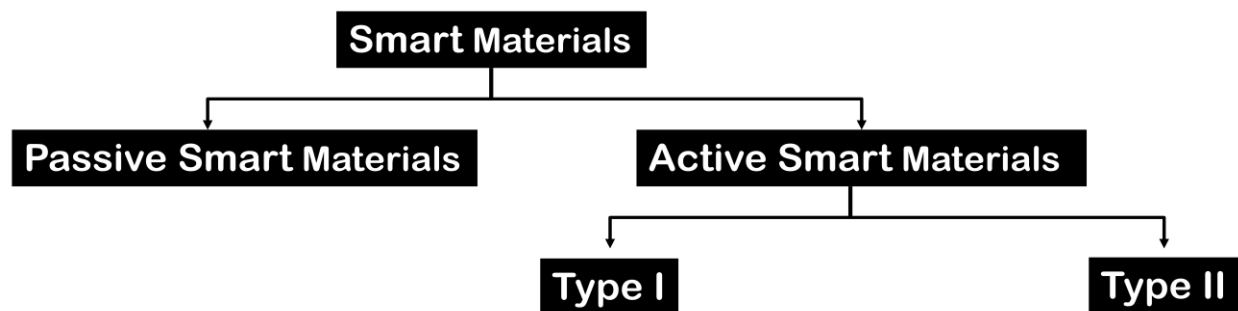


Chapter-4

Smart Materials

Smart Materials: Smart materials (intelligent materials) are materials that possess adaptive capability to external stimuli. Smart material have one or more properties that can be significantly changed in controlled fashion by external stimuli such as stress, temperature, moisture, pH, electric or magnetic fields. They are able to perceive and feel the external and/or internal stimuli, react on stimuli and develop functionality to adapt them.

The word ‘Smart’ implies that these materials are able to sense changes in their environments and then respond to these changes in predetermined manners. Smart materials can be classified into two types either active or passive.



Passive Smart Materials: Materials lack the inherent capability to transducer/actuate energy.

- ✓ Fiber-Optic – transfer electromagnetic waves
- ✓

Active Smart Materials (Type I): Active Smart Materials possess the capability of modifying their geometric and material properties under the application of external stimuli thereby acquiring an inherent capacity to transducer/actuate energy.

- ✓ Photochromatic glasses-- change color when exposed to sunlight
- ✓ Piezoelectric materials-
- ✓ ER fluids and magneto-strictive materials

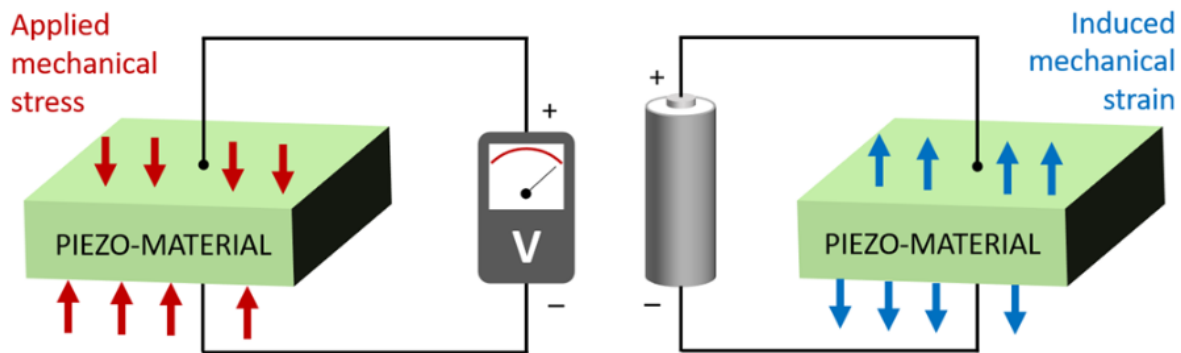
Active Smart Materials (Type II): Change energy from one form to another.

- ✓ LEDs -- convert electricity to light.

