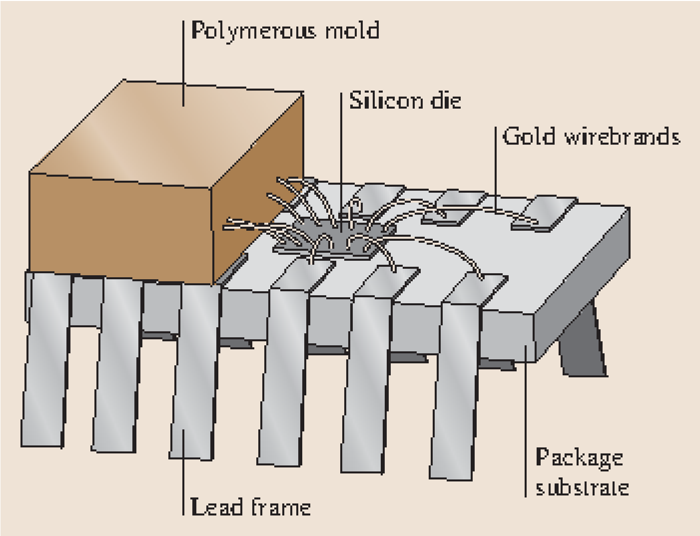
ELECTRONIC PACKAGING:

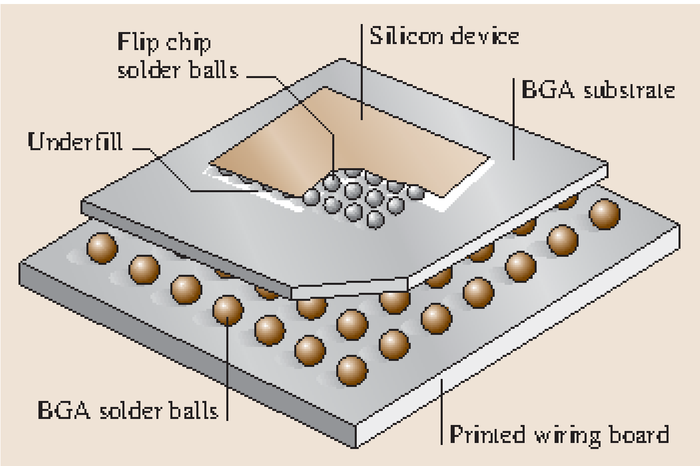
Electronic packages are divided into four levels, with three that exist beyond the integrated circuit:

- Level 0: Semiconductor chip level (integrated circuits). The interconnections in the chip are made by metalization on the circuit (Al, Cu, Au).
- Level 1: Chip or die is attached to a carrier or substrate. The die is first bonded to a substrate or lead frame called the package carrier with the help of a conductive or nonconductive adhesive or solder. The connections from the chip to the carrier are made by two techniques namely wirebonding or flip chip technology.



Wirebonded – the chip is connected to the substrate which contains copper lead frames through wires made of Ag or Au.

In the flip chip or Direct chip attachment (DCA) technologies, the electronic circuitry on the silicon chip is attached directly to the circuitry on the substrate, with the help of arrays of solder balls (called Ball Grid Array, BGA). The advantage of this technique is that the number of input/output connections is higher.



. The chip then is protected either by a lid or encapsulated with a polymer overmold.

- Level 2: The chip carrier is mounted on to a printed circuit board (PCB). The interconnections between the chip carrier and the PCB are made using solder, or conductive adhesives.
- Level 3: Board to board interconnects. The boards are interconnected to the final electronic system using friction interconnects, solder interconnects, or fiber-optic connectors.

