

1960s	:	Microalloyed steels	1966	:	Fiber optics
late 1970	:	Discovery of amorphous silicon	1976	:	Twisted Nematic liquid Crystals for display devices
1978	:	Optical fiber communication	1980	:	Shape memory polymers
1984	:	Discovery of quasi periodic crystals	1986	:	Discovery of high temperature super conductors
1987	:	High temperature glass FRP and Al and Ti MMCs	1989	:	High temperature super conductor with higher transition temperature around 165 K.
1990	:	Applications of smart materials and shape memory alloys	1991	:	Conducting polymers and light emitting polymers.
1997	:	Applications of smart materials and shape memory polymers	2000	:	Soliton based optical fiber communication at 1.55 μm

In this chapter, let us see some of the newly developed materials and their properties and uses.

11.2 Metallic glasses

The dream of an engineer to have materials with high strength, good magnetic properties, better corrosion resistance and ease of fabrication will be realised through metallic glasses and a total industrial revolution would have been brought about.

Metallic glasses are metal alloys which have no long range atomic order. To achieve this structure a suitable alloy must be quenched so rapidly that the random liquid like structure is retained in the solid. Generally a glass is an amorphous, brittle and transparent solid. It is not a metallic and does not exhibit ferromagnetism. Similarly metals are malleable, ductile and exhibit crystalline properties. Metallic glasses share the properties of both metals and glasses. They are amorphous alloys with an atomic configuration similar to that of the molten liquid that is there is no translational symmetry. Further they are all strong, ductile, malleable, opaque and brittle. Unlike glasses, the glass transition temperature for metallic alloys is about 20°C to 30°C instead of several hundred degrees. The glass transition temperature is the temperature at which the liquid like atomic configuration can be frozen into a solid. A major advantage of metallic glasses is that they can be produced easily and cheaply because they are produced directly from the molten alloy. The technique is called 'splat' quenching (very rapid quenching at the rate of 10^6 K/second). The molten alloys are very rapidly cooled by highly conducting massive rollers rotating at high speeds to give ribbons of metallic glasses.

In the twin roller system, molten alloy is passed through two rollers rotating in opposite directions. In the melt spinning system molten alloy jet impinges on a fast rotating roller. In the melt extraction system a fast moving roller sweeps off molten droplet into a strip from a solid rod. Theoretically the pure metals require extremely high cooling rates to make them glassy and this is beyond the present day technology. First class of metallic glasses arise from transition metal (Fe, Co, Ni) - metalloid (B, Si, C, P) type. So that they are called metal - metalloid glasses. Now we have metal - metal glasses which are nickel - niobium, magnesium - zinc, copper - zirconium and hafnium - vanadium alloys. Unlike metal - metalloid glasses, in the metal - metal glasses there is no restriction on composition. Normally iron - boron alloys require cooling rates of over a million degrees per second to become glassy. But palladium - copper - silicon and palladium - nickel - phosphorous alloys require the cooling rate of hundred degrees per second.

Applications

1. Even though metallic glasses are non crystalline, they are ferromagnetic. The lack of long range ordering results zero bulk magnetic crystal anisotropy on an average. Due to that, they possess low magnetic losses, high permeability and saturation magnetisation with low coercivity. Thus they resemble the very soft magnetic alloys. When we compare with permalloys these have extreme mechanical hardness, excellent initial permeability and zero magnetostriction. So these are used in tape-recorder heads, cores of high power transformers and magnetic shields.

Examples : $Fe_{75}P_{15}C_{10}$, $Fe_{24}Zr_{76}$, $Ni_{60}Nb_{40}$.

2. Metallic glasses possess high strength and tensile strength. For example $Fe_{80}B_{20}$ has its tensile strength around 3.6 GPa. Its hardness is also very high. For $Fe_{40}Mo_{40}B_{20}$, the hardness (HV) = 1950 kg/mm². Thus they are superior than common steels. This is based on their structure since the random ordering does not have any lattice defects like dislocations and grain boundaries. This makes them useful as reinforcing elements in concrete, plastic or rubber. Strong ribbons of metallic glasses can be used for simple filament winding to reinforce pressure vessels or to construct large fly wheels for energy storage.
3. They have higher workability. Thus they can be cold worked upto half their thickness without cracking. They are very pliable and can be bent back all the way through 180° over thin razor blades without breaking. This fact is also utilized to make different kinds of springs.
4. Metallic glasses have high electrical resistance with nearly zero temperature coefficient of resistance. Only at very low temperatures there is a sharp variation in resistance. So these are used to make accurate standard resistances, computer memories, magneto resistance sensors and cryothermometers (thermometers measuring very low temperatures).

