A Practical Guide to TM 1014 (Seal)

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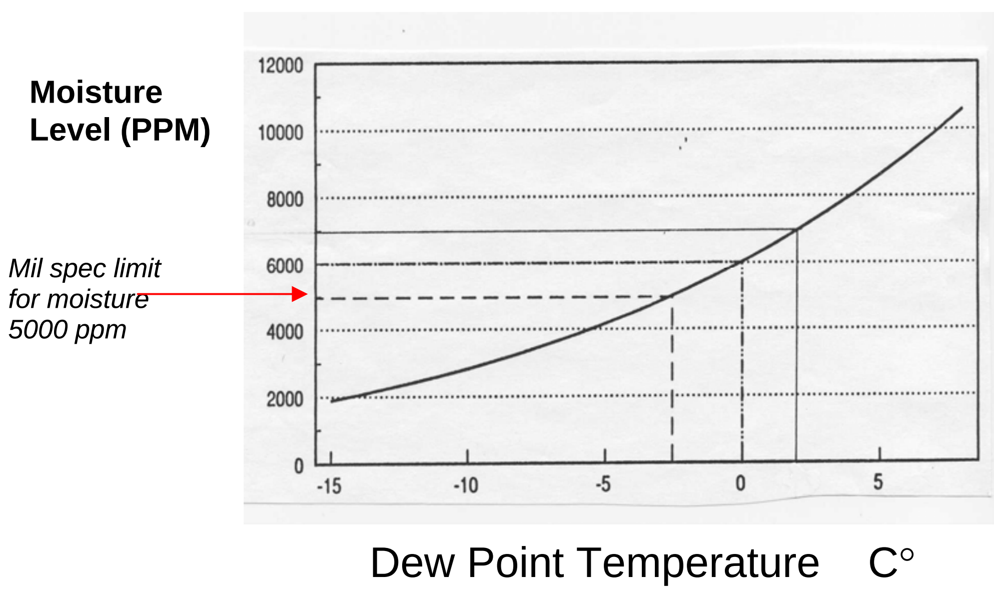
History and Background

Microelectronic components used in military, space and implant medical devices, such as pacemakers, have historically demanded the highest possible levels of quality and reliability. Since the late 1960's cavity style microelectronic packages intended for use in these systems required a "hermetic" seal. The "hermetic" seal made from glass, ceramic and or metal was designed to keep moisture out of the package, and thereby avoid any failures caused by condensing water vapor inside the cavity. Most military and space systems are designed to last 10-20 years and therefore a "leaky" package represented an unacceptable reliability risk.

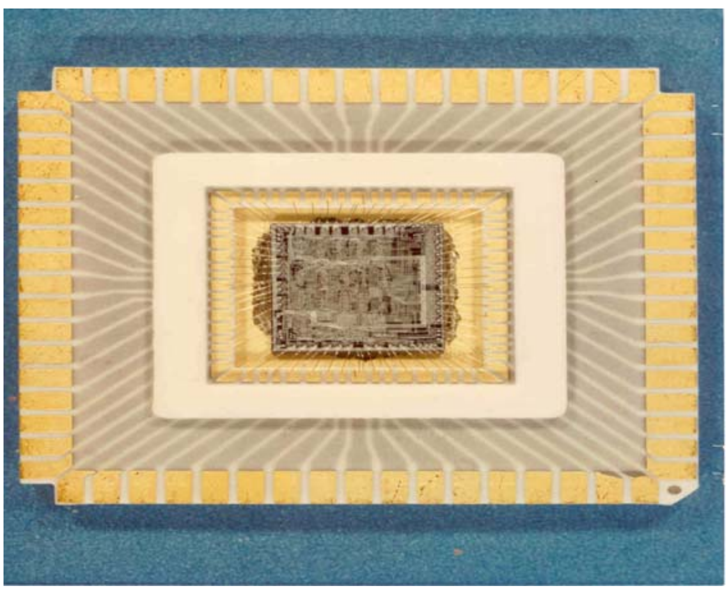
Early semiconductor devices and thin film resistor networks were very prone to moisture related failures. Several major programs experienced system level failures due to moisture related problems at the component level. As a result organizations, like Rome Air Development Center (RADC) spearheaded efforts to develop test techniques to measure air leak rates and the corresponding build up of moisture in the package [1]. The theory is to keep the moisture content within the package sufficiently low enough to avoid condensation of water droplets onto the active semiconductor devices. The intended temp range for most military systems is -55 to 125 C. So even a relatively dry package, say 8000 PPM (parts per million) water vapor will form dew inside the package at 5° C, see chart below. These moisture droplets on the surface of the device along with ionic contamination can lead to component failure with catastrophic results at the system level.