ELECTRONIC PACKING METHODS:

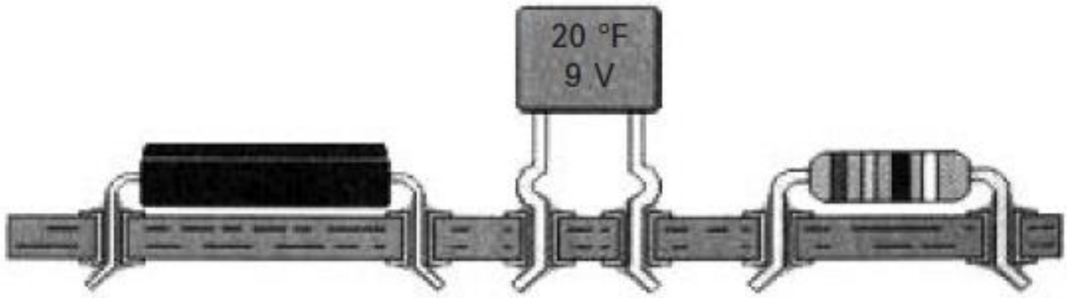
In general, based on the methodology used in assembling the IC packages to the PCB, these are classified into two categories:

(i) through-hole packages, and

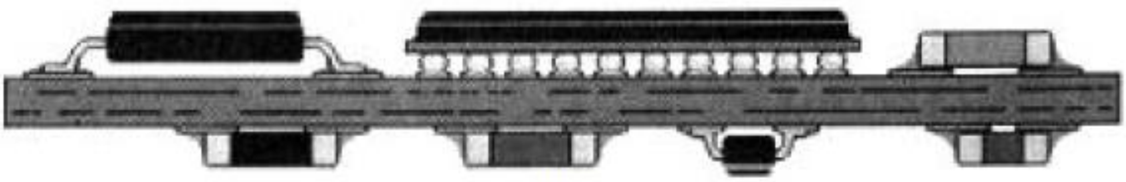
(ii) surface mount packages.

If the packages have pins that can be inserted into holes in the PCB, they are called through-hole packages (see Fig. a). If the packages are not inserted into the PCB, but are mounted on the surface of the PCB, they are called surface mount packages. These are done using adhesives and solder.

The advantage of the surface mount package, as compared to through-hole, is that both sides of the PCB can be used, and therefore a higher packing



(a)


(b)

Board level integration of the packages for (a) through-hole packages and (b) surface mount packages density can be achieved on the board.

MATERIALS USED IN ELECTRONIC PACKAGING:

- **Eutectic Alloys – Solder**
- **Adhesives**
- **Phase change materials (PCMs) for electronics cooling.**

EUTECTIC ALLOYS - SOLDER

Eutectic alloys are mixture of metals with a specific composition having the lowest melting point among all its possible compositions. Sn- Pb solder is an eutectic alloy extensively in the electronics industry. For surface mount and area array applications, the role of solder in the package is significant. In these advanced designs, the solder is an electrical interconnect, a mechanical bond and also serves as a thermal conduit to remove heat from the joined device.

The bonding action is accomplished by melting solder material, allowing it to flow and make contact with the components to be joined. Finally, upon solidification, a physical bond with all of these components is formed.

Sn-Pb has low eutectic temperature of 183°C. In electronics industry the solder used is primarily 63Sn-37Pb which is a eutectic composition, or 60Sn-40Pb which is a near eutectic composition.

Required characteristics of a solder material:

- The solder material should have low melting point.
- Should be inexpensive. Soldering process must be easy, without the need for sophisticated equipment and skilled operator
- Good stability. Metallic impurities absorbed during soldering should not influence the mechanical properties of the alloy.
- Good tensile and shear strength.
- High thermal and electrical conductivity.
- Good wettability on wide range of surfaces.

The Sn-Pb solder has all of the above characteristics and it is the Pb that enhances the wettability and the dimensional stability of the alloy.

NEED FOR LEAD FREE SOLDER

Electrical and electronic equipments are dumped in landfills. Lead may enter into the soil and underground water in these landfills. It may also spread into air. The hazardous effect of lead on human are listed as below:

1. Harm to foetus including brain damage or death].
2. High blood pressure.

3.Nerve disorders .

4. Muscle and joint pain.

Due to the negativities of lead to human and environment, there is a ban on lead usage in many countries.

Lead free solders

Almost all of the lead-free solder alternatives explored so far utilize tin as one of the primary constituent. The other elements which could be incorporated in the alloy systems in order to meet the melting temperature range requirement include, Bi, Cd, In, Zn, Au, Tl, Ga, Hg, Cu, Sb, and Ag.

Unfortunately, most of the alloys investigated do not meet all the criteria for soldering applications.

