

# Electronic materials and components-Die bonding materials

## Introduction

The term 'die bonding' describes the operation of attaching the semiconductor die either to its package or to some substrate such as tape carrier for tape automated bonding. The die is first picked from a separated wafer or wafer tray, aligned to a target pad on the carrier or substrate, and then permanently attached, usually by means of a solder or epoxy bond.

The requirements for the die bond are that it:

- must not transmit destructive stress to the fragile chip
- must make intimate contact between the chip and substrate materials, with no voids, and adhere well to both
- has to withstand temperature extremes without degrading.
- should exhibit good thermal conductivity, to remove heat generated within the chip
- should be either a good electrical conductor or a good insulator, depending on the application.

A number of materials have been developed for die bonding. Conductive epoxies, the most frequent choice for plastic packages on account of their low cost and ease of application, began to be widely accepted in the middle to late 1970s as an alternative to eutectic die attach. However, many other materials are used for die bonding for specialist applications:

- Some high-reliability applications still use gold-silicon eutectic alloy solders both to bond the die to the lead-frame or package and as the final seal of hermetic packages.
- Power semiconductors may also need a metallic bond, which is most likely to be a soft solder.
- Die attach using silver-loaded glass is favoured for assemblies in glass-sealed ceramic packages.

The choice of die bonding process will depend on the package sealing strategy and on the operating conditions and environmental and reliability requirements.

## Epoxy adhesives

Adhesive die attach materials are suspensions of metal particles in a carrier. The particles are several  $\mu\text{m}$  in size, usually in the form of thin flakes of silver. The carrier provides adhesion and cohesion to make a bond with the correct mechanical

strength, while the metal particles provide electrical and thermal conductivity. It is noticeable that conductive resins are now often used where no electrical connection is required, just to get the benefit of enhanced thermal performance.

The carrier is now most frequently a solvent-free, high purity epoxy resin, the trend being fuelled by the need to cut costs, shorten cure cycles, and provide stress relief.

- **Solvent-free** materials give reduced incidence of voids underneath the die, with better heat transfer leading to enhanced device reliability.
- **Purity** is crucial: aluminium corrosion failures were first identified in the late 1970s as being due to hydrolysable ions reacting with water vapour to form organic or organic acids. The trend has been for die bond materials to contain lower and lower levels of hydrolysable ions, in particular chlorine, sodium and ammonium.

MIL-STD-883 Method 5011.2 (Table 1) places considerable restrictions on the materials which can be used for die attach. Whilst originally written for military use, many suppliers for the commercial market work to these generally well-considered specifications. Meeting the specification is however not a guarantee that the adhesive can be handled in a production environment.

Test (Method 5011.2)	Requirements
Materials	Uniform consistency, free of lumps and foreign materials. Filler type to be specified
Pot life	≥1 hour
Shelf life	≥12 months at -40°C for 1-component ≥12 months at 25°C for 2-component
Adhesive cure	To be stated, and kept the same for all tests
Thermal stability	≤1% weight loss at 300°C
Filler content	±2% of stated content
Ionic impurities - total ionic content - pH - chloride - sodium - potassium - fluoride	≤4.5 mS/m 4.0 to 9.0 ≤3,000ppm ≤50ppm ≤50ppm ≤50ppm
Bond strength	For a die 0.025in. square: ≥2.5kg at 25°C initial value ≥2.5kg at 25°C after 1000 hr. at 150°C
Coefficient of linear thermal expansion	≤65 μm/m below glass transition temperature ≤300 μm/m above glass transition temperature
Thermal conductivity	Type I: ≥1.5W/m·°C at 121°C Type II: ≥0.2W/m·°C at 121°C
Volume resistivity	Type I: ≤5.0mΩ·m at 25°C, 60°C, 150°C and at 25° after 1000 hr. at 150°C Type II: ≥100GΩ·m at 125°C
Dielectric constant	≤6.0 at 1kHz and 1MHz
Dissipation factor	≤0.03 at 1kHz; ≤0.05 at 1MHz

Table 1: Die attach resin specification requirements in MIL-STD-883

Note particularly that the specification limits for the maximum levels of common ions, and for total ionic content and pH, are higher than the requirements of most semiconductor manufacturers. This is because the standard focuses on hermetically sealed cavities, where there is a much less moisture and a lower potential for corrosion.

In order to achieve high yields and low rework, other properties are important:

- A longer pot life than the 1 hour of the specification is essential, especially for automatic equipment. Also a partially cured adhesive may not wet a substrate well, resulting in poor adhesion. Be aware that pot life may be defined in different ways, the supplier quoting the time required for the viscosity to increase either by 10%, or 50% or 100%! When testing for pot life, it is better to check die shear strength and conductivity as a function of time.

- Controlled rheology is important both to give tighter bond line control, and to ease processing: consistency cannot be achieved if the adhesive becomes stringy or begins to clog the screen mesh.
- A resin for dispensing should be free of entrapped air, which can cause 'weeping' from the needle.

Most conductive adhesives incorporate polymers with glass transition temperatures ranging from 80–150°C. This property is important in several ways:

- If the wire bonding temperature is considerably higher than the T<sub>g</sub>, it is possible that the chip will move during bonding, leading to broken bonds.
- An adhesive with too low a T<sub>g</sub> may soften during environmental testing, and the component separate from the substrate.
- Whilst it is possible to generate localised rework temperatures up to 200°C, so as to remove chips even with adhesives with a T<sub>g</sub> as high as 150°C, this can create problems if the package contains components sensitive to high temperatures.

It is important that the adhesive be stored under the conditions specified by the manufacturer: freezer storage is typical for the one-part epoxies commonly used. Bad storage can cause the adhesive to polymerise or gel prematurely, to absorb moisture and inhibit curing, or crystallise and make it impossible to apply to the substrate with consistency.

