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Guideline for Internal Gas Analysis for Microelectronic Packages

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GUIDELINE FOR INTERNAL GAS ANALYSIS FOR MICROELECTRONIC PACKAGES

CONTENTS

	Page
Foreword	ii
1 Scope	1
2 Need for Internal Gas Analysis	1
3 Selecting an Internal Gas Analysis analytical service lab	2
4 Process of conducting an Internal Gas Analysis	2
5 Interpreting the Internal Gas Analysis results	5
6 Process control	8

ANNEXES

A Common failure mechanisms	9
B Laboratory selection checklist	11
C Alternatives to Internal Gas Analysis	13
D Compendium of references to Internal Gas Analysis	19
E Differences between JEP144A and JEP144	27

Foreword

The measurement of the moisture levels and other gases in hermetically sealed microcircuit packages is one of the key steps in demonstrating the robustness of the manufacturer's materials and sealing processes and the reliability of products. The manufacturer must be in control of all of parts, processes, materials, and process byproducts that can affect the internal package atmosphere to be confident that the products are in compliance with the relevant requirements. The manufacturer needs to understand the effects that moisture and other gases can have on the reliability of the product.

Moisture is a primary importance to the reliability and but so are other gases. Control of hermetic environments in microelectronic devices is very useful for process control monitoring and long term reliability of the product. In addition, knowledge about the presence of other gases can provide clues to help process engineers improve and control their processes. Other gases may indicate, for example, that the internal materials may not be stable for long term use and that the internal atmosphere may be changing over time and temperature, often creating additional moisture in the device atmosphere thru chemical reaction or outgassing. Other gases may also provide evidence that the devices may not actually be hermetic. This is an excellent tool to validate the effectiveness of leak test procedures and package survival to mechanical and thermal stress.

Users should keep in mind that the test results for Internal Gas Analysis reflect the gas in the internal atmosphere of the device at the time of test. Devices (particularly those containing organic materials or those with measurable leak rates) do not necessarily have a fixed (or correct) result. Test results can be a function of the historical environmental exposure of the device.

Internal Gas Analysis technology is used by many disciplines. It is best known for its use as a Military Standards Qualification test in accordance with MIL-STD-883, Method 1018, for moisture content. It is also useful as a process control tool, a process validation tool, materials outgassing studies, and as a failure analysis tool.

Numerous analytical methods can be employed to measure the composition of gasses contained in a semiconductor package. GC-Mass Spectrometry, Mass Spectrometry, and various single purpose sensors and techniques to measure moisture are available. In order to make effective use of these methods, the precision, accuracy, and sensitivity of each measurement system must be validated.

The ability to measure the gasses contained in a hermetic package from 0.0002 cc to packages over 200 cc (no upper limit on size) is available at test laboratories approved by Defense Logistics Agency (DLA) Land and Maritime, Columbus, Ohio in accordance with MIL-STD-883, Method 1018, for product compliant to military specifications.

GUIDELINE FOR INTERNAL GAS ANALYSIS FOR MICROELECTRONIC PACKAGES

(From JEDEC Board Ballot JCB-11-54 and JCB-11-68, formulated under the cognizance of the JC-13 Committee on Government Liaison.)

1 Scope

This guideline is applicable to hermetically sealed microelectronic components (including discrete semiconductors, monolithic and hybrid microcircuits). Specific cases with unique packaging, materials, or environmental constraints may not find all of the following information and procedures applicable. A compendium of references to reports, papers, and texts, relating to internal gas analysis, volatile gasses, and sealed packages is included in Annex D.

This guideline describes how to select a lab, the internal gas analysis testing process, and the interpretation of the test results. Lists of common failure mechanisms can be found in Annex A. A brief discussion of process characterization and process control is included. Annex C contains supplemental methods for measuring moisture content along with their advantages and disadvantages.

2 Need for Internal Gas Analysis

The presence of moisture and other gases in hermetically sealed microcircuit packages continues to be a concern for electronic component manufacturers and their customers. Reports indicate that moisture can lead to internal corrosion of component metallization and electrical connections; moisture induced metal migration can lead to shorts; and high current leakage can be caused by moisture on internal electronic surfaces, such as substrates.

The causes of moisture in a hermetic package can be traced to the package seal, internal construction materials, the processes used to manufacture the device and stresses incurred during subsequent screening tests, such as burn-ins or thermal cycling. Consequently, it is important for the manufacturer to understand to what degree each of the potential contributors of moisture may impact their product. Internal gas analysis is a means by which the manufacturer can obtain information about the packages, materials, processes, and screening used with the products to ultimately gain better control over the final results.

Users should remember that a failure due to moisture usually occur in low temperature, unlike most other failure mechanisms that are results of high temperature processes. Production lots where most or all of the devices have high moisture have the potential to create numerous device failures. Moisture related failures are not usually found at initial operational testing. Failures tend to occur later in time, often several years later when the systems are in the field.

