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Seal Processing for Lowest Leak Rates and the New MIL-STD-883 TM 1014 Seal

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Abstract

Current US MIL-STD-883 Test Method 1014 significantly tightened 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). By altering processing technique, including physical and electrical parameters to optimize thermal characteristics and throughput, existing parallel seam sealers and one-shot welders can routinely achieve seals with leak rates in the E-10 atm-cm^3/sec (air).

Introduction

Compound semiconductor, photonics, MEMS, microwave, power and semiconductor devices utilized for high reliability applications require hermetic encapsulation. With the value proposition of these devices and the trend towards miniaturization, significantly lower leak rate levels are required to prevent the internal package cavity from reaching the 5,000 ppm moisture limit for the device lifetime due to ingress of external ambient air. There are several factors that determine the operating life to specification of a hermetic integrated circuit package. The most significant is the hermetic encapsulation process, which is the focus of this paper.

An example of a typical microelectronic package is based upon a 25°C/50% RH external environment with an internal volume of 0.9 cm^3 and a leak rate of $1x10^{-8}$ atm-cm^3/sec air**.** This package would have an operating time to specification limit of 1.08 years from the date of sealing. For miniature packages, the operating time to specification limit is even shorter. A package with an internal cavity of 0.05 cm^3 with a leak rate of $1x10^{-9}$ atm-cm^3/sec air would have an operating hermetic lifetime of about of 219 days.

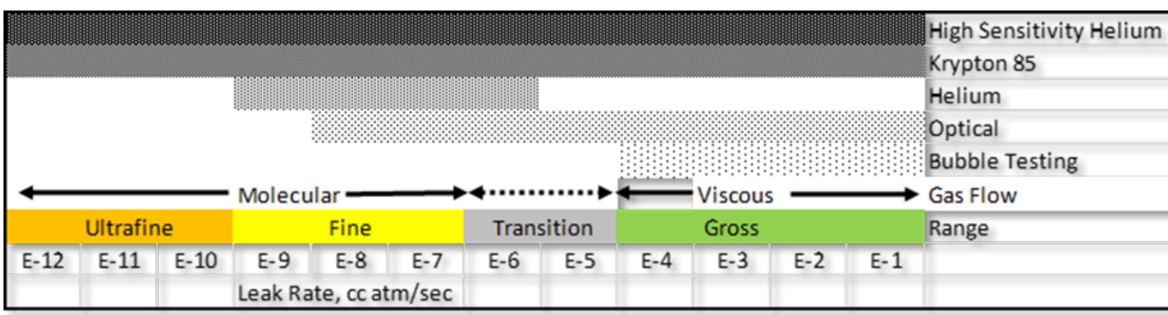


Figure 1

For testing hermetic package leak rates, MicroCircuit Laboratories (MCL) required test capability to detect both gross and ultra-fine leak rates. Gross leak testing was of considerable importance because a gross leak failure, by letting all the helium escape the package, can result in passing the fine leak. A single system that enabled simultaneously testing both gross and fine leaks was desired.

In 1974, the flexible method for determining the equivalent standard leak rate of packages was introduced to the military standards. This method, based on the Howl-Mann equation, allows the actual test conditions to be input to the equation. MCL desired automatic processing with the Howl-Mann flexible method for simplification of the manufacturing process, increased accuracy, and ability to detect both gross and fine leaks with a single system.

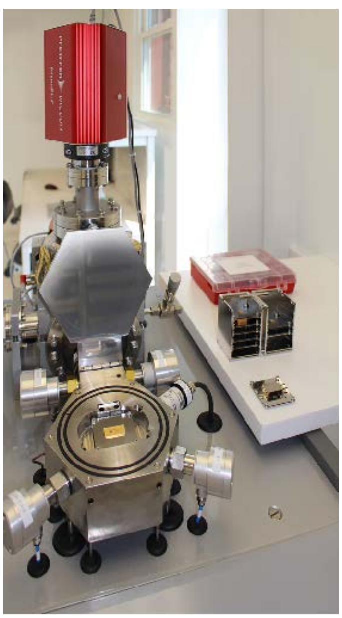
$$R_1 = \frac{LP_E}{P_o}\left(\frac{M_A}{M}\right)^{\frac{1}{2}} \left\{ 1 - e^{-\left[\frac{Lt_1}{VP_o}\left(\frac{M_A}{M}\right)^{\frac{1}{2}}\right]} \right\} e^{-\left[\frac{Lt_2}{VP_o}\left(\frac{M_A}{M}\right)^{\frac{1}{2}}\right]}$$

