# GODDARD SPACE FLIGHT CENTER

**Plastic Parts Investigation Report**

Report Number PP61206



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Plastic Parts Investigation

Project
DPA and FA practices on PEM

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## Background

A work request was submitted to the GSFC Parts Analysis Lab for developing destructive physical analysis (DPA) procedure on plastic encapsulated microcircuits (PEMs).

This study is the second investigation performed by the GSFC PA Lab aimed at an understanding of PEM construction features and peculiarities and to develop the capability to evaluate these features and perform failure analyses (see report PP54735).

This work presents recommendations for DPA procedures on PEM and indicates which of the techniques require further development.

Recommendations.

# Destructive Physical Analysis for Plastic Encapsulated Microcircuits

(a draft)

The purpose of this document is to describe the techniques required for performing destructive physical analysis (DPA) for plastic encapsulated microcircuits (PEM) for sampling, preparation, procedures, and "accept" or "reject" criteria.

It is important to notice that many problems with PEMs are not related to their packaging but due to the dice being manufactured without adequate controls or screens. This means that the dice evaluation according to the military or NASA specifications should receive particular attention.

At present, there is no universally adopted or definitive tests or procurement procedures for PEM. Thus, the DPA results should be used not only to reject devices with design defects, but as a baseline for future analyses related to product acceptance or evaluation of process changes (when a working relationship with manufacturer is installed).

## 1. External Visual Examination.

Inspect each sample at 3X to 10X magnification. One photograph of one typical device showing all marking shall be taken.

NOTICE: Failure criteria of MIL-STD-883D, Method 2009, “External visual” are applicable except paragraphs 3.3.1.b, 3.3.2.a, 3.3.3, 3.3.4, 3.3.5.e, 3.3.5.g, 3.3.6.b, 3.3.7, 3.3.8.

Look for:

- Package nonplanarity, wrapping, or bowing.
- Foreign inclusions in the package, voids and cracks in the plastic encapsulant.
- Slack leads.

## 2. X-ray Examination.

Radiographs shall be taken of each device in two views 90 degrees apart (top and side views).

NOTICES:

a. MIL-STD-883D, Method 2012, “Radiography” is applicable;
b. Using an X-ray inspection system “TORREX 150D”, the regimen 125 kV at current 3 mA and 30 seconds of exposure gives good results in the most cases.

2.1. Purpose. The purpose of this examination is to find the die and wires placement for future decapsulation and to detect internal defects of the package.

2.2. Data records. Note any anomalies and look for the following defects:
- foreign objects, voids, and filler conglomerates in the encapsulant;
- voids in the die attach material;
- misaligned leads;
- burrs on lead frame (into the package);
- poor wire bond geometry (wires that deviate from a straight line from bond to external lead or has no arc and make a straight line run from die bonding pad to lead);
- swept or broken wires;
- improper die placement.

## 3. Acoustic Microscopy.

All samples shall be subjected to the acoustic micro imaging analysis.

3.1. Purpose. The purpose of this examination is to nondestructively detect the following defects:
- delamination of the molding compound from the lead frame, die, or paddle;
- voids and cracks in molding compound;
- unbonded regions and voids in the die-attach material (if possible).

3.2. Apparatus. The apparatus and materials for this test shall include:

a. An ultrasonic imaging equipment based on reflection (pulse echo) technology in which a single focused acoustic lens mechanically scans a tiny dot of ultrasound (in frequency range of 10 to 150 MHz) through the sample. A reflection is generated at each interface and returned to the sending transducer for processing and image generating. Signal processing shall allow information to be gathered from multiple levels within the sample. A C-Mode Scanning Acoustic Microscope (C-SAM) manufactured by “Sonoscan” can be used for this purpose.

b. Deionized water shall be used as a medium fluid to provide acoustic coupling between the sample and the transducer.

3.3. Procedure.

Examination of the package for voids, cracks, and delaminations shall be performed on each sample at six areas:
- interface between the die and molding compound;
- interface between the lead frame and molding compound (top view);
- interface between the paddle periphery and molding compound (top view);
- die-to-paddle attachment interface (if possible);

- interface between the paddle and molding compound (back view);
- interface between the lead frame and molding compound (back view).

