Prof S. R Chawade
Dr Archana Sharma

Module 4: SENSORS

1. Introduction about Sensors

For an electronic circuit or system to perform any useful task or function it needs to be able to communicate with the "real world" whether this is by reading an input signal from an "ON/OFF" switch or by activating some form of output device to illuminate a single light. In other words, an Electronic System or circuit must be able or capable to "do" something and **Sensors and Transducers** are the perfect components for doing this.

A sensor is a device that receives and responds to a signal. This signal must be produced by some type of energy, such as heat, light, motion or chemical reaction. Once a sensor detects one or more of these signals (an input), it converts it into an analog or digital representation of the input signal.

Devices which perform an "Input" function are commonly called **Sensors** because they "sense" a physical change in some characteristic that changes in response to some excitation, for example heat or force and covert that into an electrical signal. Devices which perform an "Output" function are generally called **Actuators** and are used to control some external device, for example movement or sound. **Actuators** can be used to switch voltages or currents. An actuator is something that actuates or moves something. More specifically, an actuator is a device that converts energy into motion or mechanical energy. Therefore, an actuator is a specific type of a transducer.

There are many variables which affect our everyday lives: the speed of a car, the velocity of the wind, and the temperature in a home. In most of the situations these variables are continuously monitored. The elements that sense these variables and convert them to a usable output are transducers. The word "Transducer" is the collective term used for both **Sensors** which can be used to sense a wide range of different energy forms such as movement, electrical signals, radiant energy, thermal or magnetic energy etc. There are many different types of sensors and transducers, both analogue and digital and input and output available to choose from. The type of input or output transducer being used, really depends upon the type of signal or process being "Sensed" or "Controlled" but we can define a sensor and transducers as devices that converts one physical quantity into another. Electrical **Transducers** are used to convert energy of one kind into energy of another kind, so for example, a microphone (input device) converts sound waves into electrical signals for the amplifier to amplify (a process), and a loudspeaker (output device) converts these electrical signals back into sound waves and an example of this type of simple Input/Output (I/O) system is given below in Figure 1.

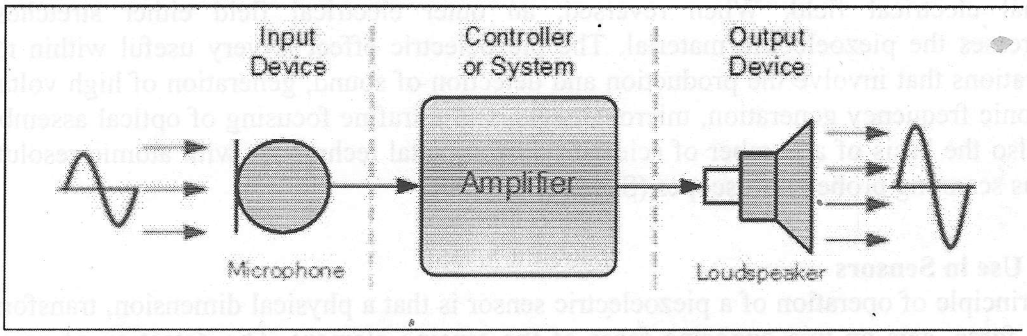


Figure 1: Electrical transducer

Because of the broad definition transducers come in many varieties converting many different types of energy.

2. Effects used in SENSORS Technology

Generally, sensors can be classified into many types based upon the applications, input signal, and conversion mechanism, material used in sensor, production technologies or sensor characteristics such as cost, accuracy or range.
The physical principles or the effects on which a sensor works is grouped in the following **Table 1**:

Domain	Examples
Mechanical	Length, Area, Volume, Torque, Pressure etc.
Electrical	Voltage, Current, Inductance, Resistance etc.
Magnetic	Field Intensity, Flux density etc.
Chemical	Electrochemical effect, spectroscopy etc.
Thermal	Temperature, Entropy, Heat flow etc.
Radiant	Intensity, Phase, Wavelength etc.

Based on the above principles we will be discussing about the following main effects that are being used in the sensors:

2.1. Piezoelectric effect:

Piezoelectric Effect is the ability of certain materials to generate an electric charge in response to applied mechanical stress. The word Piezoelectric is derived from the Greek piezein, which means to squeeze or press, and piezo, which is Greek for "push". One of the unique characteristics of the piezoelectric effect is that it is reversible, meaning that materials exhibiting the **direct piezoelectric effect** (the generation of electricity when stress is applied) also exhibit the **inverse piezoelectric effect** (the generation of stress when an electric field is applied). When piezoelectric material is placed under mechanical stress, a shifting of the positive and negative charge centers in the material takes place, which then results in an external electrical field. When reversed, an outer electrical field either stretches or compresses the piezoelectric material. The piezoelectric effect is very useful within many applications that involve the production and detection of sound, generation of high voltages, electronic frequency generation, microbalances, and ultrafine focusing of optical assemblies. It is also the basis of a number of scientific instrumental techniques with atomic resolution, such as scanning probe microscopes (STM, AFM, etc).