As a result in the late 1960's the first iteration of Mil-STD-883 Test Method 1014 (Seal) was released [2]. The proposed hermeticity test was required, and still is today, on a 100% basis for every part planned for use in a Military or Space system. Over the years the TM 1014 has been revised somewhat, but the basic content remained the same until 1995 when a new technique, Optical Leak Detection (OLT) was introduced. TM 1014.11 (dated 18 June 2004) is the latest revision of the Seal Test Method and forms part of Mil-Std-883F, which is a large document containing many test methods and procedures related to microelectronic components.

TM 1014 assured parts were properly sealed, and if sealed in a dry atmosphere could then pass the corresponding TM 1018 Internal Water Vapor Content or RGA (Residual Gas Analysis). TM 1018 limits the internal moisture content to 5,000 PPM as shown on the chart above. The rationale being that at 5,000 PPM the water vapor dew point is below the freezing mark, and therefore any moisture that would condense out inside the package would be in the form of ice crystals and not be available for corrosion processes. Designers would then have a high confidence that the devices would work as expected for the entire mission life. The purpose of TM 1014 was to verify a hermetic seal and prevent moisture from entering the package.

Today microelectronic components built on Qualified Manufacturing Lines (QML) intended for Military/Space are governed by Mil-PRF- 38535 "Monolithic Microcircuits" or Mil-PRF-38534 "Hybrid Microcircuits Specification".   Each of these documents calls out 100% Screen testing per 883 TM1014. Although lower cost plastic packages and micro packages made from advanced materials are slowly being introduced the majority of military qualified parts are still cavity style packages requiring a hermetic seal.



Typical monolithic IC in a ceramic package

What is Hermeticity?

The dictionary definition of the term “hermetic” means a seal that is gas tight or impervious to gas flow. In the context of microelectronics it implies an airtight seal that will keep moisture and other harmful gases from penetrating the sealed package. Metals, ceramics and glasses are the materials used to form the hermetic seal and prevent water vapor from accumulating inside the package. A properly made hermetic seal with a sufficiently low leak rate can keep a package dry and moisture free for many years.

TM 1014 only applies to cavity style packages and the test is designed to determine the effectiveness or hermeticity of the seal. There are several techniques for doing this, which we'll discuss later, but the most common method is to measure the rate at which helium escapes from a package that has been pressurized or backfilled with helium (the tracer gas). This measured helium leak rate is then correlated with an "air" leak rate. The hermeticity spec and the basis of TM 1014 is based on a maximum "air" leak rate for a given package volume as stated below:

TM 1014.11 paragraph 3.1.1.2.1 "Failure Criteria"

Less than 5 EE-08 atm cc/s air for vol .01 cc or less
Less than 1 EE-07 atm cc/s air for vol .01 cc to .4 cc
Less than 1 EE-06 atm cc/s air for vol .4 cc or greater

When a cavity sealed microelectronic package passes the applicable testing called out in TM 1014 the part is deemed "hermetic". When it fails it's known as a "leaker".