Type of Smart Material	Input	Output
Piezoelectric	Deformation	Potential Difference
Electrostrictive	Potential Difference	Deformation
Magnetostrictive	Magnetic Field	Deformation
Thermoelectric	Temperature	Potential Difference
Shape Memory Alloys	Temperature	Deformation
Photochromic	Radiation	Color Change
Thermochromics	Temperature	Color Change

Piezoelectric Materials:

- ✓ Piezoelectric materials are materials that have the ability to generate internal electrical charge from applied mechanical stress.
- ✓ Materials that exhibit the piezoelectric effect also demonstrate the inverse piezoelectric effect (also called the reverse or converse piezoelectric effect). The *inverse piezoelectric effect* is the internal generation of mechanical strain in response to an applied electrical field.
- ✓ The structure made with this material can bend, expand and compress.



Naturally occurring crystals:

- ✓ Sucrose (table sugar)
- ✓ Topaz
- ✓ Quartz. A stable crystal used in watch crystals and frequency reference crystals for radio transmitters.
- ✓ Berlinite (AlPO_4). A rare phosphate mineral structurally identical to quartz.

Man-made crystals:

- ✓ Gallium orthophosphate (GaPO_4), a quartz analog.
- ✓ Languisite ($\text{La}_3\text{Ga}_5\text{SiO}_{14}$), a quartz analog.

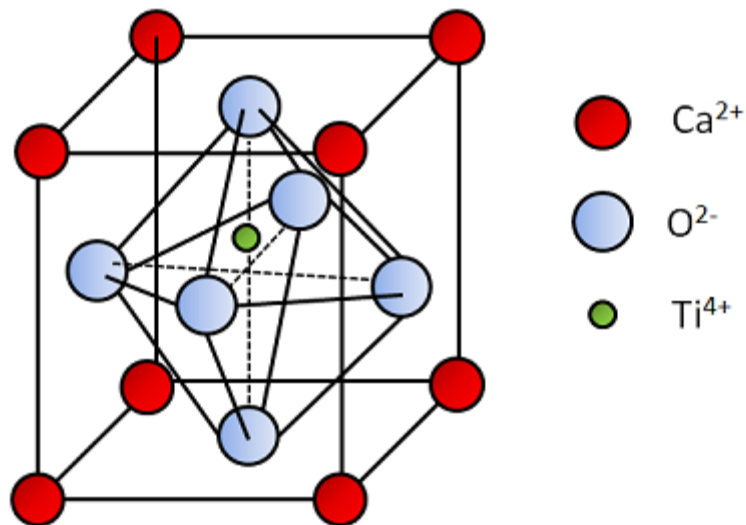
Piezoelectric ceramics:

- ✓ Barium titanate (BaTiO_3). The first piezoelectric ceramic discovered.

- ✓ Lead titanate (PbTiO_3)
- ✓ Lead zirconate titanate (PZT). Currently the most commonly used piezoelectric ceramic.
- ✓ Potassium niobate (KNbO_3)
- ✓ Lithium niobate (LiNbO_3)
- ✓ Lithium tantalate (LiTaO_3)

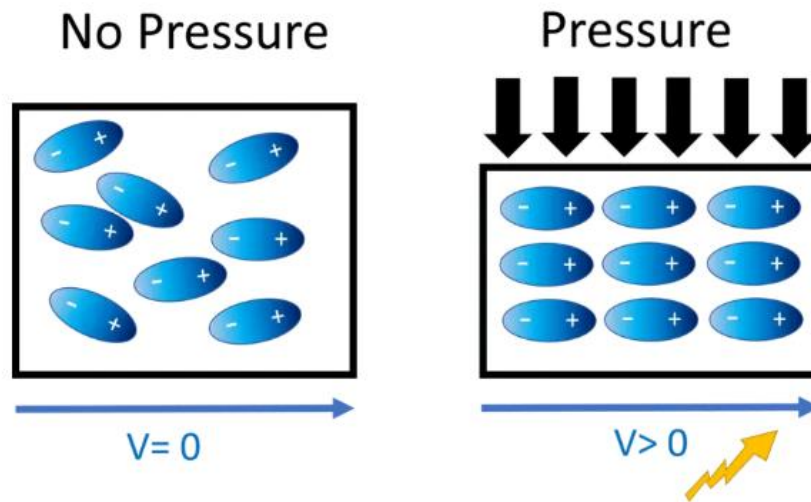
Mechanism of Piezoelectricity:

Piezoelectric Effect Arises From Crystal Structure. The piezoelectric effect is always associated with *noncentrosymmetric* crystals.



