Background Statement for SEMI Yellow Ballot 4446
NEW STANDARD: GUIDE TO EVALUATING HERMETICITY OF MEMS PACKAGES

Note: This background statement is not part of the balloted item. It is provided solely to assist the recipient in reaching an informed decision based on the rationale of the activity that preceded the creation of this document.

Note: Recipients of this document are invited to submit, with their comments, notification of any relevant patented technology or copyrighted items of which they are aware and to provide supporting documentation. In this context, “patented technology” is defined as technology for which a patent has issued or has been applied for. In the latter case, only publicly available information on the contents of the patent application is to be provided.

The intent of this document is to provide guidance on evaluating hermeticity of MEMS packages, where internal volumes are much smaller than with conventional microelectronics. Both the new challenges and opportunities provided by MEMS packaging are addressed.

Many companies, universities and government agencies are involved in making improvements in MEMS packaging. MEMS is particularly challenging due to low enclosed cavity volumes, and due to increased sensitivity of enclosed devices to chemical and particulate contamination. At the same time, a good deal of confusion has been created by the expanding range of hermeticity requirements from quasi-hermetic to ultra-hermetic, and by rapidly emerging materials such as liquid crystal polymer and new manufacturing techniques such as wafer-level and chip-scale packaging. The expected impact of this Guide is acceleration of cost reduction and product reliability improvements for the targeted MEMS devices, leading to higher levels of acceptance in the marketplace.

This document is directed towards evaluation of the hermeticity of MEMS packages. Areas that are addressed include hermeticity testing; sealing methods; and recommendations on evaluating hermeticity of packages having small volumes.

Devices where hermetic packaging is relevant included inertial navigation, i.e. gyroscopes and accelerometers; RF MEMS switches; optical mirrors and switches; pressure sensors; resonators; filters; and microfluidics including valves and pumps.

This letter ballot will be reviewed and adjudicated by the MEMS Committee on Monday, October 13, 2008 in San Jose, California at the SEMI Headquarters Office.

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SEMI Draft Document 4446
NEW STANDARD: GUIDE TO EVALUATING HERMETICITY OF MEMS PACKAGES

1 Purpose
1.1 Microelectromechanical systems (MEMS) are miniaturized systems requiring packaging for environmental protection and for interconnection. While there are a wide range of MEMS devices, a common need is for packaging that allows movement of the internal device during operation. This is in contrast to the typical integrated circuit that requires only that the device be protected from the environment and that appropriate interconnections are made. In many cases, hermeticity is critical to MEMS device functionality. In other cases, hermeticity is primarily important to reliability of MEMS devices, similarly to integrated circuits. To accelerate improvements of packaged MEMS devices, leading to higher levels of marketplace acceptance, a guide to evaluating hermeticity of MEMS packages is required.

1.2 This document is intended to provide an overview of hermetic packaging with emphasis on the evaluation of hermeticity of the smaller internal volumes typical of MEMS.

2 Scope
2.1 This guide is directed towards evaluating hermeticity of MEMS packages. Areas to be addressed include materials and equipment for producing and evaluating hermetic seals; methods for detection and measurement of leakage; and considerations and recommendation on evaluation of hermeticity.

2.2 This guide is applicable for use in connection with establishment of evaluation methods and procurement of materials, equipment and facilities relating to manufacturing, quality and reliability assurance for all phases of research, development, and production.

2.3 Devices for which this guide is expected to be relevant include, but are not limited to, gyroscopes and accelerometers; RF MEMS switches; optical mirrors and switches; pressure sensors; resonators; filters; and microfluidics devices including valves and pumps.

NOTICE: This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the users of this standard to establish appropriate safety and health practices and determine the applicability of regulatory or other limitations prior to use.

3 Limitations
3.1 Users of packaged MEMS devices require assurance that hermeticity is adequate both initially and over operating life. In turn, designers and manufacturers of MEMS packages must be able to demonstrate that internal ambient conditions of packaged devices meet design requirements:

- manufactured seals have sufficient integrity;
- material permeability to gases and liquids present in the operating environment is compatible with maintenance of internal ambient conditions over operating life and;
- outgassing is managed to ensure maintenance of internal ambient conditions over operating life.

However, the current document is primarily focused on evaluation of hermeticity at or near the time of initial manufacture. A future document will address reliability of hermeticity over operating life.

3.2 The maximum permissible leak rate of a hermetic package is unavoidably related to the degree of outgassing and permeation, since these mechanisms lead to buildup of moisture levels internal to the package. For purposes of the current document it is assumed that the packaging materials and processes are sufficiently well controlled that outgassing and permeation effects are negligible. This simplifies determination of the maximum permissible leak rate.
4 Referenced standards and documents
4.1 Referenced standards
4.1.1 SEMI MS3-0307 Terminology for MEMS technology
4.1.2 Mil-Std 883, Test Method 1014.12 and Test Method 1018 (download latest revision at www.dscc.dla.mil/)
4.1.2.1 Fine leak testing using helium
   - Fixed method – helium bomb specific time and pressure
   - Flexible method – helium bomb conditions to match mass spectrometer
   - Open can leak – expose package to flowing helium
4.1.2.2 Radioisotope fine leak test
4.1.2.3 Fine and gross leak test techniques include:
   - Gross leak bubble test
   - Gross leak, perfluorocarbon vapor detection
   - Optical leak detection (lid deflects in response to pressure changes)
4.1.2.4 Gross leak using a dye penetrant
4.1.2.5 Gross leak by weight gain measurement
4.1.3 ASTM F97-72 (2002)e1 Standard practices for determining hermeticity of electron devices by dye penetration
4.1.4 ASTM F98 Practices for determining hermeticity of electron devices by bubble test
4.1.5 ASTM F134 – Test methods for determining hermeticity of electron devices with a helium mass spectrometer leak detector
4.1.6 JEDEC JEP144 Guideline for Residual Gas Analysis (RGA) for Microelectronic Packages
4.2 Other documents
4.2.6 C. Pernicka, “The Value of RGA in Semiconductor Manufacturing” (paper presented at the RGA Task Group, JEDEC/G-12 Meeting, Columbus, OH, Sept. 8, 2003
4.2.10 Davy, J. Gordon, “How to calculate the true permissible leak rate and how to raise it by four orders of magnitude”, IEEE Transactions on components, hybrids, and manufacturing technology, Vol. CHMT-8, No.3, September 1985, pp. 359-365
4.2.11 Moisture Ingress into Nonhermetic Enclosures and Packages - a Quasi-Steady State Model for Diffusion and Attenuation of Ambient Humidity Variations, M. Tencer, Electronic Components and Technology Conference, 1994


This paper reports excessive wear-out of micro-motors in very dry ambient.


4.2.15 McIlknap, John S., “Reliability, testing and qualification of the TeraVicta RF MEMS switch”, Proceedings of SPIE, The International Society for Optical Engineering, Conference No. 5, January 2006, San Jose, CA


4.2.18 Theoretical investigation on hermeticity testing of MEMS packages based on MIL-STD-883E, Yi Tao et al., Microelectronics Reliability 45 (2005) 559–566

NOTICE: Unless otherwise cited all documents shall be the latest published versions.

