Eliminating Gross Leakers by Seal Processing for Lowest Leak Rates per MIL-STD-883 TM 1014 Seal

MicroCircuit Laboratories LLC

Gross Leakers of Hermetic Microelectronic Packages

Hermetic packaging is required for certain expanding microelectronic technologies and markets. Compound semiconductor, photonics, advanced packaging, microelectromechanical (MEMS), microwave, power, semiconductor and medical applications, along with high-reliability applications such as aerospace and military requirements, all require hermetic encapsulation with packages fabricated with a variety of feedthrough configurations.

Current U.S. MIL-STD-883 Test Method 1014 significantly tightens the leak rate requirements for all sizes of hermetic packages, with failure criteria now expressed in air with rates as low as 1E-9 atm-cm^3/sec air. In previous work, MicroCircuit Laboratories (MCL) developed and demonstrated hermetic package sealing schedules that significantly improve the lowest leak rates, in the low E-10 atm-cm^3/sec air, in a variety of hermetic package configurations.[1]

However, hermetic packages with viscous leaks in the E-1 to E-4 atm-cm^3/sec air, referred to as gross leakers, can be even more problematic and damaging than ultra-fine leakers.

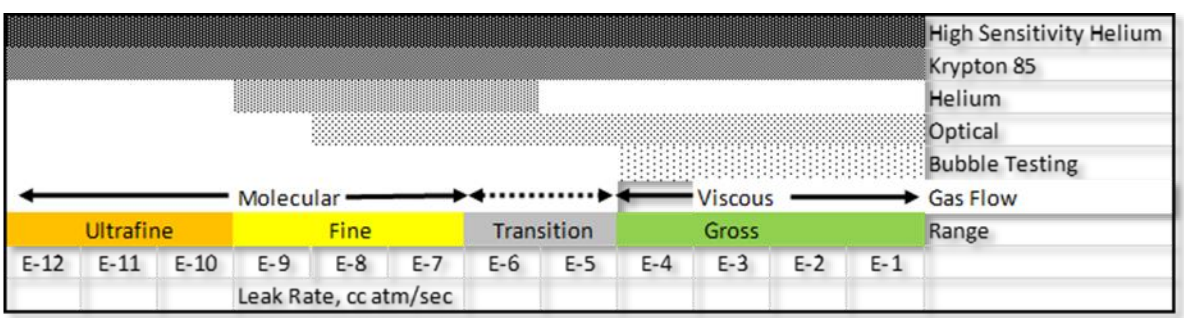


Figure 1

A gross leaker can result in a presumably hermetic package appearing to have a very tight seal and low leak rate. This can be occur when all the tracer gas that entered the package escapes rapidly. This would result in little detection gas remaining, which could be residual detection gas absorbed by interior materials inside of the package or sorption on the outside, such as feedthroughs. This would provide a false positive that the package had achieved a very low leak rate.

The recent update to MIL-STD-883 Test Method 1014, per Figure 2, significantly tightens the leak rates, and requires leak rate specifications to be stated in air. To specifically identify gross leakers, Test Method 1014 seal requires gross leak testing to occur within one hour from sealed packages' removal from the helium bombing process.

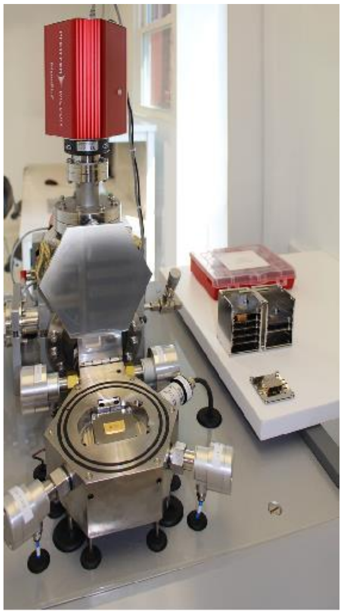
Test Limits for All Fine Leak Methods **MIL-STD-883 Method 1014, August 2016**		
Internal Free Volume of Package (cm^3)	L Failure Criteria atm-cm^3/sec (air) Hybrid Class H and Monolithic Classes B, S, Q and V	L Failure Criteria atm-cm^3/sec (air) Hybrid Class K only
≤ 0.05	5×10^{-8}	1×10^{-9}
$> 0.05 - \leq 0.4$	1×10^{-7}	5×10^{-9}
> 0.4	1×10^{-6}	1×10^{-8}

Figure 2

To meet these new leak rate specifications, packages were sealed with industry standard cover seal processes. These techniques were not able to always and consistently meet, with adequate margin, these new lower leak rates. Additionally, the existing technique resulted in a large number of gross leakers on a variety of different package types. The large deviations in leak rates were not characteristic of a well-controlled process.

To provide testing of sealed packages, MCL required a single system to detect both viscous leaks, gross leakers with rates in the E-1 to E-3 atm-cm^3/sec air, and molecular flow-type leaks, referred to as ultra-fine leakers, with rates in the E-9 to E-11 atm-cm^3/sec air range. MCL preferred to utilize this kind of system to maintain a database on all tests completed on an individual package, so that in one procedure the leak results could be captured on the gross leak test within the first hour upon removal from the helium bomb, up to the 72-hour limit of the fine leak testing per Test Method 1014.

MCL selected the Oneida Research Model 310 High Sensitivity Leak Detection HSHLD®, Photograph 1, which met these requirements with capabilities[2] for both small and large package leak testing. As of the date of this report, MCL has performed over 5,200 cycles, representing over 2,000 package test cycles in the Model 310 HSHLD®.