A perovskite unit cell showing the off-centered titanium ion.

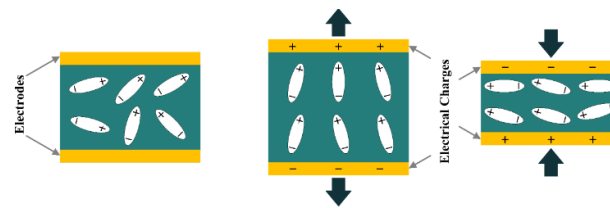
A typical noncentrosymmetric crystal structure such as a perovskite (calcium titanate — CaTiO_3) has a net non-zero charge in each unit cell of the crystal. However, as a result of the titanium ion sitting slightly off-center inside the unit cell, an electrical polarity develops, thereby turning the unit cell effectively into an electric dipole. A mechanical stress on the crystal further shifts the position of the titanium ion, thus changing the polarization strength of the crystal. This is the source of the direct effect. When the crystal is subjected to an electric field, it also results in a relative shift in the position of the titanium ion, leading to the distortion of the unit cell and making it more (or less) tetragonal. This is the source of the inverse effect.



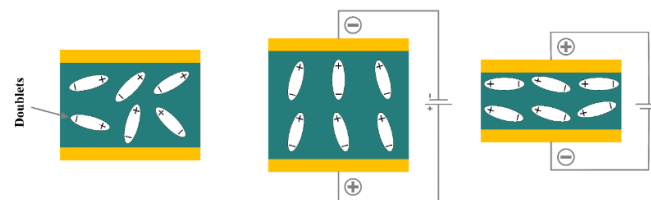
Small displacements of ions in the crystal lattice create the polarization observed in piezoelectricity. This only occurs in crystals that do not have a center of symmetry. When placed under stress, the piezoelectric crystal produces a polarization, P proportional to the stress that produced it. The main equation of piezoelectricity is

$$\mathbf{P} = \mathbf{d} \times \text{stress}$$

where d is the piezoelectric coefficient, a factor unique to each type of piezoelectric material. The piezoelectric coefficient for quartz is 3×10^{-12} . The piezoelectric coefficient for lead zirconate titanate (PZT) is 3×10^{-10} .



a) Direct Piezoelectric Effect



b) Converse Piezoelectric Effect

Applications of Piezoelectric Materials

1. In gas lighter

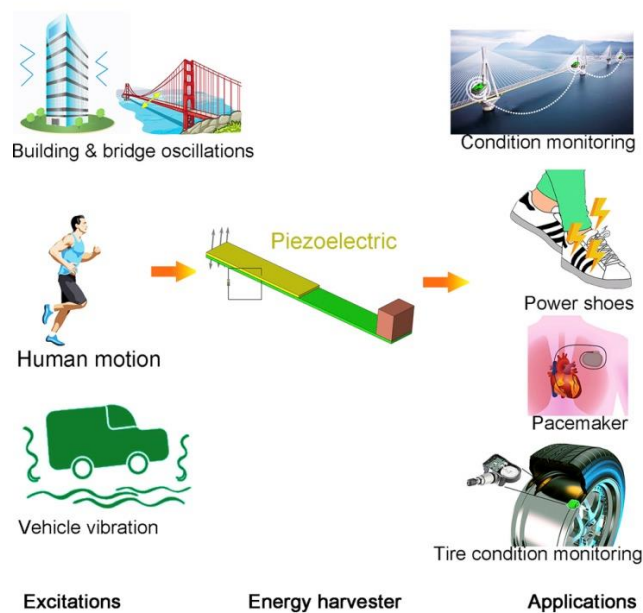


It consists of the following parts:

1. Impact Pad
2. Piezoelectric crystal
3. Ignition Head.

Impact Pad bears the hammer blows from the upper part and passes the force on the piezoelectric crystal causing it to deform and produce a spark.