5 Terminology

5.1 Abbreviations and Acronyms

5.1.1 None

5.2 Definitions

5.2.1 Device under test (DUT) – the device undergoing evaluation

5.2.2 Equivalent standard leak rate – the leak rate when the pressure one side of the package is at standard temperature and pressure (~ 760 mm Hg absolute) while the other side of the package is at vacuum (less than 1 mm Hg absolute), often referred to as the true leak rate, or the leak rate normalized for a unit pressure differential.

5.2.3 Hermetic package – completely sealed with minimal communication of either gases or liquids between the interior and the exterior of the package over operating life.

5.2.4 Hermetic vacuum package – hermetic package sealed with vacuum in the interior of the package.

5.2.5 Material permeability – the tendency of gases to directly migrate through the walls of the package. Bulk permeability depends on both chemical composition and diffusion. For example, diffusion of gases may be accelerated along grain boundaries. Stainless steel in half-hard condition will have small grain sizes relative to package wall thickness, while in fully annealed condition the grain size may be comparable to package wall thickness. In the latter case permeability is increased although the chemical composition is unchanged.

5.2.6 Measured leak rate – the leak rate of a given package as measured using a specific set of operationally defined conditions and test media, often referred to as the apparent leak rate.

5.2.7 Micro Electro-Mechanical System (MEMS) – see ¶ 4.1.1 (“integration of microelectronics devices or fabrication technology with micrometer-scale mechanical devices to form a system”).

5.2.8 Near hermetic package – at least a portion of the package materials are formed of materials having permeability as high as $10^{-8}$–$10^{-10}$ atm-cc/sec. One such material is liquid crystal polymer (LCP).

5.2.9 Outgassing – release of gases absorbed on interior package surfaces or evolution of gases due to chemical change of enclosed materials. For example, epoxies, silicones, and Teflon all tend to outgas water vapor. As the pressure is reduced below about 100 millitorr, much of the load in a vacuum hermetic package may be from outgassing. In addition, outgassing may be due to virtual leaks, or slow release of gases that have been inadvertently trapped within the enclosure.

5.2.10 Quasi-hermetic package – hermetic over a limited amount of time. Conventional package materials such as metal, glass or ceramic are used but an organic adhesive material forms the seal.
5.2.11 Seal integrity – evaluation of the seal material for any paths that could allow environmental conditions to ingress the cavity or egress from the cavity and the bond quality between the package and seal material or the seal material and the lid. The width or thickness of the seal material may also be important to the integrity, based on the permeability of the material and/or structural strength required for the application.

5.2.12 Time zero – the beginning point of the operating life of a packaged devices, generally the time at which the hermetic seal is actually formed. (Note that when surface mount reflow follows formation of the hermetic seal, this definition holds only assuming that the high reflow temperatures do not irreversibly alter the hermetic seal. Otherwise, time zero would begin at completion of surface mount reflow.)

6 Reliability categories by application requirements

6.1 The reliability categories are defined as:

<table>
<thead>
<tr>
<th>Category (see 6.2)</th>
<th>Lifetime in years</th>
<th>Temperature range °C</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1A or R1B or R1C</td>
<td>&gt; 10</td>
<td>-55 – +150</td>
<td>Military, space, aviation</td>
</tr>
<tr>
<td>R2A or R2B or R2C</td>
<td>&gt; 10</td>
<td>-20 – +65</td>
<td>Telecommunications</td>
</tr>
<tr>
<td>R3A or R3B or R3C</td>
<td>5 – 10</td>
<td>-40 – +125</td>
<td>Automotive</td>
</tr>
<tr>
<td>R4A or R4B or R4C</td>
<td>2 – 5</td>
<td>-20 – +65</td>
<td>Industrial</td>
</tr>
<tr>
<td>R5A or R5B or R5C</td>
<td>0 – 2</td>
<td>0 – +50</td>
<td>Commercial, consumer</td>
</tr>
</tbody>
</table>

* There is some arbitrariness in defining categories as above. The intention is to provide some structure to guide discussion. The specified lifetime and temperature ranges are intended to approximate requirements for the listed applications.

6.2 The reliability category is further defined by the letter “A” to indicate that the performance of the enclosed device is directly related to the package hermeticity; the letter “B” to indicate that the package hermeticity is required only for general reliability; or the letter “C” to indicate that hermeticity is only required to protect the MEMS during the assembly and surface mount processes. For example, reliability category R3B may refer to an automotive application where the required operating life is 5 – 10 years, the operating temperature range is -40 to +125 °C, and the hermeticity is required only for general reliability.

7 Hermetic sealing

7.1 Sealing materials:

7.1.1 The choice of hermetic sealing materials is intimately related to the sealing methods and equipment to be used. Generally, sealing materials comprise metals, inorganic glasses, or polymers. Metal, glass and polymer sealing materials are capable of supporting seals at the leak rate levels of about 10^-16 (calculated, not measurable), 10^-10, and 10^-6 atm-cc/s, respectively. Metal sealing materials are recommended for categories R1, R2 and R3, while glasses can be used for category R4 and perhaps for R3.

7.1.2 In the past polymer materials have not been capable of qualifying for hermetic seals. Newer materials such as liquid crystal polymer (LCP) are capable of quasi-hermetic or near hermetic seals. Such near hermetic polymer sealing materials may be considered for category R5 applications.

7.1.3 In direct bonding, the seal is composed of the interface between the two substrates being bonded. The interface layer is usually very thin, on the order of a few nanometers, and comprised of an oxide layer. For example, for direct bonding of silicon to silicon, the interface seal is comprised of only silicon and silicon dioxide.

7.2 Sealing methods and materials:

7.2.1 Intermediate layer bonding

7.2.1.1 Eutectic/Solder bonding – a wide range of low-melting point eutectic alloys have been applied as intermediate layer bonding material. Generally it is desirable to apply alloys having a low melting point. In addition, corrosion resistance or compatibility with harsh environments is often a selection criteria. The eutectic alloy of gold and tin (AuSn) has a eutectic point of 280°C and is often chosen for critical applications. For lower cost applications, both solder materials and the eutectic alloy of aluminum and germanium (AlGe) having a eutectic point of 424°C are attractive alternatives. Solder bonding is a type of eutectic bonding involving materials containing tin (Sn) alloyed with other elements. Solder material placement in the bond zone is by evaporation,
screen printing, or performs. In the past, lead-tin (PbSn) solders have been widely used. Recent trends are towards lead-free solders, such as tin-silver-copper (SnAgCu). Eutectic alloy is placed on a piece part having a metal film able to wet the alloy (for example, Gold (Au) with an underlayer is often used). Following placement the piece part is brought into close proximity with the part to which it is to be joined, and the assembly is heated above the eutectic temperature.

