

Methods for Providing a Dry Seal Environment

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Abstract

Reliability concerns associated with moisture in electronic devices are well documented in the literature. In this paper, we will identify sources of water, and suggest methods used to minimize it. We will simplify the problem by assuming true hermetic packaging. We can analyze the case of non-hermetic packaging by assuming a water leak rate and/or diffusion constants through a permeable package wall. However, for purposes of this paper we will concentrate on some common internal sources of moisture. Organic materials such as adhesives and die attach materials can adsorb and desorb water vapor. It is important to consider all sources of moisture, including the water adsorbed on various surfaces as well as the water vapor concentration in the seal gas. A pre-seal bake can assist in driving water vapor out of organic materials. Less commonly known is that even a hermetic package that contains no organic material can be a source of water vapor. In this paper, we will show current work aimed at quantifying the amount of water that can be sealed inside a package. We will also show how water may become concentrated in specific locations that may affect device performance and reliability.

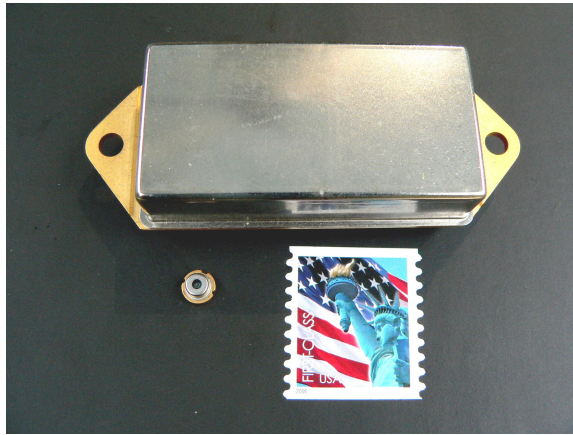
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Basis for moisture concerns

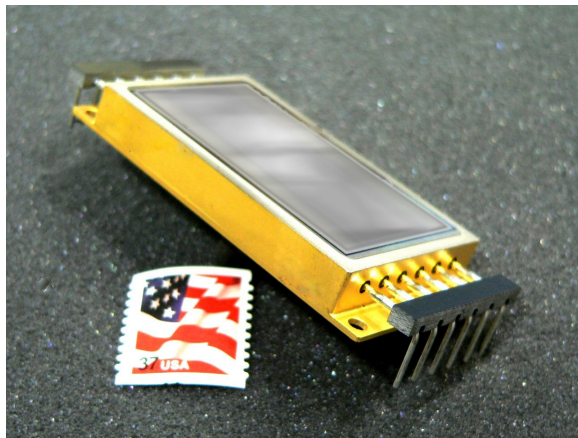
Failures of many electronic devices have been traced to contamination by water. Sometimes parametric shifts are attributed to changes in dielectric constant, but more often, water causes total failure through various types of micro-corrosion mechanisms. These mechanisms have been documented and can be found in the records of reliability symposiums and conferences. Failures have been reported in military, COTS, commercial, and industrial product lines. It is the responsibility of engineering to identify those products and devices that could be compromised by the presence of water, and to prevent water related failures. Because water is such a ubiquitous molecule, this can be a daunting task.

Applicable packaging technologies

Although the measurement methods described in this paper are applicable to a variety of electronic packaging strategies, the one-shot welded, axial leaded platform package and seam sealed, radial leaded flat package are two good examples because both these packages have a large portion of the package interior exposed to a metal cap or cover. Illus. 1 and 2 show photos of each of these package types. Table 1 provides an abbreviated comparison of the two package designs. Many in the microelectronics industry consider the one-shot seal to be obsolete. However, related business areas, for example, high frequency diodes, electro-optics, sensors, MEMs, and related product areas concerned with hermeticity, cost, and reliability issues utilize the one-shot sealing technology to their advantage.



Illus. 1 Large and small one-shot welded platform packages



Illus. 2 Large seam sealed flat-pack

Table 1. Comparison of sealing technologies

	One-shot welded platform	Seam sealed Flat pack
Package cost	Low	High
Lid cost	Low	High
Seal cost	Low	High
Seal speed	High	Low
Thermal	Ave.	Ave.
Max pkg. Size	~10 linear in.	Unlimited
Temp. rise during seal	Low	Med.-High
Hermetic yield	Exc.	Fair
Pkg. mechanical properties	Exc.	Fair



Illus.3 Modern one-shot welder in dry box

Most packaging personnel are familiar with the various parallel seam welders on the market. However, few are aware of, or have used, modern one-shot welders like the one shown in Illus.3. The trend toward surface mount packaging can explain part of the reason for the popularity of parallel seam welding. However, as one studies module manufacturer's catalogues, another possibility surfaces. Manufacturers frequently offer one-shot welded hermetic packages in their line of smaller modules, say less than one linear inch in perimeter. Between 1 and 4-inch perimeter, some manufacturers offer platform packaging while others offer flatpacks exclusively. Above about 4.0 linear inches of seal, almost all manufacturers provide only radial leaded flatpack packages. A possible explanation for this, is that manufacturers encounter processing difficulty when trying to seal larger platform packages. Equipment like the machine shown in Illus.3 make large package sealing every bit as easy as sealing the smaller packages.

