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WHITE PAPER

The Value of RGA in Manufacturing Semiconductors

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INTRODUCTION

History has a perverse way of repeating itself. Over 2,000 years ago it was common practice to reward a messenger of unacceptable news with the supreme sacrifice of death. Within the past year, we again find that unacceptable or misunderstood RGA data is met with the same naïve reward: Kill RGA. Quantitative mass spectral (RGA) data can provide invaluable information about a process and the potential reliability of a device.[6] Although RGA (residual gas analysis) is perhaps an improper acronym for this measurement, it was used by Rome Laboratory when drafting the Mil-Std test procedure in 1976 and has been improperly used for the past 27 years. Thus, we will use RGA to describe the quantitative mass spectral measurement of gasses since the term has become a familiar topic over this time period. Over the past two and one half decades, a considerable amount of valuable process information has been lost because of preoccupation of interest in only the Pass/Fail point of water and not on the other gasses in the mixture. The interaction of hermeticity on the test data has further confused ad hoc correlation studies conducted in the past and present by both manufacturers and users. The following discussions are intended to clarify the interpretation of RGA data, offer some insights in recognizing manufacturing problems, and to provide a simplified method of determining what interaction hermeticity might have on the test results.

HERMETICITY TEST PROBLEMS

Since the Mil-Std Method 1014 Leak Test is required as a prerequisite to conducting the RGA test, it seems appropriate that we address leak testing issues first. The Fine and Gross leak tests have been described in intimate detail in numerous publications, and recently, with the advent of the UA and UB package and the potential for smaller package sizes, it has become increasingly evident that we need to reassess these procedures.[13] There are actually two issues which need attention: the method for conducting the test; and the pass/fail limits. We could also delve into the moisture ingress problem as a function of measured leak rate and the minimum amount of moisture required to cause a moisture induced failure mechanism; however, these issues have been previously discused in great detail at other technical forums.[13] The following tables are useful in providing a point of reference for our thinking process in trying to visualize a leak rate relative to a package size:

Table 1. Number of seconds as a function of days

Days	Seconds
1	8.64 E4
10	8.64 E5
100	8.64 E6

Table 2. Gas volume as a function of leak rate and days

Leak Rate in scc/sec	1 Day	10 Days	100 Days
5E-9	4.32E-4 cc	4.32E-3cc	4.32E-2cc
5E-8	4.32E-3cc	4.32E-2cc	4.32E-1cc
5E-7	4.32E-2cc	4.32E-1cc	4.32 cc
5E-6	4.32E-1cc	4.32 cc	43.2 cc

Table (1) simply reminds us of how many seconds are in a day which helps us with Table (2) since our fine leak rates are expressed in scc/sec. Table (2) helps us put into perspective the amount of gas which could transfer in days for a given leak rate. Now let us consider a small package with a volume of 0.0004 scc and a measured leak rate of 5e-9 scc/sec. From Table (2) we can see that a complete exchange of gas in the package could take place in less than 24 hours. If the package were 0.001 scc in volume and had a measured leak rate of 5e-9 scc/sec, the package could go through more than 4 complete exchanges with its environment in less than 10 days. Increasing our package to 0.01 scc with a measured leak rate of 5e-9 scc/sec only gives us less than 25 days for a complete gas exchange with its external environment. These exchanges consider ideal gas flow and we know that water, being a polar molecule, does not follow the ideal gas law. In fact, water would most likely move through the leak by surface migration. The relationship between measured leak rate and moisture ingress has been presented by Aaron DerMarderosian at one of the NIST workshops.[13] What is an acceptable leak rate for a small package? Have we reached the limits of both the fine and gross leak test methods in order to provide reliable and accurate measurements on very small packages?

RGA testing of numerous small packages over the past decade suggests another problem exists which involves plugging of the leak path with the fluid used in the gross leak test. There has been strong evidence to support the theory that the plugged leak path provides a conduit for moisture to enter the package by going into solution in the leak test fluid. In addition, the leak test fluids

are hydroscopic and could contain additional moisture which is transferred into the package during plugging. Over the years RGA has identified other leak anomalies such as the "one way leak" or flexure leak. The RGA can provide very accurate data on leak testing, but yields suffer when 100% leak testing is required since it is a 100% destructive test.