5. Many metallic glasses based on titanium, niobium, lanthanum and molybdenum have been found to be superconducting. These would be used in producing high magnetic fields and for magnetic levitation of trains.
6. Further since the metallic glasses are not affected by irradiation, they seem to be ideal material for containers in disposal of radioactive waste.
7. The random ordering in metallic glasses gives very high corrosion resistance. Particularly chromium and phosphorous based metallic glasses (iron-chromium-phosphorus-carbon alloys) have high corrosion resistance and they can be used in marine cables, chemical filters, inner surfaces of reactor vessel, orthopaedical implants and surgical clips.

Thus if metallic glasses could be produced in bulk like ordinary castings, perhaps all the present engineering materials will be replaced by metallic glasses.

11.3 Fiber reinforced plastics (FRP) and fiber reinforced metals (FRM)

It is a composite material. We know that the composite materials have been developed to get improved or desired properties in them. Nowadays fiber reinforced plastics (FRP) play an important role in the machine parts where we require high strength, high modulus, heat resistance and light weight. The fibrous glass is used in reinforced plastics in the form of rovings, chopped strands, milled fibers, yarns, non woven mats and woven fabrics. Most commonly used reinforcements are (i) random chopped strand mat, bonded together with a resinous binder (polyester), (ii) mat from continuous strands, deposited in a swirl pattern and loosely bonded together with a resinous binder, (iii) filament type thin mats, (iv) preforms, (v) woven fibrous glass clothes, (vi) parallel stranded glass fibers and (vii) short stranded fibers. The glass fibers having a vinyl silane-epoxy surface treatment on the fibers are used. This treatment gives best dry and wet strength. E type glass which is one of the important glass fiber material which uses boric acid rather than soda ash as one of the component of the melt. Mostly polyester resin is used as plastic. Epoxy and phenolic resins are also used. Table 11.1 gives the important fibers used in FRP and their properties. The glass reinforced plastic is the one in which glass fibers provide strength while the polymer reduces brittleness. It is used in motor car bodies, chemical vats, sinks, etc. Carbon fiber reinforced plastics have greater resistance to fatigue and lower density. The fibers are made from synthetic textile fibers treated in such a way that the side groups are entirely removed. The carbon fiber reinforced plastics are used in aeroengines, high pressure rotor and stator blades since they can withstand higher thrusts. Silica and Boron fiber reinforced plastics have high strength and low density. But these are all costlier than glass or carbon fiber reinforced plastics.

TABLE 11.1 Important fibers used in FRP and their properties

Fiber type		Density kg/m ³	Young's modulus G Pa	Strength G Pa	Maximum operational temperature 5 °C
1.	E glass	2500 - 2600	69 - 72	1.7 - 3.5	350
2.	Boron	2400 - 2600	365 - 440	2.3 - 2.8	2000
3.	Carbon (high modulus)	1960	517	1.86	600
4.	Carbon (high strength)	1800	295	5.6	500
5.	Al ₂ O ₃	3250	210	1.8	1250
6.	Nicalon SiC	2800	45 - 480	0.3 - 4.9	1300
7.	SiO ₂	2200 - 2500	75	5.9	1100
8.	Nylon 66	1200	< 5	1	150
9.	Polyster	1380	< 18	0.8	150
10.	Kevlar 49	1450	135	3	250

Advantages of FRP

1. It has high strength to weight ratio.
2. It has low cost tooling.
3. Intricate and large shapes are possible in one piece. Since it can be fashioned more easily than a metal it is used in making complicated machine parts.
4. Excellent environment exposure-resistance can be obtainable.
5. It has excellent electrical properties.
6. It has higher heat resistance.

Disadvantages

1. The material cost is so high.
2. The strengths perpendicular to fiber orientations are low.
3. It has low rate of heat transfer and dissipation
4. It has lower flexural modulus than steel and requires higher thickness for equal stiffness.

