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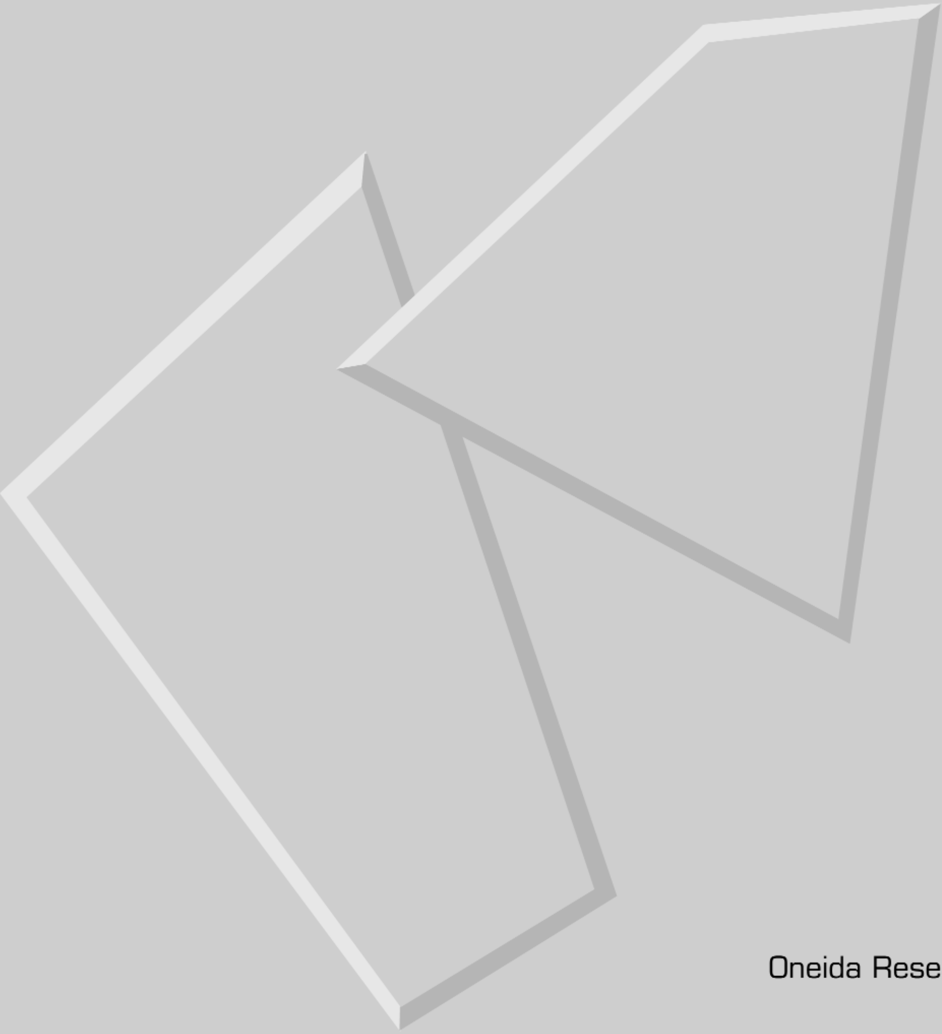
Interpretation of RGA Data



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INTERPRETATION OF RGA DATA
Including Observations on the Outgassing Characteristics of Materials

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INTRODUCTION

Residual Gas Analysis of hermetic microelectronic devices has traditionally been treated as a means for measuring a device's internal moisture content only. Too many times, the moisture reading is treated on a pass/fail basis using the MIL-STD criteria that all devices must contain less than 5000 parts per million by volume (ppmv) of moisture. In reality, the other gases routinely reported with the moisture contain a wealth of information that can be used to significantly improve product quality and reliability. The intent of this article is to summarize historical observations made at ORS concerning RGA data. While comprehensive in its scope, this article does not cover all the possible problems that can be uncovered and identified through the use of RGA data. Some of the more common problems are covered below.

Typical problems that can be identified and eliminated using RGA involve:

- Epoxy curing and bake-out (both under- and over-curing)
- Excessive thermal stresses (out-of-tolerance ovens, rework, etc.)
- Hermeticity failures and leak test escapes
- Contamination problems
- Hydrogen outgassing (resulting in moisture or hydride formation)
- Corrosion and dendritic growth sources (compounds other than moisture can promote these phenomena)
- Sealing environment problems (sealer leaks, poor helium circulation, etc.)
- Changes in vendor material formulations (adhesives, solvents, plating, etc.)