Standard measurement methods

Both these package designs have large surface areas of sheet metal in common. Frequently, the metal is either nickel, or nickel-plating. Our task was to determine how much water might be stored in, or on a commercially pure nickel surface. A common method for making this kind of measurement is to seal a package, and subsequently perform an internal vapor analysis (IVA) on the internal gas. Problems with this method are: 1) the IVA analysis does not specifically identify the source of the water and 2) we do not have the equipment required to perform this analysis. The IVA analysis generally involves baking a sealed part and then emptying its gas content into a mass spectrometer where individual molecules are identified and counted. An alternate water specific test involves placing a moisture sensitive sensor inside a sealed

package and using it to measure the partial pressure of water vapor inside the sealed package. This technique has certain advantages, but again, it does not identify the source of the water. It also requires that sensors be carefully calibrated, and that the calibration does not shift during subsequent processing. Another consideration is that sensors in small volume packages can selectively lower the partial water pressure and provide a misleading result. A simplified explanation is that if the sensor behaves like a desiccant, it will lower the dew point below what it would have been without the sensor.

One of the problems we have addressed is how moisture becomes sealed inside a part in spite of the precautions we take in choosing pure metals for the fabrication of package components, and the pre-seal precautions we employ. Once a packaging process has been developed, an analysis is often required to verify the internal gas composition. Analytic laboratories have sensitive equipment that can literally count and identify individual molecules to provide a clear picture of the internal gas composition. The problem is that the analysis can be expensive, and it may leave us wondering where the gas species originated. Since one gas specie of particular interest is water vapor, and since we have sufficiently sensitive equipment to measure water vapor, we might be able to perform these measurements without resorting to an expensive internal water vapor (IVA) test program. The problem is that our tiny electronics packages do not contain enough water molecules for us to count, with our hygrometers. But, if we were to supply a larger sample of our package material, and mix the water that outgases from it with a dry gas, we might be able to measure the actual water desorbed from various package surface per area of surface, and use this number to predict the out gassing of water vapor into a package.. Such a capability would be very useful when evaluating the out gassing characteristics of various packaging materials.

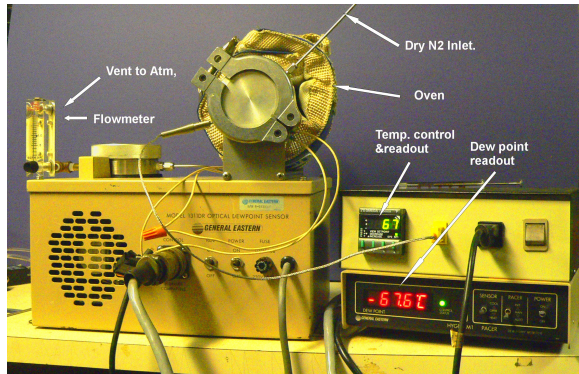
Approach to moisture measurement

Greenhouse [1] has demonstrated the role of surface to volume ratio and the contamination of internal gas by water molecules residing on the interior surfaces of the package. He also points out that smaller packages have larger surface to volume ratios. It requires sophisticated equipment and skills to analyze the water content of a very small volume package. Not having access to the required equipment, we constructed a variable surface / volume test chamber by maintaining a fixed volume and adding surface area, as required, to cover the desired range of ratios. In our test, surface area was adjusted by the addition of rolls of pure nickel foil that have a large surface to volume ratio. The nickel foil is the same material the

package covers are fabricated from. If enough area of nickel is heated in a dry gas, then the water vapor released from the metal surface can be mixed with dry gas and the increased moisture in the effluent gas can be measured with a simple dew point hygrometer. To give a feel for the scale of the test, the metal surface area of a typical TO-5 package is about 0.23 in². The nickel foil used for our testing has a surface area of 1908 square inches. Therefore, we have increased the surface area of our moisture source by a factor of more than 8000. DerMarderosian [2] employed a related test, however, his apparatus measured the dew point of a stagnant gas sample over a thermoelectrically cooled surface. To obtain accuracy in dew point analysis, the gas sample should flow across the cooled detector surface at a constant rate. Each manufacturer of analyzers publishes an optimum rate, which is normally about 1.0 ft³/hr. It would be convenient if the sample gas could be re-circulated through the apparatus and the change of total water concentration monitored as a function of time and temperature. This was attempted and was successful to a degree. The problem was that we could not locate a small re-circulating pump that would not affect the gas sample. In the end, we elected to discharge the moisturized gas sample into the atmosphere and integrate the moisture content to determine the total desorbed water.

