Measuring Leak Rates with the Cumulative Helium Leak Detector

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Abstract: The question has been raised as to "how much Helium must be in a package to conduct a valid leak test". The following discussion will attempt to answer that question. In addition, a brief description of the Cumulative Helium Leak Detection method will be presented along with some observations on real devices which were both leak tested and later analyzed by destructive RGA analysis.

Introduction.

If we are to conduct a leak test measurement on a hermetic package using Helium as a tracer gas, we can reason by intuition that some Helium must be present in the package in order to measure some leaking out. But, how much is "some", and how much do we need to make an accurate leak rate measurement? In order to answer these questions, it will help us to understand some basic principles of gas flow.

Gas Flow Summary

First, let us consider a gas molecule in a first approximation as if it was an elastic sphere with a diameter on the order of 10^{-8}cm. The motion of the molecule through a leak will depend on a number of factors, but the most important one will be the mean free path of the molecule relative to the dimensions of the flow path. The mean free path is the distance a molecule will travel before colliding with another molecule. At atmospheric pressure this will be approximately $7x10^{-6}$cm to about 5000cm at a pressure of 10^{-6}Torr. If the mean free path is short compared to the dimensions of the flow path, then collisions between molecules will predominate and the flow is referred to as viscous flow because the flow pattern is that of a viscous fluid. If the mean free path is long compared to the dimensions of the flow path, collisions between the molecules and the flow path predominate and intermolecular collisions are not important. Flow under these conditions is referred to as molecular flow, and more molecules move from a region of high density to a region of low density for purely statistical reasons. When the mean free path is the same order of magnitude as the flow path, the flow is referred to as transition flow, and has been modeled by considering it to be made up of partly viscous and partly molecular flow. Viscous flow is dependent on the pressure differential across the flow path, where as, molecular flow is dependent on the dimensions of the flow path. Although, we find ourselves in the transition flow range on many occasions, no one has actually solved the equations of flow for the general case since this is usually a transient condition which eventually comes to equilibrium in either viscous or molecular flow. It's important to remember that these theoretical discussions are based on an ideal gas molecule and do not take into account the polar nature of some molecules such as water for example.

Real Leak Structure.

All our theoretical leak rate calculations are based on one of two leak models: the pin hole leak; and the capillary leak. Real leaks are very rarely as simple as our models. Shown in Figure [1] is a typical leak in a seam seal welded semiconductor package. The Kovar package and lid are plated first with Nickel and then Gold. The lower right image shows the orientation of the lid material on the bottom and the package body on the top. Subsequent images are increased in magnification showing the leak path through the 200 micron Nickel plating layer. The large voids are actual separations in the Nickel layer.

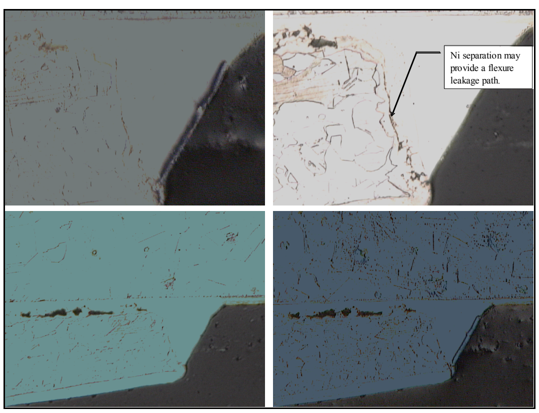

Figure 1. SEM photo of leak path.

The leak path is very irregular and has dimensions which clearly place Helium in the molecular flow range. In fact, leaks smaller than 10^{-6} atm-cc/sec are considered in molecular flow. The above example is probably equivalent to your worst nightmare since the leak is stress sensitive. Either mechanical or thermally induced stress can cause this type of leak path to randomly open and close. There are many more classes of real leak structures, however, the one common element shared by all is that none of them exactly fit our theoretical models. Large leaks sort of fit our viscous flow models and small leaks ($<10^{-6}$ atm-cc/sec) sort of fit our molecular flow models. If our only interest was the leak rate of Helium, we could make some minor adjustments to our models and be content.

Moisture.

Why should we care about moisture when we are trying to measure the leak rate of Helium? Our real interest is to infer what the leak rate of moisture is relative to the measured leak rate of Helium. In fact, our goal is to insure that any moisture ingress over the expected life of the device is less than 5000ppm of the total gas mix contained in the device. Our ideal gas flow models do not work for polar molecules such as water since other mechanisms control their behavior such as surface migration. Since moisture is present in ambient air at around 1.0% (38% relative humidity), it will be at equilibrium on the surfaces of the device we plan to leak test. Recent RGA data on mature semiconductor packages suggests that moisture can not only intrude into the packages over time, but can obstruct the leak path which prevents an exchange of ambient air with the original seal gas. Helium leak tests can be conducted and the amount of Helium and atmospheric air found inside the package is inconsistent with our theoretical models. Typically, after bombing and leak testing, the amount of Helium found in a Nitrogen filled package is greater than the atmospheric air our model would predict. Also, the amount of moisture is considerably greater than the Helium leak rate would predict. In cases where the packages were gross leak tested using Fluorocarbons, not only do we find Fluorocarbons inside the packages, but moisture levels as much as 50 times greater than the measured Helium leak rate would suggest. The moisture ingress mechanism through a Fluorocarbon plugged leak path could involve the solubility of moisture in the Fluorocarbon. This transport mechanism would be much more efficient than surface migration.