A Reason to Seal

If liquid droplets form on the surface of an IC or other active devices sensitive to moisture (e.g. MEMS), then there exists the possibility for corrosion or other electrochemical reactions that may degrade the performance of the device and lead to failure. Moisture droplets can form as the package is cooled below the dew point within the package, or if frost has formed on the chip and the package is then warmed. This surface water (H_2O) then combines with ionic contamination, such as sodium (Na) or cholrine (Cl), and along with a bias will corrode exposed aluminum metal at the bond pad or attack thin film resistor networks.

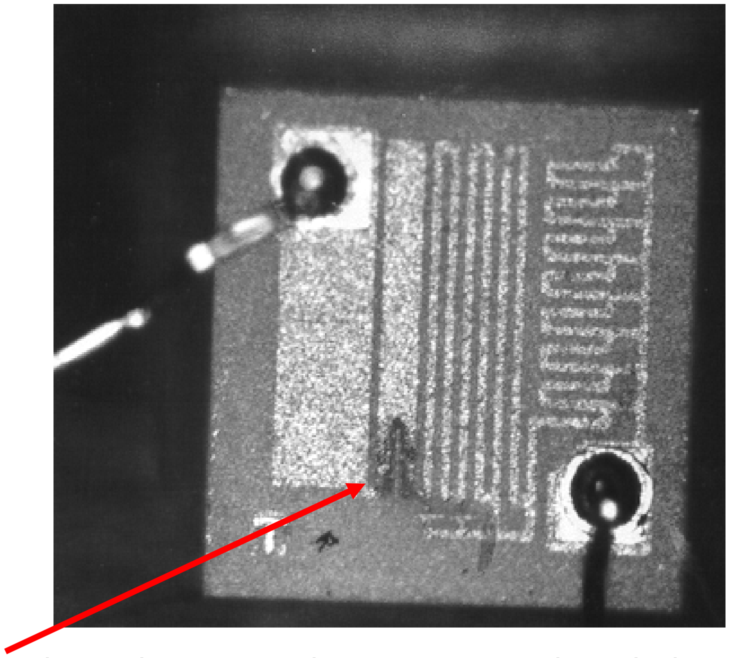


Photo above shows corrosion on an unpassivated NiCr chip resistor.

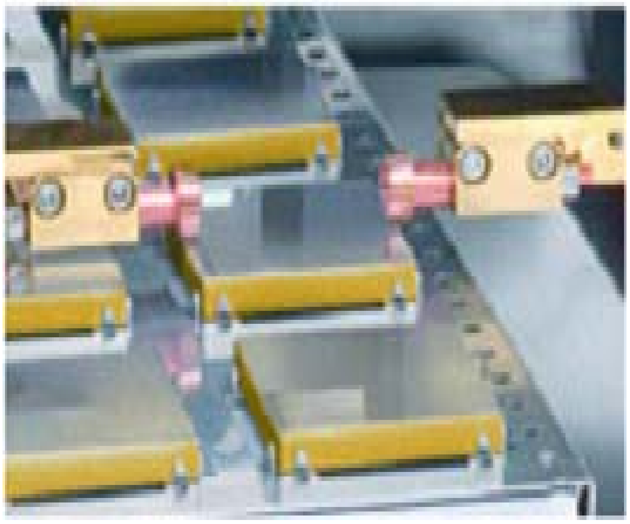
Other problems caused by moisture inside a package include: electrical leakage across pins, damage to the doped layers on a silicon chip if there are pinholes in the surface passivation, arcing in a high voltage device and "stiction" in a MEMS component. Moisture related problems over the years have been well chronicled in technical journals and discussed at length at conferences such as the Reliability Physics Symposium.

Hermetic Sealing

Per the Mil specs epoxies or other polymeric materials cannot be used to create or improve a hermetic seal, moisture will eventually penetrate through the epoxy seal and into the package. Some polymeric materials are better than others in terms of moisture permeability, and an epoxy sealed package may pass leak test. However, in time all epoxies will allow moisture into the cavity. On the other hand nothing is completely hermetic. The decision to hermetically seal depends on the sensitivity of the components to moisture and other harmful gases, customer requirements/specifications and the end use environment.

