag's antenna.

There are also semi-passive RFID tags, meaning a battery runs the circuitry while communication is powered by the RFID reader. There are three main types of RFID systems: low frequency (LF), high frequency (HF) and ultra-high frequency (UHF). Microwave RFID is also available. Frequencies vary greatly by country and region.

- **Low-frequency RFID systems.** These range from 30 KHz to 500 KHz, though the typical frequency is 125 KHz. LF RFID has short transmission ranges, generally anywhere from a few inches to less than six feet.
- **High-frequency RFID system** These range from 3 MHz to 30 MHz, with the typical HF frequency being 13.56 MHz. The standard range is anywhere from a few inches to several feet.
- **UHF RFID systems.** These range from 300 MHz to 960 MHz, with the typical frequency of 433 MHz and can generally be read from 25-plus feet away.
- **Microwave RFID systems.** These run at 2.45 Ghz and can be read from 30-plus feet away.

Applications of RFID

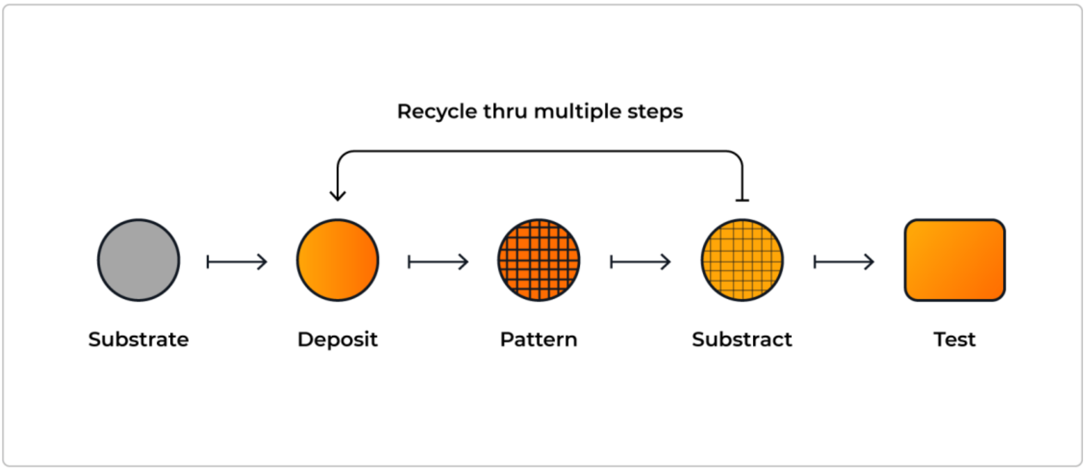
- Pet and livestock tracking
- Inventory management, asset tracking and equipment tracking
- Cargo and supply chain logistics
- Vehicle tracking, access control in security situations
- Shipping, healthcare, manufacturing & retail sales
- Tap-and-go credit card payments

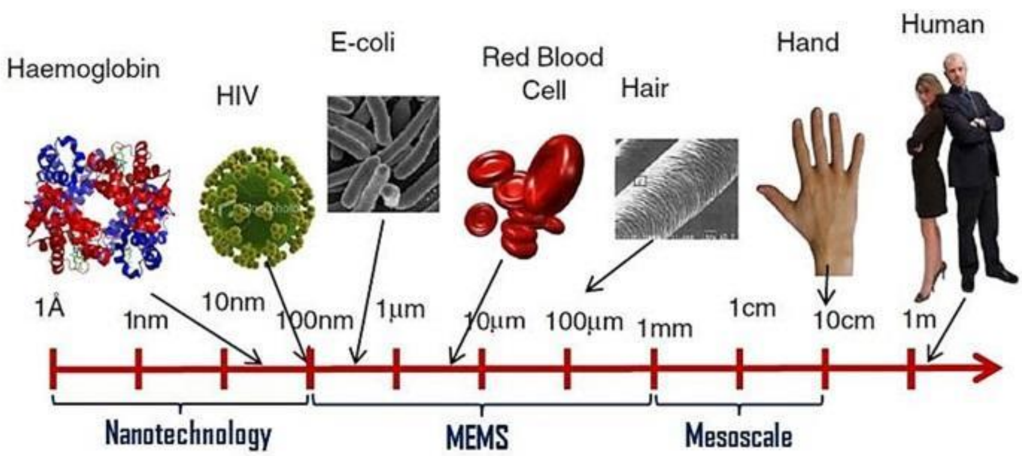
MEMS stands for Microelectromechanical systems which is the technology of microscopic devices incorporating both electronic and moving parts. MEMS are made up of components between 1 and 100 micrometers in size (i.e., 0.001 to 0.1 mm), and MEMS devices generally range in size from 20 micrometres to a millimetre (i.e., 0.02 to 1.0 mm). MEMS are composed of parts such as microsensors, microprocessors, microactuators, units for data processing and parts that can interact with exterior pieces.

Materials and Manufacturing:

MEMS devices and integrated circuit (IC) chips are manufactured via similar processes. Both start on a foundational substrate wafer (typically of silicon or glass) and are then built up and sculpted through subsequent steps:

- Adding material layers through deposition,
- Patterning the surface through masks and photolithography, and
- Subtracting unwanted sections via etching.





MEMS devices *versus* integrated circuit (IC) chips:

Four key aspects differentiate MEMS processes from IC.

