Non-Destructive Evaluation of Electronic Components for Aerospace Applications

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***Abstract*-Nowadays, electronic devices characterization became more difficult due to the continued increase in complexity and miniaturization of integrated circuits (IC). Therefore, reliable techniques for evaluation of electronic devices becomes more important than ever. Detecting a defect in the initial stages of the product life cycle reduces the costs associated with the product/system.Designers in aerospace industries are shifting from hermetically sealed ceramic micro circuits to Plastic Encapsulated Microcircuits (PEM's) due to their technology advances, improved performance and lower weight. Issue with PEM's is that these are commercially-off-the shelf components, reliability is not established and are not MIL-Grade components. Establishing andimplementing a parts program that effectively and reliablymakes use of these PEM's has become a significant portionof the job for the designers in the aerospace industry.This paperwill present the approaches for reducing the risk of using PEMsin Aerospace industry. In this paper Plastic Encapsulated Microcircuits Screening and Qualification methods by concentrating on the NDE techniques for ensuring confidence for using these state of the art devices in Aerospace applications is given in detail. In industrial manufacturing of microelectronic components, non-destructive defect analysis can be carried out by Scanning Acoustic Microscopy and X-Radiography methods. Acoustic Microscopy is a powerful tool enabling the inspection of internal structures in optically opaque materials non-destructively such as de-laminations, mold compound voids and bond failures can be detected. X-Ray radiography is another non-destructive analysis method which is used for component analysis such as assessment of internal damages, defects, and degradation in micro-electronic devices. All metal joint failures such as solder voiding, wire bond sweep and wire bond breakages etc. can be detected with X-ray analysis.**

***Keywords*- Plastic Encapsulated Micro Circuits (PEM's), Acoustic Microscopy, X-Ray Radiography, NDE, Screening, Qualification, Visual Inspection, HAST, HTOL, Temperature Cycling, Electrical test, Metal joint defects, De-laminations, moulding voids, mould cracks, Die Cracks and wire bond breakages, misaligned leads.**

I. INTRODUCTION

The evaluation of plastic encapsulated microcircuits (PEMs)for Aerospace applications by using NDE techniquesis described in this paper. PEMs are much more readily available than hermeticdevices, mainly because of market forces (cost and volume). At any given time, more part functions areavailable in plastic than in ceramic.

Unlike the military high-reliability system, users of PEMs have little visibility into commercialmanufacturers proprietary design, materials, die traceability, and production processes andprocedures. There is no central authority that monitors PEM commercial product for quality, andthere are no controls in place that can be imposed across all commercial manufacturers to provideconfidence to high-reliability users that a common acceptable level of quality exists for all PEMsmanufacturers. Consequently, there is no guaranteed control over the type of reliability that is builtinto PEM's, and there is no guarantee that different lots from the same manufacturerare equally acceptable. Hence there is a necessity to Screen and Qualify the PEM's for aerospace applications for achieving confidence of having high reliability.

The Screening and Qualification methodologies for PEM's for using in aerospace industry is described in this paper. The methodsdescribed in this paper are intended to detectpoor-quality lots and screen out early random failures from use in Aerospace applications.These tests will increase user confidence that PEMs with otherwise unknown reliability can beused in Aerospace applications. This paper concentrates more on Non Destructive Evaluation methods of Screening and Qualification testing of PEM's. Two methods of Non Destructive Evaluation techniques are described in this paper. First method is scanning acoustic microscopy, it is a powerful tool enabling the inspection of internal structures in optically opaque materials non-destructively such as de-laminations, mold compound voids and bond failures. X-Ray radiography is another non-destructive analysis method described in this paper which is used for analysis of internal damages, defects, and degradation in micro-electronic devices.

II. PRODUCT ASSURANCE SYSTEM FOR PLASTIC ENCAPSULATED MICROCIRCUITS FOR AEROSPACE APPLICATIONS

The reliability of PEM's hasincreased tremendously due toimproved encapsulating materials, die passivation, andmanufacturing processes. In particular, modem encapsulatingmaterials have low ionic impurities, good adhesion to otherpackaging materials, a high glass transition temperature, highthermal conductivity, and coefficients of thermal expansionmatched to the leadframe. Even with modern improvements to PEMs reliability, thereis still uncertainties associated with using PEMs in spaceenvironments. Some missions require the electronics to operaterelatively in benign environment while other missions aremore severe. There is a necessity to screen and qualify the PEM's for aerospace usage.