If adhesive is left too long at room temperature, it is also possible for the filler and binder to separate. Some parts of the material may be 'resin starved', resulting in a crumbly adhesive with poor shear strength, whereas 'resin rich' adhesive will flow excessively and have poor thermal and electrical conductivity.

### **Alternative resins**

Aims in the development of die-bonding materials have been:

- Increased reliability, as measured by accelerated testing. This requires a resin to be free from ionic contamination and stable under temperature/humidity stress.

Compatibility with new package constructions which may incorporate a very large die or have thin copper lead frames. This requires a formulation with low shrinkage, high adhesion and the right balance of mechanical properties to avoid both delamination and stress-induced silicon fracture

A short curing cycle to allow in-line curing, rather than off-line batch cure. Note that the resin does not need to cure completely at this stage, because this can (at least in theory) be delayed until the moulding post-cure, provided that the die

attach material has sufficient rigidity to survive the bonding process and does not outgas

Higher operating temperatures

Easier rework

Having already achieved ppb levels of ionic contamination, suppliers are giving particular priority to qualifying adhesives with low stress and which can be used for 'snap curing'.

### **Materials for high temperature use**

Polyimide die attach resins generally withstand higher temperatures than epoxies materials being available for wire bonding at 360° and CerDIP package sealing at 450°C. They are thixotropic pastes containing approximately 70% silver powder in a polyimide resin which has been dissolved in a high boiling solvent. To minimise the quantities of solvents and other vapours released during cure, the base polyimides used are low molecular weight resins which cure by an addition reaction. Although in use since the mid-1980s, the main objection to polyimides has been that it is difficult to remove all the organics which may outgas, causing device degradation.

For fast curing, Johnson Matthey have developed a single component thermoset cyanate ester die attach material, which can be cured in under 60 seconds at 200°C and has no appreciable weight loss during cure. It has a lower (40%) modulus of rigidity than conventional epoxies, but has excellent adhesive strength even to 300°C, and imparts a very low stress to the die.

### **Thermoplastics**

Epoxies have extremely large molecules which are cross-linked in three dimensions to give rigid polymers with good adhesion, low shrinkage and high modulus. This strength and rigidity, which was appropriate when ICs were much smaller, causes problems in packages with relatively large die or which are built on an organic substrate, such as the thin PWBs used in MCM-L, MCM-D and some BGA constructions. The requirement for the adhesive becomes one of mechanically decoupling a die with a low TCE from a substrate with a higher TCE, a task which needs a flexible low modulus material.

Thermoplastics are non-cross-linked, linear molecules and most are inherently low-modulus flexible materials. Table 2 gives the properties of a range of commercial polymers now available, which span a large range of properties and can be processed from well under 200°C to over 400°C.

Fillers	Tg °C	Bond temp °C	Rework min. °C	Die shear PSI @ °C	Thermal W/m.°C	Modulus PSI
None	-40	100-150	110	1,700	0.20	60,000
Ag, AlN, none	25	150-200	160	2,200	0.3-3.0	60,000
Ag, AlN, none	45	160-220	170	2,600	0.3-3.0	500,000
Ag, AlN, none	85	160-250	170	3,000	0.3-3.0	400,000
None	145	200-230	210	3,800	0.22	150,000
Ag, Au, AlN, none	180	325-400	350	4,000	0.3-3.0	360,000
None	280	350-450	400	4,900	0.25	370,000

Typical electrical conductivity is  $1 \times 10^{-4}$  ohm-cm for metal-filled and  $1 \times 10^{12}$  ohm-cm for non-metal; typical thermal conductivity is 3.0 W/m°C for silver and 1.0 W/m°C for AlN

Table 2: Properties of some typical thermoplastics

**The advantages of thermoplastic adhesives are that:**

They are supplied fully polymerised, so that the properties are determined by the manufacturer, and are thus more consistent than with thermosets. Their shelf life is virtually unlimited without refrigeration.

They can be melted and remelted without chemical change. The bonding process simply involves softening or melting the polymer while in contact with the surfaces to be bonded, and then allowing the joined construction to cool. The bonding time can therefore be extremely fast (seconds), and the process is fast, and clean.

For the same reason, the structure can be easily reworked, disassembled or repositioned by reheating while applying force. This allows defective chips to be removed and replaced, which is a particularly important feature in multi-chip modules. Localised heating of the die can be used to rework defective components, with a new die placed on the bond site without using any solvent or cleaning the bond site.

They can be bonded in a dry state, which significantly reduces the possibility of voids as compared with solvent-containing epoxies and polyimide thermosets.

A ribbon adhesive system makes it possible to automate an in-line process with no need for off line curing, with mounted chips going directly to wire bonding.

The bonding mechanism for thermoplastic adhesives is primarily a mechanical interlocking process and is therefore more dependent on surface morphology than on material composition.

At its glass transition temperature, the polymer changes to a softer state, and increasing the temperature further causes the viscosity to drop. Bonding is achieved by bringing the adhesive to a sufficiently low viscosity and applying pressure to force the softened polymer into the microstructure of the surface being bonded. Sufficient time is allowed for heat to distribute at the interface and for the polymer to penetrate the surface microstructure. As the plastic then cools, the viscosity increases and the mechanical bond structure is locked in place. Under typical bonding conditions, very little squeeze-out occurs since the viscosity is still relatively high at suitable bonding temperatures.

The three key bonding process parameters, temperature, pressure and time, are interactive and also non-linear. The relationship between them is shown in Figure 1/Table 3, which shows the process bonding window and comments on the boundary conditions.