7.2.1.2 Welding – can be accomplished by application of energy directly to the mating joint. Both laser and electron beam welding develop localized power density of about 100 Watts/cm² in the weld joint, with minimal heating of adjacent components. While both methods produce high quality joints, electron beam welding is higher cost since it must be completed under vacuum. Arc welding, having advantages of much lower capital and maintenance costs, can also be used but is considered to be less clean due to use of fillers and fluxes. The associated materials may introduce contaminants that result in outgassing during operating life. In addition, heat is not as localized as with laser or electron beam welding.

7.2.1.3 Glass frit – is generally placed by screen printing. Following a drying cycle, a glazing step done at 400 °C or greater results in volatilization of most of the binders. Then the parts to be joined are mated and the temperature is raised above the melting point of the glass frit, typically 25 °C or more above the temperature of the glazing step. Glass frits specifically designed for compatibility with MEMS devices are available for joining silicon (Si) to alumina, borosilicate glass or Kovar.

7.2.1.4 Adhesive bonding – a wide variety of materials such as epoxy and cyanoacrylate support adhesive bonding. Generally, adhesive bonding materials are incompatible with hermetic seal formation due to high permeability.

7.2.1.5 Other polymer bonding – several materials are available for spin coating or lamination. For example, benzyocyclobutene (BCB), SU8 and polyimide materials can be spin-coated onto substrates and are capable of providing a seal. Unfortunately, the seal is inadequate for many hermetic applications due to high permeability. When the polymer bond layer is thin and the joint is wide, the bond joint may qualify as being near-hermetic or quasi-hermetic. Liquid crystal polymer (LCP), available in both laminate and spin-coat formats, is capable of providing near-hermetic performance and may be considered for R5 applications. (see ref. ¶ 4.2.1, 4.2.2, 4.2.3)

7.2.2 Direct bonding

7.2.2.1 Fusion bonding – provides nearly perfect hermetic seals. The method requires that mating surfaces be polished to Ra (average of a set of individual measurements of a surfaces peaks and valleys) of less than 2 nanometers. In addition, final bond formation requires exposure to temperatures in the range of 800 – 1100 °C for several minutes. Fusion bonding is flexible for a wide range of materials, but most typically involves silicon.

7.2.2.2 Anodic bonding – provides an excellent hermetic seal. The method is applicable to a few ion exchange materials. For example, 7740 Pyrex glass is often used to join with silicon (Si). Importantly, this particular glass contains about four percent sodium oxide (Na2O), which provides ions for exchange. The mating surfaces must be polished to Ra of less than 20 nanometers, less stringent than that required for fusion bonding. The method involves simultaneous exposure to temperature in excess of 350 °C and voltage in excess of 1,000 volts.

7.2.2.3 Metal-to-metal bonding – a hermetic metal-to-metal seal may be formed by diffusion, friction-stir or ultrasonic bonding.

7.2.2.3.1 Diffusion bonding is a direct bonding process resulting in hermetic bonds with no adhesive. Sometimes interfacial materials are used to enhance the bonding process although these materials are not adhesives. Diffusion bonding can be used for a variety of solid materials and is not limited to metals. Diffusion bonding permits formation of complex shapes with minimal machining. The method requires that the mating surfaces be in intimate contact during the bonding process. Bonding is accomplished by controlled application of physical pressure and temperature over a specific time period. A partial list of test techniques relevant for determining bond integrity are peel strength testing, lap shear testing and burst testing.

7.2.2.3.2 Friction stir bonding is another technique that has been applied for joining metals. Generally, friction stir bonding is used with aluminum (Al) and aluminum alloys.

7.2.2.3.3 Ultrasonic welding has been widely used for joining of thermoplastics, but can also be used with metals. Ultrasonic welding of metals is generally limited to thin sections and small welds of materials such as aluminum, copper and nickel.

7.2.3 Wafer level sealing by encapsulation

7.2.3.1 Sealing by encapsulation provides an alternative method of hermetic sealing wherein a polysilicon shell is formed over a cavity integral to wafer fabrication. According to this method, a sacrificial thin film is deposited over
the device requiring hermetic seal. The sacrificial thin film is patterned and etched to remove the material in a region surrounding the cavity being formed. Next a polysilicon thin film having thickness of perhaps 2.0 micrometers is deposited and forms a seal to the surface. An access hole is opened in the polysilicon thin film to allow for penetration of an etchant. An etch procedure is applied to dissolve the sacrificial thin film from beneath the polysilicon shell, forming a cavity surrounding the device. Finally, depositing additional thin film material under vacuum seals the access hole. For example, the access hole may be sealed by sputtering silicon nitride (Si$_3$N$_4$) at a pressure of about 10 millitorr. This sealing method has gained favor where smallest size and low cost are required. The method requires that the device being sealed is unaffected by the etchants being used.

7.2.3.2 This method results in ultra-small hermetically sealed volumes, posing special challenges for evaluating hermeticity.

8 Seal integrity evaluation

8.1 Adequate seal integrity is one requirement for package hermeticity. Current methods for evaluation of seal integrity include acoustic (ultrasonic) and X-ray inspection. Acoustic inspection typically involves imaging based on reflection from interfaces and is highly sensitive in detecting unintended gaps between package members. X-ray inspection typically involves imaging based on transmission and is highly sensitive in detecting variations in density. Ultrasonic imaging may or may not be destructive, depending on details of implementation. X-ray inspection may be considered to be non-destructive, assuming that the packaged device is not sensitive to the radiative energy. Acoustic Microscope (AM) inspection can also be performed at wafer level, immediately after wafer bonding. (For this reason AM is often used for inspection of SOI wafer bonds.) The technique is useful during process development. However, at present it is not possible to use AM inspection when an edge is adjacent to the region to be imaged, as occurs when forming cuts in the lid of a package to access interconnect points. In addition, insight on seal integrity can be gained by integration of microsensors in the package.

8.2 AM inspection Method for inspecting package seal integrity

8.2.1 The spot size of the transducer and pixel spacing chosen for the AM imaging is selected to adequately view the details of interest.

8.2.2 The part to be examined is placed within the scan stage of the AM system.

8.2.3 The selected transducer is centered over the part to be examined.

8.2.4 Scan size and resolution (pixel spacing) are chosen to be adequate for imaging the whole wafer or the individual part being examined.

8.2.5 A time base scale adequate to view the A-Scan is selected.

8.2.6 After finding the edges of the part, the transducer is re-centered based on the edges of the part.

8.2.7 The front interface echo, which is associated with the surface of the part, is found by examining the acoustic scan.

8.2.8 The gate position (echo time slice) and width are adjusted to completely enclose the front interface echo.

8.2.9 The transducer is lowered until the acoustic scan echo from the surface is at its maximum height, indicating it is at the optimum focus level.

8.2.10 The part is scanned to produce a surface image.

8.2.11 The acoustic surface image of the seal integrity is further optimized by adjusting the transducer height and signal gain and by setting the gate so that it completely encloses the cover to cavity echo. Typically the signal gain is adjusted so that the maximum A-scan height within the gate is between 90 and 100% of maximum.