2. Energy harvesting



Convert oscillatory mechanical energy into electrical energy. This technology, together with innovative mechanical coupling designs, can form the basis for harvesting energy from mechanical motion. Piezoelectric energy can be harvested to convert walking motion from the human body into electrical power.

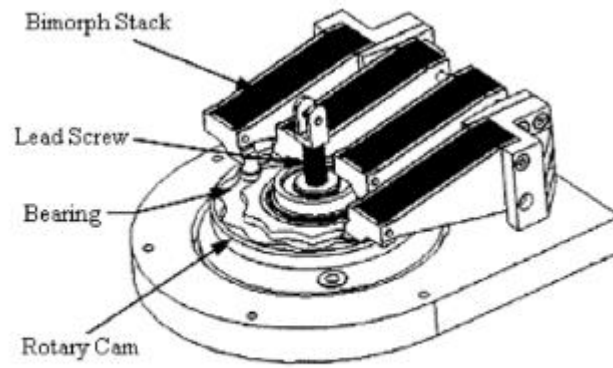
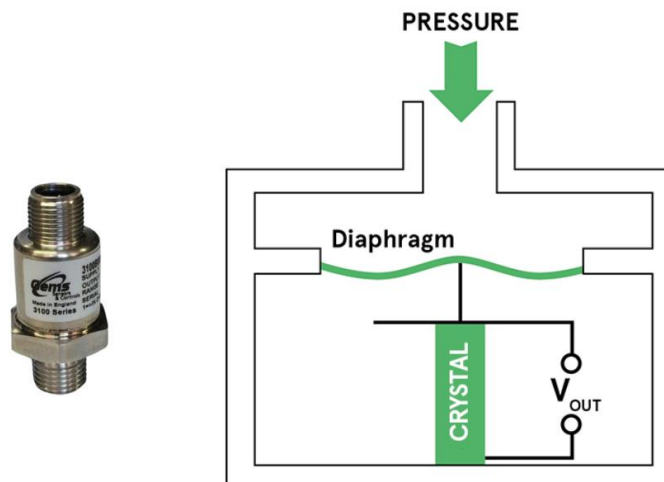


Fig. 2. Schematic of Heel Strike Generator.

The Heel Strike Generator uses Lead Zirconate Titanate (PZT-5A) piezoelectric materials to transform mechanical energy into electrical energy. The input mechanical energy is transformed into electrical energy through four PZT-5A bimorph stacks.

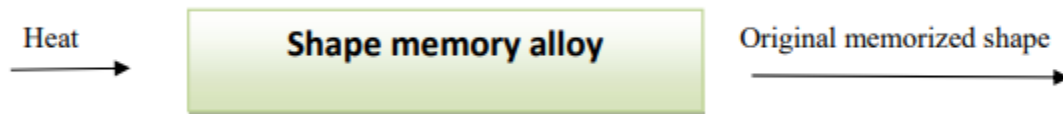
3. Pressure sensor



When a force is applied to a piezoelectric material, an electric charge is generated across the faces of the crystal. This can be measured as a voltage proportional to the pressure (see diagram to the right).

Shape memory alloys

- ✓ Shape memory alloy is very common example of smart material.
- ✓ Shape Memory Alloys (SMAs) are an intermetallic alloy that can be deformed but will return to their original shape when heated.
- ✓ SMAs have a Shape Memory Effect (SME) and pseudoplastic effect, which are related to the same underlying mechanism as elastic effects.
- ✓ These shape changes occurs between two phase martensite to austenite. Martensite phase is stable at lower temperature and austenite phase is stable at higher temperature. Basically these material exist between two phase.