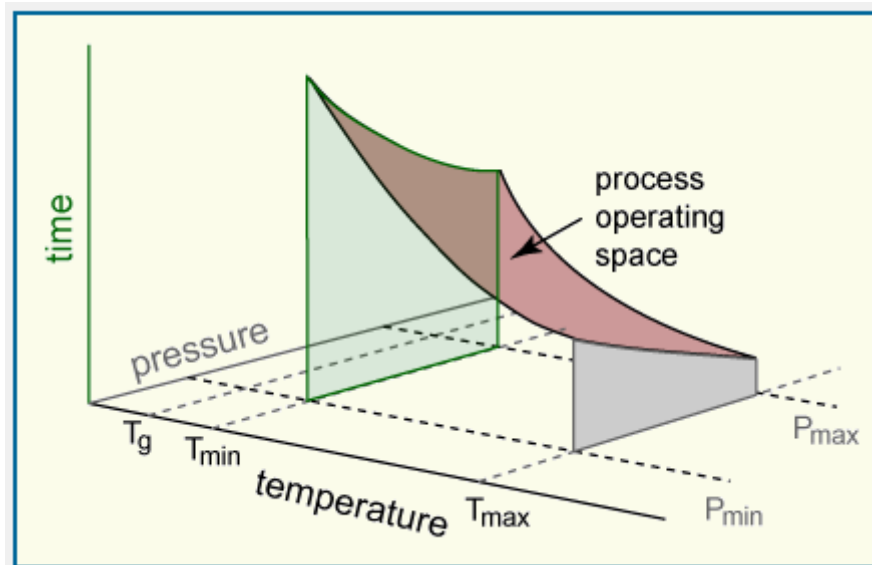


Figure 1: Inter-relationships between thermoplastic polymer bonding parameters

Inter-relationships between thermoplastic polymer bonding parameters

	Minimum	Maximum
	Has the most pronounced effect	
Temperature	Above the glass transition temperature, in a region where viscosity begins to drop off.	Must lie at a safe level below the polymer decomposition temperature.
Pressure	The minimum that will cause polymer flow, wetting and subsequent bonding.	Less well defined and may be limited by equipment, substrate and components. At very high pressure, squeeze-out can occur.
Time	Temperature and time can be increased so that no force on the die is required, but most customers apply pressure.	

Table 3: Inter-relationships between thermoplastic polymer bonding parameters

Temperature cycling, high temperature ageing and long-term humidity tests have been carried out using a standard silver-filled thermoplastic adhesive film on several substrates. As can be seen in Table 4, heat ageing and temperature cycling improved bond strength in all cases, an effect commonly seen with pressure-sensitive and thermoplastic adhesives; temperature combined with humidity reduced adhesion initially, but the adhesion stabilised over time and the values met the criteria of MIL-STD-883D, Method 2019.5.

Substrate	Conditioning	Initial bond strength	Final bond strength
ceramic	150°C, 1000 hours	2,500 PSI	4,800 PSI
gold-plated ceramic	150°C, 1000 hours	3,100 PSI	4,900 PSI
aluminium	150°C, 1000 hours	4,100 PSI	4,500 PSI
ceramic	85%RH, 85°C, 1000 hours	2,500 PSI	1,800 PSI
gold-plated ceramic	85%RH, 85°C, 1000 hours	3,100 PSI	2,600 PSI
aluminium	85%RH, 85°C, 1000 hours	4,100 PSI	3,600 PSI
ceramic	-65°C to +150°C, 500 cycles	2,500 PSI	4,000 PSI
gold-plated ceramic	-65°C to +150°C, 500 cycles	3,100 PSI	3,700 PSI
aluminium	-65°C to +150°C, 500 cycles	4,100 PSI	4,800 PSI
Bonding conditions were 180°C for 10 seconds at 135g on 2mm x 2mm Ni/Au plated Kovar tabs			

Table 4: Environmental performance of a silver-filled thermoplastic adhesive

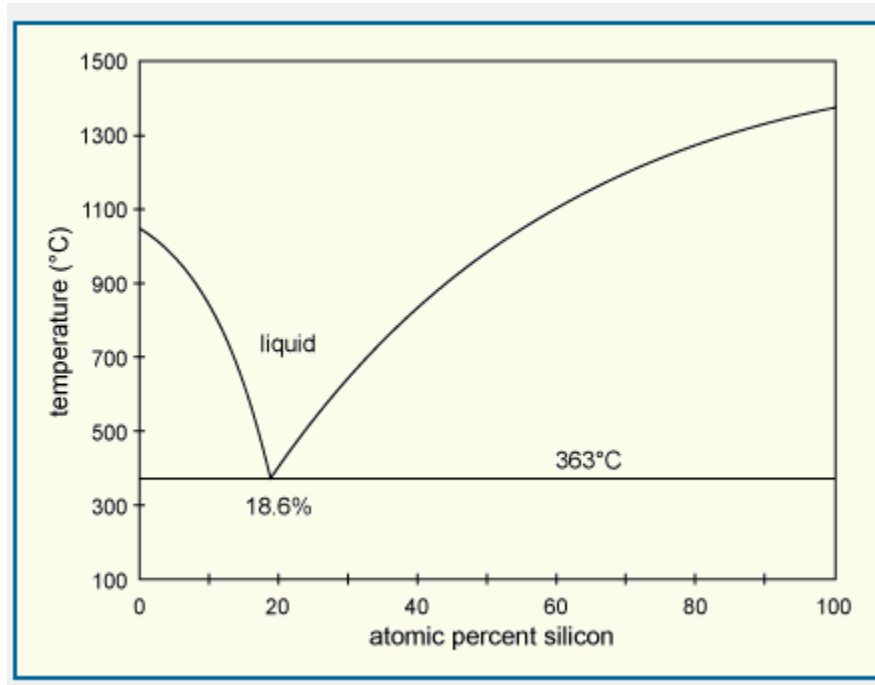
### Eutectic die attach

Studies of artefacts recovered from ancient Egyptian pyramids have revealed that a low melting gold-tin alloy was commonly used to attach handles to metal cups. The phase diagram for the silicon/gold system (Figure 2) shows that, while the melting



points of silicon and gold are 1414°C and 1064°C respectively, a eutectic alloy containing 97.15% gold and 2.85% silicon by weight melts at the comparatively low temperature of 363°C. [Note that this alloy contains 18.6 atomic per cent of silicon, because gold is a very much heavier atom]

Figure 2: Phase diagram for the gold-silicon system



In the eutectic die attach process, which was developed during the 1960s, a solder bond is formed by diffusion between the gold on the package surface and the silicon of the chip, which are heated and held in intimate contact with each other. The surfaces of both package and die must be flat enough to allow gold diffusion to take place.

