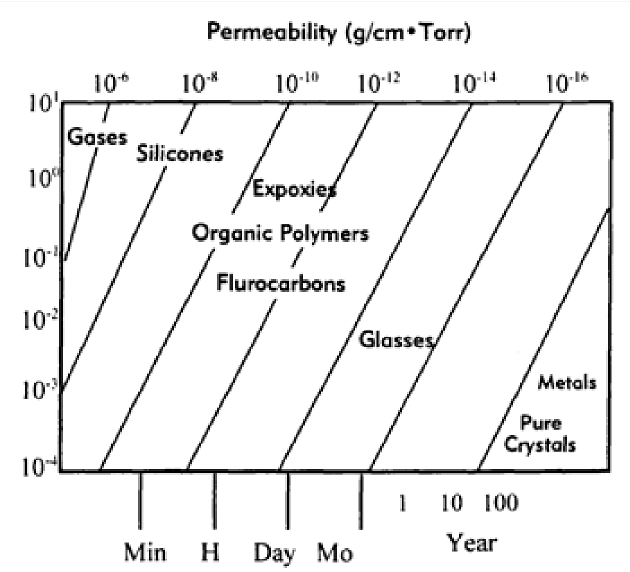
Hermetic Encapsulation

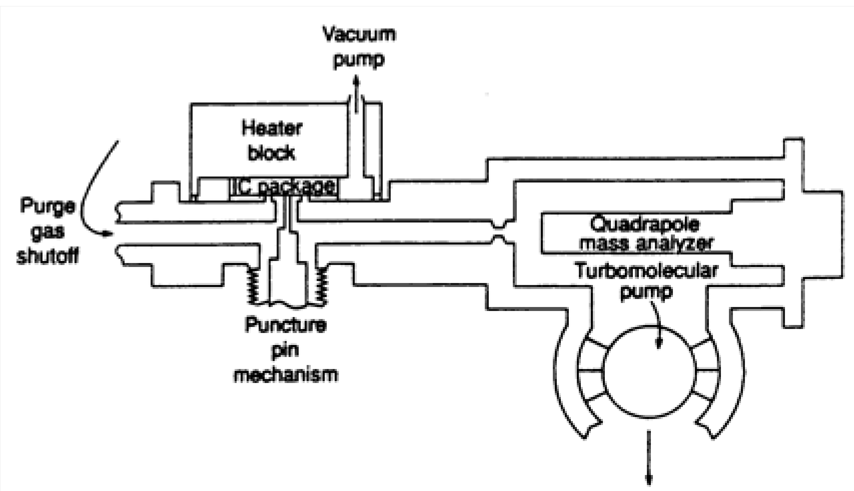
'Hermetic sealing' is defined by the Shorter OED as "air-tight closure of a vessel by fusion, soldering or welding". The term 'hermetic package' used in the electronics industry is however at best slightly misleading, in that the term is used to describe components where the die and associated bonds are sealed within a cavity in a hollow package (as distinct from being embedded in a resin), and at worst wholly inaccurate, in that these seals are generally far from air-tight. Although the packages use materials which show the greatest resistance to the passage of water vapour (Figure 1), examination of typical package contents by Residual Gas Analysis (Figure 2) shows that complete isolation from the ambient is rare.

Figure 1: Permeability of water through different organic and inorganic materials



Tummula 1996

Figure 2: Basis of residual gas analysis



For example, Sulouff evaluated devices packaged with manufactured leaks for extended periods in an 85ºC/85% RH environment and under bias. He found the failure rate of leaky packages to be very close to that of completely open and exposed devices, and the failure modes were consistent with the conclusion that leaks of greater than 10^{-6} atm cc/sec allowed the atmosphere inside the package to reach a dew point above 0ºC in under six weeks!

As examples of hermetic packaging, we describe first a range of metal-bodied constructions that are generally sealed by soldering or welding, and then some glass-sealed packages made mostly in ceramic. The final sections cover package rework, and some of the factors that affect the internal environment.

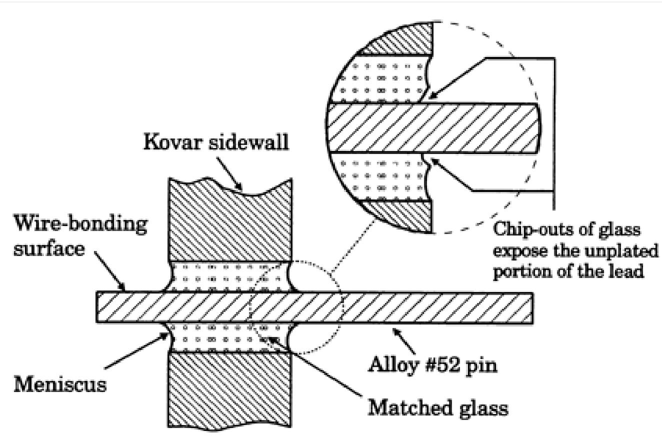
Glass-to-metal seals

Glass-to-metal seals provide a means of making electrical contact into a sealed container, with high voltage breakdown and high insulation resistance in a comparatively small size, and excluding contaminants from the enclosure by maintaining a hermetically sealed atmosphere. The seal can also provide a structural support for internal hardware. The first semiconductor application was the transistor 'TO- header', but the concept was subsequently used for multi-terminal devices such as ICs and relays, and developed into a number of different package formats.