Major Lead Free Solder Replacements

Alloy System	Composition	Melting Point
Sn/Ag	Sn,3.5Ag	221(e)
	Sn,2Ag	221-226
Sn/Cu	Sn,0.7Cu	227 (e)
Sn/Ag/Bi	Sn,3.5Ag,3Bi	206-213
	Sn,7.5Bi,2Ag	207-212
Sn/Ag/Cu	Sn,4Ag,0.5Cu	217*
	Sn,4.7Ag,1.7Cu	217*
Sn/Ag/Cu/Sb	Sn,2Ag,0.8Cu,0.5Sb	216-222
Sn/Zn/Bi	Sn,7Zn,5Bi	170-190

* Eutectic point not agreed

A number of international manufacturing companies have made successful consumer applications with Sn/Ag, Sn/Ag/Cu, and Sn/Cu pastes for soldering. At this time assembly with all three alloys have been demonstrated successfully but further long-term evaluation is still required.

Phase diagrams:

When Sn is alloyed with other elements to obtain new lead free solder alloys, the knowledge of melting temperatures of different compositions of the alloys and of what kind of solid phases are formed on solidification are of significant importance. These data can be obtained from phase diagrams of the alloy systems.

Phase diagrams are graphical representations of systems in equilibrium that provide us with the knowledge of phase composition and phase stability as a function of temperature (T), pressure (P) and composition (C). Furthermore, they permit us to study and control important processes such as phase separation, solidification, sintering, purification, growth and doping of single crystals for technological and other applications.

Phase diagrams of lead free alloy systems data provide information about

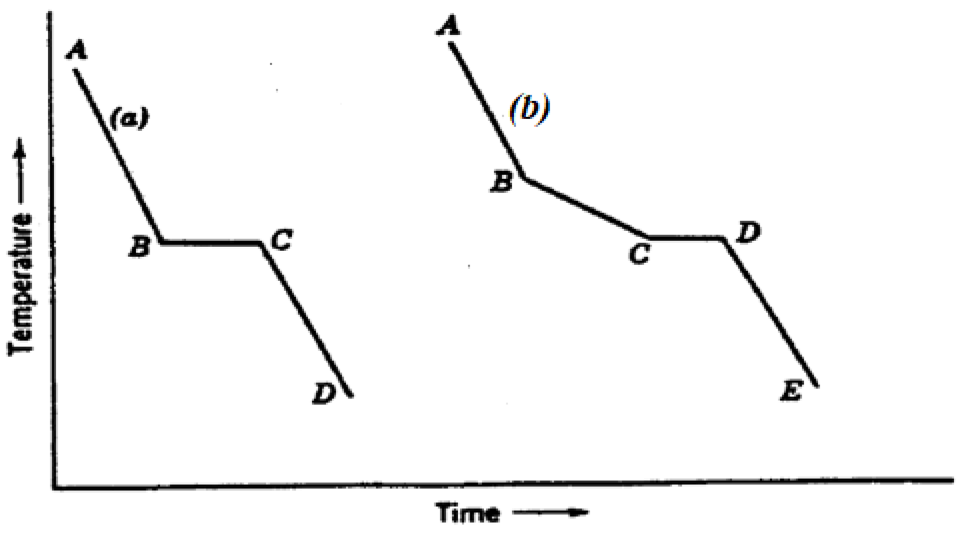
- the liquidus (temperature above which an alloy is completely in liquid state) and solidus (temperature below which an alloy is completely in solid state) temperatures of a candidate solder alloy.
- possible intermetallic phase formation, within the alloy during solidification.

Construction of Phase diagrams – cooling curves:

Solid - liquid equilibrium phase diagrams of a binary system involving metals are usually constructed from the data obtained from cooling curves, determined by thermal analysis. These curves are obtained by plotting the temperatures measured at equal time intervals during the cooling period of a melt to a solid.

