Unit V: Modern Sensors and Advanced Display Devices.

5.1 INTRODUCTION

History has shown that advancements in materials science and engineering have been important drivers in the development of sensor technologies. For instance, the temperature sensitivity of electrical resistance in a variety of materials was noted in the early 1800s and was applied by **Wilhelm von Siemens in 1860** to develop a temperature sensor based on a copper resistor. The high resonance stability of single-crystal quartz, as well as its piezoelectric properties, have made possible an extraordinarily wide range of high performance, affordable sensors that have played an important role in everyday life and national defense. More recently, a new era in sensor technology was ushered in by the development of large-scale silicon processing, permitting the exploitation of silicon to create new methods for transducing physical phenomena into electrical output that can be readily processed by a computer.

Ongoing developments in materials technology will permit better control of material properties and behavior, thereby offering possibilities for new sensors with advanced features, such as greater fidelity, lower cost, and increased reliability. As noted in the preface, the Committee on New Sensor Technologies: Materials and Applications was asked to identify novel sensor materials that could benefit the manufacture and operation of advanced systems for the Department of Defense and the National Aeronautics and Space Administration and to identify research and development (R&D) efforts that could accelerate the development and incorporation of these emerging sensor materials in particular applications with potentially high payoff.

5.1.1 Definitions

A sensor is a device that detects and responds to some type of input from the physical environment. The specific input could be light, heat, motion, moisture, pressure, or any one of a great number of other environmental phenomena.

A sensor is a device that receives a signal or stimulus and response with an electrical signal (Figure 5.1).

When input is a physical quantity and output electrical → Sensor

When input is electrical and output a physical quantity → Actuator

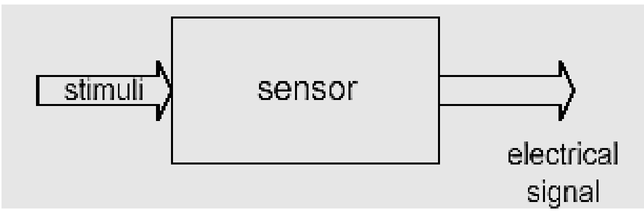


Fig 5.1 Sensor Device

Detectable Phenomenon

Stimulus	Quantity
Acoustic	Wave (amplitude, phase, polarization), Spectrum, Wave Velocity

Biological & Chemical	Fluid Concentrations (Gas or Liquid)
Electric	Charge, Voltage, Current, Electric Field (amplitude, phase, polarization), Conductivity, Permittivity
Magnetic	Magnetic Field (amplitude, phase, polarization), Flux, Permeability
Optical	Refractive Index, Reflectivity, Absorption
Thermal	Temperature, Flux, Specific Heat, Thermal Conductivity
Mechanical	Position, Velocity, Acceleration, Force, Strain, Stress, Pressure, Torque

5.1.1 Need for Sensors

Sensors are omnipresent. They embedded in our bodies, automobiles, airplanes, cellular telephones, radios, chemical plants, industrial plants and countless other applications. Without the use of sensors, there would be no automation!! Imagine having to manually fill Poland Spring bottles.

5..1.2 A good sensor obeys the following rules:

- it is sensitive to the measured property,
- it is insensitive to any other property likely to be encountered in its application,
- it does not influence the measured property.

5.1.3 Types Of Sensors

- **Direct:** A sensor that can convert a non-electrical stimulus into an electrical signal with intermediate stages, e.g. Thermocouple (temperature to voltage)

- **Indirect:** A sensor that multiple conversion steps to transform the measured signal into an electrical signal, for example a fiber-optic displacement sensor (Light Current →photons →current)

5.2 CLASSIFICATION OF SENSORS

Based on physical laws or convenient distinguishing property

1. Active and Passive sensors
2. Contact and non-contact sensors
3. Absolute and relative sensors
4. Others

5.2.1 Active and Passive Sensors

Active sensor: A sensor that requires external power to operate, e.g. carbon microphone, thermistors, strain gauges, capacitive and inductive sensors, etc. The active sensor is also called as parametric sensor (output is a function of a parameter-like resistance).

Passive sensor: It generates its own electric signal and does not require a power source, e.g. thermocouples, magnetic microphones, piezo electric sensors, photodiode. Also called as self-generating sensors

5.2.2 Contact and Non-Contact Sensors

Contact sensor:A sensor that requires physical contact with the stimulus, e.g. strain gauges, temperature sensors.

Non-contact sensor: It requires no physical contact, e.g. most optical and magnetic sensors, infrared thermometers, etc.

5.2.3 Absolute and Relative Sensors

Absolute sensor:A sensor that reacts to a stimulus on an absolute scale, such as thermistors, strain gauges, etc., (thermistor always reads the absolute temperature).

Relative scale:The stimulus is sensed relative to a fixed or variable reference, for example thermocouple measures the temperature difference; pressure is often measured relative to atmospheric pressure.

5.2.4 Others

Classification based on broad area of detection: Electric sensors, Magnetic, Electromagnetic, Acoustic, Chemical, Optical, Heat, Temperature, Mechanical, Radiation, Biological etc.

Classification based on physical law: Photoelectric, Magneto electric, Thermoelectric, Photoconductive, Photo magnetic, Thermomagnetic, Thermo optic, Electro chemical, Magneto resistive, Photo elastic etc.

***Classification as per Application**:* Agriculture, Automotive, Civil engineering and construction, Domestic appliances, Commerce, Finance Environment, Meteorology, security, Energy, Information and Telecommunication, Health and medicine, Marine, Military and Space, Recreation and toys, Scientific measurement, Manufacturing and Transportation and many more…

5.3 Pressure Sensors

A **pressure sensor** measures pressure, typically of gases or liquids. Pressure is an expression of the force required to stop a fluid from expanding, and is usually stated in terms of force per unit area. A pressure sensor usually acts as a transducer; it generates a signal as a function of the pressure imposed. For the purposes of this article, such a signal is electrical. Pressure sensors are used for control and monitoring in thousands of everyday applications. Pressure sensors can also be used to indirectly measure other variables such as fluid/gas flow, speed, water level, and altitude. Pressure sensors can alternatively be called **pressure transducers**, **pressure transmitters**, **pressure senders**, **pressure indicators**, **piezometers** and **manometers**, among other names. Pressure sensors can vary drastically in technology, design, performance, application suitability and cost. A conservative estimate would be that there may be over 50 technologies and at least 300 companies making pressure sensors worldwide.

5.3.1 Application of some pressure sensors

There are many Applications of Pressure Sensors-

- ***Pressure sensing***

  This is where the measurement of interest is pressure, expressed as a force per unit area. This is useful in weather instrumentation, aircraft, automobiles, and any other machinery that has pressure functionality implemented.

- ***Altitude sensing***

  This is useful in aircraft, rockets, satellites, weather balloons, and many other applications. All these applications make use of the relationship between changes in pressure relative to the altitude.

- ***Flow sensing***

  This is the use of pressure sensors in conjunction with the venturi effect to measure flow. Differential pressure is measured between two segments of a venturi tube that have a different aperture.

- ***Level / depth sensing***

  A pressure sensor may also be used to calculate the level of a fluid. This technique is commonly employed to measure the depth of a submerged body (such as a diver or submarine), or level of contents in a tank (such as in a water tower **Leak testing**

- ***Ratiometric Correction of Transducer Output***

  Piezoresistive transducers configured as Wheatstone bridges often exhibit ratio metric behavior with respect not only to the measured pressure, but also the transducer supply voltage.

5.4 BOURDON TUBE PRESSURE GAUGE

5.4.1 Introduction

- Bourdon Tubes are known for its very high range of differential **pressure measurement** in the range of almost 100,000 psi (700 MPa). It is an elastic type pressure transducer.
- The device was invented by Eugene Bourdon in the year 1849.
- The basic idea behind the device is that, cross-sectional tubing when deformed in any way will tend to regain its circular form under the action of pressure.
- The bourdon pressure gauges used today have a slight elliptical cross-section and the tube is generally bent into a C-shape or arc length of about 27 degrees.
- In figure, the pressure input is given to a socket which is soldered to the tube at the base. The other end or free end of the device is sealed by a tip. This tip is connected to a segmental lever through an adjustable length link.
- The lever length may also be adjustable. The segmental lever is suitably pivoted and the spindle holds the pointer as shown in the figure. A hair spring is sometimes used to fasten the spindle of the frame of the instrument to provide necessary tension for proper meshing of the gear teeth and thereby freeing the system from the backlash.
- Any error due to friction in the spindle bearings is known as lost motion. The mechanical construction has to be highly accurate in the case of a Bourdon Tube Gauge. If we consider a cross-section of the tube, its outer edge will have a larger surface than the inner portion. The tube walls will have a thickness between 0.01 and 0.05 inches.