Photograph 1:
Model 310 HSHLD®

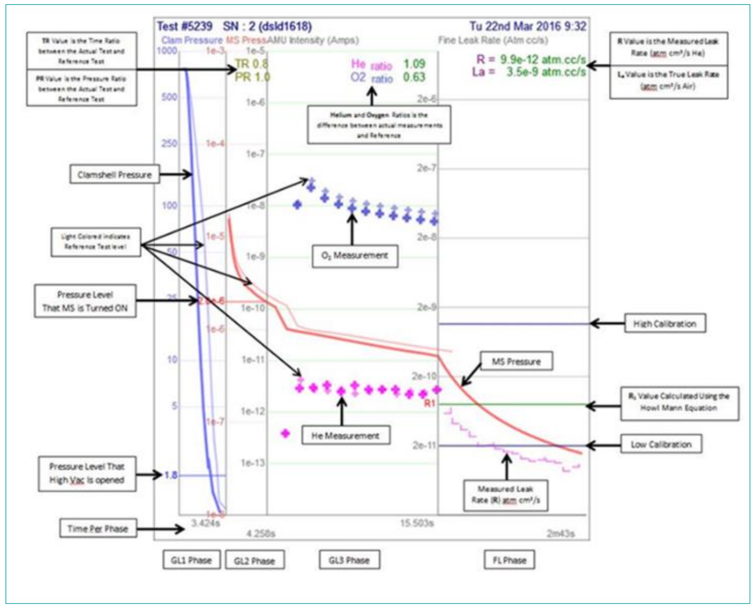


Figure 3

Per Figure 4, gross leakers are identified in a number of ways, including when a high percentage of helium is detected.

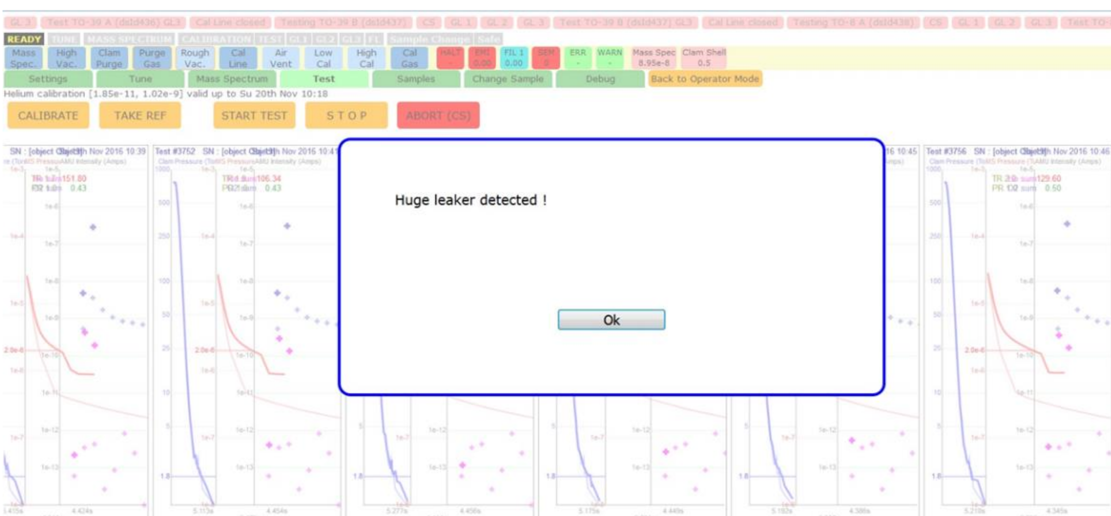


Figure 4

As shown in Figure 5, the system can identify the maximum detectable fine leak results per the variable inputs used in the Howl-Mann flexible method, including cavity size, helium bomb press and time, etc. In this example, if the leak rate remains faster than the identified leak rate of 7.8E-12 atm-cm^3/sec helium (or 9.6E-11 atm-cm^3/sec air), there is further data to support that the sealed package was not a gross leaker.

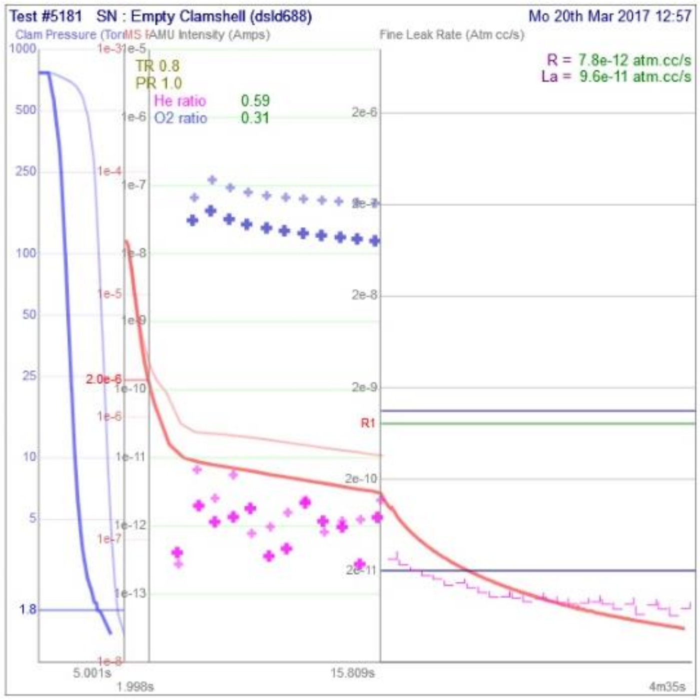


Figure 5

Hermetic Package Sealing Development

Parallel Seam Sealing (PSS), Figure 6, provides an industry standard resistance weld joining process to hermetically seal integrated circuit packages. Precise control of pre-seal moisture removal processing and internal device atmosphere, including both inert gas atmosphere and cleanliness to eliminate particulate, is provided while maintaining peak device temperatures substantially lower than die attach and adhesive material curing and processing temperatures.