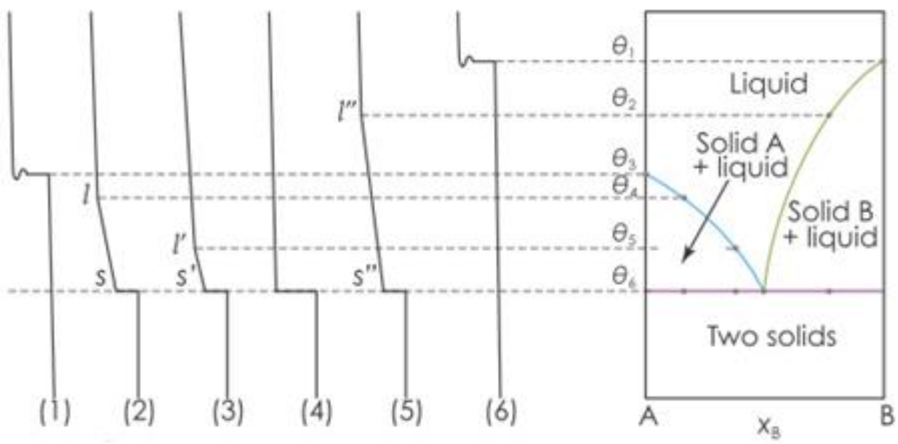
The cooling curve shown in (a) is that of a pure molten metal or a pure compound. The cooling proceeds uniformly along curve AB at a decreasing rate until point B is reached – when the first crystals being to form. As freezing continues the latent heat of fusion is liberated in such amounts that the temperature remains constant from B to C until the whole mass has entirely solidified. Further cooling from point C will cause the temperature to drop along curve CD.

Curve (b) in the figure shows a cooling curve of a binary system whose two components are completely miscible in the liquid state but entirely immiscible in the solid state i.e., a eutectic system. The liquid cools along line AB until temperature B is reached where a component that is in excess will crystallize and the temperature will fall along line BC, having a slope different than that of line AB. At point C the liquid composition has been reached at which the two components crystallize simultaneously from the solution and the temperature remains constant until all the liquid solidifies. This is known as the eutectic reaction.

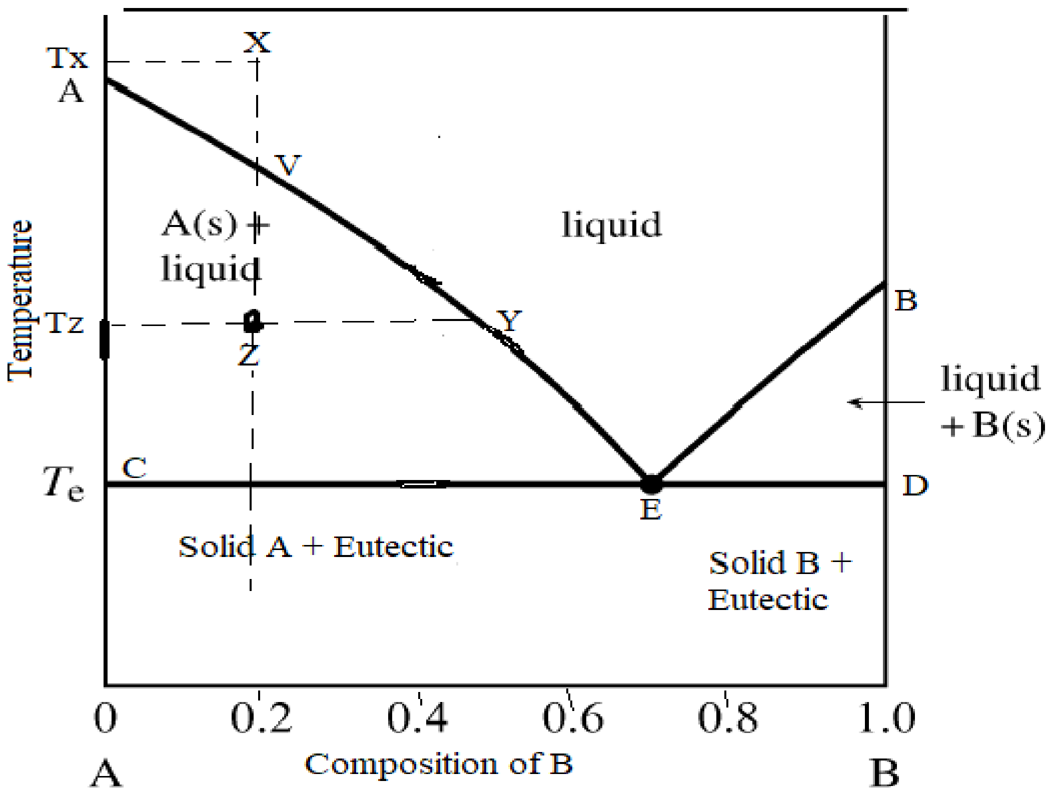


Cooling curves: (a) pure compound; (b) binary eutectic system.