NOTICES:

a. Combined C-mode scans can be performed to investigate more than one area during one scanning run.

b. Die-attach inspection shall be performed per MIL-STD 883D, Method 2030, "Ultrasonic inspection of die attach" for the parts with the die mounted onto a substrate or heat sink which is not covered with plastic (for example TO-220). This standard can be also applicable for other package types provided the resolution is adequate to detect voids in the attachment material.

CAUTION. Package surface roughness, mold marks, labels and surface defects create additional ultrasonic waves reflections and hinder analysis results. Packages with nonflat shape may require milling or grinding before analysis.

3.3.1. Remove labels from the area to be scanned. Note all mold marks or defects, which may have affected the scan results. Flatten the surface using a grinding/polishing and wet the surface with alcohol if necessary.

3.3.2. Place sample in the holder in deionized water upper surface parallel with the scanning plane of the acoustic transducer. Sweep air bubbles away from the unit surface and from the bottom of the transducer head.

3.3.3. Set the focus by maximizing the amplitude of the reflection from the die-molding compound interface and perform acoustic scanning.

3.3.4. If the lead frame-molding compound interface was not in focus, reset the focus and perform scanning of this interface.

3.3.5. Refocus the transducer to the periphery of the paddle - molding compound interface and perform acoustic scanning.

3.3.6. Refocus the transducer to the die attachment (if possible) and perform acoustic scanning. If the image is not sharp enough try to view the area from the back side of the part.

3.3.7. Turn the part over, sweep air bubbles away from the unit, focus the transducer to the back side of the die paddle, and perform acoustic scanning.

3.3.8. Refocus the transducer to the lead frame-molding compound interface and perform acoustic scanning.

## 3.4. Evaluation criteria.

In the device examination, the following aspects shall be considered as unacceptable and devices which exhibit any of the following defects 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 crack length is more than a half of the corresponding distance.

c. Any crack in the package breaking the surface.
d. Any void in molding compound crossing wire bond.
e. Any measurable amount of delamination between plastic and die.
f. Delamination of more than a half of the backside or top peripheral area of the interface between the paddle and plastic.
g. Complete leadfinger delamination from the plastic (either top or backside).
h. Delamination of the top tie bar area more than a half of its length.

NOTICES:

a. If rejectable internal cracks or delaminations are suspected, polished cross section may have been required to verify the suspected site.
b. Voiding or cracking in the die attachment area shell be evaluated per MIL-STD 883D, Method 2030, "Ultrasonic inspection of die attach".

## 4. Die penetrant/cross-sectioning test.

Two devices or 40 % of the DPA samples, whichever is larger, shall be subjected to this examination.

### 4.1. Purpose.

The purposes of this test are as following:

- to inspect wire bonding (to the die and lead frame);
- to examine die attachment for voiding and cracks;
- to characterize integrity of molding compound;
- to ensure that there is no direct way (along the leads) for moisture and contamination to reach the die.

### 4.2. Procedure.

Die penetrant test shall be performed per MIL-STD-883D, Method 1034, with the following deviations:

a. Any appropriate microscope with ultraviolet illumination can be used.
b. All samples shall be examined under ultraviolet illumination after the die penetrant hardening before cross-sectioning using low power microscope (10X - 40X). Look for external cracks in sites other than the lead-plastic interface where some separation between the lead and the package is possible.
c. Half of the samples shall be sectioned along one side and half along the other side of the package in three planes (minimum). The planes shall cross the package along the lead (approximately in the middle) in vicinity of the paddle edge, approximately in the middle of the die, and in vicinity of the other paddle edge. Parts with the paddle tie bars shall be sectioned along the bars. At least three planes shall cross the wire bond to the die and to the lead. If suitable, a sample can be sewed in two parts before potting.

### 4.3. Evaluation criteria.

The following defects shall be rejected.

a. Package cracks and delaminations;
   - any evidence of die penetration to the die or the paddle;
   - any evidence of external cracks other than between the lead and plastic;

- any evidence of die penetration of more than 2/3 of the lead length;
- any evidence of die penetration of more than a half of the tie bar length.

b. Bonding:
- lifted and shifted bonds;
- intermetallic compound formation in areas of reliability concern.

c. Die attach: voiding of more than 50%.

d. Molding compound:
- foreign intrusions;
- voids in vicinity of bonding wires.

