NEW APPROACH TO LOW COST CAVITY PACKAGING

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Abstract

Traditionally, there are three basic classes of electronic products that use cavity packaging: military based hermetic packages using solder or glass sealing, frequency sensitive communication devices, and optical devices which use glass cavity to ensure proper transmission. These types of electronic packages represent less than 1% of electronic packages. Almost all other electronic packages use epoxy molding compound encapsulation and glob-top encapsulation for mechanical and environmental protection.

The primarily reasons for the lack of usage of cavity packaging stems from cost rather than performance consideration. In this paper, we will present a new process that allows in-line lid attaching much similar to that of surface mounting a component. In addition, a low cost technology has been developed for pre-applying sealing adhesive on lids and covers. Combining the lower cost of $0.03-0.10 for pre-application of adhesive preforms and the efficiency of in-line rather than batch processing, this new approach to cavity packaging may provide cost effectiveness to be competitive with that of glob-top and molding encapsulation.

Key Words: *Cavity Package, Molding and Glob-Top, Adhesive Sealing, fine leak, gross leak*

Introduction

The functions of second level semiconductor packaging such components, chip-on-board, and multichip packages may include:

- Interconnection between chip and the third level board
- Mechanical support and protection during handling and operation
- Environmental protection from moisture, liquid or gaseous chemical elements
- And other specific requirements such as optical windows for optical devices, EMI shielding, thermal interfacing, etc.

Electronic devices in the semiconductor level are mostly protected by a solid organic encapsulation. Besides the traditional "Dual-In-Line" molded packages with epoxy molding compound, one can also create an equivalent with the use of liquid plastic epoxy "glob-top" encapsulant. However, because of the substantial difference in coefficient of thermal expansion (CTE) between the substrate and encapsulant and the peel stresses in a coated structure rather than compressive stress in molded structure, the reliability is less than that of the molded devices[1,2,3].

In some cases, an electronic device in the semiconductor level may not be able to use a solid encapsulant because of the adverse influence of stresses induced in the device with such direct contacts of encapsulant.

In some cases, there is a need for the lid or cover to be electrically conductive to provide electromagnetic interference (EMI) prevention to and from other devices. In this type of application, the lid must be conductive and linked with the electrical ground of the finished device. In some cases, the use of soldering may be inconvenient because of its effects on the devices that also uses soldering as an attachment. If one needs to rework the module, de-soldering may also cause damages or de-soldering of other electronic elements inside of the package.

Almost all of the military electronic devices used in high reliability applications, hermetic lid-seal are used to prevent moisture and other adverse elements from affecting the electronic devices. However, the costs of hermetic packages are very expensive to implement.

Lids and covers are used to a certain extent in commercial electronics for special requirements like electronic devices that are susceptible to stress induced frequency distortion such as those devices used in communication applications. These lids are generally attached with adhesive. The adhesive in the form of dispensable paste or die-cut preforms may be applied right before the bonding process.

In some cases, when the volume of usage is high, lids are precoated or pre-applied with adhesive preforms that will flow and cure when applied with heat and pressure during attachment process.

The cost of pre-coating and pre-application of adhesive preforms onto lids or covers are still quite high. The adhesives in liquidous form are typically dispensed with a programmable automatic dispenser or roller-coated onto the sealing areas of the lids. They are subsequently dried or B-staged at temperature and time substantially lower than the designed curing temperature and time. The liquidous preforms thus become solid state either through solvent evaporation or chemical cross-linking during this what we generically term as B-staging.

Stress-Induced Reliability Issue of Encapsulated vs. Cavity Packaging

Figure 1 is an illustration of stress distribution of an glob-top encapsulated or molded packaging.

There are at least three sets of separate stresses that are active in this type of encapsulated packages.

The first being the compressive stress surrounding the die because of the higher CTE of the compound. The zero stress point being the molten state during the molding process at around 165-175°C. The trapped compressive stresses may be as high as 10,000 psi.

The second being the shear stresses along the interfaces of die attach adhesive to die and substrate. Tensile stresses acting on the die attach adhesive and shear stress on the die are equal in magnitude in accordance to Newton's Third Law.