There are two basic types of glass-to-metal seal:

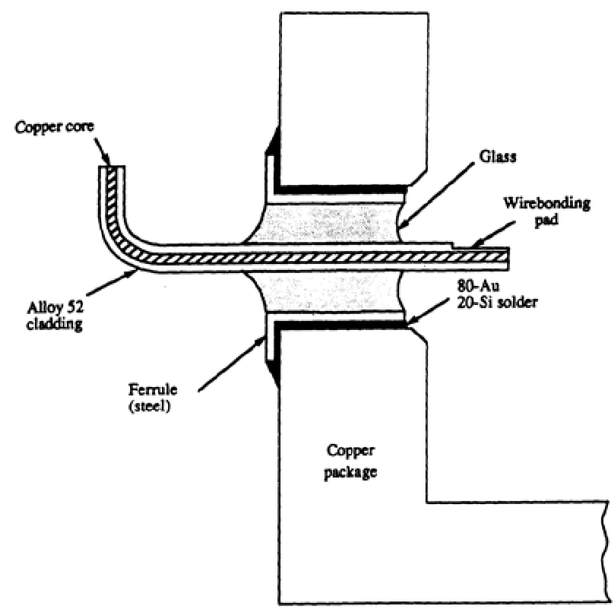
- In **matched seals** the TCEs of the glass and metal components are similar, and sealing is the result of interfacial bonds between them. Figure 3 shows a typical kovar-to-glass matched seal, where the interface is an oxide created on the nickel-cobalt-iron alloy surface before sealing, which takes place in air at around 650–700ºC.
- Matched seals are thermally rugged, have favourable electrical properties and are of minimum weight. Since the quality of the interface bond is essential in determining the strength and hermetic quality of the matched seal, the degree of oxidation of the metal parts is critical – metal oxides that are either too thick or too thin will produce interface defects which weaken the bond and promote leaks through it.

Figure 3: Pin sealing with matched glass-to-metal seal



- In **compression seals**, the TCEs of the various parts are mismatched, and sealing is accomplished by establishing compressive forces between the glass and metal members. The glass used is usually soda-lime or potash-sodium-barium, with terminals made of alloy steel containing about 6% chromium. The outer sleeve is generally cold rolled steel, which expands at the fusing temperature of the glass, but contracts at a rate greater than the glass during cooling, so that the resulting seal is under compression. Compression seals (Figure 4) are generally both mechanically stronger and larger than matched seals.

Figure 4: Section of eyelet style of compression seal



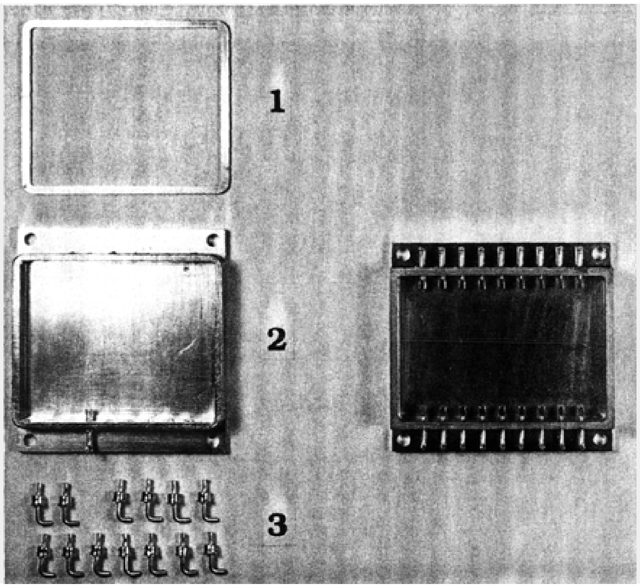
The length of the glass path between contact and outer body determines the resistance of the seal to arcing at high voltages. For matched seals, voltage breakdown is in the order of 40VAC for each 25µm of path.

The custom aspect of glass components dictates rigidly controlled small batch production. Manufacturers provide variations in glass composition with unique combinations of CTE, compatibility with different metals, firing range, electrical properties, strength, surface properties, and chemical resistance. Multi-crystalline ceramics extend and broaden the range of properties available in glasses.

Ceramic-to-metal seals are used in conditions of adverse temperature, shock and vibration, and alumina-based ceramics are most widely used because of their excellent electrical and thermal properties and moderate cost.

There are many formats of package which use individually-sealed pins or eyelets, a common style is shown in Figure 5. The body material will depend on the type of seal and the package sealing method to be employed.

Figure 5: Machined copper package assembly components (left) 1 - sealing ring; 2 - machine body; 3 - terminals with compression seal Assembled package (right)



The hermetic package consists of two parts, case and lid (Figures 6 & 7), and the mating of the two must always be carefully considered when designing the internal structure and deciding on the sealing method. It must be borne in mind, for example, that the lid may flex when the part is helium ‘bombed’ for fine leak testing, which could stress the seal or even short to internal wire bonds. As indicated in Figure 7, there is a variety of cover styles, of which the flat and stepped types are most common.