For high temperature applications, polyimides are used as matrices in carbon fiber reinforced plastics. High temperature thermoplastic systems (polyethersulfone and polyetheretherketone) have much greater toughness, strain capability and adequate high temperature properties than thermosets. Similarly HTA, an amorphous resin of the poly sulfone group exhibits adequate high temperature properties.

also used as sonar transducer but it has excessive temperature dependence. The composite of 95% Ba Ti O₃ and 5% Ca Ti O₃ is one of the low cost sonar transducer with reasonable stability at low power levels. The composite of 95% Ba Ti O₃, 4.5% Ca Ti O₃ and 7.5% Co C O₃, called NRE - 4 has good high drive characteristics but weak piezoelectric effect. PZT - 4 and PZT - 8 have curie temperature around 300°C. But Ba Ti O₃ and its composites have curie temperature around 115°C.

11.6 Biomaterials

Biomaterials science is that branch of biomedical engineering that is concerned with the materials aspects of medical devices. Any material, metal, ceramic plastic or organic brought into contact with the fluids cells and tissues of the living body comes within the domain of biomaterials science. Developments in biomaterials are the result of an interesting combination of technologists and scientists including bioengineers, biochemists, surgeons, physicians, orthopaedic researchers and cardio vascular scientists. Polymers - and ceramics are just now arriving in the field of biomaterials. They have high compatibility, high strength and corrosion resistance. Medical ceramics are emerging as replacements for some metals for structural or wear applications in implants. Typically these implants are used to strengthen or replace portions of a bone or joint. Bone joins readily with some ceramic surfaces.

i. Metals and alloys

- a. Bone screws are made from stainless steel (ASTMF - 138 and ASTMF - 139) wrought bar or strip. These have high tensile strength and modulus of elasticity. Stainless steel wires and plates are also used in implant devices.
- b. Cobalt based alloy with titanium and stainless steel are used as implant metals. Protasul from cast alloy of Co - Cr - Mo is used to make stem and head of implanted hip endoprosthesis. The improved version, protasul - 10 from Co - Ni - Cr - Mo alloy is an important hip joint alloy. ASTMF - 75 (H - 21, Vitallium, Zimmalloy, Co - Cr - Mo + 0.35 C max, cast, with elongation + 8%), ASTMF - 90 (Co - Cr - W + Low carbon, wrought, elongation 30%) are the important ones.
- c. In some cases, stainless steels are used to make stems of implanted prosthesis.
- d. ASTMF - 136 (Ti - 6Al - 4 V, EL1 alloy, forged) is a high strength alloy which is also used in implant devices. It has high strength/weight ratio, high corrosion resistance and high biocompatibility.

ii. Polymers

- a. Endoprosthesis development is made by the use of ultra high molecular weight polyethylene (UHMWPE) with and without reinforced carbon fibers. The carbon reinforcement improves strength. This material can be taken as an improved bearing material for joint replacement prosthesis. This is frequently used to replace a diseased or injured joint. Long term stability depends on the strength and integrity of the carbon - polyethylene bond.

- b. Bone cements are made from acrylic resins and methylmethacrylate acrylic copolymer.
- c. Porous polysulfone with the coating of Co - Cr - Mo is used for orthopaedic implants. Carbon reinforced polysulfone which is a light weight, high strength composite material used for bone implants and silicone for breast implants. Silicone gel and silicone solid are also used for the same.
- d. Polyethylene is used for short term indwelling. Porous high density polyethylene is used for dental and cortical implants.
- e. The other polymeric biomaterials are polyurethane vinylchloride and PTFE.

iii. Ceramics

- a. Ceramic implants (Al_2O_3 with some SiO_2 and alkali metal oxide) are used to make femoral head. This is made from powder metallurgical process.
- b. Apatite ceramics are new bioactive ceramics. These are regarded as synthetic bone, readily allows bone ingrowth, better than currently used alumina (Al_2O_3).

The general formula is $\text{M}_5\text{X}(\text{YO}_4)_3$

where

M - divalent cation such as Ca^{2+} or Sr^{2+}

X - an univalent anion such as OH^- or F^-

Y - Trivalent species such as P or occasional As which forms an ortho oxyanion.