With a more thorough understanding of RGA data interpretation, the RGA user will be better able to apply their gas analysis results in making process improvements that result in increased device reliability.

Residual Gas Analysis or Internal Water Vapor Content Analysis as outlined in MIL-STD-883, Method 1018, Procedure 1 has been used by the Microelectronics Industry as the primary method for measuring the moisture level inside of hermetic devices since the late 1970's. Since Procedure 1 is a mass spectrometry method, it also can quantify all of the other gases found in the device cavity.

As outlined in Test Method 1018, the test parameters revolve almost entirely around determining the moisture content of the package's internal atmosphere. Failure criteria for moisture are found in MIL-STD-883, Methods 5005 and 5008. Other than an additional 1000 ppmv limit for oxygen found in MIL-S-19500, no limits or guidelines on any other gases exist. This has unfortunately caused many of the other substances routinely identified on an RGA report to be largely ignored. However, as will be shown, these substances often indicate the nature of high moisture as well as several other potential reliability risks.

DISCUSSION

To begin, a review of what actually makes up typical sealing atmospheres is in order (Table 1). The most essential mixture to keep in mind is that of air (Sample 1a). Air is a mixture of nitrogen, oxygen, argon, and carbon dioxide. The moisture level in air will vary widely based on climatic conditions. Most glass frit seal devices are sealed in dry air. Devices sealed in other environments that subsequently develop leaks will eventually contain air. A key factor to note is the ratio of oxygen to argon which is approximately 22 to 1. This ratio will be useful in later discussions on leak phenomenon. For most solder and welded seal devices the sealer atmosphere is dry nitrogen (Sample 1b). The only common contaminant found is small amounts (100-200 ppmv) of argon, which is inert. Higher levels of argon accompanied by oxygen may indicate a leak somewhere in the gas handling system.

Many devices, especially hybrids, are sealed in an atmosphere containing helium as a tracer gas for enhanced leak test sensitivity. The most typical mixture is shown in Sample 1c, which is 90% Nitrogen and 10% Helium. It has been found that without adequate circulation, helium may tend to collect towards the top of the dry box. This results in lower than expected levels of helium sealed in the devices. It is, of course, desirable to know the level of helium within a device as precisely as possible in order to more accurately calculate the leak rate of that device.

TABLE 1 - Common Sealing Atmospheres

Sample ID	**1a**	**1b**	**1c**
Nitrogen, %	78.1	99.9	89.8
Oxygen, %	20.9	ND	ND
Argon, ppm	9320	125	130
Carbon Dioxide, ppm	310	<100	<100
Moisture, ppm	<100	<100	<100
Helium, %	ND	ND	10.1

Comments:
Sample 1a: Dry Air
Sample 1b: Dry Nitrogen
Sample 1c: Dry Nitrogen/Helium Mix

Glass Sealed Devices

Table 2 contains data typical of ceramic packages employing glass frit seal technology. Frit seals are usually reflowed in an air environment since the oxygen is needed to promote oxide formation in the glass which is essential for a good seal. Glass sealed devices usually employ eutectic gold/silicon die attach technology because of the high sealing temperatures (425-450°C) encountered.

The data for Sample 2a is representative of a glass sealed device with eutectic die attach. Note that the oxygen to argon ratio is slightly less than that found in air due to the oxide formation described above. Also note that the moisture level is relatively low. One interesting property of this technology is that cavity moisture levels tend to decrease with time. It is not unusual to find well handled glass sealed devices with less than 100 ppmv of moisture after one year from the seal date.

The results obtained from Sample 2b suggests the presence of the most common problem encountered in glass sealed devices. This sample has an organic contaminant in the cavity that is decomposing at the high sealing temperatures. The moisture level exceeds 5000 ppmv and is accompanied by an elevated level of carbon dioxide. Since argon is inert, it will not be involved in any reactions taking place within the package. As long as the reaction taking place involves the outgassing of other compounds, the level of argon reported will not change significantly and can thus be used to determine an "expected" level of oxygen.

Using the 22 to 1 oxygen/argon ratio, we can determine that the oxygen content has also decreased from an expected 20.3% to a reported 15.6%. In this particular case, it was determined that a new lot of ceramic lids had a hydrocarbon residue that was thermally degrading during the sealing process, consuming oxygen and generating carbon dioxide and moisture in the process. The contaminant may have been from the manufacturing operation (e.g., a mold release agent) or from the packaging used in shipping (e.g., a residual plasticizer). The device manufacturer's usual cleaning process was insufficient to remove the contaminant.