Figure 6: Critical measurements for lid sealing

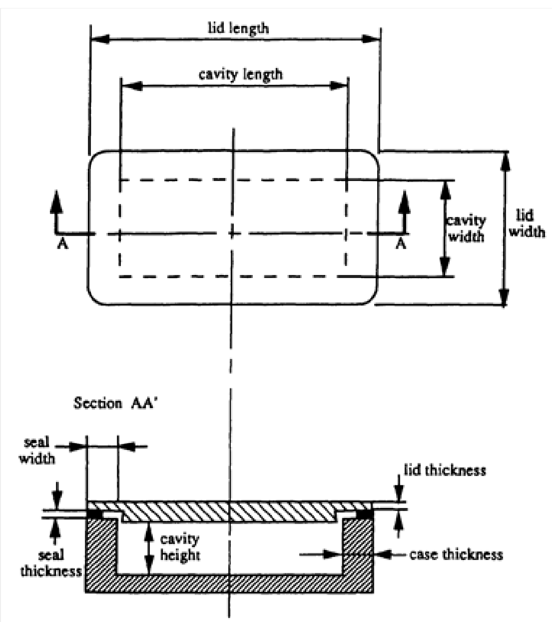
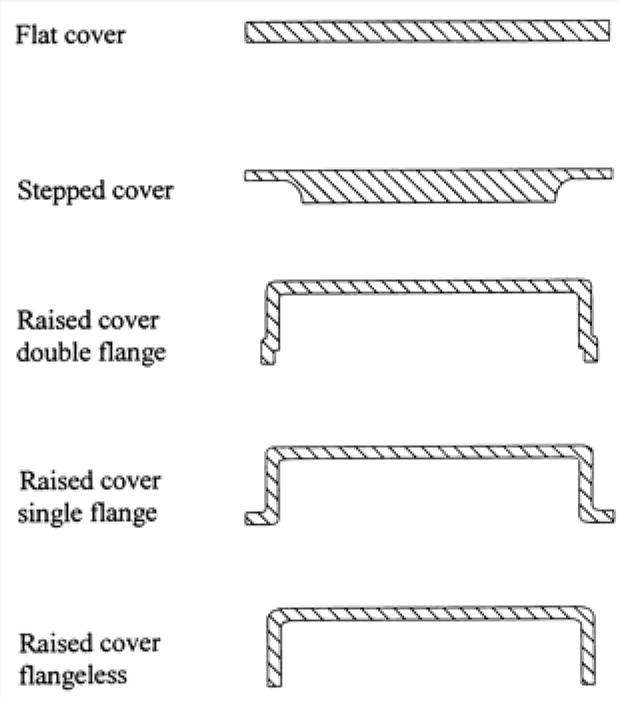


Figure 7: Typical covers used in hermetic sealing of hybrid packages



Solder and glass sealing

A flat package may be **solder sealed** by holding together a 'sandwich' made of lid, solder preform and case and applying heat. To provide corrosion resistance, the process generally uses solder with a high gold content, and the gold-tin eutectic (80% gold/20% tin, with an melting point. of 280ºC) is most commonly used.

Soldering may be carried out in a furnace or by one of a variety of heating methods, which include using seam welding and laser welding equipment with the parameters appropriately adjusted.

In a typical sealing furnace profile, the assembly is kept at 320–360º for 3–5 minutes. One of the difficulties of furnacing is that, in oder to ensure uniform spreading of the solder, the lid has to be held down by clip, spring or weights. However, this pressure must be regulated otherwise solder balling or bridging may occur.

Lids used have to be solderable, and the most common material is gold plated kovar. Ceramic lids may also be used, with a metallised rim on the underside. In both cases the gold-tin preform may be pre-assembled to the lid by spot welding at the corners. These 'combo lids' (originally a trade name of Semi-Alloys) are now widely used.

Seal quality is affected by the temperature profile used and by the flatness of the components - if the mating surfaces are not flat, a thicker preform is needed in order to fill the joint completely and create an effective seal.

Furnace sealing may also be used to produce **glass seals** using pre-glazed parts, usually made of ceramic. The cycle is extended for up to 20 minutes, with a fast heat up but relatively slow cool-down (40ºC/minute).

Whilst the resulting glass seal is inert, oxidation resistant, and impermeable to moisture, such seals are rarely used for large packages because of the high temperature required to melt even specially-designed low-melting glasses:

- The lid can be heated above the melting point of the glass, and the case kept at lower temperature. However, the fast cooling at the interface which is inevitable in this 'hot cap' method can induce stresses large enough to fracture the seal.
- An alternative method of reducing the unwanted heating of the devices inside a package is to use a beam of focused infrared light to heat the seal area of the pre-glazed lid and case assembly. This needs a special glass to absorb infrared radiation preferentially.

Weld sealing

Cold welding involves supplying enough force to crush the header or lid into the base of the package. Little heat is generated, but the technique is not suited to large complex packages, requires close tolerances and is hard to automate.

In **opposed electrode welding**, which is usually carried out on TO or other circular packages, energy is passed from one electrode to the other through the flange of the package. Resistance between the header and cover results in the build-up of heat and eventually the piece is fused.

In **resistance welding**, the power supply produces a series of pulses that pass through tapered electrodes and the lid-to-case interface. Since the resistance of the interface is higher than of either lid or case, the heat concentrates at the seal area, which reaches a temperature of around 1,500ºC, whilst the rest of the package stays at comparatively low temperature. The high temperature around the weld volatilises any contaminants, so the cleanliness of the surfaces being joined would only matter if the gases evolved affected the package contents.

Pressure is applied by the electrodes to hold the lid and case together and complete the weld, so the process can accommodate a fair degree of package and lid non-flatness. During the welding operation, the case is held in a fixture made of material with high thermal conductivity, in order to cool the bottom of the package.

