MATERIAL SCIENCE (MEE102B)

Module-4

Modern Engineering Materials

Introduction to Smart/Modern Materials

What is meant by the term Smart materials?
Can you name any examples?

- A Modern material is a material that has been designed for a specific purpose or need.

- A Smart material is a material that reacts and changes to the environment around them.

Introduction to Smart/Modern Materials

What do all these things have in common?

Introduction to Smart/Modern Materials

- We might not realise it, but smart materials are starting to make a real impact on everyday life.

- Kettles that change colour when they boil
- Garments that plug into MP3 players
- Batteries that ‘report’ their condition

- These are all examples of the application of new materials exhibiting ‘smart’ behaviour.

Features of Smart Materials

- The basic energy forms that gets interchanged are:
- Thermal energy, electric energy, magnetic energy, sound energy & mechanical energy
- Analogous to Biological Materials: adaptively, cellular function, self sensing, actuation & control Smart sensors & actuators are highly embeddable

Traditional vs. Smart Structure

❑ **Traditional structures**

▪Designed for certain performance requirements eg. load, speed,

▪Life span

▪Unable to modify its specifications if there is a change of environment

❑ **Smart Structures**

▪Can accommodate unpredictable environments

▪Can meet exacting performance requirement

▪Offer more efficient solutions for a wide range of applications

Smart materials react to their environment

- Smart materials change their properties in response to heat, light, or something else (depending on the material)
- They often change back to their original state when the heat or light (or whatever else affects them) is taken away
- Some smart materials can let you make totally new products

Types of Smart/Modern Materials

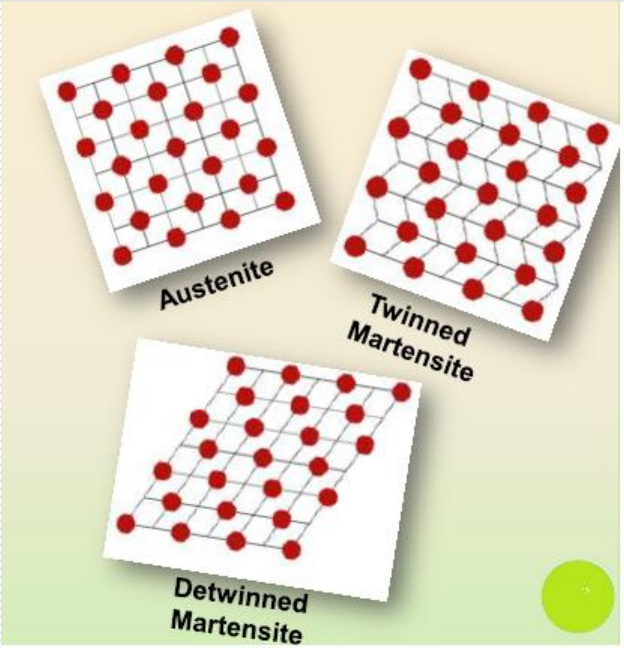
- Shape memory alloys
- Chromic materials
- Rheological fluids
- Bio-materials
- Dielectric materials
- Piezoelectric, pyro electric
- Ferroelectric materials

SHAPE MEMORY ALLOYS

- A **shape memory alloy** is an alloy that "remembers" its original, cold-forged shape: returning the pre-deformed shape by heating.
- This material is a lightweight, solid-state alternative to conventional actuators such as hydraulic, pneumatic, and motor-based systems. Shape memory alloys have applications in industries including medical and aerospace

Shape Memory Alloy

- Shape Memory Alloys are metal alloys which can undergo ***solid-to-solid*** phase transformation and can recover completely when heated to a specific temperature.
- These materials has two phases:
- **Austenite**- high temperature phase;
- **Martensite**- low temperature phase.

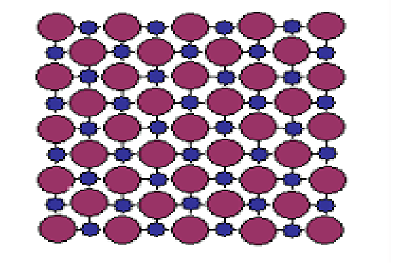


What are Shape Memory Alloys?

•Shape Memory Alloys (SMAs) are metallic alloys that undergo a solid-to-solid phase transformation which can exhibit large recoverable strains. Example: Nitinol