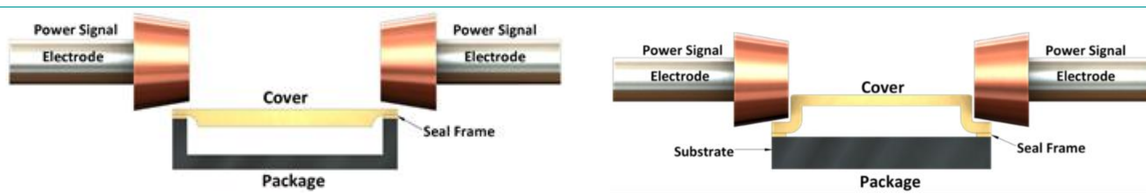
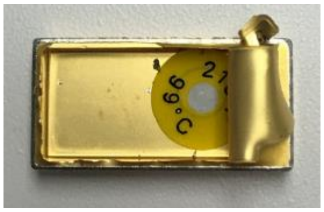
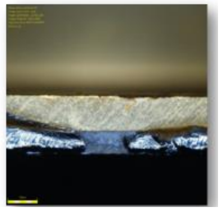


Figure 6

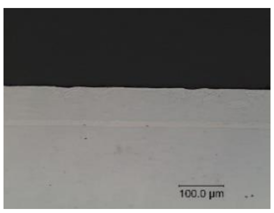
PSS of hermetic packages is performed on packages fabricated from Ceramic, Kovar™ and 1010 steel, with sizes from 1.25 mm x 1.5 mm to 100 mm x 100 mm, with a wide variety of feedthrough configurations. The package covers would range from 0.1 mm to 0.5 mm thick, with both flat and raised cover configurations with the ability to integrate feedthroughs for lenses into the covers. Typical joining materials are fabricated from Kovar™, 29Ni/17Co/Bal Fe alloy, with the most common plating being Au over Ni for a corrosion-resistant joint that will pass the salt spray test per MIL-STD-883 TM 1009.

To verify properly welded joints, peel tests, per Photograph 2, were performed on each sealing schedule. With current industry standard sealing approaches, peel tests would randomly result in seal joints that were not maintained, as shown in Photograph 2a. It is worthwhile to note that the packages sealed with the new sealing technique described in this paper never exhibited this condition.

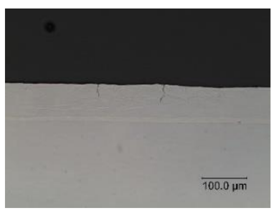

Photograph 2


Photograph 2a

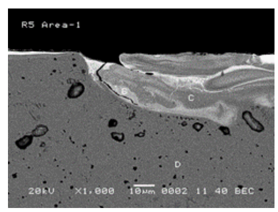
Microstructure analysis of seal joints has been performed (unetched SEM, etched SEM, and etched optical). Photograph 2b is an example of a good joint, Photograph 2c of a bad joint and Photographs 2d and 2e represent an analysis of a bad joint.



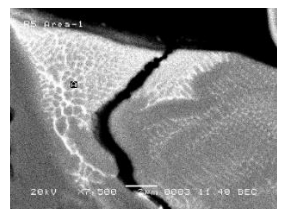
Photograph 2b



Photograph 2c



Photograph 2d


Photograph 2e

Non-leaded packages were used to enable the development of seal joints without having the variables of feedthroughs affecting leak rate tests. Once the seal joint was developed, the technique was transferred to packages with feedthroughs. Further seal process optimization was required for packages with glass feedthroughs to obtain the lowest possible leak rate.

In developing the sealing process for a variety of hermetic packages, MCL's development produced gross leakers by either of two causes. The first cause is a marginal seal joint. The faster the fine leak rate, the more gross leakers occurred.

The second realized cause of gross leakers is due to processing, regardless of whether the packages and covers were compliant with specified, standard design guidelines. When this processing technique was realized as a source of gross leaks, it was eliminated from the process. In all the schedules with E-10 air leak rates, no gross leakers resulted.

Hybrid Flatpack

For economies and to evaluate the seal process with and without glass feedthroughs, a drawn package was utilized as a bathtub with no leads and a four-lead package with Corning Glass feedthroughs. Drawn packages do not have a flat bottom nor features to easily position in a holding tool for processing. The package internal cavity of 0.9 cm^3 would require a leak rate of $1x10^{-8}$ atm-cm^3/sec air to meet current standards, which would have a time to the moisture specification limit of 1.08 years.

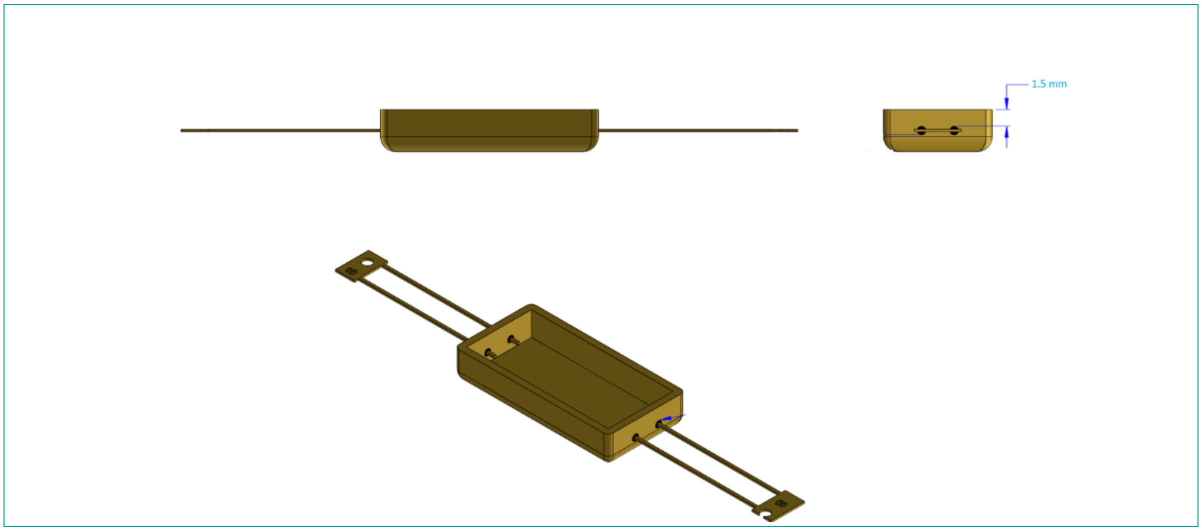
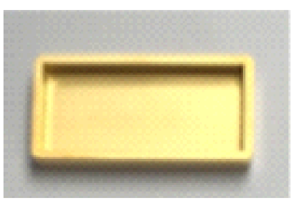
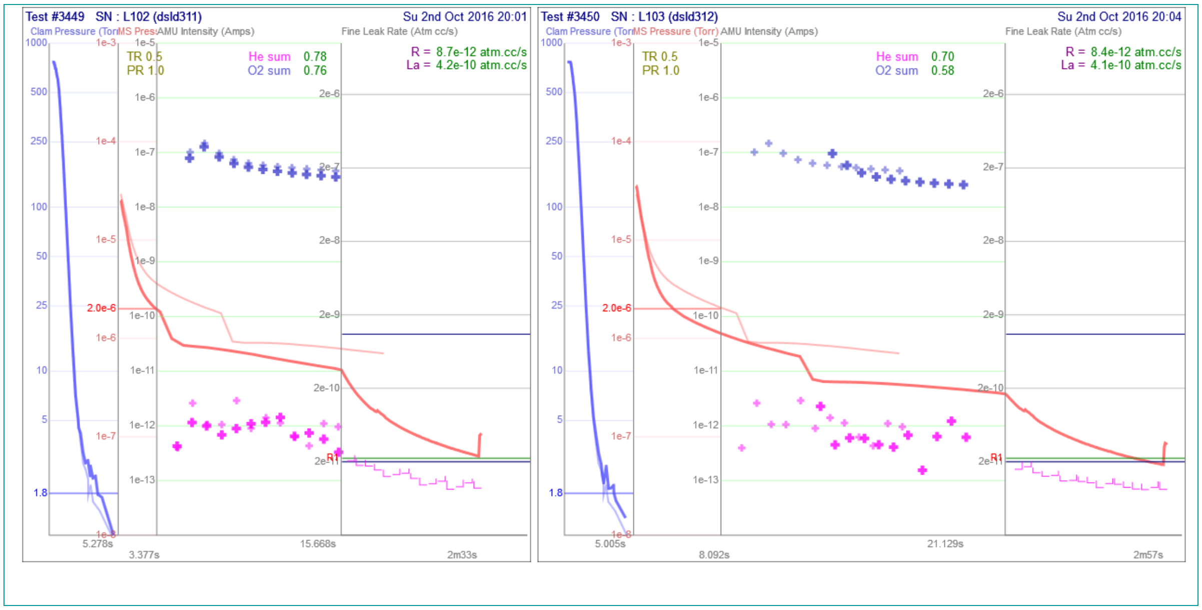
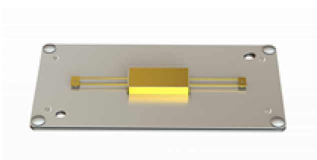