The method by which resistance welding is applied depends on the package format. In **seam welding**, the most common process, two roller electrodes are moved along opposite sides of the package whilst pulses of power are applied:

- The traverse speed is set so that the weld 'stitches' overlap, without making the weld unnecessarily wide
- The taper angle of the electrode (typically 12º) affects both the weld penetration and the uniformity of heating of the lid-case interface
- As electrode force increases, temperature control becomes less critical, but the contact resistance goes down and more heat is conducted between lid and package. The resultant weld is more homogenous, but requires higher power and the body of the component gets hotter.
- The lip of the lid must be thin enough (typically 100–150µm) to allow the seal interface to reach welding temperature without over-heating the entire package, although lid centres are often thicker for greater rigidity. This gives the advantage that the lid is self-locating within the package.

With square or rectangular packages, the seal is accomplished in two passes, with the package being rotated by 90º between passes. Unless the weld is to be unacceptably wide, the package corners cannot have a large radius. Other design limitations are that internal corners are not possible, and the rollers must be able to clear any protruding features, such as leads.

Laser welding is an alternative non-contact way to provide similar localised heat, but with fewer restrictions on weld geometry. Compared with seam welding, the laser weld quality is generally higher and the process more reproducible. Most significantly, the heat is more localised and short-term: not only does this protect the rest of the package, but it makes it possible to weld packages made with materials such as copper and aluminium. Similar results can be obtained by **electron beam** welding, where a focussed beam of electrons provides the weld energy, but the process has to be carried out in vacuum.

For all welding operations, one has to be aware of the component surface finish. For example, even thinly solder- or tin-coated surfaces weld very poorly, with spattering of the coating material. Most package components for welding are made of kovar and gold plated, with an under-plating of electro-deposited nickel, and the resulting weld is actually between *nickel* layers on lid and body, with the gold being expelled.

Be aware, however, that there are different types of nickel finish:

- Electro-less nickel has a high phosphorus content and produces welds which have a fine uniform porosity throughout the entire weld bead. This is sufficient for the gross leak test to show ‘frothing’ along the entire weld!
- Electro-plated nickel produces excellent welds, but organic brighteners can cause gas evolution in the weld and even excessive porosity

Nevertheless, welding techniques generally are highly repeatable and achieve higher yields than soldering and brazing, being less susceptible to problems of bonding surface contamination and component flatness. In fact, soldering hermetic packages can result in problems of overheating and flux-related corrosion.

Unfortunately, manufacturers with packages that are unsuited to seam welding but who cannot afford the high capital expenditure of electron beam and laser welding techniques may be forced to use some kind of soldering technique, as this can be applied to a wide range of ‘odd-ball’ designs. Some success has however been achieved in welding electronic packages by a **micro-arc TIG**process, which allows the wall thickness and bulk to be reduced. Micro-arc TIG welding uses a very small arc, and the part moves at high speed, so that the heat input is low enough for parts to be held in the hand immediately after welding.

Microwave and hybrid packages

Microwave integrated circuits are generally quite large, and have complex shapes. Aluminium is usually the preferred material for these as it can readily be machined, and is lightweight and corrosion resistant, with an excellent stiffness to weight ratio and high electrical and thermal conductivity.

Sealing such large, complex packages is not easy. One approach, which avoids any problem of TCE mismatch and makes lid removal and internal rework easy, is to use a gasket seal. As rubber materials are permeable to moisture and gases, malleable metal gaskets have to be used, and these require high sustained pressure to form a seal.

Moreover, because of the amount of hardware required, they are not space efficient, and their high moisture diffusion rates prevent them being hermetic in the long term.

For seals which are not demountable:

- Epoxy bonds are inadequate hermetically
- Soldering aluminium is not possible without aggressive fluxes
- Resistance welding requires two high resistance materials in order to form a weld joint – it is difficult to seam weld high conductivity aluminium packages, because the metal dissipates the heat as soon as it is generated

A further problem with welding is that aluminium is very active chemically, especially when molten, and the oxide formed has a dissociation temperature well above the melting point of the metal. For this reason, the oxide tends to aggregate and form brittle, porous welds.

Laser welding is however able to provide high power in an extremely localised area, forming the weld zone so quickly that thermal dispersion does not degrade the weld. Welds are typically 1–1.2mm deep, and oxidation is controlled by welding under argon.

The most generally used aluminium alloys suffer from embrittlement at temperatures just below the melting point. Because localised welds chill quickly, the shrinkage stresses that occur during cooling can exceed the tensile strength and cause cracks to appear in the weld. The problem is usually overcome by introducing a high silicon content alloy into the weld zone: for example, an alloy with 12% silicon has a melting point around 580ºC, significantly lower than the parent material. As it is difficult to introduce a preform of braze material, the normal method is to make the entire cover of high silicon aluminium, using a flat cover which is retained within a lip in the package wall.

As far as possible, all large packages are filled with dry nitrogen during the sealing process, pre-baking the parts to remove water, and carrying out the procedures in glove boxes with a controlled environment. However, in hybrid circuits with many epoxy attached devices, a breather hole of 0.5–1.0mm diameter is often drilled or punched in the lid before sealing in order to release outgassing products. The packages are then vacuum baked and the hole finally closed with a soft solder.

The CERDIP package

The term CerDIP (ceramic dual- in-line package) is used to refer to a generic style of package sealing method first used in volume in the 1970s for a ceramic version of the ubiquitous plastic DIP. For reasons of reliability and operating temperature range, military users preferred cavity packages, but there were cost and size penalties to glass-to-metal seal types, especially in larger sizes.

The first packages imitated the plastic DIP, but were made with ceramic components bonded together with glass, forming a cavity for the chip, and with the final glass seal being made after die and wire bonding (Figure 8). A number of variants of the CerDIP principle, using metal or ceramic components, are shown in Figures 9 & 10: with these, the final seal may be either glass or solder, the choice depending on the equipment available and the temperature rating of the internal assembly.