2.1.1. Use in Sensors

The principle of operation of a piezoelectric sensor is that a physical dimension, transformed into a force, acts on two opposing faces of the sensing element. The detection of pressure variations in the form of sound is the most common sensor application, which is seen in piezoelectric microphones and piezoelectric pickups for electrically amplified guitars. Piezoelectric sensors in particular are used with high frequency sound in ultrasonic transducers for medical imaging and industrial nondestructive testing.

2.1.2. Piezoelectric Motors

Because very high voltages correspond to only tiny changes in the width of the crystal, this crystal width can be manipulated with better-than-micrometer precision, making piezo crystals an important tool for positioning objects with extreme accuracy, making them perfect for use in motors. In piezoelectric motors, the piezoelectric element receives an electrical pulse, and then applies directional force to an opposing ceramic plate, causing it to move in the desired direction. Motion is generated when the piezoelectric element moves against a static platform (such as ceramic strips).

2.1.3. Piezoelectric crystals

In a quartz crystal, if an electric voltage is applied in the direction of the electrical axis; mechanical stress is produced in the direction of Y-axis. Conversely, if mechanical stress is applied along the Y- axis, electric charges appear on the faces of the crystal along the X- axis. Consider an X-axis crystal plane of thickness 't' and length 'l' (along the optic axis). When an alternating voltage is applied across the faces of this plate along electrical axis, then alternating stresses and strains are set up both in its thickness and length. If the frequency of alternating voltage is equal to the natural frequency of vibration of the plate, then resonance occurs resulting in large amplitude of oscillation.

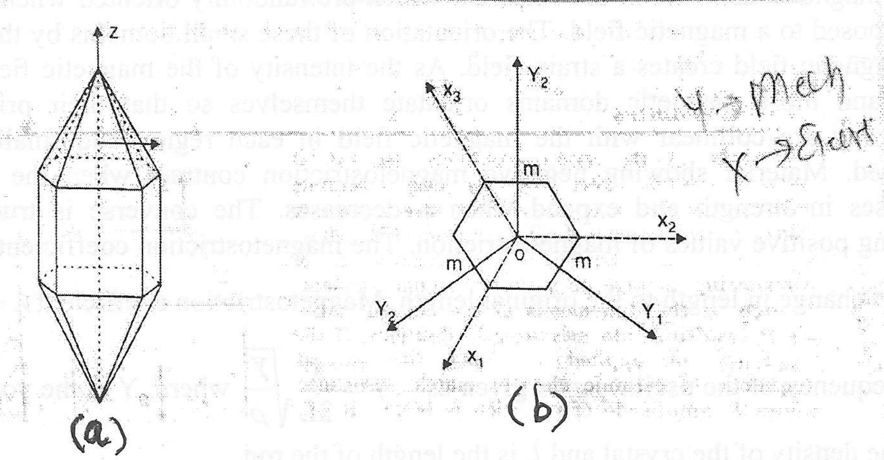


Figure 2 (a) Quartz crystal in natural form (b) shows the section of quartz crystal perpendicular to z- axis

The frequency of the thickness vibration of the crystal can be given as (along X-axis): $f = \frac{1}{2t}\sqrt{\frac{Y}{\rho}}$ where, Y is the young's modulus; ρ is the density of the crystal and t is the thickness of the crystal.

2.2. Magnetostriction effect

Magnetostriction is a phenomenon observed in all ferromagnetic materials. It couples elastic, electric, magnetic and in some situations also thermal fields and is of great industrial interest for use in sensors, actuators, adaptive or functional structures, robotics, transducers and MEMS.

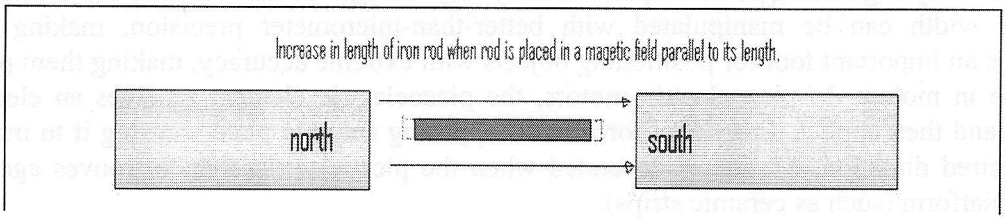


Figure 3: Magnetostriction effect

Magnetostriction is property of ferromagnetic materials that causes them to change their shape or dimension during the process of magnetization (as shown in Figure 3). The variation of materials magnetization due to the applied magnetic field changes the magnetostrictive strain until reaching its saturation value. The effect causes energy loss due to frictional heating in susceptible ferromagnetic cores.