Experimental Apparatus

A photograph of the test apparatus is shown in Illus. 4. The chamber is constructed from stainless steel vacuum flange parts with KF blank-offs at each end. UHP nitrogen gas flows into the chamber through a needle valve to control the flow rate. External electrical band heaters heat the chamber. A simple proportional temperature controller is used to set and control the chamber temperature. Gas flows thru the chamber and exits at the far end where it flows into a General Eastern model 1311 DR optical dew point sensor. This sensor utilizes a 3-stage thermoelectric cooler that provides an 80°C depression capability. Accuracy of the General Eastern Hygro M1 is rated at 0.2°C. After exiting the dew point cell the gas is discharged to atmosphere through a flow meter. Flow is regulated with the inlet needle valve to the recommended 1.0 scfh. All tubing is stainless steel. Poly-flow and other plastic tubing was tried, and found to outgas moisture into the dry sample gas. In use, testing always begins at room temperature and the test chamber power is controlled so that the chamber-heating rate is slower than the slew rate of the hygrometer. The reason for controlling the heating rate of the test specimen is to avoid rapid transient changes in water vapor concentration. The moisture monitoring system is most accurate when used for tracking gradual changes.



Illus.4 H₂O desorption test station

The test concept relies on moisture originating only from the test specimen. In practice, we found that the internal surfaces of the tubing and the test chamber itself were hygroscopic and added some moisture to the gas. However, it was determined that if the empty test chamber is heated and cooled with dry gas flowing through it, that the room temperature test chamber could be opened long enough to install the test specimens (< 1.0 minute) without a significant increase in adsorbed background moisture.

Experimental results

We might not expect the solid nickel cap of a TO-5 package to be a major source of water. At about .226 in², it would be difficult to measure the amount of water released by the surface of the metal. However, we can obtain nickel foil from the supplier of the nickel caps. In one example, we obtained a coil of nickel foil, consisting of 1908 in² of surface area, equivalent to 8,442 To-5 covers. With this amount of material, we can determine the total quantity of water desorbed. Illustration 1 shows the experimental device used for these measurements. A small air tight stainless steel tube oven is heated by external pipe heaters controlled by a simple temperature controller. UHP nitrogen gas flows into the oven inlet where it mixes with the desorbing water vapor and then exits the oven, through a dew point hygrometer. The flow rate is controlled by a needle valve at the oven inlet and is set to 1.0 cfh. This flow rate is selected because it provides most accurate hygrometer data and optimal transient response. In use, the nickel foil is inserted into the previously baked out oven at room temperature. After an equilibration period, the heaters are activated, and temperature versus dew point is recorded. As the oven temperature increases, water desorbed from the nickel foil, mixes with the nitrogen gas, and the dew point temperature is measured with the hygrometer and recorded. As the oven heats, the dew point of the