A leak test method developed more than 13 years ago is currently being implemented and undergoing replicate testing.[14] This method requires the package to be Helium bombed but does not require a gross leak test since the measurement technique accumulates the total Helium coming out of the package during the test procedure. Leak rates as low as 1.0e-12 scc/sec and up to 1.0 scc/sec can be easily measured in the same time interval a conventional Helium leak test is performed. This new/old method should help solve the problems encountered when testing small packages as well as larger packages. The Helium Leak Rate is determined by measuring the slope of the Helium signal as shown in Figure 1. The slope is near vertical for a gross leak, where as, a fine leak has a near horizontal slope.

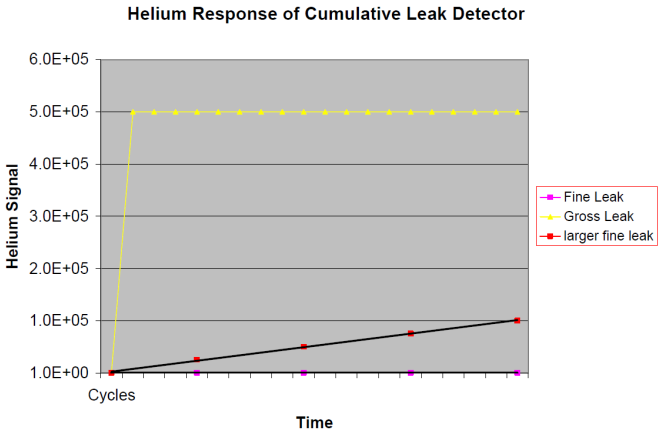

Figure 1: Helium Response of Cumulative Leak Detector

EXAMPLES OF INVALID CONCLUSIONS

The following RGA data collected on real devices was accepted or challenged in each case based on the expectations of the person submitting the parts for analysis not on the technical merits of the data.

Example 1: Engineer had technician run packages through 8-hour vacuum bake prior to entering dry box in preparation for sealing, and moisture monitor on Nitrogen line into dry box indicated 6 ppm moisture. RGA test results indicated parts were sealed in room air with slight depletion of Oxygen noted and 1.3% moisture. Parts passed both fine and gross leak test. Engineer concluded test lab made mistake and sent out additional packages to another lab and obtained the result he was looking for: 99% N2 and less than 5000ppm moisture. A suggestion was made to review the process. Upon examination of the dry box, it was apparent a technician attempted to improve on the process. He reasoned that water must be heavier than air for when it rains; the drops come down from the sky. He therefore reasoned that: to let the last bit of moisture out of the dry box, he would take a hole saw and cut six, 4-inch diameter, holes through the bottom of the dry box along the back. Which lab now had the most acceptable data? measurements of moisture in atmospheric air at a flow rate of 1.0 cubic foot hour. Using a commercial hygrometer with gasses other than atmospheric air at flow rates higher than 1.0 CFH brings into question the accuracy of the measurement. In general, the dew point measured will most likely be lower for a given amount of moisture than would be measured using air and the proper flow rate. This will result in biasing the mass spectrometer to provide lower measured values of moisture, since a larger amount of moisture is being defined as a smaller value during calibration.

Example 1. Case of mysterious air

Test Lab	EAG	FGL
Pressure (Torr)	1.211	
Hydrogen	0.0000	ND
Helium	0.0005	ND
CH4	0.0096	0.0242
Water	1.3102	0.3800
Nitrogen	80.0715	99.5000
Oxygen	17.6356	ND
Argon	0.8165	ND
CO2	0.1555	0.0136
Fluorocarbons	0.0000	ND
NH3	0.0000	

Parts tested at 100ºC.

Analysis done by EAG Laboratories Mass Spec #0092 and FLG

Example 2: CerDip manufactures have experienced high moisture on process lines which have produced low moisture packages in the past. In almost all cases, the high moisture packages also contain high CO_2. The one to one correlation between water and Carbon Dioxide usually indicates a binder burn out problem. The sealing glass is applied to the lid using an organic binder which must be fired prior to assembling the package. If some of the binder is still present during the sealing process, it will combust at high temperature in the Oxygen rich sealing environment producing CO, CO_2, C, and Water. If the CerDip contains any organic material, then high water and CO_2 usually indicate excessive temperatures in the process have caused the material to break down. Another problem has been observed which looks like binder burn out, but careful analysis of the data indicates that high porosity in the thinned lid (necessary to prepare the package for analysis) resulted in a leak which allowed air and moisture to enter the package just prior to the RGA test.