Figure 8: Isometric drawing and schematic section of CerDIP package

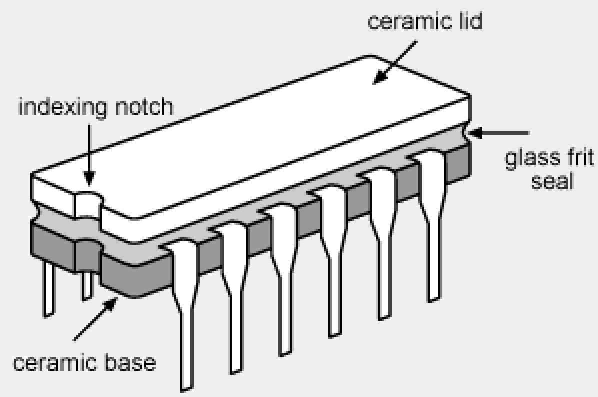


Figure 9: The flat-pack construction

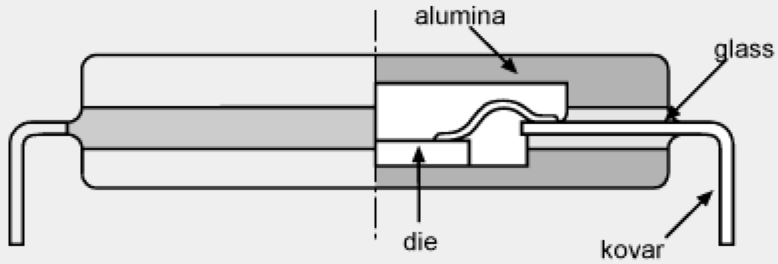
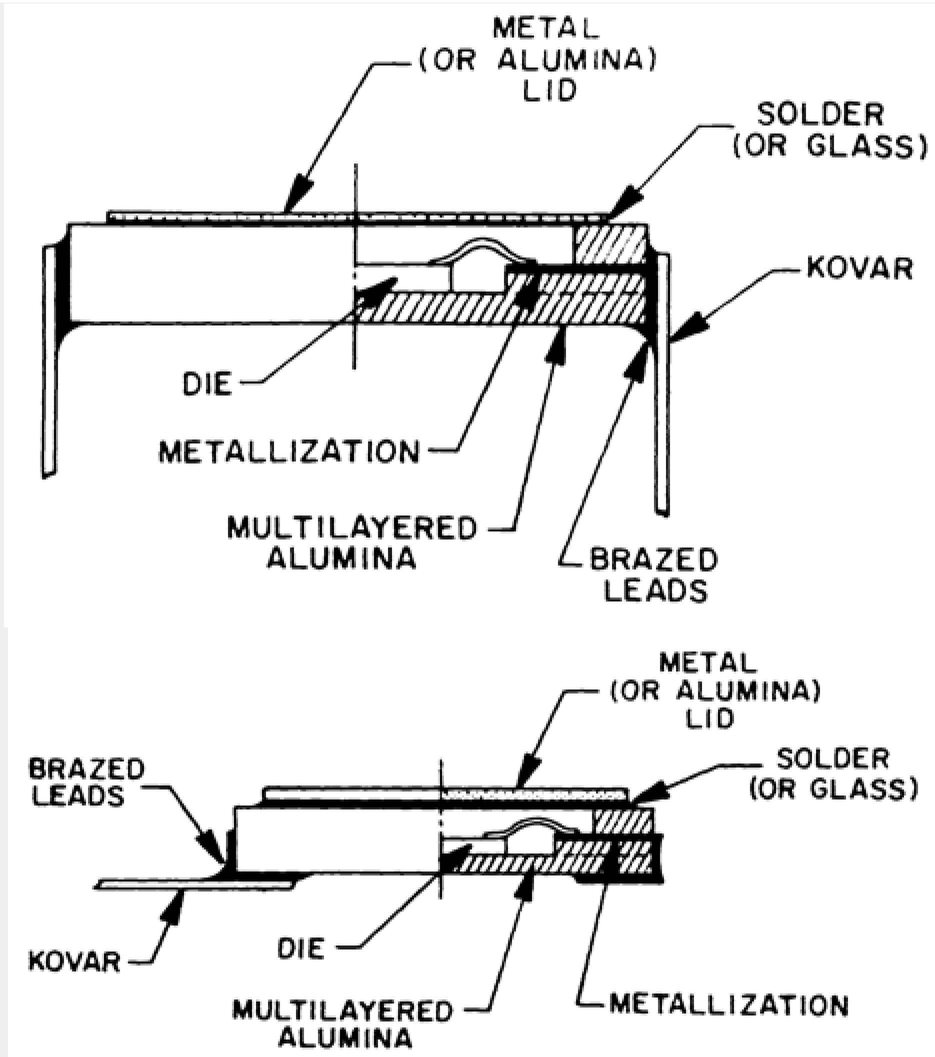