8.2.12 The scan command is executed to acquire an AM image of the seal level.

8.2.13 Images are saved as appropriate.

8.2.14 Seal integrity is evaluated by analyzing the AM image manually or with image analysis software. The actual width of the window seal bond surrounding the cavity is measured to determine if it is within an acceptable range for the application and whether any channels or paths that could allow contamination of the cavity are present.

8.3 X-ray inspection

8.3.1 Methods for determination of seal integrity by X-ray inspection are very similar to that for ultrasonic inspection except that it is a through transmission rather than a reflection technique.
8.3.2 Rather than adjusting for variation in pulse echoes as with ultrasonic inspection, X-ray inspection imaging requires adjustment of energy level and contrast to compensate for variations in density to obtain an image of the seal being inspected.

8.4 Integrated sensors

8.4.1 Sensors may be integrated into the package for the sole purpose of providing information on the level of hermeticity.

8.4.2 Examples of micro sensors available for integration to package cavities to detect the presence of air instead of the normal packaging atmosphere include:

- Pirani gauge for measurement of thermal conductivity
- Resonator for measurement of absolute pressure
- Spark gap for measurement of dielectric strength
- Inter-digitated combs for measurement of surface moisture conductivity

8.5 Fourier transform infrared (FTIR) Inspection

8.5.1 When the bonding atmosphere is a gas whose main infrared (IR) absorption peak lies within the lid IR transmission window (for example sulfur hexafluoride with a silicon lid), reflective FTIR spectroscopy (¶4.2.17) may be used to detect the presence of gas in the cavity.

8.5.2 The reduction or absence of the characteristic absorption peak in the FTIR spectrum is interpreted as due to a gross leak. The technique is useful during the development phase as it is non-destructive and may be used at wafer level and even after die singulation. However, it is time-consuming unless fully automated, which is difficult.

8.5.3 The method is incompatible with the presence of a strongly absorbing or reflective layer on the lid.

9 Detection and measurement of hermetic package leakage

9.1 The most commonly used method of testing hermeticity involves application of a tracer gas. The method relies on first forcing a tracer gas into the interior volume of the package (bombing) and later monitoring the evolution of the tracer gas back out of the package (fine leak testing). Helium is predominantly used as the tracer gas. Optical lid deflection is evolving as an alternative to tracer gas testing, but may place additional constraints on the package design. With optical lid deflection testing the package is also subjected to pressure bombing. The lid must both deflect sufficiently to enable optical measurement and withstand the bombing pressure without rupture.

9.2 Helium leak testing is specified in referenced standards ¶ 4.1.2. The test method is based on the assumption that a small gap or opening in a hermetic seal, often called a capillary, allows for diffusion of gas from the surrounding ambient to an enclosed cavity at a finite rate. The rate of diffusion is assumed to be proportional to the pressure differential across the package. Helium gas is first diffused into the enclosed cavity by placing the DUT into a high-pressure helium-filled chamber to force helium through the opening and into the enclosed cavity. The DUT is then removed and placed into a second chamber that is evacuated. For a given range of openings in the hermetic seal helium will leak out at a rate that can be detected using a mass spectrometer tuned to helium. For an opening that is too large, helium will leak out rapidly and no helium will be detected during the fine leak test. Such DUTs may be found by performing an additional gross leak test. For an opening that is too small or for very small enclosed cavities, little helium is captured in the enclosed cavity during the initial high pressure step. Of the helium that is captured, only a small amount will be available to leak out during the second step, making detection challenging. The minimum detectable opening size depends on the exact test parameters and on the resolution limit of the mass spectrometer. The special problem of MEMS devices is that enclosed cavity sizes are very small, leading to a challenging problem for helium leak detection.

9.3 Radioisotope fine leak test is also specified in referenced standards see ¶ 4.1.2. The method is similar to that used in helium leak detection. Instead of using helium, a radioactive tracer gas such as Krypton-85 is forced into the DUT enclosed cavity during an initial high pressure step. Leak of the tracer gas is detected during a second step involving a Geiger counter for detection of the radioactive gas. The special problem of MEMS devices is the same, namely a very small enclosed cavity sizes. The resolution limits of the radioisotope fine leak test must be separately considered.
9.4 Optical lid deflection is also specified in referenced standards see ¶ 4.1.2. According to this method, a DUT must have a lid that is thin enough to deform with atmospheric pressure applied to the exterior and vacuum in the interior of the package. Lid deflection is measured by optical interferometer analysis. According to the method an initial measurement of lid deflection is made on both calibration devices and DUTs. Following a time interval that may include a pressurization step a second measurement of lid deflection is made. With the optical lid deflection test method gross leaks are discovered during the initial measurement as there is little or no deflection. Again, the minimum detectable opening size depends on the exact test parameters and on the resolution limit of the interferometer.

9.5 Gross leak test methods including bubble test, vapor detection, dye penetrant and weight gain are specified in referenced standards (¶ 4.1.2, 4.1.3, 4.1.4). Although in general there are no special challenges posed by executing the test for MEMS devices, the smallest leak rate that can be detected using this method is in the range of $10^{-4}$ to $10^{-5}$ atm-cc/s (¶ 4.2.4, 4.2.18). As will be seen in later discussion, this is an important limitation for small volume packages.

9.6 Micro-residual gas analyzer (micro-RGA) is a relatively new, time-of-flight technique allowing for destructive analysis of the gaseous contents of a package. The technique involves rupture of the package followed by real-time analysis of the gases evolving from the interior. Micro-RGA may be used during a design qualification stage to establish that materials permeability and outgassing are compatible with requirements for a given reliability category. In addition, micro-RGA may be used for ongoing statistical sampling to provide correlation to gross and fine leak test results (¶ 4.2.5). For small volume packages typical of MEMS, once hermetic sealing is achieved outgassing is often the primary limit on package lifetime. Therefore, micro-RGA appears to be a valuable tool.

9.7 Cumulative helium leak detection (CHLD) is another relatively new test method in which a cumulative measurement is made of helium that has escaped the package volume. According to this technique, a cryopump system is used to pump an unvented chamber. In operation, cryopumps freeze all gases except for hydrogen and helium. Since helium is not pumped, the concentration of helium in the vacuum chamber continues to rise as helium escapes the package. Similar to conventional helium leak detectors, gases evacuated from the test chamber pass through a mass spectrometer for analysis. Rather than using the amplitude of helium detected, the rate of increase of helium with time is used to calculate leak rate. This method enables a much more sensitive measurement approaching $10^{-14}$ atm-cc/sec (¶ 4.2.6) and also allows for determination of both fine and gross leaks in a single chamber.

9.8 High throughputs, commercially available systems can perform both gross and fine leak testing in the same chamber by pressure decay technique. With this method the DUT is placed inside a small hermetic pressure vessel. The vessel is pressurized and the vessel internal pressure is monitored over time. Any package leak will let air from the vessel into the package cavity. The larger the leak, the faster the drop in vessel internal pressure. Packages are screened according to the pressure drop rate.