- First, MEMS employ more diverse depositional materials such as piezoelectrics (for example, lithium tantalate, lithium niobite, and PZT) and noble-metal electrode layers (such as gold and silver).
- Second, to produce intricate three-dimensional structures, MEMS fabrication requires a broader assortment of process steps, including deep reactive ion etching (which results in near-vertical sidewalls), wafer-level packaging, and depositing very thin layers that may be less than one micron thick.
- Third, the shaping of a MEMS microstructure occurs both within the deposited layers and within the substrate.
- Fourth, for MEMS processes, testing occurs as much in the physical world as the digital. Most IC chips require only that they receive electrical current to determine whether their digital output passes or fails. MEMS, on the other hand, are made to sense or interact with physical parameters.

Applications:

- **Size** is the most obvious benefit. MEMS can be installed in locations impossible for full-size components. Smartphones and electronic wearables would not be essential parts of daily life without these tiny machines.
- MEMS are **fast**. Electrical distances between components are short, cutting response time.
- MEMS yield a level of **performance and precision** unattainable with conventional full-size components
- With **power consumption** a small fraction of that for traditional components, there is considerably less demand on batteries for portable products.
- MEMS exhibit **high reliability**. Silicon materials can bear repeated flexure with very little fatigue and can offer an extremely long life under an incredible number of cycles.

NEMS stands for Nanoelectromechanical systems which are devices integrating electrical and mechanical functionality on the nanoscale level. They form the next logical miniaturization step from so-called microelectromechanical systems, or MEMS devices. NEMS typically integrate transistor-like nanoelectronics with mechanical actuators, pumps, or motors, and may thereby form physical, biological, and chemical sensors.

Examples of NEMS include nanoresonators, nanoaccelerometers, and integrated peizoresistive detection devices. NEMS applications are envisaged in sensing, displays, portable power generation, energy harvesting, drug delivery, and imaging. Another example of a NEMS device is a carbon nanotube nanomotor produced with hybrid top-down bottom-up fabrication. NEMS devices, like other examples of nanotechnology, work in nano scale dimensions of size. This means that they feature extremely low mass, high resonance frequencies and may operate according to the non-intuitive laws of quantum mechanics by exploiting a high surface-to-volume ratio or zero point motion.

Principle:

NEMS systems rely on two basic principles of fabrication: photo/electron beam lithography, and molecular self-assembly. All aspects of MEMS, NEMS and micromanufacturing technology are covered comprehensively in the Inspec Database**.**

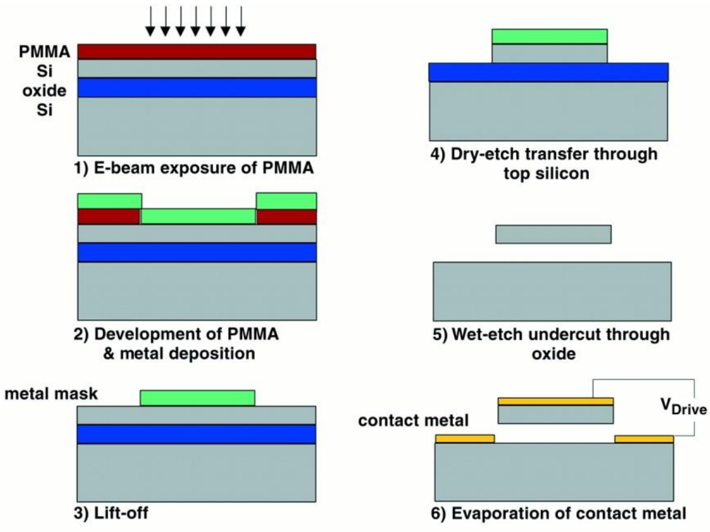
(**Inspec is a major indexing database** of scientific and technical literature, published by the Institution of Engineering and Technology, and formerly by the Institution of Electrical Engineers)

Materials:

Carbon nanotubes have specifically found so much use in **NEMS** that methods have already been discovered to connect suspended carbon nanotubes to other nanostructures. This allows carbon nanotubes to form complicated nanoelectric systems. Because carbon based products can be properly controlled and act as interconnects as well as transistors, they serve as a fundamental material in the electrical components of NEMS.

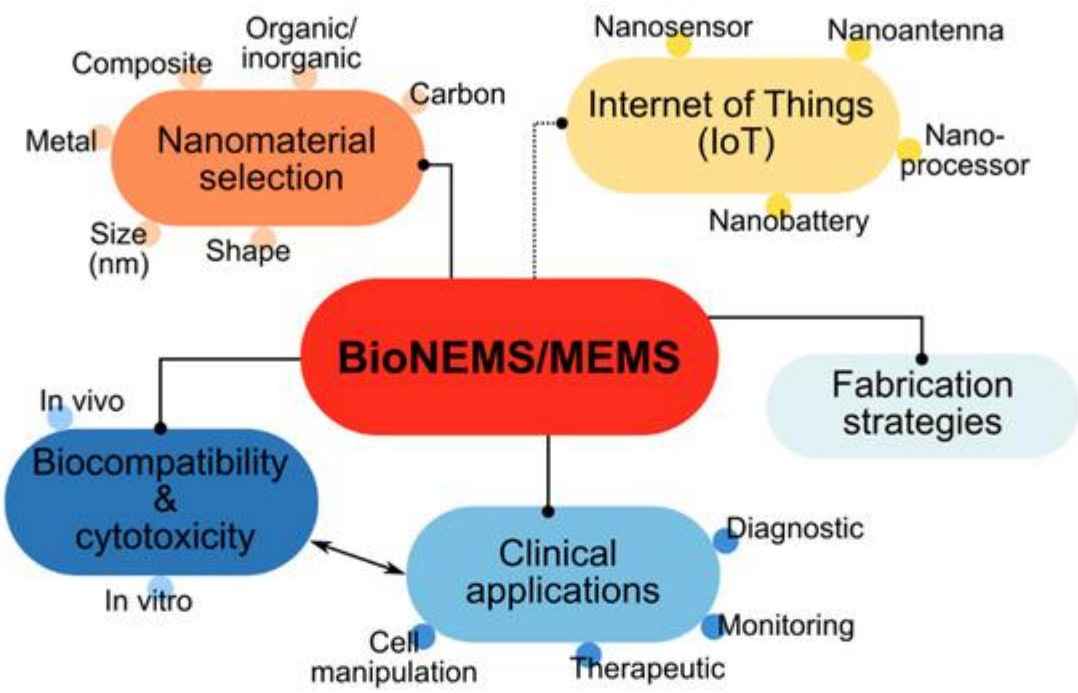
PDMS is frequently used within NEMS technology. Polydimethylsiloxane (PDMS)-coated nanoelectromechanical system diaphragm embedded with silicon nanowires (SiNWs) to detect chloroform vapor at room temperature.