Where:

- R = The actual leakage measurement of tracer gas (He) through the leak in atm cm^3/s He.
- R_1 = The calculated reject limit maximum allowable leakage measurement.
- L = The maximum allowable equivalent standard leak rate limit (see Table VII of paragraph 3) in atm cm^3/s air.
- P_E = The pressure of exposure in atmospheres absolute.
- P_O = The atmospheric pressure in atmospheres absolute. (1 atm)
- M_A = The molecular weight of air in grams (28.96).
- M = The molecular weight of the tracer gas (He) in grams. (4 amu's)
- t_1 = The time of exposure to P_E in seconds.
- t_2 = The dwell time between release of pressure and leak detection, in seconds.
- V = The internal free volume of the device package cavity in cubic centimeters.

Figure 2

The Oneida Research Model 310 High Sensitivity Leak Detection HSHLD®, Photograph 1, met these requirements with capabilities[2] for small and large package leak testing. The system provides rapid, single-step processing for both gross and fine leak testing, Figure 3, with complete data collection on each test for a sealed package. ORS provide high-level support with remote PC desktop operation for training and knowledge based on 40 years of leak test processing.



Photograph 1
Model 310 HSHLD®

Photograph 2: LACO Technologies helium bombing systems

As of the date of this paper, MCL has performed over 5,200 cycles, representing over 2,000 package test cycles in the Model 310 HSHLD®.

Processing utilizing the Howl-Mann flexible method provides the manufacturer benefits to utilize a more sophisticated helium bombing capability. This includes the ability to update the leak test process with actual He bomb time, which is very convenient for the manufacturer. MCL utilizes the LACO Technology Model HCS, per Photograph 2, with absolute certified transducer operation and complete digital control with programmable sampling rate for data collection provided with .csv files.

The recent update to MIL-STD-883 Test Method 1014, per Figure 4, significantly tightened the leak rates and required leak rate specifications to be stated in air. To meet these new leak rate specifications, packages were sealed with industry standard cover seal processes. These techniques were not able to consistently meet or meet with adequate margin these new lower leak rates. Additionally, the existing technique resulted in a large number of gross leakers on different package types. The large deviations in leak rates were not characteristic of a well-controlled 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	$5 X 10^{-8}$	$1 X 10^{-9}$
> 0.05 - ≤ 0.4	$1 X 10^{-7}$	$5 X 10^{-9}$
> 0.4	$1 X 10^{-6}$	$1 X 10^{-8}$

Figure 3

Hermetic Package Sealing Development

Parallel Seam Sealing (PSS), Figure 5, provides an industry standard resistance weld joining process to hermetically seal integrated circuit packages. Precise control of the internal device atmosphere, including both inert gas atmosphere and particles, is provided while maintaining peak device temperature substantially lower than device and die attach and adhesive material requirements.

Sealing of hermetic 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™, 29=Ni/17-Co/Bal Fe alloy, with most common plating Au over Ni for a corrosion resistant joint that will pass the salt spray test per MIL-STD-883 TM 1009.

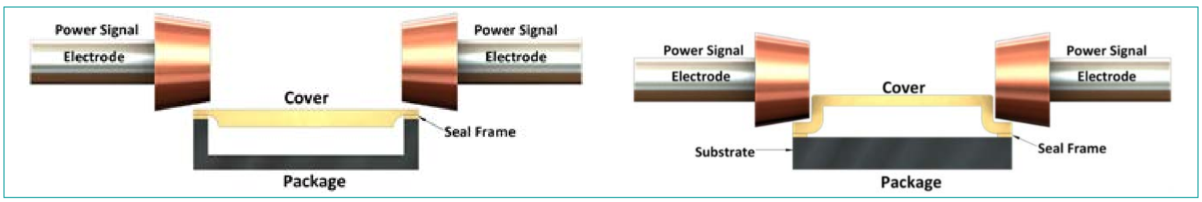
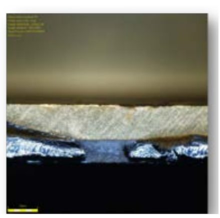


Figure 4

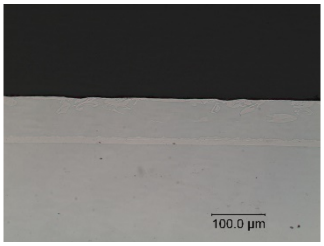
To verify properly welded joints, peel tests, per Photograph 3, were performed on each sealing schedule. With current industry standard sealing approaches, peel tests would randomly result in seal joints that were not maintained, per Photograph 3a. It is worthwhile to note that the packages sealed with the new sealing technique described in this paper did not exhibit this condition.