Explanation: A magnetostrictive material develops large mechanical deformations when subjected to an external magnetic field. This phenomenon is attributed to the rotations of small magnetic domains in the material, which are randomly oriented when the material is not exposed to a magnetic field. The orientation of these small domains by the imposition of the magnetic field creates a strain field. As the intensity of the magnetic field is increased, more and more magnetic domains orientate themselves so that their principal axes of anisotropy are collinear with the magnetic field in each region and finally saturation is achieved. Material showing negative magnetostriction contract when the magnetic field increases in strength and expand when it decreases. The converse is true for materials showing positive values of magnetostriction. The magnetostriction coefficient is given as the ratio of change in length to the original length. Magnetostriction coefficient $\lambda = \frac{\delta L}{L}$.

The frequency of the oscillation is given as $f = \frac{1}{2L}\sqrt{\frac{Y}{\rho}}$ where, Y is the young's modulus; ρ is the density of the crystal and L is the length of the rod.

2.2.1. Magnetostriction Transducers:

A magnetostriction transducer is a device that is used to convert mechanical energy into magnetic energy and vice versa. Such a device can be used as a sensor and also for actuation as the **transducer** characteristics is very high due to the bi-directional coupling between mechanical and magnetic states of the material. This device can also be called as an electro-magneto mechanical device as the electrical conversion to its appropriate mechanical energy is done by the device itself. In other devices, this operation is carried out by passing a current into a wire conductor so as to produce a magnetic field or measuring current induced by a magnetic field to sense the magnetic field strength.

2.3. Magnetoresistance

The resistance of some of the metal and the semiconductor material varies in the presence of the magnetic field, which is called the magnetoresistance. The materials showing this property are known as the magnetoresistor. The magnetoresistor is used for determining the presence of a magnetic field their strength and the direction of the force. It is made of the indium antimonide or indium arsenide semiconductor material. The resistance of the magneto resistor is directly proportional to the magnetic field, i.e., their resistance increases with the increase in the intensity of magnetic field. The variation in resistance occurs because of the magneto effect. The magnetoresistor operates without physical contacts which is their major advantage. It has various applications like it is used in the hard disk of the computer, an electronic compass, for measuring the current etc.

Explanation: The working principle of a magneto resistor works on the concept which relates the direction of current and that of magnetic force. The magnetic field strength is highest, when the current is in same direction as that of the magnetic force, while weakest when it is 90^0 to the magnetic force. So how does it affect the resistance of the material? The answer is simple. What is current? Current is nothing but flow of free electrons. When a material is placed in the absence of any magnetic force, these electrons move in an orderly fashion, mostly in straight lines. As soon as it is subjected to magnetic force, the free electrons get excited and start moving in an indirect motion creating collision among them. These collisions restrict the flow of free electrons such that only few can flow freely. This means the flow of current is restricted, that means the electrical resistance has increased with increase in magnetic field strength. Thus, to put in short terms, the resistance of a magneto resistor increases with increase in magnetic field strength and decreases with a decrease in magnetic field strength.

2.4. Seebeck effect

Consider two wires of different metals (say copper and iron) joined at their ends to form two junctions A (Hot junction) and B (Cold junction) as shown in Figure 4. Such an arrangement is called a thermocouple. If one junction is kept hot and other cold, it is observed that the galvanometer shows deflection. This means an e.m.f. is generated in the circuit. The e.m.f. thus produced is called thermo e.m.f. and the resulting current is known as thermoelectric current. Hence, the phenomenon of generation of e.m.f. in a thermocouple when its two junctions are at different temperature is known as Seebeck Effect.

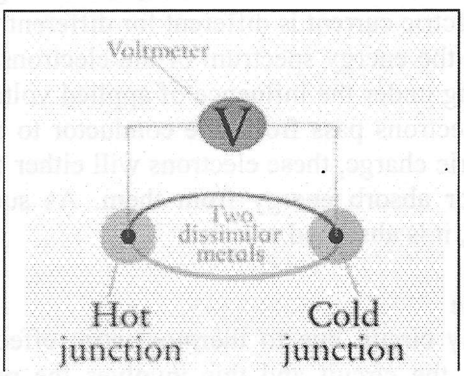


Figure 4: Seebeck effect

Explanation: Seebeck effect is a manifestation of the fact that if two points in a conductor (or a semiconductor) are maintained at different temperatures, the charged carriers (electrons or holes) in the hotter region, being more energetic (and, therefore, having higher velocities) diffuses towards region of lower temperature. The diffusion stops when the electric field generated because of movement of charges has established a strong enough field to stop further movement of charges. For a metal, carriers being negatively charged electrons, the colder end would become negative so that Seebeck coefficient is negative. For a p-type semiconductor on the other hand, holes diffuse towards the lower temperature resulting in a positive Seebeck coefficient. Performance of a thermocouple is determined by the Seebeck coefficient of the pair of metals forming the thermocouple.