- c. Synthetic hydroxyapatite is the raw material for dental and orthopaedic purposes.
- d. Porous ceramics (alumina containing an organic flock filler) are used for mitral valve prosthesis and are injection moulded polypropylene.
- e. Further we have bioglass, ceravital and AW glass. Bioinert bioceramics, expected to join alumina, include carbon titania and zirconia. These are used in the synthetic bones and implants.

11.7 Ceramics

Ceramic materials are those materials which consist of phases which are compounds of metals and non metals. Ceramics are hard, strong and dense. These are completely stable even at high temperatures and are chemically inert. They have high compression strength and possess excellent dielectric properties. Already we have seen that the different types of ceramics and their uses as insulating materials in dielectric materials. Now let us see some of the ceramic tool materials with superior properties. In recent years, there have been significant developments in such materials available today : (i) The traditional ceramic tool

material has been aluminium oxide-alumina which is coming under the pure oxide ceramics. It is white and can be manufactured by cold pressing powder in a die with subsequent sintering. But it has lower value of toughness and thermal shock resistance. Further it has low thermal conductivity. The modern alumina ceramic contains a proportion of Zirconium oxide - Zirconia, which toughens the material. Further it has higher value of thermal shock resistance and thermal conductivity. (ii) In mixed ceramics oxide plus carbide and nitride are mixed. These have better thermal shock resistance than pure oxide ceramics, in addition to being harder and able to retain their hardness at high temperatures. (iii) The third class of ceramic tool material is that based on silicon nitride. Silicon nitride has a very low coefficient of thermal expansion which reduces the stresses set up between the hotter and cooler parts of an insert, so its thermal shock resistance is excellent. Sialon ceramics are silicon nitride plus alumina.

The present day use of ceramics for steel machining is largely confined to turning of hardened or low alloy steels and both pure oxide and mixed ceramics are used. Nitride ceramics find their most suitable application in rough-turning the intermittent operations whereas pure oxide ceramic is likely to give the longest tool life in semiconducting good quality castings under stable continuous cutting conditions. For finishing operations mixed ceramic is the best choice. The mixed ceramic is also used for high speed machining of heat resistant steels. Thus ceramics can offer increased metal removal rates, extended tool life and an ability to machine hard work piece materials.

The ceramic ultrasonic transducers are used to produce ultrasonic waves at very high frequencies (~ 100 MHz) and are designed at any shape with a given fundamental frequency. These are acting as SAW materials and soner transducers. To day we have fine ceramics as the active ceramics.

Modern applications of fine ceramics

Fine ceramics are synthesized ceramics from highly refined new material, vigorously controlled composition and strictly regulated forming and sintering. These have specialized functions. Table 11.3 shows the applications of fine ceramics.

11.8 Cermets

Cermets are the composite materials consist of combination of metals and ceramics. The metal acts as a binder. These are made by powder metallurgy; the sintering temperature is above the melting point of the metal powder. In the finished cermets, the metal contributes high toughness and thermal shock resistance, while the ceramic contributes higher refractory properties, creep resistance, superior chemical stability and abrasion resistance. These properties are depending upon the ratio of combination of metal and ceramics. Generally two types of cermets are available based on the type of ceramics used.

- a. Oxide ceramics based cermets, in which ceramics are bonded by iron, chromium and tungsten.
- b. Carbide ceramics are bonded by iron, nickel and cobalt.

Uses

1. Due to their higher hardness, these are used to cut and shape many refractory materials such as glass, procelain and high temperature resistant brittle alloys which are considered to be unmachinable.
2. These are also used to manufacture cutting tools and dies in metal working industry and rotating drills in the mining industry.
3. Further high speed, heavy duty cutting tips and inserts are made from cermets.

11.9 High temperature materials

The high temperature materials used in machine parts and structural components should have high thermal shock resistance and high creep resistance. Thermal shock resistance is a property of a material which indicates its ability to be subjected to rapid temperature changes without physical failure. So by means of this property a material can retain its shape and not distort, crack or shalter, due to a sudden change in its temperature. Creep is a time dependent strain occurring under stress. Creep can take place and lead to fracture at static stresses much smaller than those which will break the object when loaded quickly. Normally creep rate is enormous at high temperatures. Creep resistance is a property by which the material can withstand stresses without fracture at high temperatures and during quick loading. To obtain creep resistance at high temperatures, we must use metal with high melting point and FCC structure with low stacking faulty energy. To improve the creep resistance in high temperature materials, dispersion hardening method is adopted. For high temperature applications, the fine grained materials and materials with grain boundaries are not useful since they have very weak creep resistance and generally the coarse grained materials are more useful since they show a better creep resistance.