Photograph 3

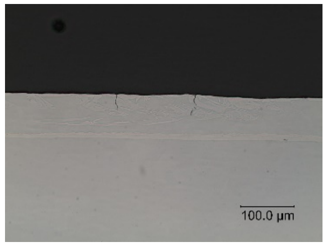


Photograph 3a

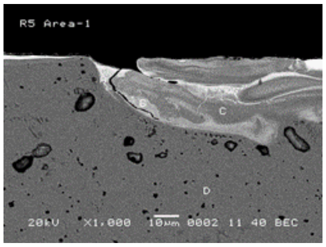
Microstructure analysis of seal joints have been performed (unetched SEM, etched SEM, and etched optical). Photograph 3b is an example of a good joint, Photograph 3c of a bad joint and Photographs 3d and 3e represent an analysis of a bad joint.



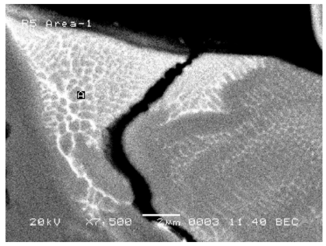
Photograph 3b



Photograph 3c



Photograph 3d



Photograph 3e

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.

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. It is worthwhile to note that 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 specification of 1.08 years.

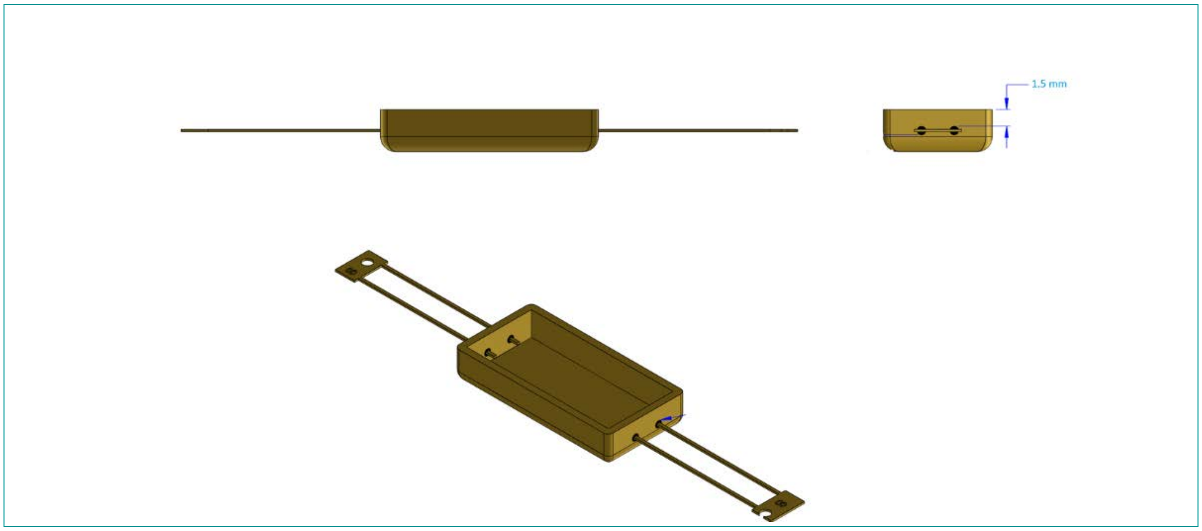
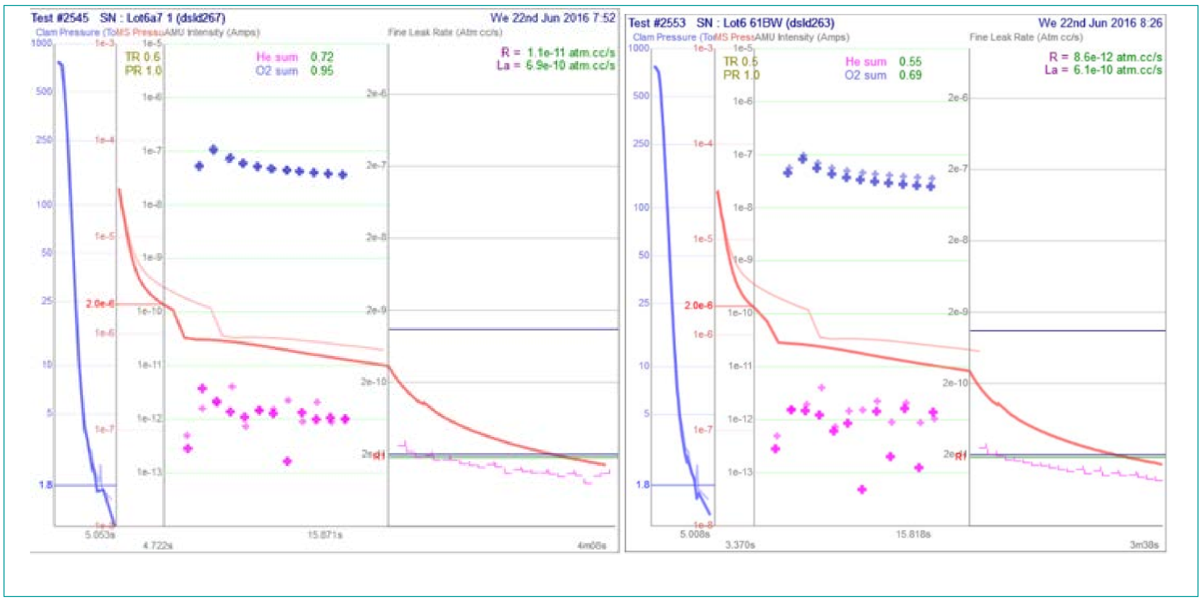