Described below are two methods to create a hermetic seal. Other materials and processes are also used including a variety of solder sealing techniques.

*Seam Sealing.....*is a process whereby the metal platings on the package are melted and a hermetic joint is formed. The sealing is done in a chamber that usually contains 100% nitrogen or a nitrogen/helium mix and is dried out to a very low (below 5000 PPM) moisture level. In a seam sealing process rollers contact the lid and a current is passed through the lid to package interface where the high resistance creates heat and locally reflows the plating materials (usually gold or nickel). The packages and lids often made from Kovar (a trade name for an iron-nickel-cobalt alloy), but other materials can be used provided the resistance is high enough to generate sufficient heat to melt the platings.



Above photo shows electrode rollers contacting the package (Ref SSEC website)

Laser Welding... is another hermetic seal process that is commonly used in the RF and Microwave industries. In this process a high powered 400 Watt Nd:YAG Laser impinges on the top cover and simultaneously melts the lid and package which results in a true weld. The laser is fixed and a CNC machine moves the part along the seal boundary. The package is often made from an aluminum 6061 alloy and the lid from Al 4047. Laser welds are generally stronger than seam sealed lids. Below is a photo of a laser weld setup.

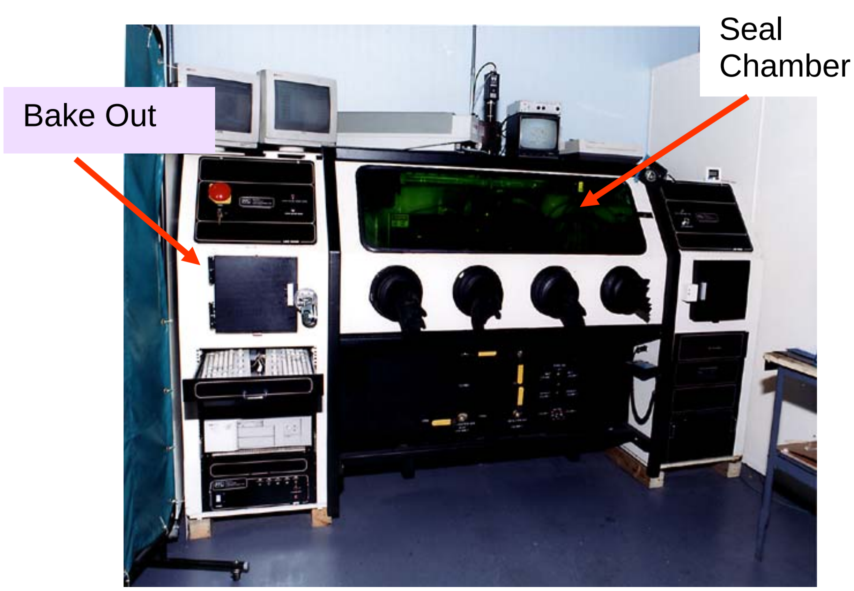


Photo of a laser sealing equipment set up (Ref EB Industries)

Each of the above methods has it's advantages and disadvantages from a quality and cost perspective, but they each serve the same purpose, and that is to seal the sensitive semiconductor element in a dry inert atmosphere and to guard against the harmful effects of moisture. Usually nitrogen or nitrogen with a small amount of tracer gas is the preferred sealing gas atmosphere.

Once successfully sealed the parts ready for leak testing per TM1014.

<u>1014 Step by Step</u>

All the test methods in Mil-Std-883 are written in a similar format. They include sections titled: Purpose, Definitions, Apparatus, Test Conditions, Procedure, Failure Criteria etc. The following is an attempt to clarify and simply the leak test techniques contained in TM 1014. It is meant as a guide and not as a replacement for TM 1014.

