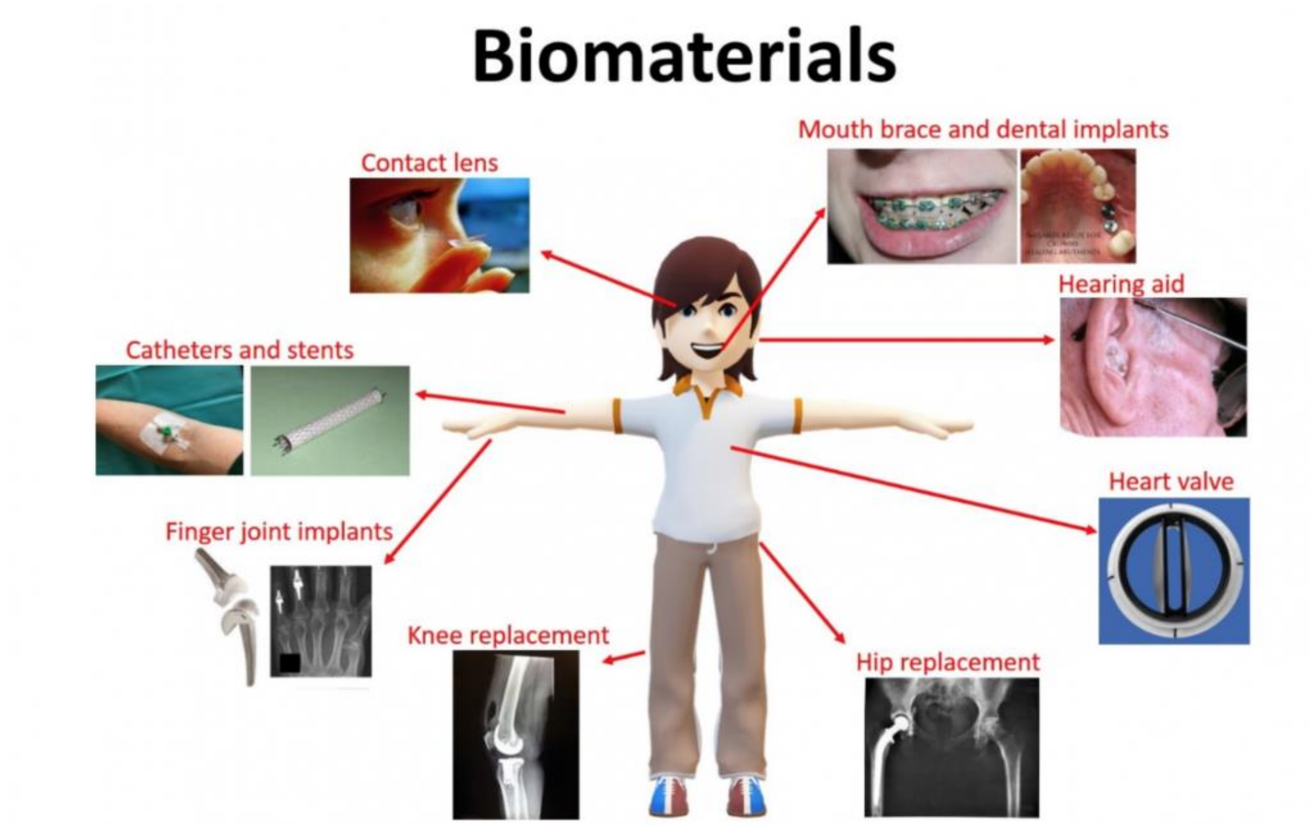
# WEEK-04

**Advanced materials -Biomaterials- Properties and applications, Smart Material - Piezoelectric materials (Quartz, PZT and PVDF), Shape memory alloys (Nitinol, Ni–Mn–Ga)- Properties and applications, Energy Materials- Solar Energy, Battery- Properties and applications, Nano-Materials-Classification, properties and applications, Carbon – based CNT and Graphene.**

## BIOMATERIALS:

Biomaterials are defined as the synthetic material that is used to replace or restore function to a body tissue and is continuously or intermittently in contact with body fluids.




**Properties of Biomaterials:**

Following are the important properties of biomaterials.

1. These materials must not produce toxic substance.
2. Biocompatibility: It must not any allergic or immune reaction in the body.
3. Mechanical strength: It should have sufficient strength to withstand body forces such as movement, pressure and load.
4. Corrosion and Wear resistance: It must resist corrosion, wear and degradation when it contact with body fluids.
5. Biofunctionality: It must perform the desired biological function effectively.
6. They should not cause adverse biological reactions.
7. They should be reliable and durable.

**Applications:**

Following are the important aplications of biomaterials:

1. Used for joint replacement.
2. Used for bone plates.
3. For dental implants for tooth fixation.
4. Used for artificial ligaments and tendons.
5. Used for cancertherapy.
6. For intracular lenses for eye surgery.
7. Used for Cardiovascular -artificial heart valve, stunt, etc.
8. Used for skin repair devices(artificial tissue).

**SMARTS MATERIALS:**

Smart materials are the intelligent materials which are able to sense changes in their environment and then respond to these changes in predetermined manners.

The smart materials are also called as responsive materials. These are designed materials have one or more properties that can be sigficantely changed in a controlled fashion by an external stimuli, light, temperature, pH or chemical compounds.

**Types of Smart materials:**

1. Piezoelectric materials.
2. Electrostrictive materials.
3. Magnetostrictive materials.
4. Thermoresponsive materials.
5. Electrochromic materials.
6. Smart glass.

**Properties of Smart materials:**

Following are the important properties of smart materials.

1. Excellent response to the change in theirenvironment.
2. They are self detective and self diagnostic.
3. Self corrective, self controlling and self healing.
4. High sensitivity.
5. Their response time very less.