2.5. Peltier Effect

The Peltier effect is the reverse phenomenon of the Seebeck effect. The electrical current flowing through the junction connecting two materials will emit or absorb heat per unit time at the junction to balance the difference in the chemical potential of the two materials (Figure 5).

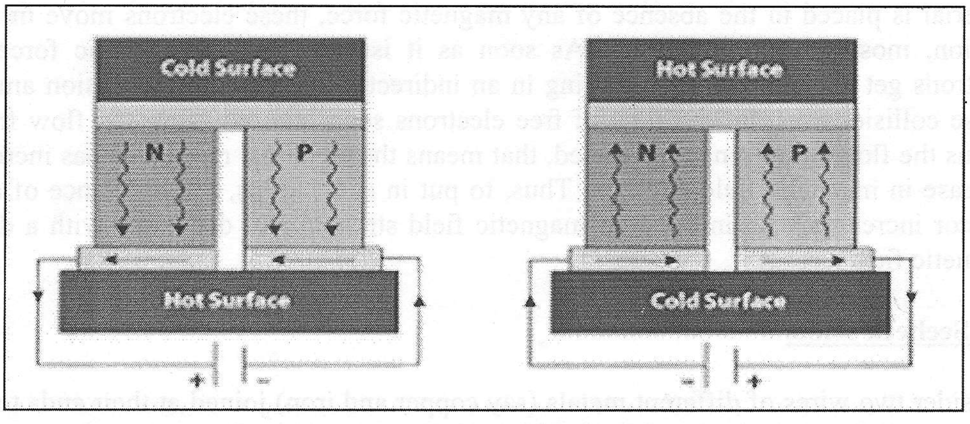


Figure 5: Peltier effect

Explanation: The Peltier effect states that, when an electric current flows through a circuit comprising dissimilar conductors, thermal energy is absorbed from one junction, and is discharged at the other, making the former cooler and the latter hotter. Thus, a thermal gradient develops from the flowing current, making the Peltier effect inverse of the Seebeck effect. The Peltier effect occurs due to the fact that, the average energy of the electrons involved in the transfer of electric current is different for different conductors. It is dependent on several factors, including the energy spectrum of the electrons, their concentration in the conductor, and their scattering under the influence of applied voltage. At the junction of two dissimilar conductors, the electrons pass from one conductor to the other. Depending upon the direction of flow of electric charge, these electrons will either transfer their excess energy to the surrounding atoms, or absorb energy from them. As such, in the former, heat is dissipated, while in the latter, it is absorbed.

2.5.1: Laws of thermocouple

In measuring the emf in any circuit due to thermoelectric effects it is necessary insert a galvanometer somewhere in the circuit and this involves the presence of more than two original metallic junctions, it is important to formulate the laws accoprding to which the emfs produced by additional junctions may be added.

Law of Intermediate Metals: The insertion of an additional metal into any circuit does not alter the whole emf in the circuit provided that the additional metal is entirely at the temperature of the point of the circuit at which it is inserted. Consider a circuit consisting of three metals A, B & C as shown in the Figure 6.

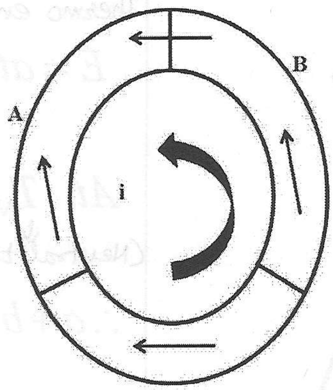


Figure 6: Law of Intermediate Metals

If in the circuit all the junctions are at the same temperature, then the algebraic sum of the three contact potential differences must be 0. i.e. $V_1+V_2+V_3=0$. When the temperature of junction AB is changed, the contact potential difference at this point changes to new value say V_1' but V_2 and V_3 remains the same. The resultant thermo e.m.f in the circuit will be given by $E=V_1'+V_2+V_3$. As $V_2+V_3 = -V_1$, the e.m.f $e = V_1'-V_1$. It shows that if the junction of the thermocouple of elements A & B is opened and third metal 'C' is inserted, the e.m.f for the couple AB remain the same provided both the junctions of the metal 'C' are at the same temperature.