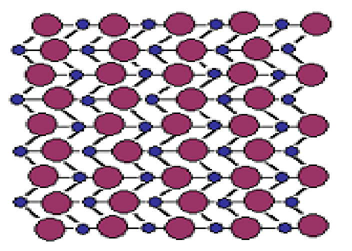
Austenite

• High temperature phase

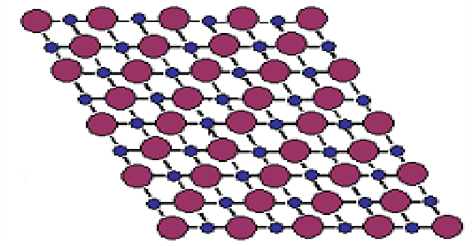


Martensite

•Low temperature phase

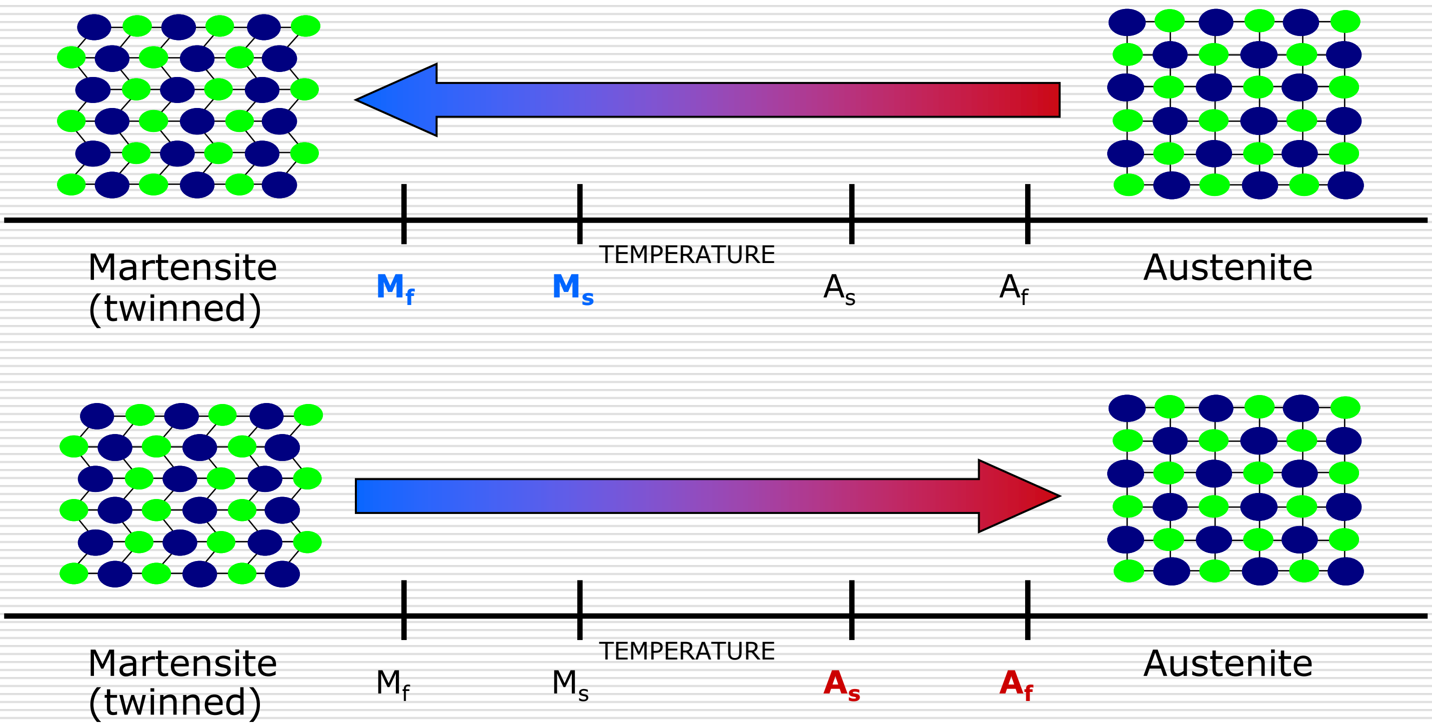


Twinned Martensite

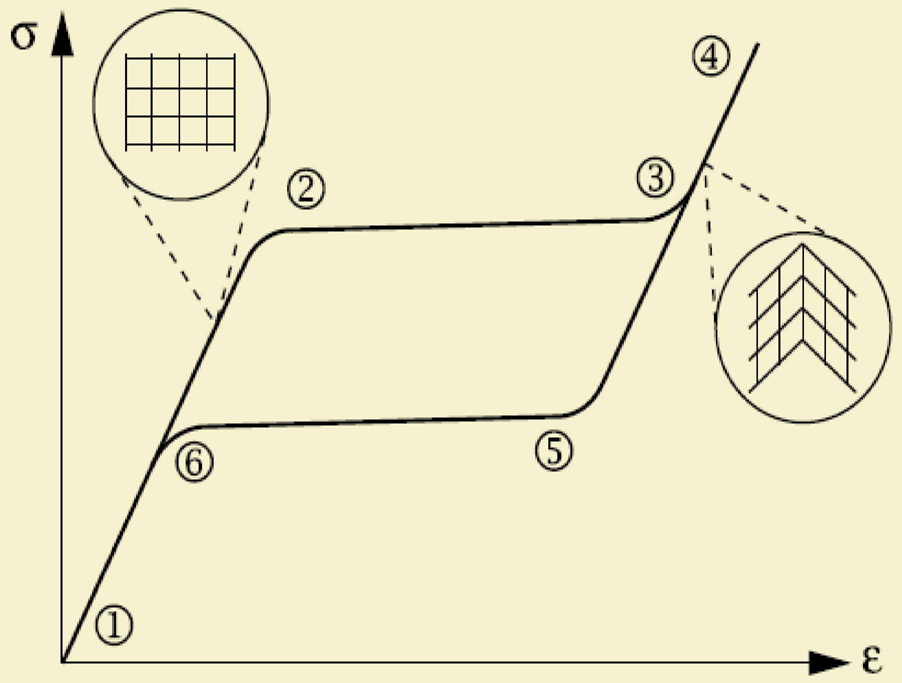


Detwinned Martensite

Thermally Induced Phase Transformation in SMAs



Characteristic temperatures:
M_f=Martensitic Finish
M_s=Martensitic Start
A_s=Austenitic Start
A_f=Austenitic Finish



Temperature > A_f

Loading

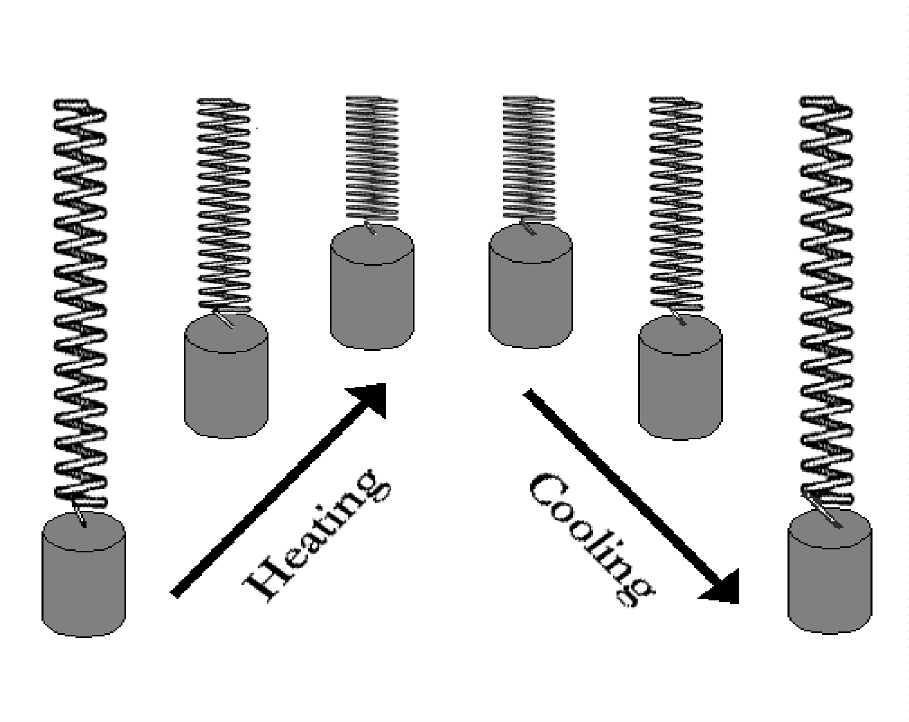
(1) Austenite
(2) Martensite start forming
(2-3) Austenite +Martensite
(4) Martensite

Unloading

(5) austenite start forming ; reverse transformation
(5-6) Martensite + Austenite
(1) Austenite

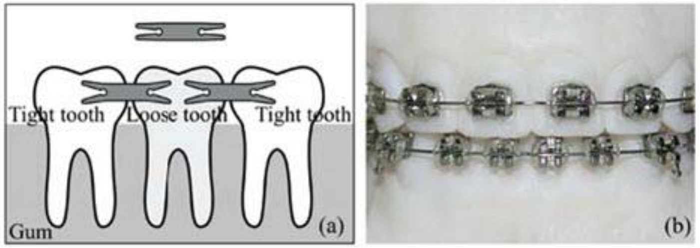
Advantages of SMA

- High strength
- Good elasticity
- Fatigue Resistance
- Wear resistance
- Easy fabrication
- Light weight