## 5. Suggested Decapsulation Techniques.

### 5.1. Purpose.

The purpose of this section is to define guidelines for possible decapsulation methods for failure analysis (FA) and destructive physical analysis (DPA) of plastic encapsulated semiconductor devices. It also intended to characterize the advantages and disadvantages, and indicate possible pitfalls.

### 5.2. Preliminary steps.

5.2.1. X-ray analysis should be performed before decapsulation to learn the die shape, placement and size; and determine the height of the bond wires. This information will assist in choosing the correct mask or gasket and/or depth of the trench to be milled in the package surface.

5.2.2. The samples should be baked according to conditions of Appendix 2 before wet decapsulation. This step is intended to remove all moisture from the package so that damage will not occur due to acidic corrosion of the metallization.

CAUTIONS:

a. Results of the subsequent examinations depend heavily on the decapsulation quality. Detailed records about the decapsulation process irregularities and possible artifacts should be maintained.

b. Do not expose the wire bonds at the lead frame when use wet etching techniques. These bonds are frequently made to a silver plated areas and chemical etchants will quickly degrade them.

### 5.3. Milling.

This step is not necessary but is often useful for Method I (manual wet etching) and Method III (Plasma etching).

5.3.1. Purpose. Milling prevents the leads from breaking off by ensuring that the chip surface is exposed before the lead frame is and reduces the time required for etching.

5.3.2. Apparatus. Any suitable milling machine. Use of a dental drill to create a

small impression is possible but not preferable because a flat surface would not result.

5.3.3. Procedure.

5.3.3.1. Using X-ray data calculate the depth of the trench to be milled.

5.3.3.2. Install the part into a fixture of milling machine. The surface being worked should be parallel with the milling plane.

5.3.3.3. Start milling, moving the mill tip down to the calculated depth. Mill the trench slightly longer and wider than the die.

CAUTION:
To ensure that the bond wires remain intact during milling, it is recommended that approximately 0.2 mm of plastic be allowed to remain covering them.

## 5.4. Method I. Manual wet etching

Advantage: A quick result is possible with ready available equipment. Disadvantage: Removal of contamination from the surface of the die preventing chemical analysis; the method requires very careful attention to safety.

5.4.1. Apparatus and materials.

a. A heating plate, metal block, beaker, aluminum weighing dish, and disposable dropper.

b. Red fuming nitric or sulfuric acid can be used as etchants. Acetone, isopropanol, or methanol can be used for rinsing.

NOTICES:

a. Red fuming nitric acid can be used in the most cases. Sulfuric acid can be used as a solvent specific to anhydride epoxies.

b. Red fuming nitric acid has little effect on plastic at room temperature, but elevating the temperature to approximately 100°C will cause it to decapsulate a device in few minutes. Higher temperatures will only decompose the acid. When heated in an open beaker, the acid will evaporate $NO_2$ and absorb moisture with time, thus becoming diluted and converting into a yellow nitric acid. Dilute (yellow) nitric acid is not suitable for decapsulation purposes because it reacts with the metal in the devices.

c. To have an effect on epoxy, sulfuric acid must be heated to about 150°C. Use deionized water for rinsing.

5.4.2. Procedure.

5.4.2.1. Mill a trench or create a small impression according to 5.3.

5.4.2.2. Make a mask using aluminum foil adhesive tape shielding the specific areas not to be etched.

5.4.2.3. Install the part on a metal (copper or aluminum) block to provide heat directly to the bottom of the device. Then place it in an aluminum weighing dish on a plate heated to approximately 90°C and wait several minutes to allow the package to heat up.

5.4.2.4. Pour a small quantity of red fuming acid into a beaker and apply several drops to the device with the dropper.

5.4.2.5. Cleanup: rinse with cold nitric acid for a few seconds, rinse in a spray of acetone, then in isopropanol or ultrasonically clean in methanol. Blow with a dry air.

5.4.2.6. Repeat p. 5.4.2.3. to p. 5.4.2.1. until the die is exposed.

5.4.2.7. If necessary, perform a plasma cleanup with a 10:1 mixture of $0_2$:$CF_4$ in a barrel plasma (50W, 30-60 min.).

CAUTIONS:

a. It is very important to keep the part hot and the exposure to react with acid very short.

b. There are safety hazards with this process. All chemical handling procedures should be complied with.

## 5.5. Method II. Wet chemical jet etching.

Advantage: This method eliminates some safety problems inherent to Method I and provides quick, clean, and localized removal of encapsulant in the die area, usually with no damage to the part.