Law of Intermediate Temperatures: Let e (1-2) be the e.m.f for the T1-T2 couple and e (2-3) be that for T2-T3 couple [See Figure 7 (a)]. If the junctions at the temperature T2 be placed in contact, no change is observed, because like metals at the same temperature are only joined. If then the junctions be opened to form the arrangement [See Figure 6 (b)], there is again no change in the resultant e.m.f; for the two contact destroyed, both had the same Peltier effect at temperature T2. We therefore conclude that e[1-3] = e[1-2] + e[2-3].

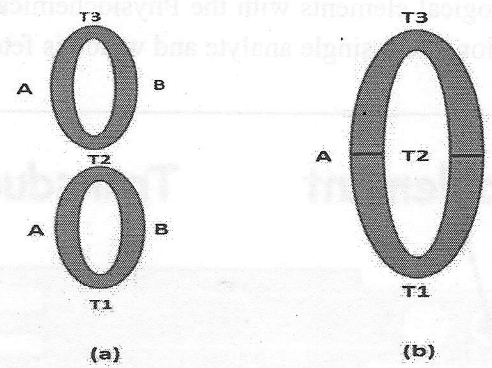
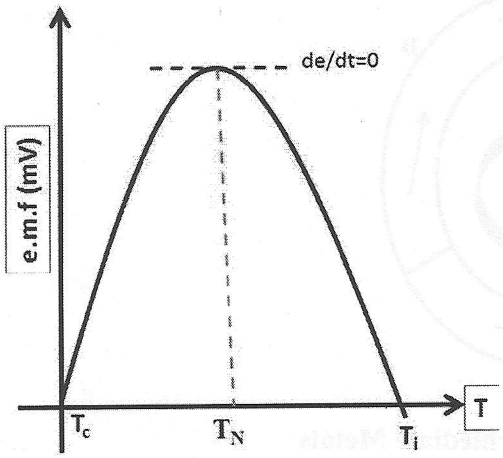


Figure 7: Law of Intermediate Temperature

Variation of e.m.f with temperature: In a thermocouple, as we increase the temperature of the hot junction, keeping the cold junction at 0° C, the thermo e.m.f increases with increase in temperature till it reaches to it its maximum limit. Then for further increase in temperature of hot junction, thermo e.m.f begins to decrease till it returns to zero.



Thermo emf

$$E = at + \frac{bt^2}{2}$$

$$At \quad T_N; \quad \frac{de}{dt} = 0$$

(Neutral temp)

$$\therefore a + bt = 0 \Rightarrow t = -\frac{a}{b}$$

Figure 8: Variation of e.m.f with respect to the Temperature

If we plot a graph of thermo e.m.f in mV and temperature difference between the two junctions, we get a parabola as shown in the Figure 8. The temperature of the hot junction at which the e.m.f achieves its maximum limit is called Neutral temperature T_N and it is constant for a given pair of dissimilar metals. The temperature at which the reversal of e.m.f takes place is called the Temperature of inversion T_i i.e. at T_i the direction of e.m.f is reversed. The value of neutral temperature can be calculated as $T_N = \frac{T_C + T_i}{2}$. T_N is independent of the cold junction temperature and inversion temperature. The inversion temperature T_i depends upon T_c and is as much above the neutral temperature T_N as the cold junction below it.

3. BIOLOGICAL SENSORS

The sensor integrates the biological elements with the Physiochemical transducer to produce an electronic signal is proportional to a single analyte and which is fetched into a detector.

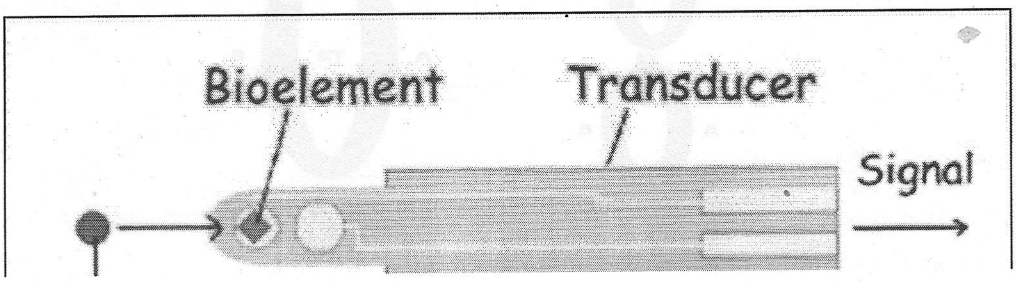


Figure 9: Biosensor

The term 'biosensor' is often used to cover sensor devices used in order to determine the concentration of substances and other parameters of biological interest even where they do not utilise a biological system directly.