Typical temperatures are 200°C at the die collet and 400°C+ at the heater block which transmits heat to the package, giving a die attach temperature in the region 375°C–410°C. Higher temperatures are generally recommended as producing better joints, and sufficient time has to be allowed for the package to reach bonding temperature.

As the bond-line temperature increases, gold atoms start to diffuse rapidly into the silicon, and a very thin liquid film forms at the interface once enough gold has diffused to equal the eutectic composition. As the temperature rises above the eutectic temperature, a larger volume of eutectic alloy is produced. Alloy formation

continues until one of the two reacting materials is used up, the limiting factor usually being the gold available from the package.

The die and package are invariably 'scrubbed' together: manual bonder operators became very adept at picking up the die by the side using a pair of fine tweezers, positioning it in the package cavity and moving it in a semi-circular scrubbing motion whilst applying light pressure. A visual indication that die attachment is complete is the presence of eutectic braze around the die perimeter.

Operators have now been almost entirely replaced by machines. Their visual feedback is substituted for by process controls on time and temperature, and the scrubbing action is frequently performed by transmitting longitudinal vibration to the collet. However, a rotary backwards and forwards action gives better wetting and results in improved yield.

Preforms for eutectic die attach

The gold finish on the substrate is generally the limiting factor:

- If the gold is too thin, the bond established will not be very strong.
- If the quality of the gold plating is poor, the whole gold surface may be depleted, breaking the gold-silicon interface. This is a particular hazard where the gold is incorporated with glass in a thick film conductor.

For this reason it has been industry standard practice to start the reaction and make more solder available by placing on the substrate a small preform of near eutectic composition and around 40µm thick. Preform and substrate are heated above the eutectic temperature, usually to 400°C–425°C: when the preform becomes a silvery colour, the die is laid on top of the melt and gently agitated.

The procedure is relatively simple and tolerates a range of conditions. However, the preform needs to wet both the back of the die and the gold on the die bond pad and this bond is often not continuous, with voids remaining between die and substrate (Figure 3).

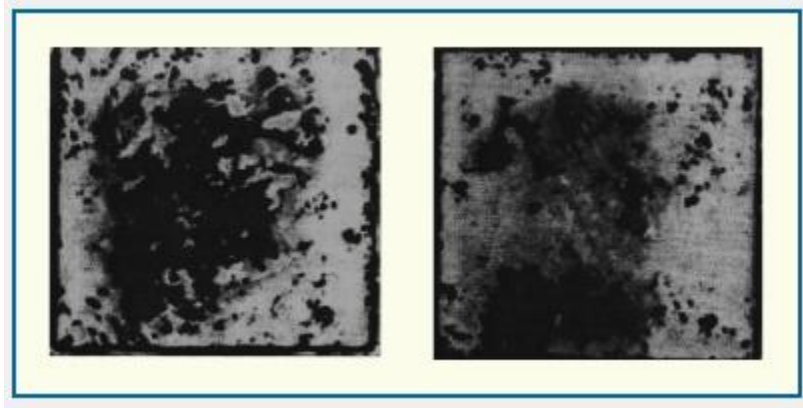


Figure 3: Acoustic microscope images of Au-Si eutectic die attach

Acoustic microscope images of Au-Si eutectic die attach

This shows (left) 45% (right) 20% good die attach by area

Dark areas are well bonded; light areas are unbonded

Investigations have shown that bond failure is accompanied by evidence of poor wetting between the braze alloy and the gold or silicon surfaces. This can result in the related (but subtly different) effects of poor mechanical adhesion and high electrical resistance.

Hoge found the primary cause of poor wetting to be oxidation at interfaces. Analysis of Auger spectra of typical assembled devices identified silica at the surfaces of dice and gold-silicon preforms, and oxides of nickel and iron on gold-metallised substrates. Examination of die and substrates mechanically separated after die bonding showed that the oxides impair wetting, inhibit silicon diffusion, and prevent the formation of chemical bonds at the interfaces.

Two inherent difficulties with the gold-silicon preform die attach method are that:

- The silicon at the preform surfaces oxidises during heat up and liquid formation. [This is inevitable unless the ambient is strongly reducing]
- The liquid preform may not transmit to the die reverse sufficient shear stress to remove oxide scales

Evident for the first is that preforms change shape very little during melting and later solidification, rather than taking the smooth lenticular shape you would expect from a non-reacting, wetting liquid. This is due to silica (and concentrated traces of calcium) at the surface forming a 'skin' which acts as a barrier to proper wetting and flow.

## **Alternative preform materials**

Kitchen observed that melting a eutectic preform in contact with gold makes it gold-rich, causing the overall composition to shift to the left of the eutectic. This sharply increases the melting point, and has the detrimental effect that the resulting alloy is in equilibrium with gold rather than silicon. This suggests substituting alloys containing more silicon than the eutectic. When these are cooled, crystals of silicon precipitate out, growing until the eutectic temperature is reached, at which point the remaining liquid forms the eutectic structure. Such alloys would be in equilibrium with silicon and thus wet the surface of the die. However, adding only a small amount of silicon to the eutectic significantly increases the melting point.