Fabrication: A photoresist is first coated onto the flat surface of the substrate. The substrate with photoresist is then exposed to a set of lights through a transparent mask with the desired pattern. Patterns on the mask are photographically reduced from macro or mesosizes to the desired microscale.



Applications of NEMS:

NEMS have played key roles in many important areas, for example transportation, communication, automated manufacturing, environmental monitoring, health care, defense systems, and a wide range of consumer products



Definition, Materials, Mechanism and Applications of e-nose

An e-nose is a device that can detect and recognize odors and flavors using a sensor array. The materials used for the sensors in e-nose are called chemoresistive materials. They can change their electrical resistance when they interact with different molecules.

Some examples of chemoresistive materials for e-nose are:

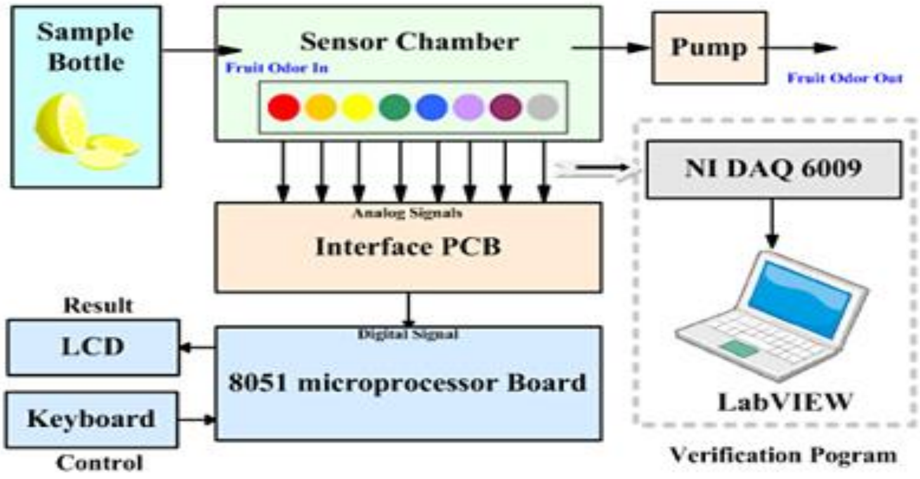
- Metal oxides such as tin oxide, zinc oxide, and titanium dioxide. They are widely used because of their high sensitivity, low cost and easy fabrication.
- Organics, such as polymers and carbon-based materials. They have advantages such as low operating temperature, high selectivity and easy functionalization.
- Two-dimensional materials such as graphene, molybdenum disulfide, and tungsten diselenide. They have promising properties such as high surface-to-volume ratio, tunable band gap and fast response and recovery.
- Metal-organic frameworks (MOFs) which are porous crystalline materials composed of metal ions and organic ligands. They have advantages such as high porosity, large surface area and adjustable functionality.
- There are also other materials such as nanowires, nanotubes, quantum dots, etc. that can be used for e-nose sensors.

Mechanism & Working Principle:

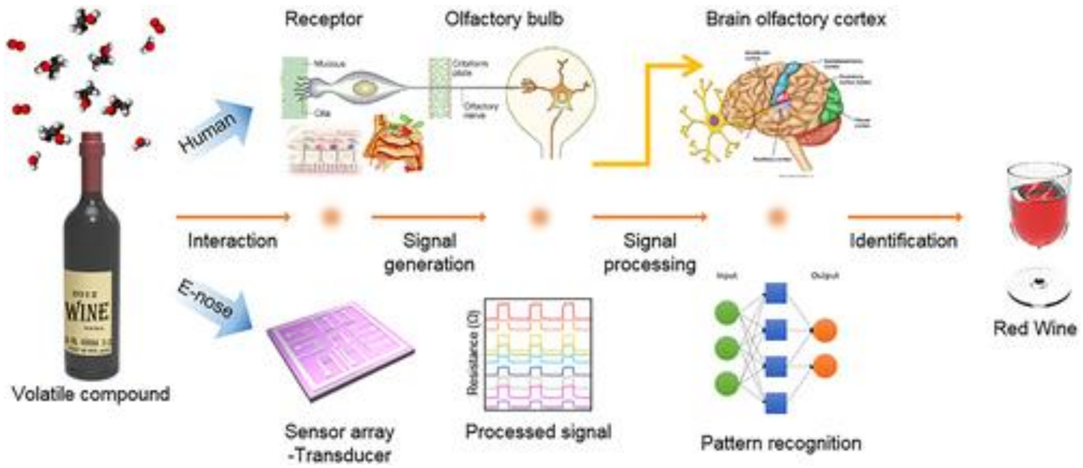
An electronic nose (e-nose) is a device that detects the smell more effectively. It consists of an array of gas sensors that are overlapping selectively along with a pattern reorganization component. The electronic nose was developed in order to mimic human olfaction whose functions are based on the recognition of patterns. The more commonly used sensors in an electronic nose are metal oxide semiconductors (MOS), conducting polymers (CP), and quartz crystal microbalance (QCM).