It is important to note that all of the devices sealed using these lids failed. If only one device out of several had failed, the source of the failure would more likely have been at the assembly point. These more random failures are typically caused by some unique anomalous condition such as a stray fiber or spittle contamination introduced during the assembly operation.

TABLE 2 - Glass Sealed Devices with Eutectic Die Attach

Sample ID	**2a**	**2b**
Nitrogen, %	81.0	78.9
Oxygen, %	17.9	15.6
Argon, ppm	9221	9211
Carbon Dioxide, %	0.11	3.67
Moisture, ppm	541	8795
Comments:		
Sample 2a: "Good"		
Sample 2b: "Bad"		

Table 3 contains data from glass seal devices that have a polyimide alpha particle barrier applied to the die surface. Alpha particles have long been known to induce "soft" errors in devices and are more common in ceramic devices due to the higher number of radioactive decay events occurring in alumina. The polyimide layer has been found to significantly reduce the incidence of these errors.

The results shown for Sample 3a are typical of a device that has been properly processed using this technology. The most pronounced effect is the severe amount of oxygen depletion occurring during sealing. This is expected when an organic material is exposed to high temperatures in an oxidizing environment. The main gaseous by-product appears to be carbon dioxide. Also given off is methane and hydrogen. The initial reaction appears to be an oxidation of the polyimide resulting in the outgassing of carbon dioxide and methane. As the oxygen becomes depleted, a pyrolysis reaction takes over and hydrogen becomes the dominant outgassing product. As will be discussed later, hydrogen can be involved in a number of other reactions.

One alternative that appears to be successful in maintaining a low moisture level when using polyimide is to custom blend the sealing atmosphere (Sample 3b) rather than simply using compressed dry air. In this case, oxygen and argon are mixed with nitrogen at levels much lower than typical atmospheric concentrations. By keeping 1-3% oxygen levels, a good glass seal can still be obtained but the oxidation reaction of the polyimide is severely curtailed. Interestingly, while some carbon dioxide and methane are still generated, hydrogen has not been detected. This implies that either the oxidation reaction is a crucial precursor to the pyrolysis reaction or the lower level of hydrogen being generated is more easily consumed in subsequent reactions.

TABLE 3 - Glass Sealed Device with Eutectic Die Attach and Polyimide Alpha Particle Barrier

Sample ID	**3a**	**3b**
Nitrogen, %	86.1	94.8
Oxygen, %	5.09	1.55
Argon, ppm	9808	724
Carbon Dioxide, %	5.49	3.05
Moisture, ppm	2207	642
Hydrogen, %	1.29	ND
Methane, ppm	8745	4458
Comments:		
Sample 3a: Dry Air		
Sample 3b: Custom Blended Air		

Solder Sealed Devices

Devices that employ a solder to make the hermetic seal are typically sealed in dry nitrogen. RGA results of a solder sealed device using a nickel/gold plated Kovar™ lid and eutectic die attach are listed in Table 4. The atmosphere is predominantly nitrogen with low levels of carbon dioxide and moisture. The carbon dioxide can evolve from trace organic residues found within the device such as organic brighteners used during the lid plating process. Moisture may also come from the same source or from entrapment sites within the device, such as small scratches. These sites can act as capillaries, filling with moisture before sealing, and then outgassing during sealing or later post-seal thermal stressing.

Also of note is the hydrogen which is evolving from the lid. Kovar™ and other ferrous alloys may contain hydrogen.[1] Plating processes also generate significant amounts of hydrogen which can become entrapped within the plating layers. Elevated temperature processing, from sealing to environmental screening, will cause this entrapped hydrogen to outgas from the lid. As will be discussed later, hydrogen can be involved in forming moisture if the proper oxygen source is available.