Kitchen proposed adding tin to the gold-silicon eutectic. Tin and gold themselves form a complex system but, if the tin content is limited to 37.4% by weight, the gold-silicon-tin ternary alloy has the characteristics of a eutectic system. The final alloy selected was, by weight, 0.35% silicon, 20% tin and 79.65% gold. This has a melting point of 274°C, and consistently wetted gold-plated surfaces.

Hoge's alternative approach used an all-gold preform. Compared with gold-silicon:

- Only the back of the die will oxidise
- Shear stress can be transmitted very effectively from the metallic preform to the die reverse to remove oxide 'skin'

The same type of bond can be achieved without a preform by using a lead-frame selectively plated with thick gold. For lead-frames this form of bonding has several advantages:

- Preforms are often difficult to position and maintain on die bond pads on lead-frame strips
- The preform to substrate interface is eliminated
- Less gold is needed to achieve the bond

## **Eutectic die bonding challenges**

There are a number of ways in which the ability of the eutectic solder to wet the surfaces of package and die may be impaired:

By alloying elements in the surfaces of die and substrate

By oxides on the surfaces of die and substrate. In particular, dice with an unprotected reverse surface will always have some coating of oxide, the 'native oxide' thickness on exposed silicon being of the order of 2.5nm

By the presence on the surfaces of carbon and organic materials resulting from exposure to solvents, or poor storage or handling

By contaminants from plating solutions

If the surface of the die is too rough or uneven, and only a few points are in contact with the gold

If the reacting members oxidise during bonding, undesirable visual defects may be generated, a problem which can be prevented by carrying out the process in an inert atmosphere such as nitrogen. Eutectic die bonders usually have a nitrogen or forming gas blanket at least around the heated stage.

### **Reverse plating**

One way of minimising the effect of both oxide and contamination is to deposit a layer of gold on the reverse of the wafer, but care must be taken in preparing the surface and selecting the process, since poor adhesion and non-ohmic contact can cause rejects. The problem is made worse when:

The gold coating has been evaporated: the alternative of sputter deposition starts with a short sputter etch to remove surface impurities

The coating temperature is too high – silicon can diffuse rapidly through grain boundaries at temperatures as low as 100°C, forming a surface layer enriched in silicon within only a few minutes. This will subsequently oxidise to form silica.

After deposition, the gold-silicon interface is sometimes alloyed by heating it above the eutectic temperature, but this can also lead to oxidation of silicon on the surface, depending on the rate of cooling and level of oxygen in the ambient.

### **Substrate plating**

The gold layer covering die bonding pads is usually plated over a barrier of nickel or on an alloy containing nickel, such as kovar. Although the rate at which nickel diffuses through the gold is low at most operating temperatures, the rate of diffusion at grain boundaries can be quite high, and for this reason nickel oxide is very often encountered at the surface of gold metallised die bonding pads. Along with impurities such as organic films, this oxide can impair the wetting of gold-silicon preforms. In extreme cases, the preforms will not wet at all and will just put 'ball up'.

Wetting characteristics can be improved with greater surface roughness, although this may also be associated with non-uniform gold films produced during plating, which can themselves impair wetting by the preform.

### Larger die

Eutectic bonds between large dice and the package can crack as a result of excessive stress from the TCE mismatch, but the extent of the problem depends very much on the process and parameters used. Hund and Burchett found that:

Stress is significantly reduced if assemblies are cooled slowly rather than quickly

Shear stresses are much higher for eutectic brazes less than 50µm thick

Cracked die were only observed (under the experimental conditions) for eutectic braze thicknesses less than 20µm

Tensile and shear stresses in die can be greatly reduced by a stress-relieving temperature soak at 150°C, followed by slow cooling to room temperature

### Soft soldering

A range of commonly used solders is given in Table 5. For power devices, high-lead materials with elevated melting points are generally preferred, but account has to be taken of any soldering operations which are to be carried out at the same time, for example, the assembly of other components in a hybrid microcircuit.

Alloy	Solidus (°C)	Liquidus (°C)
95% Pb, 5% Sn	310	314
80% Au, 20% Sn	280 (eutectic)	
63% Sn 37% Pb	183 (eutectic)	
50% Pb, 50% In	180	209
62% Sn, 36% Pb, 2% Ag	179 (eutectic)	

Table 5: Some common soft-soldering materials for die attach

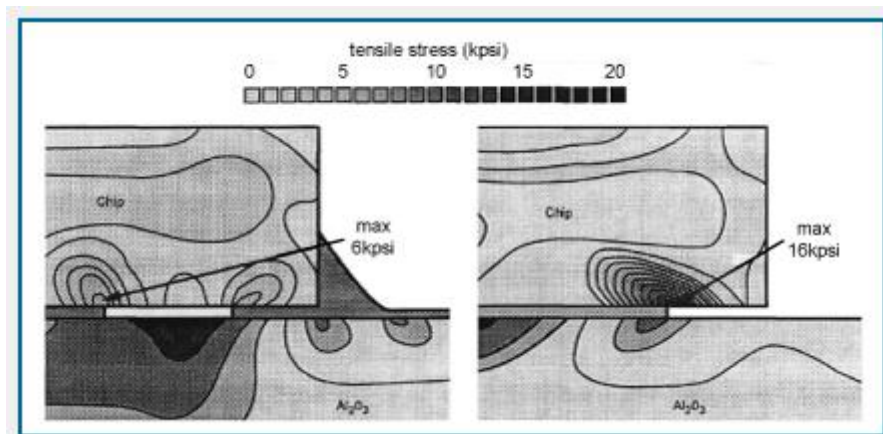
As with surface mount assembly, die attach with soft solders presents the problems of first getting the solder to the joint and then protecting from oxidation during the soldering process. Some of the options for this are shown in Table 6.