Figure 7

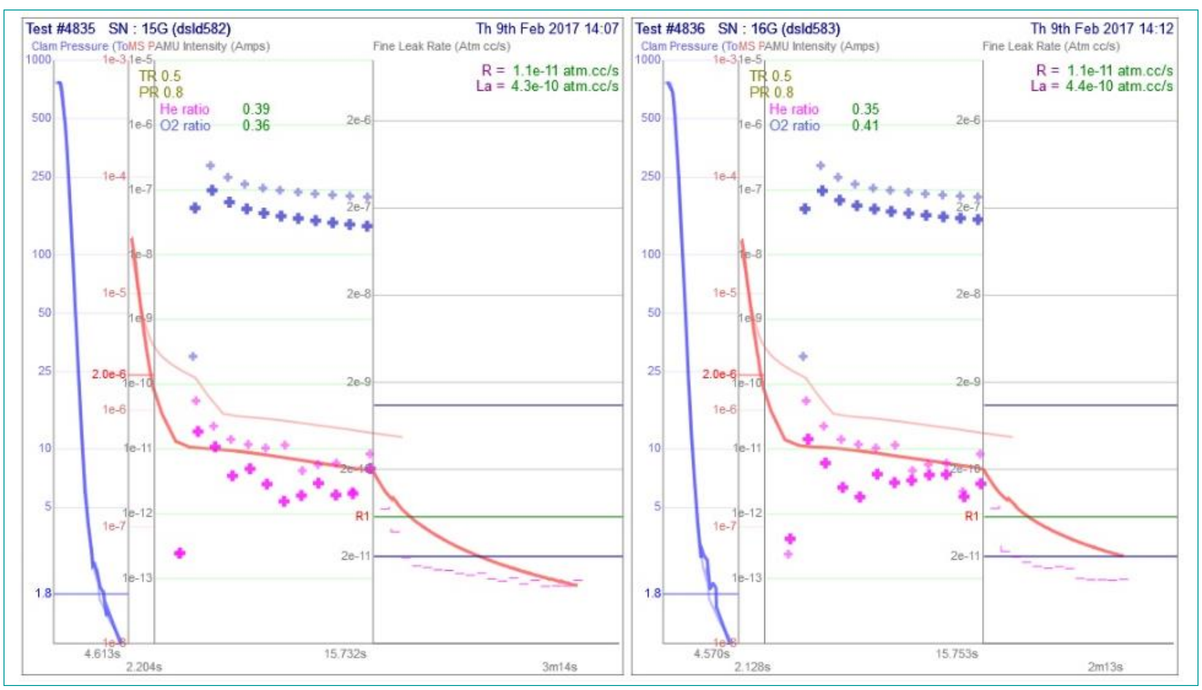


Sealing Schedule 3 was developed and used to compare the sealing results for different lots from package and cover suppliers. These packages and covers were from Materials Lot 1. All passed gross leak; the fine leak test mean was 4.3E-10 atm-cm^3/sec air with Std Dev 0.35.





With further seal schedule optimization, packages with glass feedthroughs were sealed with Sealing Schedule 4. All sealed packages passed gross leak; fine leak test mean of 4.4E-10 atm-cm³/sec <u>air</u> with Std Dev 0.05 was realized.



Per the schedules developed below, with leak rates in the E-10 atm-cm³/sec <u>air</u>, much lower than specification, no gross leakers were realized. Packages with a superior joint that provide the lowest leak rates are also less likely to have the problems associated with an inferior joint, such as a gross leaker.