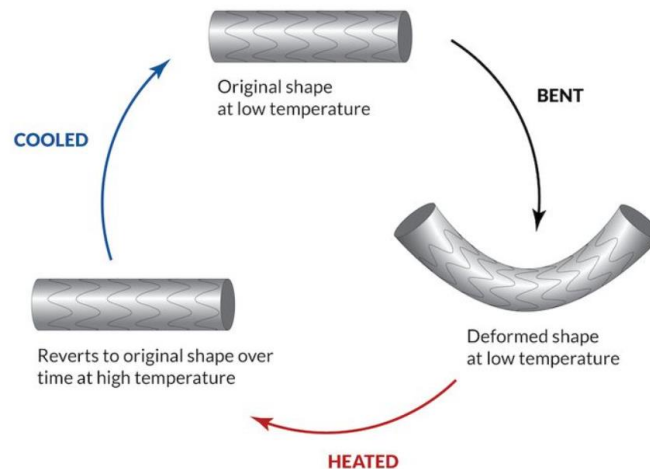


Current shape memory alloys are:

- ✓ NiTi, or nitinol. This is the most developed SMA, with excellent mechanical properties. It is pretty much the only commercially viable SMA.
- ✓ Cu-Al-Ni, Fe-Mn-Si, and Cu-Zn-Al systems. These have poorer mechanical properties and are still in development, although they may one day offer advantages over NiTi such as higher transformation temperatures
- ✓ Ni-Mn-Ga. A magnetic shape memory alloy, which is affected by magnetic fields rather than temperature. Magnetic shape memory alloys are also in the developmental stage.
- ✓ Other alloys also exist, which are even less commercially viable. Alloys with gold, silver, platinum, and palladium have made good SMAs in the laboratory, but they will probably never be worth the cost of the raw materials.

Alloy	Composition	Transformation range (°C)
Ag–Cd	44–49% Cd	–190 to –50
Au–Cd	46.5–50% Cd	30 to 100
Cu–Al–Ni	14–41.5% Al; 3–4.5% Ni	–140 to 100
Cu–Au–Zn	23–28% Au; 45–47% Zn	–190 to 40
Cu–Sn	15 at.% Sn	–120 to 30
Cu–Zn	38.5–41.5% Zn	–180 to –10
Cu–Zn–Al	3–8% Al	0 to 150
	4–6% Al; 22–28% Zn	Room temperature
In–Ti	18–23% Ti	60 to 100
Ni–Al	36–38% Al	–180 to 100
Ni–Ti	49–51% Ni	–50 to 110
Fe–Pd	30% Pd	–100
Fe–Pt	25% Pt	–130
Mn–Cu	5–35% Cu	–250 to 180
Fe–Mn–Si	32% Mn; 6% Si	–200 to 150

- ✓ SMAs are said to exhibit a crystallographically reversible martensitic transformation (structural change). At high temperatures, the SMA exists as an austenite phase (the parent or memory phase) with long range order. On cooling below the transformation temperature, the austenite transforms to a thermoelastic martensite whose structure has many variants, typically sheared platelets. Because the martensitic structure is self-accommodating, the deformation on transformation to martensite is zero. The martensite deforms by a twinning mechanism that transforms the different variants to the variant that can accommodate the maximum elongation in the direction of the applied force. The interfaces between platelets in the martensite phase slip very readily and the material is deformed at low applied stresses. The austenite phase has only one possible orientation, thus when heated, all the possible deformed structures of the martensite phase must revert to this one orientation of the austenite memory phase and the material recovers its original shape.



✓

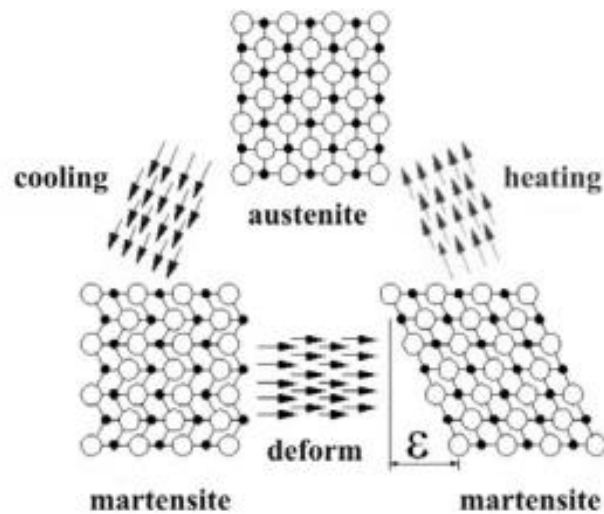


Fig. 1: The Shape memory effect (atomistic, schematically)