For constructing the phase diagram of a eutectic alloy syatem, a number of mixtures of the two metals of different compositions are prepared. These are heated above their melting points so that only liquid phase exists in every case. Each liquid is then allowed to cool slowly and the temperature is recorded after small intervals of time. In this way several cooling curves are obtained as shown in the figure below. The first break in each curve occurs at the freezing point. As the mixtures differ in their compositions their freezing will commence at different temperatures. The second break occurs at the eutectic temperature which will be the same in all the mixtures irrespective of their initial compositions.



2,3,4 and 5 are the cooling curves of the mixtures of the two metals of different compositions and 1 and 6 are those of the pure components



Information obtained from the diagram:

- A is the melting point of metal A and B is the melting point of metal B
- AE and EB are the liquidus curves which give the temperatures above which the alloy exists in the liquid state for different compositions.
- In the area AEC, there are two phases, solid A and liquid. The metal mixture will be in the form of a paste. Similarly in the area BED, solid B and liquid exists i.e., as a paste
- CED is the solidus line below which only solid state exists.
- E is the eutectic point where solid A, solid B and the liquid phases exist in equilibrium. Te is the eutectic temperature, the lowest melting point, and the composition of the alloy corresponding to the eutectic point is called the eutectic composition.

Changes that occur during the cooling of a metal mixture:

- Let us consider a mixture with a composition of 20% of B and 80% of A. This mixture at temperature Tx exists completely in the liquid state. On cooling the mixture, it remains in the liquid state till the temperature Tv. When it is reaches the point V corresponding to temperature Tv, solid A starts freezing out from the liquid. As it is cooled further, more and more of solid A crystallises out and the composition of the liquid changes along the curve VE. At the point E corresponding, to the temperature Te, Solid A and Solid B simultaneously crystallise out in a ratio corresponding to the eutectic composition.

  If we consider the metal mixture at the point Z corresponding to temperature Tz, it contains solid A and a liquid having a composition corresponding to the point Y (from the diagram around 48% of B and 52% of A). The mixture will be in the form of a paste.

From such data, the alloy composition suitable for soldering applications and its melting temperature can be obtained.

Ternary and quaternary alloy systems containing Sn have also been investigated for use as solders. Since thermal analysis is tedious, thermodynamic calculation of phase equilibria with the CALPHAD method has been used and found to be extremely useful for obtaining quantitative information about these higher-component systems.

ADHESIVES IN ELECTRONICS:

Adhesives used are:

Thermoplastic polymers – polymers that can be melted or softened with heat,or

Thermosets – which resist melting and cannot be re-shaped. Thermoset epoxies are by far the most common adhesive matrices and for electrically conductive adhesives they have found use since the early 1950s. Thermosets are crosslinked polymers and generally have an extensive three-dimensional molecular structure.

Modes of adhesive bond formation:

1. **Thermoplastics** can bond to the substrates by drying and by hot melt process.

   (a) Drying adhesives:

The adhesive formulation is in the form of solution of the polymer and other additives in a solvent. The solution is coated on to the substrate using a dispenser. As the solvent evaporates, the adhesive hardens and bonds with the sbstrate.

   (b) Hot melt adhesives:

Hot adhesives, also known as hot melt adhesives, are thermoplastics and are applied in molten form (in the 65-180 °C range). Upon solidification they form strong bonds between a wide range of materials.

2. **Thermoset adhesives** bond to substrates through a crosslinking reaction. They can be one part or multicomponent adhesives.