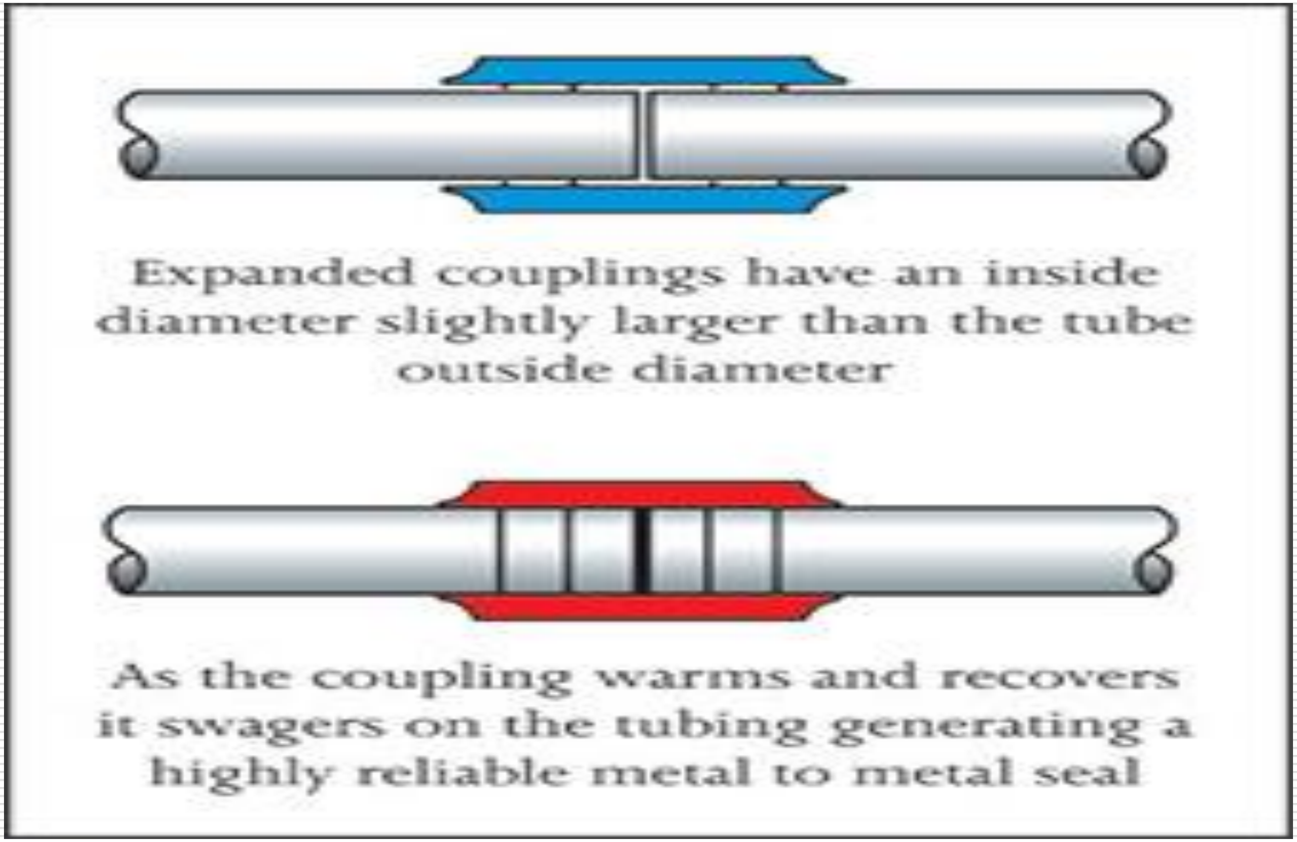


Applications of SMA

- Various thermal actuators then came into existence as a part of electric appliances and automobile engineering.
- Fire alarm
- Aerospace application (Control the flaps on trailing edge of aircraft wings)
- Bio medical: Blood Flitter, Bone, stents,Dental Braces



Advantages of SMA



Chromic Materials

- **Chromism** is a process that induces a change, often reversible, in the colors of compounds.
- In most cases, chromism is based on a change in the electron states of molecules,
- The major kinds of chromism are as follows:-
  - Thermochromism.
  - Photochromism.
  - Electrochromism

Chromic Materials

- **Thermochromism** :-

Chromism that is induced by heat, that is, a change of temperature.

- **Photochromism** :-

Induced by light irradiation.

- **Electrochromism** :-

Induced by the gain and loss of electrons

Thermochromic Materials

Thermochromic pigments change colour with heat

- **Thermochromic pigments change back to their original colour when they cool**
- They can be used in paints to create images that change when they get hot
- Thermochromic inks can be printed onto a range of materials, such as plastic and paper
- Thermochromic films are sheets that have been printed with thermochromic ink - you could use them for displays that change colour when touched
- Example of thermochromic material:Leuco dye, cholesteryl benzoate, cyanobiphenyls, VANADIUM PENTOXIDE (V2O5) ,

Cholesteryl nonanoate, Octadecylphosphonic acid

Thermochromic Materials

2D heat-sensitive temperature gauge

Changes colour when food is too hot for a baby's mouth.

Smart inks change colour with temperature

Useful for marketing materials

Has your egg been hot enough for long enough?

Application

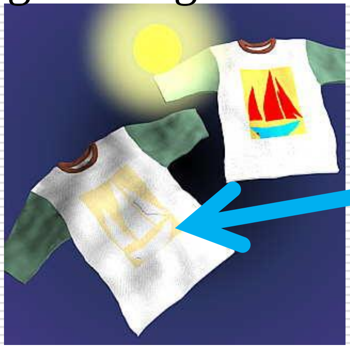
- Kettles
- Thermometers
- Heat Sensitive Ceramics
- Heat Sensitive Paper
- Clothing

Photochromic Materials

Lenses become darker with increased

Glass changes from transparent to opaque as level of light increase, saving energy

MINI's 'Rainbow' paint options gives a rainbow effect in bright sunlight

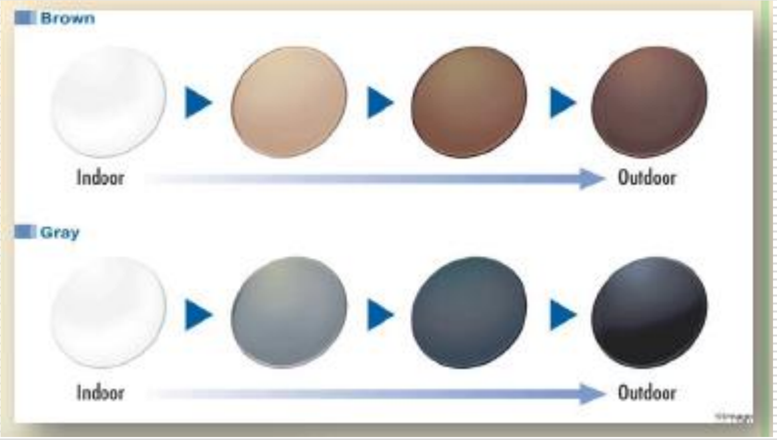


Colour changing wristbands indicate when sun cream needs to be re-applied, or when it's time to move into the shade

Photochromic inks used to print t-shirt designs that only show up in sunlight

Photochromic Materials

- Photochromic materials change color in response to the intensity of light.



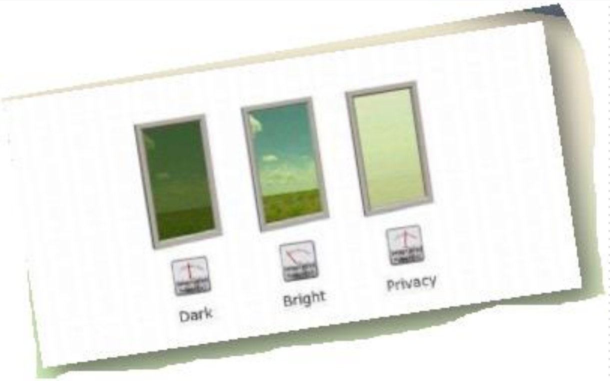
General Materials used are:

- ✓ ***Azobenzene;***
- ✓ ***Diarylethene;***
- ✓ ***Spiropyran;***
- ✓ ***Silver Chloride***