This paper discusses about the part assurance system to mitigate the risk of PEM's usage, evaluatelong-term reliability of the parts, and prevent failures. PEMs are primarily designed forbenign environments and are considered as high-risk parts when used in Aerospace applications. For thisreason, no PEMs are considered acceptable in high-reliability applications "as is" withoutadditional testing and analysis to assure adequate reliability.

A) Primary Elements of the Part Assurance system

Qualification: The purpose of qualification testing isto prove that the design of part, the processes and evaluation method are adequate to declare part is reliable. This activity is done to approve a particular part or a new manufacturer. It is generally a onetime evaluation method.

Screening: The purpose of screening is to detect and remove defective parts and reduce infant mortalityfailures. The screening process proactively evaluates the reliability of the lot. The terminology "screening" traditionally implies 100% verification testing at piece-part level. Complimentary sample-based tests such as mechanical inspection may be performed, as well. The screening includes electrical verification at the missiontemperature profile, acoustic inspection, radiographic inspection, and visual &mechanical inspection. The detailed screening procedure is given in the subsequent section.

III. QUALIFICATION TESTING OF PLASTIC ENCAPSULATED MICROCIRCUITS

Objectives of the qualification testing is to evaluate theeffectiveness of new materials, processes, and design; to supplyroutine information on the quality of a product; to developinformation on the integrity of a device and its structure; and toestimate its expected service life. Qualification tests aredestructive by nature. Most tests are not conducted at theapplication conditions, but incorporate accelerated levels ofstress to accelerate failure mechanisms, often at known sites indevice.

Unlike the device manufacturer who must balance devicereliability and product yield, the aerospace-user is strictly concernedassuring device survival during integration, test, launch,operation, and (if necessary) storage. In application conditionswhere the environment is not controlled, the load profiles oftemperature, humidity, vibration, contamination, and radiation,a function of time, must be predicted based on pastexperience

The major areas of reliability concern for PEMs are:

- Mechanical Failures due to mechanical stresses in the package (package level wear-out).
- Contamination Failures caused by moisture and contamination in the molding compound or at the die surface.
- Wear-Out Failures related to the degradation processes in the die (die level wear out).
- Radiation Effects Failures caused by die susceptibility to degradation caused by gamma-irradiation and high-energy charged particles.

The qualification test flow is given in fig: 1 for PEMs.

Visual inspection shall be carried for checking any initial defects. Then Acoustic Microscopic Scanning shall be carried out to see any initial internal defects. Then moisture soaking shall be carried out, if any cracks are available in the PEM molding, it will absorb moisture. Now reflow simulation test shall becarried out, to see the impact. Solder Reflow Simulation and Extended Temperature Cycling are intended to demonstrate susceptibility of the parts to thermal stresses.Surface mount technology (SMT)

PEMs experience a high temperature shock during solder reflow processes.

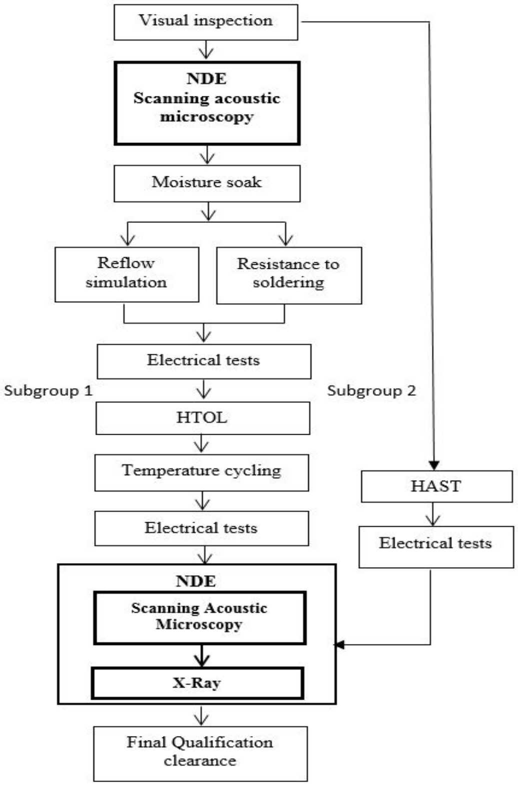


Fig: 1

The reflow temperature exceeds maximum processing temperatures experienced by parts during the curing of molding compounds and the glass transition temperature of the plastic. This can cause significant mechanical stresses, resulting in observable or latent damage to the package and die.