TABLE 4 - Solder Sealed Device with Eutectic Die Attach

Sample ID	**4a**
Nitrogen, %	**99.4**
Carbon Dioxide, ppm	**154**
Moisture, ppm	**473**
Hydrogen, ppm	**5845**

Table 5 shows the RGA results from solder sealed devices that contain typical silver loaded lead borate glass die attach materials. The results for Sample 5a are typical of devices that have been properly assembled and sealed. Relatively high levels of carbon dioxide are often reported and appear to generate from a dissociation of the silver carbonate in the glass.[2]

The most common type of moisture-related failure associated with silver glass is illustrated in Sample 5b. As mentioned previously, significant amounts of hydrogen can evolve from the lids used on these packages. By its very nature, silver glass of this type has large amounts of silver oxide, silver carbonate and lead oxide. It has been shown that these compounds are readily reduced by hydrogen, the by-products being moisture, and in the case of silver carbonate, carbon dioxide.[2] Hydrogen evolving from the lids has reduced these compounds at the fillet area of the die attach and produced unacceptably high moisture levels. The solution to this problem is to introduce a preseal bakeout of the device in a forming gas (reducing) atmosphere immediately prior to sealing. While hydrogen will still evolve from the lids, this step limits the amount of oxides available for reaction with hydrogen and keeps moisture from forming.

TABLE 5 - Solder Sealed Devices with Silver Glass Die Attach

Sample ID	5a	5b
Nitrogen, %	99.0	99.8
Carbon Dioxide, ppm	3420	3150
Moisture, ppm	439	6240
Hydrogen, ppm	5556	450
Comments: Sample 5a: "Good" Sample 5b: "Bad"		

A newer development in silver glass technology is the introduction of new "low temperature" lead vanadate glass systems. The low processing temperatures of these glasses (some below 300°C) is attractive to manufacturers with large die size and small device geometries because the potential for thermally induced damage is minimized.

The results listed in Table 6 are from devices employing this technology. Typically with these materials, as moisture levels increase, so do carbon dioxide levels (Sample 6a vs. 6b). This implies that the source of moisture is organic in nature, most likely the organic binders employed to give the glass proper dispensing properties during assembly. One significant processing difference between "high" and "low" temperature glasses is how these organic binders are removed during die attach. Traditional glasses employ a two step organic burn-off (OBO) and glass sinter profile. This allows the organic materials to be removed prior to reaching the glass transition temperature. The new lead vanadate materials employ a one step OBO/sinter profile which may result in a higher level of entrapment of residual organics in the glass. These organics can then thermally degrade over time to produce carbon dioxide and moisture in the cavity of the device. Careful control of the temperature ramp rate in order to achieve a more complete burn-off prior to the onset of glass sintering will help to prevent this problem.

TABLE 6 - Solder Sealed Devices with "Low Temperature" Silver Glass Die Attach

Sample ID	6a	6b
Nitrogen, %	99.2	97.1
Carbon Dioxide, %	0.41	1.43
Moisture, %	0.29	1.26
Hydrogen, ppm	1252	1985
Comments: Sample 6a: "Good" Sample 6b: "Bad"		

Another interesting group of die attach materials is thermoplastics. These materials offer very low thermal stress, good bond strength and very low moisture levels. Table 7 contains typical data for these materials. The most notable item is the extremely low moisture level. It appears that, while moisture is generated during cure, the material itself reacts chemically with it and effectively acts as a getter, keeping the internal atmosphere dry. Very high levels of carbon dioxide are found in the cavity but is not, in and of itself, a problem. The other significant outgassing product is identified here simply as hydrocarbons and appears to be a thermal degradation by-product of the thermoplastic which evolves during sealing.

TABLE 7 - Solder Sealed Device with Thermoplastic Die Attach

Sample ID	7a
Nitrogen, %	**89.6**
Carbon Dioxide, %	**9.27**
Moisture, ppm	**511**
Hydrogen, ppm	**4587**
Hydrocarbons, ppm	**5590**

Welded Seal Devices

Weld sealing is used on devices employing all metal package designs such as TO cans and hybrids. The sealing is performed in a dry box with a controlled atmosphere of nitrogen or a mixture of nitrogen and helium.

Most TO packaged devices employ eutectic die attach technology and have internal atmospheres very similar to solder seal devices containing the same. Other TO cans and most hybrids use epoxy die attach materials, which have their own particular processing problems.

For a number of years there were no formal guidelines for epoxy formulations in the industry. As long as such properties as bond strength, dispensability, and thermal/electrical conductivity were acceptable, no other controls were deemed necessary. In the late 1980's it was found that several failure mechanisms could be traced to the epoxies employed and an effort was made to establish minimum guidelines for epoxy formulations. These guidelines were then implemented as Test Method 5011 in MIL-STD-883. Table 8 shows some of the differences in epoxies from an RGA standpoint before (pre-5011) and after (post-5011) the advent of Test Method 5011.