10 Test equipment

10.1 Tracer gas leak detection:

10.1.1 The typical tracer gas leak detection system involves a pressure bombing station and a fine leak detection station. Units passing fine leak must also be tested for gross leak using a separate system. The most commonly used tracer gas is helium. Radioactive Krypton gas is an alternative. Since the methods are very similar, helium gas leak detection is discussed in depth.

10.1.2 The general consensus is that the raw sensitivity of helium gas detection is limited to about $1.0 \times 10^{-11}$ atm-cc/sec. This may be referred to as the instrument baseline. Given the several unknowns relating to background concentration of helium, it may be practical to perform pass/fail tests at $5.0 \times 10^{-11}$ atm-cc/sec. However, to meet a suggested signal to noise ratio of 20 the minimum level for performing pass/fail tests is $2.0 \times 10^{-10}$ atm-cc/sec. Under ideal circumstances and with conventional package volumes of 0.2 cc or greater, pass/fail testing at $5.0 \times 10^{-9}$ atm-cc/sec can be accomplished in about one minute. Increasingly longer test times are required to demonstrate compliance to tighter hermeticity requirements, as the measured leak rate asymptotically approaches the baseline. In a well-characterized and repeatable system, testing can be speeded up by capturing the zero offset and adjusting the measured value accordingly. Using this approach, testing to $2.0 \times 10^{-10}$ atm-cc/sec can often be completed in less than 2 minutes.

10.1.3 Tracer gas pass/fail type testing is qualitative in nature and has merit only for devices with relatively large cavity volumes for which there is a one-to-one correspondence between the measured and true leak rates in the domain of interest for the fine leak test. The Howl and Mann equation (¶ 4.2.7) has an inherent advantage in that it...
can be used more quantitatively with user specified test and rejection criteria in the form of the Flexible Method (¶ 4.1.2, 4.1.5). However, it should be noted that good packages can fail and bad ones can pass under the current Mil Std. criteria if the cavity volumes are smaller than about 10⁻³ cc (ref. ¶ 4.2.8, 4.2.18).

10.1.4 A typical pressure bombing station has throughput of about 20 - 200 parts per cycle. In operation DUTs are often placed in a basket, and the basket is placed inside the bombing chamber. The pressure is raised to the target value of 2 – 10 atmospheres and held for the required time, typically 2 – 10 hours. The bombing station may be vented with air or nitrogen with a stream directed onto the packages in order to blow off helium that may be clinging to the exterior of the packages.

10.1.5 Once the basket of parts is removed from the bombing station, batches of 4 – 6 parts are typically placed into a small cup and loaded into the fine leak system. The chamber holding the DUTs is mechanically pumped to a few millitorr, a valve is opened and the gases in the chamber are sampled through an orifice connected to a turbopumped mass spectrometer. At the level of 5.0 X 10⁻⁹ atm-cc/sec and conventional package volumes of 0.2 cc or greater, a typical cycle time to pump to baseline and measure tracer gas is less than one minute. Roughly, 40 batches of parts can be tested per hour with these conditions. The measurement cycle increases as the volume decreases. For this reason larger batch sizes may be considered when measuring DUTs having small packager interior volumes.

10.1.6 The dwell time between bombing and helium leak testing may vary considerably. The first batch to be leak tested may see a dwell time of only two or three minutes. All DUTs that have completed the bombing cycle should be completed through tracer gas detection within 60 minutes of completing bombing (ref. ¶ 4.1.2). The effect of dwell time must be taken into account for the most precise determination of leak rate. However, past practice has been to ignore this variable as long as dwell time is limited to 60 minutes.

10.1.7 When a given batch fails, additional testing is required to isolate the flawed DUT.

10.2 Optical lid deflection leak testing:

10.2.1 The typical optical lid deflection leak detection system involves only a pressure bombing station. Both gross and fine leak are detected in a single chamber. Although in principle any gas will work, helium is used to generate the pressure due to its small atomic radius, chemical inertness, and ready availability.

10.2.2 It is not straightforward to compare sensitivity of optical lid deflection of tracer gas leak detection methods, as the degree of lid deflection depends on design variables such as internal volume, lid area, thickness, and material. Generally, comparable sensitivity may be achieved by appropriate package design.

10.2.3 In operation, typically about 100 parts are loaded into a tray having pockets designed to accurately locate the DUTs. The tray is then loaded into the test chamber and pushed against locating pins to establish a reference position relative to a camera that images the entire tray. For conventional DUT the tray area may be about 30 to 60 square inches, while for small packages typical of MEMS the tray area may be only about 5 to 10 square inches. It is desirable to acquire a minimum of 100 pixels per DUT. The test chamber is first purged and then pressurized to 2 – 4 atmospheres, with helium. Following a stabilization period, typically about one minute in duration, the pressure is modulated in order to extract the rate of change of lid deflection with pressure. Typical modulation may be a sinusoid having amplitude of 0.5 – 5.0% of the full applied pressure and period of 1 – 5 minutes. Larger modulation amplitudes are required for devices having stiffer lids or smaller enclosed package volumes. A typical test time is 4 - 10 minutes, although longer times and higher pressures may be required to obtain desired sensitivity for testing of small volumes.

10.2.4 Laser interferometry is used to quantify changes in lid deflection with time and applied pressure. However, similarly to tracer gas leak detection, qualitative pass/fail type test results are the norm. An advantage is that both gross and fine leaks are detected in a single chamber.

10.2.5 The interpretation of test results may require advance characterization and compensation for materials. For example, with material such as LCP the lid deformation has a visco-elastic behavior instead of a purely elastic behavior as with a material such as silicon. (Same for the pressure decay technique.) A good practice is to obtain and optically test a small population of packaged parts that are known to be hermetic. Test parameters intended for follow-on testing of this particular package should be used, with lid deflection versus pressure data extracted.

10.2.6 Whereas tracer gas leak detection is susceptible to false signals due to tracer gas adsorbed onto external package surfaces, optical leak detection is completely insensitive to this type of error.
11 Comments on quality and reliability assurance

11.1 Design verification may involve extensive testing on a few units with the goal of measuring key parameters and validating key design assumptions. Both permeability and outgassing in hermetic packages occur continuously over operating life and may not be testable at time zero. Therefore, performance for these attributes is typically guaranteed by design. For example, the permeability of a package is governed by the material type and thickness of the package walls. Typically, coefficients of permeability are assumed during the design phase and the design is completed. Verification of overall package permeability is required on initial production units and may not be required for future production. Design verification often involves a series of non-destructive followed by destructive tests.

11.2 Design surveillance may be required depending on the characteristics of the specific package materials. For example, polysilicon is the material comprising the sidewalls of many MEMS hermetic packages. The coefficients of permeability of polysilicon may vary depending on the deposition conditions and the thermal history of the films, which may also vary between production lots. Therefore, some form of ongoing surveillance may be required to monitor possible changes in the permeability of the polysilicon films. Design surveillance may also involve a series of non-destructive followed by destructive tests.

11.3 Batch qualification is a useful method for screening a batch of production devices. The intention of batch qualification is to avoid incurring significant costs in further assembly and testing of units that are members of a batch of material having a common flaw. Batch qualification testing is typically not visible to the user and is seldom standardized. However, batch qualification may become more important for reliability categories R4 and R5, or when applying new technology such as wafer-scale polysilicon sealing of MEMS devices.