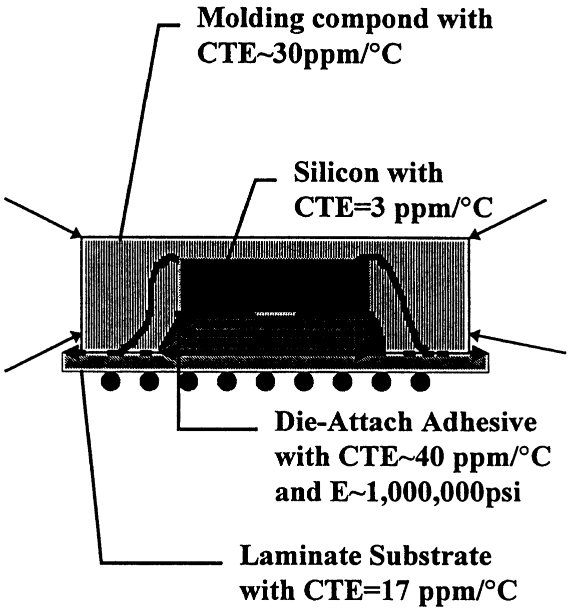

Figure 1: Molded or Glob-Top Encapsulated Packages Stress Distribution

The stress levels depend on the CTE difference, the curing temperature and the modulus of the adhesive. They may be as high as 10,000 psi for traditional die-attach with modulus of 1,000 Kpsi or as low as few hundred psi for flexible die-attach with modulus of 20 Kpsi [4,5].

The third set of stresses being that between the substrate and molding compound. The interfacial stresses are substantially lower in magnitude because of the smaller CTE mismatches between molding compound and copper leadframe or FR4 substrate.

In the case of cavity packages, the stress fields are less complicated and easier to manage. Figure 2 is a schematic representation of a cavity package with relevant stresses. Unlike that of the molded devices, there are two major sets of stresses that may affect the reliability of the devices.

The first set being the same shear stresses along the interfaces of die attach adhesive to die and substrate. Again, tensile shear stresses within die attach adhesive and shear stress on die are the same in magnitude in accordance to Newton's Third Law.

The second set being the similar interfacial shear stresses between the lid attach adhesive to lid and to substrate. The interfacial stresses arise between the mismatches of CTEs of the typical 35-60 ppm/°C of the adhesive and 17 ppm/°C of the typical FR4 substrate.

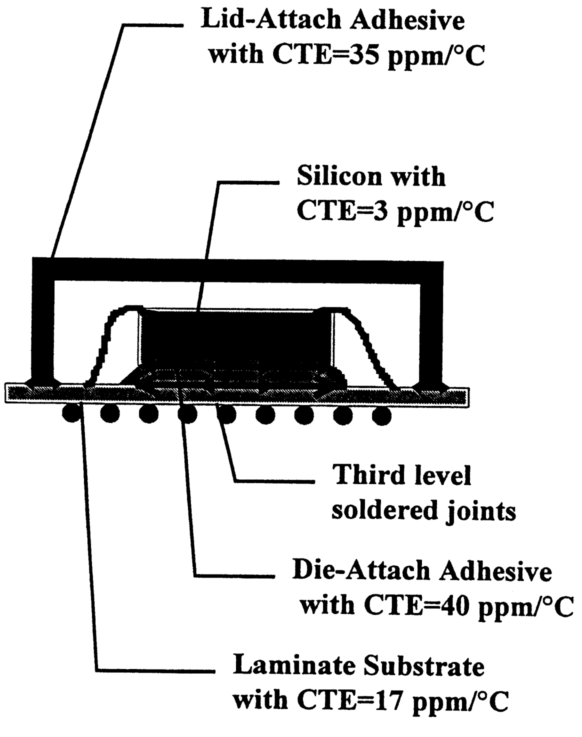

Figure 2: Stress Distribution Within On Board or Component Cavity Package

Moisture Ingression and Reliability Issues for Encapsulated and Cavity Packaging

The effect of moisture in corrosion of metallization and interconnection is well documented. There is one requirement for the corrosive effect to take place, that is there is a condensation of moisture into water molecules. In most cases, there is also a requirement of the presence of ionic species such as chloride, sodium, potassium and other active ions to enhance the corrosion effect of water[1,2,6].