5.5.1. Apparatus and materials.

a. Jet etcher (B&G decapsulator, model 250).

b. Red fuming nitric or sulfuric acid, acetone, isopropanol.

NOTICES:

a. See notices 1.4.

b. Decapsulation of the first part may require from 3 to 6 steps followed by low power optical examination. After the process regimen is readjusted, decapsulation can be done in one - two steps (three - five minutes).

5.5.2. Procedure.

5.5.2.1. Choose a gasket according to the die size, calculated by X-ray data.

5.5.2.3. Adjust the part and the gasket onto the fixture.

5.5.2.4. Set parameters of the process (etching temperature, etching time, and volume of etching acid) using manufacturer's data and experience and perform decapsulation.

5.5.2.1. Rinse the part in acetone and then in isopropanol after each step of etching. Blow with dry air.

5.5.2.6. If necessary, perform a plasma cleanup with a 10:1 mixture of $0_2$:$CF_4$ in a barrel plasma (50W, 30-60 min.)

CAUTION:

Decapsulation of thick packages with relatively small surface area (like DIP-8) may have resulted

in the cavity wall depression which halt the etching process. To avoid this, use gaskets of a lesser size.

### 5.6. Method III. Plasma etching.

Advantage: Plasma etching has very high selectivity (the technique minimizes etching of the die metals and lead frame). The safety and contamination problems of wet chemical processes are avoided. Plasma treatment is a gentle process compared to wet etching and sometimes makes it possible to expose bonds at both ends of the wires.
Disadvantage: Significantly more time is required.

5.6.1. Apparatus and materials.

a. A non reactive ion etching mode plasma system should be used. Plasma GIGA-ETCH 100-E system (Technics Plasma GmbH) is preferable. In this system the plastic molding compound is removed from the device automatically and up to 12 devices can be treated simultaneously. The filler material (quartz powder) is automatically blown from the surface with brief blasts of compressed air in time intervals of several minutes.
b. Deprocessing is performed at approximately 0.5 - 1 mbar pressure of the gas mixture $O_2$:$CF_4$ (80:20).

NOTICE.
The process time varies typically between 5 and 15 hours depending upon the type of the device and the trench depth.

5.6.2. Procedure.

5.6.2.1. Mill a trench according to 1.3.
5.6.2.2. If necessary cover the package with an aluminum foil mask so only the area to be etched is exposed to the plasma.
5.6.2.3. Adjust and secure samples under the blow nozzles and start the process.

CAUTION:
Oxygen/freon plasma (mostly used for deprocessing) does not affect Al and Au, but can attack the other metals and glassivation (especially $Si_3N_4$).

## 6. Internal visual inspection.

All decapsulated samples shall be subjected to this examination.

**6.1. Purpose.** The purpose of this test is to verify that the quality of the performed decapsulation is adequate for further analysis, to examine decapsulated device for visual defects, and to discriminate those, which had been caused by decapsulation.

**6.2. Procedure.** The device shall be examined microscopically at a low power (30X to 60X) magnification and then at a high power magnification (75X to 200X) to determine the existence of

the defects as described in 6.3 and 6.4. All failures from p. 6.3. should be analyzed to confirm that the failure mechanism is associated with decapsulation technique used.

### 6.3. Verification of the decapsulation quality.

a. Confirm acceptance of the specimen for the further bonding examination. At least 25% or 3 wire bonds, whichever is more, should meet the following criteria: be clean, have no damage, and be exposed more than approximately 2/3 of their length.
b. Confirm acceptance of the specimen for the further glassivation integrity and SEM examinations. At least 75% of the die area, should be clean and have no damage caused by the deprocessing.
c. Record any artifacts which may have affected the DPA results.

### 6.4. Criteria.

Evaluation criteria per MIL-STD-883D, Method 2013, "Internal visual inspection for DPA" are applicable.

Additionally, no device shall be acceptable that exhibits the following defects:

a. Foreign intrusions in exposed plastic material.
b. Glassivation pinholes, peeling or cracks (in particular those, which are specific for the filler particle-induced damage).
c. Metallization voids, corrosion, peeling, or lifting.

## 7. Glassivation layer integrity.

One sample or 20% of the lot, whichever is larger, which met the requirements per p. 6.3.b. shall be subjected to a glassivation layer integrity test.