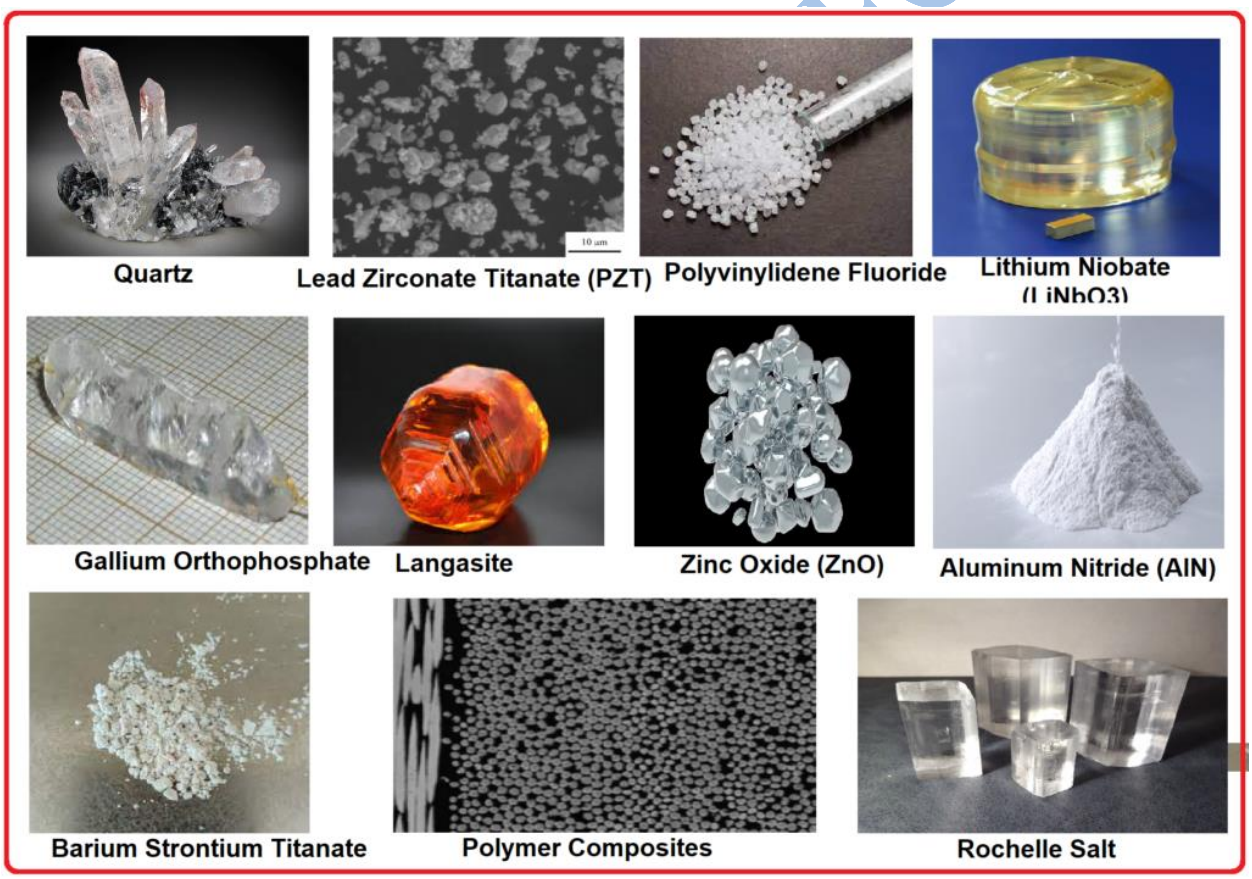
**Applications of Smart materials:**

Following are the important application are .

1. Used in electronic display.
2. Used in actuator and sensors.
3. Used for data storage units and energy conversion devices.
4. Used for insulin pumps.
5. Used for ultrasonic therapy.
6. Used for ultrasonic cataract removal devices.
7. Used in computer, microactuators for hard discs.
8. Used in micro-electro mechanical systems.

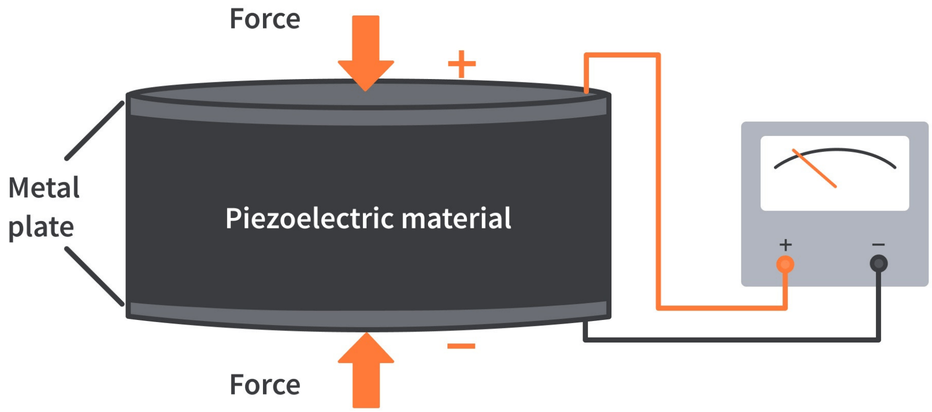


**<u>PIEZOELECTRIC MATERIALS:</u>**




Piezoelectric materials generate an electric charge (voltage) when mechanical stress is applied and conversely deform when an electric field is applied. This property is known as the piezolelectric effect.

Examples: Quartz, lead zircronate titanate(PZT) , Polyvinylidene fluride(PVDF).