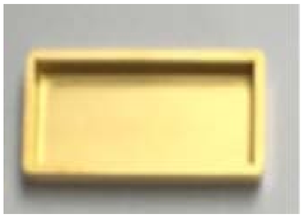
Figure 5

Hybrid Flatpack Sealing Schedule 1

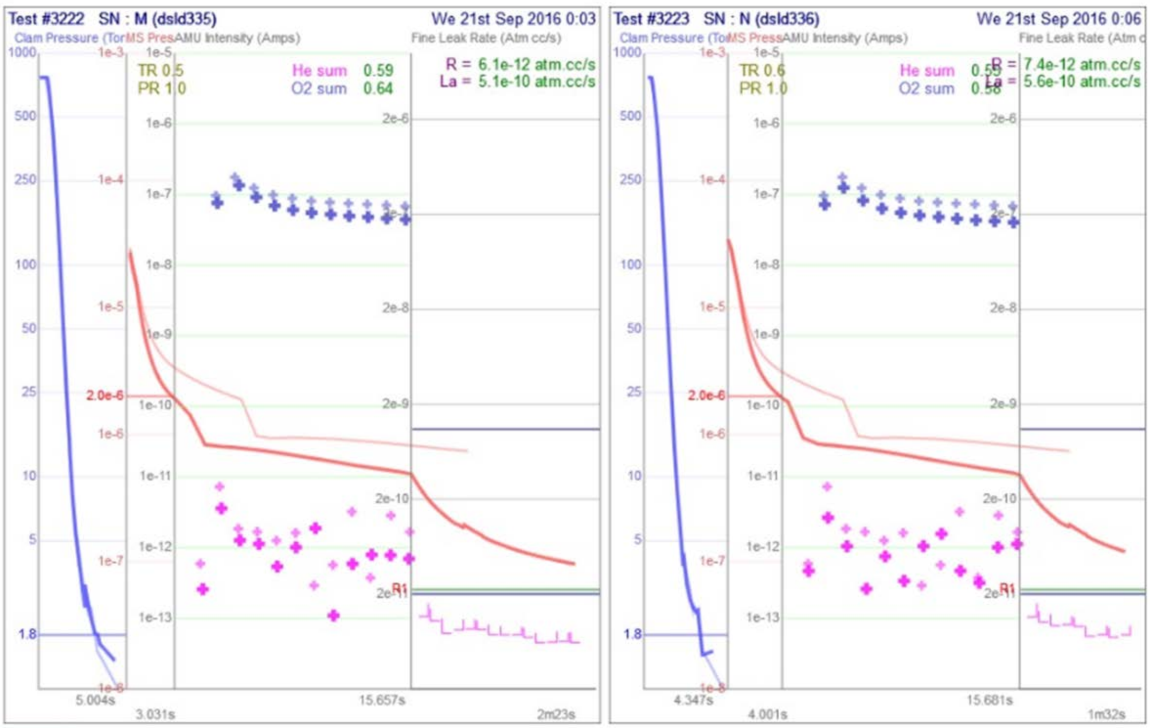
Sealing Schedule 1 was the first developed to meet E-10 air leak rates. There were no gross leakers realized with this schedule. This leadless bathtub package realized a fine leak test mean of 6.5E-10 atm-cm^3/sec air with Std Dev 0.56.