11.4 Individual unit testing is often unavoidable and may be required at each of the first and second package levels. The industry norm for hermetic packages having reliability category R1, R2 and R3 is to perform Gross and Fine leak testing on 100% of individual units. Statistically based sampling plans may be applied for reliability categories R4 and R5 in order to reduce manufacturing costs. It is typically assumed that permeability and outgassing over life are guaranteed by design and cannot be verified by individual unit testing.

11.5 Integrated sensors are useful for individual unit testing. In some cases data may be extracted immediately following wafer fabrication. In any case such data may be collected following surface mount.

12 Considerations in evaluating hermeticity

12.1 Hermeticity of a packaged device is compromised with time due to a combination of leak and permeation of the packaging materials. In addition, internal out-gassing or surface desorption of contaminants such as hydrogen, carbon dioxide, water vapor, organic residues or other chemically-reactive gases lead to an increase in vacuum level over time.

12.2 Leaks can be considered to be due to an actual opening in the package, typically a defect incorporated in the sealing material. Consequently, a leak can be modeled as an opening of a fixed diameter and path length, with either a pressure difference, a species concentration difference, or both between the interior and exterior of the package driving communication of gases.

12.3 Out-gassing or surface desorption is due to transfer of material from being incorporated on or in the interior surfaces of the package to being in the gas phase. Such transfer may be due to simple desorption or to chemical reaction resulting in the production of gases.

12.4 Permeability is a temperature dependent material property. The rate of permeation of a hermetic package depends on the temperature, geometries, the material properties, and the partial pressure difference between the outside and the inside of the package. In addition, it should be kept in mind that for reliability category B the permeability of water is of primary concern, and the permeation rate is often concentration dependent. For all-metal enclosures the effect of permeability is generally much less than the effect of leaks. There is less cumulative experience with non-metal enclosures and some caution should be exercised in considering permeability.

12.5 Individual unit testing can be applied to measure hermeticity at or near time zero. Individual unit testing of hermeticity over operating life is not practical (except perhaps when integrated sensors are applied). A combination of design verification, design surveillance and batch testing can be applied to make statistically based predictions on hermeticity over operating life.

12.6 The maximum permissible leak rate is determined by the package internal volume, the required operating life of the package, and the maximum permissible moisture level inside the package. According to military standards (supported by literature), the maximum permissible moisture level is taken as a partial pressure of 5000 ppmv at...
100°C (¶ 4.1.2, 4.2.9, 4.2.10, 4.2.11, 4.2.12). It has been shown that this level is a good approximation of the point at which an adsorbed surface layer of water is capable of sustaining current flow for dendritic growth or corrosion, specifically for a cubic package with internal volume of 1.0 cc, this corresponds to a total of three monolayers of surface moisture. The small enclosed volumes of MEMS packaging further increases the already large ratio of internal surface area-to-volume typical of microelectronics packages. And, in the case of a micromotor, where surfaces are in rubbing contact during operating life, it has been demonstrated that the moisture level must be kept above a minimum to avoid premature wearout (¶ 4.2.13). In addition, the maximum permissible leak rate depends on the average ambient moisture level in the operating environment. For this reason the maximum permissible leak rate to be tested is often determined experimentally for a given product or by negotiation between the user and the manufacturer.

12.7 Many evolving MEMS technologies rely on geometries and materials that are ideally suited for hermeticity. At the same time, enclosed volumes are so small as to challenge existing hermeticity test methods. For these reasons, individual unit testing of hermeticity is likely to be less important for MEMS as opposed to conventional microelectronics packages. For example, an enclosed volume created by direct silicon fusion bonding is ideal in the sense that:

- Silicon, a very low permeability, ultra-high purity material, is the only “package” material involved.
- Fusion bond annealing involves temperatures of 1000°C or higher, sufficient to cause reaction to completion of water, oxygen or organic materials remaining in the enclosed volume. In addition, any free hydrogen generated by chemical reactions will rapidly diffuse from the package at high temperatures.
- Enclosed volumes are typically so small that leakage rates too small to measure will result in venting to atmosphere during further manufacturing and prior to final testing.

12.8 Another concrete example is a volume encapsulated by a polysilicon shell. Again, the processes and materials are ideally suited for hermeticity, yet the enclosed volumes are very small.

12.9 In keeping with Mil-Std 883 Test Method 1018 (¶ 4.2.1) the recommended minimum signal to noise ratio of any instrument is 20.

12.10 RGA laboratories should conform to published guidelines (¶ 4.1.6).

12.11 It should be noted that all techniques that rely on the application of an external pressure higher than the internal pressure may cause leaks due to delamination to close, resulting in false negative test results. Therefore, caution should be used in interpreting test results.

13 Recommendations on evaluating hermeticity for various applications

13.1 For sensing devices where performance is dependent on hermeticity (reliability category A), as is the case with accelerometers and gyroscopes, one option for evaluating hermeticity is inferential testing. Hermeticity is determined by measuring the packaged device itself at two separate times and inferring the rate of degradation from the shift in output. The required time differential depends on the sensitivity of the packaged device to the change in the interior pressure.

13.2 For devices requiring hermetic packaging solely for reliability (category B), optical lid deflection testing is an option when the lid is sufficiently wide and thin to deflect by a detectable amount. Optical testing is clearly the preferred method for MEMS devices having small enclosed volumes. An RF switch is one example of a MEMS application where reliability depends on preventing moisture infiltration (¶ 4.2.14, 4.2.15) and where the package can likely be designed for compatibility with optical lid testing.

13.2.1 A rule-of-thumb can be applied in determining whether the package design enables optical lid deflection testing (¶ 4.1.2, 4.2.16):

\[
A \leq \frac{R^4}{ET^3}
\]

where,

- \(R\) is the minimum free width of the lid
- \(E\) is the modulus of elasticity
- \(T\) is the lid thickness
In cgs units, \( A = 3.9 \times 10^{-9} \text{ cc/dyne} \) \((1.0 \times 10^{-4} \text{ in/PSI} \) in English units). For a square, silicon lid with \( R = 1.0 \text{ mm} \) and \( E = 1.5 \times 10^{12} \text{ dyne/cm}^2 \) the maximum allowable lid thickness is about 26 \( \mu \text{m} \). Clearly, capability for optical lid deflection testing must be considered as a design criteria during package development. In addition, consideration should be given during the design process to the maximum pressure to which the lid may be exposed.