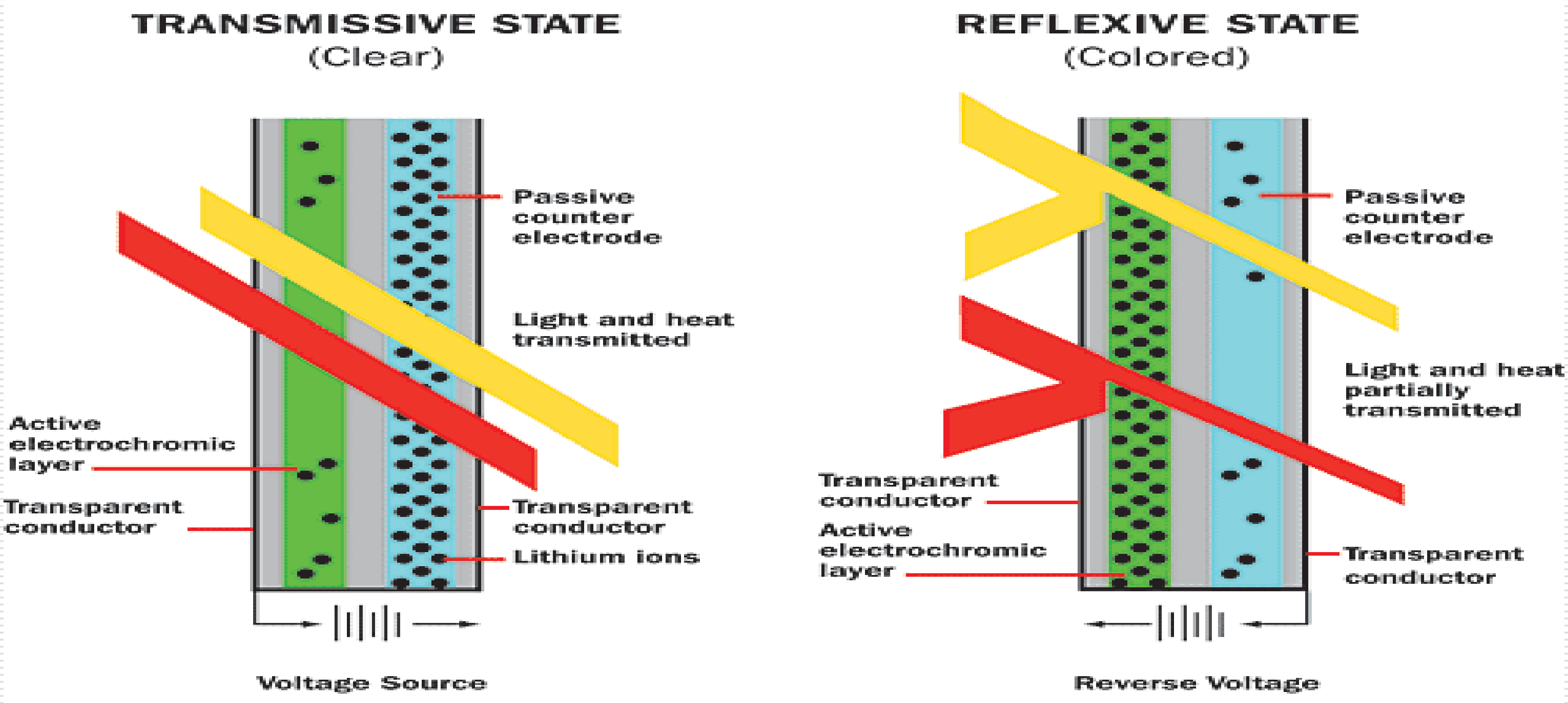
Electrochromic Materials

- General materials used are:
- ***NiO;***
- ***TiO2;***
- ***Polyaniline;***
- ***Polythiophene***

- Major applications:
- **Smart Glass;**
- **Devices for optical**
- **Rear-view mirrors;**
- **Protective eyewear**



EC windows



TRANSMISSIVE STATE
(Clear)
Passive counter electrode
Light and heat transmitted
Active electrochromic layer
Transparent conductor
Transparent conductor
Lithium ions
Voltage Source
REFLEXIVE STATE
(Colored)
Passive counter electrode
Light and heat partially transmitted
Transparent conductor
Active electrochromic layer
Transparent conductor
Reverse Voltage

EC windows

•The electrochromic windows, also known as smart windows, are new technological arrangement for achieve energy efficiency in buildings, with variable transmittance of light and solar energy.

•The "smart windows" can automatically control the amount of light and solar energy passing through the windows and provides indoor comfort.

•Smart windows are currently being used in an increasing number of buildings and vehicles. The Boeing Company provide electrochromic windows for the passenger cabin of the all-new 787 Dreamliner, which will allow passengers to electronically shade their windows.

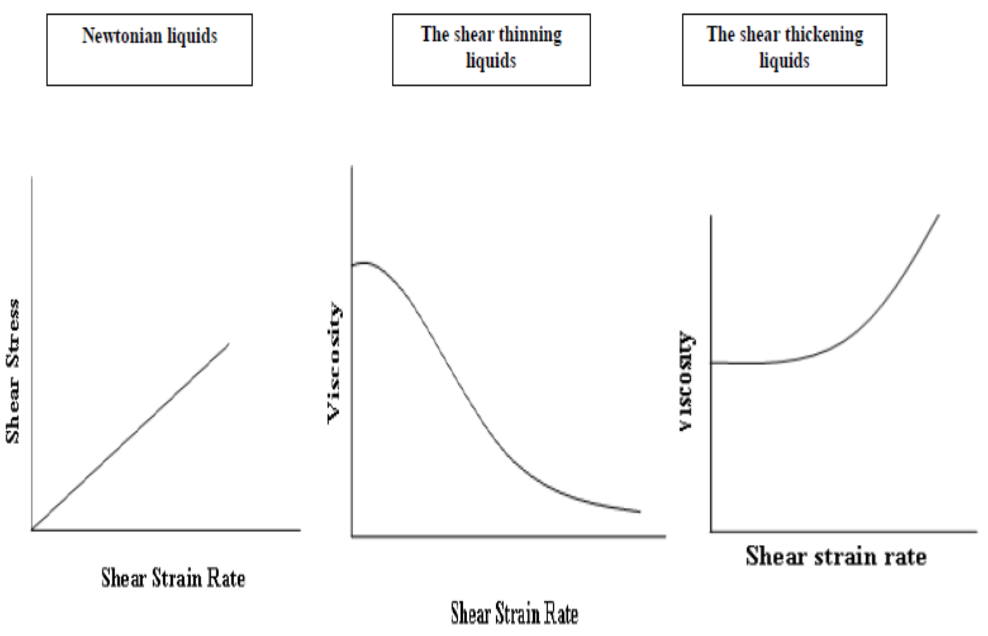
Rheological fluids

- RHEOS (Greek word) = to FLOW (English word)
- RheoLOGY= Science of material flow under external load conditions
- MAGNETO rheological FLUID= Fluid, whose apparent viscosity increases, with application of MAGNETIC field.
- Liquids that harden or change shape when they feel a magnetic field

Rheological fluids

A key statement is "The viscosity is a function only of the condition of the **fluid**, particularly its temperature." Water, oil, gasoline, alcohol are **examples of Newtonian fluids**. **Examples** of non-**Newtonian fluids** are slurries, suspensions, gels and colloids

Liquid Behaviour



Non-Newtonian fluids

- Oobleck is an example of a fluid whose viscosity is not constant; it's viscosity changes depending on the stress or forces applied to it.
- If you poke it with your finger and apply a large force, it becomes very viscous and stays in place. If you gently pour it, applying little force, it will flow like water.
- This kind of fluid is called a dilatant material or a shear thickening fluid. It becomes more viscous when agitated or compressed.

Why does Oobleck behave the way it does?

- When sitting still, the granules of starch are surrounded by water.
- The cushion of water provides quite a bit of lubrication and allows the granules to move freely.
- But, if the movement is abrupt, the water is squeezed out from between the granules and the friction between them increases rather dramatically.

Non-Newtonian fluids

- Another non-Newtonian liquid is ketchup. Ketchup behaves in the opposite way from Oobleck. You could even call it the “anti-Oobleck.”
- It becomes less viscous when agitated. Liquids like this are called shear thinning liquids. If you leave a bottle of Ketchup on a shelf, it becomes thicker or more viscous.
- Nearly everyone has experienced this while trying to pour the liquid from a new bottle – it refuses to move. If you shake the bottle or stir it up, it becomes less viscous and pours easily.