Example 3: Numerous manufactures have submitted small packages for RGA after passing the fine and gross leak test. The test results usually indicate high moisture levels on those packages which have leak rates of the same order of magnitude as the fine leak test pass/fail point. Small packages usually are RGA tested in a batch

The Value of RGA in Manufacturing Semiconductors

process which requires the entire package to be placed in a vacuum chamber prior to being punctured. Some of the gas in the package leaks out during the test interval, and since water is a polar molecule, it tends to leak out slower than the other gasses which increases its concentration in the final test result. It is also not unusual to fine remnants of the fine and gross leak test inside the package. This problem is very acute for packages smaller than 0.01 cc. In the following example, package (A) seems to have leaked less than (B) and (C). All contain Helium which was used to leak test the packages. (A) had the highest burst pressure and the lowest moisture level. (B) and (C) had half the burst pressure and double the moisture. Do these packages fail the moisture test or are they really non-hermetic?

Example 3.

Case Study of Gas Leaking Out in Vacuum Chamber

Sample ID	A	B	C
Pressure (Torr)	0.006	0.003	0.003
Hydrogen	0.3177	0.0636	0.0871
Helium	0.0548	0.0807	0.0901
CH4	0.0114	0.0111	0.0110
Water	0.4802	1.1987	1.0363
Nitrogen	97.8975	97.3689	97.5532
Oxygen	0.0882	0.4069	0.3713
Argon	0.0078	0.0184	0.0169
CO2	1.2290	0.8451	0.8284
Fluorocarbons	0.0000	0.0006	0.0005
NH3	0.0000	0.0000	0.0000

Parts prebaked and tested at 100°C.

Analysis done by EAG Laboratories Mass Spec #0092

Example 4: Manufacture used Silver glass in a gold plated Kovar package and lid. The process line always produced dry packages which did not contain Silver glass. RGA test results indicated high moisture. Reaction between Hydrogen released from between plating layers during seal with oxidized Silver produced the water in the package. Solution was to deplete the Hydrogen from the package and lid prior to seal, or not use Silver glass.

Example 5: Manufacture was trying to develop a process for sealing a new product using a DAP sealer. The packages went through several vacuum bake steps prior to being filled with dry Nitrogen with less than 10 ppm moisture. RGA test results continued to indicate high moisture along with Oxygen and Argon in addition to the dry Nitrogen used as the sealing gas. Parts were passing the fine and gross leak test and little Helium was detected in the packages. Was this possible or did the test lab make a mistake? Examination of the solder seal on the inside of the package indicated the Oxygen measured was present at the time of seal. A die cut solder preform was used. The preform fit between the lid and package so well that with an excessive preload on the lid, there was little, if any, gas transfer occurring during the process. Using lids with the solder attached allowed the package to breath.

Example 6: Engineer submitted a failed package for RGA test prior to conducting a failure analysis examination. The RGA test (A) indicated a moisture level of 3800 ppm, some Hydrogen 1.2% and the balance Nitrogen. Since Hydrogen was not used in the process, its presence was dismissed as a test lab error by the Engineer. Upon delidding the package, a bond wire was found to have separated from a header pin by a moisture induced corrosion process. The Hydrogen measured was simply one of the reaction products. Subsequent test (B) on similar packages which were not subjected to burn in indicated moisture levels over 1.2% and very little Hydrogen.

Example 6. Case Study of Failed Part

Sample ID	A	B
Pressure (Torr)	1.232	1.241
Hydrogen	1.2399	0.0079
Helium	0.0006	0.0000
CH4	0.0118	0.0119
Water	0.3778	1.2237
Nitrogen	98.3220	98.7089
Oxygen	0.0083	0.0100
Argon	0.0009	0.0009
CO2	0.0382	0.0364
Fluorocarbons	0.0000	0.0000
NH3	0.0000	0.0000

Parts prebaked and tested at 100°C.

Analysis done by EAG Laboratories Mass Spec #0092

Example 7: Engineer submitted 12 packages for RGA testing. All the packages passed fine and gross leak test. 11 packages were found to contain Nitrogen and less than 500 ppm moisture. Package (C) contained over 25% moisture in addition to Hydrogen, Oxygen, Nitrogen, and Fluorocarbons. In addition to the unusually high moisture content, this package also indicated that the gas volume released during puncture was approximately 25% greater than the average volume of the other 11 packages. This is a good example of moisture passing through a Fluorocarbon plugged leak.

Example 7. Case Study of Water Penetrating Leak

Sample ID	A	B	C
Pressure (Torr)	1.928	1.958	2.447
Hydrogen	0.0000	0.0000	0.4233
Helium	27.9535	27.3149	19.4607
CH4	0.0013	0.0013	0.2360
Water	0.0190	0.0160	26.9900
Nitrogen	0.2203	0.7456	2.5893
Oxygen	0.0041	0.0169	0.0466
Argon	71.7845	71.8799	49.7813
CO2	0.0144	0.0227	0.6989
Fluorocarbons	0.0002	0.0002	0.0064
NH3	0.0000	0.0000	0.0000

Parts prebaked and tested at 100°C.