The most notable substance outgassed from some pre-5011 epoxies is ammonia (Sample 8a). These epoxies use a dicyandiamide curing agent which can result in the formation of ammonia during post-seal thermal screening. It is believed that ammonia can be corrosive to the aluminum wires and metallization in a device. Unfortunately, this corrosion mechanism is difficult to prove since analysis of a corroded area will not reveal the presence of any ionic or corrosive agent as it would if, for example, chlorine is the culprit. However, device failures have been investigated where there were no other assignable causes to a corrosion event.

TABLE 8 - Pre- Versus Post-5011 Epoxies

Sample ID	8a	8b
Nitrogen, %	91.0	85.1
Carbon Dioxide, ppm	2091	5792
Moisture, ppm	1680	4720
Helium, %	8.34	13.3
Ammonia, ppm	3161	ND
MEK, ppm	ND	1446
Methanol, ppm	ND	1826
Tetrahydrofuran, ppm	ND	862
Comments: Sample 8a: Pre-5011 Epoxy Sample 8b: Post-5011 Epoxy		

With this in mind, post-5011 epoxies are designed as thermally curing systems that do not involve the amine curing agent. Typical RGA results for these adhesives are shown in Sample 8b. Though, the ammonia is absent, it has been replaced by some of the organic solvents used to maintain viscosity during dispensing (e.g., tetrahydrofuran). Methyl ethyl ketone (MEK) is used as a viscosity modifier by the vendors of the silver flake used in conductive epoxies. Recent investigations[3] have also shown that silver (a known catalyst) may be involved in a number of reactions with the epoxy which result in the outgassing of compounds such as methanol.

Table 9 illustrates the recurring problem of inadequate pre-seal bakeout. The key indicators are high moisture levels accompanied by high residual solvents and low levels of carbon dioxide. For most organic compounds, carbon dioxide is an excellent indicator of the amount of thermal stressing that has been applied. A low level of carbon dioxide associated with excess moisture indicates that additional baking is required to lower moisture levels.

TABLE 9 - Epoxy with Poor Pre-Seal Bakeout

Sample ID	a
Nitrogen, %	95.3
Carbon Dioxide, ppm	1220
Moisture, %	1.05
Hydrogen, ppm	350
MEK, %	1.80
Methanol, %	1.32
Hydrocarbons, ppm	3250

The opposite condition is shown in Table 10. Excessive thermal stressing can be just as detrimental to internal water vapor levels as an insufficient bakeout. In Sample 10a, the pre-seal bakeout was too severe, as indicated by the complete absence of the typical solvent residues and the high level of carbon dioxide. Sample 10b shows a similar overstress condition but one that has occurred after sealing. This can be identified as post-seal thermal overstress because the residual solvents would have been removed during pre-seal overstress otherwise. This condition could indicate several problem areas such as an out of control burn-in oven, a malfunctioning power supply during biased burn-in or an oven with a poor or uneven thermal profile. Investigators have reported oven temperature variances as large as 70°C from top to bottom. RGA results will be greatly influenced by the particular position a device occupies in an oven possessing a substantially uneven thermal profile. This condition can account for erratic moisture readings encountered within a particular lot.

TABLE 10 - Thermally Overstressed Epoxies

Sample ID	**10a**	**10b**
Nitrogen, %	95.6	92.0
Carbon Dioxide, %	2.35	2.07
Moisture, %	1.93	1.89
Hydrogen, ppm	1220	9780
MEK, %	ND	1.42
Methanol, %	ND	1.20
Hydrocarbons, ppm	ND	4725
Comments: Sample 10a: Pre-seal overstress Sample 10b: Post-seal overstress		

It should be noted here that such operations as element rework can have a dramatic impact on moisture readings for a particular device. The hot gas rework tools often used to remove bad elements from a substrate can generate very high local temperatures. The result is that the substrate attach adhesive under the element being reworked can be severely overstressed during this operation. The carbon dioxide and moisture generated by the overstress will outgas into the package's internal atmosphere. Depending on the size of the device and the severity of the overstress, this evolution may occur for a substantial period of time.