5.4.2 Working

As the fluid pressure enters the bourdon tube, it tries to be reformed and because of a free tip available, this action causes the tip to travel in free space and the tube unwinds. The simultaneous actions of bending and tension due to the internal pressure make a non-linear movement of the free tip. This travel is suitable guided and amplified for the measurement of the internal pressure. But the main requirement of the device is that whenever the same pressure is applied, the movement of the tip should be the same and on withdrawal of the pressure the tip should return to the initial point.

A lot of compound stresses originate in the tube as soon as the pressure is applied. This makes the travel of the tip to be non-linear in nature. If the tip travel is considerably small, the stresses can be considered to produce a linear motion that is parallel to the axis of the link. The small linear tip movement is matched with a rotational pointer movement. This is known as multiplication, which can be adjusted by adjusting the length of the lever. For the same amount of tip travel, a shorter lever gives larger rotation. The approximately linear motion of the tip when converted to a circular motion with the link-lever and pinion attachment, a one-to-one correspondence between them may not occur and distortion results. This is known as angularity which can be minimized by adjusting the length of the link.

Other than C-type, bourdon gauges (Figure 5.2) can also be constructed in the form of a helix or a spiral. The types are varied for specific uses and space accommodations, for better linearity and larger sensitivity. For thorough repeatability, the bourdon tubes materials must have good elastic or spring characteristics. The surrounding in which the process is carried out is also important as corrosive atmosphere or fluid would require a material which is corrosion proof. The commonly used materials are phosphor-bronze, silicon-bronze, beryllium-copper, inconel, and other C-Cr-Ni-Mo alloys, and so on.

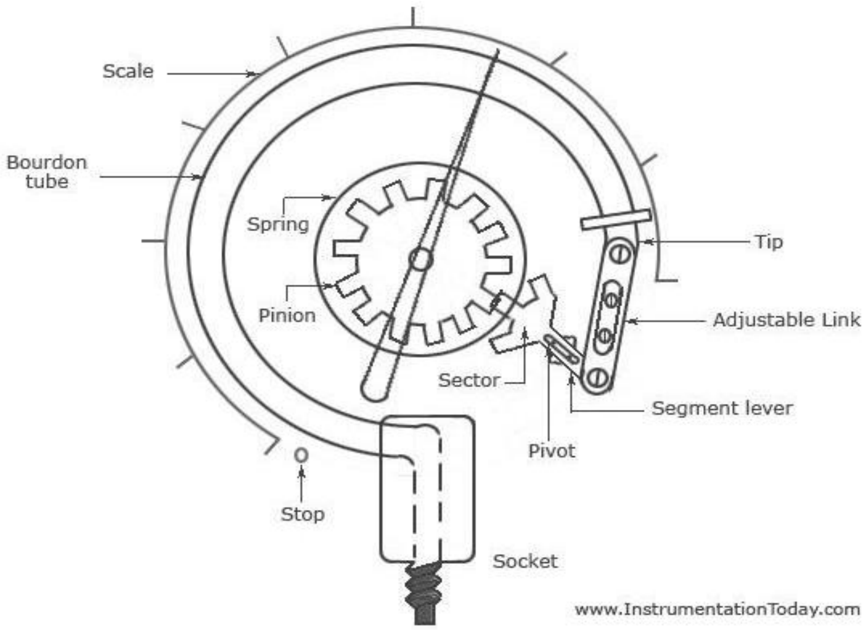


Fig 5.2 Bourdon Tube Pressure Gauge

In the case of forming processes, empirical relations are known to choose the tube size, shape and thickness and the radius of the C-tube. Because of the internal pressure, the near elliptic or rather the flattened section of the tube tries to expand as shown by the dotted line in the figure 5.3 below (a). The same expansion lengthwise is shown in figure (b). The arrangement of the tube, however forces an expansion on the outer surface and a compression on the inner surface, thus allowing the tube to unwind. This is shown in figure (c).

5.4.3 Expansion Of Bourdon Tube Due To Internal Pressure

Like all elastic elements a bourdon tube also has some hysteresis in a given pressure cycle. By proper choice of material and its heat treatment, this may be kept to within 0.1 and 0.5 percent of the maximum pressure cycle. Sensitivity of the tip movement of a bourdon element without restraint can be as high as 0.01 percent of full range pressure reducing to 0.1 percent with restraint at the central pivot.

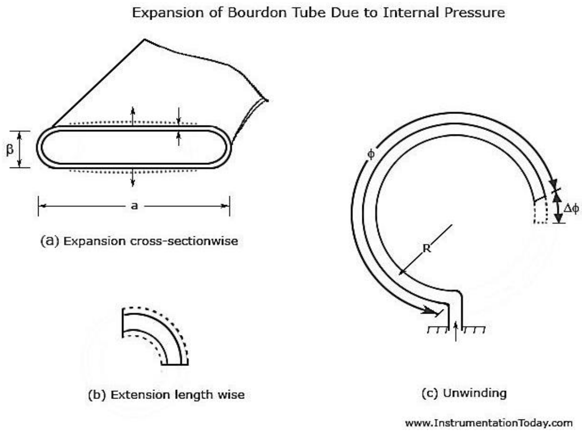


Fig. 5.3 Expansion of Bourdon Tube due to Internal Pressure

5.4.4 STRAIN GAUGES

A strain gauge (or strain gage) is a device used to measure strain on an object. Invented by Edward E. Simmons and Arthur C. Ruge in 1938, the most common type of strain gauge consists of an insulating flexible backing which supports a metallic foil pattern. The gauge is attached to the object by a suitable adhesive, such as cyanoacrylate. As the object is deformed, the foil is deformed, causing its electrical resistance to change. This resistance change, usually measured using a Wheatstone bridge, is related to the strain by the quantity known as the gauge factor. Strain gauges are devices whose resistance changes under the application of force or strain. They can be used for measurement of force, strain, stress, pressure, displacement, acceleration etc.

Principle of Strain Gauges

Each metal has its specific resistance. An external tensile force / (compressive force) increases/decreases the resistance by elongating/contracting it. Suppose the original resistance is R and a strain-initiated change in resistance is ‘ΔR’.

$$\text{Gauge factor (K)} = \frac{\Delta R / R}{\Delta l / l}$$

where, ‘K’ is a gauge factor, the coefficient expressing strain gauge sensitivity. General purpose strain gauges use copper-nickel or nickel-chrome alloy for the resistive element.

Derivation of Strain Gauges

The Strain Gauge Derivation is an example of a passive transducer that uses the variation in electrical resistance in wires to sense the strain produced by a force on the wires. It is well known that stress (force/unit area) and strain (elongation or compression/unit length) in a member or portion of any object under pressure is directly related to the modulus of elasticity. Since strain can be measured more easily by using variable resistance transducers, it is a common practice to measure strain instead of stress, to serve as an index of pressure. Such transducers are popularly known as strain gauges

When force is applied to any metallic wire its length increases due to the strain.

Thus, a tensile stress tends to elongate the wire and thereby increase its length and decrease its cross-sectional area. The combined effect is an increase in resistance, as seen from the following equation

$$R = \rho \, l/A$$

where ‘ρ’ = the specific resistance of the material in Ωm.