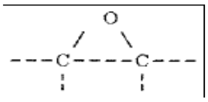
In this type low molecular weight polymers are take and crosslinking agents are added to it aand applied on to the substrate. The polymers undergo crosslinking reaction and harden (called as curing) with an external energy source, such as radiation, heat, and moisture. Ultraviolet (UV) light curing adhesives, also known as light curing materials (LCM), have become popular within the manufacturing sector due to their rapid curing time and strong bond strength.

Polymers used in adhesive for electronics:

The commonly used adhesives are epoxy resins, acrylates like butylmetacrylate, cyanoacrylates and silicones

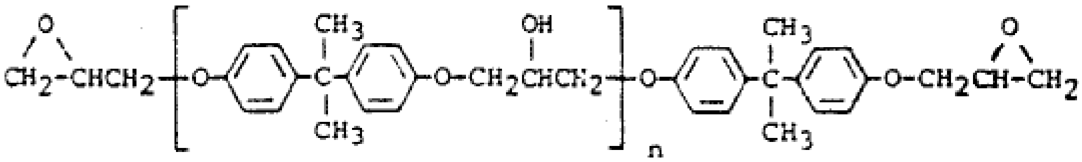
Epoxy adhesives

Epoxy resins are polyether resins containing more than one epoxy group capable of being converted into the thermoset form. The epoxy group also known as oxirane contains an oxygen atom bonded with two carbon atoms, which in their turn are bound by separate bonds as below:



Being polar they are excellent adhesives and are popularly known as **araldite.**

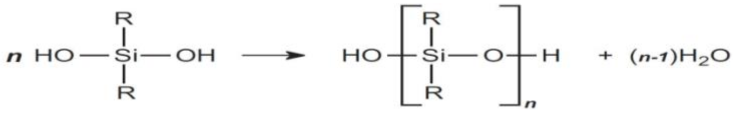
The simplest epoxy resin is prepared by the reaction of bisphenol A (BPA) with epichlorohydrine. Bisphenol A (BPA), on reaction with epichlorohydrin (ECH) in the presence of caustic soda to give the resin.



Here n varies from 0 to 25.

SILICONES

Silicones are synthetic polymers with a silicon-oxygen backbone similar to that in silicon dioxide (silica), but with organic groups attached to the silicon atoms by C-Si bonds. The silicone chain exposes organic groups to the outside.



ADHESIVES IN ELECTRONICS:

The surface mount packages use adhesives for mounting the various components of the board. The polymeric systems used in adhesives form the basic bonding components. These polymers have very poor electrical and thermal conductivities. All the adhesives used in electronics are required to have good thermal conductivities. Electrical conductivities also may be required. These conducting properties are imparted by adding fillers.

The types of adhesives used in electronics are:

Thermally conducting adhesives

- All polymeric materials (epoxy or other types, thermoset or thermoplastic) have very low thermal conductivity, in the range of 0.2 to 0.3 W/m◊K.
- Thermal conduction is provided by adding conductive additives. Thermally conducting fillers in the form of micro- or nanometersized balls, flakes, wires, fibers, etc. are dispersed randomly in a polymer matrix.
- The fillers used are alumina, synthetic diamond, boron nitride which are thermally conducting but electrically insulating.
- Higher the filler content, the better the thermal conductivity of the adhesive. Generally filler contents as hich as 40-50% the weight of the polymer are added to achieve high

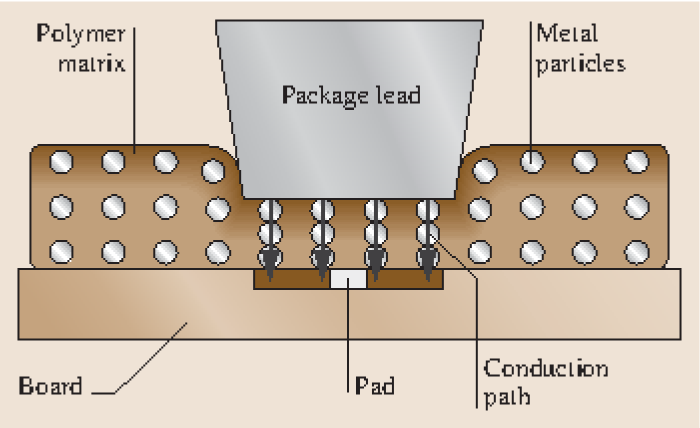
thermal conductivities. At this concentration, all conductive particles contact each other and form a three-dimensional network facilitating thermal conduction. Higher conductivity is obtained when micro-sized particles of filler are used,