<u>Leak Phenomenon</u>

Efficiently screening out leaking devices is a common problem facing the hybrid industry today. Devices which have passed prior hermeticity testing have been identified as leakers during RGA due to the presence of high moisture, oxygen, argon, helium and fluorocarbons. There are several factors that contribute to this apparent discrepancy. One is that the failing leak rate specified for devices in many programs is simply too lenient. Leak rate limits of 1 x 10^{-7} atm-cc/sec He and greater are not uncommon, yet devices close to these limits actually are leakers. Another factor is the assumption that a device's leak rate remains constant under all conditions. Factors such as temperature and pressure have been found to alter a device's leak rate by several orders of magnitude. There is also a good deal of evidence that the leak test conditions in Method 1014 itself are not adequate when dealing with larger packages.[4]

The RGA results summarized in Table 11 are a good example of this problem. Sample 11a had previously passed hermeticity testing per MIL-STD-883, Method 1014 but is obviously not hermetic. In this case, it appears that a pressure dependent leak exists. The presence of significant levels of helium and fluorocarbons with relatively low levels of moisture, oxygen and argon indicates that this device is not leaking under all conditions. The physical effects of typical leak test bombing pressures on a package have been theorized to result in a temporary loss of hermeticity, most likely by disturbing the intergranular oxide boundary of the glass-to-metal seals.[5] These stresses are the complete opposite of those put on the package during the detection portion of leak testing (i.e., vacuum or internal pressure induced by heat). This may make it easier for leak test materials to enter the package than for them to escape in a detectable quantity.

Sample 11b shows results from a device with a leak that is more thermally dependent. This is evidenced by the presence of higher levels of oxygen and argon with no helium or fluorocarbons and very high levels of moisture. In this case, temperature cycle testing was identified as the source of the problem.

Most packages are built with "matched" glass seals, meaning that the package, glass insulator bead and the lead all have matching temperature coefficients of expansion. At any given temperature, all parts of the package will, therefore, have expanded or contracted the same amount and package integrity should be maintained. However, because of their physical characteristics, each of these components will have a very different rate of change of expansion. The leads are a thin metal strip or wire with significant surface area, making them excellent radiators, while the glass bead is, by definition, a good insulator. The package body itself is likely somewhere in between, with significant surface area but also most of the thermal mass. This means that, when going from hot to cold for example, the lead will be contracting much faster than the insulator. In many cases this difference may be enough for hermeticity to be momentarily compromised, allowing moisture and other gases to move through the seal. This is where another aspect of temperature cycle testing contributes to the results of 11b; that is, that a significant amount of humidity is encountered in the cold side of most temperature cycle chambers. As the device is experiencing this momentary loss of hermeticity, it is also encountering a very moist environment. This would account for detected moisture levels which are often much higher than the ambient humidity surrounding the device.

Pressure dependent and temperature dependent leak phenomenon are most likely interrelated. A package seal that has been disrupted by thermal stresses will probably be more susceptible to pressure dependent phenomenon afterward. Sample 11c contains data typical of this situation. Devices exhibiting results such as these have been traditionally called "One Way Leakers", indicating that moisture and other gases could leak into the device but not out. It would appear that this condition might more accurately be termed "Intermittent Leaker", since the leak actually occurs during, or at least is greatly affected by, certain environmental conditions.

TABLE 11 - Intermittent Leak Phenomenon

Sample ID	**11a**	**11b**	**11c**
Nitrogen, %	96.1	90.5	87.7
Oxygen, %	0.12	6.07	4.87
Argon, ppm	274	2940	2415
Carbon Dioxide, ppm	1210	1575	2750
Moisture, %	0.36	3.04	2.72
Hydrogen, ppm	897	425	890
Helium, %	2.44	ND	3.07
Fluorocarbons, %	0.76	ND	1.02
Comments: Sample 11a: Pressure dependent Sample 11b: Temperature dependent Sample 11c: Combined Effect			

Often overlooked is the effect subsequent system level assembly operations are going to have on such devices. Processes such as Wave Soldering, Vapor Phase Reflow Soldering and Vapor Degreasing all generate very similar temperature profiles as those shown to influence the "Intermittent Leak" phenomenon. The difference is the environment outside of the device, which now contains some very volatile and potentially corrosive compounds. RGA results for a field failed device are shown in Table 12. The presence of chlorinated solvents in the cavity is indicative of a leak that occurred during board level assembly. When mixed with moisture, exposed to temperature and, perhaps, electric current, it is possible for the chlorine (and other ionics such as fluorine) to dissociate from the solution and initiate corrosion reactions within the device.[6]