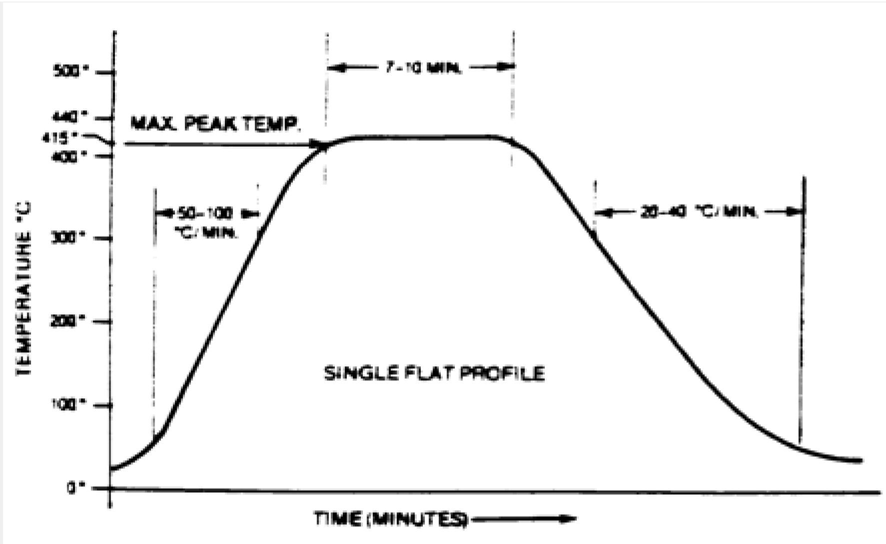
Figure 10: Ceramic package constructions: side-braze (left) and chip carrier (right)



The CerDIP technique uses glasses containing a high percentage of lead oxide, which will melt and seal at low temperature. Most of these ‘solder glasses’ are vitreous glasses since they typically have a lower moisture content and will seal at lower temperatures. The glass is powdered, mixed into a paste using organic vehicles, screen printed on to the package base and lid, built up to the desired thickness and fired, before the package components are delivered to the device manufacture.

The temperature profile required depends on the sealing material used and the thermal characteristics of the package, but all profiles will specify rate of temperature rise and cooling, maximum peak temperature, and time for which the glass is fluid enough to form a seal. A typical profile for CerDIP sealing with lead oxide glass (Figure 11) would show a 50–100ºC/minute rise rate, a dwell at 450ºC for 7–10 minutes, and a cooling rate of 20–40ºC/minute.

Figure 11: Single flat profile for CerDIP sealing



A double flat profile is also used in many sealing applications, with a ramp up to 300ºC and 7–8 minute dwell time, then an second ramp up to approximately 430ºC with 8–12 minute dwell time, as shown in Figures 12 & 13. The first dwell ensures thorough outgassing of the moisture within the sealing glasses and any residual binders and solvents used in solder sealing and die bonding.

Figure 12: Double flat profile for CerDIP sealing

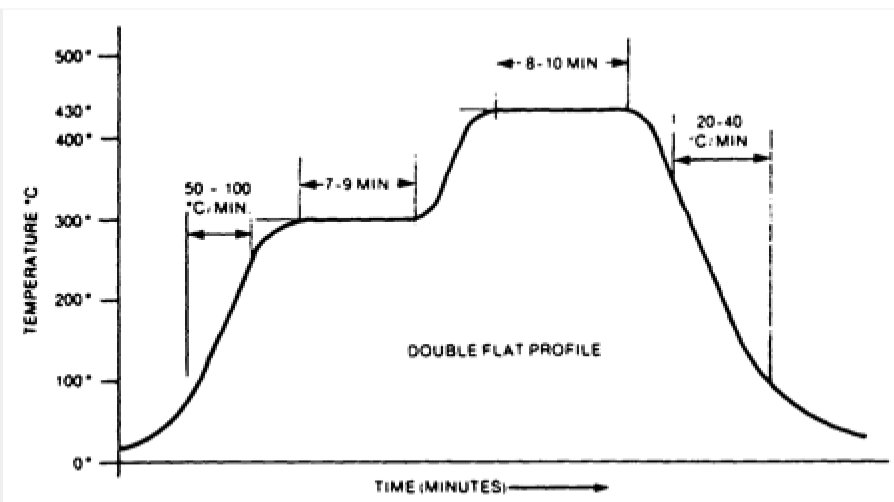
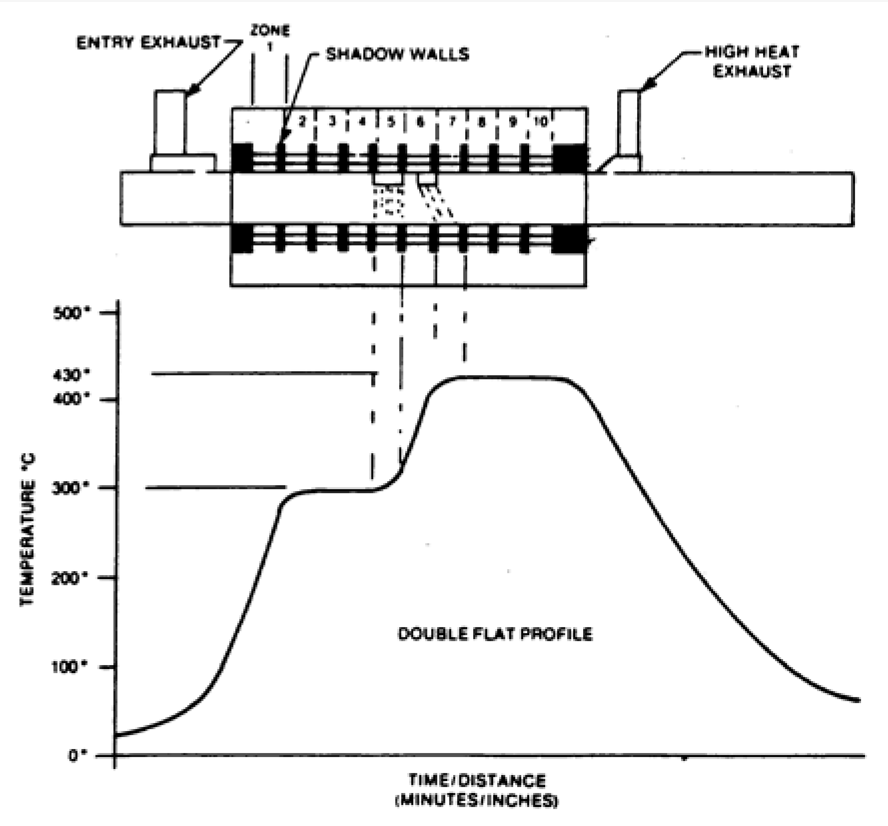