- The working principle of an electronic nose is based on the detection of volatile organic compounds (VOCs) present in the air.
- The VOCs are adsorbed onto the surface of the sensor and cause a change in its electrical properties.
- This change is then measured and analysed by a pattern recognition algorithm.

The schematic diagram is of e-nose is as shown:



The below picture shows the comparison of human nose versus e-nose:



Applications: The electronic nose due to its advanced sensing features is being greatly utilized in various manufacturing Industries.

- It helps in maintaining quality control and grading, product uniformity and consistency, processing controls, gas leak detection and environmental effluents monitoring.
- The electronic nose can be used for medical diagnostics and health monitoring, detection of explosives, space applications (NASA), research and development industries, quality control laboratories, the process and production department, detection of drug counterfeiting and many more.
- The electronic nose can be used for various applications such as food quality-related properties determination.

Definition, Materials, Mechanism and Applications of e-skin

Electronic skin (e-skin) is a thin, flexible material that can mimic the function and mechanical properties of human skin. It has sensors embedded to measure pressure, temperature, humidity, and airflow.

E-skin is considered rehealable because of "reversible bond exchange" meaning that the bonds holding the network together are able to break and reform under certain conditions such as solvation and heating. The use of tiny electronic wires allows the skin to generate impulses, similar to that of the body's own nervous system.

Electronic skin (e-skin) is made up of a network of covalently bound polymers that are thermoset, meaning cured at a specific temperature. However, the material is also recyclable and reusable. Because the polymer network is thermoset, it is chemically and thermally stable. CNTs, organic polymers, graphene, and silicon are typical materials that have been used for making tactile e-skin elements. The most common materials used to simulate skin are liquid suspensions, gelatinous substances, elastomers, epoxy resins, metals and textiles. Nano- and micro-fillers can be incorporated in the skin models to tune their physical properties

Difference between human skin and e-skin:

Human skin is composed of three layers: the epidermis, the dermis, and the hypodermis. The epidermis is the outermost layer of the skin and is responsible for protecting the body from environmental factors such as UV radiation and pathogens. The dermis is the middle layer of the skin and contains blood vessels, nerves, and hair follicles. The hypodermis is the deepest layer of the skin and contains fat cells.

Electronic skin (e-skin) is a flexible, stretchable and self-healing electronic device that can mimic functionalities of human or animal skin. It has sensors embedded to measure pressure, temperature, humidity, and airflow. The use of tiny electronic wires allows the skin to generate impulses, similar to that of the body's own nervous system.

Principle:

The principle of the flexible tactile sensor is the piezoresistive effect of the graphene film. When a micro-pressure is applied to the surface of the sensor, the upper bump will collect the stress evenly to the graphene film. This stress will fracture or crack the C–C bond of the graphene film, and the resistivity of the graphene film will change, as shown in Figure. Therefore, we can measure the applied micro-pressure according to the varied resistance of the graphene film. Benefiting from the excellent sensitivity and flexibility of graphene film, the sensor can obtain a high sensitivity.

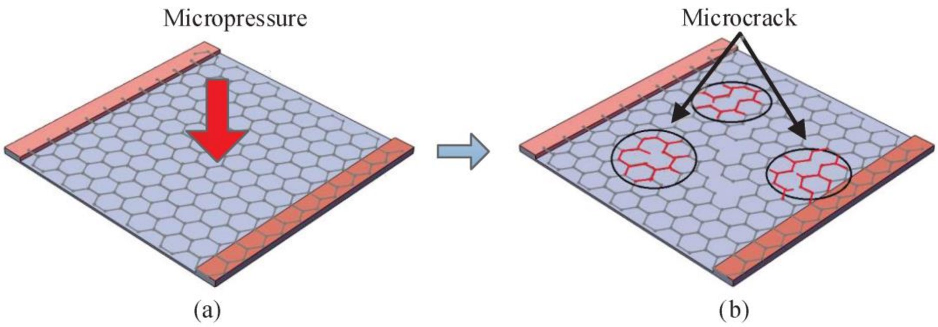


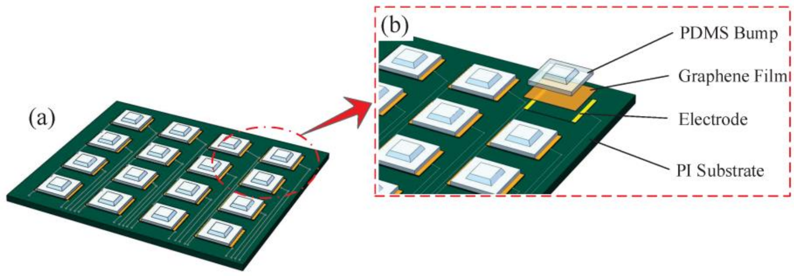
Figure. Schematic diagram of the working principle of the sensing unit. (**a**) Morphology of graphene thin films before being subjected to micropressure; (**b**) Microstructure of graphene film under compression.