Inherent in all of the electronic packaging protection, moisture is to be prevented from ever penetrating into the package under all normal and extreme condition even for the longest time of exposure. This hermeticity can normally only be achievable with use of either metallic or inorganic glass seals. The interatomic and molecular spacings are such that they are much smaller than water molecules to permit penetration under most conditions.

In the case of polymers, at least for almost all of the common polymers, such molecular free-space are big enough for moisture to go through at some rate. Some polymers are basically "transparent" to moisture, such that moisture can pass through "freely". One of the more extensively used polymer is silicone. A membrane of such a polymer will allow fast permeation of moisture until partial pressure is the same on both sides of the membrane. Most all of the other polymers will allow slow and different rates of permeation[7,8,9].

In the case of encapsulated or molded devices, trapped water between the delamination areas along the interfaces of molding compound and substrate has caused the well-known "pop-corn" effect during the solder reflow[10].

Most of all encapsulations and molding compounds are highly cross-linked epoxy formulations. Moisture is allowed to penetrate and escape relatively slowly into the package. Because of the relatively high CTE mismatches, parts of one or all three interface areas may have voids or micro-delaminations developed during processing or operation. Moisture will condense at these interfacial spaces when temperature is dropped slightly. Any moisture and water accumulation at the interfaces tend to remain there for a long time before they can escape even when the environment outside has returned to low humidity and temperature condition.

The implications with the use of these polymers as moisture seals will be dramatically different. If the environment outside the package is high in moisture and temperature, the moisture will be brought to equilibrium inside to the same as outside without condensation. Once the temperature and moisture are dropped outside, the moisture inside will also quickly permeate out without being condensed if the seals are not a good moisture barrier.

An earlier study by Hakim[6] comparing reliability of plastic and hermetic packages is noteworthy. A group of packages with leak rate greater than 1x10E-5 was found to have similar reliability to that of the hermetically packages devices after 3 years tests under high humidity and salt environments. There is a school of thought that packaging with free moisture movements may actually be better than those with good but non-hermetic packages.

There may be two schools of thought on moisture sealing of packages. One allowing moisture to get into and out of the sealed packages freely and quickly, while the other prefers simulation of moisture impermeability close to that of the hermetic packages. Both of these approaches may be achieved with simple modification of the adhesive used for sealing application.

In a cavity package, moisture may be prevented from ingression much like a hermetic package. In fact, we will show in the following that even optical devices may be sealed and stay functional after 85°C/85%RH exposure.

Alternatively, moisture may be allowed to penetrate and escape relatively easily into the package. In this case, moisture condenses on the surfaces rather than at the interfacial surfaces. With a good moisture barrier or water condensation prevention coating similar to silicone or other hydrophobic molecular structure polymeric coating or moisture prevention coating will be important to prevent corrosive degradation within the package.

With relatively simple engineering coating, cavity package may be much more reliable than glob-top and molded devices.

Fine-Leak, Gross-Leak After Stringent Environmental Exposures

Standard tests of packaging leakage have been tested for some of the lid-seal adhesives. It should be emphasized that, like all other adhesive applications, different molecular structures of the adhesives will demonstrate divergent results.

Table 1: Fine and Gross Leak Test Results of High Moisture Barrier Lid-Seal Adhesive

	Gross-Leak	**Fine-Leak**
As Cured & Sealed ESP7675	**Pass**	**Pass**
After 196 hr 85°C/85% RH ESP7675	**Pass**	**Pass**
After Cycling from -65 to 150°C ESP7675	**Pass**	**Pass**
After Mechanical Shock & Vibration ESP7675	**Pass**	**Pass**
After Thermal Shock ESP7675	**Pass**	**Pass**
	0.5 hr vacuum, and 1.0 hr @45 psi	Bomb for 4 hr. @60 psi <4.5X10E-08

Table 1 represents testing results based on optical package with glass window lid and ceramic package.

Adhesive Properties After High Temperature and Humidity

Bond strength of adhesive may also be adversely affected by high temperature and humidity exposure. With proper molecular structure engineering, both flexible lid-seal and high strength lid-seal may withstand such exposures with little or no change in bonding characteristics to assure the package integrity.

The substrates tested include FR4, optical glass, aluminum, and copper alloys. ESP7675 and ESP7355 have been found to have similar stability after temperature-humidity exposures.

