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Package Reliability as Affected By Materials and Processes

The semiconductor industry is faced with the problem of how to increase the level of reliability of semiconductor parts being used in electronic systems which have had their lifetimes extended through new and better system designs.

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The word "reliability" has been used in the semiconductor industry over the years in every imaginable way. It may refer to why the cost is so high, the delivery so late, the documentation so voluminous, or, it may be why the system is successful. When discussed in the true sense of the word, perhaps reliability has no greater importance than in aerospace systems.

Until this year, a spacecraft system had a projected life of three to five years. Since an orbiting system cannot be considered in a "repair/replace" category, a component was required to have an extremely high level of reliability. The required lifetime for an orbiting system has now been lengthened to eight to ten years. As a result, the question arises—how do we increase the level of reliability to meet that extended lifetime? If we assume that no revolutionary new development is presented, we are left with the variables of presently known materials, processes and designs. The semiconductor industry has enough experience, in the packages used in the past, to supply a data base with a relatively high level of confidence.

This article will discuss the three basic package constructions commonly used in large scale integration/integrated circuits (LSI/IC), and how they are subdivided into various structures/designs which may affect their reliability. In addition, the materials used in each construction and how they affect reliability will be analyzed.

Other papers have been presented which show the failure mechanisms and failure modes arising from improper materials and processing; this article will present the failure mechanisms and failure modes which can arise when proper processing is used. Emphasis will be placed upon the effect of design and/or the materials and how the latter may control the former.

The initial condition to be defined here is that the packages to be considered for high reliability application will be hermetic. By virtue of the definition used in government specification,[1] plastic packages are not acceptable and will not be considered in this paper. The acceptable packages, which will be discussed, are all commercially available and presently being used in high volume in industry. It is not the intention of this article to present any new, revolutionary packaging approach, but rather to compare the advantages and disadvantages of the major types as they relate to reliability.

The actual choice of which package to use will not be presented here since that choice is too highly dependent upon the unique conditions of each individual case.

PACKAGE FAMILIES

The basic package families are divided into three groups; these three groups, in turn, can be subdivided and they, in turn, can also be subdivided. Only the major families will be discussed, although some of the subdivisions will be acknowledged.

CERDIP
- Nucleating or vitreous glass
- Planar or through hole (DIP) mount
- "Sandwich" seal or solder lid seal

Hard glass (7052/Kovar)
- Glass body/Kovar body—glass beads
- Plain glass/alumina loaded
- Metal floor/alumina floor
- Planar or through hole (DIP) mount
- Glass sealed/solder sealed lid

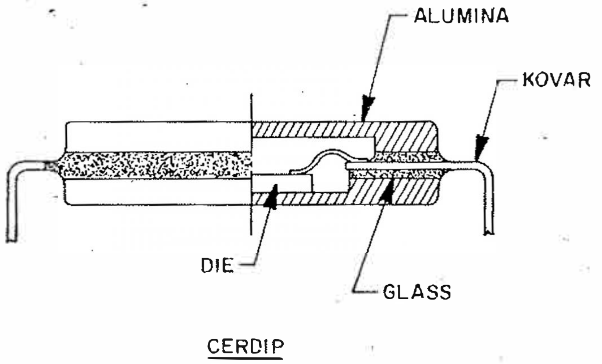
Ceramic package (co-fired alumina)
- Multilayer or single layer metallization (SLAM)
- Planar or through hole (DIP) mount
- Leadless/leaded
- Flexibility of design

CHARACTERISTICS

The following discussions will center around the basic characteristics of the package family. A subdivision in that family may have a varying characteristic (e.g., different metallization location, different comparative size, etc.), but would not impact the general statements which apply. The sketches shown are not to scale, but are drawn to emphasize the structure and/or design of the package. In actual fact, the parts may well differ in size, dimension, etc.

CERDIP

The CERDIP package, in various forms, is one of the most widely used and accepted packages in the



1. The structure of the CERDIP package.

monolithic LSI industry. It meets all the requirements of an hermetic package and is probably the most low-cost one available. As shown (Fig. 1), the structure is basically composed of two ceramic plates sandwiching a lead frame, all of which are held together by glass.

The ceramic plates formed with center cavities as shown are of what is traditionally called "electronic grade alumina." This usually means 92-94% Al_2O_3, which is the body used for nearly all forms of microelectronic packages. Its characteristics, processing, and history have been well and fully proven and therefore require no amplification. The silicon die is either epoxy or eutectic die attached to a metallization pad in the bottom cavity. Subsequently, either gold or aluminum wires are bonded between the die and the Kovar lead of the package. The lid is then sealed by either passing the package through a furnace operation, or having localized heat applied to the top plate (hot cap sealing). After the package is sealed, the leads have a finish coating applied (e.g., tin, tin/lead, etc.). Thus, the physical assembly is completed.