Highly Accelerated Stress Testing (HAST) is used to detect moisture and contamination-related susceptibility to failures.

High Temperature Operational Life (HTOL) Testing is performed at high temperatures and maximum operation voltage and is intended to accelerate most of the die-related degradation processes.

After completing the reflow soldering and thermal stress testing, all the components again goes through the NDE. During NDE both X-Ray Radiography and Acoustic Microscopic Scanning tests shall be carried out.

This paper concentrates on these two methods of NDE evaluation (Scanning Acoustic Microscopy and X-ray Radiography) techniques of PEM's for aerospace applications. These two NDE techniques are explained in detail in the following sections.

III. SCREENING OF PLASTIC ENCAPSULATED MICROCIRCUITS

Screening is the only element of the part assurance system, which is applied to all flight parts by testing and inspecting every sample, and it proactively affects reliability of the lot. The fig: 2 shows typical test flow for screening of PEMs.

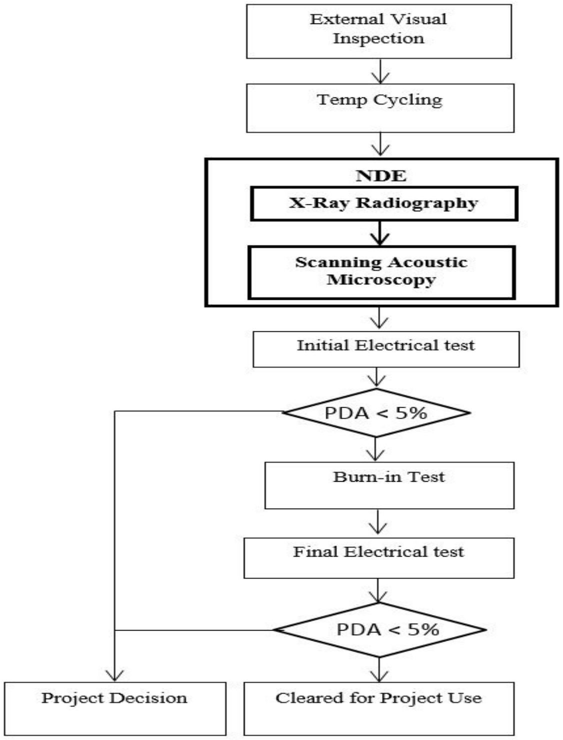


Fig: 2

Visual inspection shall be performed on 100% basis, in accordance to the nearest applicable standard (military, JEDEC or best commercial practices, etc.). Then temperature cycling shall be carried out. If at all any molding voids or cracks are available in the PEM, the thermal stress due to temperature cycling may aid for increasing voids and cracks for observing in NDE testing. Immediately after temperature cycling NDE (X-Ray Radiography and Scanning Acoustic

Microscopic Test) shall be carried out to detect any defect and to weed out the defective components. Then initial electrical test, followed by burn in and final electrical test shall be carried out for further screening. Then final visual inspection shall be carried out for accepting the components for project usage.The NDE analysis methods are covered in the subsequent sections.

V. ACOUSTIC MICROSCOPY

Studies have shown that delamination at the moldcompound/die interface can be the primary cause of electricalfailure during temperature cycling. Mold compound/diede-lamination has been shown to initiate at the die corners andproduce stress-induced passivation damage over a large area ofthe die as the delamination spreads. After delamination, sheardisplacement in the delaminated regions causes wirebonddegradation. Also, metal corrosion is accelerated in thedelamination regions. Acoustic Microscopy has been shown to be animportant tool for the detection of delamination in threedimensions within a package. Acoustic Microscopy inspection isnon-destructive and package damage can be tracked throughsuccessive stages of reliability testing.