13.2.2 The leak rate sensitivity \( L \) is defined as:

\[
L = \left( -\frac{V_0}{k_2 t} \right) \cdot \ln(1 - \frac{D_{yt}}{P_0 L_0})
\]

where,

- \( L \) is the leak rate sensitivity of the test in atm-cc/s
- \( V_0 \) is the volume of the package in cc
- \( k_2 \) is the leak test gas constant (air = 1.0, He = 2.7)
- \( t \) is the test duration time in seconds
- \( D_{yt} \) is the measured deformation of the package lid in cm
- \( P_0 \) is the chamber pressure during the test in dyne/cm²
- \( L_0 \) is the lid stiffness constant calculated from the package dimensions (cm/dyne)

The stiffness constant \( L_0 \) can be approximated using the formula:

\[
L_0 = \alpha \frac{b^4}{ET^3}
\]

where,

- \( \alpha \) is the aspect ratio constant
- \( b \) is the lid width (measure of the shorter side) in cm

The aspect ratio constant \( \alpha \), often selected from a table based on the dimensions of the deflecting member of the package and the boundary conditions (fixed vs. flexible), ranges from .044 to .142 for flexible boundary conditions, and from .013 to .028 for fixed boundary conditions. Alternatively, \( L_0 \) can be determined by modeling using finite element analysis methods.

For example, consider a package having a silicon lid of length 1.0 mm, thickness 26 \( \mu \text{m} \) and fixed edges, enclosing volume \( V_0 = 10^{-4} \text{ cc} \), and tested with 1.0 bar of helium. Let \( \alpha = 0.1 \), leading to \( L_0 = 3.8 \times 10^{-4} \text{ cm/dyne} \). For a 1 minute test time, and \( D_{yt} = 10^{-5} \text{ cm} \) (0.1 \( \mu \text{m} \)), \( L = 1.6 \times 10^{-14} \text{ atm-cc/s} \). Clearly the test is very capable at these conditions. Importantly, the leak rate sensitivity is directly proportional to volume, a clear advantage for small volumes typical of MEMS.

13.2.3 According to the method, calibration devices having known volumes and seal quality are tested initially to calibrate the device stiffness values used in calculating the leak rates. With an optical interferometer set to monitor lid deflection, the chamber is then pressurized or evacuated as appropriate. A Gross leak test is completed first to demonstrate that some response is detected. Units passing Gross leak test are submitted to Fine leak test, which involves pressurizing the chamber with helium and holding the pressure for a fixed time. Any helium infiltrating the package over time will cause a change in the measured deflection. Lid deflection may be monitored as a function of both pressure and time. In addition, many units may be tested simultaneously, limited only by the optical field of view within the test chamber.

13.3 For all other devices, individual unit testing must rely on tracer gas leak testing such as helium or radioisotope leak testing.

13.3.1 The capability of helium leak testing, by far the most commonly used method, can be considered in simple terms. First, it is important to recognize that helium leak testing does not measure hermeticity. Rather, Gross and Fine helium leak tests together establish upper and lower limits on the leak rate. Fine leak testing can establish a first bound on the leak rate, but cannot independently distinguish between a good package and a package having a gross leak. Since helium can leak out very rapidly when a gross leak exists, Gross leak testing must follow Fine leak testing to establish a second bound on the leak rate. Gross leak testing is capable of determining a leak in the range of \( 10^{-3} - 10^{-5} \text{ atm-cc/second} \) or greater (at this level of leak, bubbles can be seen escaping during Gross leak testing). The lower limit of Fine leak testing depends on the capability of the test equipment, but is also highly dependent on procedures and the DUT. For example, when the DUT(s) has a very high surface area, helium may absorb onto the
exterior of the package and evolve slowly during leak testing. This creates an error source. In such cases, stabilization time prior to beginning Fine leak test may be as long as 15 minutes. Depending on procedures and the DUT, the equipment capability may range from $2.0 \times 10^{-10}$ to $10^{-9}$ atm-cc/second. This limitation is very important when dealing with small enclosed volumes.

13.3.2 For example, for an enclosed volume of $10^{-2}$ cc and a leak rate of $10^{-9}$ atm-cc/sec (perhaps at the capability limit of the test equipment), the internal pressure could rise to 0.96 bar in one year – almost to atmospheric pressure. Clearly, the expense of hermetic packaging and testing cannot be justified if a given unit can leak back this rapidly. For the same enclosed volume and test equipment and procedures capable at a leak rate of $10^{-11}$ atm-cc/sec, the internal pressure will rise about 30 mBar per year, while at $10^{-12}$ atm-cc/sec, the internal pressure will rise about 3 mBar per year. Note that for small pressure rise, the internal pressure is almost linear with time. For small leaks, the value of $(1- \exp^{-x})$ is well approximated as $x$ when $x$ is small. Although the leak rate depends exponentially on the pressure differential, for the range used in the example a linear assumption is valid.

13.3.3 For helium leak testing, the critical parameter is the ratio of leak rate to enclosed volume. For leaks exhibiting molecular flow, the measured leak rate after bombing is described by the Howl and Mann equation as (assumes that permeability is negligible):

$$R = \frac{P_E}{P_0} \left( \frac{M_A}{M} \right)^{1/2} \left[ 1 - \exp \left( - \frac{L}{V} \frac{M_A}{M} \right)^{1/2} \exp \left( - \frac{L}{V} \frac{M_A}{M} \right)^{1/2} \right]$$

where

- $R$ is the measured leak rate of helium gas through the leak in atm-cc/s
- $L$ is the equivalent standard leak rate in atm-cc/s
- $P_E$ is the pressure of exposure during bombing in atm
- $P_0$ is the atmospheric pressure, generally taken as 1.0 atm
- $M_A$ is the molecular weight of air (28.7)
- $M$ is the molecular weight of helium (4.0)
- $t_1$ is the time exposure to $P_E$, in seconds
- $t_2$ is the dwell time between release of bombing pressure and leak detection, in seconds
- $V$ is the internal package volume

The first exponential term describes the increase of tracer gas partial pressure inside the package during bombing, while the second exponential term describes the decrease of tracer gas partial pressure during leak testing, when a vacuum containing no tracer gas exists outside of the package volume.

For helium leak testing, the ratio $\left( \frac{M_A}{M} \right)^{1/2}$ is fixed at about 2.7. To illustrate a point, it is useful to consider the case where $t_2 = t_1/100$. For $\frac{L}{V} = 10^{-5}$, $t_1 = 10^4$ s, and $P_0 = 1$ atm, $\exp \left[ - \frac{2.7L}{VP_0} \right] = 1.3 \exp \left[ - \frac{2.7Lt_1}{VP_0} \right]$. Substituting these values and defining $A$:

$$A = \exp \left[ - \frac{2.7Lt_1}{VP_0} \right]$$

allows restructuring of the Howl and Mann equation in the form of:

$$R = \frac{(2.7 * 1.3)P_E}{P_0} (1 - A) \cdot A; \text{ or rearranging } A^2 - A + \frac{3.5RP_0}{LP_E} = 0$$
By quadratic formula, there are two solutions to this equation:

\[ A = \frac{.5 + \sqrt{1-4 \frac{R P_0}{L P_E}}}{.5} \]

The first solution (plus sign) corresponds to a fine leak, where tracer gas is diffusing out of the package volume at a very low rate. The second solution (minus sign) corresponds to a much faster leak rate, where much of the tracer gas may have already diffused out of the package volume prior to testing for the presence of tracer gas.