3.1. Environmental sensing by plants (Tropism)

Tropisms are the means by which plants grow toward or away from environmental stimuli such as light, gravity, objects to climb, moisture in soil, or the position of the sun. Although plants appear not to move, they have evolved adaptations to allow movement in response to various environmental stimuli; such mechanisms are called tropisms. There are several kinds of tropism, each of which is named for the stimulus that causes the response. For example, gravitropism is a growth response to gravity, and phototropism is a growth response to unidirectional light.
Tropisms are caused by differential growth, meaning that one side of the responding organ grows faster than the other side of the organ. This differential growth curves the organ toward or away from the stimulus. Growth of an organ toward an environmental stimulus is called a positive tropism; for example, stems growing toward light are positively phototropic. Conversely, curvature of an organ away from a stimulus is called a negative tropism. Roots, which usually grow away from light, are negatively phototropic. Tropisms begin within thirty minutes after a plant is exposed to the stimulus and are usually completed within approximately five hours.

3.1.1.Phototropism

Phototropism is a growth response of plants to light coming from one direction. Positive phototropism of stems results from cells on the shaded side of a stem growing faster than cells along the illuminated side; as a result, the stem curves toward the light.

3.1.2.Gravitropism

Gravitropism is a growth response to gravity. The positive gravitropism of roots involves the root cap, a tiny, thimble-shaped organ that covers the tip of roots. Decapped roots grow but do not respond to gravity, indicating that the root cap is necessary for root gravitropism. Gravitropism increases the probability of two important results: Roots will be more likely to encounter water and minerals, and stems and leaves will be better able to intercept light for photosynthesis

3.1.3. Thigmotropism

Thigmotropism is a growth response of plants to touch. The most common example of thigmotropism is the coiling exhibited by specialized organs called tendrils. Tendrils are common on twining plants such as morning glory and bindweed.

3.1.4. Hydrotropism and Heliotropism

Roots also grow toward wet areas of soil. Growth of roots toward soil moisture is called **hydrotropism**. Roots whose caps have been removed do not grow toward wet soil, suggesting that the root cap is the site of moisture perception by roots.
Heliotropism, or "solar tracking," is the process by which plants' organs track the relative position of the sun across the sky, much like a radio telescope tracks stars or satellites. Different plants have different types of heliotropism. The "compass" plants that

grow in deserts orient their leaves parallel to the sun's rays, thereby decreasing leaf temperature and minimizing desiccation.

3.2. Environmental sensing in Animals (Sharks)

Sharks are one of the most feared creatures on Earth. But they are also one of the most sophisticated and enduring. One of the main reasons sharks are such effective predators is their keenly attuned senses. Initially, scientists thought of sharks as giant swimming noses. When researchers plugged the nasal openings in captive sharks, the sharks had trouble locating their prey. This seemed to demonstrate that the shark's other senses weren't as developed as the sense of smell. The shark's nose is definitely one of its most impressive (and prominent) features. As the shark moves, water flows through two forward facing nostrils, positioned along the sides of the snout. The water enters the nasal passage and moves past folds of skin covered with sensory cells. Sharks have a solid reputation for locating prey by smell, especially over long distances.
They can also pick up on the small electrical fields generated by other animals. Near the nostrils, around the head and on the underside of the snout, or rostrum, are small pores called ampullae of Lorenzini. Connected to the pores are long, jelly-filled bulbs that lead to nerves below the skin. Electrical signals coming from muscle movements of other organisms are received by the ampullae and transmitted through jelly-filled bulbs where they strike the nerves and signal the brain. When light is scarce in murky water or at depths, and vision is impaired, this electromagnetic sense is especially useful for locating prey. Sharks can use their ampullae to navigate the globe by tracking earth's electromagnetic field also.

4. MEMS: Micro-electromechanical system

MEMS: It is a process technology used to create tiny integrated devices or systems that combine mechanical and electrical components. They are fabricated using integrated circuit (IC) batch processing techniques and can range in size from a few micrometres to millimetres. These devices (or systems) have the ability to sense, control and actuate on the micro scale, and generate effects on the macro scale. The interdisciplinary nature of MEMS utilizes design, engineering and manufacturing expertise from a wide and diverse range of technical areas including integrated circuit fabrication technology, mechanical engineering, materials science, electrical engineering, chemistry and chemical engineering, as well as fluid engineering, optics, instrumentation and packaging.

MEMS can be found in systems ranging across automotive, medical, electronic, communication and defence applications. Current MEMS devices include accelerometers for airbag sensors, inkjet printer heads, computer disk drive read/write heads, projection display chips, blood pressure sensors, optical switches, biosensors and many other products that are all manufactured and shipped in high commercial volumes.

MEMS have several distinct advantages as a manufacturing technology. In the first place, the interdisciplinary nature of MEMS technology and its micromachining techniques, as well as its diversity of applications has resulted in an unprecedented range of devices and synergies across previously unrelated fields (for example biology and microelectronics). Secondly, MEMS with its batch fabrication techniques enables components and devices to be manufactured with increased performance and reliability, combined with the obvious advantages of reduced physical size, volume, weight and cost. Thirdly, MEMS provides the basis for the manufacture of products that cannot be made by other methods. These factors make MEMS potentially a far more pervasive technology than integrated circuit microchips.

