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White Paper

Moisture in Hermetic Packages

By Craig Hillman, PhD

5110 Roanoke Place, Suite 101 College Park, Maryland 20740
Phone (301) 474-0607 Fax (240) 757-0053
www.DfRSolutions.com

Moisture in Hermetic Packages

Hermetic packaging of micro-electronic and opto-electronic devices is commonly utilized to protect the devices from aggressive application environments (submarine; outdoor industrial and telecom; space). While many failure modes exist (seal failures; outgassing of organics; evolution of secondary gas species), the most commonly observed failure modes are due to trapped water vapor and possible condensation onto critical surfaces/devices. General guidelines and test procedures are standard across many industries, but even the best device packaging companies occasionally experience water vapor-induced issues due to material selection, process/supplier changes, and/or equipment degradation.

<u>Examples</u>

- NASA has experienced serious failures which were attributed to moisture sealed inside of hermetic semiconductor packages. In September 1994, a NASA advisory was issued against a transistor (GX04715C) which reportedly caused an on-orbit anomaly during the first Hubble Space Telescope (HST) servicing mission. Samples from excess HST stock of the same date code were subjected to residual gas analysis (RGA) and found to possess moisture levels ranging from 1.17% (11,700 PPM) to 2.7% (27,000 PPM).
- A GIDEP Alert was issued by National Semiconductor for numerous high reliability part numbers (including MIL-M-38510 JAN B). The devices were assembled at an off-shore assembly house in the Philippines. The date codes (which ranged between H9315 and H9339) exhibited internal water vapor contents as high as 46,600 PPM.

<u>Test Methods and Acceptance Criteria</u>

Two US military standards (MIL-STD-883 and -750, both using Method 1018, Procedure 1) are commonly referenced regarding the test method for residual gas analysis (RGA). The general acceptance criterion is that the initial water vapor content be below 5,000 ppm, with less than 1,000 ppm being a desired result. The pass/fail level is based on the observation that many industries specify a lower device operating temperature limit of -5 to 0ºC, and 5,000 ppm is sufficient to cause condensation at a case temperature of -2ºC. Individual OEMs may have more stringent requirements, including the maximum acceptable levels of other gas species (notably hydrogen, carbon dioxide, and oxygen) as well as organic species (IPA, methanol, and other species due to cleaning agents and/or epoxy reactions).

Manifestations of Water Vapor- and Condensation-Induced Damage:

The presence of appreciable water vapor and/or condensed water is a requirement for many failure mechanisms. These include:

- **Corrosion of solder joints and other materials under electrical bias (per EMF)**
  For the example of eutectic SnPb solder joints, Pb is the most susceptible surface species to oxidation as gold is noble and Sn rapidly forms a thin protective oxide layer. Pb reacts with the moisture to form PbO_2, which is black in color and slightly powdery. Oxidation will tend to occur at the anode, because electrons are being removed from the anode source and oxidation reaction is a removal of electrons from the metal. Once the Pb is ionized, two potential reactions can occur. If moisture is present, the Pb will stay in the ion form and be subjected to the electromotive force (EMF) between conductors at different potentials. This will induce migration of Pb ions to the cathode, where they will plate and form a conductive path back to the anode. An optical micrograph of capacitors that failed by this mechanism is shown in Figure 1, with associated elemental analysis of the solder on the cathode and anode in Figure 2. If moisture is not present, the ionized Pb will immediately react with oxygen to form PbO_2.
- **Shorting due to droplet formation**
  Sufficiently large water droplets may bridge adjacent conductive traces on PCBs as well as MEMS components, causing immediate shorting. Because the water droplets may evaporate during the shorting event and/or removal from the field environment for failure analysis, these failures may often be diagnosed as no trouble found (NTF). Residual gas analysis of hermetic packages is strongly advised in such cases as an initial step in the failure analysis process.
- **Stress corrosion cracking of glass seals, passivation layers, dielectric layers, and epoxy/substrate interfaces**
  Glasses, ceramics, and polymer-substrate interfaces are well known to be prone to stress corrosion cracking in the presence of water and water vapor. Glass package seals with initial defects and/or high residual stresses may crack and rupture over time, particularly in cold environments, leading to hermeticity failures. Silicon oxide, oxynitride, and nitride coatings and dielectric layers may have high deposition-induced stresses, which combined with water may lead to crack growth and subsequent shorting. Debonding of die attach and underfill adhesives has been observed for water vapor levels as low as 100 ppm when combined with high curing-induced stresses.