‘l’ = the length of the conductor in m

‘A’ = the area of the conductor in m^2

As a result of strain, two physical parameters are of particular interest. The measurement of the sensitivity of a material to strain is called the gauge factor (GF).It is the ratio of the change in resistance ΔR/R to the change in the length Δl/l

$$GF(K) = \frac{\Delta R / R}{\Delta l / l}$$

where ‘K’ = gauge factor

‘ΔR’ = the change in the initial resistance in Ω’s

‘R’ = the initial resistance in Ω (without strain)

‘Δl’ = the change in the length in m

‘l’ = the initial length in m (without strain)

Since, strain is defined as the change in length divided by the original length,

$$\text{i.e. } \sigma = \frac{\Delta l}{l} \qquad (1)$$

Eqn (1) can be written as

$$K = \frac{\Delta R / R}{\sigma} \qquad (2)$$

where ‘σ’ is the strain in the lateral direction. The resistance of a conductor of uniform cross-section is

$$R = \rho \frac{\text{length}}{\text{area}}$$

$$R = \rho \frac{l}{\pi r^2}$$

$$r = \frac{d}{r} \therefore r^2 = \frac{d^2}{4}$$

$$R = \rho \frac{1}{\pi d^2 / 4} = \rho \frac{1}{\pi / 4d^2} \tag{3}$$

where ‘ρ’ = specific resistance of the conductor

‘l’ = length of conductor

‘d’ = diameter of conductor

When the conductor is stressed, due to the strain, the length of the conductor increases by ‘Δl’ and the simultaneously decreases by ‘Δd’ in its diameter. Hence the resistance of the conductor can now be written as,

$$R_s = \rho \frac{(1+\Delta l)}{\pi / 4(d-\Delta d)^2} = \frac{\rho(1+\Delta l)}{\pi / 4(d^2 - 2d\Delta d + \Delta d^2)}$$

Since ‘Δd’ is small, Δd^2 can be neglected,

$$R_s = \rho \frac{(1+\Delta l)}{\pi / 4(d^2 - 2d\Delta d)}$$

$$= \frac{\rho(1+\Delta l)}{\pi / 4d^2 \left(1 - \frac{2\Delta d}{d}\right)} = \frac{\rho l(1+\Delta l / l)}{\pi / 4d^2 \left(1 - \frac{2\Delta^2}{d}\right)} \tag{4}$$

Now, Poisson’s ratio ‘μ’ is defined as the ratio of strain in the lateral direction to strain in the axial direction, that is,

$$R_s = \frac{\rho l(1+\Delta l / l)}{(\pi / 4)d^2(1 - 2\mu\Delta l / l)} \tag{5}$$

Rationalizing we get.

$$R_s = \frac{\rho l(1+\Delta l / l)}{(\pi / 4)d^2(1 - 2\mu\Delta l / l)} \frac{(1+2\mu\Delta l / l)}{(1+2\mu\Delta l / l)}$$

$$R_s = \frac{\rho l}{(\pi/4)d^2}\left[\frac{(1+\Delta l/l)}{(1+2\mu\Delta l/l)}\,\frac{(1+2\mu\Delta l/l)}{(1+2\mu\Delta l/l)}\right]$$

$$R_s = \frac{\rho l}{(\pi/4)d^2}\left[\frac{1+2\mu\Delta l/l+2\Delta l/l+2\mu\Delta l/le\Delta l/l}{1-4\mu^2(\Delta l/l)^2}\right]$$

$$R_s = \frac{\rho l}{(\pi/4)d^2}\left[\frac{1+2\mu\Delta l/l+\delta l/l+2\mu\Delta l^2/l^2}{1-4\mu^2\Delta l^2/l^2)}\right] \qquad (6)$$

Since ‘Δl’ is small, we can neglect higher powers of ‘Δl’,

$$R_s = \frac{\rho l}{(\pi/4)d^2}$$

$R_s = R + \Delta R$

$$\Delta R = \frac{\rho l}{(\pi/4)d^2}(\Delta l/l)(1+2\mu) \qquad (7)$$

The gauge factor will now be

$$K = \frac{\Delta R/R}{\Delta l/l} = \frac{(\Delta l/l)(1+2\mu)}{\Delta l/l}$$

$= 1 + 2\mu$

K = 1 + 2μ

Applications of the Strain Gauges

The strain gauges are used for two main purposes:

1) Measurement of strain: Whenever any material is subjected to high loads, they come under strain, which can be measured easily with the strain gauges. The strain can also be used to carry out stress analysis of the member.

2) Measurement of other quantities: The principle of change in resistance due to applied force can also be calibrated to measure a number of other quantities like force, pressure, displacement, acceleration etc since all these parameters are related to each other. The strain gauges can sense the displacements as small as 5 µm. They are usually connected to the mechanical transducers like bellows for measuring pressure and displacement and other quantities

5.5 TEMPERATURE SENSOR /THERMAL SENSOR/ THERMODYNAMIC SENSOR

Temperature is the most often measured environmental quantity. The physical, chemical, mechanical and biological systems are affected by temperature. Certain chemical reaction, biological process and even electronic circuits perform best within limited temperature ranges. Temperature sensing can be done either through direct contact with the heating source or without direct contact with the source using radiated energy instead.

Types: There is wide variety of temperature sensors, including Thermocouples, Resistance temperature detector (RTD), Thermistor, Infrared & Semiconductor Sensors.

Temperature sensor classification

(i) *Primary Sensor:* If it is possible to relate the temperature (T) directly in the form of Q=NU (Q> any physical quantity, N-number and in unit (U)).eg: Gas sensor, Pressure sensor, Vapour sensor etc.

(ii) Secondary Sensor: If the relation between the temperature (T) with Q,N and U is not direct. eg: Thermal expansion types- solid, liquid and gas; Resistance thermometer- thermocouple, thermistor etc.

Application

Monitoring:	Portable Equipment
	CPU Temperature
	Battery Temperature
	Ambient Temperature
Compensation:	Oscillator Drift in Cellular Phones
	Thermocouple cold-junction compensation
Control:	Battery Charging
	Process control

5.5.1 Resistance Type Thermal Sensor

5.5.1.1 *Thermocouple*

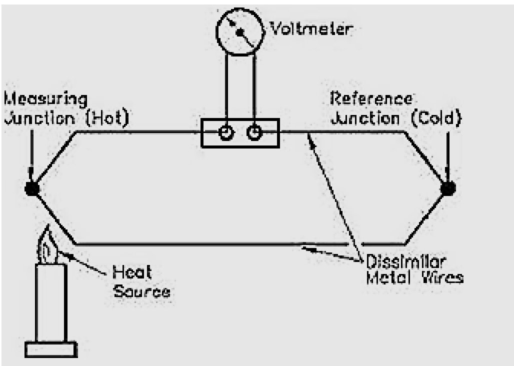


Fig.5.4 Thermocouple

Thermoelectric sensor works on the principle of Seebeck effect and Which is made by joining of two dissimilar metal wires (A,B) are welded together at its ends thus forming 2 junctions (J1 & J2). The two junctions are maintained at two different temperatures (T1 & T2) then an emf (electro motive force) is generated between the 2 junctions because of temperature difference. This is called as Thermo emf/ Tic potential. This effect is called Seebeck effect. The emf appears across the free ends of the thermocouple wires, where it is measured and converted into units of heat calibration. Thermocouples are suitable to be used in temperature ranges from -450F to -4200 F. The magnitude of thermo emf depends on the, (i) composition of two metal wires (ii) temperature T1 & T2 of the respective junctions J1 & J2 (Figure 5.4).

Peltier effect: It states that in a thermocouple, if a current (I) is allowed to flow in the circuit, heat is generated at the cold junction and is absorbed at the hot junction. This effect is known as Peltier effect. Heat flow is proportional to the current I in the circuit.

$$\mathbf{Hf = \pi I}$$

π – Peltier co-efficient.

Thomson effect: With a current flowing through a single metal wire, its heat content changes and a temperature gradient exists along the length. Heat flow is proportional to the current I and temperature gradient.

$$\mathbf{Hf = \sigma\, I\, .\Delta T}$$

σ – Peltier co-efficient

ΔT- temperature gradient.

Types of Thermocouples

1) Base metal type: consists of elements metal & their alloys they are identified by letters E,J, K, N, T. Examples: Chromel Alumel, Chromel constantan, Copper constantan.
2) Nobble/ Precious metal type: made from nobble metal & their alloys. They are identified by letters G, C, D, B, R, S. Example: pt(6%)-Rhodium, pt(30%)-Rhodium.
3) Non-metallic type.

Important Factors

High thermoelectric power, low electrical resister, linearity of E-T curve over the range, high melting point, material should be available as pure & homogeneous, should be stable.

Applications

- Thermocouples are suitable for use in industrial furnaces Applications
- Plastic injection molding machinery
- Food processing equipment
- Deicing
- Semiconductor processing
- Heat treating
- Medical equipment
- Industrial heat treating
- Packaging equipment

Advantages

- Simple, Rugged
- High temperature operation
- Low cost
- No resistance lead wire problems

- Point temperature sensing
- Fastest response to temperature changes

Disadvantages

- Least stable, least repeatable
- Low sensitivity to small temperature changes
- Extension wire must be of the same thermocouple type
- Wire may pick up radiated electrical noise if not shielded
- Lowest accuracy

Limitation

- Non linear
- Low voltage
- Reference required
- Least stable
- Least sensitive output vs. temperature change.