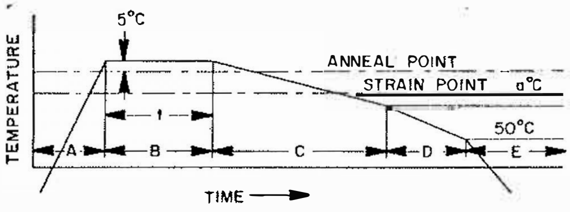
The most outstanding characteristic in the assembly of the CERDIP package, a characteristic which differs from all others, is that the final lid seal is also the sealing member to the leads which exit the package. In essence, the leads are final sealed into the package by the same process which seals the lid. Consequently, the sealing cycle must be carefully controlled, lest the attention paid to one be at the expense of the other. The normal glass-to-Kovar seal forms a meniscus on the lead which signifies good wetting. However, too long a meniscus can cause a serious problem in corrosion resistance well after the circuit is installed on a printed circuit board (PCB). The meniscus can have the tapered edge broken off during subsequent normal handling procedures after the lead finish has been applied. If this happens, bare Kovar is exposed and corrosion is being invited. In addition, the type of glass used is extremely important.

The glasses which may be used for this purpose must all be at the comparatively low working range of about 430°C. The higher temperature glasses (approximately 1100°C) would, of course, destroy the already installed silicon die. In order to achieve this lower working point, the glasses have a very high lead oxide content. This is true in both nucleating as well as vitreous glasses. When the package has been sealed and the leads are being prepared for the finish coating, it is necessary to remove the oxide from the leads. This oxide was previously developed for the purpose of making a good glass-to-metal seal. The oxide is removed by means of a chemical reducing agent which has a stripping action. These are commercially available solutions (e.g., "Kovar dip," etc.) or may be "home brew." These stripper formulations can do an excellent job of reducing the lead oxide, but also have a reducing effect on the lead oxide on the surface of the glass. In fact, it is not only possible to reduce the surface resistivity between leads, but possible to have a dead short. This is a recurring problem that continues in today's industry.[2] Within the realm of high lead (lead-oxide) glasses, is yet another choice—nucleating or vitreous glass.

~800°F

Nucleating glasses offer much higher mechanical strength and are therefore more desirable in that regard than the vitreous type. However, nucleating glasses have "chemically" combined water content which is given off during the lid sealing operation.[3] The moisture continues to be given off after the closure has been made while the glass is still within the working "molten" range. Consequently, moisture is trapped within the sealed package. That moisture is undesirable and has been fairly well-documented ~~and discussed~~.[4] Commercially available, high temperature, inorganic dessicants[4] have been developed for the purpose of eliminating this detrimental condition. However, the result is a "band-aid and baling wire" solution which still leaves the basic problem intact. The formation of the final seal presents yet one other major consideration—the use of oven or "hot cap" sealing.

All glasses, regardless of the method used to attain the fluid stage, will develop and retain stresses upon cooling. The intensity, "polarity" (compressive or tensile), and distribution depend upon the cooling (annealing) cycle, the material characteristics, and the physical design of the bodies involved. Since the last two conditions are dictated by the needs of the electronic parameters, the cooling cycle is the variable to be addressed. The use of an oven process is more desirable than "hot cap" because all parts of the package tend to be heated with less of a thermal difference between parts. Since stress is greatly dependent upon that temperature difference, less strain is the result. However, that very characteristic of less thermal difference means that the silicon die and its wire bonds are also exposed to an elevated temperature; this is an undesirable feature. The "hot cap" method introduces the heat directly down through the top plate, into the glass and partially into the bottom plate, maintaining a lower ambient temperature at the die site. The die and wire bonds do not see the previously mentioned higher temperature. The result is that greater stresses are induced, higher strain exists, and the possibility of lids falling off is present.[5] The typical glass annealing curve (Fig.