- The adhesive not only provide the mechanical bonding, but also aids in heat dissipation and acts as an insulating layer. that

Electrically conducting Adhesives (ECAs):

- Electrically conducting adhesives consist of a polymer resin and electrically conductive fillers, mostly silver, although gold, nickel and copper are also used. The size of the metal particles ranges between 5 and 20 μm.
- The metals typically are in the form of flakes, plates, rods, fibers, or spheres. Ag is the popular filler because it is less expensive than gold (Au) with superior conductivity and chemical stability, and, unlike nickel (Ni), Ag oxides show high conductivity. Silver, with thermal conductivity 420 W/m◊K, also suitable material also as the thermally conductive filler.
- Regardless of the filler metal, the flakes require lubrication to resist the tendency to 'clump' together during processing, e.g. with stearic acid
- The greater the metal content, the better the electrical conduction, but the poorer the strength of the adhesive. The metal content depends upon whether the adhesive is an isotropic or anisotropic conductor (described below), but does not usually exceed 40% by volume.
- ECAs are available in two types of conductors, isotropic and anisotropic. In isotropic adhesives, the conduction path is uniform in all directions with a filler metal content sufficiently high to create a percolation path for the conductor.

  Anisotropic ECAs (also called a *z*-axis conductors) only have one direction of conduction. In general, anisotropic ECAs are prepared by dispensing metal particles in the polymer matrix at a level far below the percolation threshold(the concentration of filler at which a continuous contact between the filler particles is formed enabling conduction). Pressure is imposed on the contact so that the particles come into contact with one another in one direction (parallel to the direction of imposed pressure). In the areas where no pressure is imposed, there is no conduction path and the adhesive is electrically insulated.



The pads on the board contain metal contact points and the filler in the adhesives align and with the points making a conduction path. Thus these electrically conducting adhesives can replace solder.

Roles of Conducting Adhesives:

- **As electrical interconnects:**
  Electrically conducting adhesives are low-process temperature alternatives to solder alloys. They are used to provide electrical contact between components. Here, the method of depositing the ECA must be precise (or use an anisotropic ECA) so that electrical shorts do not occur.
- **As an underfill:**
  In the microchip package, the silicon chip is bonded to plastic substrate through solder balls. These substrates have a much higher coefficient of thermal expansion (CTE) than the silicon chip, as well as the solder bump connections. Therefore, during repeated thermal stress, the solder bumps connecting the circuitries of the chip and the substrate may crack and result in failure of the assembly.

  In order to prevent this, thermally conducting adhesives are made to flow through the gaps between the chip and the substrate and solidify, which is called as underfill. These adhesives reinforce the solder balls, preventing their cracking. These adhesives should be less viscous to allow them to flow and fill the gaps.
- **As Encapsulation:**
  Encapsulation of electronic packages is required to protect the electronic components from environmental degradation such as moisture contamination and mechanical damage, and provide electrical isolation.

  The encapsulation material is an adhesive typically a thermoset cross-linking polymer. The polymer resin portion consists of epoxy resin, a hardener and a curing agent. The resin is filled with thermally conducting fillers like alumina which helps to reduce the thermal expansion coefficient of the polymer and add strength. Small amounts of pigments (to add color), accelerants, flame retardants, antistatic agents and antioxidants are also added to the resin compound.

Factors influencing adhesive bond strength:

- Surface tension: The interfacial tension between the adhesive and the adherend should be low for formation of strong ahsive bonds. This is possible if the intermolecular attractive forces between the adhesive and the adherend are high.

  For example if the substrate is polar, an adhesive having polar groups will bind strongly.

- Temperature and pressure: Time and temperature determines whether complete curing and drying of adhesive films have taken place or not. Complete curing and setting is required for maximum adhesion.

  Pressure indirectly controls the thickness of the adhesive films. Perfectly smooth and non-porous substrates require very little pressure because the adhesive material may squeeze out. If the substrate is porous, high pressure is required for sufficient bond strength to be developed.