Hybrid Flatpack Summary **0.9 cm^3 Internal Volume**						
Feedthrough	**Cover Plate**	**Volume cm^3**	**Schedule**	**Leak Rate Mean**	**Std Dev**	**Time to Specification**
None	Au/Ni	0.9	1	6.5E-10 atm-cm³/sec **<u>Air</u>**	0.56	16.6 Years
None	Au/Ni	0.9	2	5.4E-10 atm-cm³/sec **<u>Air</u>**	0.4	20 Years
None	Au/Ni	0.9	3	4.3E-10 atm-cm³/sec **<u>Air</u>**	0.35	25 Years
None (Materials Lot 2)	Au/Ni	0.9	3	4.5E-10 atm-cm³/sec **<u>Air</u>**	0.35	24 Years
Corning Glass	Au/Ni	0.9	3	6.2E-10 atm-cm³/sec **<u>Air</u>**	0.1	17 Years
Corning Glass	Au/Ni	0.9	4	4.4E-10 atm-cm³/sec **<u>Air</u>**	0.05	24.5 Years

Figure 8

With an optimized hermetic sealing schedule on hybrid flatpacks with glass feedthroughs, the hermetic package life is limited by a leak rate of 4.4E-10 atm-cm³/sec <u>air</u>, which is 2.27 times less than the most stringent aerospace leak rate specification, representing an increased time to the moisture limit specification from 1.08 years to 24.5 years.

<u>Microwave Module</u>

Precision machined Kovar™ housings, with and without glass feedthroughs, were used for development. This package provided sealing challenges due to both corner radius and feedthrough distances from seal ring that were not within standard industry practices. The package internal cavity of 0.05 cm³ would require a leak rate of $1x10^{-9}$ atm-cm³/sec <u>air</u> to meet current standards.

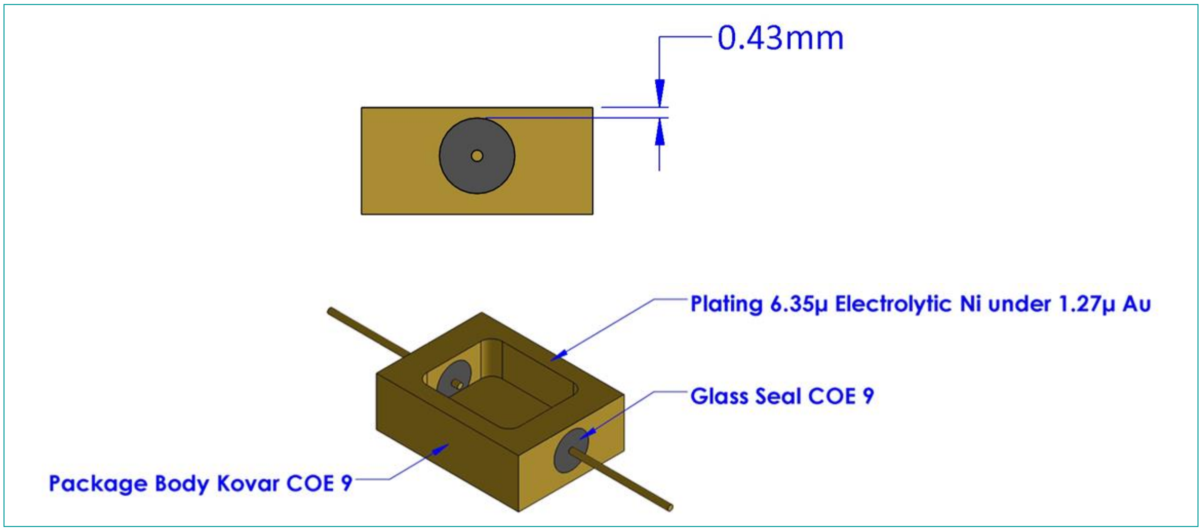


Figure 9

The initial sealing development of bathtub packages realized a very large number of gross leakers. For packages that did not have gross leakers, the fine leak test results were within the range of current specifications.

In developing the seal joints for lower leak rates, gross leakers on the leadless bathtubs were eliminated. However, when the seal process was transferred from the leadless bathtub packages to packages with glass feedthroughs, large numbers of gross leakers were realized, per Figure 10. This process condition was repeatable on both covers with Ni plate and Au/Ni Plate.