TABLE 12 - Intermittent Leak at System Level

Sample ID	**12a**
Nitrogen, %	86.9
Oxygen, %	6.85
Argon, ppm	3220
Carbon Dioxide, ppm	8990
Moisture, %	1.20
Hydrogen, ppm	1875
Helium, %	1.05
Fluorocarbons, ppm	3540
Trichloroethane, ppm	6770
Isopropyl Alcohol, %	1.20
Freon TF, ppm	3525
Methylene Chloride, ppm	325

Another leak related phenomenon is illustrated in Table 13. This device exhibits characteristic leak traits such as the presence of helium and fluorocarbons as well as oxygen and argon. However, the oxygen to argon ratio is significantly off from the expected 22 to 1 ratio. This is indicative of an oxidation reaction occurring after the leak has allowed air to enter the device. This reaction is similar to that described previously in the section on "Glass Sealed Devices". Oxygen is participating in the thermal degradation of the epoxy during elevated temperature testing of the device. As before, the outgassing products are primarily carbon dioxide and water vapor. Thus, the leak not only allows moisture to enter the device, it also enhances the generation of additional moisture by accelerating the thermal degradation of the adhesive.

TABLE 13 - Leak with Oxygen Enhanced Thermal Degradation

Sample ID	**13a**
Nitrogen, %	95.7
Oxygen, %	1.20
Argon, ppm	1550
Carbon Dioxide, %	1.02
Moisture, ppm	8975
Hydrogen, ppm	273
Helium, ppm	8950
Fluorocarbons, ppm	1210

The solution to the "Intermittent Leak" problem will likely involve a significant re-evaluation of the current design rules for glass-to-metal seal packages. Parameters such as the Intergranular Oxide Thickness, Glass Bead Aspect Ratio and Lead Pitch will need reviewing. Secondly, the inadequacies of Test Method 1014 will need to be addressed. Extensive efforts to this end are currently underway in the industry.

Hydrogen Outgassing

In recent years, a great deal of interest has been focused on the role that hydrogen plays in limiting long-term device reliability. Hydrogen has been known to affect the formation of moisture within devices. As devices have grown more complex, however, hydrogen has begun to be implicated in other types of failures, most notably in the formation of metal hydrides in Gallium Arsenide microwave devices.[1] Many of the metals being used in devices today (e.g.; titanium, platinum, palladium, etc.) are fairly reactive with hydrogen.

Table 14 shows the before and after effects of a hydrogen reduction reaction in solder seal packages. The results for Sample 14a were typical for this particular device type. Results for Sample 14b were typical for failed devices. Surface analysis via Scanning Auger on the lids of failed devices revealed that a high level of nickel had diffused to the surface of the gold plating. Nickel quickly forms a native oxide layer when exposed to air. After sealing, the evolved hydrogen reacted with the nickel oxide layer to form moisture. As can be seen, the elevated moisture levels were accompanied by a decrease in the average hydrogen level that was characteristic for this device type.

TABLE 14 - Hydrogen Outgassing

Sample ID	14a	14b
Nitrogen, %	98.0	98.7
Carbon Dioxide, ppm	915	890
Moisture, ppm	1220	8950
Hydrogen, %	1.15	0.30
Comments: Sample 14a: "Passed" unit Sample 14b: "Failed" unit		

It should be emphasized that free oxygen is not necessary for hydrogen to form moisture. In fact, the reaction of free hydrogen and free oxygen usually requires a significant activation energy. However, many of the metal oxides routinely encountered in microelectronic devices are much more likely to react with hydrogen. Oxides of silver, tin, lead and nickel are very susceptible while oxides of aluminum and silicon are not. The Gibbs Free Energy calculations for many of these reactions are highly negative, indicating that they are thermodynamically favored. It is highly probable that some of these reactions could occur at room temperature and very likely that they would occur at typical device operating and processing temperatures.

CONCLUSION

The amount of information contained in a typical RGA report far exceeds a simple measurement of moisture content. While certainly not covering all possible problems that can be identified through RGA, an attempt was made to cover those that are most common. By presenting the basics of RGA data interpretation, the RGA end-user will be better able to use the supplied data to make the process improvements that lead to improved product reliability.

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If you have any questions or would like further information on the Residual Gas Analysis services offered at ORS, please call Daniel J. Rossiter at (315) 736-5480.

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