Figure 13: Double flat profile for CerDIP sealing, showing furnace arrangement with zones and exhaust



Normally clean dry air is used for glass sealing, but the process chamber atmosphere must be free from any ambient moisture. As with reflow soldering in an inert atmosphere, the dry environment is maintained by fitting gas inlet plenums and door curtains and balancing the exhaust flow. An atmosphere sampling system would normally be fitted, with sample ports located at both ends of the muffle, and the atmosphere monitored to ensure that exhausts and inlet flow rates are adjusted correctly. It is recommended that the moisture level be kept below −70ºC dew point.

Rework

Defective small packages are rarely repaired, but occasionally it is necessary to open a large or expensive sealed unit to make a repair, and microwave or hybrid packages need to be repairable to original performance standards in order to be acceptable to the industry.

Package recovery starts by machining out the covers to the original cover seat dimensions, leaving about half the original weld around the periphery of the housing. After repairs have been completed, a new cover is put in place, with a braze alloy preform where required, and the replacement cover is welded, using the same weld schedule as the original cover. As long as the remnants of the original weld are solid and clean, the repair weld will not be not degraded.

Rework machining should be carried out dry, without coolants, to avoid contaminating the package interior. Extreme care has to be taken to avoid both damage to the case and leaving debris inside the package. However, it should always be presumed that chips and flakes of unwanted material will be present, and thorough cleaning and inspection is mandatory.

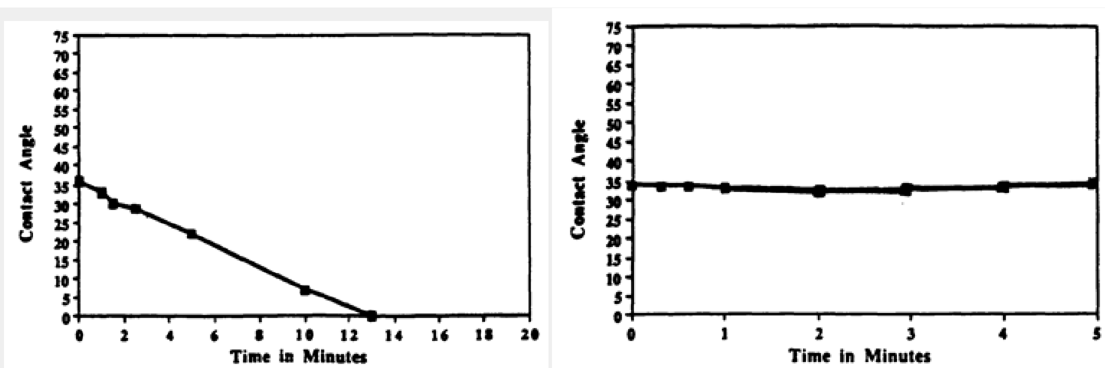
Cleaning

Naturally prevention is the best cure, but it is not always possible to maintain cleanliness in complex packages, especially hybrids, which might experience protracted exposure to the environment during both assembly and test.

Pre-encapsulation cleaning methods and controls are critical in determining the reliability of such package devices. Wong and McBride demonstrated that measurements of contact angle in a 100% RH environment were a simple, fast and reliable method of assessing substrate surface cleanliness, particularly in detecting hydrocarbon contamination in the outer 1nm layer of the surface.

The usual contact angle test, carried out in laboratory conditions, is relatively unreliable because the water drop evaporates quickly at room temperatures, as shown in Figure 14a. By contrast, using a 100% relative humidity ambient provides a stable reading (Figure 14b).

**Figure 14: Variation with time of the contact angle of a water drop on silica at 65%RH (14a – left)
and 100%RH (14b – right)**



The process producing the best results for removing organic contaminants was a sequence involving successive immersion in a terpene (*d*-limonine), isopropanol, and de-ionised water rinses, followed by a vacuum bake and exposing the structure to reactive oxygen (using ultra-violet light to produce ozone). This final treatment was very effective in removing the final few mono-layers, producing a very impressive and dramatic reduction in contact angle virtually to zero.

It is of course necessary to identify the nature of the soil. For ionic contamination, high purity water (resistivity >18MΩ) is needed in combination with low levels (50ppm) of surfactant.

The internal atmosphere

The atmosphere inside a package can be measured by Residual Gas Analysis. This is a destructive test, in which a package is pierced under vacuum and the evolved gases are analysed by mass spectroscopy, as outlined in Figure 2.

For reliability, the moisture content should be kept as low as possible, because moisture will cause corrosion where otherwise inert ionic materials are present: USA military cavity package specifications suggest that maximum water vapour levels of either 3,000 or 5,000ppm are acceptable, depending on the end use.

Based on data from controlled moisture experiments, it has been observed that long pre-baking, using dry gases, and so on, does not necessarily lower the cavity water content much below 1,000–5,000ppm, and the moisture content appears to vary considerable between different factories and products.