Analysis done by EAG Laboratories Mass Spec #0092

The Value of RGA in Manufacturing Semiconductors

In example 7a, Package (C) had almost fully equilibrated to room air. Notice Oxygen and Argon at almost room air levels and high Fluorocarbons.

Example 7a. Case Study of Water Penetrating Leak

Sample ID	A	B	C
Pressure (Torr)	25.15	28.25	24.95
Hydrogen	0.0000	0.0000	0.0000
Helium	14.6032	14.7717	0.0005
CH4	0.0274	0.0346	0.0242
Water	0.0228	0.0302	5.1616
Nitrogen	85.0062	84.6920	74.9553
Oxygen	0.0035	0.0054	18.8803
Argon	0.0000	0.0000	0.7885
CO2	0.2968	0.4247	0.0721
Fluorocarbons	0.0005	0.0009	0.0719
NH3	0.0033	0.0033	0.0000

Parts prebaked and tested at 100°C.

Analysis done by EAG Laboratories Mass Spec #0092

Example 8. The Engineer loaded a seal lot of packages into a Nitrogen purged air lock and let them purge for 15 minutes. The packages were then moved into the sealer dry box which was being purged with Nitrogen at 6 ppm moisture. However, the moisture monitor was not in the dry box. The packages were then sealed over a three-day period. The engineer randomly selected five groups of five packages each from one sealing lot and sent them to five laboratories for the RGA test to be conducted per Mil-Std 883C, Method 1018.2, Procedure 1. The packages all passed fine and gross leak tests and contained no organics so no prebake was required prior to testing. The data received back from the labs looked like random data and the mean values are given for moisture measured by the various labs in Chart 1. Three of the five labs had mean values below 5000 ppm and two of the labs had means above. The engineer expressed the opinion that the RGA test was not accurate nor a valid test to either be used as a process monitor or as a means of predicting reliability. EAG Laboratories suggested that if the engineer would provide them with the first package sealed out of the next seal lot and a package pulled approximately each hour during the sealing process, the EAG Laboratories would test the parts at no charge and provide the data to the engineer. The resulting moisture data is plotted in Chart 2. The two peaks, one on day (1) and one on day (2), corresponded approximately to the time interval a test engineer removed packages from the dry box. The gaps in the data indicate evening periods when no parts were being sealed. The longer parts were in the dry box prior to seal, the dryer the packages

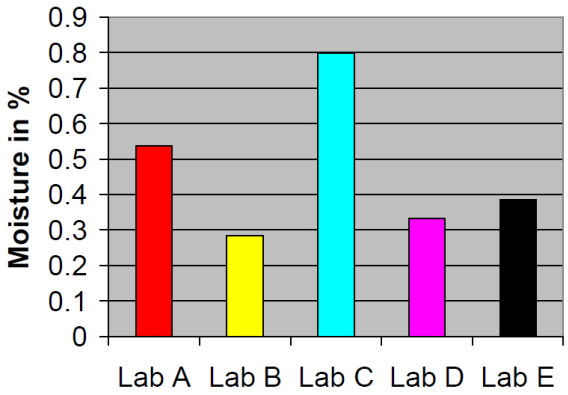

Figure 2: Summary of RGA data for 5 Labs testing random samples taken from the Same Manufacturing Lot.

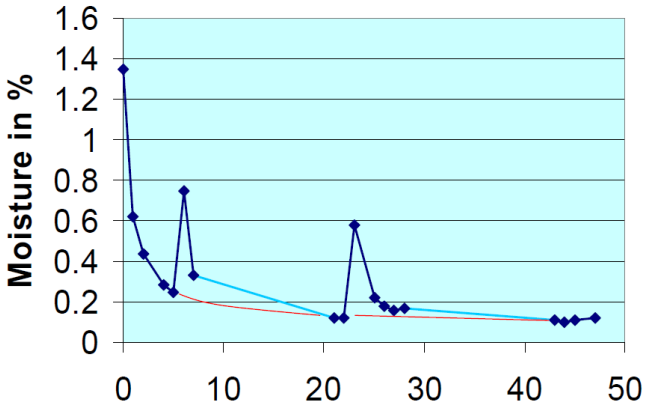

Figure 3: Example 8a. RGA Process Data taken over time to seal one manufacturing lot.

became with the exception of the time interval coincident with the package removals. If we ignore the two peaks, the reduction in moisture in the sealed packages as a function of time in the dry box looks exponential. We tend to ignore the variations in a given production lot and assume all packages are the same. This invalid assumption coupled with hermeticity issues has led to a great deal of frustration amongst users and manufacturers. The only solution to this dilemma is to help everyone concerned understand the importance of all the data on the data sheet, and focus on what is truly known not what is expected.