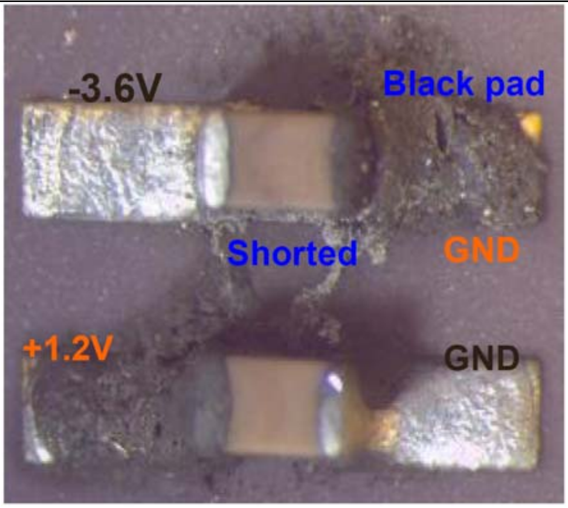
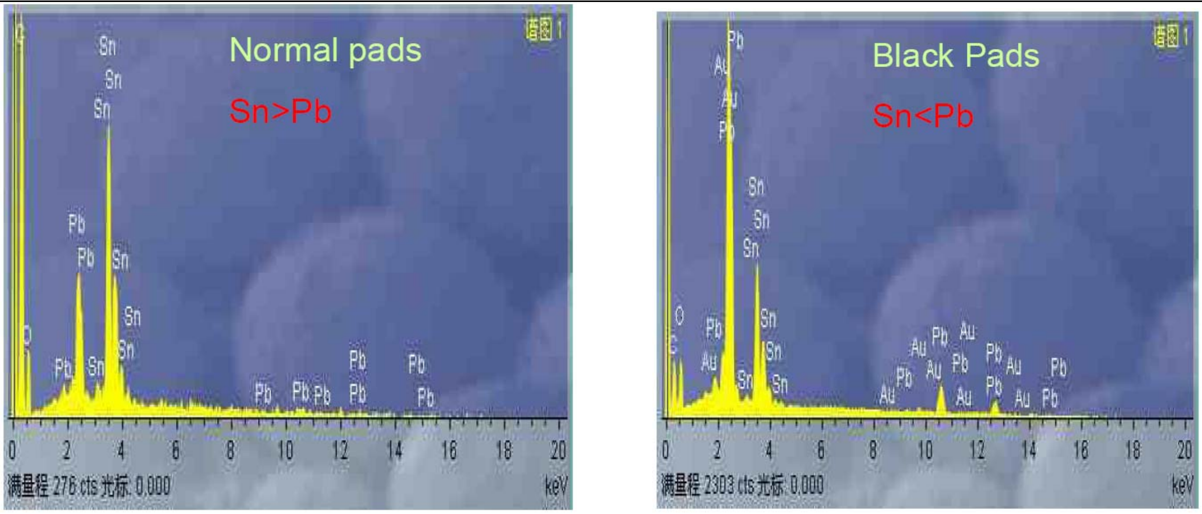


Figure 1: Optical micrograph of capacitors that failed due to water vapor-induced corrosion & migration of Pb and subsequent shorting.



(a) (b)

Figure 2: EDX scans of the capacitor pads shown in Figure 1, showing the elevation of Pb on the black pads due to electro-chemical migration.