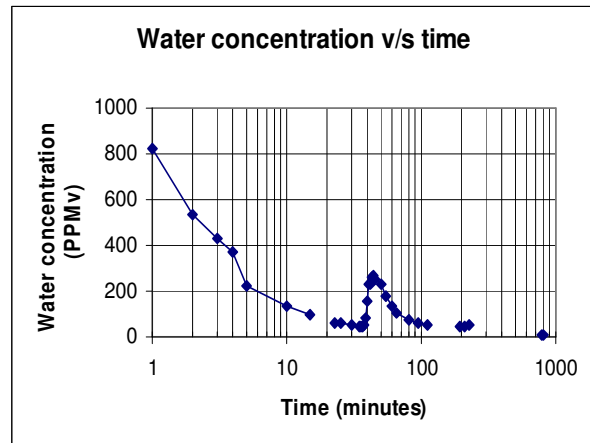


Fig. 1 Water concentration v/s time – overview

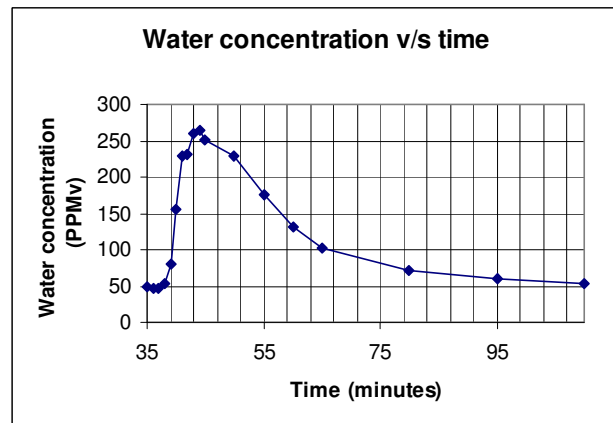


Fig.2 Water concentration v/s time - desorption

gas mixture from a low initial temperature, to a higher temperature, and then back down to a lower temperature, as the surface water is desorbed. The integral of the resulting time/ water concentration curve provides the total amount of water desorbed from the foil. Although it is tempting to try to accumulate the wet nitrogen and measure the dew point of the total volume of the collected gas, we have been unable to locate a pump to circulate the wet gas at the proper flow rate, without contaminating the gas or losing any of the sample. Therefore, we are content to discharge the used gas into the atmosphere and integrate the data. Fig. 1 is an overview of an entire event. The oven has been pre-dried and allowed to cool with dry gas flowing through it. The oven is briefly opened, the sample material loaded, and then re-sealed. At that point we begin to record dew-point. After the dry carrier gas reduces the exit gas to a low background moisture level, the oven is activated, and allowed to stabilize, in this case, at 121 degrees C. Fig. 2 is a magnified view of the desorb portion of Fig.1. Water concentration v/s time is integrated. In

the case above, the integral is 7830 ppm_v - minutes. One of the several methods that can be used to perform the moisture analysis is described below.

1. Total gas flow = 1.0 scfh = 472 cm³/min x 75 min = 35400 cm³.
2. Integrated moisture content = 104.4 ppmv (-41.76°C dew point) for 75 minutes.
3. From tables, the water concentration for a dew point of -41.76 ° C = .07658e-6 gH₂O/cm³
4. Total desorbed water = 35400 cm³ x .07658e-6 g/cm³ = 2711e-6g H₂O
5. Water desorbed/unit area = 2711e-6g / 1908in² = 1.42e-6g/in² = 0.22e-6g/cm²

Note that even though little moisture (0.22 micrograms) is desorbed from a single cm² of nickel foil, by scaling the test to a large surface area, we provide adequate water to make the measurement practical. An application of this calculation would be a cubic container measuring 0.1 cm on a side. The surface area of this package is 0.06 cm² and the volume is 0.0010 cm³. The water evolved would be 0.06cm² x .22e-6g/cm² = 13.2e-9gH₂O, and the water concentration in the package would be 13.2e-9/.001cm³ = 13.2 e-6g/cm³. This is not an insignificant amount of water to inject into a small package as it will add 16,430 ppm_v to an otherwise dry package. Some may claim that the water will be re-adsorbed as the package cools. However, cases exist where this may not occur. For example, if the package were to contain a thermo-electrically cooled sensor, most of the 13.3 nano-grams would condense directly on the cooled device. The actual size of a single droplet with this volume, would depend on some factors that we don't know, however, if the drop were to be a hemisphere, its diameter would be about .0015 inches. With line spacing of many devices measured in a few microns, a 60 micron diameter drop of water might not be a welcome contaminate. Another variable that has not been mentioned, is that we know water does not re-adsorb instantly. Under conditions of rapid cooling, water may condense before it can be re-adsorbed onto the surface it came from. These are considered advanced potential reactions. We are not ready to predict the internal weather patterns inside a sealed package. It is likely that the native nickel hydroxide [Ni(OH)₂] is acting as a desiccant layer, and adsorbing some moisture. Future plans include removing the native oxide layers and repeating the test.

Another useful application of this test method is to determine the effectiveness of pre-seal bake parameters in the removal of water vapor. By inspection of Fig.2, it is apparent that at 121°C, it

would take at least 1 hour to desorb most of the water. If 3 monolayers of water is the threshold thickness for corrosion reactions, the 5.5 monolayers removed from our test material by a simple baking process, may have been cause for concern.

How much water should be allowed?

The question of how much water to allow in a hermetic package is currently specified in documents such as Mil Std-883 at 5000ppmv. Some investigators suggest that more water can be tolerated in small volume packages because of an "effective dew point reduction" in small volumes. Based on our experience in this area, we suggest that the maximum amount of water allowed, should be specified by the smallest drop that would cause a reliability concern, if all the water vapor in a package were to condense in the most vulnerable location of the package. For example, if the smallest conductor spacing in a package is 0.5 mils, the maximum amount of allowable water vapor would be the vapor concentration that would result in a 0.5 mil diameter droplet.

References

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- [2] Aaron DerMarderosian Sr. Behavior of Moisture in Sealed Electronic Enclosures Proceedings IMAPS 39th International Symposium on Microelectronics 2006