The purpose of this examination is to non-destructively detect the following defects:

- Delamination of the molding compound from the lead frame, die, or paddle (top side and bottom side separately).
- Voids and cracks in molding compound.
- Unbonded regions and voids in the die-attach material (if possible).

Acoustic Microscopy Requirements: The acoustic microscopy scanning procedure for screening should comply with the following requirements:

- A clean bath and deionized water should be used during acoustic examinations of the flight parts.
- The test personnel shall be ESD certified for “ESD control.”
- Depending on storage conditions of the parts, a 1-hour bake at 125 °C should be performed to remove moisture from the parts after immersion into the water bath of an acoustic microscope.

Package Examination Sites. Examination of the package for voids, cracks, and delaminations shall be performed on each sample at six areas:

- Interface between the die surface and molding compound (top view).
- Interface between the lead frame and molding compound (top view).
- Interface between the die paddle periphery and molding compound (top view).
- Die-to-paddle attachment interface (if possible).
- Interface between the die paddle and molding compound (back view).
- Interface between the lead frame and molding compound (back view).

The following points are to be noted while scanning:

- Combined C-mode scans can be performed to investigate more than one area during one scanning run.
- A-scan data (wave form analysis) should be performed to verify any de-laminations (if observed).
- Die-attach inspection shall be performed as per MIL-STD 883E, Method 2030, “Ultrasonic inspection of die attach” for the parts with the die mounted onto a substrate or heat sink. This standard can also be applicable for other package types provided the resolution is adequate to detect voids in the attachment material.
- Package surface roughness, mold marks, stamped marking, and surface defects create additional ultrasonic wave reflections that hinderanalysis results. Labels should be removed from the area to be scanned.
- Anomalies and/or de-laminations (if observed) should be verified using A-scan analysis.

Evaluation Criteria. The following shall be considered as gross defects and the lot shall be rejected:

a) Cracks in plastic package intersecting bond wires.
b) Internal cracks extending from any lead finger to any other internal feature (lead finger, chip, die attach paddle) if the crack length is more than 0.5% of the corresponding distance.
c) Any cracks in the package extending to the surface.

d) Any void in molding compound crossing wire bond.

e) Any measurable amount of delamination between molding compound and die surface or lead frame in the area of wire bond (bonds to lead fingers or to the die paddle).

The following aspects shall be considered as reliability concerns and additional testing and screening of the lot might be necessary:

a) Delamination of more than half of the backside or top peripheral area of the interface between the paddle and molding compound.

b) Delamination of the top tie bar or lead area of more than 0.5% of its length.

c) Delamination at the top of the die paddle of more than 0.5% of the periphery area.

A. *ACOUSTIC MICROSCOPY ANALYSIS*

Acoustic Microscopy employs ultrasonic waves for inspection. Ultrasonic waves refers to sound waves having frequency range above 20 kHz. Ultrasonic Waves freely propagate through liquids and solids, interacts differently with material at flaws compared to surrounding material and capable of being focused and can be transmitted straight. These are harmless to the human body and are non-destructive to the material.

A transducer produces a high frequency sound wave which interacts with the sample as shown in fig: 3.High frequency sound waves cannot propagate through air, which require a medium. The medium is called couplant. The couplant is a material used to carry the high frequency sound waves. Water is the most common couplant for immersion testing.

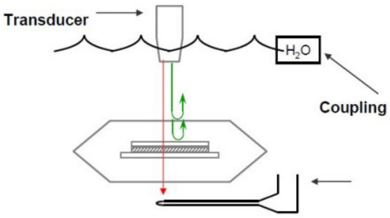


Fig: 3

Acoustic Microscopy analysis is carried out using fast scanning acoustic microscope equipped with several transducers covering a frequency range from 15 MHz up to 110MHz. The focal length of the transducers also differed from 8 mm @ 110 MHz up to 12 mm @ 15 MHz Echo signals were digitized with a sampling rate of 500 MS/s at a resolution of 8 bit. The unprocessed digital RF-signals were stored on the microscopes internal hard drive for further off-line analysis. During scanning, the samples were submerged in de-ionized and degassed water which acted as the coupling medium for the acoustic wave propagation. The A-Scan image is shown in fig: 4.