Refractory oxides such as MgO and Al_2O_3 have high melting points and so they are very suitable for high temperature use. Further these materials should not react with the materials that they are in contact with. The Austentic stainless steels are used for continuous service upto $1100^\circ C$. It contains 74% iron, 18% Chromium and 8% Nickel. The commonly used high temperature alloys are iron-base, nickel base and cobalt-base alloys :

- Fe 62%, Ni 34% and Cr 4% alloy is mainly used as a resistance wire and has maximum working temperature of 700°C.
- Ni 80% and Cr 20% alloy is used for heaters and has a maximum working temperature of 1150°C.
- The alloy consisting of chromium, nickel and cobalt has high strength and corrosion resistance even at temperatures upto 1200°C. Normally chromium based alloys are called heat resistant alloys which are used in high temperature applications.

In various heat engines and energy conversion devices like MHD generators and nuclear reactors, high temperature materials are used.

11.10 Thermoelectric materials

Thermoelectric materials are used to construct thermocouple. In a thermocouple, a voltage is induced between the hot and cold junctions of two dissimilar metals which increases with increasing temperature differences between hot and cold junctions. If we connect thermocouples in series, then that system can act as a voltage generator. Now a days thermocouples are widely used for temperature measurement, refrigeration, heating and generation of electrical power.

A good thermocouple which develops more voltage is defined by its figure of merit 'Z' such that

$$Z = \frac{S^2 \sigma}{K}$$

where S is called thermoelectric power which is the thermoelectric voltage developed per unit degree rise of temperature. This is a constant in each metal. Further according to Wiedemann-Franz Law, in metals the ratio between thermal conductivity 'K' and electrical conductivity 'σ' is directly proportional to absolute temperature.

$$\text{i.e., } \frac{K}{\sigma} = \frac{1}{3} \left(\frac{\pi k}{e} \right)^2 T$$

$$\text{or } \frac{K}{\sigma T} = \frac{1}{3} \left(\frac{\pi k}{e} \right)^2 = L$$

where L is called Lorentz number and it is a constant. Its value depends upon the absolute temperature of the metal. So at a particular temperature $\frac{K}{\sigma}$ is a constant. The possibilities of increasing Z are very limited. Similarly common semi conductors like germanium and silicon have high thermal conductivity and so there are some semiconductor alloys in which larger thermoelectric effects occur than in metals. Bismuth and Antimony tellurides or selenides have high figure of merit.

The semiconductor alloys such as 75% of Bi_2Te_3 + 25% of Bi_2Se_3 and 50% of Bi_2Te_3 + 50% of Sb_2Te_3 have lower thermal conductivities but substantially high electrical conductivities. Similarly lead telluride semiconductor (where lead is the n - type semiconductor and tellurium is the p type semiconductor) with 61.9% of Pb + 38.1% of Te is a very good thermoelectric material. For the electrical power generation or refrigeration, the maximum thermoelectric efficiency is about 10% only.

11.11 Electrets

Electrets are ferroelectric materials and are electrostatic analog of permanent magnets in that they possess a gross permanent electric dipole moment. They are manufactured from certain types of waxes, plastics and ceramics. When these waxes are subjected to high electric fields ($=10^6\text{V/m}$) they are polarised in their molten state and retain a permanent polarization after solidifying even though the external polarising field is removed. Some barium titanate ceramics and carnauba waxes can be polarised in this way. A number of new electret applications are based on the piezoelectric or pyroelectric effects in polarised polymers. The interest in polymer electrets is due to the fact that these show extremely good charge storage capabilities and are available as flexible thin films. Polytetrafluoroethylene and polyvinylidene fluoride are important polymer electrets.