Example 9: Teledyne Case Study. The following analysis done by Seal Laboratories indicated a problem existed with a Hybrid Fiber Optic receiver. All three packages tested failed the 5000 ppm moisture limit. In the original process, the epoxy cure was done at 85°C for 24 hours. The same parts were delidded and reprocessed at 85°C for 96 hours and resealed. The retested parts all contained dramatically less than 5000 ppm moisture and thus passed the RGA test. The lower test and cure temperatures

The Value of RGA in Manufacturing Semiconductors

were used because of temperature sensitive components in the receiver. The change in the epoxy cure time was optimized with the help of RGA data.

Teledyne Case Study Submitted 4 September 2003

Sample ID			
Pressure (Torr)	16	33	31
Hydrogen	3680ppm	5289ppm	5008ppm
Helium	12.7%	12.6%	12.7%
CH4	513ppm	249ppm	171ppm
Water	1.2%	5508ppm	5360ppm
Nitrogen	85%	86%	86%
Oxygen	2961ppm	563ppm	1027ppm
Argon	486ppm	411ppm	398ppm
CO2	1641ppm	911ppm	791ppm
Fluorocarbons	ND	ND	ND
NH3	1561ppm	762ppm	574ppm

Parts prebaked and tested at 75 °C.

Analysis done by SEAL LABORATORIES RGA No: R5188

Teledyne Case Study Submitted 4 September 2003 (after additional cure and reseal)

Sample ID			
Pressure (Torr)	16	33	31
Hydrogen	470ppm	530ppm	540ppm
Helium	6.25%	5.27%	3.59%
CH4			
Water	100ppm	130ppm	200ppm
Nitrogen	93+%	94+%	96+%
Oxygen	590ppm	730ppm	900ppm
Argon	160ppm	220ppm	160ppm
CO2	150ppm	200ppm	130ppm
Fluorocarbons	ND	ND	ND
NH3			

Parts prebaked and tested at 75°C.

Analysis done by Atlantic Analytical on MS2

RGA DATA INTERPRETATION

In order to discuss data interpretation, we must first understand what we are going to analyze. We expect that the semiconductor package to be tested will contain one or more "pure" gasses which we intentionally want in the package and some other contaminants. Gaseous contaminants can enter a package at numerous times during the manufacturing process, and can also enter after a package is sealed. Most often leaks, both virtual and real, are the source of contaminants. Real leaks in the process equipment or package will usually result in room air getting into the analyzed gas sample. Room air contains moisture and a number of other contaminants as well as the gasses shown in the table below:

Composition of Clean Dry Air

Component	% by vol.	Molecular wt.
Nitrogen	78.0840000	28.0134
Oxygen	20.9476000	31.9988
Argon	0.9340000	39.948
CO2	0.0314000	44.00995
Neon	0.0018180	20.183
Helium	0.0005240	4.0026
Krypton	0.0001140	83.8
Xenon	0.0000087	131.3
Hydrogen	0.0000500	2.01594
Methane	0.0002000	16.04303
NO	0.0000500	44.0128
Ozone	0.0000070	47.9982
SO2	0.0001000	64.0628
NO2	0.0000020	46.0055
Ammonia	0 to trace	17.03061
CO	0 to trace	28.01055
Iodine	0.0000010	253.8088

Handbook of Geochemistry, Vol. 1, Springer-Verlag Berlin, 1969

All of the gasses which exist in room air have different molecular sizes, and as a result, may leak in or out of a package at different rates under certain leak conditions. In addition to size differences, some molecules, such as water, are polar in nature and tend to behave differently than an ideal gas such as Helium.

Virtual leaks usually are the result of trapped gasses evolving from the materials used to manufacture the semiconductor device. Most often Water and Hydrogen evolve from virtual leak sources. Other contaminants such as oils, greases or other materials which have a significant vapour pressure can be included in the virtual leak category. Room air can also creep into a package as a virtual leak. Remembering that real and virtual leaks are bidirectional, allows us to include chemical reaction as a virtual leak.