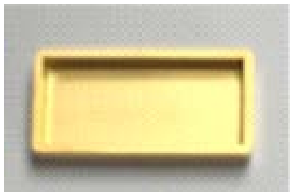
Hybrid Flatpack Sealing Schedule 2



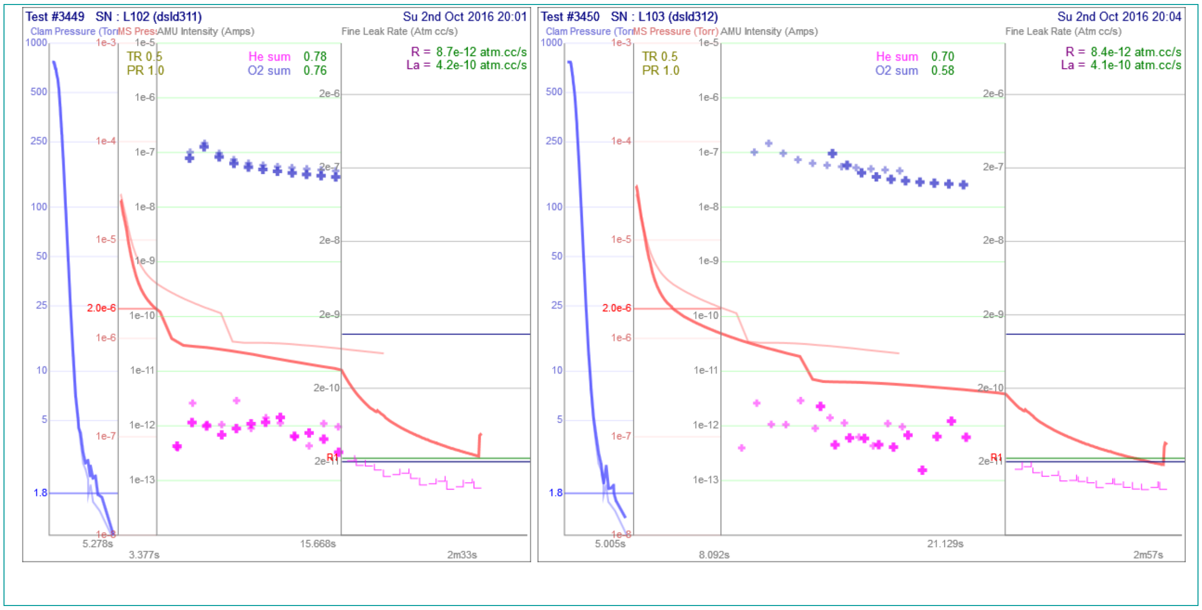
Adjusting the key sealing process parameters, leadless bathtub packages were sealed with a lower fine leak rate of 5.4E-10 atm-cm³/sec air with Std Dev 0.4 No gross leakers were realized.