4.1. NEMS: Nano- electromechanical system

Nano-electromechanical systems (NEMS) are made of electromechanical devices that have critical dimensions from hundreds to a few nanometres. By exploring nanoscale effects, NEMS present interesting and unique characteristics, which deviate greatly from their predecessor micro-electromechanical systems (MEMS). For instance, NEMS-based devices can have fundamental frequencies in microwave range (~100 GHz); mechanical quality factors in the tens of thousands, meaning low-energy dissipation; active mass in the femtogram range; force sensitivity at the attonewton level; mass sensitivity up to attogram [2] and subattogram [3] levels; heat capacities far below a "yoctocalorie" [4]; power consumption in the order of 10 attowatts [5]; extreme high integration level, approaching 1012 elements per square centimetre [1]. All these distinguished properties of NEMS devices pave the way to applications such as force sensors, chemical sensors, biological sensors, and ultra-high frequency resonators.

The interesting properties of the NEMS devices typically arise from the behaviour of the active parts, which, in most cases, are in the forms of cantilevers or doubly clamped beams with dimensions at nanometre scale. The materials for those active components include silicon and silicon carbide, carbon nanotubes, and gold and platinum, to name a few. Silicon is the basic material for integrated circuit (IC) technology during the past few decades, and MEMS and is widely used to build NEMS. However, ultra small silicon-based NEMS fail to achieve desired high-quality factors because of the dominance of surface effects, such as surface oxidation and reconstruction, and thermo elastic damping. Limitations in strength and flexibility also compromise the performance of silicon-based NEMS actuators. Instead, carbon nanotubes can well represent the ideas of NEMS, given their nearly one-dimensional structures with high-aspect ratio, perfect terminated surfaces, and excellent electrical and mechanical properties. Because of significant advances in growth, manipulation, and knowledge of electrical and mechanical properties, carbon nanotubes have become the most promising building blocks for the next generation of NEMS. Several carbon nanotube–based functional NEMS devices have been reported so far. Similar to carbon nanotubes, nanowires are another type of one dimensional novel nanostructure for building NEMS because of their size and controllable electrical properties.

4.2. MEMS/NEMS Fabrication

Traditionally MEMS/NEMS are thought of in the context of microelectronics fabrication techniques which utilize silicon. For device fabrication, the basic approach to device construction is generally the same. Material is deposited onto a substrate, a lithographic step is used to produce a pattern, and material removal is conducted to create a shape. For traditional microelectronics fabrication, the substrate is often silicon, material deposition is achieved by vapour deposition or sputtering, lithography involves patterning of a chemically resistant polymer, and material is removed by a chemical etch. Alternatively, for soft MEMS/NEMS materials, fabrication often utilizes a glass or plastic substrate, material in the form of a monomer is flowed into a region, a lithographic mask allows exposure of a pattern to UV radiation triggering polymerization, and the unpolymerized monomer is removed with a flushing solution. For both hard and soft MEMS/NEMS fabrication there are a number of variations of these basic steps. The processes involved for designing MEMs/NEMs devices are summarized below.

1. Lithography
2. Thin film deposition
3. Electroplating
4. Deposition
5. Etching
6. Machining
7. Bonding
8. Surface modification
9. Annealing