Solder format	Soldering process	Protection mechanism	Problem areas
preform or	scrubbing	local cover gas	oxidation/voiding
	inert soldering	inert or reducing atmosphere	need for jiggling or clamping
pre-plating	vacuum soldering	absence of oxygen	cycle time
paste	pre-flow and scrub	flux	wetting/voiding
	reflow	inert or reducing atmosphere	controlling the solder volume

Table 6: Options for soft-soldering processes for die attach

Although high power devices with as much as 50% voiding may well function within their electrical specification, reliability is impaired because of stress in the die. These stresses are quite high, as shown in Figure 4. A typical specification, based on X-ray inspection, is an allowable maximum of 10% voids, with no individual void contributing more than 50% of the total.

Figure 4: Maximum principal tensile stresses calculated by FEA techniques for voids in eutectic attach under the die



Maximum principal tensile stresses calculated by FEA techniques

Moore 1993

Void free soldering depends on the wettability of the surfaces, the accuracy of the solder volume, and on protecting the process from oxygen, and void levels of 3–5% can be achieved with appropriate materials and process.

As an alternative to a nitrogen atmosphere, forming gas (nitrogen with 6–10% of hydrogen) is sometimes used in ovens, although examination of the thermodynamic

properties of the system suggests that hydrogen will not reduce oxides at temperatures below 400°C.

A high degree of cleanliness in the die bonding operation is required in order to wire bond and encapsulate successfully:

- Flux residues which do not reduce surface resistivity or cause corrosion, may have an adverse impact on the adhesion of the moulding materials, or even inhibit the encapsulant curing process leaving soft spots: both tin salts and amines affect the cure of many encapsulants, particularly silicone formulations.
- Although most users monitor initial bond strength, which will expose immediate problems of contamination, materials from die mount may shorten bond wire life.

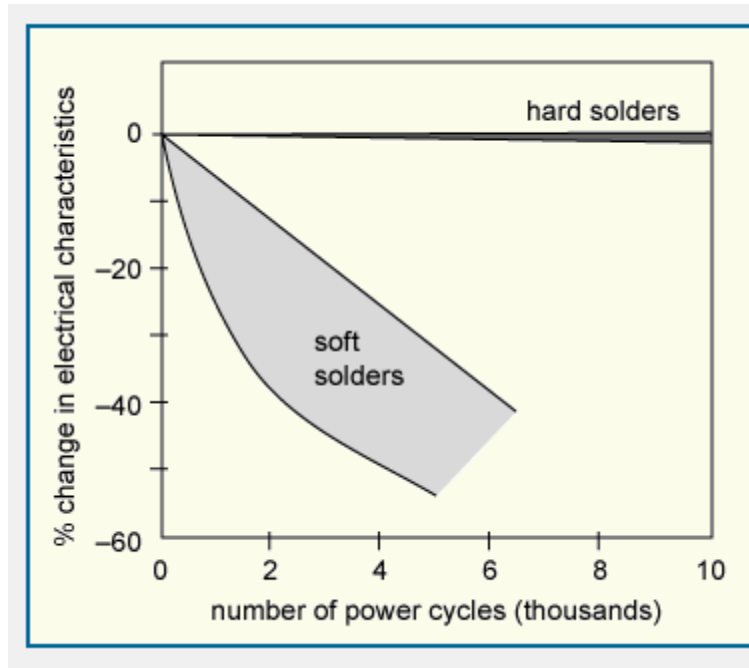
### **An intermediate solder**

When power devices are operated, the assembly is thermally cycled by changes in the power input as well as variations in the ambient temperature. This produces severe stresses where there are large differences in TCE for the materials. A gold-based 'hard solder' joint is relatively strong, so that thermal stresses result in die fracture, whereas joints made with relatively weaker indium, lead and tin-containing 'soft solders' commonly fail because of thermal fatigue within the joint.

Work by Olsen emphasised the comparative ability of hard solder devices to resist thermal fatigue as against the steady decline in performance of soft solder devices shown in Figure 5.

Figure 5: Percentage change in electrical characteristics during power cycling for hard and soft solders

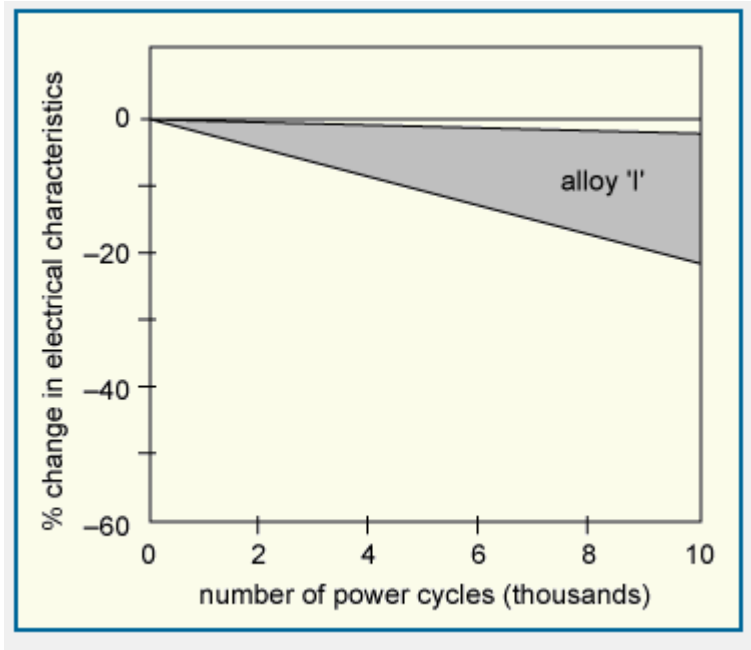




Percentage change in electrical characteristics during power cycling

However a number of intermediate alloys have been developed, with the aim of producing a material with a mechanical strength lying between that of hard and soft solders, avoiding damage to the die whilst resisting thermal fatigue within the joint. Olsen's results for 'Alloy I' are given in Figure 6.