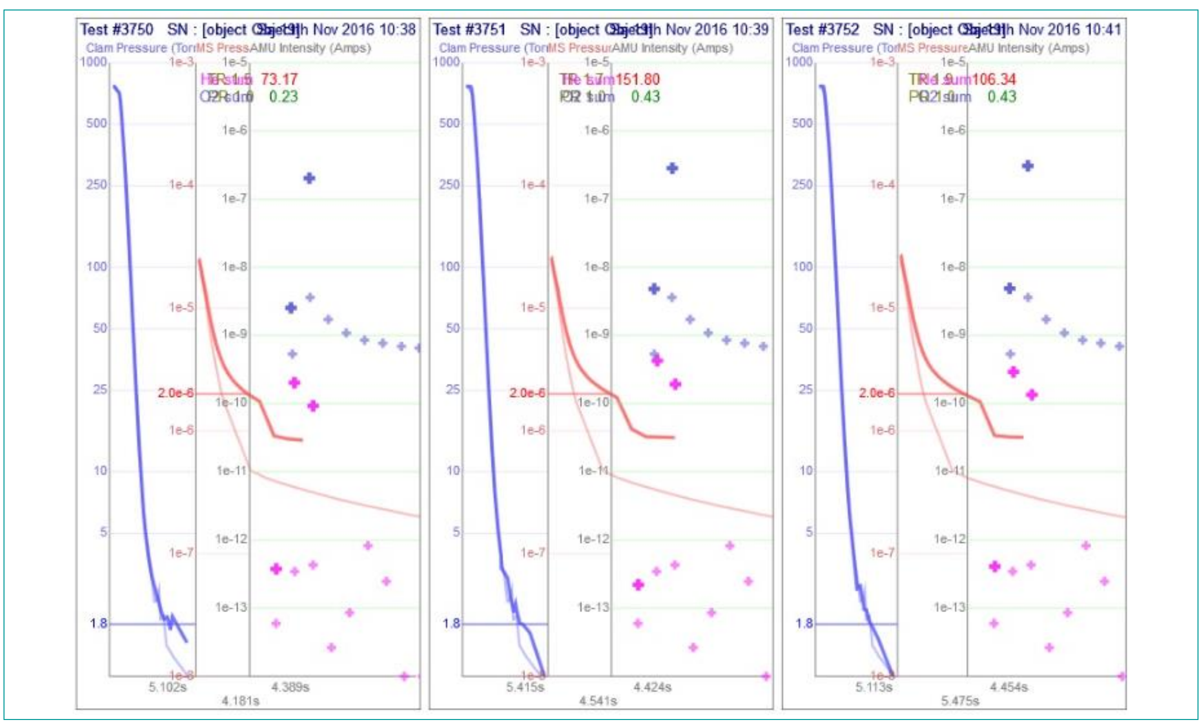


Figure 10

Microwave Module Summary
0.05 cm³ Internal Volume

Feedthrough	Cover Plate	Volume cm³	Schedule	Leak Rate Mean	Std Dev	Time to Specification
None (Materials Lot 1)	Au/Ni	0.05	3	4.5E-10 atm-cm³/sec **Air**	0.4	486 Days
None (Materials Lot 2)	Au/Ni	0.05	3	4.5E-10 atm-cm³/sec **Air**	0.5	486 Days
None	Au/Ni	0.05	4	1.7E-10 atm-cm³/sec **Air**	0.19	3.5 Years
Corning Glass	Au/Ni	0.05	4	4.4E-10 atm-cm³/sec **Air**	0.4	497 Days
None	Au/Ni	0.05	5	1E-10 atm-cm³/sec **Air**	4.80E-12	5.9 Years
Corning Glass	Au/Ni	0.05	5	4.4E-10 atm-cm³/sec **Air**	0.4	497 Days

Figure 11

Seal Schedule 5 is the optimum process for sealing a bathtub package with no glass feedthroughs. There were no gross leakers with fine leak rate of 1E-10 atm-cm³/sec air with Std Dev 4.8E-12.

Per Figure 13, it is interesting to note that the fine leak results were never lower than the minimal detectable leak rate per the exact conditions of the leak test per the Howl-Mann flexible method for this particular package and conditions, with minimal detectable limit for this of 9.8E-11 atm-cm³/sec air.

Photograph 4

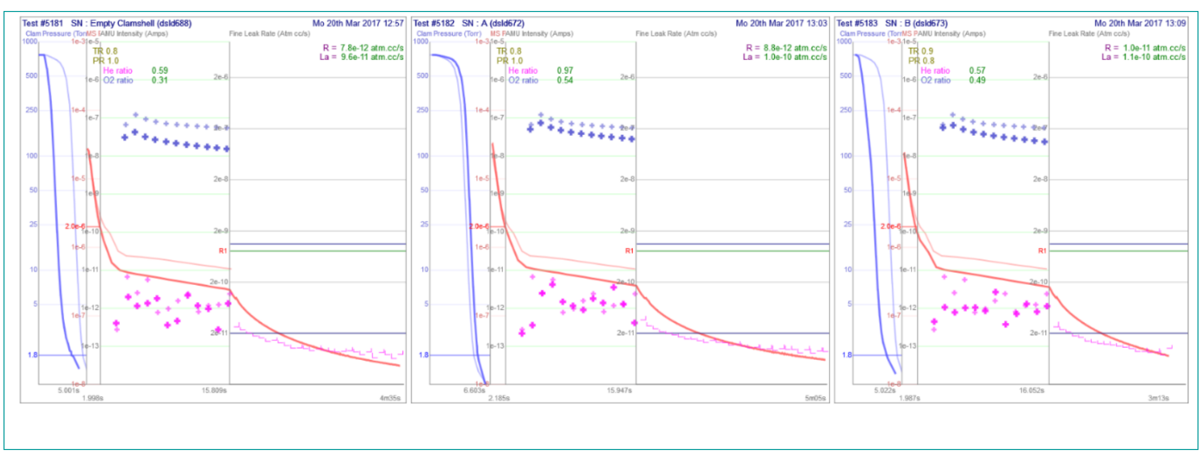


Figure 12

Seal Schedule 5 was also utilized for cover sealing of packages with glass feedthroughs. No gross leakers were realized. Per Figure 14, fine leak results are 4.4E-10 atm-cm^3/sec <u>air</u> with Std Dev 0.4.

Photograph 5

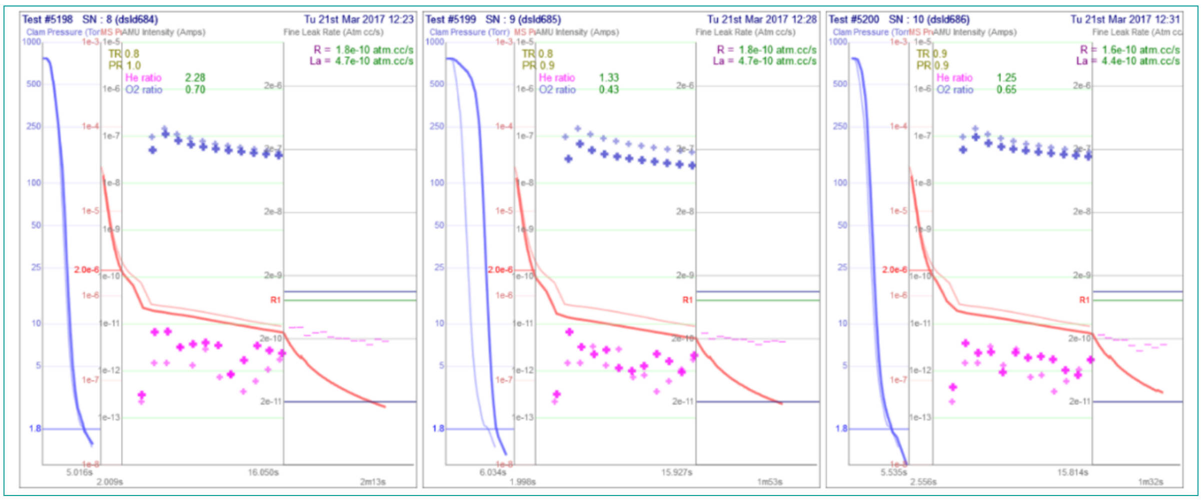


Figure 14

The following package examples were sealed with very limited quantities. This shows the new sealing process technique is readily applied to different hermetic packages with minimal development to surpass current specifications for fine leak rates. No gross leakers were realized in any of these schedules.