Common requirements of e-skin

E-skin requires heterogeneous integration between sensors, active devices, interconnects, communication interfaces, energy management circuits, data storage, processing components, energy harvesting components. Some of the common requirements of these components are biocompatibility, conformability to skin topography, flexibility, stretchability to various degree, sustainability to various strains due to body motion, minimal discomfort, reasonable adhesion, reasonable shelf life and service life and lightweight.

Materials and Mechanism:

The electronic skin is composed of 4 × 4 tactile sensing units which contains three layers: The lower substrate (polyimide substrate, or PI substrate), the piezoresistive layer (graphene/polyethylene terephthalate film), and the Polydimethylsiloxane (PDMS) bump layer. **Fig.**Structure of the electronic skin (**a**); Partial enlarged detail of the electronic skin (**b**).



The piezoresistive curve showed two segments. The first one is from 0 kPa to 4 kPa, which corresponds to relatively small pressures. A small pressure deforms the PDMS bump, which presses the graphene film and generates many small cracks on the graphene film. Because of the low Young's modulus of PDMS, a large deformation can be generated by small stress. As a result, the resistance of the sensor in the first segment increased obviously. The second segment is from 4 kPa to 500 kPa, which corresponds to relatively large pressures. In this segment, the deformation of PDMS bump was saturated. However, with the increased pressure, the PET substrate was deformed, generating more small cracks on the graphene film. Due to the high Young's modulus of PET, a larger pressure is needed to deform the PET, which leads to a reduction in sensitivity.

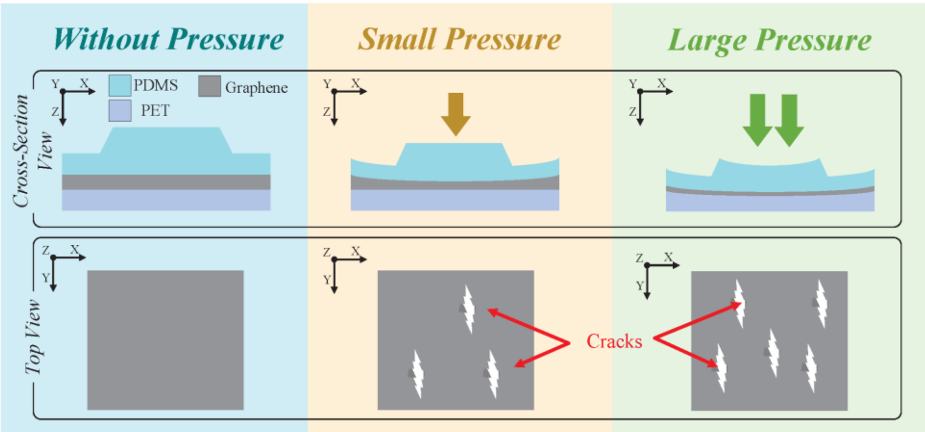
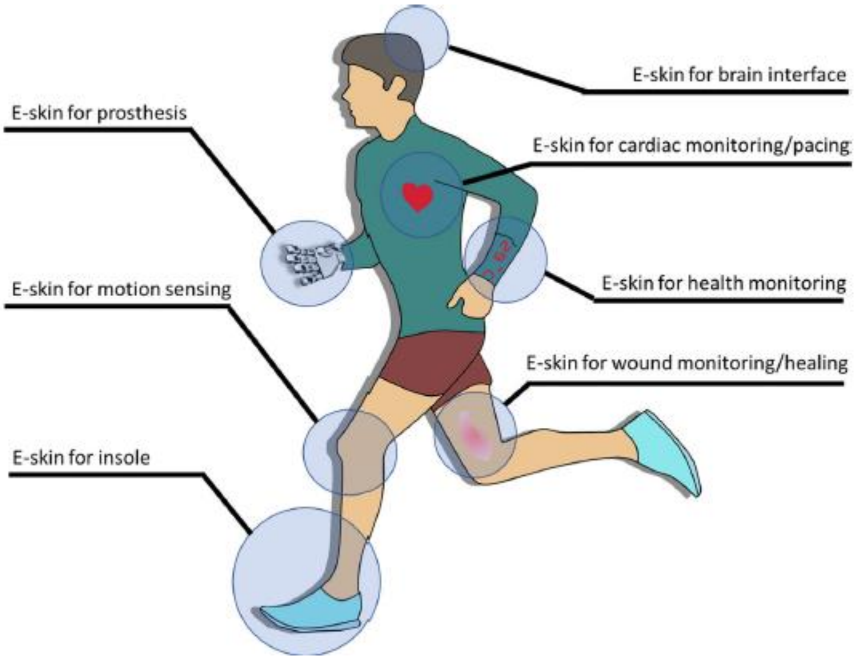


Figure. Mechanism of the electronic skin

Applications of e-skin:

- E-skin can be used for various applications such as monitoring your health, wireless mechanical sensors.
- Electronic skin (e-skin) can be used for various applications such as prosthetics that can mimic the sense of touch, monitors for life signs such as respiration rate and temperature, wound care, and drug delivery.
- E-skin can also be used in wearable or skin attachable devices, robotics, and prosthetics.
- It is important for diabetics to be able to know their blood sugar changes all the time. Continuous blood glucose monitoring system can measure the patients' blood glucose concentration with sensors containing specific enzymes.