Figure 3 is a plot of bond strength tested under 85°C/85%RH aging. Different polymeric adhesives will demonstrate quite different bond strength retention under this higher temperature and moisture condition. Moisture sensitivity are mostly attributable to the moisture absorption and interfacial adhesion weakening.

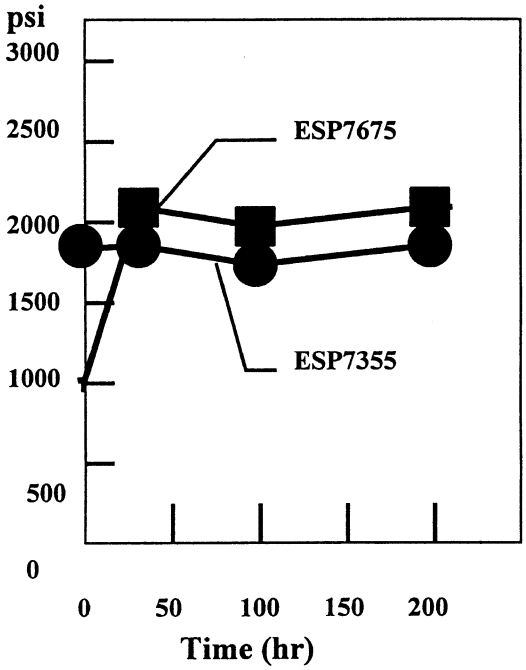

Figure 3: Die-Shear Bond Strength After Exposure to 85°C/85%RH for Die-to-Alumina Assembly

Fuel Chemical Resistance

In some applications, fuel and other similar chemicals may be in contact with the cavity package. Again polymeric adhesives will demonstrate dramatically different behaviors under different chemical exposure conditions.

Table 2 below is results of adhesive strength of ESP7675, a high strength epoxy film adhesive and ESP7355, a flexible epoxy film adhesive when exposed to fuel at 65°C. Both these adhesives demonstrate adequate stability for long-term exposures.

Table 2: Die-Shear Adhesion Strength After Fuel Exposure @65°C

	ESP7675 **High Strength Epoxy Film Adhesive**	**ESP7355** **Flexible Epoxy Film Adhesive**
Bond Strength As Cured	**1200 psi**	**2000 psi**
Bond Strength After 24 hr.	**1800 psi**	**2000 psi**
Bond Strength After 100 hr.	**1200 psi**	**1500 psi**
Bond Strength After 200 hr.	**1400 psi**	**1300 psi**

The test solution used CM30 mixture recommended by Society of Automotive Engineers Cooperative Research Program.

- 350 ml of toluene, 350 ml of iso-octane, 300 ml methanol, 30 ml water, 0.005 gm of NaCl, 0.05 ml of 60 ppm formic acid, 6.8 ml of 70% t-butyl hydroperoxide
- There were several other adhesive tested at the same time but failed quickly

Cost Comparison of Cavity vs. Encapsulation Packaging

The use of molding compound and transfer molding process has been perfected to such a degree that it represents more than 90% of the electronic packaging today. Molding compounds for traditional devices cost less than $10/Kg with the more advanced compound cost no more than $30/Kg. The cost of transfer mold and molding equipment is relatively inexpensive for even moderately small run. There is no driving force for improvements or changes for traditional devices with limited I/O and size limitation.

While the mechanical aspect of molding and glob-top encapsulated devices may have similar stress consideration. The processing and cost of implementing glob-top encapsulation for chip-on-board are much more expensive. This is particularly true for the larger area dies and devices that have close spacing that requires separate process in building a dam to control the flow-out of the glob-top encapsulation.

The primary driver for the choice of packaging schemes as always is the cost consideration. For most part, cost is traded with performance and some of the times reliability of the devices. Table 3 is a summary of the various packaging schemes in protecting semiconductors based on applications and its requirements of reliability, performance, and cost consideration.