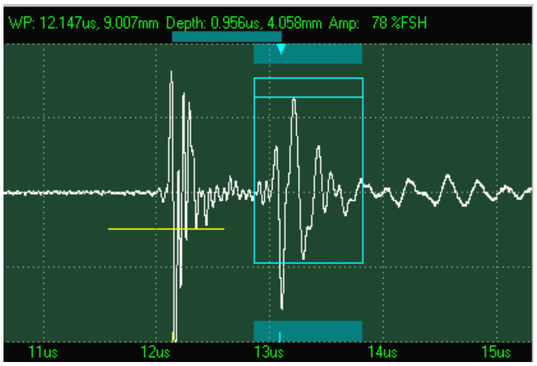


Fig: 4

Acoustic analysis is carried out on some of the PEM packages and are discussed as follows.

Acoustic analysis carried out on PEM based microprocessor by submerging the device in de-ionized water. 35MHz @12mm focal length transducer is used for scanning.The bottom and top scan images are shown in fig: 5.

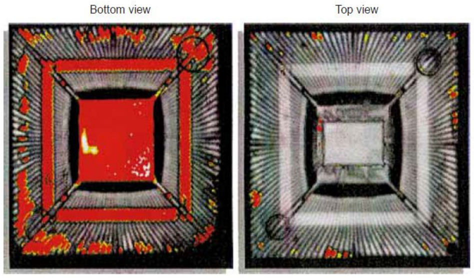


Fig: 5

When the scan is examined the following observations are made. Redcolour areas indicates delamination sites. It was noticed that approximately 100%delamination on the bottom of the lead frame, presenting a possible conduit for moistureto reach the die.

In another PEM package acoustic microscopic analysis was carried out and observations are as given below. The package was functionally tested and found that not meeting the laid down specifications. Analysis carried out with Acoustic Microscopy, 15MHz @12mm focal length transducer is used for scanning.

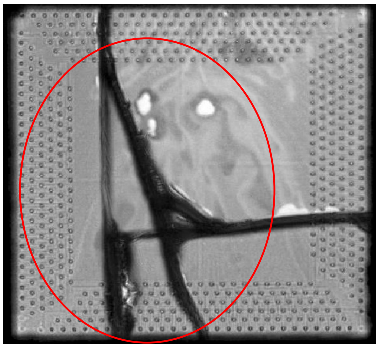


Fig: 6

Scan image is shown in fig: 6. When the scan image is examined, die cracks are observed as shown with red circle. Other defects apart from the defects explained above can also be found with acoustic scanning technique by following the same scanning procedure.

VI. X-RAY RADIOGRAPHY ANALYSIS METHOD

The purpose of this examination is to detect internal defects of the package and to determine die, metallic interconnectand wire bond placement. Inspection shall be carried out for detecting following defects:

- Foreign objects and voids in the encapsulant.
- Voids in the die attach material.
- Misaligned leads.
- Burrs on lead frame (inside the package).
- Poor wire bond geometry (wires that deviate from a straight line from bond to external lead or have no arcfrom die bonding pad to lead).
- Swept or broken wires.
- Improper die placement.

Radiographs shall be taken of each device in two views 90 degrees apart (top and side views). MIL-STD-883E, Method 2012, “Radiography” is applicable. It is to be noted that when real-time radiography is used for screening, the dose rate that the equipmentemits should be estimated. Certain type of radiography can expose microcircuits tounusually high dose rates, such that damage can be introduced to sensitive parts. TheRadiation Effects Group should be consulted as necessary.

By taking X-ray images in different views enables the PEMs user to develop a three-dimensional abstraction of the device internal construction. Performance of X-ray should not be viewed in the context of pass/fail criteria attributed to lot rejection. While individual nonconforming partshould be rejected, the true benefit derived from performing the examination is to gain knowledge regarding overall device construction that will help in testing similar device next time and for providing device failure database.

With the use of X-Ray analysis method internal metallic failures can be detected. The failures include solder voiding, wire bond sweep and wire bond breakages etc., The fig: 7 shows the typical IC package X-ray image. As we can see that in this fig 7 all metal connects are clearly visible.