A breakdown of TM 1014 by Test Condition:

Test Condition A: Fine Leak using helium tracer gas

- A1: Fixed method
- A2: Flexible method
- A4: Open Can Leak for Unsealed Packages

Test Condition B: Fine Leak using a Radioactive tracer gas

Test Condition C: Gross and Fine Leak Teat Techniques

- C1: Gross Leak Bubble Test
- C3: Gross Leak Vapor Test
- C4/C5: OLT Optical Leak Detection (Gross and Fine)

Test Condition D: Gross Leak using a Dye Penetrant (Destructive)

Test Condition E: Gross Leak by Weight Gain Measurement

<u>Test Condition A</u> Fine Leak Testing Using a Helium Trace Gas

The helium fine leak detector is the most common means of testing for hermeticity. The helium leak detector is simply a mass spectrometer that is tuned to the helium peak, an easily identifiable and characteristic peak in the mass spectrum. In the leak detection equipment the helium ions strike a detector and produce a current, which in turn is proportional to the partial pressure of helium in the chamber.

The first step in helium fine leak testing is to pressurize the sealed package in a 100% helium atmosphere also known as "bombing ", and if the part has a leak some of the gas will enter through the leak path. The amount of helium that penetrates the package will depend on the size of the leak channel, the bomb time and bomb pressure. Some companies backfill with helium during the seal process to provide a quick check on hermeticity just after seal, but the TM as written requires the helium bomb. Below is a picture of the leak detector and associated bombing equipment.

Helium "bomb" chamber

Helium Leak Detector (Varian Inc)

After removal from the helium pressure bomb the part is connected to the input chamber of the helium leak detector. After a short pump down cycle the absolute amount of helium escaping from the package is measured and compared to a standard calibrated leak. This measured leak rate depends on the size of the leak path and the partial pressure of helium within the package, which in turn is a function of the internal volume of the package.

The mathematical relationship representing this physical phenomenon is known as the "Howell-Mann Equation". A form of this equation as it appears in TM 1014 is shown below and forms the basis for the test.

Part 1	Part 2	Part 3

$$R_1 = \frac{LP_E}{P_o}\left(\frac{M_A}{M}\right)^{\frac{1}{2}} \left\{ 1 - e^{-\left[\frac{LT_1}{VP_0}\left(\frac{M_A}{M}\right)^{\frac{1}{2}}\right]} \right\} e^{-\left[\frac{LT_2}{VP_0}\left(\frac{M_A}{M}\right)^{\frac{1}{2}}\right]}$$

Where:

R_1 = The measured leak rate of tracer gas (He) through the leak in atm cc/s He.
L = The equivalent standard leak rate in atm cc/s air.
P_E = The pressure of exposure in atmospheres absolute.
P_O = The atmospheric pressure in atmospheres absolute. (1)
M_A = The molecular weight of air in grams. (28.7)
M = The molecular weight of the tracer gas (Helium) in grams. (4)
t_1 = The time of exposure to P_E in seconds.
t_2 = The dwell time between release of pressure and leak detection, in seconds.
V = The internal volume of the device package cavity in cubic centimeters.

This complex equation can be easily broken down and solved using a computer or simple Excel spreadsheet. The equation contains three parts:

Part 1: Converts the true air leak rate to that of helium
Part 2: Calculates the amount of helium entering the package during the bomb cycle t_1
Part 3: Represents the amount of helium remaining in the package at test time t_2

From a practical standpoint the important parameters to track are

Bomb time t_1
Bomb pressure P_E
Package volume V
Dwell time t_2

Example using the Flexible Method

Problem: Given a hermetic package with an internal volume of .03 cubic centimeters what is the Reject limit using condition Test Condition A2 of TM 1014?

