Appendix D - Hermeticity Testing White Paper

Hermeticity test methods for MEMS

A White Paper

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***Abstract* – This white paper reports the difference between MEMS packages and integrated circuit packages for which the traditional hermeticity test methods were designed. The variety of new packaging materials and technique used in the MEMS industry to accommodate the various device types are presented. The limitations of hermeticity test methods when applied to MEMS packaging are explained and alternative methods offered.**

1. INTRODUCTION

Traditional integrated circuits, microelectronics and semi conductors are commonly sealed in ceramic packages to ensure that the device is protected from contaminants. MEMS devices however have sensitive mechanical, chemical, optical or biological structures that require some interaction with the outside world to allow the parts to operate as sensors or actuators. For this reason the packaging of MEMS is device dependant and therefore the traditional test methods to detect the hermeticity of packages are not always suitable. In section 2 common MEMS package types will be describes. Section 3 will explain the types of leak that should be expected in each package type. The limitations of leak detection methods currently available when applied to typical MEMS volumes with typical expected lifetimes will be highlighted in section 4. Section 5 describes how MCS can help you to identify the leak types present in your package, quantify this leak and provide solution to your hermeticity problem.

2. MEMS PACKAGE TYPES

Some MEMS can be packaged in ways similar to traditional IC's. The main objective of these packages is to keep contaminants out of the package. For this type of MEMS, wafer level bonding is most commonly used. Direct wafer bonds can be formed between a wide range of wafer materials although most often silicon is involved. The wafers to be bonded are polished and brought into intimate contact before covalent bonds are made at 800°C to 1000°C creating a nearly perfectly hermetic bond. Eutectic or solder bonding can also be used to make a hermetic bond at wafer level. Solder or eutectic alloy is deposited on one wafer before the wafers are brought together and heated to above the eutectic temperature.

A very good hermetic seal can be formed using anodic bonding. As anodic bonding requires one wafer to be made of glass, this is often used in Micro-Opto-Electro-

Mechanical Systems (MOEMS) where optical access to the device is required. As with direct wafer bonding the surface to be joined must be polished before the wafers are brought together. A potential of 200-1000V is applied across the wafers causing sodium in the glass to move toward the cathode leaving space negative charges at the silicon-glass interface. Covalent bonds can be made at temperatures above 350°C.

Other MEMS, particularly those designed for military and aerospace applications require that the device has a long lifetime of between 20 and 50 years. Many of these devices require a vacuum ambient for optimum operation. In particular MEMS resonant devices are adversely affected by mechanical damping and require a known vacuum ambient throughout the device lifetime. These devices are often bonded using the most hermetic wafer level methods as previously described. These bonds must however be made in a vacuum environment, adding a further complexity to the process.

Some MEMS do not require such hermetic packages allowing far simpler and less costly methods to be employed. This type of package is particularly useful for MEMS designed for consumer industries where lifetimes are short and costs must be kept low. The device can be individually or wafer level packaged using intermediate bonding layers of polymers or adhesives. The most popular polymers are Benzo-Cyclo-Butene (BCB) and Liquid Crystal Polymer (LCP). Packages made using these materials are not hermetic but due to their low moisture diffusion properties they are considered to be near-hermetic.

3. LEAK TYPES

There are 3 main leak types for consideration in MEMS packaging; leak channels through package walls or seals, permeation leaks through package walls or seals or outgassing from internal material layers. The type of leak that is likely to exist is dependent on the package materials and the bonding method used.

A leak channel exists when there has been imperfect bonding or the package has been stressed causing a crack through the package to the internal cavity. This crack or leak channel will allow gas to flow from the outside environment to the internal cavity. The rate of this flow will depend on the diameter of the leak channel, the length of the channel and the pressure differential from outside to inside the package. Depending on the radius of the leak channel and the size of the gas molecules flowing through it, the flow will be molecular, viscous or transitional. If flow is molecular, the leak rate is likely to be relatively low as the mean free path of the gas is greater than the characteristic dimension of its container, the leak channel. If flow is viscous, the leak rate is likely to be higher as the mean free path of the gas is less than the characteristic dimension of the container so flow is restricted. This means the gas sticks to the outside perimeter of the channel allowing fast flow through the centre of the channel, just as water flows through a pipe. Transitional flow describes flow that is between molecular and viscous.

Permeation leaks are generally not significant when describing leaks in hermetic packaging since non-porous packaging materials are used. Permeation leaks in near-hermetic packages made using BCB and LCP are however likely to be dominant. Permeation of gas through a material happens in three stages; sorption onto the surface material, diffusion through the bulk material and desorption into the package cavity. It is assumed that all particles that diffuse through the bulk will desorb into the package cavity, so permeation rate is often approximated to the product of diffusion and sorption rates. The rate of permeation through a material is dependent on the size of the gas particle, the porosity of the material and the chemical nature of both the gas and material. For this reason it is very difficult to relate the rate of diffusion of one gas to another through the same material.