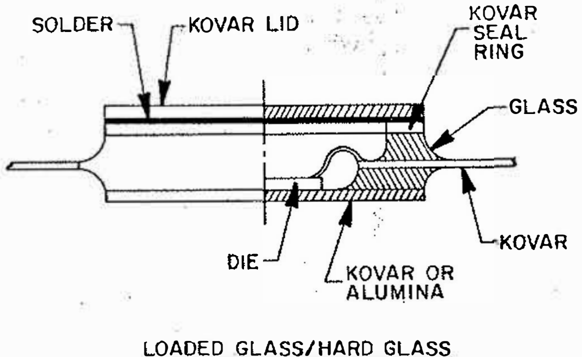


2. *Stress release and glass annealing curve.*

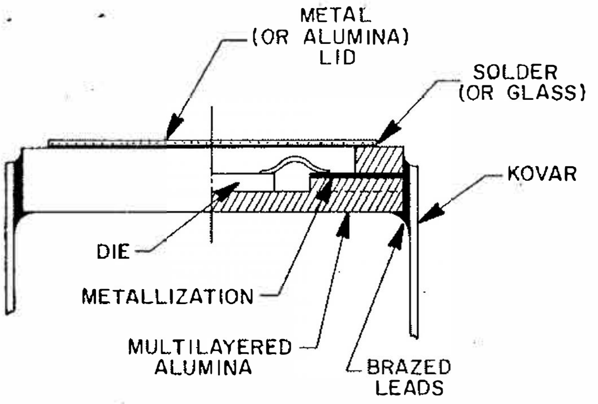
2) is seldom, if ever, possible to follow in a high production commercial environment.

Hard glass

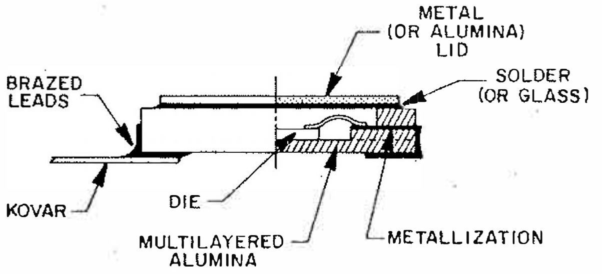
The second major family to be considered is the "hard glass" package which consists primarily of a borosilicate glass (e.g., Corning 7052) and Kovar. These two components are probably the most used in microelectronic hermetic packages. The vast history of data accumulated from the processing and use of TO-5 headers has established the validity of the 7052/Kovar system. As can be seen (Fig. 3), the typical hard glass package is composed of the glass body through which Kovar leads penetrate. The floor may be Kovar, alumina, or beryllia. The glass itself may be loaded with fine alumina powder, or remain plain. The seal ring is Kovar and presents a solderable surface so that the lid can be sealed with a typical solder, such as gold-tin. Since all glass seals on this



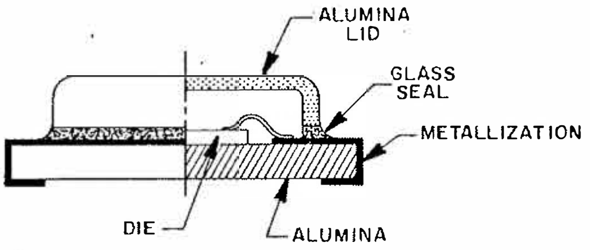
3. *Typical hard glass package which is composed of the glass body through which Kovar leads penetrate.*



4a. Side braze ceramic package.



4b. Chip carrier.



4c. Chip carrier (SLAM).

package are formed before the installation of the silicon die, they can be formed at as high a temperature as necessary, and this is in the range of 1050-1100°C. The final lid sealing temperature, using gold-tin as the solder, is usually carried out at about 320°C, well below the critical temperature for silicon die processing. The processes used in forming these packages have been well established and documented.[6] Two characteristics which have been referred to in the section on CERDIP also apply here.

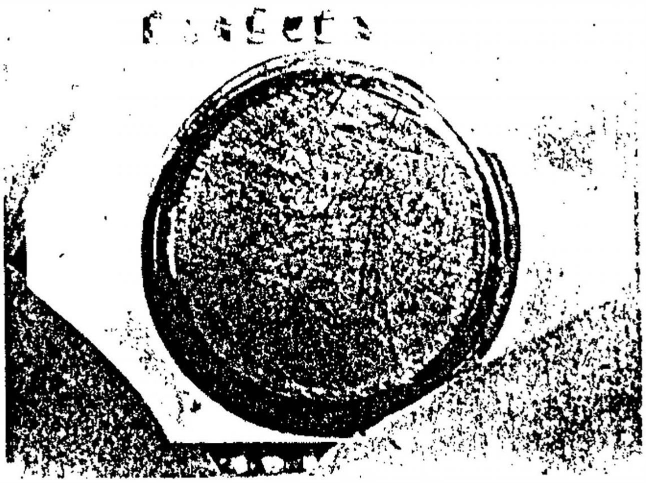
In order to have an acceptable seal around the leads, a meniscus must be formed. Consequently, during handling the meniscus may fracture, exposing bare Kovar and subsequent corrosion failure. In addition, the presence of residual strain in the glass can cause ultimate failures due to thermal shock. Where CERDIP possible failure mechanisms included chemical attack because of the high lead oxide content in the glass, this is not a significant factor in the 7052 glass package. The primary failure mechanisms are mechanical and thermal. The fracturing of the meniscus may result in a leaking seal or may result in failure due to corrosion. Both of those failure modes may well be catastrophic in nature.