Photograph 6

Ceramic Chip Carrier Summary 0.02 cm³ Internal Volume						
Feedthrough	**Cover Plate**	**Volume cm³**	**Schedule**	**Leak Rate Mean**	**Std Dev**	**Time to Specification**
None	Au/Ni	0.02	1	2.4E-10 atm-cm³/sec **Air**	NA	364 Days
None	Au/Ni	0.02	2	2.9E-10 atm-cm³/sec **Air**	NA	302 Days
None	Au/Ni	0.02	3	1.9E-10 atm-cm³/sec **Air**	0.1	460 Days
None	Au/Ni	0.02	4	1.1E-10 atm-cm³/sec **Air**	NA	2.1 Years

Figure 15

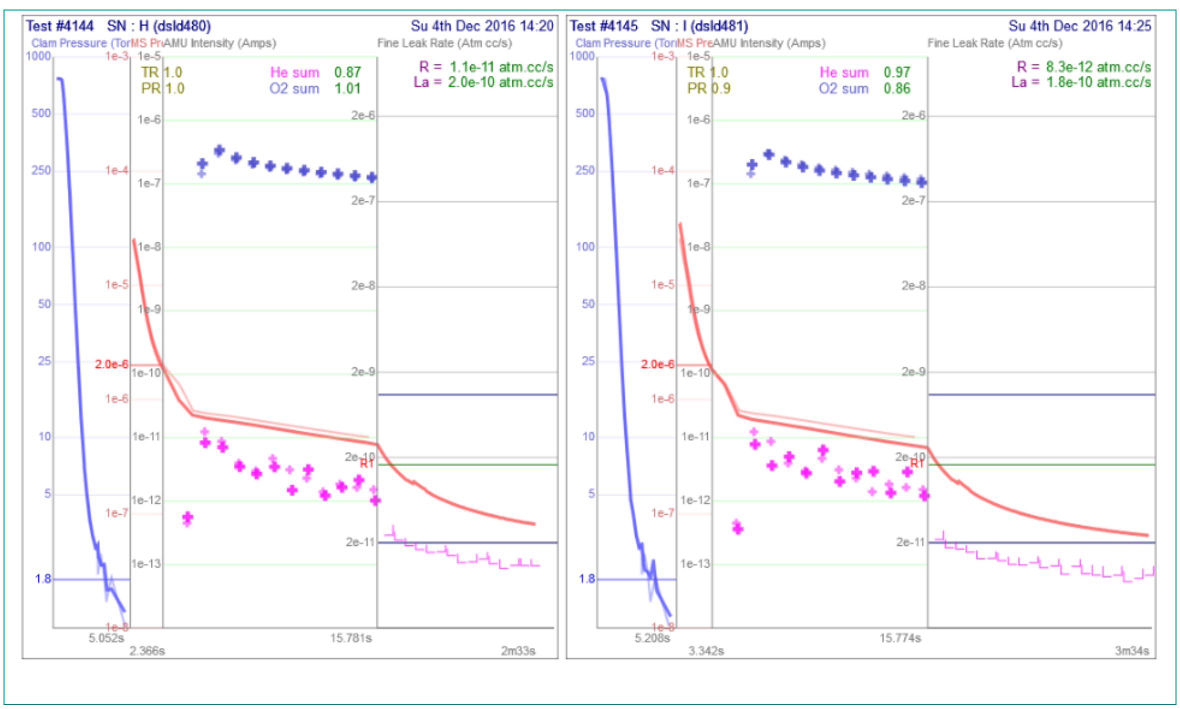


Figure 16

Power Hybrid Summary
2.2 cm³ Internal Volume

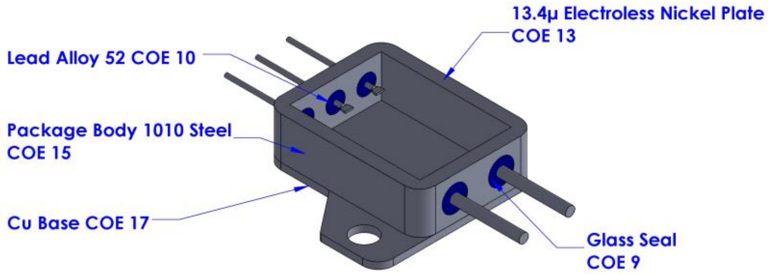


Figure 17

Photograph 7

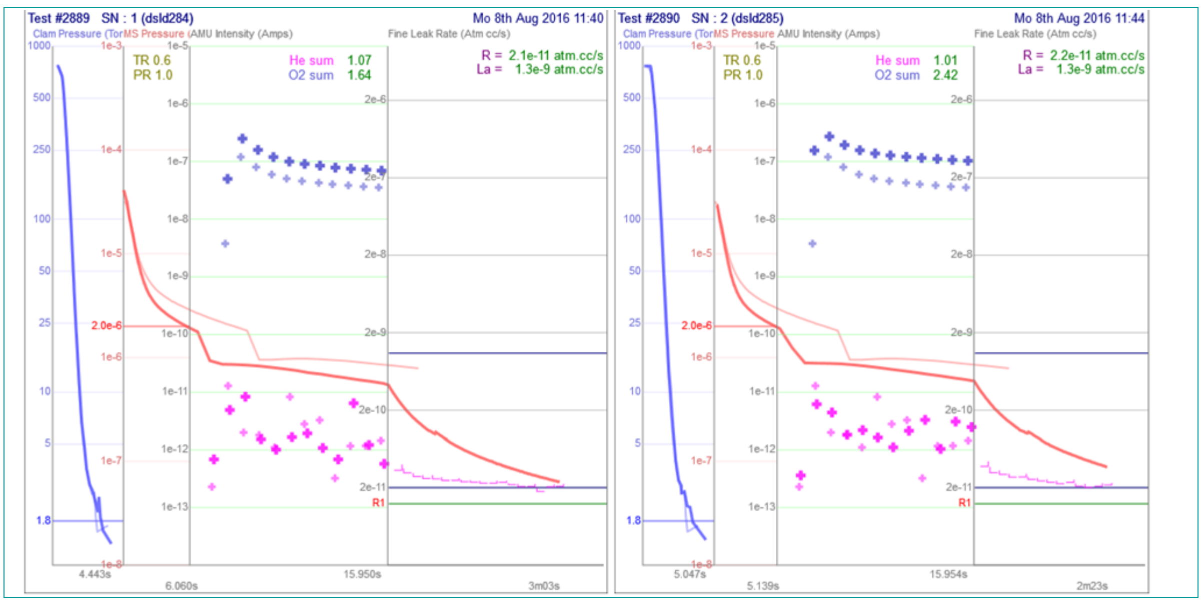
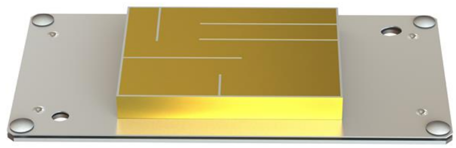