Figure 6: Percentage change in electrical characteristics during power cycling for Alloy 'I'



Percentage change in electrical characteristics during power cycling

'J Alloy', with a composition of 25%Ag/10%Sb/65%Sn, aimed at meeting this requirement, but the additives have limited solid solubility in tin, and both the normally cooled alloy and foil made from it contain coarse particles of Ag<sub>3</sub>Sn, some of which are larger than 10µm. During reflow, the tin matrix melts first, and then dissolves the Ag<sub>3</sub>Sn particles, which have a melting temperature of 480°C. The longer time and higher temperature needed to dissolve the particles results in incomplete melting of conventional J alloy during transient heating and cooling.

Tan found that improvements could be made to the material by using a very high cooling rate. His 'Rapid Solidification' process used cooling rates of around 10°C/s, producing a fine and homogenous microstructure. The same Ag<sub>3</sub>Sn phase was present, but with the particles finely dispersed. The RS alloy had a well defined reflow solidification temperature and allows lower soldering temperatures to be used. Joints prepared with RS alloy foil showed that the finely dispersed microstructure is retained when appropriate soldering procedures are used.

### **Solder preforms**

Using a soft solder preform, the die can be attached as with gold-silicon eutectic, and with the same problems. With components, the requirements for a void-free attach process are normally met by using solder preforms and an atmosphere which is either inert or reducing. This requires either jigging or clamping of the assembly.

In vacuum soldering, components are assembled within a graphite block, which is heated under vacuum by passing a high current through it. Inside the jig are placed successively the package, a graphite slip with cavities for preform and die, a solder preform, and the die. The soldering cycle takes typically 10–15 minutes.

For the increasing number of applications which generate substantial heat, the solder bond must be as free of voids as possible to give minimum thermal resistance. However, it is almost impossible to achieve void-free bonds when using solder preforms, since the area of contact between flat and rigid surfaces is rarely more than 20% of the nominal contact area, and films of air (as thin as  $0.1\mu\text{m}$ ) are invariably trapped at the interfaces. The solder does not flow sufficiently to displace all this air to the die periphery, and much remains trapped after soldering as voids within the bond. The larger the bond area, the greater is the potential for air entrapment.

It was demonstrated with a similar problem in resin-bonded aircraft structures that, if curing was started in vacuum and the vacuum released when the resin became fluid, that the voids would collapse, so that the resulting bond was essentially void-free. Bascom demonstrated that the same 'vacuum release' technique could be used to reduce voids in large area, solder-preform bonding from 50% to less than 10%.

This is because the trapped films are more or less continuous, so that their internal pressure is reduced when the chamber is first evacuated. When the solder melts however, surface tension and gravitational forces cause the solder to flow into this space and segregate the air into discrete bubbles. If the chamber is returned to atmospheric pressure whilst the solder is still molten, hydrostatic pressure will collapse the voids and considerably reduce their volume.

If the molten solder has wetted well to the substrate, and the solder viscosity is sufficiently low, the trapped air pockets and resulting voids will be displaced from the interface. The aircraft experiment suggests that, even with poor wetting, void elimination would still occur, the hydrostatic forces overwhelming the surface forces, but that the collapsed voids would be trapped at the interface.

Providing solder as a preform involves handling, and it is possible instead to deposit suitable materials on the die reverse. Work has been carried out using lead-tin materials, with a gold outer layer to protect from oxidation, and a chromium seed layer to enhance bonding to the reverse of the wafer. Coating is carried out at high vacuum to prevent oxidation of the tin.

## **Solder paste for die attach**

A major drawback is that solder pastes contain around 50% by volume of flux vehicle: either this must leave no residue after soldering, or the residue must be totally removable. Given that water-based pastes contain more aggressive fluxes than rosin-based systems, and that solvent cleaning tends to leave residues, the choice is generally between zero residue and water-soluble products.

The volume and shape of the paste deposit is important:

- In contrast to surface mount solder terminations, which have a small area but large vertical fillets, die attach solder needs to be thinly spread over a large area
- Stencil printing is therefore the preferred process.
- For small components, the stencil aperture should be less than the die size
- For larger die, a modified St Andrew's cross shape is favoured as this both supports the squeegee and generates minimum voids, in the same way that a similar pattern is commonly used when dispensing resin.

The die attach system needs control of the force applied to the die in order to produce a defined bond line thickness, and a practical automatic bonder for hermetic packages may need a depth sensor to allow for variations in cavity depth.

## **Solder reflow issues**

There are three critical phases in solder paste reflow for die attach:

- The temperature rise on entry must be slow enough to prevent fast outgassing and maintain correct die orientation
- The temperature 'spike' must be sufficient to heat the solder paste quickly and take it to reflow without drying out the flux
- In the cooling zone, the rate of temperature fall should be as slow as possible, in order to reduce thermal stress

Fenner has reported that, in order to allow the solder to wet the entire reverse of the die, the assembly needs to be above liquidus for longer than with conventional surface mount. This is demanding on the flux activation system, and a rapid ramp is required to keep process time low and avoid flux exhaustion before the soldering is complete. The process parameters are however just within the acceptable range for regular surface mount, so bare dice can be processed alongside conventional components in a single reflow operation.

An alternative view is that the solder alloy being liquid for some time produces a crystalline structure with relatively large particles, with the result that cracks easily develop along the boundaries during thermal cycling. If a short liquid phase of perhaps 12–13 seconds can be used, the alloy will remain fine-grained and homogenous, giving better thermal cycling performance. Unfortunately, this is not compatible with simultaneously performing surface mount assembly.