5.6 VIBRATION SENSORS

Vibration is one of the most popular phenomena that exists in our daily life, which is everywhere and at all the time. Vibration is generated as a result of mechanical disturbance from sources such as music/sound, noise, engine, wind and many more. Detection of vibration is an important sensor technology for monitoring the operation of machines, bridges and buildings, warrant of security, prediction of natural disasters and more. As we know, the vibration sensor testing technology has been developed gradually from early last century. With scientists' exploring and researching, and accordingly the test methods and the types of sensors are evolving and maturing. Vibration measurements usually include vibration displacement, velocity, acceleration and others' measurement, usually, the device that converse the vibration into the electrical is called as vibration sensor. Especially in recent years, vibration measurement has become an important method in mechanical structural product's research, design, produce, apply and maintenance. Thus, a variety of vibration sensors made by the effect of physical have drawn more and more attention, with the development of computer technology, electronic technology and manufacturing process, a variety of vibration sensors have come forth in succession in order to using in different areas.

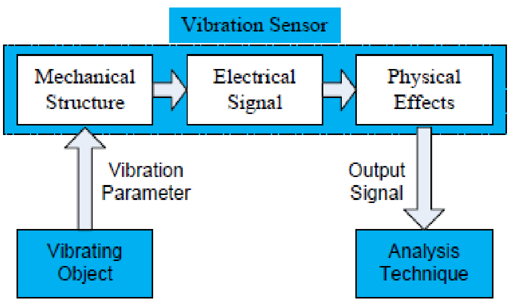


Fig.5.6 Basic Measurement Principle of Vibration Sensor

1) **Measurements on Structures or Machinery Casings-** Used in gas turbines, axial compressors, small and mid-size pumps. These sensors detect high frequency vibration signals

related to bearing supports, casing and foundation resonances, vibration in turbine/compressor vanes, defective roller or ball bearings, noise in gears, etc.

2) Displacement measurements relative to rotating shafts: Proximity Probes (capacitance or eddy-current)

Used in turbomachinery supported on fluid film bearings, centrifugal compressors, gears and transmissions, electric motors, large pumps (>300HP), some turbines and fans. These sensors detect shaft static displacements, unbalance response, misalignment, shaft bending, excessive loads in bearings, dynamic instabilities, etc.

Optic Fiber vibration Sensor

Generally, by the optical fiber sensor, laser and light detector composed of the three parts of Optic fiber sensors. According to the different Operating Principle of Optical fiber sensor can be divided into functional and non-functional. The former is the use of the characteristics of the fiber itself, and use the optical fiber as the sensitive components. The latter is the use of other sensitive components to detect changes of the measured physical quantity; just optical fiber is used as transmission medium to transport the optical signal from distant or inaccessible location of. In practice, the optical fiber as the sensitive components of vibration information directly is difficult to separate the impact of changes from other physical quantities, therefore, the non-functional optical fiber vibration sensors is widely used in the field of vibration detection, where the basic principle is the use of other sensitive detect changes of the measured physical quantity, and the light parameter is modulated by sensitive components. Figure 5.7 is a phase-modulated optical fiber vibration sensor schematic diagram. The vibrating object change the relative phase of signal beam and reference beam, which result in a phase modulation, and by demodulation and detection the phase modulation, you can get the corresponding vibration amplitude.

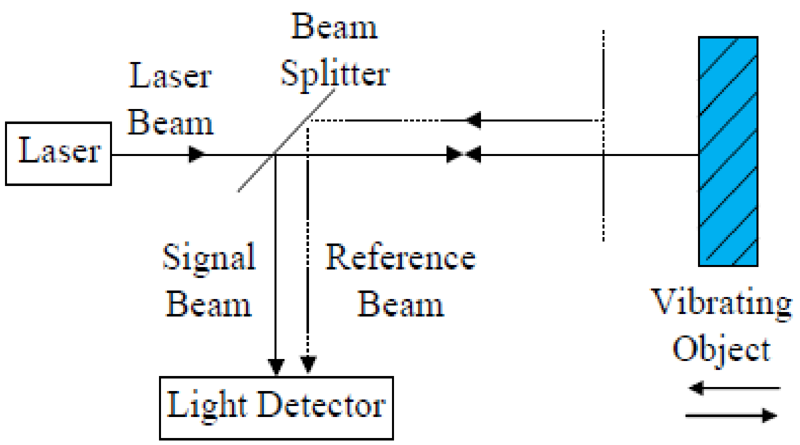


Fig.5.7 Schematic diagram of a phase-modulated optical fiber Vibration Sensor

The prominent features of the optical fiber sensor conclude their ability to be lightweight, very small size, high sensitivity, fast response, resistance to electromagnetic interference, corrosion resistance, electrical insulation, soft bend, suitable for long-distance transmission, and easy to connect with the computer and make telemetry network with fiber optic transmission systems, especially can long-distance vibration in harsh industrial environments. Practice has proved that it has high sensitivity and reliability of persistent work, which can detect the vibration amplitude from 10-12 meters and can be used to three-dimensional vibration measurements.

The disadvantages conclude the narrow range of measurement frequency, high cost and unfamiliarity to the end user. Therefore, the optical fiber vibration sensor has the broad value of further research and development.

5.7 ACOUSTIC SENSORS

Acoustic sensors detect sound via means of using microphones, or other types of filters. Surface acoustic wave sensors are a class of microelectromechanical systems (MEMS) which rely on the modulation of surface acoustic waves to sense. The most common sensor used for acoustic measurement is the microphone. Measurement-grade microphones are different from typical recording-studio microphones because they can provide a detailed calibration for their response and sensitivity. Other sensors include hydrophones for measuring sound in water or accelerometers for measuring vibrations causing sound.

5.7.1 Acoustic Wave Sensors

Acoustic wave sensors are so named because their detection mechanism is a mechanical, or acoustic, wave. As the acoustic wave propagates through or on the surface of the material, any changes to the characteristics of the propagation path affect the velocity and/or amplitude of the wave. Changes in velocity can be monitored by measuring the frequency or phase characteristics of the sensor and can then be correlated to the corresponding physical quantity being measured. Virtually all acoustic wave devices and sensors use a piezoelectric material to generate the acoustic wave. Piezoelectricity refers to the production of electrical charges by the imposition of mechanical stress. The phenomenon is reciprocal. Applying an appropriate electrical field to a piezoelectric material creates a mechanical stress. Piezoelectric acoustic wave sensors apply an oscillating electric field to create a mechanical wave, which propagates through the substrate and is then converted back to an electric field for measurement. Among the piezoelectic substrate materials that can be used for acoustic wave sensors and devices, the most common are quartz (SiO_2), lithium tantalite ($LiTaO_3$), and, to a lesser degree, lithium niobate ($LiNbO_3$). An interesting property of quartz is that it is possible to select the temperature dependence of the material by the cut angle and the wave propagation direction. The advantage of using acoustic waves (vs electromagnetic waves) is the slow speed of propagation (5 orders of magnitude slower). For the same frequency, therefore, the wavelength of the elastic wave is 100,000 times shorter than the corresponding electromagnetic shortwave. This allows for the fabrication of very small sensors with frequencies into the gigahertz range with very fast response times. Solid state acoustic detectors have the electric circuit coupled to the mechanical structure where the waves propagate. The sensor generally has two (piezoelectric) transducers at each end. One at the transmitting end (generator) and one at the receiving end (receiver) where the wave is converted into an electric signal.

5.8 LIGHT DEPENDENT RESISTOR (LDR)

A photoresistor or Light-Dependent Resistor (LDR) or photocell is a light-controlled variable resistor. The resistance of a photoresistor decreases with increasing incident light intensity; in other words, it exhibits photoconductivity as shown in Figure 5.11. A photoresistor can be applied in light-sensitive detector circuits, and light- and dark-activated switching circuits.

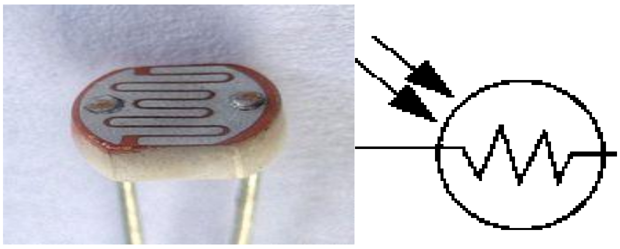


Fig.5.11 The symbol for a photoresistor

Working Principle of LDR

A light dependent resistor works on the principle of photo conductivity. Photo conductivity is an optical phenomenon in which the materials conductivity is increased when light is absorbed by the material. When light falls i.e. when the photons fall on the device, the electrons in the valence band of the semiconductor material are excited to the conduction band. These photons in the incident light should have energy greater than the band gap of the semiconductor material to make the electrons jump from the valence band to the conduction band. Hence when light having enough energy strikes on the device, more and more electrons are excited to the conduction band which results in large number of charge carriers. The result of this process is more and more current starts flowing through the device when the circuit is closed and hence it is said that the resistance of the device has been decreased. This is the most common working principle of LDR.