Rheological fluids

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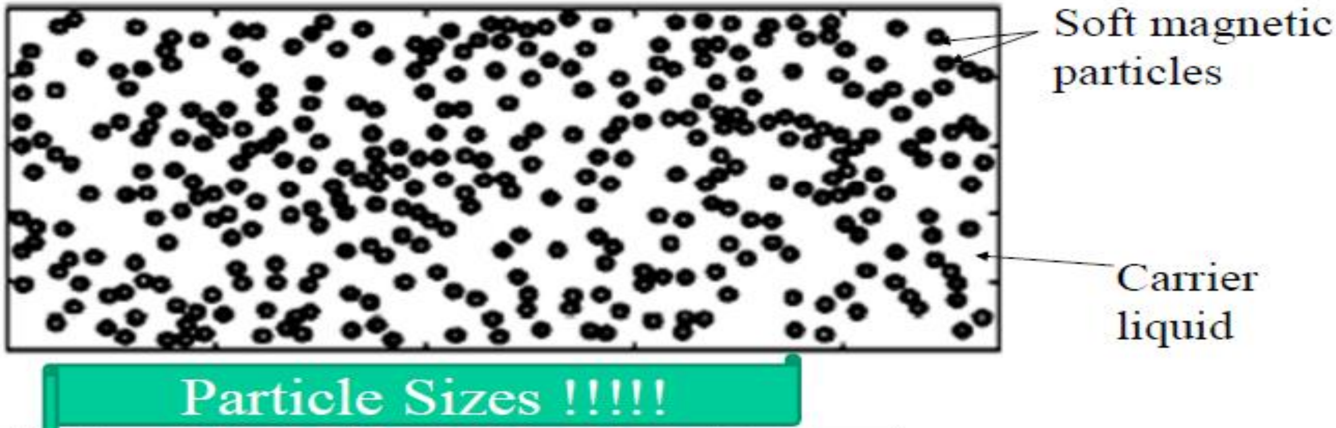
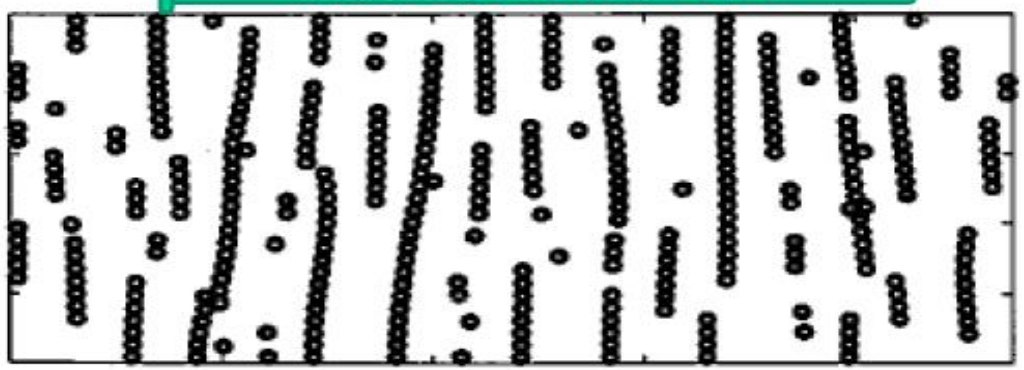
- MAGNETO rheological FLUID= Fluid, whose apparent viscosity increases, with application of MAGNETIC field.
- Liquids that harden or change shape when they feel a magnetic field

MR Fluids:

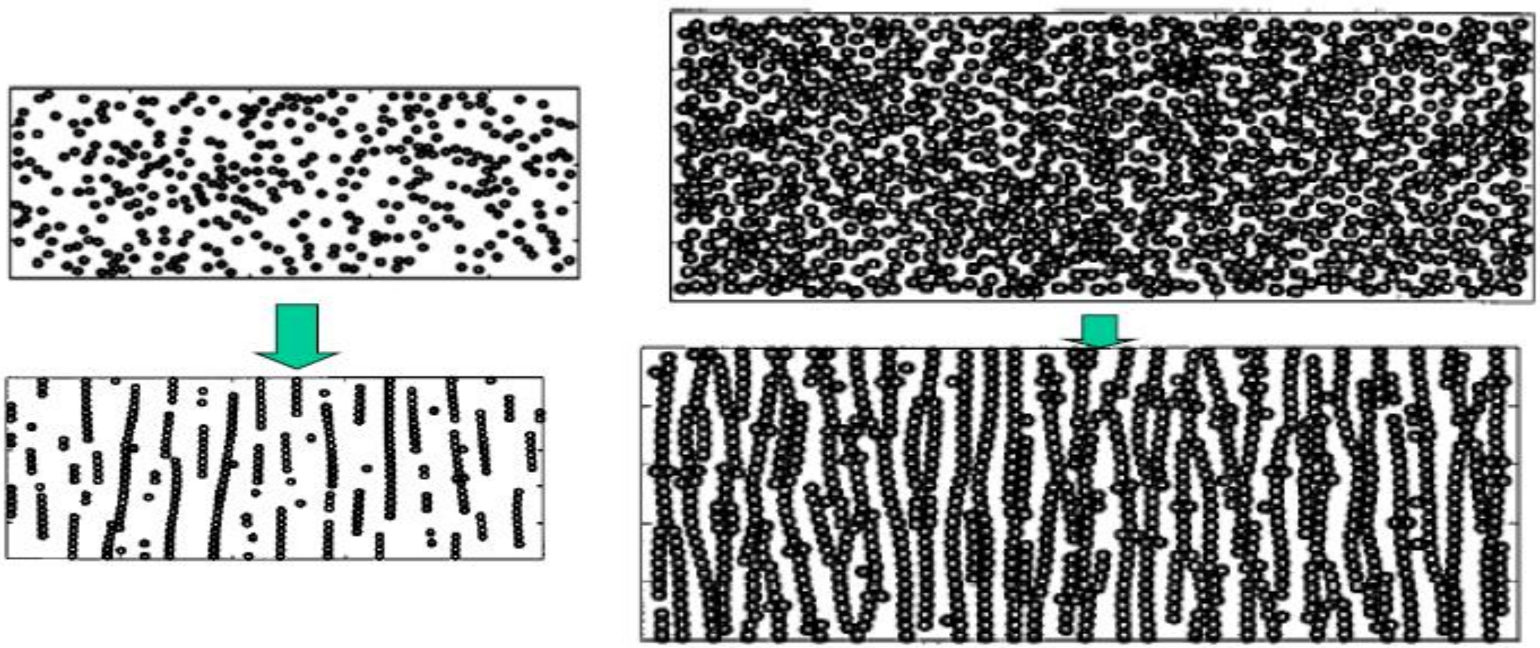




Application of magnetic field, polarizes and align magnetic particles. Particle chain formation limits particle movement, which in turn limits the movement of the fluid.

MR Fluids:

- Consist micron (1-10 μm) sized, magnetically polarizable (soft magnets) dispersed in a carrier liquid such as mineral, oils, kerosene, water.



MR Fluids:

MR-FLUID…………..

- Make device smart by changing system's properties(damping, viscosity) in a desirable manner.
- Useful in active control of vibration & motion, i.e. engine mount, shock absorbers, seat dampers etc.

Application of MR Fluids:

Application of MR Fluid in Engine Mount?

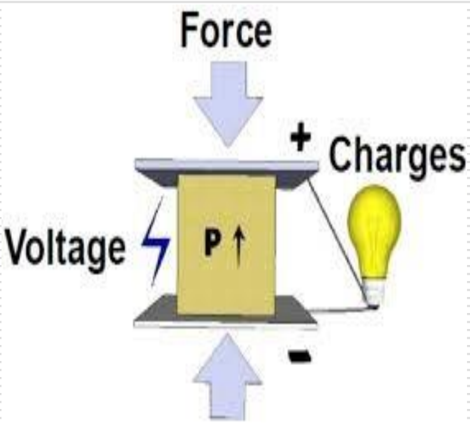
Basic Function: To connect the Engine firmly to Chassis / Frame. Vibration isolation, to reduce vibrations transmitted from the engine to the frame.

Piezoelectric Materials

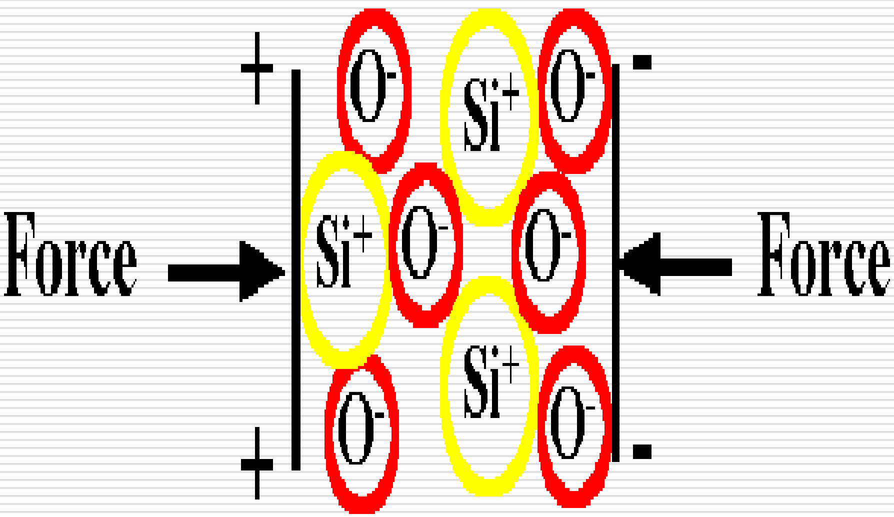
- Appearance of an electric potential across certain faces of a crystal when it is subjected to mechanical pressure
- The word originates from the greek word “piezein”, which means “to press”
- Discovered in 1880 by Pierre Curie in quartz crystals.
- Conversely, when an electric field is applied to one of the faces of the crystal it undergoes mechanical distortion.
- Examples --- Quartz, Barium titanate.