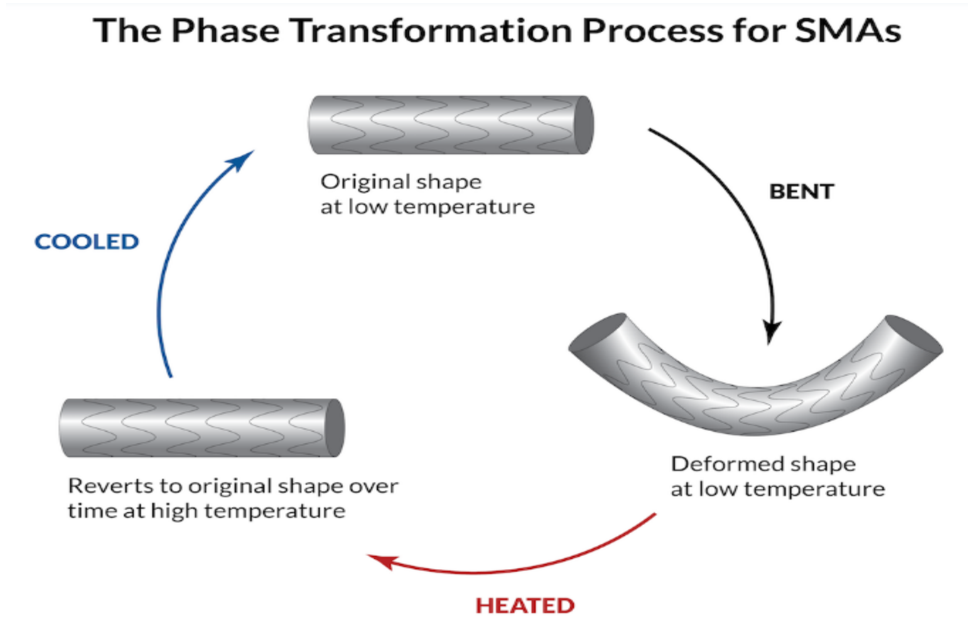

**Properties of Piezoelectric materials:**

1. Exhibit direct and converse piezoelectric effect.
2. Are anisotrophic- behaviour depends on direction of force or field.
3. Possess moderate to high dielectric constant.
4. Show good mechanical strength under stress and vibration.
5. Respond well to high-frequency signals.
6. Must have a non-centrosymmetric crystal structure.
7. Can be natural(quartz) or synthetic.
8. High permitivity- store large amount of electric energy.

**Appliation of Piezoelectric materials:**

| Sl no | Application Area | Uses of Piezoelectric material |
|---|---|---|
| 1 | Sensors | Convert pressure or force in to voltage (airbags, scale) |
| 2 | Actuators | Produce movement from voltage (robicts, optics, camera lenses) |
| 3 | Ultrasound devices | Generate and receive sound waves(medical) |
| 4 | Microphones/Speakers | Convert between sound and electrical signals |
| 5 | Earthquake monitoring | Detect seismic waves through stress-induced charge |
| 6 | Ignition system | Spark generation from mechanical parts |
| 7 | Accelerometers | Used in smart phones |

## <u>SHAPE MEMORY ALLOYS(SMA):</u>




A shape memory alloy is an alloy that can deformed when cold but returns ot its original shape when heated( depends on temperature), transitiong from derformed martensitic phase to an austenitic phase upon heating.

Examples: Copper-aluminium-nickel and Nickel-titanium(Nitinol)

**Properties of Shape Memory Alloys:**

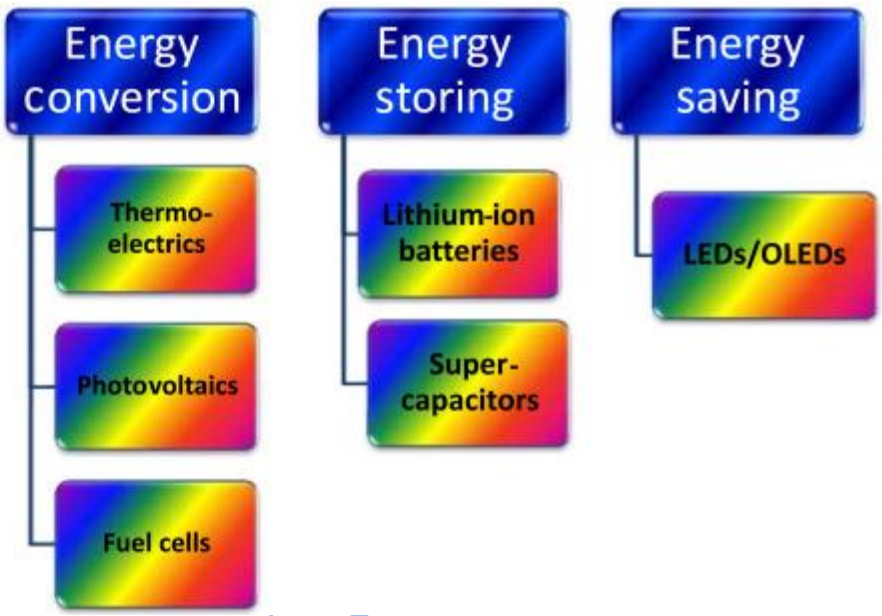
1. Ability to return to a predefined shape when heated, even after being deformed at a lower temeparture.
2. Exhibit good corrosion resistance.
3. Ability to undergo large elastic deformation and recover the original shape upon removal of stress.
4. Exhibit changes in electrical resistance during phase transformations.

**Applications of Shape Memory Alloys:**

1. Biomedical devices- used in stunts that can be compressed for insertion and then expands to original shape within the body.
2. Aerospace- Deploying structure and adaptive wing components.
3. Used in seismic protection.
4. Used in Textiles.

## ENERGY MATERIALS:

Energy materials are substances engineered for energy related applications like storage, conversion and generation. These materials are crucial for advancements in renewable energy technologies, electric vehicles and grid storage. They consists a wide range of substances, used in applications like batteries, fuel cells, solar cells and thermoelectric device. These materials are important for developing sustainable energy solutions and improving energy efficiency.




**Examples:** Lithium-ion batteries, Solar cell materials, Fuel cell, Thermoelectrics & Supercapacitors.

**Properties of Energy Materials:**

1. Good thermal conductivity.
2. Excellent charge carrier mobility.
3. Excellent electrical conductivity.
4. High strength and toughness.
5. Low cost and long lifespan.
6. Materials must be stable under the electrochemical conditions.

**Applications of Energy materials:**

1. Used in electric vehicles.
2. Used in renewable energy sources.
3. Used in portable electronic equipments like smartphones, laptops etc.
4. Used in industrial processes for improving energy efficiency and reducing emissions.