NOTE Not all semiconductor devices have failure modes which are related to “high” moisture concentrations. Devices should be characterized through accelerated life testing in humid environments to assess the potential for moisture related failure mechanisms. Other gasses such as Hydrogen or Oxygen can be detrimental to the performance and/or reliability of a device. Characterizing a device’s failure modes relative to gas mixtures is an important step in the interpretation of Internal Gas Analysis data.

3 Selecting an Internal Gas Analysis analytical service lab

Laboratory selection is one of the most important decisions to be made in the internal gas analysis process. The manufacturer must have confidence in the laboratory's ability to perform the required procedures accurately and repeatedly. When a good working relationship is established with a laboratory, the manufacturer can build a database of internal gas analysis results that can be used as a metric for the stability of the processes. Many of the user's requirements can be met by selecting a lab that has received certification for performing internal gas analysis from the by DLA Land and Maritime. This is frequently a contractual requirement. A checklist for lab selection can be found in Annex B.

The facility and the way that it is operated must match the needs of the user of its services. The way that the lab operates, i.e., business/technical aspects of the lab should be compatible with the user's needs and expectations. The lab should be able to explain its methodology for performing the tests and interpret the test results to the user's satisfaction.

The user needs to ensure that the products submitted for internal gas analysis will be properly handled and not mistreated in a way that could compromise the results of the analysis. This is particularly true of packages with thick walls or lids that must be "thinned" in order to open them in the analytical apparatus. The lab should have experience performing the internal gas analysis on packages of the same size and type as the prospective users.

When parts are being tested to demonstrate conformance to a specification, the test report should clearly indicate which measured gasses are being evaluated for purposes of specification conformance. The applicable specification/document number, and the allowable limit, as required, for each gas in that specification should be listed in the report. If the specification is provided by the user, a laboratory analysis submission form should clearly identify the requirements of the specific test.

4 Process of conducting an internal gas analysis

Prior to submitting the devices to internal gas analysis, it is recommended that the user submit the samples to fine and gross leak testing in accordance with MIL-STD-883, Method 1014, to verify the integrity of the hermetic package.

Note: Air equivalent leak rates of less than $3E-10$ atm-cc/sec are needed to prevent moisture ingress or to prevent significant gas exchanges from taking place.

Internal gas analysis testing requires a number of pieces of equipment. These include a mass spectrometer, moisture dew point analyzer, package opening system, mercurial barometer, pressure gauges, pre-bake oven, small grinding tool, and calibration gasses, including nitrogen gas, room air, and certified mixes typical of the manufacturing processes used for the devices to be tested. Gasses typically found in an internal gas analysis include water vapor, oxygen, nitrogen, carbon dioxide, argon, helium, hydrogen, perfluorocarbons, methane, pump oil, and other organic compounds. Some procedures require confirmation of the hermeticity of the package prior to starting the test. It is recommended that any hermeticity measurements be made after any mechanical alterations to the test package.

4 Process of conducting an internal gas analysis (cont'd)

A mass spectrometer for internal gas analysis should be capable of detecting the gasses of interest, and as a minimum, should include the gasses specified in Mil-Std 883, Method 1018. The package opening system has a piercing device that operates from inside an opening chamber or transfer passage. The piercing device must be able to pierce a sample package without otherwise damaging the package seal or breaking the mass spectrometer chamber vacuum. Due to the piercing of the package, this is a destructive test. This system must be able to handle a variety of package sizes and shapes, and should be able to hold the devices in place to allow for proper transfer of the gasses to the mass spectrometer. The opening chamber and transfer passage must be capable of maintaining a vacuum and a constant temperature.

Calibration is necessary for all of the equipment used in the internal gas analysis testing procedure. The National Institute of Standards and Technology (NIST) has specific procedures for calibration of the gas analyzer. MIL-STD-883, Method 1018 (latest revision) for internal water-vapor content testing, for example, requires that the moisture dew point analyzer be calibrated at least once per year. Also mentioned in Method 1018 is the calibration of the mass spectrometer, which is performed using a package simulator capable of providing three known volumes of gas to use as calibration points.

Periodic calibrations are needed for equipment used to measure hermeticity, pressure, and temperature.. Calibrated thermocouples should be used when checking the oven temperature and transfer passage temperature. The pre-bake oven stability should be checked to ensure that the temperature over a 24-hour period is held at 100 °C, +/-5 °C. Often a multi-point profile of 5 or 9 points is used, depending on how many shelves of an oven are used. A number of daily calibration records also need to be maintained. These include the calibration coefficients and factors for gasses including moisture and other independent variables, such as, sample gas volume, and calibrated moisture level.

Ceramic packages may need to have the lid thinned, by grinding for example, to reduce the chance of the package seal breaking while being punctured. Localized thinning of the ceramic near the puncture point is desirable to minimize the exposed surface area of freshly broken ceramic after puncture since this surface acts as a getter for moisture and can distort the measurement result. Devices with thick (> 0.015 inches) metal lids may need to be thinned to insure a proper puncture with out damaging the hermetic seal of the package. The manufacturer should define special puncture point of specialized packaging. The devices should be kept clean during and after any mechanical preparation. For packages that undergo mechanical preparation prior to testing, the laboratories need to take precautions to maintain hermeticity and technicians need to be trained to carefully perform these operations.