Piezoelectric Effect

- The effect is explained by the displacement of ions in crystals. When the crystal is compressed, the ions in each unit cell are displaced, causing the electric polarization of the unit cell.
- Because of the regularity of crystalline structure, these effects accumulate, causing the appearance of an electric potential difference between certain faces of the crystal.
- When an external electric field is applied to the crystal, the ions in each unit cell are displaced by electrostatic forces, resulting in the mechanical deformation of the whole crystal.



Piezoelectric Effect



- displacement of electrical charge due to the deflection of the lattice in a naturally piezoelectric quartz crystal
- The larger circles represent silicon atoms, while the smaller ones represent oxygen.
- Quartz crystals is one of the most stable piezoelectric materials.

Applications

Industry	Application
Automotive	Air bag sensor, audible alarms, fuel atomiser
Computer	Disc drives, inkjet printers.
Consumer	Depth finders, fish finders, humidifiers, jewellery cleaners, musical instruments, speakers, telephones
Medical	Disposable patient monitors, foetal heart monitors, ultrasonic imaging
Military	Depth sounders, guidance systems, hydrophones, sonar.

Common Piezoelectric Materials

NATURAL	SYNTHETIC
Quartz	Lead zirconate titanate (PZT)
Rochelle Salt	Zinc oxide (ZnO)
Topaz	Barium titanate ($BaTiO_3$)
Sucrose	Gallium orthophosphate ($GaPO_4$)
Tendon	Potassium niobate ($KNbO_3$)
Silk	Lead titanate ($PbTiO_3$)
Enamel	Lithium tantalate ($LiTaO_3$)
Dentin	Langasite ($La_3Ga_5SiO_{14}$)
DNA	Sodium tungstate (Na_2WO_3)

Applications of Piezoelectric

GYMS AND WORKPLACES

- Vibrations caused from machines in the gym.
- At workplaces, piezoelectric crystal are laid in the chairs for storing energy.
- Utilizing the vibrations in the vehicle like clutches, gears etc.

Applications of Piezoelectric

MOBILE KEYPADS & KEYBOARDS

- Crystals laid down under keys of mobile unit and keyboard.
- For every key pressed vibrations are created.
- These vibrations can be used for charging purposes.

Dielectric Materials

- The word " Dielectric come from Greek prefix 'Di' or 'Dia' meaning across.
- Dielectric materials are basically plain and simple electric insulators.
- These electric insulators get polarized.
- Dielectric materials have no free charges because, all the electrons are bound and associated with the nearest atom.

Dielectric Materials

The polar molecules in the material will be in random alignment when there is no peripheral electric field as shown in figure1

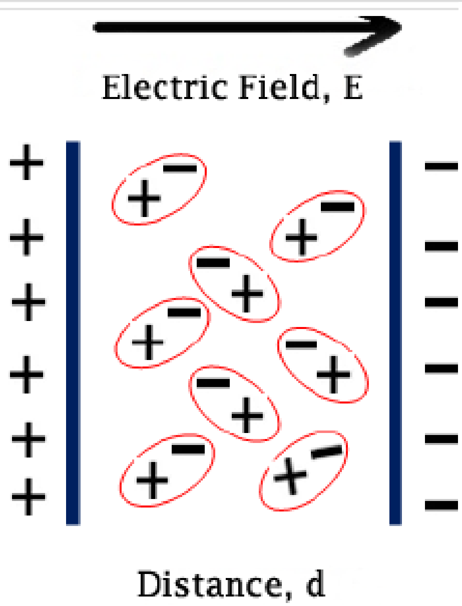


Figure-1

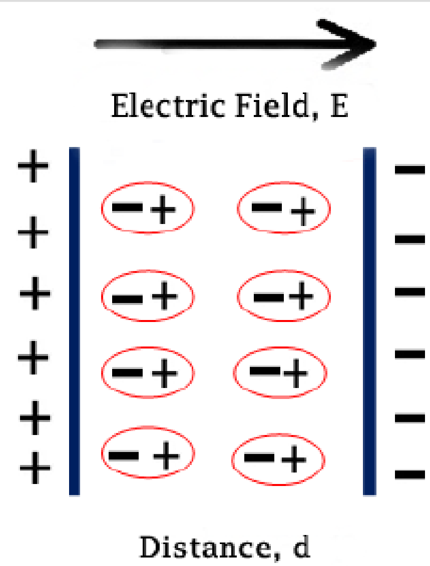


Figure 2

- When we place a dielectric material in an electric field, practically no current is flowing through them, rather polarisation of molecules happens. It transfers electrical energy through the shifting of current and not through the process of conduction. This is shown in Figure 2.

Applications

- Dielectric materials can be used in capacitors for energy storage..
- It is used in photosensitive materials for charge storage in laser printers & copying machine.
- A *dielectric resonator oscillator (DRO)* - to control the frequency of the radio waves generated.

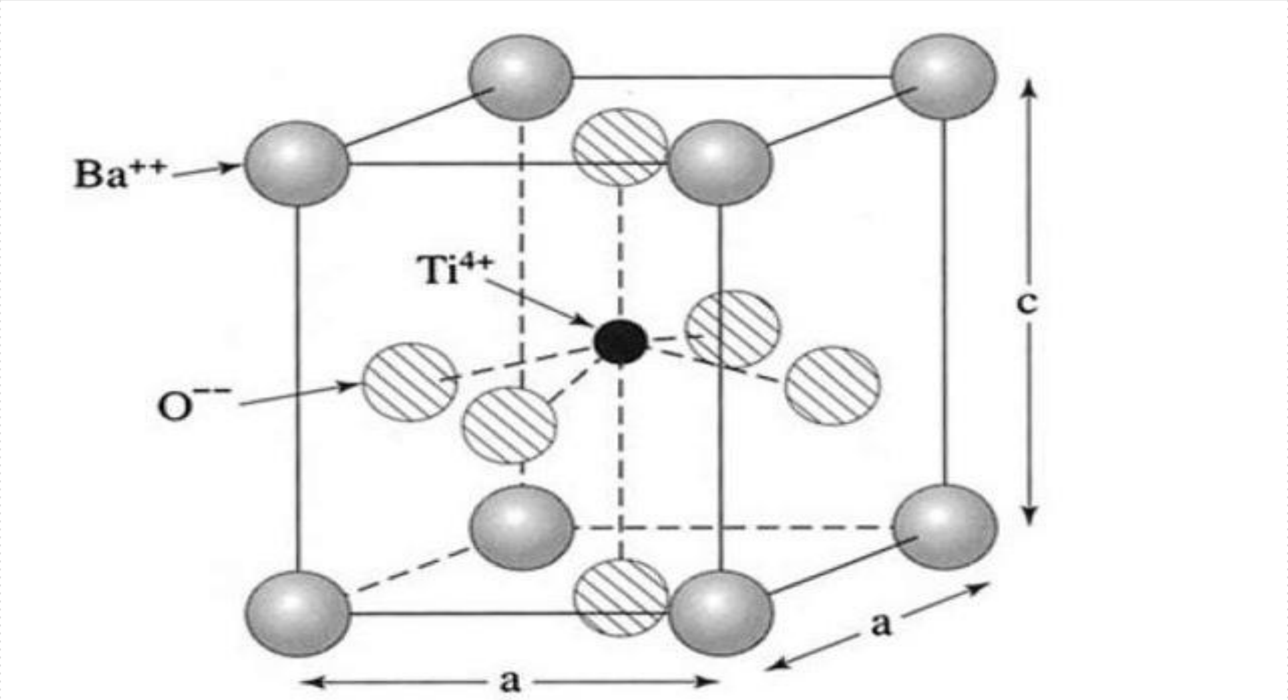
Ferro electricity

- **Ferro electricity is a characteristic of certain materials that have a spontaneous electric polarization that can be reversed by the** application of an external electric field.
- A group of dielectric materials that display spontaneous polarization. In other words, they possess polarization in the absence of an electric field.
- The term is used in analogy to ferromagnetism, in which a material exhibits a permanent magnetic moment.
- Thus, the prefix ferro, meaning iron, was used to describe the property despite the fact that most ferroelectric materials do not contain iron.
- An important ferroelectric material for applications is lead zirconate titanate (PZT), which is part of the solid solution formed between ferroelectric lead titanate and anti-ferroelectric lead zirconate.