Characteristics of LDR

LDR's are light dependent devices whose resistance is decreased when light falls on them and that is increased in the dark. When a light dependent resistor is kept in dark, its resistance is very high. This resistance is called as dark resistance. It can be as high as $10^{12}\ \Omega$ and if the device is allowed to absorb light its resistance will be decreased drastically. If a constant voltage is applied to it and intensity of light is increased the current starts increasing. The Figure 5.12 shows resistance Vs illumination curve for a particular LDR .

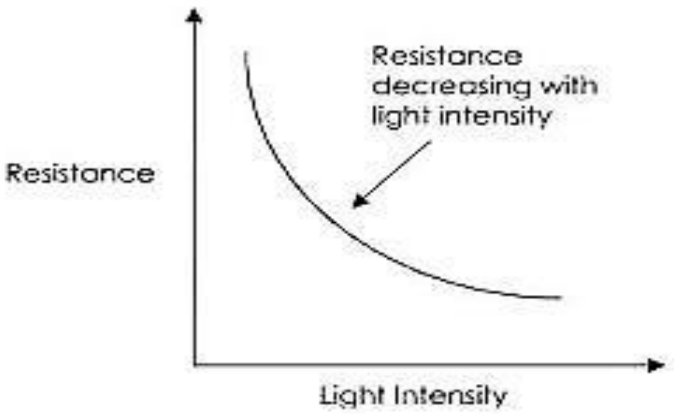


Fig.5.12 Variation of resistance Vs light intensity

When light is incident on a photocell it usually takes about 8 to 12ms for the change in resistance to take place, while it takes one or more seconds for the resistance to rise back again to its initial value after removal of light. This phenomenon is called as resistance recovery rate. This property is used in audio compressors. Also, LDR's are less sensitive than photo diodes and photo transistor.

Types of Light Dependent Resistors

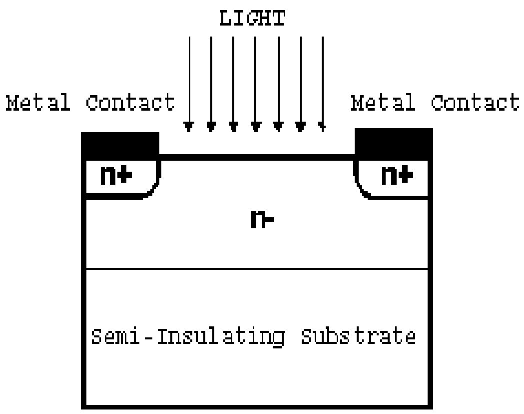
Based on the materials used they are classified as:

i) Intrinsic photo resistors (Undoped semiconductor): These are made of pure semiconductor materials such as silicon or germanium. Electrons get excited from valance band to conduction band when photons of enough energy fall on it and number of charge carriers is increased.

ii) Extrinsic photo resistors: These are semiconductor materials doped with impurities which are called as dopants. These dopants create new energy bands above the valence band which are filled with electrons. Hence this reduces the band gap and less energy is required in exciting them. Extrinsic photo resistors are generally used for long wavelengths.

Construction of a LDR

The structure of a light dependent resistor consists of a light sensitive material which is deposited on an insulating substrate such as ceramic. The material is deposited in zigzag pattern in order to obtain the desired resistance & power rating. This zigzag area separates the metal deposited areas into two regions. Then the ohmic contacts are made on either sides of the area. The resistances of these contacts should be as less as possible to make sure that the resistance mainly changes due to the effect of light as shown in Figure 5.13. Materials normally used are cadmium sulphide, cadmium selenide, indium antimonide and cadmium sulphonide. The use of lead and cadmium is avoided as they are harmful to the environment.



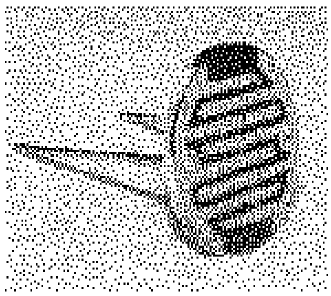


Fig.5.13 Construction of a Photocell

Applications of LDR

1. LDR's have low cost and simple structure.
2. They are often used as light sensors.
3. They are used when there is a need to detect absence or presence of light as in a camera light meter.
4. Used in street lamps, alarm clock, burglar alarm circuits, light intensity meters, for counting the packages moving on a conveyor belt, etc.

5.9 PHOTODIODE

Introduction

A photodiode is a semiconductor device that converts light into current. The current is generated when photons are absorbed in the photodiode. A small amount of current is also produced when no light is present. Photodiodes may contain optical filters, built-in lenses, and may have large or small surface areas. Photodiodes usually have a slower response time as their surface area increases. The common, traditional solar cell used to generate electric solar power is a large area photodiode. Photodiodes are similar to regular semiconductor diodes except that they may be either exposed (to detect vacuum UV or X-rays) or packaged with a window or optical fiber connection to allow light to reach the sensitive part of the device. Many diodes designed for use specifically as a photodiode use a PIN junction rather than a p–n junction, to increase the speed of response. A photodiode is designed to operate in reverse bias.

Principle of Operation

A photodiode is a p–n junction or PIN structure. When a photon of sufficient energy strikes the diode, it creates an electron-hole pair. This mechanism is also known as the inner photoelectric effect. If the absorption occurs in the junction's depletion region, or one diffusion length away from it, these carriers are swept from the junction by the built-in electric field of the depletion region. Thus holes move toward the anode, and electrons toward the cathode, and a photocurrent is produced. The total current through the photodiode is the sum of the dark current (current that is generated in the absence of light) and the photocurrent, so the dark current must be minimized to maximize the sensitivity of the device.

Photovoltaic Mode

When used in zero bias or photovoltaic mode, the flow of photocurrent out of the device is restricted and a voltage builds up. This mode exploits the photovoltaic effect, which is the basis for solar cells – a traditional solar cell is just a large area photodiode.

Photoconductive mode

In this mode the diode is often reverse biased (with the cathode driven positive with respect to the anode). This reduces the response time because the additional reverse bias increases the width of the depletion layer, which decreases the junction's capacitance. The reverse bias also increases the dark current without much change in the photocurrent. For a given spectral distribution, the photocurrent is linearly proportional to the illuminance (and to the irradiance). Although this mode is faster, the photoconductive mode tends to exhibit more electronic noise.

I-V Characteristic of a photodiode

The linear load lines represent the response of the external circuit and is shown in Figure 5.14. I = (Applied bias voltage-Diode voltage)/Total resistance. The points of intersection with the curves represent the actual current and voltage for a given bias, resistance and illumination.

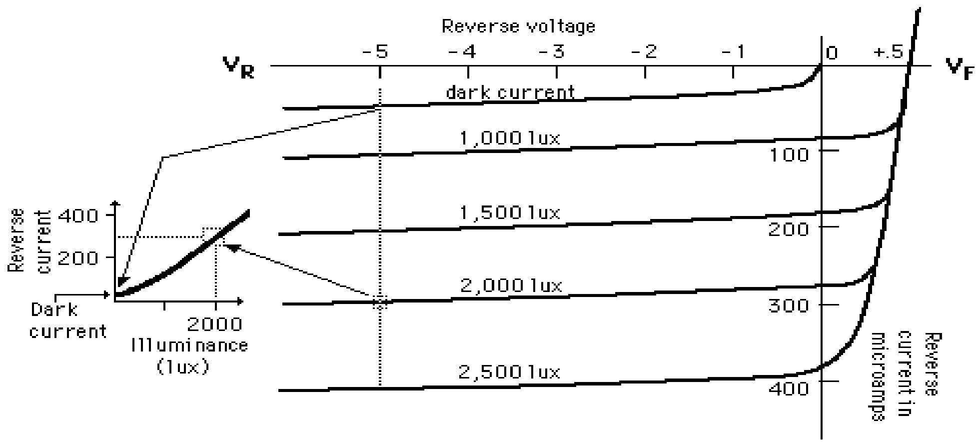


Fig 5.14 I-V Characteristic of a photodiode

Materials commonly used to produce photodiodes

The material used to make a photodiode is critical in defining its properties, because only photons with sufficient energy to excite electrons across the material's band gap will produce significant photocurrents.

Material	Electromagnetic spectrum wavelength range (nm)
Silicon	190–1100
Germanium	400–1700
Indium gallium arsenide	800–2600
Lead (II) sulfide	<1000–3500
Mercury cadmium telluride	400–14000

Applications of photodiode

1. p–n photodiodes are used in similar applications to other photodetectors, such as photoconductors, charge-coupled devices, and photomultipliers tubes.