- Speech recognition system (ASR) is an e-skin device attached to the throat of human body. It can monitor the weak pressure changes produced by muscle movement and transform them into speech, helping the deaf and mute to communicate.



Synopsis:

E-skin is made by integrating a combination of rigid (off-the-shelf chip components) and soft (a brand-new polymer film called polyimine) materials through a low-cost fabricating method, where the components are printed onto a substrate. The e-skin developed by the Takao Someya Group at the University of Tokyo consists of a network of covalently bound polymers that are thermoset, meaning cured at a specific temperature.

E-Waste: Types, Environmental risks, Recycle Management:

Electronic products that are unwanted, broken, or nearing or exceeding their "useful life" are classified as e-wastes. Everyday electrical items that generate wastes include computers, televisions, VCRs, stereos, copiers, and fax machines. The problem of how to properly dispose of used and unwanted electronics isn't new; it traces back to at least the 1970s. E-waste is not harmful if it is stored in a safe place, recycled using scientific processes, or transferred in parts or in its entirety in the formal sector. However, e-waste that is recycled using primitive technologies might be harmful.

- Electronic-Waste (E-Waste) is a term that describes **out-dated, end-of-life**, or **abandoned electronic appliances**. It contains all of their parts, consumables, and spares.
- **Toxic compounds** naturally leak from the metals inside e-waste when it is buried, making it particularly harmful.
- Informal or uncontrolled e-waste processing, particularly in developing countries, can be harmful to **human health** and pollute the **environment**.

E-waste types:

- **Type 1**- Major appliances (refrigerators, washing machines, dryers etc.)
- **Type 2** – Small appliances (vacuum cleaners, irons, blenders, fryers etc.)
- **Type 3** – Computer and telecommunication appliances (laptops, PCs, telephones, mobile phones etc.),

In general following are the compounds/elements present in e-waste:

Particulars	Sources	Health Effects
Lead	• Used in computer monitor gaskets and glass panels. • Solder components and printed circuit boards.	• Humans' central and peripheral nervous systems, circulatory systems, kidneys, and reproductive systems are all affected by lead. • It also has an impact on the endocrine system and impedes brain development in children.
Cadmium	• SMD chip resistors, infrared	• Cadmium molecules that are toxic

	detectors, and semiconductor chips all contain it. • Cadmium is included in certain older cathode ray tubes.	accumulate in the human body, particularly in the kidneys.
Mercury	• Electrical and electronic equipment is projected to account for 22% of global mercury consumption each year. • Thermostats, sensors, relays, switches, medical equipment, lamps, mobile phones, and batteries all contain mercury. • Mercury use in flat panel displays is expected to rise as cathode ray tubes are phased out.	• Mercury can harm organs such as the brain and kidneys, as well as the developing foetus. • When inorganic mercury dissolves in water, it is converted to dimethyl mercury, which bioaccumulates in living species and concentrates through the food chain, especially through fish.
Hexavalent Chromium/ Chromium VI	• Chromium VI is used to protect untreated and galvanized steel plates from corrosion, as well as to decorate and harden steel housings. PVC (and other plastics). • When PVC is burned, dioxin is emitted. • Cable and computer housings contain PVC components.	• Chromium VI is particularly hazardous in the environment and can destroy DNA.
Barium	• Barium is a soft silvery-white metal that is used in computers to protect users from radiation in the front panel of a CRT.	• Short-term barium exposure causes brain enlargement, muscle weakness, and heart, liver, and spleen damage, according to studies.
Beryllium	• Beryllium can be found on many motherboards and finger clips. • It's a copper-beryllium alloy that keeps electrical conductivity while strengthening connections and tinyplugs.	• Lung cancer can be caused by Beryllium exposure. • Beryllium also produces a skin condition marked by slow wound healing and wartlike lumps. • People can develop Beryllium disease many years after their last exposure, according to studies.
Toners	• Found in the black and colour toner cartridges of a plastic printer cartridge.	• The principal route of exposure is inhalation, and acute exposure can cause respiratory tract irritation. • Carbon black is recognised as a class 2B carcinogen that may cause cancer in humans. • Heavy metals have been found in colour

		toners (cyan, magenta, and yellow), according to reports. •
Phosphor and additives	• Phosphor is an inorganic chemical compound that is placed to the inside of the CRT faceplate as a coat. • Heavy metals, such as cadmium, and other rare earth metals, such as zinc and vanadium, are used as additions in the phosphor coating on cathode ray tubes.	• These metals, as well as their derivatives, are extremely dangerous. • For those who deconstruct CRTs by hand, this is a severe risk.

E-waste - Impacts

On Environment

- The manufacturing, reprocessing, and disposal of electrical and electronic equipment creates an interface between the e-wastes and the environment.
- **Environmental degradation** is caused by the release of fumes, gases, and particulate matter into the air, the discharge of liquid waste into water and drainage systems, and the dumping of hazardous wastes.
- There are several ways in which e-waste recycling can be harmful to the environment.
- Burning wires and cables to recover metal produces brominated and chlorinated **dioxins**, which **pollute the air**.
- Toxic substances with little commercial value are simply discarded during the recycling process in the informal sector.
- Toxic industrial effluent is pumped into **subsurface aquifers**, causing major **groundwater contamination** and rendering the water unfit for human consumption or agricultural use.
- Dismantling activities pollute the atmosphere by releasing dust particles laden with heavy metals and flame retardants into the atmosphere.