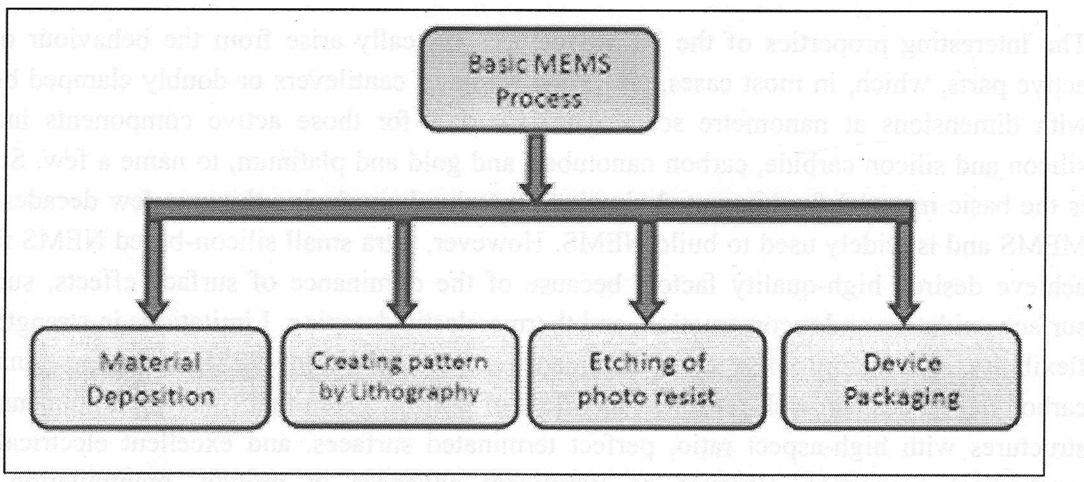


Figure 10: Steps for designing MEMS design

The sensors, actuators and passive structures developed as MEMS and NEMS devices require a highly interdisciplinary approach to their analysis, design, development and fabrication. Experimental mechanics plays a critical role in design development, materials selection, prediction of allowable operating limits, device characterization, process validation, and conduct quality control inspection. Commercial devices exist and research in the area of MEMS/NEMS is extremely active, but many challenges still remains. Advanced materials must be well characterized and MEMS/NEMS testing must be further developed

Diagram showing the steps followed to fabricate MEMS device:

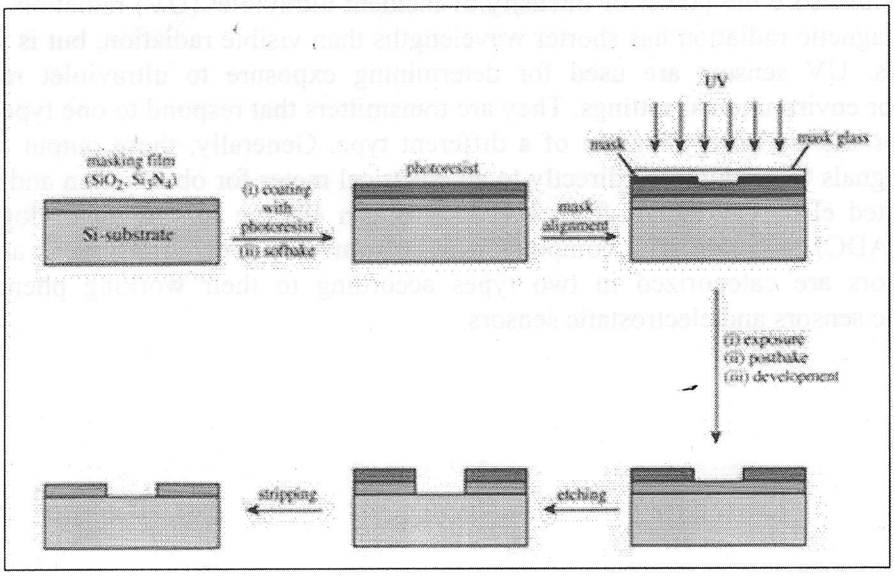


Figure 11: Steps for fabricating MEMS device

5. Other Sensors

<u>5.1. IR Sensors</u>

An infrared sensor is an electronic instrument that is used to sense certain characteristics of its surroundings. It does this by either emitting or detecting infrared radiation. Infrared sensors are also capable of measuring the heat being emitted by an object and detecting motion. Infrared technology is found not just in industry, but also in every-day life. Televisions, for example, use an infrared detector to interpret the signals sent from a remote control. Passive Infrared sensors are used for motion detection systems, and LDR sensors are used for outdoor lighting systems. The key benefits of infrared sensors include their low power requirements, their simple circuitry and their portable features.

The physics behind infrared sensors is governed by three laws:

1. **Planck's radiation law**: Every object at a temperature T not equal to 0 K emits radiation.
2. **Stephan Boltzmann Law**: The total energy emitted at all wavelengths by a black body is related to the absolute temperature.
3. **Wein's Displacement Law**: Objects of different temperature emit spectra that peak at different wavelengths

All objects which have a temperature greater than absolute zero (0 Kelvin) possess thermal energy and are sources of infrared radiation as a result.

Sources of infrared radiation include blackbody radiators, tungsten lamps and silicon carbide. Infrared sensors typically use infrared lasers and LEDs with specific infrared wavelengths as sources. A transmission medium is required for infrared transmission, which can be comprised either of vacuum, the atmosphere or an optical fiber.

5.2. UV Sensors

UV sensors measure the power or intensity of incident ultraviolet (UV) radiation. This form of electromagnetic radiation has shorter wavelengths than visible radiation, but is still longer than X-rays. UV sensors are used for determining exposure to ultraviolet radiation in laboratory or environmental settings. They are transmitters that respond to one type of energy signal by producing energy signals of a different type. Generally, these output signals are electrical signals that are routed directly to an electrical meter for observation and recording. The generated electrical signals from UV sensors can also be sent to an analog-to-digital converter (ADC), and then to a computer with software for generating graphs and reports. These sensors are categorized in two types according to their working phenomenon – piezoelectric sensors and electrostatic sensors.