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Sources of Water Vapor

- Multiple sources of water vapor may be present inside of hermetic packages. These include:
- **Hydrogen desorption from Kovar packages and subsequent reaction with surface oxides**
  The work of Peter wh Schuessler of Loral (formerly IBM) has demonstrated that hydrogen desorbed from Kovar package material (trapped during forming operations) may react with available surface oxides to produce water. The amount of trapped hydrogen is expected to increase with increasing Kovar package thickness, nickel oxidation (due to transport within Kovar and through gold overplating), and increased grain boundary density. The net amount of water produced can't be predicted with any accuracy, but this source has been attributed as the failure mode for numerous past product alerts and recalls.
- **Water generated as a by-product of curing in die attach adhesives**
  Some epoxy chemistries generate water as a by-product of the polymerization reactions during curing, while others used adsorbed moisture to accelerate curing. Generally, water produced in this fashion may be eliminated by completing the curing process prior to sealing or selecting epoxy chemistries with no water by-products.
- **Desorption of trapped water from porous ceramics and polymeric materials**
  Porous ceramics like alumina, beryllia, and aluminum nitride are commonly used as substrate materials as well as in the plates of thermo-electric coolers (TECs) due to their thermal conductivity. Water may be present as vapor or adsorbed films in pores, and subsequently escape during elevated temperature storage and/or use.
- **Water contamination in sealing gas containers**
  Nitrogen, helium, and/or clean dry air are frequently used to backfill hermetic packages prior to sealing. Due to poor gas control and/or sealing, water vapor may become trapped in the tanks and subsequently introduced into the package.
- **Fine package leaks (which pass helium fine leak tests)**
  The pass/fail criterion for helium fine leak testing is typically $<1x10^{-8}$ atm-cc/sec maximum to prevent ingress of moist ambient air into the package over its useful life. However, for sufficiently sensitive devices deployed in aggressive operating/storage conditions, small amounts of water vapor ingress may nonetheless be enough to cause failure.

Remediation

Intelligent selection of subcomponent materials, material pre-conditioning, and tight process control are required to consistently produce hermetic packages with low water vapor content. The following remediation methods have been employed:

- **Pre-baking of package materials**
  Annealing of Kovar in appropriate environments may substantially reduce or effectively eliminate trapped hydrogen. Baking of porous ceramic components at elevated temperature in vacuum, especially with multiple purges (see below) may eliminate trapped or adsorbed moisture. Subsequent storage in dry boxes, ideally in the same area as final packaging, is recommended to prevent resorption of water vapor. Some process development may be required to optimize the conditions.
- **Argon or oxygen plasma-cleaning of assembly prior to sealing**
  Plasma cleaning, with either argon or oxygen plasma, has been successfully used to eliminate adsorbed moisture on exposed surfaces as well as in joints and crevices, in addition to thin organic layers resulting from epoxy outgassing and trapped non-volatile residues. For devices with sensitive surface layers, i.e. facet passivation or dielectrics, process studies should be performed to identify possible damage in the devices after cleaning.
- **Pump-purge cycling prior to vacuum sealing to increase surface activity of gases**
  Conventional package sealing involves drawing vacuum on single or multiple packages prior to backfilling with inert gas and subsequent electrode/weld/solder sealing. Multiple vacuum/inert gas “pump-purge” cycles substantially increase the activity of gases on the device surfaces, thereby enhancing removal of adsorbed water vapor and organic films. Some process development may be required to optimize the conditions.
- **Use of getters (deposited films, adhesive films**)
  Getters are an attractive option for removing water vapor that may have been introduced by any of the above mechanisms and/or unintended process changes. However, the getter material must be selected with knowledge of the potential gas species in the package and their concentrations (as determined by RGA), and some level of qualification testing performed (such as high temperature storage) to identify how much water vapor is left and what, if any, gas species evolve out of the getter over time.
- **Encapsulation of moisture sensitive components in silicone epoxies**
  Generally, the addition of silicone epoxy over-layers will only slow the ingress of water vapor to the device surfaces. Furthermore, water vapor and other species initially present on the surface may become trapped by the silicone. Hence, engineering resources are better spent on the other remediation methods, which may provide more reliable and longer-term solutions.

DfR Solutions can provide guidance regarding material selection, cleaning & sealing processes, process monitoring tests, qualification testing, and additional characterization methods to enable reliable long-term performance of your hermetic components.

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