1. **Solar Energy Materials:**

Solar energy materials are materials that convert sunlight in to electrical energy using the photovoltic effect.

Examples: Silicon, Cadmium telluride & Copper indium gallium selenide.

**Properties of Solar Energy materials:**

1. High photoelectric conversion efficiency.
2. Good stability.
3. Durability.
4. Suitable bandgap.

**Applications of Solar Energy materials:**

1. Solar panels for residential, commercial and industrial power generation.
2. Solar powerred calculators, lamps and street lights.
3. Solar cells in satellities and space applications.

2. **Battery materials:**

Battery materials are materials used to store electric energy chemically and release it on demand through electrochemical reactions.

Examples: litium-ion batteries, lead-acid batteries, Nickel-metal hydride.

**Properties of Battery materials:**

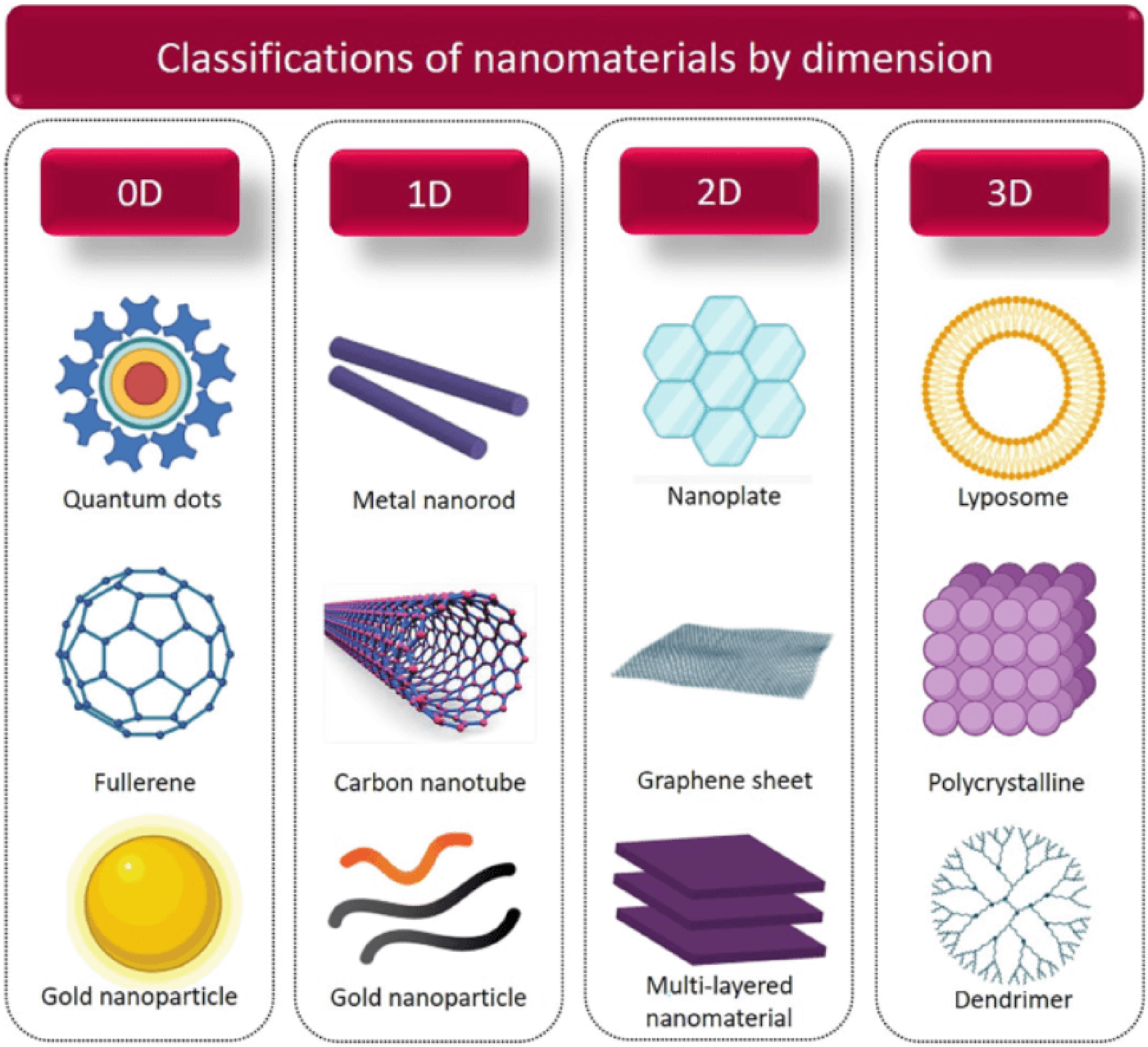
1. High energy density- It can store large amounts of energy in a small volume.
2. Long cycle life-It can be charged and discharged multiple times.
3. Good electrical conductivity- It ensures efficient current flow.
4. Safety and stabilitty- resistant to leakage, overheating or short circuiting.
5. Lightweight-Ideal for portable devices.

**Applications of Battery materials:**

1. Portable electronic devices-Mobile phones, laptops.
2. Electric vehicles- Lithium-ion batteries for cars and bikes.
3. Backup power systems- Lead-acid batteries in UPS.
4. Renewable energy storage- Solar and wind energy storage systems.

### 3. Nano-materials:

Nanomaterials are substances with at least one dimension between 1 and 100 nanometers (nm), exhibiting unique optical, electrical, mechanical, and magnetic properties different from their bulk counterparts due to their high surface area and quantum effects.




**Properties of Nanomaterials:**

1. Excellent hardness.
2. Higher sriffness.
3. Improved fracture toughness.
4. They can exhibit elastic behaviour.
5. They have a low melting point.