Barium Titanate ($BaTiO_3$)

- The Ba^{2+} ions are in the corners, they have a tetragonal symmetry. The O^{2-} ions are displaced below the centers of each of the six faces and the Ti^{4+} ion is displaced upward from the unit cell center by the same amount.
- The permanent ionic dipole moment comes from the relative displacements of the oxygen and titanium ions from their symmetrical positions.
- When a ferroelectric material is heated above its Curie Temp. then the unit cell becomes cubic, all the ions assume symmetric positions within the cubic unit cell and ferroelectric behavior ceases.
- Spontaneous polarization is a result of interactions between adjacent permanent dipoles which mutually align, all in the same direction.

Barium Titanate ($BaTiO_3$)



Examples and application of Ferroelectrics

Barium Titanate, Rochelle salt, potassium dihydrogen phosphate, potassium niobate, and lead zirconate-titanate (PZT)

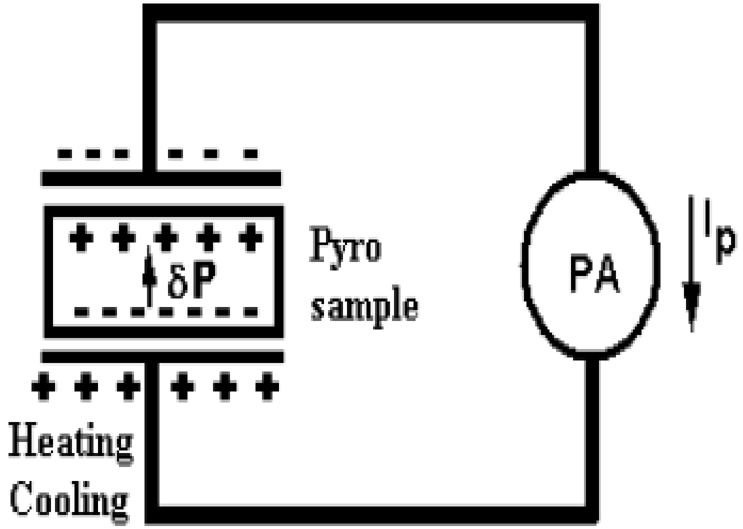
Applications for Ferroelectric Materials

- Capacitors
- Non-volatile memory
- Piezoelectrics for ultrasound imaging and actuators
- Electro-optic materials for data storage applications
- Oscillators and filters
- Light deflectors, modulators and displays

Pyroelectric Materials

- Pyro electricity is the capacity of some materials to generate a voltage when they are subjected to heat or cold.
- The term Pyroelectricity was originated from Greek word Pyr meaning fire and the term electricity.
- Due to the variation in the temperature, slight changes occur in the position of atoms with in the crystals as a result, the polarization of the crystal changes.
- This develops a voltage across the crystal. The voltage that develops across the crystal is not stable and when the temperature change remains as such, the voltage ceases due to leakage of current.
- This may be due to the movement of electrons in the crystals.

Pyroelectric Materials



A pyroelectric current flows between electrodes due to a temperature change

Pyroelectric Materials

- Some Pyroelectric crystals change their crystal property in response to very minute change in temperature level as seen in the crystals used to make the PIR Sensors.
- In these Passive Infra Red sensors, the passive infrared emissions due to the body heat of human beings generate voltage across the crystals.
- Predominant pyroelectric structure is the perovskite [calcium titanate (CaTiO3).]

Pyroelectric materials

- Triglycine sulphate (TGS)

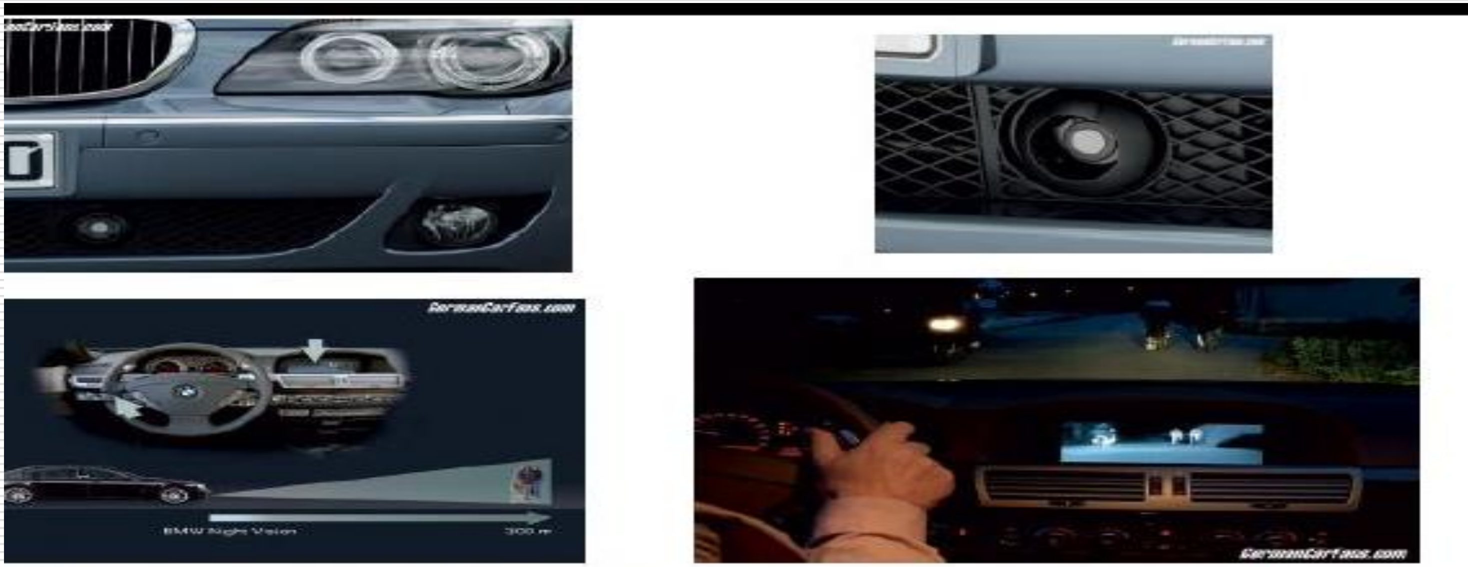
TGS has been extensively studied for thermal imaging applications and is well known for its use in infrared detectors.

- Ceramics- Ferroelectric BaTiO3 ceramics exhibits spontaneous electric polarisation, Another important ceramic is lead zirconium titanate (PZT), which is well known as a perovskite ferroelectric

Application of Pyroelectric materials

- The efficient conversion of thermal energy into electrical energy using pyroelectric materials is of considerable importance in their applications and these materials can be used to develop temperature-sensing devices .
- It is well known that pyroelectric materials react to changes in detectable radiation intensity.
- As a result they may be used in a wide variety of applications such as radiometry, thermometry, remote temperature measurement, solar energy conversion.
- Pyroelectric detectors are used in intruder/burglar and fire alarm security systems Intruder alarms ,an electrical signal is generated as the intruder moves in and out of area covered by the mirror(s) which is focused onto the detector.
- Pyroelectric detectors also have become a popular in medicine because they are used to sense cells which are warmer than usual that can show the disease malignant tumours.