Applications

- a. These are used in capacitor microphones. Here there is an electret diaphragm with metal layer at its top for electrical connection purpose. Further there is an air gap in between the back metal plate and bottom end of the electret diaphragm. If a sound wave impinges on diaphragm, it undergoes deflection and hence change in thickness of air gap is produced. The output voltage developed which is taken between the top metal layer and bottom metal back plate through a load is directly proportional to the frequency of sound waves. The same technique is also used in earphones. Here alternating voltage applied between the top and bottom of the earphone produces sound waves. Thus these are acting as electroacoustic transducers in an efficient manner with higher sensitivity and fidelity.
- b. An electret recorder is a in which events lasting as little as 0.1 micro second are stored as electrets on the surface of plastic foil by a puncture of a thin air gap. The foil is not damaged and can be erased after readout.
- c. These are also used in gas filters which use corona charged electret fibers to capture submicron particles by electrostatic attraction.
- d. Further these are used in motors, relay switches, optical display systems, electrophotography and radiation dosimeters.
- e. In medical field, electrets are used in so many ways. It was shown that foil electrets placed in contact with bones of animals in vivo cause accelerated growth of callus, necessary for fracture healing. Moreover electret bandages put on skin incisions considerably improve the tensile strength of the wound over a given period of time and thus speed the healing process.

- f. Now-a-days so many piezoelectric transducers and pyroelectric devices are manufactured from electrets.

11.12 Nuclear engineering materials

The materials used in nuclear reactors may be classified into the following main groups

- i. Fuel Materials
- ii. Moderator Materials
- iii. Fuel Cladding Materials
- iv. Control Materials

i. Fuel materials

- a. **Uranium** : Uranium is very reactive and easily oxidised. In pure form it is heavy, hard and nickel like metal. It retains its hardness at much higher temperatures. In natural uranium, the following isotopes are present :
Uranium - 238 (99.3%) and Uranium - 235 (0.7%). Uranium 238 is a fertile material. But it can be converted into fissionable material as Plutonium - 239 by neutron bombardment. Uranium - 235 is a fissionable material. It is used as a fuel in most thermal reactors. Enriched uranium which contains slightly increased percentage of uranium - 235 in natural uranium is also used as fuel. Uranium Oxides or carbides are also used as Nuclear fuels in some reactors.
- b. **Plutonium** : Plutonium - 239 is very reactive, easily oxidised and highly toxic. It is a concentrated nuclear fuel and is not found in nature. It is produced from uranium - 238. It can undergo fission chain reaction even by fast neutrons. So plutonium reactors would not use moderator to thermalize the fast neutrons.
- c. **Thorium** : It is a radio active material. Thorium - 232 is a fertile material. It can be converted into fissionable Uranium - 233 by neutron bombardment. Thorium is less susceptible to irradiation damage. In pure form it is soft and weak. In India, thorium is available in Kerala sea shores.

ii. Moderator materials

Moderators are used to thermalize the fast neutrons and by that way the fission yield can be increased. Any reactor with moderator is a thermal reactor. Nuclear fuel rods are surrounded by moderator material. Deuterium (D_2O) and graphite are very good moderators since they have high moderating ratio. Beryllium is the best metallic moderating substance as it occupies small spaces and has low absorption cross section for neutrons. Moderators are also helpful in controlling and stabilizing the reactor power level during its operation. In some reactors moderators can also act as coolant and reflector.

iii. Fuel cladding materials

Fuel cladding materials are used to improve the mechanical strength of fuel rods and to increase their corrosion resistance. They should not absorb any neutrons and should be stable even at high temperatures. They should possess higher thermal conductivity. For thermal

reactors aluminium, magnesium beryllium and zirconium are preferred. For high power reactors zirconium and stainless steel are used since they can withstand at high temperatures.

iv. Control materials

The power level of the reactor or neutron flux in the reactor is controlled by inserting control rods which are high neutron absorbers. These are made from boron, silver and cadmium.

11.13 Nanophase materials

11.13.1 Introduction

Nanophase materials or simply nano materials are the nano structured materials having a characteristic length less than 100 nm. These are recently developed new materials having so many new properties. These have a three dimensional structure with a domain size smaller than 100 nm. These are characterised by a large number of grain boundary interfaces in which local atomic arrangements are different from those of the crystal lattice. A cluster of nano particles contains less than 10^4 molecules or atoms corresponding to a diameter of only a few nanometre. Thus one can conclude that particle's size in nano materials is about 1 nm. With these small sized particles one can get the different properties (electronic, optical, electrical, magnetic, chemical and mechanical) which are different from the bulk materials. Having a size between the molecular and bulk solid state structures, the nano particles have hybrid properties. They have nonlinear optical and magnetic properties.

