Plastic Encapsulated Microcircuits (PEMS) Failure Analysis

Michael Strizich, Analytical Solutions Inc.

The military and aerospace electronics industries are making their switch over from hermetically sealed packages to plastic encapsulated packages with no retreat on expected performance. This is the result of the ever-increasing demand for electronic parts and declining production of hermetically sealed parts by most major semiconductor manufactures.

Since the 1970s, plastic-encapsulated microcircuits (PEMs) have advanced significantly in achieving lowest cost, highest availability of functions, high reliability, and wide applications. Enhanced encapsulant materials, robust design, and improved process control have made PEMs highly reliable for a large variety of applications. The automobile industry can be credited with pushing these advancements and setting higher reliability standards for PEMs operating in harsh environments.

While plastic encapsulated microcircuits offer a number of inherent cost advantages over hermetically sealed ceramic packages, improperly designing them into military applications and aerospace equipment can result in reliability risks never encountered with hermetically packaged parts.

Designers and product engineers need to stay vigilant with their part selection. In most military applications, some risk of electrolytic leakage forming at the die level is inevitable; after all, these are non-hermetic packages. Fortunately this does not affect most digital circuits with new and improved passivation schemes. Even corrosion of the aluminum bond pad metal is no big deal, since most chips now have refractory barrier metals such as Ti:W which are corrosion resistant. However, this becomes a different story with regard to analog circuits such as operational amplifiers that have very small input bias requirements. A small amount of electrolytic leakage (10 – 50 nA in some cases) extending between the bond pad and chip edge can result in catastrophic failure modes.

Although major advancements in PEM reliability have been made, concerns still exist in the areas of moisture penetration into the package, and operating temperature. The semiconductor industry has arrived to inherently low semiconductor failure rates, however these gains are offset when plastic packages are used in applications which encroach their intended design. This also sets up a conflict of interest, and often times an arduous relationship between the suppliers of PEMS and their military, aerospace customers.

As a consequence, qualification testing and subsequent failure analysis are focused on package related failures which typically develop during the qualification. The testing is focused on the performance of the package and involves temperature stressing, thermo-mechanical and moisture penetration sensitivity. Non-destructive tests such as X-ray and CSAM are typically used as non-destructive tools to monitor package related defects along the way. This becomes a critical element in the qualification testing since electrical failures may only identify secondary failure mechanisms (moisture on die, passivation cracks or corrosion). The root failure mechanism, such as package delamination between the molding compound and the lead frame or voids in the molding compound is often overlooked.

Failure analysis and destructive physical analysis offer different challenges on PEMs as compared to hermetically sealed packages. This is not news to the semiconductor industry or independent failure analysis labs that see a large variety of part types. The most challenging part of the analysis may come down to a successful decapsulation. Using jet etch decapsulation techniques which involve nitric or sulfuric acid to remove the molding compound above the die often times introduces unwanted artifacts such as pad corrosion and die or wire bond lifts when done improperly. Additional problems arise from the decapsulation of GaAs RF devices, which typically have no glassivation and polyimide as an interlevel dielectric. Additional challenges involve the every shrinking size of the packages; some look no larger than a grain of pepper requiring them to be potted in a socket prior to decapsulation. At the other extreme is Chip on Boards (COB) which requires exposing a zillion wires without the solder bumps reflowing.

The harsh acid is only part of the risk, the additional risk comes from the elevated temperatures used during decap. This can cause moisture related failures (such as electrolytic leakage or dendritic growth related shorts) to suddenly recover. Worse yet, the sudden increase in temperature can introduce package cracking commonly referred to as pop-corning. Therefore, it is good practice to vacuum bake all parts at 100 C for 4 hours prior to decapsulation. Following the bake-out, the electrical failure mode should be re-verified prior to proceeding with the decapsulation process.

In the case of performing destructive physical analysis (DPA), caution should be used in the interpretation of the wire pull and die shear test results. Over exposing the lead frame during decapsulation can result in undercutting the lead frame finger plating resulting in weak wire bond pull results. Most plastic packages use silver loaded epoxy die attach which can be compromised while exposing the die surface. More often than not, this makes die shear testing impractical. Being aware and minimizing both of these problems will help avoid incorrectly failing parts during a DPA.

The common theme for analyzing plastic parts is to perform as much non-destructive electrical testing and inspections as possible prior to performing the risky decapsulation process. One of the more important tools now used to non-destructively inspect PEMs is Scanning Acoustic Microscopy (SAM) and real time X-radiography. The very high frequency ultrasound in acoustic micro imaging behaves differently from X-ray where imaging depends on internal interfaces rather than on atomic weight. This technique is non-destructive and works off of the principles of ultrasonic imaging. A transducer produces a high frequency sound wave which interacts with the sample through a coupling medium (typically water). Yes, you have to dip a non-hermetic package into water to perform this test, all the more reason to bake it out prior to decapsulation. When a sudden change of acoustic impedance is encountered, like material boundary, a portion of the sound is reflected and the remainder propagates through the boundary. SAM detects “interface gap-type” defects such as delamination, cracks, voids, or debonding. These are the type of defects that X-ray imagining typically misses.