Application of Pyroelectric materials



PIR sensors allow you to sense motion, almost always used to detect whether a human has moved in or out of the sensors range.

Biomaterials

- Biomaterials are used to make devices to replace a part or a function of the body, in safe, reliably, economically, and physiologically acceptable manner.
- A variety of devices and materials are used in the treatment of disease or injury. Commonplace examples include suture needles, plates, teeth fillings, etc.
- Biomaterial: A synthetic material used to make devices to replace part of a living system or to function in intimate contact with living tissue.
- Bio-compatibility: Acceptance of an artificial implant by the surrounding tissues and by the body as a whole.

Biomaterials

- A variety of devices, such as the heart, lung and blood dialysis machines are used commonly in medical technology.
- The availability of human organs is difficult which has paved the way for the use of synthetic materials .

Functions Of Biomaterials

- The functions of implants fall in to one of the categories:
- Load bearing or transmission
- The control of fluid flow in order to stimulate normal physiological function or situation
- Passive space filling either for cosmetic reasons or functional reasons.

Properties of Biomaterials

1.Toxicology

•A biomaterial should not be toxic, unless it is specifically engineered for such requirements (for example a "smart" bomb" drug delivery system that targets cancer cells and destroy them).

•Toxicology for biomaterials deals with the substances that migrate out of the biomaterials.

• It is reasonable to say that a biomaterial should not give off anything from its mass unless it is specifically designed to do so.

Properties of Biomaterials

2- Biocompatibility

•It is the ability of a material to perform with an appropriate host response in a specific application.

•"Appropriate host response" includes lack of blood clotting, resistance to bacterial colonization and abnormal heating.

•The operational definition of biocompatible "the patient is alive so it must be biocompatible".

Properties of Biomaterials

3- Healing

•Special processes are invoked when a material or device heals in the body.

•Injury to tissue will stimulate the well-defined inflammatory reaction sequence that leads to healing.

•When a foreign body is present in the wound site, the reaction sequence is referred to as the "foreign body reaction". This reaction will differ in intensity and duration depending upon the anatomical site involved.

Properties of Biomaterials

4.Mechanical Properties of Biomaterials

- Biomaterials that have a mechanical operation must perform to certain standards and be able to cope with pressures.
- Biomaterials that are used with a mechanical application, such as hip implants, are usually designed using CAD (Computer Aided Design)

5.Thermal Properties

•Wide temperature fluctuations occur in the oral cavity due to the ingestion of hot or cold food and drink.

•Thermal Conductivity is the rate of heat flow per unit temperature gradient.

6.Chemical Properties

•One of the main factors, which determine the durability of a material, is its chemical stability.

•Material should not dissolve, erode or corrode, nor should they leach important constituents into oral fluids.

Different types of Biomaterials

Metallic biomaterials

- Stainless steel
- Co-Cr alloys
- Au-Ag-Cu-Pd alloys
- Amalgam
- Ni-Ti
- Titanium

Polymeric Biomaterials

- Acrylics
- PVC
- polyamides
- polyesters
- PTFE
- Polyethylene
- Polyurethane

Bioceramics

- Alumina
- Zirconia
- Silicate glass
- Calcium phosphate (apatite)
- Calcium carbonate

Selection of Biomedical Materials

The process of material selection should ideally be for a logical sequence involving:

•Analysis of the problem;

•Consideration of requirement;

• Consideration of available material and their properties leading to:

•Choice of material.

•Mechanical and chemicals properties

•No undersirable biological effects toxic, allergenic.

•Possible to process, fabricate and sterilize with a good reproducibility

•Acceptable cost/benefit ratio

Applications

- Joint replacements -Titanium, stainless steel, polyethylene
- Plate for fracture fixation - Stainless steel, cobalt-chromium alloy
- Bone cement - Poly(methyl methacrylate)
- Artificial tendon and ligament-Teflon, Dacron
- Dental Implants-Titanium, alumina, calcium phosphate

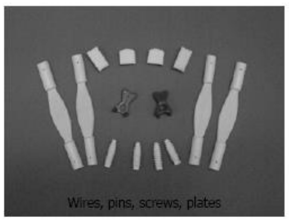
Applications

Materials	Advantages	Disadvantages	Examples
Polymers (nylon, silicon Rubber, polyester, PTFE, etc)	Resilient Easy to Fabricate	Not strong Deforms with time, May degrade	Blood vessels, Sutures, ear, nose, Soft tissues
Metals (Ti and its alloys Co-Cr alloys, stainless Steels)	Strong Tough ductile	May corrode, dense, Difficult to make	Joint replacement, Bone plates and Screws, dental root Implant, pacer, and suture
Ceramics (Aluminum Oxide, calcium phosphates, including hydroxyapatite carbon)	Very biocompatible Inert strong in compression	Difficult to make, Brittle Not resilient	Dental coating Orthopedic implants Femoral head of hip
Composites (Carbon-carbon, wire Or fiber reinforced Bone cement)	Compression strong	Difficult to make	Joint implants Heart valves

TYPICAL BIOMATERIAL APPLICATION

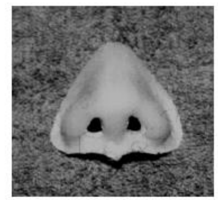
EXAMPLES

Hard tissue: long bone



Hard tissue: long bone

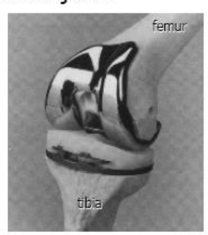
Soft tissue: skin/maxillofacial



Soft tissue: plastic surgery

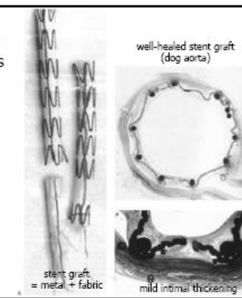
Hard tissue: Total hip arthroplasty

Hard tissue: joint

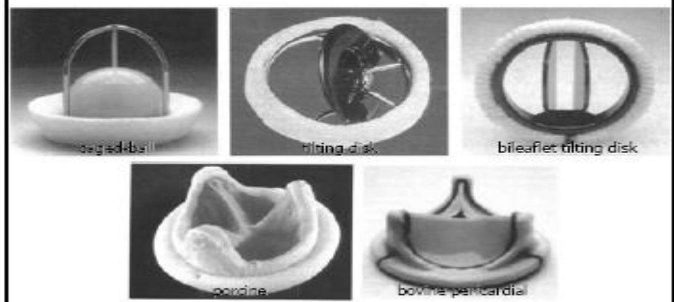


Soft tissue: blood vessel

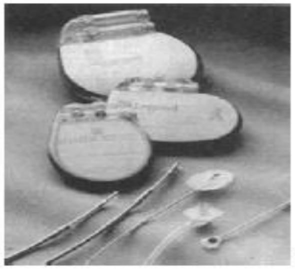
Soft tissue: Stent grafts

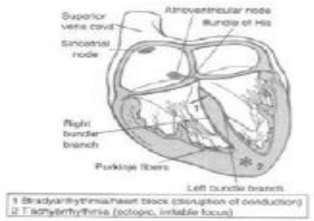


Soft tissue: (modern) heart valves



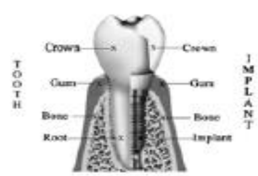
Cardiac pacemakers





Powered by batteries (service life: 5-12 yr)

Hard tissue: dental implants



- Subperiosteal
- Endosteal

Hard tissue: dental sealant

THANK YOU