Table 3: Packaging Methods Based on Need and Cost Considerations

Application Type	Cavity	Glob-Top	Molded
Military/Aerospace/Medical	Must have: need of hermeticity		
DIP to CSP			Whenever reliable enough
Chip-On-Board		Most of the time	
Multichip Modules and Hybrids	Must have: stress consideration		
Stress Sensitive die	Must have: stress consideration		
Optical and Sensors	Must have: Other consideration		

With the advancement of chip scale packages where die sizes are significant, molded packages in most cases are not as reliable as the traditional dual-in-line low I/O packages. If cost effective cavity packaging can be realized, most of the more difficult packaging problems can be solved. The following are some cost structures considerations based on material and other manufacturing costs.

Cost Reduction in Cavity Packaging:

In order for lid-attach to become commercially significant, the cost per application must be significantly reduced. There are three factors that must be addressed to lower the cost of cavity packaging.

The first being the cost of lids and covers. In the case of plastic lids, the material cost is insignificant. In high volume plastic molding, per part cost including amortization of mold and equipment along with material is typically in the range of 2-3 times of the material cost. For the large volume applications, cost per parts may be in similar range of the traditional plastic molding. However, most of the cavity packaging, the volume of lids never reaches high enough volume to reduce the cost of parts to 5-10 times that of the material costs. In fact, most cases, each of the small plastic lids cost in the range of \$0.05-0.15 each. The business model will require the producer of lid cavity solution. Typically, producers of plastic lids are not producers of adhesives used in the lid-attach. Each lacks the expertise to help in lowering the total cost of each application. There is very limited drive to lower the cost of molding low volume high temperature specialty applications. If one can develop low cost molding process and mold making to be flexible enough to produces different sizes at low cost much the same way that high volume molding of plastics, one can then produce parts at 2-3 times of plastic costs. The simplicity of lids and cover shape actually permits such scenario to become reality. Plastic parts of dimension 10mmx10mm have been produced at \$0.01-0.03 each for reasonable volume.

More importantly, the cost of dispensing adhesive on rims of lids and covers is even more costly than the parts themselves. Typical method of dispensing with the use of automated needle dispenser and program to put adhesive on the designed areas on the lids. They can range anywhere from \$0.05 to \$0.20 per applications depending on both volume and size or linear length of the rim of the lid.

If preforms are cut and laminated onto the contact area, the cost per application is even higher. There is a need for an efficient method of precoating and preapplication of adhesive onto lids and covers to provide a cost effective solution in protecting devices such as sensitive electronics. Special method of adhesive film pre-applications has been developed [11] with cost to be in the range of \$0.03 to 0.10 each.

Instant Melt-Bondable Thermoplastic Seal

There is also a need of providing a lower temperature attachment process for providing EMI shielding lids or covers. It will be even more useful if the adhesive is conductive and bonded instantly upon reaching the temperature substantially below the general soldering temperature of 220°C. It will also be important that lids and covers be removable below this soldering temperature to eliminate the possible damage or misalignment of parts inside the packages.

There are thermoplastic lid-seal adhesives that have been tested and exhibit stable moisture sealing characteristics. Figure 4 is a summary of the die-shear bond strength of two types of flexible, instant melt-bondable film adhesives that have been exposed to humidity and temperature exposures.

The bonding characteristic also remains constant under -65°C to 150°C thermal cycling testing for glass-lid attachment applications.

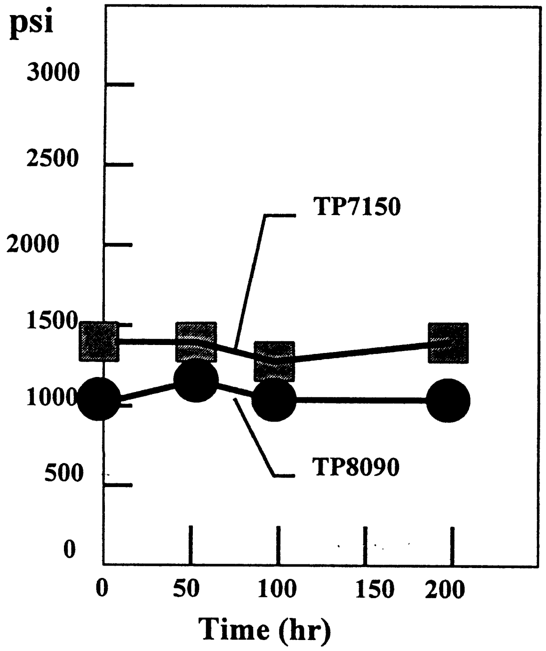

Figure 4: Die-Shear Bond Strength After Exposure to 85°C/85%RH for Die-to-Aluminum Assembly