- Surface properties of the adherent:

  Generally if the surface of the adherend is smooth without pores the adhesive bong strength will be high. Surface compounds reduce the bond strength. For example, on a copper surface, copper oxide will be present which reduces the bond strength. Hence a coating of Nickel and gold is provided on the copper surface which gives improved adhesion.

  If moisture is present in the surface, the adhesion will be less.

- Internal stress generated in adhesives:

  Adhesives always shrink during curing and hence residual stress (internal stress) is induced in the adhesive layer of joints. Stresses may also develop during thermal cycling due to differences in the thermal expansions between the substrate and the adhesive. These stresses decrease the adhesive bond strength.

  The shrinkage can be prevented by selecting a polymer having a low elastic modulus. The thermal expansions can be minimised by adding fillers. But the adhesive strength significantly decreases when the adhesive contains an excessive amount of filler.

- Moisture absorption:

  Moisture absorption in the adhesive layer is a serious problem in forming reliable adhesive joints. The amount of moisture absorption generally increases with increasing concentration of polar functional groups in adhesives. Moisture enters in to the amorphous regions of the polymer. The elastic modulus and T_g of adhesives are decreased, depending on the amount of moisture absorption. This reduces the adhesive bond strength.

Phase Change Materials(PCMs):

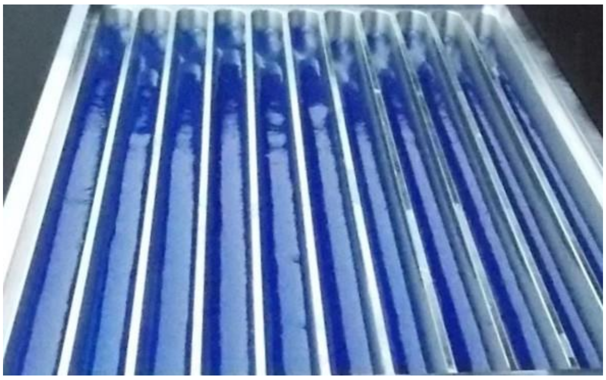
Many of electronic devices are designed to withstand temperatures upto 60-70℃. Modern high power electronic devices consist of a large number of integrated circuits for switching and supply applications. As the density of ICs increase the amount of heat dissipated increases. These electronic circuits are extremely sensitive to over-heating. The fans provided for cooling may not be sufficient to dissipate the heat. Other materials that serve as heat sinks are required. Phase change materials are one among them.

PCMs are substances that change phase, most often from solid to liquid, as they absorb heat. Examples of PCMs are waxes, salts, paraffins, etc. PCMs find applications in solar water heaters, construction materials, automobiles, electronics, green houses.

PCM in electronics cooling:

An ideal PCM should have

- high heat of fusion per unit weight and volume.
- Melting point should be low in the desired temperature range.
- high thermal conductivity
- high specific heat and density
- long term reliability during repeated thermal cycling
- dependable freezing behaviour.
- Non-corrosive and chemically inert.
- Low changes in volume during phase change and low vapour pressure to avoid containment problems.•
- Non-flammable & non-toxic, chemically stable, low cost and low containment cost.



Close-up image of internal PCM, including void space to allow for PCM volume change.

Materials:

Paraffin waxes are the most common PCM for electronics thermal management because they satisfy most of the requirements. They are chemically compatible with most metals. But when designing a cooling system with paraffin PCM, void management is important due to the volume change from solid to liquid (see Figure given above). But paraffin PCM's have a low thermal conductivity. Fillers are added to improve their thermal conductivity.

The following table shows some high purity paraffin waxes used in many electronics applications. Temperature ranges of 72-76°C, 66-70°C and 59-66°C are good to ensure safe operation of many electronic devices.

Typical Paraffin Wax PCMs.

Examples of Paraffins	**$C_{36}H_{74}$**	**$C_{32}H_{66}$**	**$C_{30}H_{62}$**
Density$_{solid}$ (kg/m^3)	857	809	810
Latent Heat (kJ/kg)	223	261	249
T_{melt} (°C)	72 to 76	66 to 70	59 to 66