11.13.2 Preparation of nanomaterials

Nanocomposites consist of nano particles dispersed in an continuous matrix, creating a compositional heterogeneting of the final structure. The nanocomposites usually involve a ceramic or polymeric matrix and are not restricted only to thin film. The nano materials are produced by gas phase processes and aerosol processes. Gas phase processes contain no impurity : i.e., pure nano materials can be developed. Aerosol processes are used to create complex chemical structures which are useful in producing multi component materials such as high-temperature superconductors. Thin film of nano particles are produced at a lower cost. Further the deposition rate of particles is very high being a nonvacuum technique. Mostly in aerosol processes, chemical vapour deposition techniques are adopted.

11.13.3 Applications

1. There are two types of applications. The structural applications are based on the mechanical properties of the nano structured or nanophase materials. These are used to produce super plastic ceramics and extremely hard metals.
2. Functional applications are based on the transformation of external signals such as the filtering of the incident light, the change of electrical resistance in different gas concentrations and luminescent behaviour when electrically activated.
3. These are used to produce very tiny permanent magnets with high energy products ($B_r H_c$). Thus these are used in high density magnetic recording.

ii. Electrostrictive SMART materials

Electrostrictive SMART materials are the materials in which mechanical change (i.e., change in length) is proportional to the square of the electric field and vice versa. LiNbO_3 acts as an electrostrictive SMART material.

iii. Magnetostrictive SMART materials

Magnetostrictive SMART materials are the materials in which there is a mechanical change (i.e., change in length) when the material is subjected to a magnetic field and vice versa. Terfenol-D or ferrites are the examples of magnetostrictive SMART materials.

iv. Shape memory alloys

These will undergo phase transformations which will produce shape changes when they are subjected to a thermal field. It deforms to its 'martensitic' condition with low temperature and regains its original shape in it, 'austenite' condition when heated (high temperature) Example : Nitinol (Ti Ni alloy).

v. Sensor based optical fiber SMART materials

Using intensity, phase, frequency or polarisation modulation, they can measure strain, temperatures, electrical/magnetic fields, pressure and other measurable quantities. These are high quality sensors.

vi. Other types of SMART materials

Textile material like SMART T-shirt can detect a variety of signals from the human body and weather conditions so as to allow for greater comfort. Catalytic material can detect the progress of a reaction or distinguish the reaction of a product.

11.17 Conducting polymers

We know that the polymeric materials are usually characterised by a strong covalent bonds along the polymer chain, while bonding between chains are considerably weaker. Today there are very large numbers of organic monomers available to make organic polymers for getting a wide range of applications by modifying the properties of polymers. Even though the polymers are electrical insulators due to their wide bandgap, a low carrier mobility and a low melting point, using new synthetic methods, highly conducting doped polymers such as polyacetylene are developed. They have defects free polymer chain and have high electrical conductivity as that of copper. These are doped conjugated polymers. Thus the conjugated polymers act as conductors. Polyaniline and polypyrrole semiconducting conjugated polymers are converted into conducting polymers when they doped with sufficient concentrations. These are used as battery electrodes, conductive coatings for electrostatic speakers, capacitor electrolytes, transparent conductive coatings, interconnecting wires in IC circuits instead of copper. The transport of charge carriers in these conducting polymers involves the transport rate, scattering, trapping processes, recombination, tunneling and hopping.

Commercial applications of conducting polymeric materials

a. For making field effect transistors and Schottky barrier diodes

- Examples : Polyactylene,
Polythiophene,
Polypyrrole

b. For making large area light emitting device (LED) displays.

- Examples : Poly (p-phenylenevinylene),
Poly (p-di ethynylene phenylene),
Poly (arylenevinylenes),
Poly (p-pyridines),
Poly (p-pyridinvinilenes),
Polythiophenes

c. For making photoconductors.

- Examples : Poly (N-vinylcarbazole),
Poly (vinylpyrene)
Poly (2-vinylcarbazole)

Thus the modern polymers play an important role not only in the field of biomaterials but also in the optoelectronics.

Figure 11.9 shows the structures of polymer light emitting devices.