Appropriate fixtures should be available for such procedures. Also, if any electrical or failure analysis is to be done after testing, the devices should be handled using precautions against ESD.

Prior to testing a sample, a number of steps need to be performed. The system should be stabilized using a moisture level and gas mixture similar to that to be analyzed. If these are not known, room air or nitrogen with 5000 ppmv water vapor should be used. In addition, it is important to ensure that the device under test is maintained at 100 °C, +/-5 °C for a minimum of ten minutes prior to puncturing. The moisture dew point analyzer should also be checked.

4 Process of conducting an internal gas analysis (cont'd)

Three sets of data are needed for an internal gas analysis test: background, calibration, and sample. The background spectrum data allows correction for the gasses present in the system. Any moisture present in the background must be eliminated to prevent the possibility of moisture in the sample being masked due to the small volume of many packages. Calibration data allows the system to be used to measure a constant volume of gas containing a known quantity of moisture to ensure repeatability of the system. The sample data can be obtained after the sample package is opened, a mass spectrum recorded, and the background data subtracted out of the resulting spectrum. Device manufacturers may require special handling procedures for some devices. Also, since the sensitivity factor changes with the volume of gas being analyzed, each lab is to calibrate their measurement instruments in decade increments. The calibration is to be done using a three volume calibration jig or an equivalent process, typically for volumes of 0.01 cc to 0.1 cc, 0.1 cc to 1.0 cc, and 1.0 cc to 10.0 cc.

An understanding of gas dynamics and mass spectroscopy is necessary to successfully conduct an internal gas analysis test. Training is most often provided by experienced equipment operators or the internal gas analysis equipment manufacturers, as there are no known schools or companies that provide such training. Documented training program requirements should exist for any company performing internal gas analysis testing and operators' training records should be compared to these requirements for completeness.

Often device manufacturers send 5 devices to be tested, with only 3 to be tested if no failures occur. Failures occurring due to mishandling of parts should be handled as part of the lab's corrective action system. Failures due to hermetic issues should be counted as hermetic failures and not internal gas analysis failures. When failures or conflicting test results occur, another lot of samples may be sent to a different laboratory. If both labs give similar results then this should confirm the findings. If the results from the two labs differ significantly, there may be a correlation problem, which may need to be addressed by the device manufacturer or by DLA Land and Maritime. The labs should be able to assist when failures occur by analyzing the types, amounts, and ratios of gasses involved. The analysis can provide information about the manufacturing process and materials. Currently, the major factors which influence correlation between laboratories are sample preparation and hermeticity.

4.1 DLA Land and Maritime certified labs

DLA Land and Maritime certified laboratories performing internal gas analysis testing periodically receive comprehensive audits to ensure requirements for testing are being adequately met over a limited size and range of specific military packages. A lab must have an overall quality program meeting one of the Military Specifications such as MIL-PRF-38534, MIL-PRF-38535, or MIL-PRF-19500. Procedures must meet the specified test method (latest revision) such as Method 1018 of MIL-STD-883. The audit includes review of the quality program and the aspects of document control, calibration, operator training, device handling procedures, retention of data, self-audit, corrective action, and statistical process control, where applicable. Also verified are that the equipment operators follow documented procedures, equipment functions properly at the start of testing, and that the proper apparatus, materials, and gasses are used for testing. Travelers are reviewed for completeness, to ensure that operations are performed in the correct order, and to confirm that the appropriate stabilization bakes and hermeticity testing are performed. Laboratories also test DLA Land and Maritime supplied parts to ensure that the laboratory is able to report expected results.

5 Interpreting the internal gas analysis results

Internal gas analysis results contain significant information about the manufacturing processes and materials used to produce a product. It is also an indicator of the likelihood of the product successfully performing its intended function. To best use the results of an internal gas analysis, the manufacturer needs to understand what they mean. Rather than looking at the results as a go/no-go test, the device manufacturer should be ready to interpret them as a reflection of their processes and be ready to use the results to make the processes more robust if necessary. Internal gas analysis provides the best indicator of the presence of hermetic issues and/or process issues.

5.1 5000 ppm pass fail criteria

At a pressure of one atmosphere, a closed container of gas at 0 °C at 100 % Relative Humidity contains 6000 ppm moisture. If a package is cooled down to 0 °C with more than 6000 ppm moisture, water will condense inside the package. As a further reference, at +20 °C, 100% relative humidity equates to approximately 23,000 ppm moisture. This is illustrated in the nomograph in Figure 1 below.

The JEDEC JC-13 Committee and DLA Land and Maritime approved a compromise between the measurement equipment capabilities and a variety of failure thresholds. Part of this agreement is that the government would show that the DLA Land and Maritime approved moisture measurement labs would be able to correlate their moisture readings to within plus/minus 10% at 5000 ppm, with correlation standards containing only nonorganic materials.

NOTE A DLA Land and Maritime laboratory correlation program was initiated in 2000. This program intends to obtain comparable internal gas analysis data from all of the DLA Land and Maritime certified internal gas analysis labs. The goal of the program is to bring all of the comparable data from the different labs into an acceptable variance range.