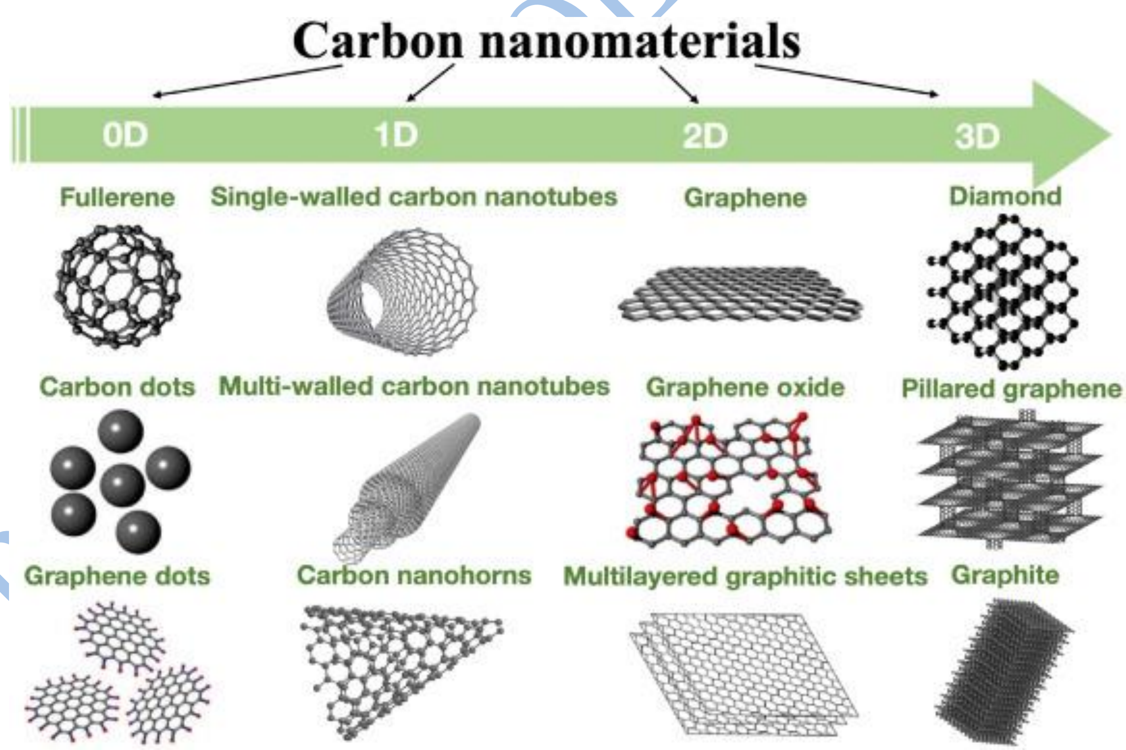
6. Enchanced Electrical and Thermal conductivity.
7. They can exhibit photoconductivity.

**Applications of Nanomaterials:**

| Field | Applications |
|---|---|
| **Electronics** | Sensors, Memory devices, Nano transistors |
| **Medicine** | Drug delivery systems, Cancer treatment, Diagnostic imaging |
| **Energy** | Solar cells, Fuel cells and Batteries |
| **Environment** | Water purification, Air filters, Pollution control |
| **Textiles** | Antibacterials Fabrics |

**Carbon nanotubes(CNTs):**

A carbon nanotube is a carbon allotrope (different structural forms) that resembles a tube of carbon atoms. Carbon nanotubes are extremely robust and difficult to break, but they are still light.



# Week 5

**Additive Manufacturing:**

- **Introduction to Additive Manufacturing, Materials - metal, polymer, ceramic, and glass materials used in Additive Manufacturing, and its properties & limitations.**
- **Types of Additive manufacturing Technologies- Overview of FDM, SLA & SLS technologies.**
- **Step-by-step additive manufacturing process.**
- **Applications of Additive Manufacturing.**

**ADDITIVE MANUFACTURING(AM):**

Additive manufacturing is a process of making three dimensional solid objects adding material layer by layer from a digital CAD model. It is also called as 3D printing. By using 3D printing it is possible to produce objects of almost any shape and form.

**ADDITIVE MANUFACTURING MATERIALS:**

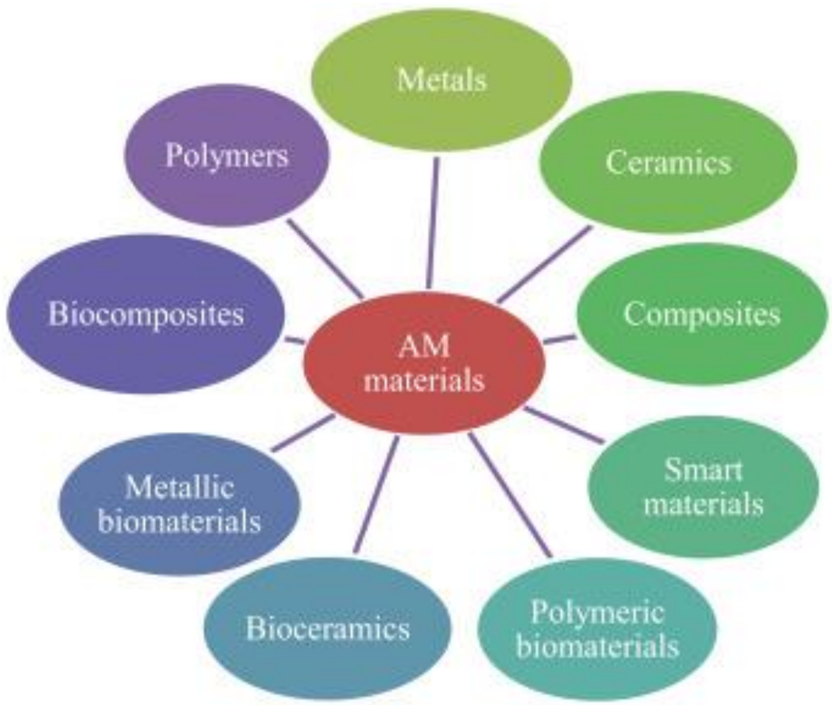



**Fig: Additive manufacturing materials**

1. **Metals:**

Metals commenly used in addtive manufacturing to produce parts such as Stainless Steel, Titanium, Aluminium, Cobalt based alloy, Nickel based alloy, Copper, Gold etc.