Outgassing is a type of leak that comes from the internal material layers within the package. After some cleaning processes and fabrication steps it is possible for gases to sorb and diffuse into the bulk of material layers. This gas can be released at any stage in the package lifetime but it is commonly released during high temperature bonding, causing the internal pressure to rise. Even without high temperature, outgassing will occur over time. Some materials are more prone to outgassing than others and some processes are well known to add to the problem. Careful consideration of materials and processes at the design stage can minimise this type of leak rate. Outgassing is of particular concern in ultra high vacuum applications where the bonding technique has been optimised to ensure leak channels are minimised.

4. LEAK DETECTION METHODS

The most commonly used leak detection method is the helium fine leak test used in conjunction with the gross bubble test. These test methods along with radioisotope leak detection, optical leak detection and Cumulative Helium Leak Detection (CHLD) are described and regulated in military standards, MIL-STD-883 TM 1014.13 and MIL-STD-750 TM 1071.8 [1, 2].

The helium fine leak test and gross bubble test can be used to find leak rates caused by leak channels in packages. The military standards give a table or equation based on molecular flow to calculate the true leak rate of packages. Any leak rates caused by transitional or viscous flow should be measured by the gross leak test. A limitation however exists when the cavity volume of the package is reduced below $3mm^3$[1]. Below this volume, a gap in the detectable leak range of the helium fine leak and gross bubble test develops. This means that faulty packages are able to erroneously pass the leak test. Typical MEMS have cavity volumes around $0.1mm^3$; therefore this traditional test method should be used with caution.

Permeation leaks cannot be measured by the helium leak test as the equations to quantify the leak are based on molecular flow. There are also issues concerning the use of helium to measure leak rates caused by leak channels in glass packages. Due to the inert nature and small size of its molecules, helium is able to permeate through glass. The leak rate measured using helium leak detection would therefore include the true helium leak rate through any leak channels plus the permeation rate of helium through the glass package. As most constituents of air are unable to permeate glass, conversion of the helium leak rate to an air leak rate of glass packaged device would be inaccurate.

No tracer gas method is able to detect leak rates caused by outgassing. Table 1 shows a summary of the types of leaks the helium leak test and gross bubble test are able to measure and an outline of the other available methods capabilities.

Table1: Leak types detectable using currently available techniques

	Leak channels	Permeation	Outgassing
Helium Leak detection	Y	N	N

Radioisotope leak detection	Y	N	N
Optical leak detection	Y	Y	N
CHLD	Y	N	N

Radioisotope leak detection and CHLD are able to measure the permeation rate of the specific tracer gas used through packages. However conversion from the permeation rate of the tracer gas to another gas type is not trivial. These tests cannot be used to accurately predict the permeation rate of contaminants such as water vapour and oxygen in practical situations.

For a constant leak rate, the lower the cavity volume, the more the pressure inside the cavity will increase. For this reason it is important that as the cavity volume is reduced, the acceptable leak rate is also reduced. For a package with a typical volume of $0.1mm^3$, an initial internal ambient of $1x10^{-2}$ atm which should not increase more than 10% throughout its 10 year lifetime, the maximum acceptable leak rate is $3.17x10^{-16}$ $atm.cm^3.s^{-1}$. None of the methods listed in table 1 are able to detect leak rates this low.

Outgassing could be measured by the optical leak detection method. This method uses measurement of the deflection of the cap as the internal pressure changes. The minimum detectable leak rate of this method is therefore dependant on the cap material type and thickness as well as the measurement methods sensitivity. The optical leak rate is typically able to detect leak rate down to $10^{-9}atm.cm^3.s^{-1}$. Outgassing generally occurs either during high temperature bonding or slowly throughout the device lifetime. Due to the minimum leak rate limit of this method, it is unlikely that it will be a useful method to measure outgassing in real applications. Currently, the only way to measure outgassing is by using residual gas analysis (RGA). This is a powerful technique but it is destructive, time consuming and costly. This method uses Quadruple Mass Spectrometry (QMS) to determine the gas type and pressure contained in the cavity.

For accurate detection of MEMS leak rates, new hermeticity test methods must be developed.

5. HOW CAN MCS HELP?

MCS have specialist knowledge in the area of MEMS leak detection and are able to offer a leak detection service. This service includes analysis of your package to determine the leak types that are likely to be of concern, identifying the best test method to quantify this leak and offering advice to help reduce critical leak rates. Our knowledge of the traditional test methods available ensures that experimental parameters can be exploited to enable use of these methods in some situations. For those that are not compatible with traditional leak detection methods, MCS has developed further test methods with typical MEMS packaging in mind.

REFERENCES

[1] MIL-STD-883H, TM1014.13, available at http://www.dscc.dla.mil/ (23/04/10)

[2] MIL-STD-750E, TM1071.8, available at http://www.dscc.dla.mil/ (23/04/10)

[3] Millar S., Desmulliez M.P.Y. and McCracken S. *'Leak detection methods for glass capped and polymer sealed MEMS packages'*, Design, Test, Integration and Packaging of MEMS/MOEMS, Seville, Spain, 5-7th May 2010.