2. Photodiodes are used in consumer electronics devices such as compact disc players, smoke detectors and the receivers for infrared remote-control devices used to control equipment from televisions to air conditioners. Either type of photosensor may be used for light measurement, as in camera light meters, or to respond to light levels, as in switching on street lighting after dark.

3. Photosensors of all types may be used to respond to incident light, or to a source of light which is part of the same circuit or system. A photodiode is often combined into a single component with an emitter of light, usually a light-emitting diode (LED), either to detect the presence of a mechanical obstruction to the beam (slotted optical switch), or to couple two digital or analog

circuits while maintaining extremely high electrical isolation between them, often for safety (optocoupler).

4. Photodiodes are often used for accurate measurement of light intensity in science and industry. They generally have a more linear response than photoconductors.

5. They are also widely used in various medical applications, such as detectors for computed tomography (coupled with scintillators), instruments to analyze samples (immunoassay), and pulse oximeters.

6. PIN diodes are much faster and more sensitive than p–n junction diodes and hence are often used for optical communications and in lighting regulation.

5.10 DISPLAY DEVICES

The **display devices** are output devices to display the information in visual form by means of various types of display systems. The classification of display devices are-

They are classified as analog and Digital displays

1.Analog display devices
•Oscilloscope tubes
•TV CRTs

2**.Digital display devices**
•LED (including OLED) displays
•LCD (liquid crystal) displays
•Thin Film Transistor-LCD (TFT-LCD)
•PDPs (Plasma display panels)

3**.Others**
•Electronic paper (e-paper)
•Using principles of nanoelectronics (carbon nanotubes, nanocrystals) were developed and they serves as low dimensional display devices.

Another classification is –

1. **Active display devices-** the visual information is presented by emitting light. They are based on different luminescence phenomena. *Luminescence* is the general term used to describe the emission of electromagnetic radiation from a substance due to a non-thermal process. Luminescence occurs from a solid when it is supplied with some energy.

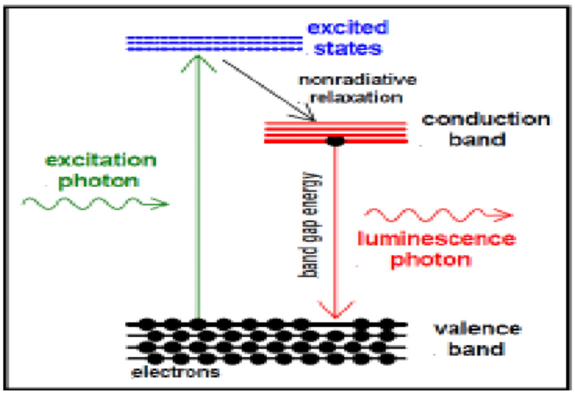
Photoluminescence (abbreviated as **PL**) is light emission from matter (usually semiconductor, dielectric) after the absorption of photons (electromagnetic radiation).

The phenomenon is like this - Light is directed onto a sample, where it is absorbed and imparts excess energy into the material in a process called *photo-excitation*. One way this excess energy can be dissipated by the sample is through the emission of light, or *luminescence*. In the case of photo-excitation, this luminescence is called *photoluminescence*.

Photo-excitation causes electrons within a material to move into permissible excited states. Following excitation, various relaxation processes typically occur in which other photons are re-radiated. When these electrons return to their equilibrium states, the excess energy is released and may include the emission of light (a radiative process) or may not (a nonradiative process). The energy of the emitted light (photoluminescence) relates to the difference in energy levels between the two electron states involved in the transition between the excited state and the equilibrium state. The quantity of the emitted light is related to the relative contribution of the radiative process.

Other type of luminescence are-

- *Cathodoluminescence*- material is excited by bombardment with a beam of electrons.
- *Electroluminescence*- is a result of excitation from the application of an electric field.
- *Fluorescence*- persists for a short lifetime of the transition between the two energy levels.
- *Phosphorescence* persists for much longer time (more than 10^{-8} s).



2. **Passive display devices –** visual information is presented by reflection or modulation of light

Attributes of a good display device

•Pixel Resolution

It depends on

•No. of pixels per unit video display. Ex: Video Graphics Array (VGA)

•720 pixels across by 400 pixels down in text mode

•640 pixels across by 480 pixels down in graphics mode.

•Display size

•Measured as distance from one corner to the diagonally opposite corner.

•Usually measured in INCHES.

•Viewing angle

•It is angle from which the screen can be seen from side.

•It is larger for CRT as compared to LCD

•Response time

•The minimum time necessary to change a pixel's color or brightness.

•Persistence
•How long a phosphor continue to emit light.

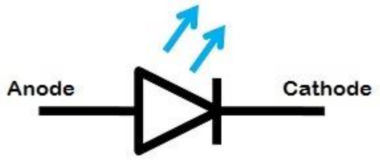
•Lower persistence phosphors require higher refresh rate to maintain a picture on the screen without flicker.

•Aspect ratio
•This number gives the ratio of vertical points to horizontal points to produce equal-length lines in both directions on the screen.

•Brightness
•The amount of light emitted from the display (more specifically known as **luminance**).

5.11 LIGHT EMITTING DIODE (LED)

The light emitting diode is a p-n junction diode. It is a specially doped diode and made up of a special type of semiconductors. When the light emits in the forward biased pn junction diode, then it is called a light-emitting diode. It acts as an active display device.
The LED symbol is similar to a diode symbol except for two small arrows that specify the emission of light, thus it is called LED (light-emitting diode). The LED includes two terminals namely anode (+) and the cathode (-). The LED symbol is shown below.



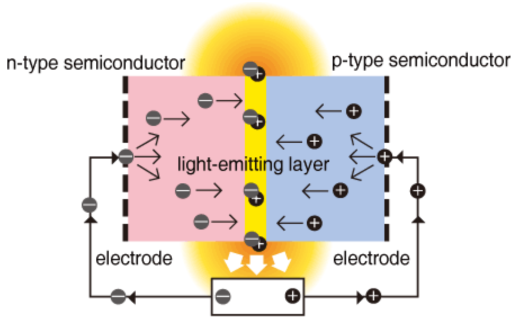
Construction and operation of LED

The construction of LED is very simple because it is designed through the deposition of semiconductor material layers over a substrate. These layers are - P-type region and N-type region. In the construction, the P-type region includes the holes; the N-type region includes electrons whereas the junction of themincludes both holes and electrons called depletion region

When the voltage is not applied to the LED, then there is no flow of electrons and holes so they are stable. Once the voltage is applied then the LED will forward biased, so the electrons in the N-region and holes from P-region will move to the depletion region. Because the charge carriers i.e. holes include a positive charge whereas electrons have a negative charge, recombination of opposite polarity charges gives a little burst of energy in the form of a tiny packet or photon of light i.e. light is generated at recombination.

The emitted light may be visible or invisible. The amount of light output is directly proportional to the forward current. Thus, the higher the forward current, the higher is the light output.

The diagram shows how the light-emitting diode works and the step by step process of the diagram are

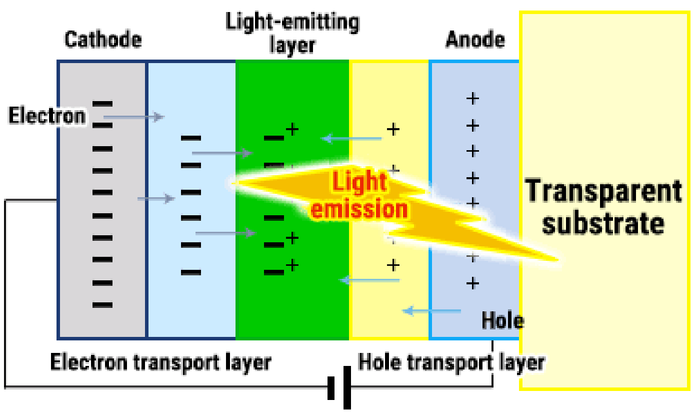


- From the above diagram, we can observe that the N-type region is in red color including the electrons which are indicated by the black circles.
- The P-type region is in the blue color and it contains holes, they are indicated by the white circles.
- The power supply across the p-n junction makes the diode forward biased and pushing the electrons from n-type to p-type. Pushing the holes in the opposite direction.
- Electron and holes at the junction are combined.
- The photons are given off as the electrons and holes are recombined.