In-Line Lid Attachment Using Standard Pick-and-Place Equipment

Besides the reduction in parts and pre-application costs, the cost of processing must also be reduced. Typical processes used in the lid attachment is batch in nature. Special fixtures are used for multiple cavity packaging. The temperature is allowed to increase slowly to prevent the air-pressure within the cavity to build up excessively and causes "blow-out" holes along the rim of the adhesive seal. In fact, this type of attachment method and process is covered by Ross, et.al, in US patent # 5,056,296[12].

The cost of using lid-attachment for cavity package can also be decreased with the use of in-line processes that allowed automated assembly process. The following flow chart is a typical representation of the patent-pending process that have been developed.

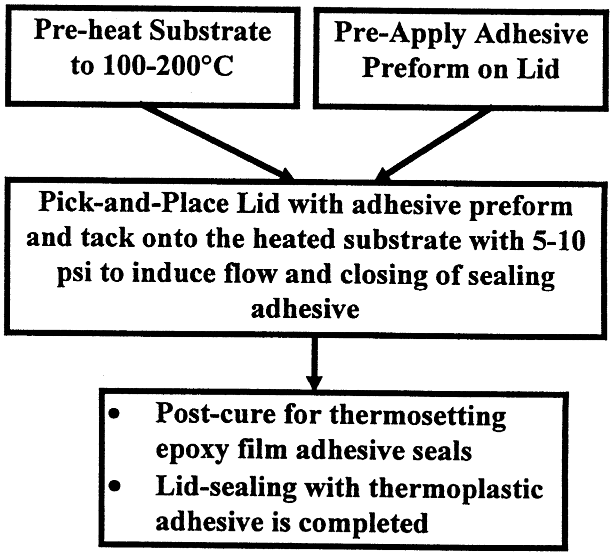

Figure 5: Flow Diagram of In-Line Lid Attachment Process Using Thermoplastics or Thermosetting Preform Adhesive

Figure 5 is a flow chart representation of a in-line process using either thermoplastic or thermosetting adhesive that allow "tacking" at either melt-flow or liquidous temperature under minimal pressure. Special air-bleeding channels have been incorporated in the adhesive preforms.

Optical Window Attachment for CCD and CMOS opto-electronic packaging

Cavity packaging represents the only solution for optoelectronic device. They have been typically extremely costly and may in fact cost as much as 30% of the finished device.

Figure 6 represents one of the typical opto-electronic packages.

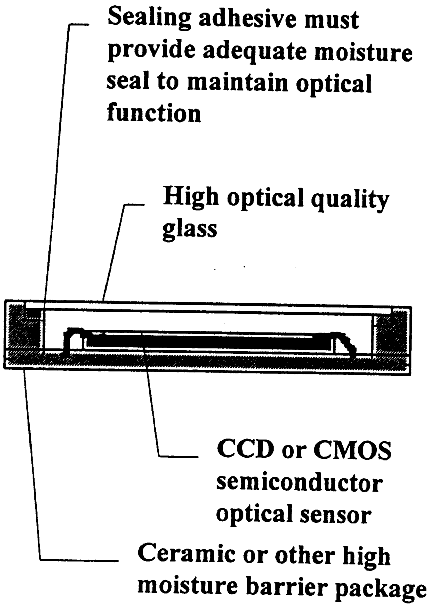

Figure 6: Optical sensor packaging requires much high level of moisture barrier to maintain its normal functioning

In optical sensor sealing, adhesive must be precisely dispensed with controlled flow pattern. Most importantly, they must maintain outstanding moisture sealing characteristics. Alternatively, lid-sealing should allow easy moisture in and out of the package may also equally reliable solution to the same problem.

Conclusion

Cavity packaging using suitable lid-sealing adhesives offers more reliable solutions for high pin count packages as well as chip-on-board and module packaging.

With a new process of pre-application of adhesive preforms and in-line bonding process, the cost of cavity packaging is similar to that of the COB packaging and offers versatility for thermal and EMI management solutions.

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