**Properties:**

Following are the properties of metals used in additive manufacturing:

1. High strength to weight ratio.
2. Good corrosion and wear resistance.
3. Good biocompatibility.
4. Excellent thermal & electric conductivity.

**Limitations:**

Following are the limitations of metals used in additive manufacturing:

1. High cost of metal powder.

2. Requires controlled atmosphere( inert gas or vacuum) during.
3. Post processing(heat teratment or machining) often required.
4. Rapid heating and cooling cycles can induce internal stresses and defects.

**Applications:**

Metals are widely used in industries such as aerospace (turbine blades), automotive, healtcare and engineering.

2. **Polymer:**

Polymer or plastic are versatile materials widely used in additive manufacturing due to their ease of processing and wide range of properties. Different types of plastic used are Arcylonitrile Butadiene Styrene(ABS), Polylactide(PLA), Polyethylene terephthalate(PET).

**Properties:**

1. Lightweight and low cost.
2. Flexible & Chemical stability.
3. Ability to integrate complex functionalities.
4. Good surface finish.
5. Customization.

**Limitations:**

1. Low strength and temperature resistance compared to metals.
2. High porosity in the polymer parts, affecting their strength an density.
3. Limited long term durability.
4. Not suitable for heavy load or structural parts.

**Applications:**

Prototypes,consumer goods, automotive and electronics.

3. **Ceramics:**

A ceramic is a material that is neither metallic nor organic. Different types of ceramics are alumina, zirconia, silicon carbide, silicon nitride & hydroxyapatite.

**Properties of Ceramics:**

1. High mechanical strength & hardness.
2. High resistance to chemical attact & corrosion.
3. Excellent thermal and chemical stability.
4. Light weight components.

5. Excellent electrical insulation.
6. Biocompatibility.

**Limitation of ceramics:**

1. Brittle in nature- poor tensile &impact strength.
2. Defficult to process & requires sintering after printing.
3. Achieving a good surface quality and high dimensional precision is also a challenge one.

**Appications:**

Biomedical implants, turbine components etc.

4. **Glass materials:**

Glass is a solid like and transparent material that is used in numerous applications in our daily life. Different types of glass materials are silica glass, borosilicate glass, soda-lime glass & bioactive glass.

**Properties of Glass materials:**

1. High optical transparency.
2. High hardness and compressive strength.
3. Excellent chemical resistance.
4. High temperature stability.
5. Biocampatible.

**Limitation of Glass materials:**

1. Very high melting point.
2. High machining costs.
3. Defects like porosity, cracks & micro-voids can easily form in the printed glass.
4. Lower mechanical strength.

**TYPES OF ADDITIVE MANUFACTURING TECHNOLOGIES:**

1. VAT Photopolymerization. Vat polymerization uses a vat of liquid photopolymer resin, out of which the model is constructed layer by layer.
2. Material Jetting.
3. Binder Jetting.
4. Material Extrusion.
5. Powder Bed Fusion.
6. Sheet Lamination.

7. Directed Energy Deposition.

## Overview of FDM, SLA & SLS technologies:

1. **FDM-Fused Deposition Modeling:**

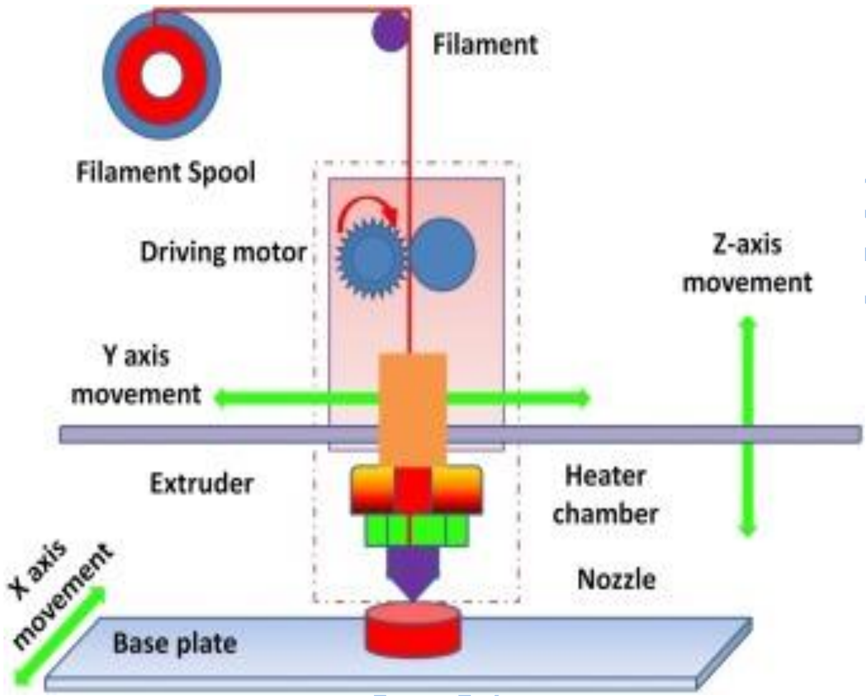



**Fig: Fused Deposition Modeling**

- FDM is an additive manufacturing process in which a part is created layer by layer by melting and depositing thermoplastics material.
- In FDM nozzle moves in X & Y directions, while the platform moves in Z direction to create the complete 3D part.
- A plastic filament like PLS or ABS is fed form the coil reel into the printer.
- The driving motor pushes the filament in to the extruder, inside the extruder, the filament is heated and converted into molten paste in heating chamber. The molten material flows out through the nozzle tip.
- The nozzle moves in X & Y directions to draw the shape of each layer. The base plate moves in the Z direction, allowing the next layer to be deposited on top of the previous one.
- The molten material quickly cools and solidifies, forming the part. This continues until the entire 3D object is built layer by layer.