- These particles either redeposit (wet or dry deposition) near the emission source or can be carried over vast distances, depending on their size.
- The dust can also **infiltrate** the soil or water systems, where it can combine with compounds found in wet and dry depositions to **pollute the land and water.**
- When dangerous compounds including lead, mercury, cadmium, arsenic, and polychlorinated biphenyls (PCBs) are dumped in landfills, they contaminate the soil causing **soil pollution.**

On Human Health

- Human health is harmed by the complicated nature and inappropriate treatment of e-waste.
- An increasing amount of **epidemiological and clinical evidence** has raised concerns about the potential hazard of e-waste to human health, particularly in emerging nations like India and China.
- Processes such as dismantling components, wet chemical processing, and cremation results in direct chemical exposure and inhalation.
- **Gloves, face masks,** and **ventilation fans** are nearly unknown, and workers sometimes have no idea what they're dealing with.
- In terms of health risks, open burning of printed circuit boards, for example, raises **dioxin** levels in the surrounding environment.
- **Inhalation** of these **chemicals** by workers and locals increases the risk of **cancer**.
- During the laborious extraction and collecting of small amounts of precious metals, toxic metals and poison can enter the bloodstream, and employees are constantly exposed to dangerous chemicals and vapours of extremely concentrated acids.

- Burning **insulated wires** to recover resalable copper causes **neurological problems**, and acute exposure to **cadmium**, which is contained in semiconductors and chip resistors, can harm the **kidneys** and liver, as well as induce **bone loss**.
- Long-term exposure to **lead** from printed circuit boards, computer and television screens can impair the **central and peripheral neurological systems** as well as the **kidneys**, with **children** being particularly **vulnerable**.

E-waste Recycling

There are four methods of managing waste – **recycling, landfilling, composting and burning**. Each method has its strengths and weaknesses.The benefits of the e-waste recycling process are obvious. In present scenario everyone owns an electronic device in today's environment. Recycling electronic garbage has become a need to preserve energy, resources, and landfill space. Consider the following benefits to better comprehend the positive impact of E-waste recycling.

- Conserve natural resources
- Protects the environment
- Create Jobs
- Reduces global warming and saves landfills
- Makes things more affordable
- Reduces business costs
- ·Supports non-renewable recycling
- Conserve both land and energy

Recycle Management

Collection: Gathering E-waste from various sources, enterprises, organizations and individuals.

Storage: While safe storage may not appear critical, it can prove very important. For example, the glass screens of Cathode Ray Tubes (CRT), TVs and monitors are highly contaminated by lead. In the past, they were recycled into new computer monitors, but the growth of new technology and subsequent decline in demand for CRT products means much of this glass is now simply being stored indefinitely.

Manual Sorting, Dismantling and Shredding: Disintegration of all the components and materials of the E-waste to analyse which can be reused and which can go as scrap. E-waste is then shredded into small pieces allowing for accurate sorting of materials, a key part of the process.

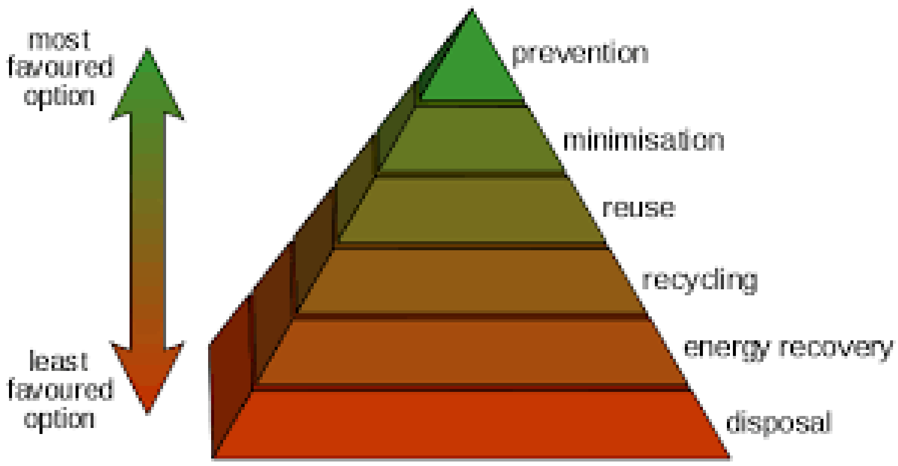
Mechanical Separation: The mechanical separation of the different materials actually consists of several processes one after the other. The two key steps are magnetic separation and water separation.

a) Magnetic separation: The shredded E-waste is passed under a giant magnet, which is able to pull ferrous metals such as iron and steel from the mix of waste. In addition to this, an eddy current may also be used, separating the nonferrous metals. These materials can then be diverted to dedicated recycling plants for smelting. Other materials such as metal-embedded plastic and circuit boards are also separated at this stage.

