# The limits of hermeticity test methods for micro-packages

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**Abstract**

Hermeticity is crucial for the long-term implantation of electronic packages. Pushed by advances in micromachining, package volumes are decreasing and current leak detection methods are no longer sensitive enough. This paper reviews the limits of the most common methods and exposes their inadequateness for medical electronic applications where the devices life is 50 years or longer.

**Keywords** Micro-packaging, hermeticity, active electrode, functional electrical stimulation, long-term implantation.

## Introduction

As detailed elsewhere in these proceedings [1], one way to increase the number of stimulation channels in an implant is by using active electrodes, where some of the electronics is embedded with the electrodes. The embedded IC may be protected from corrosion by enclosing it in a dry atmosphere in a hermetic micro-package. To minimise the package size we propose to bond a silicon cap directly onto the silicon wafer, covering only the active area [2]. The choice of a sealing method is crucial as it will directly influence the hermeticity of the package, hence the lifetime of the implant.

## Methods

### Hermeticity testing

We are primarily concerned with the ingress of water vapour from the environment into the package over the implant's lifetime (50 years). Methods to measure the hermeticity of a package and what values of the measured leak rate are acceptable are defined in military standards (method 1014.13 of MIL-STD-883, method 1071 of MIL-STD-750 and appendix C of MIL-PRF-38534G). There are discrepancies between standards but the most stringent limit, for internal volumes smaller than $10mm^3$, is a leak rate $\leq 510^{-9}cm^3.s^{-1}$ of dry air at 25 ℃ and 1 atm. These standards also suggest a maximum acceptable moisture level of 5000 ppm at 100 ℃ (6.7 % relative humidity at 37 ℃), corrected (lowered) for packages of internal volume smaller than $10mm^3$ sealed in a furnace or with applied pressure. As will be shown in this paper, the leak rates rejection limits are not suitable for the lifetime expected from an implant. Further, the physical detection limits of the methods described in the standards are at the edge of significance for our application. This statement only echoes what has been found in other engineering disciplines [3–5]. Most of the recent work on hermetical packaging has been concerned with micro-electro-mechanical systems (MEMS) where the focus is on the entrance of air inside a cavity with a low internal pressure. Our interest is to prevent (or estimate) the ingress of water vapour inside a package that may, depending on the sealing method, be filled with a dry gas at or above atmospheric pressure. It is important, for the advance of implant technology, to demonstrate simply the limits of hermeticity testing in our fields and encourage alternative thinking on the subject.

### A note on leak rate units

The units used in the military standards, $atm.cm^3.s^{-1}$, leads to rates only valid at the given measurement temperature. If the device is used at a different temperature, this rate must be converted to $mol.s^{-1}$ then translated to the new temperature. Therefore, in the rest of this paper, leak rates will be expressed in $mol.s^{-1}$. For comparison, 1 $mol.s^{-1}$ correspond to a flow rate of $25.4 * 10^3 cm^3/s$ at 37 ℃and a relative pressure difference of 1 atm.

### The limits of fine leak tests: Helium detection

The most common method for fine leaks is the detection of a tracer gas using a mass spectrometer. Helium is often used due to its rarity in normal atmosphere. The packages under test are "bombed" in a helium chamber at high pressure for a given time then quickly transferred to the detector chamber for detection. The lower leak limit of a good helium detector is of the order of $10^{-16}mol.s^{-1}$. Using a simplification of the Howl and Mann equation, this limitation on the measured leak rate may be converted to a limitation on the "standard" or "true" leak rate. That is the leak rate of helium for a partial pressure difference of 1 atm at 25℃. The true rate is dependent on the cavity volume, bomb time and pressure. Assuming a cavity of a few $mm^3$, a bomb time of 12

Table 1: Conversion factors for leak rates measured using He

| Gas | $He$ | $H_2O$ | $Air$ |
|---|---|---|---|
| Molecular weight (g) | 4 | 18 | 28.7 |
| Conversion | 1 | 0.471 | 0.373 |

hours at 5 atm and a lowest detectable leak rate of $210^{-16} mol.s^{-1}$, the lower limit of the standard rate is of the order of $10^{-14} mol.s^{-1}$. An alternative to the bombing method, known as "backfilling", is to fill the package with a fraction of helium prior to sealing and test it shortly afterwards. The true leak rate for helium may then be approximated as the measured rate divided by the helium fraction. So far, all rates are for the leakage of helium, a gas with smaller molecules than water. For the prediction of moisture ingress the helium leak rate must be converted to a water leak rate: $L_{H_2O} = \sqrt{\frac{M_{He}}{M_{H_2O}}} L_{He}$. The conversion factors for air, water and helium are given in table 1. These conversion however are of limited use as a leak channel may simply be too small for a larger molecule, especially polar ones as in $H_2O$ (over-estimation of $L$) and the leak rate may be affected by chemical reactions between the gas and the seal.

### Other leak detection methods

There are two other fine leak detection methods proposed in the MIL standards. Using a radioactive tracer gas (mix of krypton-85 and air), equivalent standard leak rates as low as $10^{-15} mol.\ s^{-1}$ may be detected. Optical detection relying on the deflection of the cap is popular for full wafer bonding but the lowest reported equivalent standard leak rates are in the range of $10^{-13} mol.s^{-1}$. One further method that achieves lower leak rates is cumulative helium leak detection (CHD), where the helium leak rate is measured over time. Manufacturers of detection equipment (Pernicka), claim leak rates measurements limits as low as $10^{-14} atm.\ cm^3.s^{-1}$ or $10^{-18} mol.s^{-1}$. However the formula for conversion to a standard rate is not given. Other methods exist and Millar has reviewed a total of 10 methods of hermeticity testing applied to MEMS cavities [3]. She concludes that none of the external methods set in the military standards, nor those developed more recently, are suitable for the small cavity volumes and high hermeticity requirements typical of MEMS. Only *in situ* methods, using some form of pressure sensor, can achieve relevant leak rates detection.