We have established acceptable standards for real leaks and a method and criteria for measuring them. The only virtual leak that has been addressed is the limit imposed on moisture content. Since water can enter a package through a real leak as well as a virtual leak, careful consideration must be given to the real leak test criteria as it is applied to small packages.

Most semiconductor packages are intended to be filled with one or more inert gasses such as Nitrogen, Helium, Argon, Krypton, and/or Xenon. Some processes add Hydrogen to the mix during seal to remove or prevent oxidation. Glass sealed packages can typically contain dry air, synthetic air (80% N_2, 20% O_2 and no Argon), Nitrogen and some Oxygen (<20%), or reverse air (20% N_2, 80% O_2). Special semiconductor applications may require other gasses or even chemical vapours to fill the package.

The Value of RGA in Manufacturing Semiconductors

Knowledge of the process and materials used in the semiconductor package are necessary to intelligently interpret the RGA test results. Starting with what is known, we can logically step our way through the process to determine what should or should not be in the package. When test results reveal unexpected gasses, the assumption of "what is known for sure" must be revisited. It is possible that errors in the process or analysis led to the unexpected result. In most instances, our assumption of "what is known" is usually where the problem starts.

CALIBRATION

The analysis of the gas contents (including moisture) of a hermetic structure is one of the more challenging analytical procedures1. Many different calibration techniques have been successfully employed, but the use of the multivolume calibrator (TVCV) in conjunction with a general purpose humidifier (GPH) allowed the Mil-Std RGA program to be implemented.[2,3,4,5,6]. As new semiconductor devices evolve, other gases besides moisture have become critical parameters in assessing the potential reliability of a device.[7,8] Analytical methods beyond those specified in Mil-Std 883D, method 1018.2, Procedure 1 are required to provide accurate information on Hydrogen, Oxygen, and other gases as well as moisture.[9] The following experiment describes a method and procedure for generating gas volumes and mixtures traceable to NIST for the calibration of mass spectrometers used in the analysis of the gas contents of hermetic structures.

Three variations of the (TVCV) have been developed (Table 3) and the original (TVCV) has been expanded to include 10cc, 100cc, and 200cc volumes.

Calibrator Volume Ranges

Calibrator	A	B	C	D
Vol. Range in CC	0.0002	0.001	0.002	0.02
	0.001	0.01	0.10	
	0.01	0.1	1.0	
	0.1	0.2-1.0*	10.00	100
*Variable Vol.				200

Two of the multivolume calibrators are simultaneously connected to the sample chamber of a mass spectrometer (Figure 4).

If you maintain gases A and B at the same temperature and pressure, then we can apply Boyle's Law and the resulting gas

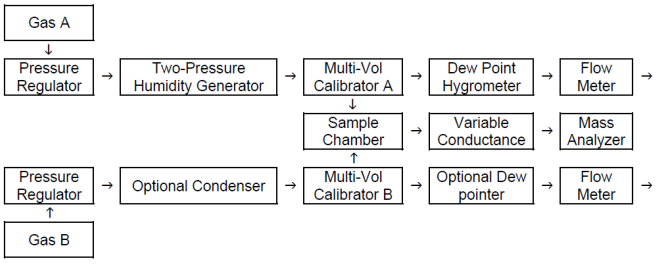

Figure 4: Experimental Configuration

mixture is simply given by:[10]

$$\text{Gas (A)} = (VA/(VA + VB)) \times 100\% \quad (1)$$

$$\text{Gas (B)} = (VB/(VA + VB)) \times 100\% \quad (2)$$

Selecting the largest volume (200cc) for Gas (A) and small volume (0.001cc) for Gas (B) allows us to make a 5.0 ppm mixture. If Gas (A) is humidified, then the resulting moisture will be subjected to the same dilution factor given in Eq(1). Optionally one could vary both temperature and pressure to increase the number of combinations available, however the General Gas Law will have to be applied.[11]

The first experiment consists of using Nitrogen for Gas (A) and Hydrogen for Gas(B). The second experiment uses Room Air for Gas (A) and Helium for Gas (B). Table (3) summarized these test results.