Solution:

Package Volume V = .03 cc

Using the flexible method allows for any combination of bomb time, bomb pressure and dwell time provided that the measured value R_1 is greater than the minimum sensitivity of the detector and a minimum of 30 PSIA is used for the bombing pressure. With that in mind the following test parameters are chosen:

Bomb time t_1 = 2 hours

Bomb pressure P_E = 75 PSIA or 60 PSIG

Dwell time t_2 = 1 hour

Equivalent Standard
Air Leak Rate L = 1 EE-07 atm cc/s per TM 1014
(for a package volume of .03 cc)

Plugging this information into the Howl and Mann equation and knowing the molecular weight of air and helium we calculate a measured helium leak rate

R_1 = 8.0EE-08 atm cc/s He

This means after subjecting this part to the conditions specified above the measured helium leak rate R_1 must be less that 8.0 EE-08 atm cc/s He to pass hermeticity.

For years TM 1014 allowed the use of a table to simply the process (see below) . The measured leak rate (R_1) was related to the test parameters in a Table as shown below. This was known as the "Fixed" method. However, the latest release of TM 1014 requires the "Flexible" method, unless otherwise specified in the procurement documents.

MIL-STD-883E

TABLE II. Fixed conditions for test condition A_1.

Volume of package (V) in cm^3	Bomb condition			R_1 Reject limit (atm cc/s He)
	Psia ±2	Minimum exposure time hours (t_1)	Maximum dwell hours (t_2)	
<0.05	75	2	1	5×10^{-8}
$\geq$0.05 - <0.5	75	4	1	5×10^{-8}
$\geq$0.5 - <1.0	45	2	1	1×10^{-7}
$\geq$1.0 - <10.0	45	5	1	5×10^{-8}
$\geq$10.0 - <20.0	45	10	1	5×10^{-8}

Example using the Fixed or Table Method

Using the same parameters specified above we can simply read the Table to determine the reject limit. So for a package volume = .03 cc we simply read across line one of the Table which shows that the part must be bombed at 75 PSIA for 2 hours and tested within 1 hour with a corresponding measured reject limit

R_1 = 5.0EE-08 atm cc/s He

Note: there is a slight difference in the reject limit when using the Table values vs. the Flexible equation.

Test Condition A4 : Open Can Leak

Test condition A4 is often referred to as "open can" leak testing. In this method and unsealed package is flipped upside down on a foam mat that sits on top of the input port to the leak detector. The operator then squirts helium through a needle value and moves slowly around the perimeter of the package. If there is a localized leak in the package or glass to metal feedthrough then the detector will immediately measure this spike, and the part fails. The failure criteria is 1 EE -08. The test is typically run 100% of the time by the package supplier and on a sample basis at incoming inspection by the OEM. This test not only confirms a "hermetic" package to start, but in the event of a failure pinpoints the location of the leak path. This is useful in evaluating new designs and as a process control tool.

Test Condition B: Radioisotope Fine Leak Test

This technique is similar to the helium fine leak test method except the tracer gas is a mixture of radioactive krypton-85 and dry nitrogen. Krypton 85 is a radioactive inert noble gas that emits very weak gamma rays and beta particles. Parts are soaked in the radioactive gas for a minimum of 12 minutes at 2 PSIA. Parts are then air washed to remove surface gas and placed in a chamber connected to a scintillation crystal detection system that actually counts the number of Kr-85 particles inside the package. This is different than the helium fine leak test, which measures the rate of helium leaking out of the device. The "absolute" leak rate of the device is calculated by a simple formula based on the concentration of Kr85/N2 tracer gas used, the bombing time and pressure, and the measured reading on the device.

Manual Counting Station

Ref: Iso Vac Engineering website

Refer to Table III in TM 1014 for the specification limits for different size packages.