### **Silver-glass**

Silver-glass adhesives are a potential substitute for gold-silicon eutectic, as they have high thermal conductivity and a TCE close to that of silicon. Silver-glass has been evaluated for the manufacture of power hybrids, and for attaching active devices with gold or silver back metallisation to substrates which are metallised with nickel or silver-plated copper.

A typical silver-glass paste contains 80–85% by weight of silver flake and lead borate glass dispersed in a organic vehicle system. The paste is dispensed into the package cavity, the die placed on the paste, and the package inserted in a furnace. The heat removes the organic vehicle, and then centres the residual solder and glass to bond the die strongly to the ceramic.

The bond material must form a smooth fillet, and the bond must be free of voids and cracks: to achieve this, the conventional process includes a pre-drying step of from 2–10 hours at 60–80°C, depending on die size. Sufficient solvent needs to be eliminated to avoid the formation of voids, and the void density depends on the drying temperature. However, too high a drying temperature can result in reduced shear strength because there is no intimate contact between die and glass. With optimised conditions, an X-ray non destructive test by Dequidt revealed voids less than 1%.

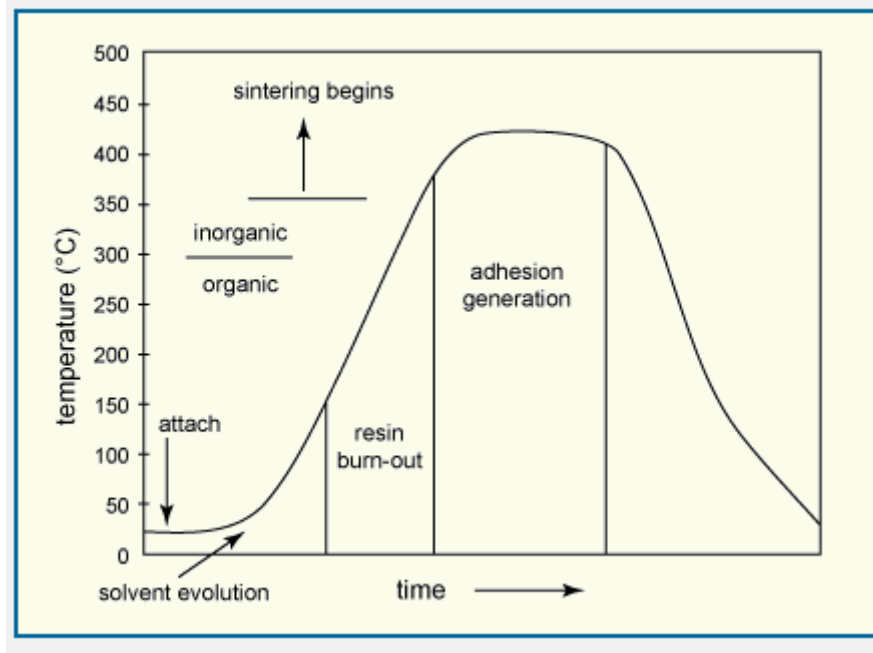


Figure 7 illustrates the sequence of events which happen to silver glass paste during firing. Solvent evaporation (50–200°C) is followed by polymer resin burn-out (300°C). The glass starts to soften at 340°C, which causes silver-glass sintering to accelerate and further wet the surfaces of die and substrate. Reaction bonding of silver-glass with silicon and alumina also starts at about 340°C, and the reaction is completed when the temperature has been maintained at 410–430°C for approximately 10 minutes.

Figure 7: Firing profile for silver-glass

### Firing profile for silver-glass

Shear strength increases with sintering temperature towards an asymptotic value, probably due to the densification of silver particles. A compromise is therefore necessary between the optimum temperature and the maximum acceptable for the silicon die before the aluminium to silicon ohmic contact starts to degrade.

SEM observation shows that the attachment to the die is not continuous, that there is a high concentration of lead at the interface between the silver-glass and the substrate, and adhesion seems to be the result of diffusion of silver into the gold layer. Dequidt explained the absence both of gold in the silicon and of any gold-silicon eutectic by the nickel or titanium under-layer preventing migration of gold into the silicon. Similarly, bonds between the silver glass and the plated package are probably interdiffusion mechanisms, whereas bonds between alumina and silver glass are chemical and similar to conventional thick film.

In investigating the process, thermogravimetric analysis (TGA) is used to determine the temperature at which solvents are eliminated from the binder, and differential thermal analysis (DTA) to characterise the glass and show its recrystallisation.

Developments in silver-glass die attach materials have aimed to produce:

- stress relief for large area dice
- a single pass firing process with no pre-drying
- precise rheology for high speed dispensing
- lower firing temperature

As with resin attach, provided that the thickness and modulus of the die bonding material is small compared to the thickness and moduli of die and substrate, the TCE of the bonding material is not a significant factor in die stress. However, cracks due to thermally induced stresses arising from a TCE mismatch between silicon and ceramic have been reported by Nguyen for die larger than 10mm side, and the bond line thickness has to exceed a minimum value for acceptable performance.

The stress in the bonding material is related to the sintering behaviour of the silver/lead borate glass mixture. Control of the sintering rate is typically achieved by small quantities (0.1–1%) of proprietary additives which increase the surface roughness and slow down regrouping of the particles. This helps to eliminate cracks without adversely impacting on adhesion and void formation.

Despite the claim that silver-filled glass offers lower cost, faster processing, high yield, better thermal performance, and a lower die stress than gold-silicon eutectic, it has not replaced eutectic or other solders for high power chips. This seems to be because companies are reluctant to change. The material is however widely used in the fabrication of CerDIP packages, on account of its resistance to the high temperature of the furnace sealing involved.

Author: Martin Tarr

**Source:** [http://www.ami.ac.uk/courses/topics/0203\\_dbm/index.html](http://www.ami.ac.uk/courses/topics/0203_dbm/index.html)