- ✓ When martensite is deformed and then heated to the austenitic state, the material returns to the shape it had before the pseudoplastic deformation. The pseudoplastic deformation is characterized not by gliding and generation of dislocations but rather by the movement of twin boundaries thereby reducing the number of different martensitic variants. Upon subsequent cooling, the shape remains unchanged. This phenomenon is known as one-way shape memory effect since there is a shape change during heating only and not during cooling. It is a natural crystallographic property of shape memory materials (Fig. 1, 2). Strain values up to 8% can be recovered in polycrystalline NiTi alloys.

Medical uses of the shape memory alloy nitinol

A coronary stent is a mesh tube that is used to treat narrow or weak arteries, a stent is placed in an artery to restore blood flow through narrow or blocked arteries by supporting the artery. Self-expanding stents are manufactured with a diameter larger than the target vessel, and a transformation temperature set at around 30 °C.

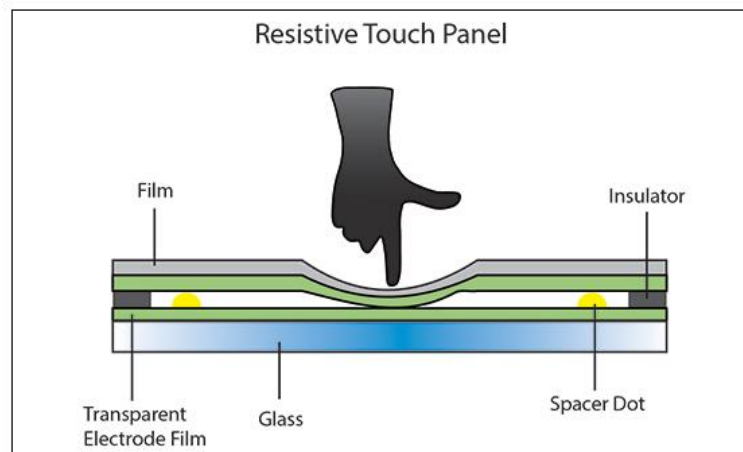
The stent is plastically deformed in the low-temperature face and stored in a protective cover to avoid premature enlargement. When at body temperature inside the patient it will expand when the cover is removed. The stent will then resist forces on it with an opposing radial force.



Touch Screen: A touch screen is a display that can detect the presence and location of a touch within the display area

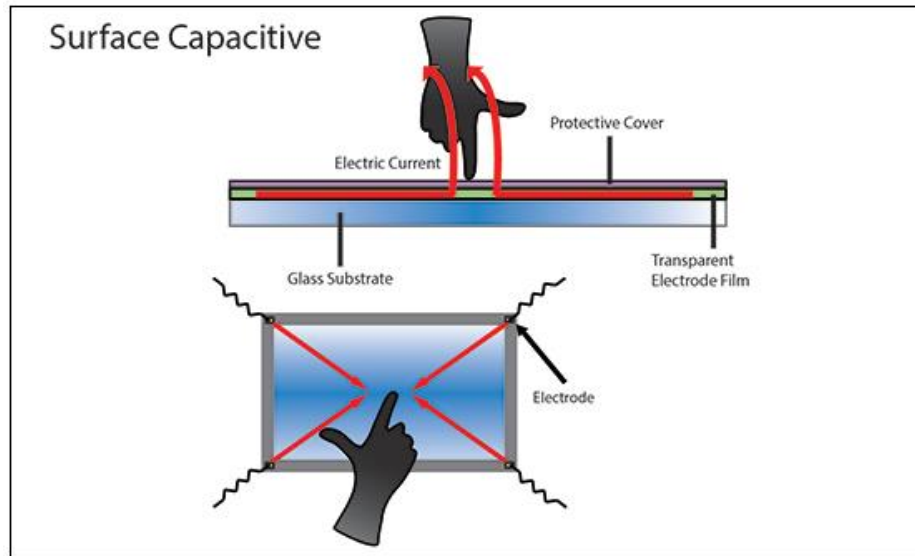
It uses more than two piezoelectric transducers located at some positions of the screen to turn the mechanical energy of a touch (vibration) into an electronic signal. The screen hardware then uses an algorithm to determine the location of the touch based on the transducer signals. Touch screen can be broadly categorised into Resistive, Capacitive, Surface Acoustic Wave and Infrared.