Significantly, the cavity may also contain substantial quantities of hydrogen, a gas which is easy to overlook, but can have a substantial impact on the reliability of certain types of device (mostly GaAs-based) which use titanium resistors.

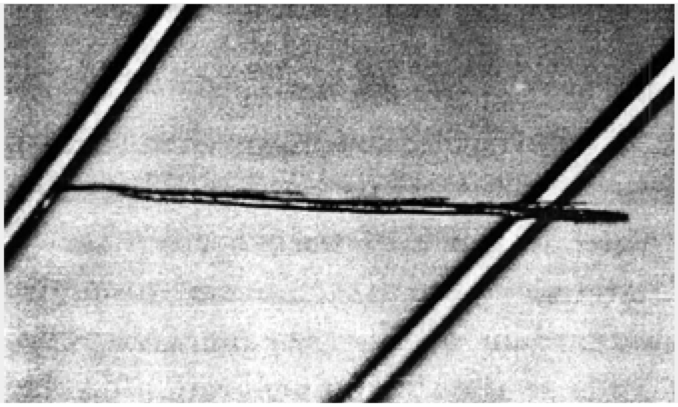
A detailed discussion is beyond the scope of this booklet, but some of the issues are outlined below:

- With eutectic die attach, most residual moisture will be removed by the oxidation of elemental silicon partially exposed during the sealing cycle, a reaction which however liberates hydrogen.
- In CerDIP packages, the air sealing method oxidises exposed silicon, so that other precautions must be taken to ensure that glass sealed ceramic packages are dry.
- The manufacture of co-fired ceramic packages involves metallisation firing and brazing, processes during which hydrogen is used. Another significant hydrogen source is gold plating. Substantial amounts of hydrogen may be released over life. The level of hydrogen varies and is process dependent, and the only solution is to select lids and packages with low residual hydrogen content.
- Silver particle surfaces oxidise during manufacture, but silver oxides are unstable and tend to be reduced by hydrogen to produce water. The situation is complicated by the fact that during silver-glass binder burn-out, carbon monoxide and dioxide are generated, and silver oxide will absorb these to form silver carbonate, which itself is easily reduced by hydrogen to produce water.
- Pre-treating the silver-glass after firing with a reducing gas reduces the amount of oxides available for hydrogen reaction when solder-sealed metal lids are used.
- The lead oxide glass in silver-glass is susceptible to reduction and will also absorb some moisture, depending on humidity and exposure time.

Gettering

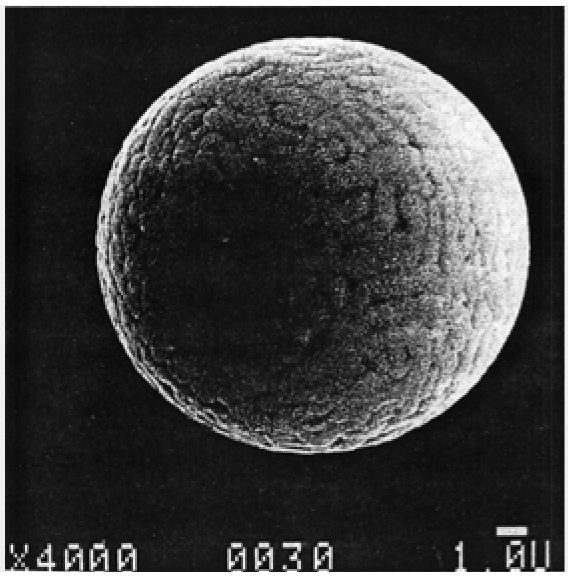
Loose particles in a hybrid microcircuit have a substantial adverse effect on its reliability. Conductive particles can cause short circuits (Figure 15), with adjacent pads on semiconductor devices being particularly vulnerable; larger particles (Figure 16), such as loose ceramic chip capacitors, can cause considerable damage under shock or vibration, and may make the circuit incapable of being reworked.

Figure 15: SEM of eutectic die attach particle shorting bond wires in a hermetic package



Moore 1993

Figure 16: SEM of silicon-gold eutectic lead seal PIND reject particle captured in tape in a hermetic package



Moore 1993

Two common methods of detecting loose particles are x-ray scanning and what is referred to as a Particle Impact Noise Detection Test. There are problems with both of these tests:

- x-rays are incapable of detecting small particles and there are problems due to the shadowing effect of conducting materials
- PIND testing, whilst quite effective in detecting loose particles, is highly susceptible to ambient noise and vibration and not a repeatable test

There is also a possibility that particles such as chips from the substrate or loosened components may be generated after the tests have been performed.

There are two generic ways of dealing with the problem: the first is to use a conformal coating such as Parylene to coat the circuit; the second is to apply to a suitable internal surface, usually the lid of the package, a coating of a polymeric gettering material which will trap and hold loose particles.

A typical gettering material is an uncured silicone, with a solvent used to adjust for correct viscosity. No catalyst is added, so that the material remains at the pre-polymer stage. On evaporation of the solvent, it becomes a highly viscous liquid which remains tacky and will attract particles over a very wide temperature range (−65ºC/+200ºC). Typically a silicone getter is made by dispensing small dots of material into the package lid and drying for 24 hours at 150ºC.

Tests using Residual Gas Analysis on completed packages showed that the silicone getter does not contribute appreciably to the water vapour, carbon dioxide or other gasses. In particular, the majority of the water is due to the circuit itself, particularly any epoxy materials used.

Source : http://www.ami.ac.uk/courses/topics/0261_herm/index.html