### 7.1. Procedure.

This examination shall be performed per MIL-STD-883D, Method 2021, "Glassivation layer integrity.

## 8. Bond pull test

Each sample which met the requirements per p. 6.3.a. shall be subjected to a destructive bond pull test.

### 8.1. Procedure.

The wire bonds shall be pulled to destruction according to MIL-STD-883, Method 2011, "Bond strength (destructive bond pull test)", Condition D.

NOTICES:

a. According to the procedure MIL-STD-883, Method 2011, the pull is applied by inserting a hook under the wire approximately in the center of the loop. Normally, decapsulation exposes approximately 75% of the loop (exposure of the wire-to-lead bond would weaken the bond strength due to chemical attack). The wire tension in the case when a pull force is applied not in

the middle of the loop and part of the loop is buried in plastic may differ (up to two times) from the case described in MIL-STD-883. This means that the rejection criteria per MIL-STD-883, Method 2011 may be not applicable.

b. Typically, the ball neck is the weakest site of the bonding (in particular, because it has been annealed during ball formation). If another site of the wire bond is found to be broken, the site could indicate a problen (especially in the case of the ball-lift).

c. A wire bond strength test may be greatly influenced by the history of the sample. Thermocycling or storage of the sample under high temperature and humidity environments can cause deterioration of the wire bond strength. Enhanced degradation of the intermetallic region of the gold wire-aluminum bonding pad interface occurs in the presence of some flame retardants in epoxy molding compounds (such as bromine or antimony containing). In some cases, to ensure an adequate quality of the part and its long term reliability, different types of accelerated tests are recommended before the sample is subjected to the wire pull test.

d. The ball shear test is considered a more sensitive test (as compare to the wire pull test) and provides a better measure of the consistency and reliability of ball bond formation. However the test is more labor consuming and risky. Additional experiments are necessary to evaluate its reproducibility and suitability for PEM.

8.2. Data records. Results of the bond pull test shall be recorded in the DPA history records.

## 9. Scanning electron microscope (SEM) Examination.

All samples, except those which were subjected to glassivation integrity examination, which met the requirements per p. 6.3.b. shall be subjected to this test.

NOTICE. In most cases PEM manufacturer does not use military specifications in the wafer or die fabrication. Thus this examination should be regarded as a major test for the die compliance to the high reliability requirements.

9.1. Purpose. The purpose of this examination is to evaluate quality of the wire bonding, glassivation integrity, and acceptability of the die interconnect metallization.

9.2. Procedure. Half of the samples shall undergo SEM inspection for bonding, glassivation and metallization quality. The other shall be subjected to a SEM examination followed by a cross-sectioning.

9.2.1. Samples intended for wire bonding and glassivation integrity evaluation shall be covered with a thin (approximately 100Å) gold film for following SEM examination.

9.2.1.1. Glassivation shall be examined for delamination, pin holes, and cracks.

9.2.1.2. Wire-to-die bonding shall be examined for the following defects:

a*. cratering of the bond pad on the die;
b*. bond liftoff;
c*. wirebonds which are sheared from the die pads;

d. intermetallic compounds visible more than 0.1 mil beyond the ball attachment periphery.

* - only wires which were not subjected to the bond pull test.

9.2.2. Cross-sectioning. Samples intended for cross-sectioning shall be separated from the plastic package.

9.2.2.1 Die separation. The die can be removed from the package in two ways:

a. by etching away the paddle;

b. by removing the most part of the molding compound around the paddle followed by a heating the part to the temperature above the eutectic or solder melting point.

9.2.2.2. the subsequent examination shall be performed in accordance with MIL-STD-883, Method 2018.

CAUTION. It is important to remove all polymer residues from the die before cross sectioning. Otherwise, the acid absorbed in the polymer remnants would mix with deionized water (during polishing) and cause corrosion of aluminum metallization.

9.3. Evaluation criteria. No device with defects mentioned in paragraphs 9.2.1.1. and 9.2.1.2. shall be accepted. The acceptability of the die interconnect metallization shall be evaluated in accordance with MIL-STD-883, Method 2018.

## 10. Soldering simulation (for surface mount devices).

Half of the DPA samples shall undergo this test before decapsulation. The test shall be performed in accordance with EIA/JEDEC standard "Moisture induced stress sensitivity for plastic surface mount devices", Test method A112-A.