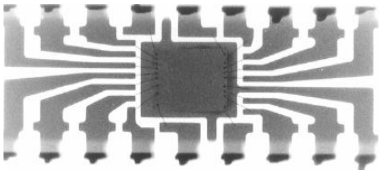
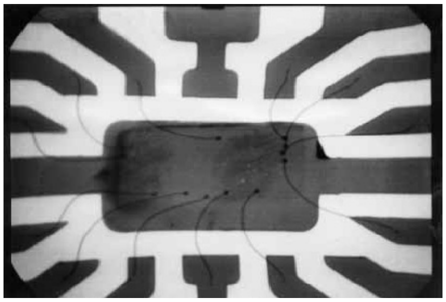


Fig: 7

X-Ray Failure analysis carried out on some of the electronic packages and the results are explained as below:

X-Ray radiographic inspection carried out using MIL-STD-883, method 2012 on PEM package. Out of the 40 samples inspected, 32 parts met the MIL-STD-883 criteria. The failure modes detected are inadequate die attach, misalignment, void in molding compound, wire crossing wire (worst offender in 4cases), and foreign material in encapsulant. None of the failures were a consequence of long-term dormant storage; rather, they were a result of manufacturing and workmanship flaws. Fig:8 shows the radiographic images of the IC. This shows a typical example of the failure mode “wire crossing wire.”, however these are not in direct contact, since wire bonds are crossing each other and it may cause direct contact, hence it is not acceptable.

4 parts exhibited this failure mode.


Top view

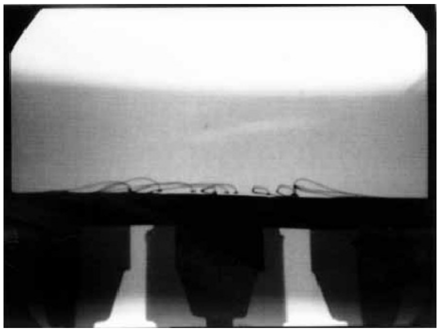

Side view

Fig: 8

A. Analysis of IC package

Analysis carried out on another PEM package reported for analysis. The package was functionally tested and found that not meeting the laid down specifications. X-ray Analysis carried out and it was observed that there is a break in wire bond metal joints as shown in fig: 9.Other defects apart from the defects explained above and are given under X-Ray Radiography can also be found with this analysis technique by following the sameprocedure.

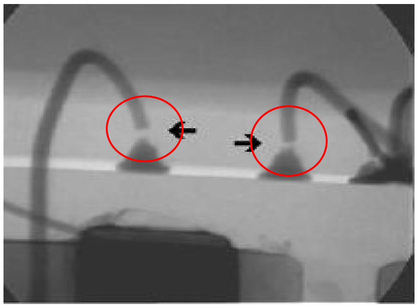


Fig: 9

VII. CONCLUSIONS

This paper explained the Evaluation of Plastic Encapsulated Microcircuits (PEM's) for Aerospace applications. Screening and Qualification tests which are required to be followed for using PEM's in Aerospace industry are clearly brought out. The test flow charts and procedures are explained. This paper primarily concentrated on NDE techniques followed in Screening and Qualification testing of PEM's. The two NDE techniques discussed are Acoustic Microscopy and X-Ray Radiographic analysis.These two methods are complementary to each other. With these two non-destructive analysis methods the complete internal defects can be identified.These two NDE techniques testing procedure, type of defects which can be detected, the defects which are considered detrimental to the component and leads to rejection of the component and lot are clearly explained with test cases.This Screening and Qualification testing provides confidence to the aerospace designers for using these functionally advanced and light weight PEM's in the aerospace electronic systems. Apart from these Screening and Qualification tests there is another test flow called Destructive Physical Analysis (DPA) which can also be carried out for getting further more confidence on the PEM components.The purpose of DPA is to determine whether the lot has anydesign, material, workmanship, or process flaws that may not show up during screening and qualificationtests and cause degradation or failures during the hardware integration period and during missionlifetime. The DPA test flow is also consists of the two NDE analysis techniques which are explained in this paper.

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