Ceramic package

The ceramic package is primarily an alumina composition of approximately 92-95% Al_2O_3 and has a metallization system of either molybdenum or tungsten; the common feature of the ceramic and metallization is that they are fired at a temperature of approximately 1550-1600°C. Any normal subsequent processing does not affect the package in any way. This package family is probably the most stable package type available today. Because of the great demands in new systems, such as VHSIC, development work is being conducted by some of the leading package suppliers in the use of beryllia for LSI semiconductor packaging.[7]

The ceramic package has many variations, such as side braze (DIP), bottom braze, top braze, chip carrier (leaded and leadless), pin array, grid array, multilayer or SLAM. All are based upon the same materials, processes, and design principles. In order to define the differences and similarities of some of the above forms, Figs. 4a-4c are sketches showing three of the most popular ceramic packages: Fig. 4a—side braze, Fig. 4b—chip carrier, and Fig. 4c—chip carrier (SLAM). No specific discussion will be applied to certain package types (e.g., chip carriers, grid arrays, etc.) since the length of this article is restricted; they are included only to show that they conform to the general statements to be made.

The structure of the ceramic package of multilayer construction (Figs. 4a and 4b), and usually the SLAM (Fig. 4c), is based upon a co-fired alumina tape process. When fired at the high temperature of 1550-1600°C, the alumina goes through a shrinkage to final size while the metallization assumes the "pure" metal form. The multilayers become a single homogeneous monolithic body with buried conductors as an integral part of the body.[8] Once fired, the packages go through a lead brazing operation and final platings. As can be seen in the sketches, the leads on the ceramic packages do not go through any seals; consequently, any flexing or bending of leads cannot affect the integrity of the seals. Figure 5



5. This 42-leaded top-brazed, ceramic multilayered package had all leads and sections of the body intentionally broken off to test the leak rate over an extended period.

Table 1: Package Failure Characteristics

Characteristic	CERDIP	Hard glass	Ceramic package
Lead conductivity	A	A	C
Resistance—Thermal shock	B	B	A
Resistance—Mechanical shock	B	C	A
Resistance—Chemical attack	C B	B	A
Seal integrity		B	A
Moisture entrapment	C/A	A	B/A
Cost	A	B	C

A = Best
B = Medium
C = Worst

shows a 42-leaded, top-brazed, ceramic multilayered package which had all leads and sections of the body intentionally broken off. Before being broken, the package was leak tested to MIL-STD-883 and the leak rate recorded. After being broken, the package was leak tested periodically for one year; at the end of the year, no discernible difference in leak rate could be detected. In addition to this characteristic, the ceramic package also incorporates probably the highest resistance to thermal shock, mechanical shock, and chemical attack.

One factor which has been found to be a possible liability is the "poisoning" of the tungsten metallization. This can be overcome by the appropriate design of the metallization path leaving the package.[9] The metallization of the package also presents one other negative factor—its electrical conductivity. The requirements of new systems designed for high speeds are now showing where the tungsten metallization ($0.015\ \Omega/\square$, can be a limiting factor. As in the case of beryllia development for power dissipation, development is underway to make available more highly conductive metallization. The major negative factor at this time is the comparatively high cost of the multilayered package and its associated parts (metal lid, sealing preform). These costs are lower in the case of the SLAM.

The SLAM version (Fig. 4c) is basically a flat alumina plate having metallization over which a glass seal is formed to seal the cup-shaped alumina lid. The glass used to make the lid seal exhibits the same characteristics as mentioned in the above sections as far as strain, thermal shock and moisture are concerned. In addition, another feature affecting reliability is the "down bonding" of the wire from the die to the package metallization. As can be seen in Fig. 4c, the top surface of the silicon die is on a higher plane than the top surface of the metallization to which the wire is bonded. As a result, it is entirely possible for the wire to touch the edge of the die during vibration or mechanical shock. The result of this may be either a dead short if metallization extends to that area, or a severed lead due to the abrasion along the sharp edge of the die. These are dominant conditions which may arise at a later, critical time.

SUMMARY

The above discussions are not complete, nor are they conclusive in themselves. They are intended to show some of the factors which must be taken into account. If quality is considered as a first order characteristic, then reliability should be considered as its next higher order. Reliability is not the concern solely of government agencies, but certainly is within their areas of concern. In particular, relationships are constantly being sought between packages and reliability and various reports have been written on this subject. Reference 10 attempts to show the relationship of package failures to lead count and type of package seal. A general matrix of some of the major factors, as discussed, is shown in Table 1. The proper choice of the family, and the subdivision within that family, is dependent upon the conditions of the particular system. No formula exists which can automatically trade off cost versus reliability.

Acknowledgements

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