**2. SLA- Stereolithography:**

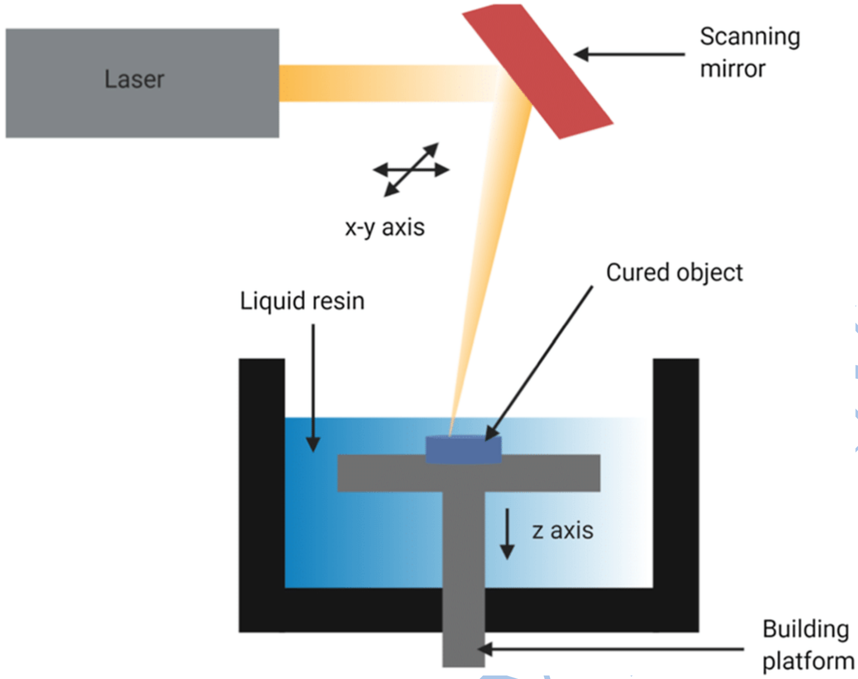



**Fig: Stereolithography**

- Stereolithography process is one of the rapid prototyping processes in which liquid polymer is used as material for layer by layer 3D part building with the help of laser for solidification of liquid resin.
- Stereolithography is also known as VAT Photopolymerisation.
- Stereolithography machine consist of the following components.
  1. Laser source-Laser source is used to supply a laser to solidify liquid resin to build the part in layer.
  2. Container- Container is filled with the liquid resin, when the laser falls on the liquid resin, the liquid resin gets solidified.
  3. Platform-Platform helps in the part building it moves an upward & downward direction.
- Required model is prepared by the any CAD model software & it is converted into STL file.
- When the laser source gets ON, the laser falls on the liquid resin above the platform. Hence due to the laser, the liquid resin layer above the platform gets solidified.

- Therefore platform moves downwards and a new solidified layer of liquids forms on the old solidified layer.
- The average thickness of one layer is between 0.025 to 0.5mm. After each layer of resin, it must be cured using ultraviolet light.
- This process of photo polymerization uses motor controlled mirrors to direct the UV across the resin surface, causing it to harden. These steps are repeated to add layers.

**3. SLS-Selective Laser Sintering:**

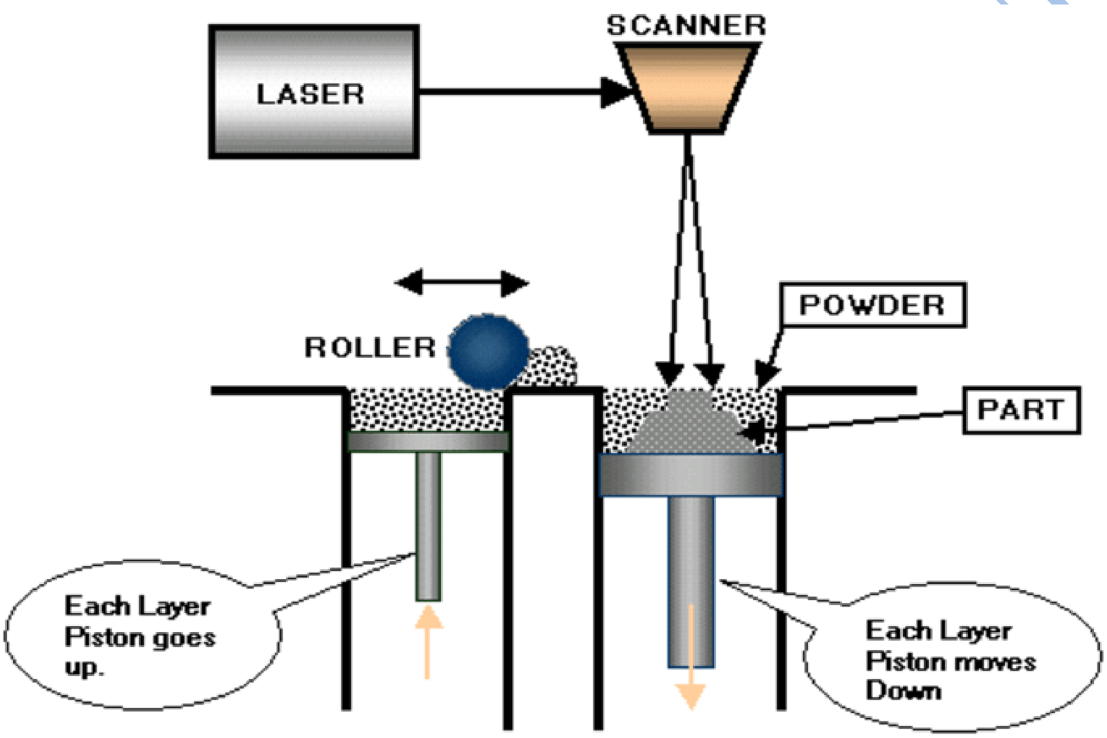
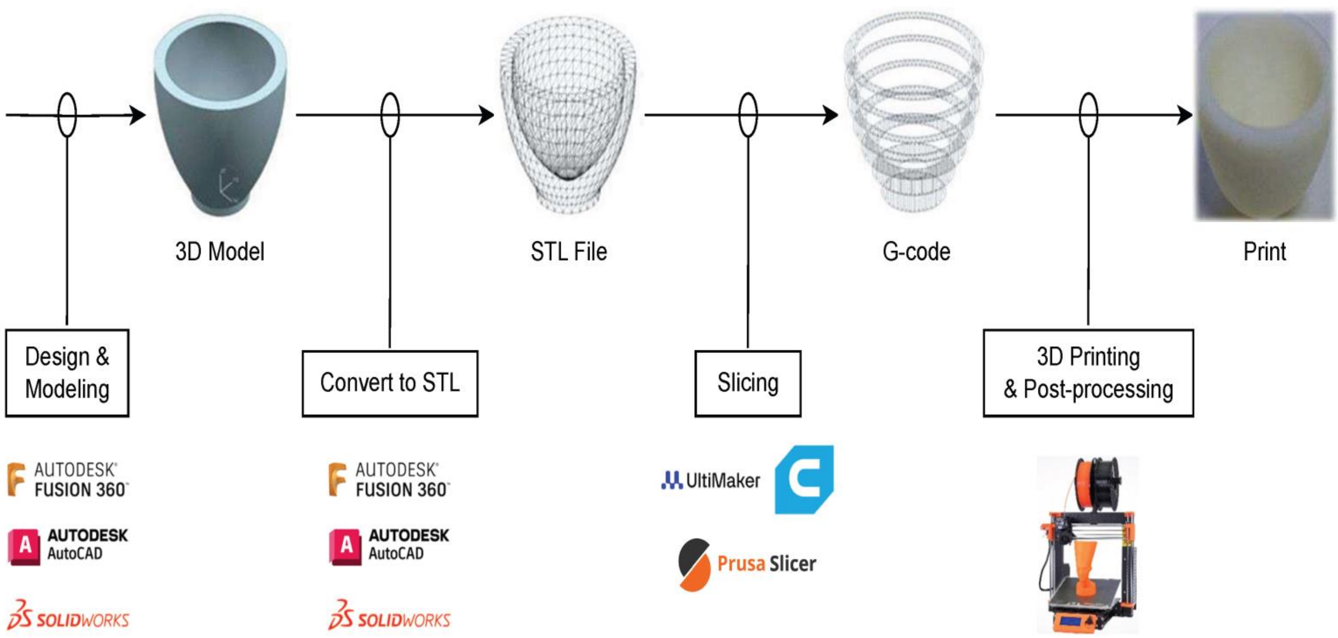