A LED display is a flat panel display that uses an array of light-emitting diodes as pixels for a video display. By varying the brightness of each LED, the diodes jointly form an image on the display. To create bright colour image, the principles of additive colour mixing are used, whereby new colours are created by mixing light in different colours. LED display contain red, green, blue LEDs. These three colours combine to form a pixel. By adjusting intensity of light from each LED, billions of colours can be formed. When we look at LED screen from certain distance, the array of coloured pixels are seen as image.

Types of Light-emitting diode (LED) display

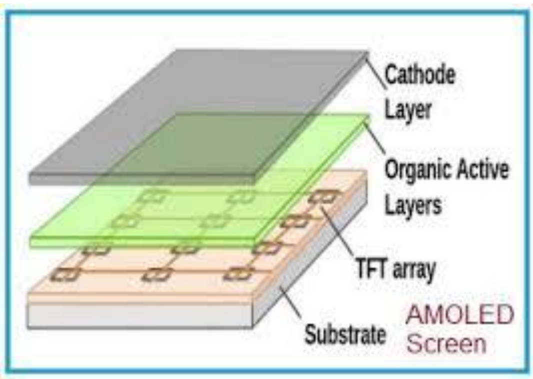
<u>OLED display</u>- OLED's are simple solid-state devices comprised of very thin films of organic compounds in the electro-luminescent layer. OLED emits light by conducting electricity to the organic materials that are sandwiched between the electrodes. Out of these one of the electrodes should be transparent. The result is a very bright and sharp display with power consumption lesser than LED.



How does this sandwich of layers make light?

1. To make an OLED light up, we simply attach a voltage (potential difference) across the anode and cathode.
2. As the electricity starts to flow, the cathode receives electrons from the power source and the anode loses them (or it receives holes).
3. Now we have a situation where the added electrons are making the cathode negatively charged (similar to the n-type layer in a junction diode), while the anode is becoming positively charged (similar to p-type material).
4. Positive holes and negative electrons jump to the organic layer. Electrostatic forces bring the electrons and the holes towards each other and they recombine forming an exciton, a bound state of the electron and hole. The decay of this excited state results in a relaxation of the energy levels of the electron, accompanied by emission of radiation whose frequency is in the visible region. The frequency of this radiation depends on the band gap of the material. This process happens many times a second thus OLED produces continuous light for as long as the current keeps flowing.

AMOLED display- AMOLED (active-matrix organic light-emitting diode) is a variant of OLED display device technology. OLED describes a specific type of thin-film-display technology in which organic compounds form the electroluminescent material, and active matrix refers to the technology behind the addressing of pixels. An AMOLED display consists of an active matrix of OLED pixels generating light (luminescence) upon electrical activation that have been deposited or integrated onto a thin-film transistor (TFT) array, which functions as a series of switches to control the current flowing to each individual pixel.



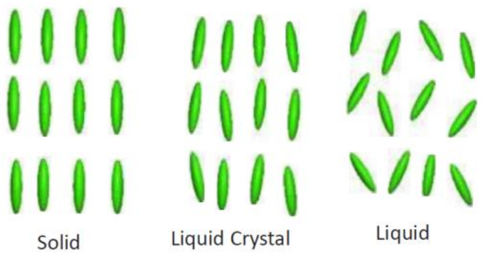
AMOLED thus improves basic OLED technology for larger televisions, monitors and laptop displays by introducing a Thin Film Transistor (TFT) layer that enables greater control over the light emitted by the OLEDs by controlling the current to each pixel. The TFT layer provides an enhanced, "active matrix" of light control.

5.12 LIQUID CRYSTAL DISPLAY (LCD)

A **liquid crystal display** is a thin, flat passive display device made up of any number of pixels arrayed in front of a light source or reflector. This contains the liquid crystals and these displays do not contain the tubes. So, there isn't any electronic gun as well and one doesn't have to worry about the electrons painting the display like CRT. Instead, there is a back light that always keeps the liquid crystal display on. The power is given to a transistor which then repolarizes light and that's what enables the light to come out and show a specific colour. Since there is always a light that is shining through, the LCD displays do not contain the black set blacks. It uses very small amounts of electric power, and is suitable for use in battery-powered electronic devices.

What is liquid crystal?

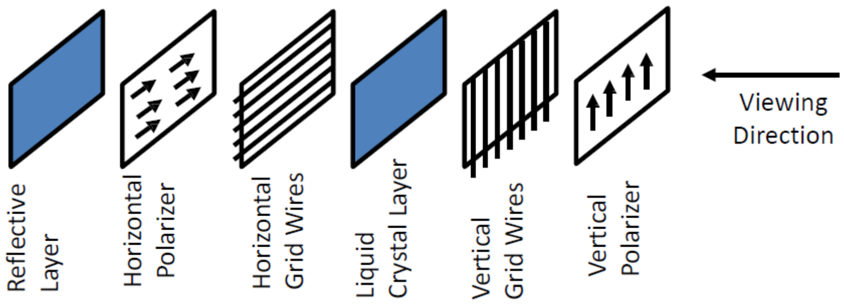
A liquid crystal (usually, an organic compound) is a substance that flows like a liquid, but its molecules orient themselves in the manner of a crystal. That is, it is an organic compounds, whose macroscopic behavior resemble that of liquid but shows physical properties of crystals. As is well-known, the molecules in ordinary liquids have random orientation but in a liquid crystal, they are oriented in a definite crystal pattern.



LCD Construction

•Each pixel of an LCD consists of a layer of molecules aligned between two transparent electrodes, and two polarizing filters, whose axes are perpendicular.

•Orientation of the liquid crystal molecules is determined by the alignment at the surfaces.

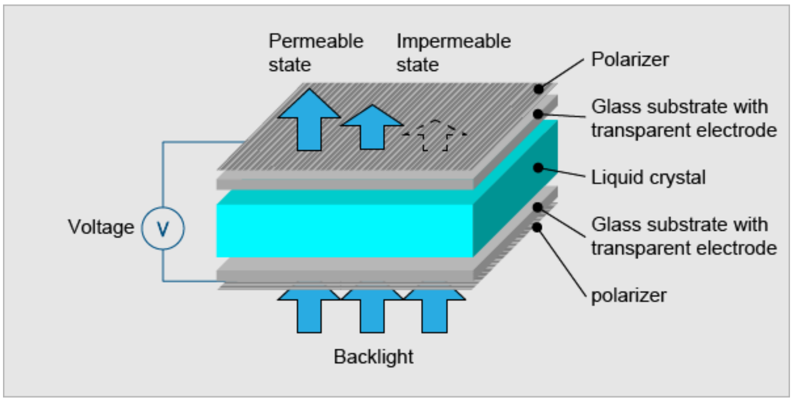


How does LCD work?

A liquid crystal display (LCD) has liquid crystal material sandwiched between two sheets of glass. Normally, a thin layer of the liquid crystal is transparent to incident light but when an electric field is applied across it, its molecular arrangement is disturbed causing changes in the light that falls on an activated layer of a liquid crystal, it is either absorbed or else is scattered by the disoriented molecules.

Without any voltage applied between transparent electrodes, liquid crystal molecules are aligned in parallel with the glass surface. When voltage is applied, they change their direction and they turn vertical to the glass surface. They vary in optical characteristics, depending on their orientation. Therefore, the quantity of light transmission can be controlled by combining the motion of liquid crystal molecules and the direction of polarization of two polarizing plates attached to the both outer sides of the glass sheets. LCDs utilize these characteristics to display images.

An LCD consists of many pixels. A pixel consists of three sub-pixels (Red/Green/Blue, RGB). In the case of Full-HD resolution, which is widely used for smartphones, there are more than six million (1,080 x 1,920 x 3 = 6,220,800) sub-pixels. To activate these millions of sub-pixels a TFT is required in each sub-pixel. TFT is an abbreviation for "Thin Film Transistor". A TFT serves as a control valve to provide an appropriate voltage onto liquid crystals for individual sub-pixels. A TFT LCD has a liquid crystal layer between a glass substrate formed with TFTs and transparent pixel electrodes and another glass substrate with a color filter (RGB) and transparent counter electrodes. In addition, polarizers are placed on the outer side of each glass substrate and a backlight source on the back side. A change in voltage applied to liquid crystals changes the transmittance of the panel including the two polarizing plates, and thus changes the quantity of light that passes from the backlight to the front surface of the display. This principle allows the TFT LCD to produce full-color images.