Regardless of allowed differences in the bombing time and the dwell time there must always be two solutions to the Howl and Mann equation. Because of this both gross and fine leak tests must be completed in order to confirm hermeticity.

In practice, the ratio \( \frac{P_E}{P_0} \) ranges from about 2 to 10. Also \( t_1 \), the time exposure to \( P_E \), is usually limited by practical considerations to 2 – 10 hours (7,200 – 36,000 seconds), while \( t_2 \), the dwell time, is a few minutes. Regardless of the choice of test parameters, for package volumes of about \( 10^{-2} \) cc or less the second solution to the Howl and Mann equation may be a leak rate that is less than the minimum detectable by Gross leak testing. In this case the tracer gas leak testing method is simply incapable of evaluating hermeticity.

13.3.4 In fact, there are two volume-related issues with Gross leak testing. Gross leak testing is capable of detecting minimum leaks of \( 10^{-4} - 10^{-5} \) atm-cc/sec, as the method relies on visibility of bubbles escaping the package volume. First, for a gross leak of slightly less than \( 10^{-5} \) atm-cc/sec and therefore undetectable, the package interior may fully deplete of perfluorocarbon vapor in the short time period between removing the unit from bombing and observing for bubbles. For example, for an enclosed volume of \( 5.0 \times 10^{-3} \) cc and a leak rate of \( 1 \times 10^{-5} \) atm-cc/sec, the interior pressure will rise to 0.7 bar (70% of atmospheric pressure) in 2 minutes. Optimistically, a requirement is that \( \frac{L}{V} \leq 10^{-3} \) in order to have any hope of detecting Gross leak by the bubble method. Second, for the same example a unit passing Gross leak testing may leak to atmospheric pressure long before even the shortest operating life with R5 reliability requirement.

13.3.5 Davy (see ¶ 4.2.9) has calculated the maximum permissible leak rates based on the condition of internal partial pressure of water rising to 5000 ppmv as:

\[ L_{office} = 1.1 \cdot 10^8 \frac{V}{t_{pre}} \text{ atm-cc/year} \]

For tropical environments, the maximum permissible leak rate is about 1/4th that for office environments. Based on the calculation for office environment, bombing at 6 atm for 10 hours, dwell time of 5 minutes, and optimistic assumption that \( R_{min} = 5.0 \times 10^{-11} \), calculations of the measurable leak rate and lifetime projections using the Howl and Mann equation are shown for different volumes in Table 1.

<table>
<thead>
<tr>
<th>Enclosed Volume cc</th>
<th>Measurable He Leak rate atm-cc/sec</th>
<th>Time to leak to 5000 ppmv H2O in years</th>
<th>Time to leak to 0.95 atm in years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>5.6E-09</td>
<td>2.0</td>
<td>17.0</td>
</tr>
<tr>
<td>0.50</td>
<td>4.0E-09</td>
<td>1.4</td>
<td>11.9</td>
</tr>
<tr>
<td>0.20</td>
<td>2.5E-09</td>
<td>0.88</td>
<td>7.6</td>
</tr>
<tr>
<td>0.10</td>
<td>1.8E-09</td>
<td>0.61</td>
<td>5.3</td>
</tr>
<tr>
<td>0.05</td>
<td>1.3E-09</td>
<td>0.42</td>
<td>3.7</td>
</tr>
<tr>
<td>0.02</td>
<td>8.0E-10</td>
<td>0.28</td>
<td>2.4</td>
</tr>
<tr>
<td>0.01</td>
<td>5.6E-10</td>
<td>0.20</td>
<td>1.7</td>
</tr>
</tbody>
</table>
13.3.6 Overall, the capability of conventional Gross and Fine tracer gas leak detection methods cannot be justified when package volumes are less than about .02 cc, even for R5 reliability category. Further improvements in the detection limit of Fine leak testing are likely not helpful, since the detection limit of Gross leak testing is also reached with smaller volumes.

13.3.7 It must be recognized that Mil-Std 883 specifications have not been changed in response to considerable analysis demonstrating that the test method is inadequate for evaluating hermeticity of small volume packages. Perhaps this is due to cumulative evidence that failure rates of packaged devices evaluated using the Test Method 1014.12 are acceptable. If this is the case, it must further be recognized that the bulk of such empirical evidence is based on package volumes of 0.2 cc or larger (i.e. TO style packages). Table 1 illustrates that for this volume and measurable leak rate, failures may be postponed for several years.

13.3.8 The technique Cumulative Helium Leak Detection holds some promise of improving on the limitations inherent in Gross and Fine leak testing. According to this technique all helium is captured within the system, enabling a much more sensitive measurement of perhaps $10^{13}$ atm-cc/sec. Additional information can be gained by analysis of cumulative helium detected as a function of time.

13.3.9 Unfortunately, smaller volume packages have increasingly larger surface area-to-volume ratios. And, since outgassing is proportional to surface area, the effect becomes more and more pronounced as the package volume is decreased. For this reason, extending capability for detection of external leaks below about $5.0 \times 10^{-11}$ atm-cc/sec may simply lead to frustration as failures of packaged parts occur even when external leak rates are shown to be negligible.

14 Design for Hermeticity Testability

14.1 Regardless of the chosen hermeticity test method, the package must be designed with a view towards testability.

14.2 For tracer gas leak testing the package must be designed to withstand the bombing pressure with sufficient guardband to ensure no degradation of the reliability of the package due to testing itself.

14.3 For optical lid deflection testing the package must be designed with a deformable portion, which deflects sufficiently to enable optical measurement. Increasing the bombing pressure allows for reduction in the time between two consecutive measurements. Therefore, it may also be necessary to design the package to withstand a large bombing pressure, depending on the exact test technique being applied.

14.4 Integration of microsensors providing ongoing feedback on hermeticity level is one method of designing for testability.
APPENDIX 1
Additional References

NOTICE: The material in this appendix is an official part of SEMI [insert designation, without publication date (month-year) code] and was approved by full letter ballot procedures.

A1-1 Additional References
A1-1.1 ANSI/ASQC Z1.4-1993 Sampling procedures and tables for Inspection by Attributes
A1-1.2 ANSI/ASQC Z1.9-1993 Sampling procedures and tables for Inspection by Variables for percent nonconforming
A1-1.3 ASTM F97-72 (2002)e1 Standard practices for determining hermeticity of electron devices by dye penetration
A1-1.4 ASTM F979-86 (2003) Std. test method for hermeticity of hybrid microcircuit packages prior to lidding
A1-1.5 ISO-Std-2859 Sampling procedures for Inspection by Attributes
A1-1.6 JEDEC JESD22-A102 – Moisture resistance 96 Hr; 100%RH; 121 C
A1-1.7 JEDEC JESD22-A104 – Temperature cycling 600 cycle; -65 to +150 C
A1-1.8 Mil-HDBK-108 Quality control and reliability - Sampling procedures and tables for Life and reliability testing (based on exponential distribution)
A1-1.9 Mil-Std 690 Failure rate sampling plans and procedures
A1-1.10 Mil-Std 750 Test Method Standard Test Methods for Semiconductor Devices

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