(include CSAM photo here)

As mentioned earlier, most failure analysis on PEMS takes place during the plastic package qualification testing; therefore it is critical to have a good failure analysis capability teamed up with a competent test lab. The failure analyst should be well informed relative to all test conditions the part as seen. This will help guide the failure analysis process in anticipating certain failure mechanisms and associating them back to the actual test condition, and ultimately with the use condition.

Qualification Testing and Anticipated Failures:

Timely failure analysis on qualification failures enables early identification of failure mechanisms distinguishing them as either normal wear out failure mechanisms or testing induced failures. This allows the customer to make an informed decision on part selection early-on in the qualification process.

A large amount of activity over the last five (5) years has centered on statistical reliability monitoring (SRM) designed to address the obvious vulnerabilities of PEMs.

The primary tests now being performed to stress certain package features include:

IR Pre-Conditioning:

Preconditioning simulates board assembly manufacturing processing. The most common failure mechanism which results from this test is package cracking which is commonly referred to as “pop-corning”.

Pop-corning is the result of moisture accumulating at the die or die paddle to molding compound interfaces. The moisture can accumulate in the package through simple absorption and voids in the die attach or molding compound. Also, delamination along the lead frame or die attach paddle and the molding compound can result in large accumulated surface areas of moisture. The next step in the screening process is the three (3) solder reflow cycles. This causes the moisture saturated device to undergo a sudden increase in temperature thereby developing a large hydrostatic pressure in the areas where moisture accumulated. This hydrostatic pressure results in the package cracks that typically develop starting at the die attach paddle, extending out to the top edge of the package. These cracks commonly result in the wire bonds breaking resulting in electrical opens.

(pop-corning figure here)

Temperature Cycling:

Temperature cycling is performed to test the durability of the package by undergoing extreme temperature variations over a given period of time. Temperature is usually varied around a mean value with a constant ramp rate followed by a dwell time. This test exposes the package to thermo-mechanical stresses and accelerates failure modes associated with differing coefficients of thermal expansion between die and encapsulate materials. Typical failure mechanisms include die cracking, shorts and opens on the die, passivation fracturing, wire bond cratering, excessive intermetallic growth, and poor solder joints.

(solder ball crack figure here)

Highly Accelerated Stress Test (HAST):

HAST is performed to evaluate non-hermetic packaging in humid environments. The use of high temperature (typically 130 C), high relative humidity (85%), under high atmospheric pressure conditions (3 atm typically) accelerates the penetration of moisture through the molding compound, or along lead frame to package interfaces. This test is intended to precipitate failure mechanisms associated with metallization corrosion caused by delamination at the molding compound to lead frame interface. Caution should be used in analyzing the failure mechanisms generated by this rather harsh test. One should associate the test condition with the use condition and determine if this mechanism would have occurred during the normal life time of the part.

The harsh nature of this test typically results in more testing induced failures than normal wear out failures. Typical corrosion problems result from the test lab not wearing finger cots while handling the parts. The exterior lead plating starts to corrode making electrical contact problematic. To solve the problem, the parts are re-solder dipped and "Pop!", you develop pop-corning.

It should be noted that HAST is a predecessor to Temperature Humidity Bias (THB) testing. THB testing with less stringent conditions became less useful as the reliability of the PEMs has increased dramatically.

(corrosion photo here)

Environmentally Safe – what environment?

Green Mold Compound and lead (Pb) free solders are now being introduced as new "environmentally friendly" PEMs. In response to environmental concerns, some mold compound suppliers are starting to eliminate Bromine (Br) and Antimony (Sb) as flame retardants. They were replaced with inorganic red phosphorus which is now well-known for creating additional reliability problems after showing up as field failures (corrosion related).

Lead (Pb) free solders typically translate to pure Tin (Sn) solders which are known for whisker growth. Particularly the popular matte Tin (Sn) finishes, which have large grains and a thickness under ten (10) microns. Although some improved processes such as Ni plating and reduced grain size have improved whisker immunity, it is still having difficulty gaining acceptance by the aerospace community having been down that path before.

(whisker photo here)

Conclusions:

Plastic Encapsulated Microcircuits (PEMs) have made a lot of progress over the past few years, and will remain a staple in the military and aerospace industries. Caution should be used during the selection process, qualification process and analysis of PEMs. This care is especially important when performing a failure analysis, it is best to perform as many non-destructive tests as possible before moving into the destructive phase of the analysis. Plan out the analysis strategy several moves ahead of the actual implementation, and closely analyze the results in-between analysis step. Understanding the package and die technology is critical to the successful analysis.