**Fig: Selective Laser Sintering**

- Selective laser sintering is a powder based additive manufacturing system.
- Selective laser sintering (SLS) uses a moving laser beam to sinter heat-fusible powders in areas corresponding to the CAD geometric model one layer at a time to build the solid part.
- After each layer is completed, a new layer of loose powders is spread across the surface using a counter rotating roller.
- The powders are preheated to just below their melting point to facilities bonding and reduce distortion.

- Layer by layer, the powders are gradually bonded into a solid mass that forms the three dimensional part geometry.
- In areas not sintered by the laser beam, the powders remain loose so they can pour out of the completed part. Layer thickness is 0.075 to 0.50mm.
- After cooling, the completed part is removed from the build chamber and any excess powder in the build platform is cleaned off.

## STEP-BY-STEP ADDITIVE MANUFACTURING PROCESS:




1. **Design & Modeling:** A 3D model of the part is created using CAD software.
2. **STL file conversion:** the CAD model is converted into STL file format, which is used by AM machines.
3. **Slicing in Software:** The STL file is sliced into thin layers using slicing software and G-code is generated.
4. **Machine setup:** The AM machine must be properly setup prior to the build process, such setting would relate to the build parameters like the materials constraints, energy source, layer thickness, timings etc.
5. **Part Building:** The machine prints the object layer by layer until the part is complete.
6. **Post-processing:** Once the part removed from the machine, parts may require an amount of additional cleaning up before they are ready for use. This may involves abrasive finishing, like polishing and sand papering or application of coatings.

7. **Quality Control & Testing:** After finishing the product, the final step is to inspect the printed products to ensure that the product should meet the required specification and standards.
8. **Application:** Parts may now be ready to be used.

**ADVANTAGES OF ADDITIVE MANUFACTURING:**

The following advantages are:

1. Rapid prototyping & design flexibility.
2. Low material waste.
3. Customization and small-batch production.
4. Reducing tooling requirements.
5. Ability to produce complex structures.

**LIMITATION OF ADDITIVE MANUFACTURING:**

The following are the limitations are:

1. Limited material options.
2. High equipment cost for industrial system.
3. Size constraints of printers.
4. Post-processing often required.

**APPLICATIONS OF ADDITIVE MANUFACTURING:**

The following are the applications are:

1. Aerospace industry- Lightweight parts.
2. Medical industry- For producing the surgical instrument, implants, dental crowns etc.
3. Construction-Small printed structures, for fabricating the building components.
4. Consumer goods industry- Footwear, eyewear & toys.
5. Automotive industry- production of engine components.
6. Production of products with complex geometries, internal structures.
7. For producing the moulds, patterns, tools & jigs etc.

## REVIEW QUESTIONS

**Multiple Choice Questions:**

1. Additive manufacturing is also known as:
   a) Subtractive manufacturing c) 3D printing
   b) Casting d) welding

**ANS: c)**

2. In additive manufacturing objects are created:
   a) By removing material c) By joining sheets
   b) By adding material layer by layer d) By molding

**ANS: b)**

3. Material is commonly used as filament in FDM technology?
   a) Titanium c) Epoxy resin
   b) ABS plastic d) silicon carbide

**ANS: b)**

4. The abbreviation SLS in AM refers to
   a) Surface layer simulation c) Solid light structuring
   b) Selective laser sintering d) Standard laser sheet

**ANS: b)**

5. What is full form of FDM in additive manufacturing?
   a) Functional design modeling c) Fused deposition modeling
   b) Final deposition method d)Formed direct machining

**ANS: c)**