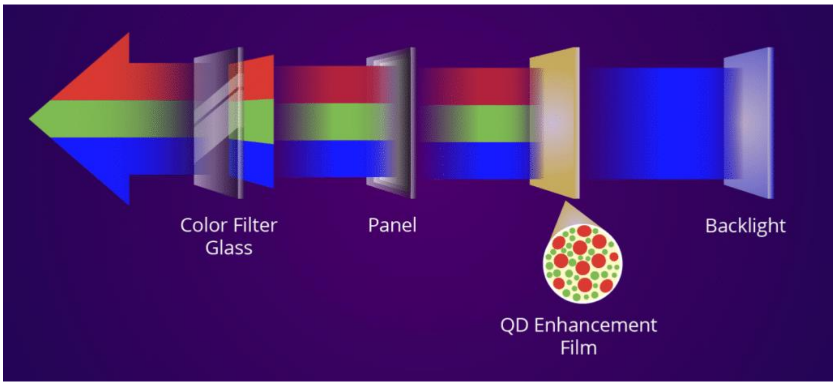


5.14 QUANTUM DOT DISPLAY

A **quantum dot display** is a display device that uses quantum dots (QD), semiconductor nanocrystals which can produce pure monochromatic red, green, and blue light.

A Quantum Dot is a nanoparticle that has semiconductor properties. They're tiny, ranging in size from two to 10 nanometers, with the size of the particle dictating the wavelength of light it emits, and therefore the color. When Quantum Dots are hit with a light source, each dot emits a color of a specific bandwidth: Larger dots emit light that is skewed toward red, and progressively smaller dots emit light that is skewed more toward green.

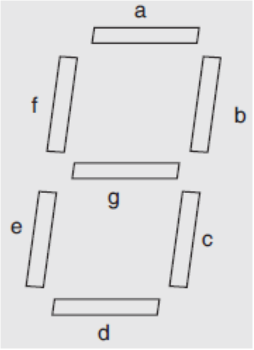
Quantum Dots are usually applied to a sheet of film that sits as a layer in that "sandwich" in front of the LED backlight that's used to illuminate an LCD. The light passes through the LCD display stack, with the Quantum Dot color filter layer enhancing and enabling the LCD to reveal a wider and more saturated range of colors than would otherwise be possible. *Photo-emissive* quantum dot particles are used in LCD backlights and/or display color filters. Quantum dots are excited by the blue light from the display panel to emit pure basic colors, which reduces light losses and color crosstalk in color filters, improving display brightness and color gamut.



5.15 SEGMENT DISPLAY (SEVEN SEGMENT DISPLAY)

Segment displays- Some displays can show only digits or alphanumeric characters. They are called **segment displays**, because they are composed of several segments that switch on and off to give appearance of desired glyph. The segments are usually single LEDs or liquid crystals. They are mostly used in digital watches and pocket calculators. Common types are **seven-segment displays** which are used for numerals only, and alphanumeric fourteen-segment displays and sixteen-segment displays which can display numerals and Roman alphabet letters.

A seven-segment display, or seven-segment indicator, is a form of an electronic display device for displaying decimal numerals. A seven-segment display, as its name indicates, is composed of seven elements (LEDs). Each of the seven LEDs is called a segment because when illuminated the segment forms part of a numerical digit (both Decimal and Hex) to be displayed. The seven segments are arranged as a rectangle of two vertical segments on each side with one horizontal segment on the top, middle, and bottom. Additionally, the seventh segment bisects the rectangle horizontally. An additional 8th LED is sometimes used within the same package thus allowing the indication of a decimal point, (DP) when two or more 7-segment displays are connected together to display numbers greater than ten.



The above figure shows a seven-segment display. It is used to display alphanumeric characters. It consists of 7 rectangular light-emitting diodes designated by the letters a, b, c, d, e, f, and g. Each LED is called a segment because it forms a part of the character being displayed.

Each one of the seven LEDs in the display is given a positional segment with one of its connection pins being brought straight out of the rectangular plastic package. These individually LED pins are labelled from “a” through to “g” representing each individual LED. The other LED pins are connected together and wired to form a common pin.

So, by forward biasing the appropriate pins of the LED segments in a particular order, some segments will be light and others will be dark allowing the desired character pattern of the number to be generated on the display. This then allows us to display each of the ten decimal digits 0 through to 9 on the same 7-segment display.

The displays common pin is generally used to identify which type of 7-segment display it is. As each LED has two connecting pins, one called the “Anode” and the other called the “Cathode”, there are therefore two types of LED 7-segment display called: **Common Cathode** (CC) and **Common Anode** (CA).

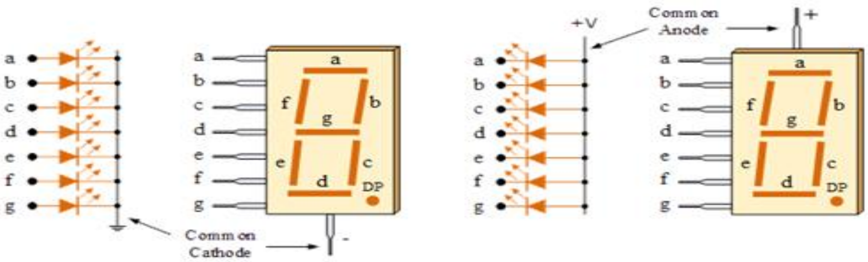
The difference between the two displays, as their name suggests, is that the common cathode has all the cathodes of the 7-segments connected directly together and the common anode has all the anodes of the 7-segments connected together and is illuminated as follows.

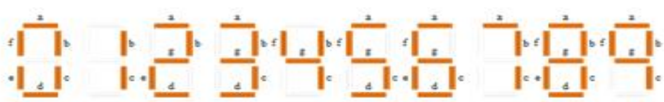
1. The Common Cathode (CC) – In the common cathode display, all the cathode connections of the LED segments are joined together to logic “0” or ground. The individual segments are illuminated by application of a “HIGH”, or logic “1” signal via a current limiting resistor to forward bias the individual Anode terminals (a-g).

2. The Common Anode (CA) – In the common anode display, all the anode connections of the LED segments are joined together to logic “1”. The individual segments are illuminated by applying a ground, logic “0” or “LOW” signal via a suitable current limiting resistor to the Cathode of the particular segment (a-g).

In general, common anode displays are more popular as many logic circuits can sink more current than they can source. Also note that a common cathode display is not a direct replacement in a circuit for a common anode display and vice versa, as it is the same as connecting the LEDs in reverse, and hence light emission will not take place.

Depending upon the decimal digit to be displayed, the particular set of LEDs is forward biased. For instance, to display the numerical digit 0, we will need to light up six of the LED segments corresponding to a, b, c, d, e and f. Thus, the various digits from 0 through 9 can be displayed using a 7-segment display as shown.





Warren Seymour Johnson

Warren Seymour Johnson (November 6, 1847 – December 5, 1911) was an American college professor who was frustrated by his inability to regulate individual classroom temperatures. His multi-zone pneumatic control system solved the problem. Johnson's system for temperature regulation was adopted worldwide for office buildings, schools, hospitals, and hotels – essentially any large building with multiple rooms that required temperature regulation. To manufacture and market his system, Johnson established the Johnson Electric Service Company which eventually became Johnson Controls.

Johnson had an inquisitive mind and was particularly interested in electricity. In 1883, he developed a thermostat, which he deployed at the State Normal School. He called the instrument an "electric tele-thermoscope" in the patent application. It was a bi-metal coiled thermostat with a mercury switch, which could be used to ring a bell to alert the fireman to open or close the heating damper. While not the first bi-metal thermostat, Johnson received a patent for the device and interested William Plankinton, heir to the Plankinton Packing Company, to provide financial backing to manufacture the device.

While it might have seemed crude by the modern standards that we have today, this thermostat was able to keep temperatures within a degree of accuracy something that a better than some of the low quality thermostats on the market today! The first motion sensor used for an alarm system came about in the early part of the 1950s, and was the invention of Samuel Bagno. His device made use of ultrasonic frequencies as well as the Doppler Effect

Part B QUESTIONS

1. Briefly explain the principle, construction and working of Bourdon pressure.
2. Briefly explain the principle, construction and working of vibration sensor and acoustic sensor
3. Illustrate with suitable diagram, the principle and working of LDR.
4. Explain in brief the principle and working of temperature sensor. Give its advantages and disadvantages.
5. Define Strain Gauge. Explain the principle, types and applications of strain gauge.
6. What is a photo diode? Explain the two modes of its operations.
7. Explain the phenomenon of photoluminescence.
8. Write a note on the construction and operation of LED.
9. Differentiate OLED and AMOLED.
10. Explain how does a LCD works.
11. Describe how usage of Quantum dots help towards betterment of display.
12. Write a short note on seven segment display. Mention its usage.