Figure 18

Feedthrough	**Cover Plate**	**Volume cm³**	**Schedule**	**Leak Rate Mean**	**Std Dev**	**Time to Specification**
Compressed Glass	Ni	2.2	1	1.3E-9 atm-cm³/sec **Air**	NA	20 Years

Figure 19

Microwave Hybrid
6.48 cm³ Internal Volume



Photograph 8

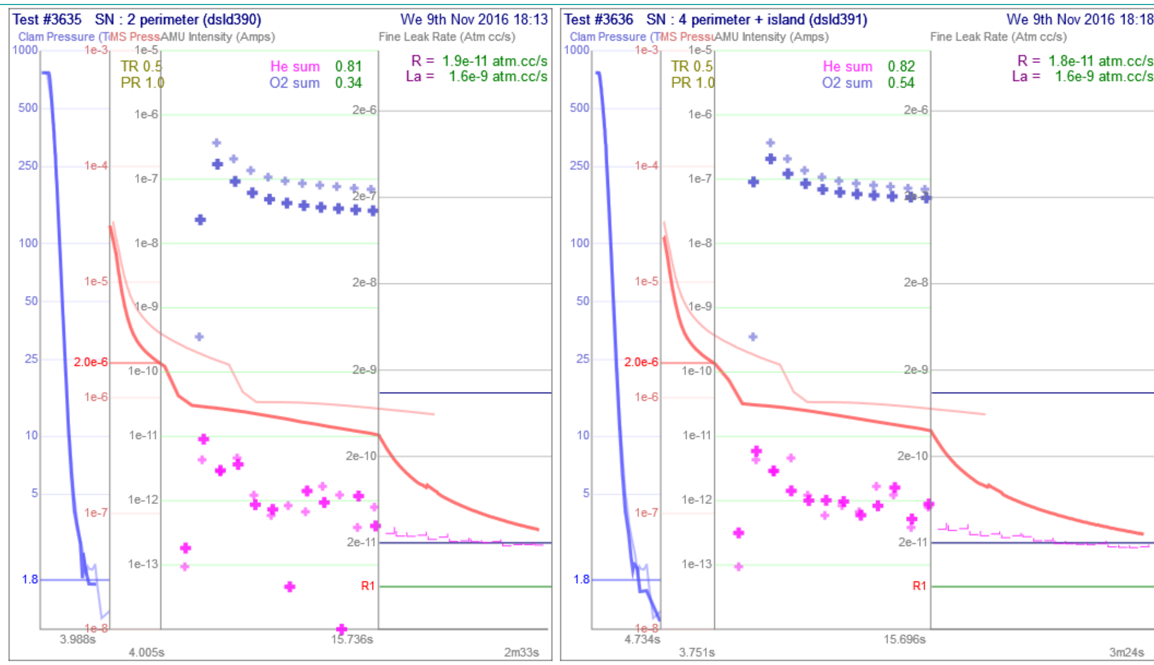


Figure 20

Feedthrough	Cover Plate	Volume cm³	Schedule	Leak Rate Mean	Std Dev	Time to Specification
None	Au/Ni	6.48	1	2.9E-9 atm-cm³/sec **Air**	NA	38 Years
None	Au/Ni	6.48	2	1.6E-9 atm-cm³/sec **Air**	0.2	59 Years

Figure 21

Conclusions

By altering process technique on existing parallel seam sealers, superior hermetic joints were obtained. The joints resulted in no viscous leaks in the E-1 to E-4 atm-cm^3/sec air, referred to as gross leakers. Molecular leaks, which are referred to as ultra-fine leakers with rates in the E-9 to E-11 atm-cm^3/sec air, are achieved, which extend the time to moisture limit specification of the sealed device.

An optimized hermetic sealing schedule on 0.9 cm^3 internal volume hermetic package results in a leak rate of 4.4E-10 atm-cm^3/sec air, 2.27 times less than the most stringent aerospace leak rate specification. This will result in an increased time to moisture limit specification from 1.08 years to 24.5 years.

Endnotes

1 Seal Processing for Lowest Leak Rates and the New MIL-STD-883 TM 1014 Seal, Rich Richardson, MicroCircuit Laboratories LLC, April 2017.

2 ORS Model 310 HSHLD™ standard sensitivity is 5E-12 atm-cm^3/sec helium with a standard chamber. The system is calibrated with a low- and high-leak standard.

References

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Miyachi Benchmark SM8500 Technical Datasheets
Avionics 1099 One Shot Sealer User Manual, Nippon Avionics

About MCL

MicroCircuit Laboratories (MCL) is an OSAT for hermetic package sealing of integrated circuit devices. MCL provides design and development with a Process of Record (POR) for each individual package. The POR may be transferred to other manufacturers or processed with MCL, which has capacity for 1,000 packages per month. As your needs require HVM, a copy exact fabrication cell enables no risk transfer of your POR, while maintaining a development partner and second source by design. More information is available at www.microcircuitlabs.com.