## Results

The time taken for the partial water pressure $P_{H_2O,in}$ inside a package of volume $V$, leaking at a true rate $L_{H_2O}$ to reach a given pressure $P_{H_2O,MAX}$ is calculated using equation:

$$t_1 - t_0 = \frac{V}{L_{H_2O}} ln(\frac{\Delta P_{H_2O,t_0}}{\Delta P_{H_2O,t_1}})$$

where $\Delta P_{H_2O,t_i} = P_{H_2O,out} - P_{H_2O,in}$ at instant $t_i$ and $P_{H_2O,out}$ is at all time the saturation pressure of water at 37℃. This is illustrated in figure 1. After testing a package, and converting if necessary the measured rate to the true helium rate $L_{He}$, $\frac{V}{L_{He}}$ may be calculated to find the time before $P_{H_2O,in}$ reaches a set limit. Thi fraction, $\frac{V}{L_{He}}$, at a given temperature and pressure difference, is a usefull parameter to compare the performances of different packages.
For the purpose of illustration, 5 partial water vapour pressure limits are displayed on the graph. The first two limits, 2994 and 5000 ppm, are set in MIL-STD-883H, 5000 is a general value and 2994 is corrected for a cavity smaller than $10 mm^3$ sealed in a heated furnace (350℃ in this case). Greenhouse suggest using the partial pressure of a volume of water sufficient to form 3 monolayers of water on all internal surfaces upon condensation [5]. This value is dependent on the package's inner surface area. In fig.1, the package dimensions were: 4 x 2.5 x 0.1 mm. Finally, two relative humidity limits are plotted, 10 and 99%.

Table 3: Minimum true He leak rates for a time to limit of 50 years at 37℃for a $1 mm^3$ internal cavity.

| Limit | L ($mol.s^{-1}$) |
|---|---|
| Corrected ppm (2994) | $1.0310^{-18}$ |
| 5000 ppm | $1.6310^{-18}$ |
| 10% relative humidity | $2.6410^{-18}$ |
| 3 monolayers of water | $2.1710^{-17}$ |
| 99% relative humidity | $1.1410^{-16}$ |

## Discussion

For a set "time to limit", whatever the limit be defined as, a reduction of the cavity's volume requires an equivalent reduction of the leak rate. The previous sentence highlights a key question: how is the limit defined? What is the maximum relative humidity inside the package before failure occurs? For applications where corrosion is the most likely cause of failure, the onset of corrosion related damages need to be linked to a relative humidity inside the package. The presence of traces of salts with low vapour pressure will encourage water formation at low relative humidities [6]. Once a maximum relative humidity is known, the highest acceptable leak rate may be computed. To illustrate this, table 3 shows the true rates acceptable to guarantee that a $1 mm^3$ package

Table 2: Leak testing methods and their lowest detectable leak rates (expressed as standard helium leak rates).

| Method | optical deflection | He bombing | krypton-85 | He backfilling | CHD |
|---|---|---|---|---|---|
| Comments | | $P_b$ = 5atm, $t_b$ = 12h, V=1$mm^3$ | | 100 % He | |
| True helium leak rate ($mol.s^{-1}$) | $10^{-13}$ | $10^{-14}$ | $10^{-15}$ | $10^{-16}$ | $10^{-18}$ |

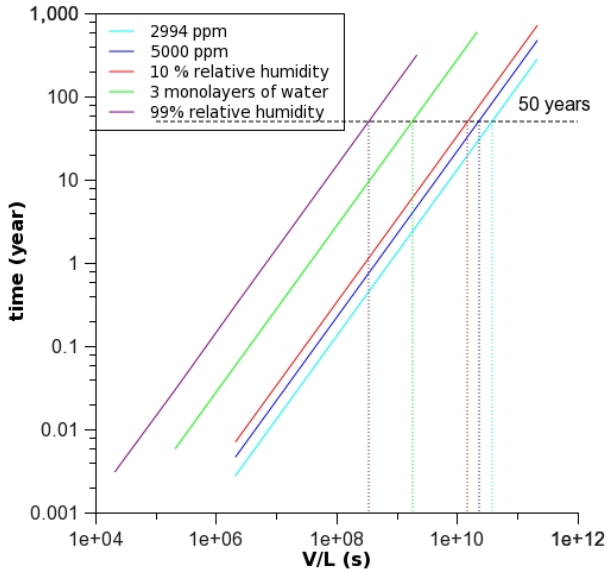


Figure 1: Time to limit as a function of $\frac{V}{L}$ for 4 different limits.

will not reach a given limit within 50 years. These are at the edge of what is currently achievable, see table 2.

# Conclusion

In packages where corrosion is the most likely cause of failure, humidity should be kept low. Currently, the lowest detectable leak rates are not low enough to guarantee acceptable relative humidity levels over the lifetime of the implant. If the humidity cannot be estimated from tests prior to implantation, one alternative is to monitor it after implantation. Humidity sensors may be integrated on the surface of the circuit with only a small increase in overall package dimensions. There are however major design challenges to overcome if the sensors are to be sensitive, stable and precise enough to detect very low humidity levels and slow increases over years [7]. This simple presentation of the issues related to hermeticity testing relies on the assumption that a safe limit for the relative humidity is known. This safe limit will depend on the application, the surface contamination and more.

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