CHLD Testing

The Cumulative Helium Leak Detector system and method of operation have been discussed numerous times. Using a specially designed Cryo-Pump, the CHLD simply accumulates all of the Helium which escapes through a leak path during the test interval. The measurement uses the rate of increase or slope of the Helium signal ratioed to a standard to determine the leak rate.

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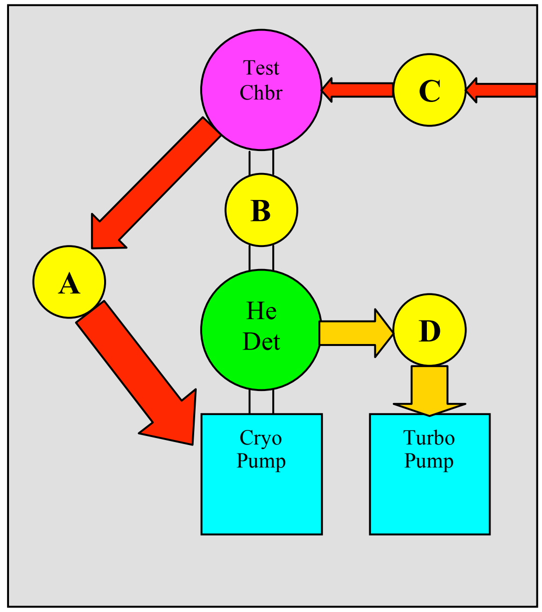

Figure 2. CHLD Block Diagram

Since all of the gasses which evolve from the test chamber including a leak pass through the Cryo-Pump, only Helium reaches the detector. The minimum detectable Helium signal is not reduced by the scattered ions from the other gasses as is the case in a conventional Helium leak detector. More importantly, the size of the leak is not a dependent variable as is the case for a conventional Helium leak detector. A conventional Helium leak detector must rely on a continuous flow of Helium to make a measurement. If the leak is too large, all of the Helium is evacuated from the test package during the test interval which causes the amplitude of the signal to drop and give a false low leak rate measurement when in fact the leak is large. The CHLD has a minimum measurable leak rate as small as 4×10^{-14} atm-cc/sec and an upper limit greater than 1.0 atm-cc/sec. If a package has a large gross leak, and the Helium sealed or bombed into the package has left so that all that remains in the package is atmospheric air, the 5ppm of Helium in ambient air is all that is necessary to make a measurement. The test chamber is purged with dry Nitrogen which contains less than 1.0ppm Helium just prior to opening the test chamber to the Cryo-Pump. When the Valve [A] in Figure [2] is opened, the Helium signal will rise. The rate of rise is what is important, not how much Helium is present. The Helium in the dead volume of the test chamber will contribute a fixed offset to the zero or base line of the CHLD. If we assume that the dead volume of the test chamber is equal to the volume of the test package and contains 0.5ppm Helium, a gross leak would show up as a signal 10 times greater than the base line offset. In actual practice, the gross leak will show up as a step increase in the Helium signal by 5 or 6 orders of magnitude. Any leak less than a gross leak will be indicated by a steady or linear increase in the Helium signal. For leaks $<10^{-6}$atm-cc/sec which are in molecular flow, the slope of the Helium signal will be independent of the pressure differential across the leak path.

Important Observations.

A number of experiments have been conducted recently which have some important implication. We have been able to obtain both CHLD leak test and RGA data on several groups of semiconductor and medical packages which were manufactured in some cases over 10 years ago. This real time life data has been used to draw the following conclusions:

1. Fluorocarbons can plug leak paths slowing up the exchange of atmospheric gasses and at the same time enhancing the ingress of moisture.
2. Moisture can plug leak paths again slowing up the exchange of atmospheric gasses while accumulating in the package by surface migration.
3. The above observations have been misinterpreted in the past during RGA analysis and the packages have, in some cases, been labeled as “one way leakers”. This phenomena has added to the confusion when trying to find flexure or stress sensitive leaks.
4. The current Mil-Std leak test standards are inadequate to insure that moisture ingress will not become a reliability issue.
5. Most hermetically sealed packages are leak tight several orders of magnitude better than the leak test screening levels. Most conventional Helium leak detectors are simply used to pass/fail packages at their screening levels and are not able to accurately measure how good the packages really are down to these levels. Packages which just pass current Mil-Std leak rate specifications seem to have moisture ingress and reliability problems.
6. Once packages are subjected to Fluorocarbons, additional fine leak testing is at best difficult.
7. Using CHLD we have been able to re-screen previously leak tested packages and determine which leaks are potentially plugged with Fluorocarbons and distorting the fine leak measurement. These

packages have been found to contain large amounts of moisture and could be potential reliability risks.