Test Data Summary

Ratio (VB/VA)	Gases	Meas. H20 (PPM)	Expected H20 (PPM)
5.418E-6	H2/N2	1062 +/- 50	1015-43
5.418E-6	HE/AIR	4613 +/- 50	4652-38
1.078E-4	H2/N2	1283 +/- 50	1252-42
1.078E-4	HE/AIR	4880 +/-50	4821-39
1.176E-3	H2/N2	2295 +/- 50	2364-41
1.176E-3	HE/AIR	5320 +/- 50	5330-40
1.100E-2	H2/N2	4875 +/- 50	4920-40
1.100E-2	HE/AIR	8510 +/- 50	8601-46
1.200E-1	H2/N2	3410 +/- 50	3362-41
1.200E-1	HE/AIR	7723 +/- 50	7715-45

The expected moisture level is the value measured by the Dew Point Hygrometer (Figure 1.) multiplied by the dilution factor (eq.1.). The negative values applied were taken from the calibration data provided by General Eastern for the Hygrometer used in the experiment. The uncertainty of the General Eastern Transfer Standard is given as +/- 0.056 C and includes the NIST uncertainty.[12]

A Princo Nova Barometer was used as a pressure standard. An MKS Model 116A was calibrated using the TVCV and in turn the Baratron was used to determine the volume ratio's given in Table (2).

Many factors influence the data obtained from a Mass Spectrometer and have been reported previously.[9] Since these factors are instrument dependent and unique to a particular design, the dual TVCV calibration method provides a procedure for measuring the sensitivity, linearity, and dynamic range of an instrument for various gas mixture and volumes only requiring pure gases for this assessment.

GAS COMPOSITION ANALYSIS OF HERMETIC STRUCTURES AS A NON-DESTRUCTIVE TEST

Experiments using a laser drill have been conducted to demonstrate the feasibility of analyzing gases in hermetic structures, backfilling the structure, and then resealing the structure. This

The Value of RGA in Manufacturing Semiconductors

work has been included to provide typical RGA accuracy data. The following chapter presents a brief history of the evolution of the test procedure, a comparison of accuracy of the standard method verses the laser method and recommendation for implementation of the test method.

INTRODUCTION

Tests of this type, first conducted in 1967 by the author using a large double focused magnetic sector mass spectrometer, have been considered to be a destructive test even when applied to DPA or failure analysis. Once the hermetic integrity of the package is breached in order to extract the gas sample, the package is usually discarded unless further physical or electrical examination is required.

As the value of the semiconductor device increases the motivation to reuse the package increases. The author had developed ESD handling procedures such that a high value package can be reprocessed after the moisture test but this procedure amounts to remanufacturing the device with very little savings in time or cost.

A considerable amount of interest and encouragement was received from RADC, TRW, Litton, JPL and Lockheed to proceed with experiments designed to reduce the cost of reprocessing.

The following experiments were designed to test the feasibility of analyzing the contents of a hermetic package using MIL-STD 883, Method 1018.2, Procedure 1, then backfilling the package with a clean dry gas and resealing the package. The basis for this work originated in 1975 when the author designed, manufactured and tested a similar system for Argonne National Laboratory to analyze fission gases in nuclear reactor fuel rods. This procedure consisted of:

- Fixturing the fuel rod and forming a vacuum tight seal to the surface
- Laser drilling a hole to release the gas sample
- Analyzing the gas sample
- Backfilling the rod with a tag gas
- Welding the hole closed with 95% material thickness in weld area
- Leak testing the weld area

APPLICATION QUESTIONS

Applying the above procedure to semiconductor packages seems straight forward; however, a number of questions had to be answered, namely:

- Would laser drilling and/or rewelding created particulates which would impact the reliability and operation of the device under test?
- Can the various materials used to package semiconductor devices be laser drilled and rewelded reliably to insure hermeticity?
- Would laser drilling and/or rewelding damage the semiconductor devices?
- Would laser drilling impact the accuracy of the moisture measurement?
- What moisture level can be expected in the resealed package?
- Is the procedure economically viable?

EXPERIMENTS

The following four experiments were conducted over two years with lots of encouragement and little or no funding from any of the parties involved:

1. Test of particulate generation, reweldability, and circuit damage
2. Test reweldability, circuit damage, and performance of the resealed device
3. Test of moisture data accuracy
4. Test of moisture level in resealed package.

Experiment 1

The author received two lids and three large hybrid packages (approximately 4.0cc in volume). Two of the sealed packages were empty and the third contained a scrap circuit on a large substrate which filled the entire package. Pin tests had been performed on all three packages as well as fine and gross leak tests. A series of 200 holes were drilled and rewelded on the two sample lids in order to optimize the laser operating parameters. Next six holes were drilled and rewelded in each of the three packages using the optimum settings on the laser. Pin test were then performed on the resealed packages. The packages were then opened and the rewelds and substrate were examined. The results of the pin tests and visual examination indicated that the procedure for drilling and rewelding would not create any particulates, the hermeticity could be maintained after the reweld, and the location of the penetration is critical to prevent damage to the circuitry.