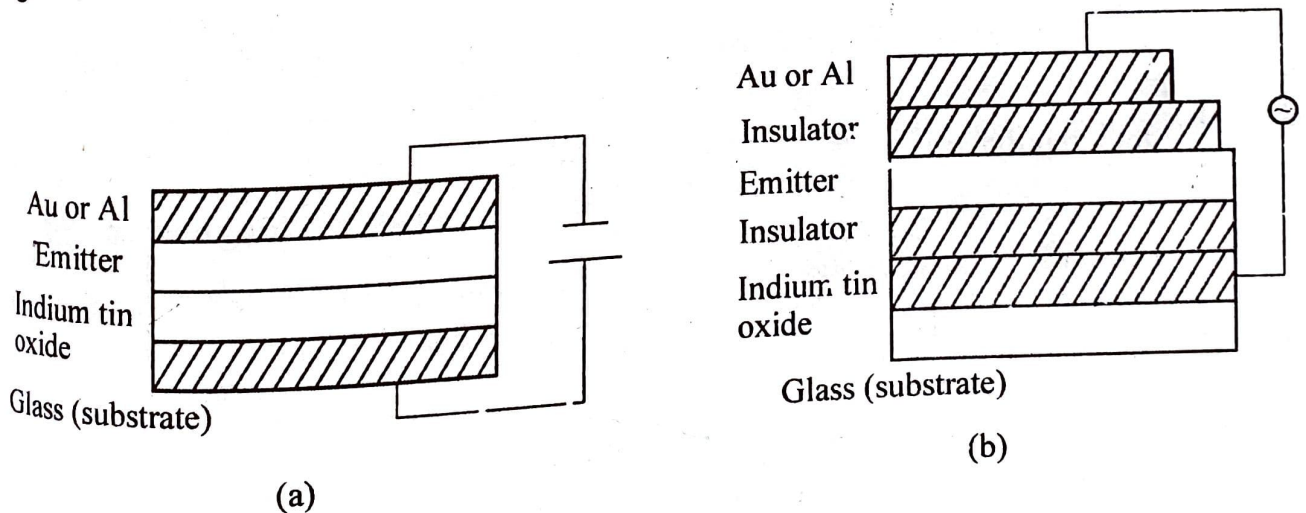


Figure 11.9 a) Single layer light emitting device b) SCALE device

Figure 11.9 (a) and (b) show the various light emitting device structures available with conducting polymer as the light emitter. Light emitting polymer layer is sandwiched between a cathode and an anode, Indium tin oxide is used for the anode and gold or aluminium is used as the cathode. The indium tin oxide is coated on glass by spin coating and aluminium is

deposited on the top electrode by evaporation. Figure 11.9(a) shows the structure of a simple (single layer) light emitting device and it works under a forward d.c. bias. Figure 11.9(b) shows the efficient configuration of light emitting device called a Symmetrically Configured Alternating Current Light Emitting (SCALE) device which works under a.c. as well as forward and reverse d.c. bias.

The working principle of light emitting polymer device can be explained as follows: When a voltage is applied electrons are injected from one electrode and holes from the other into polymer layer. They migrate across the polymer layer and can meet up to form an excited state known as the singlet exciton which can decay by emitting a photon. The colour of the light emission is determined by the energy difference between the highest occupied molecular orbital (valence band) and lowest unoccupied molecular orbital (conduction band). Table 11.5 shows the recently developed high technology polymers and their applications.

Table 11.5 High technology polymers and their uses

High technology polymers		Applications
1.	Photoresists	used in Lithographs.
2.	Conductive polymers	used as electrodes of battery and transparent conductive coatings.
3.	Dielectric polymers	used for packaging and high voltage insulation.
4.	Photoconductive polymers	used in laser printing
5.	Piezo and pyroelectric polymers	used as sensors and to produce ultrasonic waves.
6.	Optical polymers	for making lenses, fibers and passive thermo-optical switching elements.
7.	Nonlinear optical polymers	for doing light modulation and frequency conversion.
8.	Photochromic and photo refractive polymers	used for optical data storage.
9.	Hole burning polymers	used for optical multiplex and data storage.
10.	Electroluminescent polymers, light emitting polymers and liquid crystalline polymers.	for making large area display.