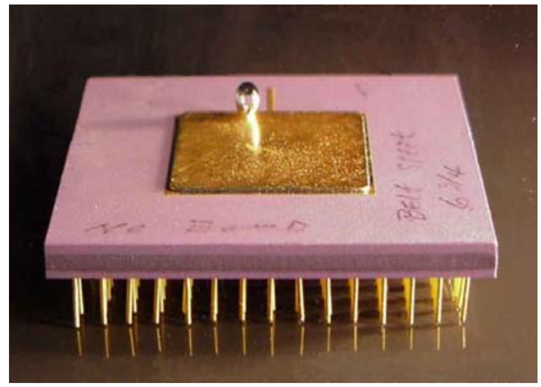
Note of caution: There are many local and federal laws that limit the discharge of radioactive gas into the atmosphere to protect operator personnel. In addition, even if a part passes the test there may still be a sufficient concentration of tracer gas to cause soft errors in complex small geometry devices.

<u>Test Condition C1</u>: Gross Leak "Bubble" Test

Historically, the most common means to check for a gross leak is to use the "Bubble" tester. During this test the operator actually looks for a stream of bubbles, or one or two large bubbles, which indicate a leaker and hence the name bubble test. The bubble test is used in conjunction with other fine leak test methods because it only indicates the presence of a large or gross leaker. The fine leak test must run first, since the detector fluid used in the gross leak test may mask a fine leak.

To start the test devices are pressured in a bath of type I detector fluid (Boiling point < 100 C) for a given time and pressure as spelled out in Table IV of the TM 1014. The parts are then dried and immersed in a bath of type II detector fluid set at 125 C. The apparatus used looks like a fish tank (see below) with a large magnifying glass in front to aid in looking for the bubbles. If during the type I pressurization cycle fluid leaks into the package it would then boil off when immersed in the higher BP detector fluid and produce a stream of bubbles. No bubbles means the part passed.

Web Model 6000 Bubble Tester



Bubbles seen escaping from the package indicating a leaker

<u>Test Condition C3</u>: Gross Leak Vapor Detection

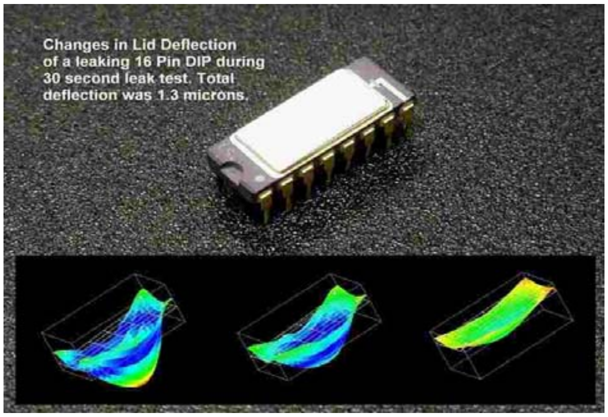
The gross leak vapor test is very similar to the bubble test. Devices are pressurized per Table IV in TM 1014 in Type I detector fluid, air dried and then, instead of placing the devices in a bath and looking for bubbles, the parts are placed in a vapor detection chamber heated to 125 C. The detector collects and measures the amount of Type I detector fluid that evolves from the package at elavated temperature. A failure occurs if the detector measures more than 0.167 microliters of type I detector fluid. There are other details spelled out in the test that must be followed such as chamber purge time for a given volume (Table V) and other precautions regarding fluid filtering, lighting etc...

Note: Type I,II and II detector fluids are perfluorocarbons containing no chlorine or hydrogen and are generally considered insert relative to microelectronic assemblies.

<u>TEST CONDITION C4/C5:</u>   OLT Optical Leak Detection (Gross and Fine)

The optical gross and fine leak test technique does not use a tracer gas or detector fluid to measure a leak, but instead measures lid deflection in response to a changing ambient pressure. The amount of lid deflection or lack thereof over the course of the test is directly correlated to a helium leak rate. Parts are placed in a vacuum/pressure chamber with an integrated laser interferometer, which is capable of precisely measuring out of plane distortions. During the test a pressure/vacuum cycle is applied and the lid of a hermetic package will distort. If the part is hermetic the lid deflection will correlate to the changing ambient pressure. If there is a large gross leak in the package the lid will not move at all as the pressure inside the package and the chamber quickly come to equilibrium. If the package has a fine leak the rate of lid movement can be measured and compared to know good devices. Knowing the pressure change inside the package a helium leak rate can then be directly calculated [3].