Experiment 2

The second experiment consisted of analyzing ten devices whose performance was particularly sensitive to high moisture levels. Five of the samples exhibited normal performance and five were electrically unstable. All ten devices were subjected to laser drilling, analysis, of the gas mixture, backfilling with grade 4.5 nitrogen, and rewelding. The results of this experiment indicated that those packages with high moisture levels were unstable and all rewelded packages exhibited normal performance.

Experiment 3

The third experiment consisted of analyzing 96 packages (MC1 420GXKOREAJHBIK) randomly selected from a lot of 1200 packages, which were manufactured about 18 years ago for EAG Laboratories. The packages were divided into 4 groups. The first group of 24 was to be analyzed using an external test fixture and mechanical puncture device. The second group of 24 was to be analyzed using a batch fixture and mechanical puncture device. The third and forth group of 24 each were to be laser drilled

using an external fixture and batch fixture respectively. Each group was further divided in A and B subgroups of 12 packages which represented approximately one days work on the mass spectrometer.

Prior to each day's analysis the mass spectrometer moisture calibration was checked using a high pressure saturator and General Eastern model 1500 which was calibrated by GEIagainst their NIST transfer standard. The uncertainty of the transfer standard was reported at +/-0.04ºC in measurement range of interest and our instrument difference reading varied from 0.02ºC to –0.08ºC over the same range. Converting the above dew points to ppm per unit volume yields an accuracy of +/-18.4ppm –9.2ppm to –36.8ppm. A series of ten measurements were made each morning and the mean and standard deviation for each subgroup are summarized in the Table (4) below:

Table 4: Subgroup Moisture Calibration Summary

Subgroup	Dewpoint Measured	Mass Spectrometer Reading
1A	5280ppm+/-18ppm	5305ppm+/-25ppm
1B	5177ppm +/-25ppm	5160ppm+/-30ppm
2A	5220ppm+/-15ppm	5210ppm+/-27ppm
2B	5152ppm+/-20ppm	5151ppm+/-28ppm
3A	5210ppm+/-23ppm	5200ppm+/-22ppm
3B	5230ppm+/-20ppm	5243ppm+/-29ppm
4A	5212ppm+/-24ppm	5210ppm+/-30ppm
4B	5198ppm+/-26ppm	5205ppm+/-28ppm

After the ten calibration checks were made, 12 packages of each respective subgroup were analyzed per the requirements of MIL-STD 883D, Method 1018.2, Procedure 1. The results of these tests are summarized in Table (5) below:

Table 5: Subgroup Moisture Measurement Summary

Subgroup	Mean Value in %	Standard Deviation
1A	1.2229	.6398
1B	1.1531	.6523
2A	1.2374	.7511
2B	1.1003	.6887
3A	1.2577	.8012
3B	1.3049	.7212
4A	1.2168	.6656
4B	1.2446	.7143

Careful review of Table (4) and Table (5) suggests that the packages selected for this experiment were by no means optimum. However, one might conclude that variations between the mean values measured for each subgroup were considerably less than the standard deviation, and therefore, acceptable under the MIL-STD.

EXPERIMENT 4

The packages laser drilled in the above experiment were backfilled with Grade 4.5 Nitrogen after each package was analyzed except that those packages analyzed in the batch mode were also filled as a batch and then rewelded. The packages in subgroups 3A and 3B were remixed and randomly divided into 3A1 and 3B1. Similarly 4A1 and 4B1. Subgroups 3A1 and 4A1 were analyzed by mechanical puncture in the batch and external fixture mode respectively. Where as subgroups 3B1 and 4B1 were analyzed using the laser drill in the batch and external fixture mode respectively. The following Table (5) summarizes the test results of the rewelded packages:

Table 5: Rewelded Subgroup Moisture Measurement Summary

Subgroup	Mean Value in PPM	Standard Deviation
3A1	2280	759
3B1	2850	612
4A1	2631	937
4B1	2174	453

CONCLUSION

The laser drill and reweld procedure as applied to the moisture analysis test can be applied without apparent distortion of the test result, or damage to the performance of the device under test provided that extreme caution is exercised in selecting the location of the puncture site. The economic benefit of applying this technique to analyze packages and/or rework packages depends entirely on the cost of the original package and retesting requirements. Not all package configurations lend themselves to this procedure; however designers can incorporate the requirements of this procedure to new designs.

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