Resistive touch screen: Resistive touch screens consist of a glass or acrylic panel that is coated with electrically conductive and resistive layers made with indium tin oxide (ITO). The thin layers are separated by invisible space.



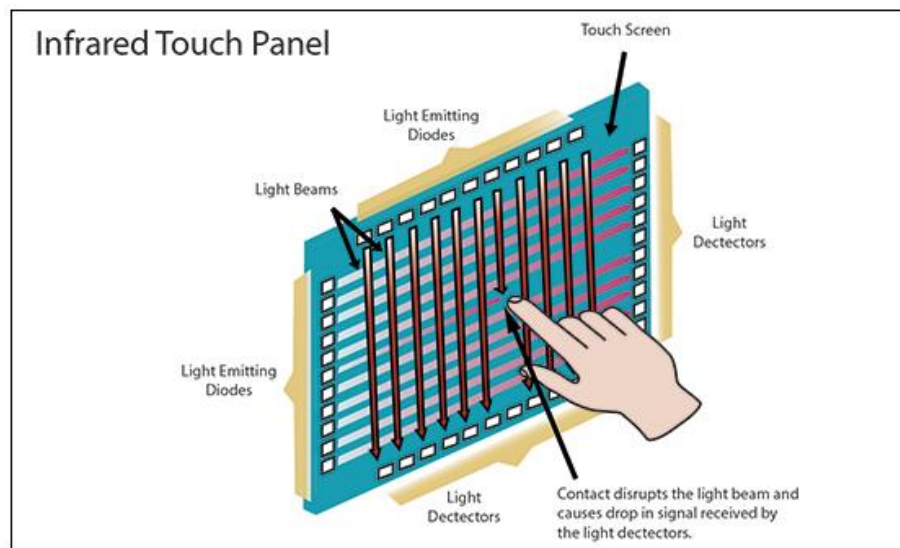
- ✓ Applied pressure brings two conductive layers together which creates an electrical connection that can be sensed and located.

Capacitive touch screen: Capacitive sensing is a technology, based on capacitive coupling that takes human body capacitance as input. Capacitive sensors detect anything that is conductive or has a dielectric different from that of air.



- ✓ A surface capacitive works by measuring current. A protective cover is placed over the transparent electrode film which lies on top of the glass substrate. Voltage is applied to the corners and when a finger or stylus makes contact with the surface it disrupts the current. The controller then registers and determines point of contact.

Infrared Touch Screen



- ✓ Consists of infrared LEDs (Light emitting diode) and light sensors that are placed on the perimeter of the panel. LEDs transmit beams of light that run parallel to the assigned light sensor create a light grid. Anything that disrupts the light or reduces the light such as a finger or stylus will register a touch.

Magneto strictive Materials: when subjected to a magnetic field, and vice versa (direct and converse effects), this material will undergo an induced mechanical strain. Consequently, it can be used as sensors and/or actuators.

Chromic materials are **dyes and pigments that exhibit a distinct colour change when exposed to an external stimulus**, such as Radiation, Pressure, Temperature, Chemical, Electric field, Magnetic Field etc.

Thermo-responsive Smart Polymers : Thermoresponsive polymers are the ones that exhibit conformational changes in response to temperature stimuli, especially near body temperature.

Example: : Polyethylene oxide, Poly vinyl methylether and Poly hydroxyethyl methacrylate etc