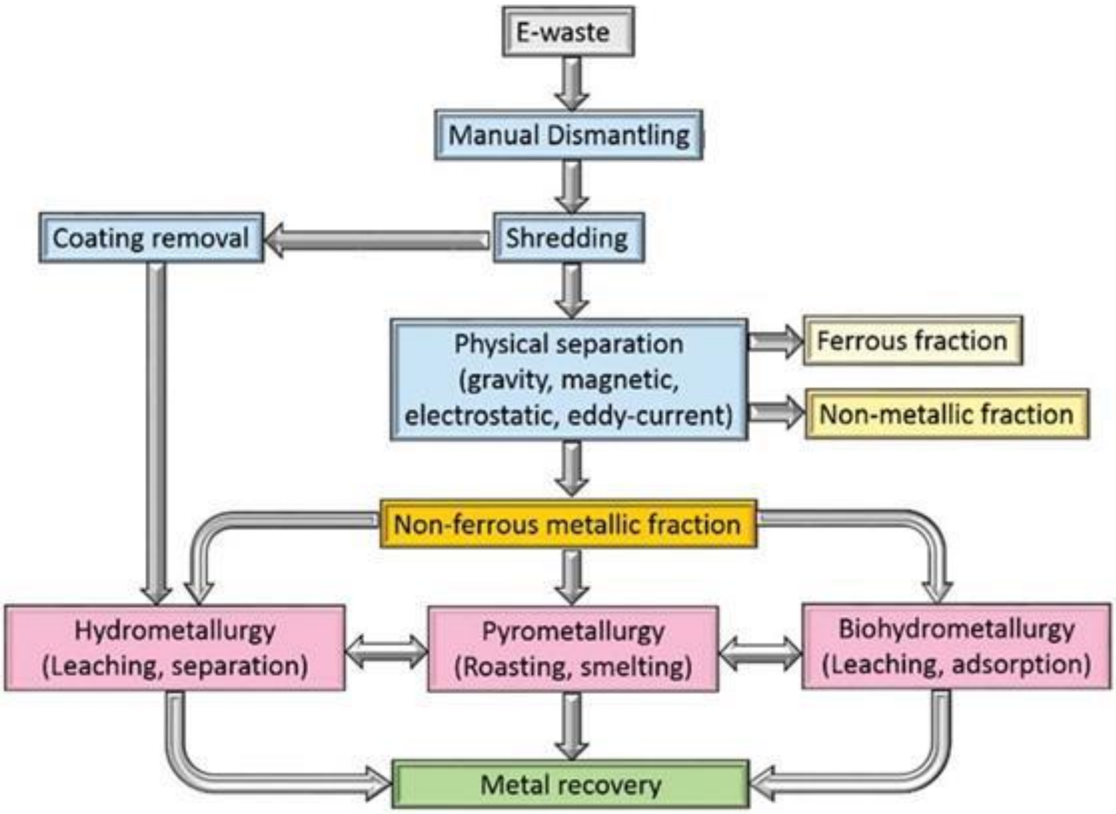
b) **Water separation:** With a solid waste stream that now consists mainly of plastic and glass, water is used to separate the materials, further purifying for the separation of different plastics as well as hand-sorting obvious contaminants.

Recovery:

The materials, now separated, are prepared for sale and reuse. For some materials, such as plastic or steel, this means joining another recycling stream. Others may be processed onsite and sold directly alongside usable components separated in the early stages.



General steps for recycling of E-waste as shown below:



Extraction of valuable metals from E-waste

E-waste is classified as hazardous material therefore should be managed properly. However, the presence of precious metals (PMs) in E-waste such as gold (Au), silver (Ag), platinum (Pt), Gallium (Ga), palladium (Pd), tantalum (Ta), tellurium (Te), germanium (Ge) and selenium (Se) makes it attractive for recycling.

Electronic products have become an integral part of the common man's life. The rapid growth in the electronic industry with technological advancements has resulted in significant changes in consumer patterns. This has accelerated the rate at which these equipment reach their end of 'useful' life leading to an increased rate of obsolescence in the electronics industry. This has resulted in an increase in e-waste generated, rendering it the fastest-growing segment of municipal waste. The Basel Convention requires waste substances or objects to be disposed

The quantum of E-waste generated is increasing at a rate of 5–10% per year and is a growing concern globally because of its toxicity. RoHS (Restriction of Hazardous Substance) directive restricts the use of certain hazardous substances like Pb, Hg, Cd, Cr, and polybrominated biphenyls in electrical and electronic equipment. These pose a risk to health or environment when treated inappropriate ROHS requires minimizing or substitution of these toxic substances with safer materials. This will reduce the load on a recycling plant and the negative impact on the environment.

Synopsis:

Electronic waste, as known as e-waste, is generated when any electronic or electrical equipment becomes unfit for the intended use or if it has crossed its expiry date. Due to rapid technological advancements and the production of newer electronic equipment, the old ones get easily replaced with new models. It has particularly led to an exponential increase in e-waste in India. People tend to switch to the newer models and trending technologies; also, the lives of products get reduced with time. But the issue is left with e-waste management in India and its challenges. Consumers are the key to better e-waste management in India. ***Initiatives such as Extended Producer Responsibility; Design for Environment; (3Rs) Reduce, Reuse, Recycle technology*** platform for linking the market facilitating the circular economy aim to encourage consumers to correctly dispose of the e-waste, with an increased reuse and recycling rates, and also adopt sustainable consumer habits.

E-waste management in India is a great challenge for governments of many developing countries. It is becoming a huge public health issue and is exponentially increasing by the day. It has to be collected separately, treated effectively, and disposed of e-waste. It is also a diversion from conventional landfills and open burning. It is essential to integrate an informal sector with the formal sector. The competent authorities in developing countries need to establish mechanisms for handling and treating e-waste safely and sustainable manner.