The expected amount of lid deformation can be calculated using a standard formula for stress and strain on a flat plate having a uniform load over the entire surface area. This in essence determines the leak test sensitivity and is described in detail in the TM. There needs to be some observable lid movement in response to a changing pressure in order to run the test. For some packages it's simply a matter of increasing the test time and/or test pressure. A package with a very stiff lid, such as glass, is difficult to test. However, the majority of most metal kovar cans and ceramic packages are easily tested using OLT. A typical chamber working pressure is about 3 atmospheres with a test time of about 4-8 minutes. In the OLT process multiple packages can be tested at the same time and unlike helium fine leak testing the failed devices are easily identified. The technique provides for a gross and fine leak check during a single test cycle and is also valid for parts already assembled onto Printed Circuit Boards.



Lid deflection as a function of a changing ambient pressure

Optical Leak Test Equipment (Ref Norcom Systems Inc)

Test Condition D: Gross Leak using a Dye Penetrant

This is a destructive test, which is sometimes used to verify a gross leak failure or as a means to identify the location of the leak path through the device. The device is pressurized (105 PSIA min 3hours or 60 PSIA min 10 hours) in a florescent dye solution (e.g. Zyglo). During the pressurization cycle, if a leak is present, the dye will find it's way into the internal cavity. The package is then carefully delidded and an ultraviolet light source (3550 A for Zyglo) is used to verify the presence of the dye penetrant, thus verifying a failure. This test is only valid as a means to verify a gross leak failure, but typically provides useful information regarding the leak path.

Test Condition E: Gross Leak by Weight Gain Measurement

Another way to determine a gross leaker is by simply weighing the package before and after a pressurization cycle in a bath of Type III detector fluid. A leaky package will naturally weigh more after pressurization cycle due to the added weight of the detector fluid. An analytical balance capable of weighing devices accurately to 0.1 milligram is required along with Type III detector fluid meeting the requirements of Table 1. The devices are dried out and accurately weighed prior to the liquid flourinrert pressurization cycle. Afterwards the devices are again dried, measured and catagorized.

The parts are rejected if the device:

Gains more than 1.0 milligrams for volume < 0.01 cc
Gains more than 2.0 milligrams for volume > 0.01 cc

References:

1. R.W. Thomas "Moisture Myths and Microcircuits" RADC 1972
2. The latest copy of MIL-STD-883 can be obtained at www.dscc.dla.mil/
3. Ref eq. 3-10 p. 55 Hermeticity of Electronic Packages by Hal Greenhouse (ISBN # 0-8155-1435-2)

About the author.....

Mr. Thomas Green is an independent consultant and respected teacher. He has over twenty-five years experience in the microelectronics industry and has worked at Lockheed Martin Astro Space and USAF Rome Laboratories. At Lockheed he was a Staff engineer responsible for the materials and manufacturing processes used in building custom high reliability space qualified microcircuits (Hybrids, MCMs and RF modules) for military and commercial communication satellites. Tom has demonstrated expertise in seam sealing and leak testing processes. He has conducted experiments and presented technical papers at NIST (National Institute Standards and Technology) and IMAPS (International Microelectronics and Packaging Society) on leak testing techniques and optimization of seam welding processes through statistical DOE methods. At USAF Rome Labs he worked as a senior reliability engineer and analyzed component failures from AF avionic equipment along with providing technical support for a variety of Mil specs and standards (e.g. MIL-PRF-38534 and MIL-STD-883). Tom is an active IMAPS member and currently serves on the Executive Board as the Northeast Regional. He has a B.S. in Materials Engineering for Lehigh University and a Masters from the University of Utah.

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