Hybrid Flatpack Sealing Schedule 3

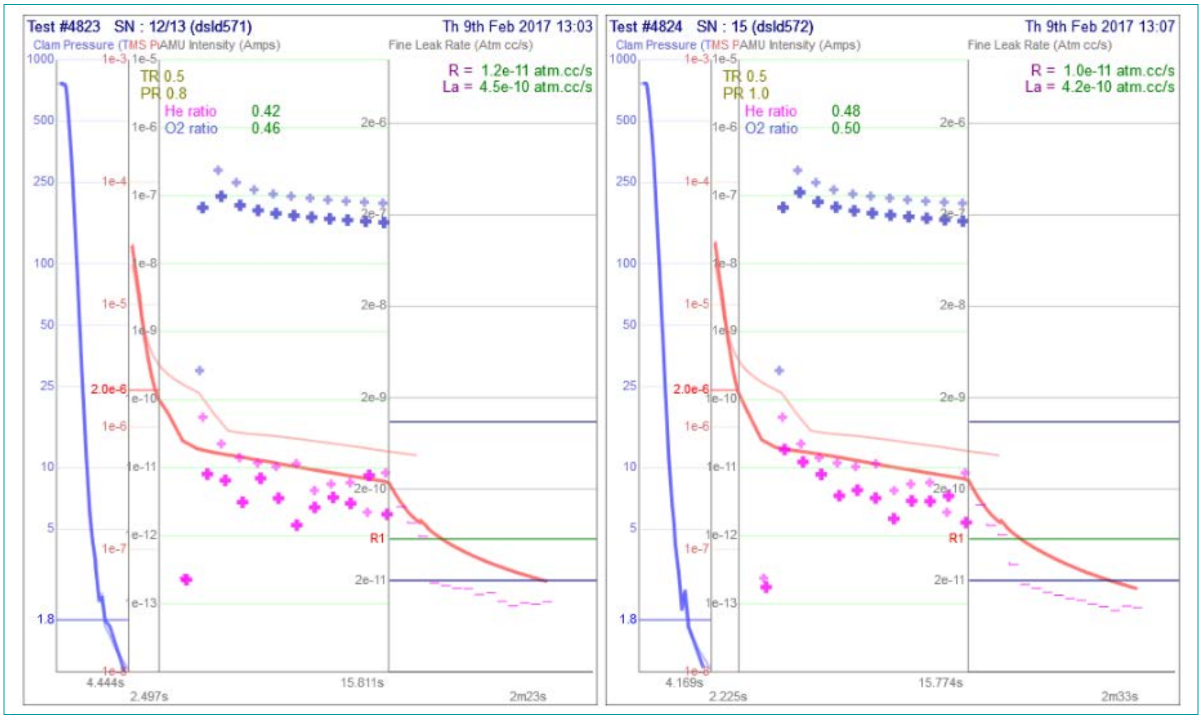


Sealing Schedule 3 was developed and used to compare the sealing results for different lots from package and cover suppliers. These packages and covers were from Materials Lot 1.
All passed gross leak; fine leak test mean of 4.3E-10 atm-cm^3/sec air with Std Dev 0.35.



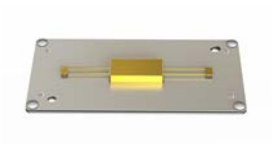
Hybrid Flatpack Sealing Schedule 3 (Repeat with New Packages and Covers)

Materials Lot 2 with all seals passing gross leak and fine leak test mean of 4.5E-10 atm-cm^3/sec <u>air</u> with Std Dev 0.35.

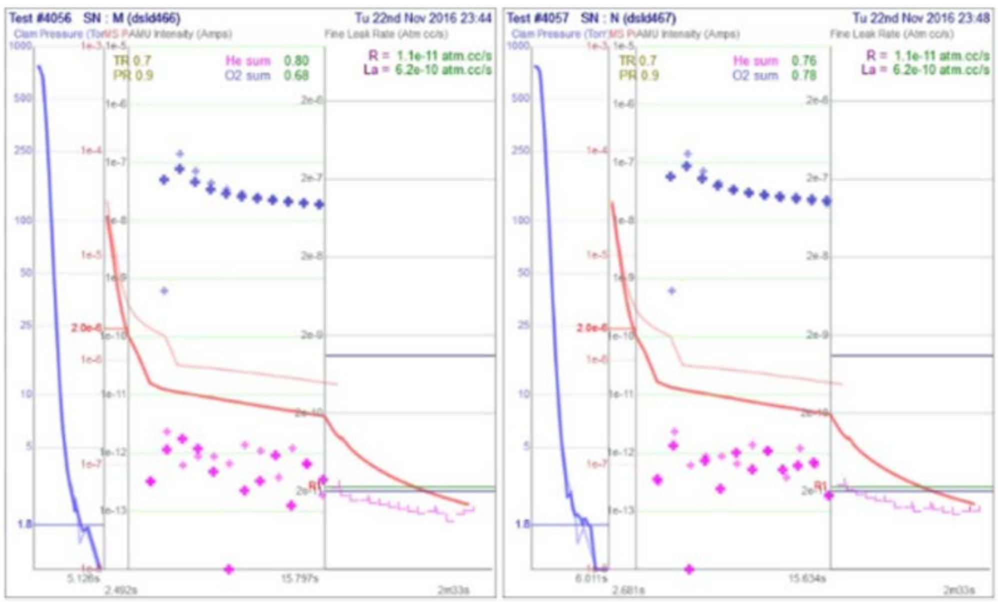


The Sealing Schedule 3 shows that a sealing technique has enough margin to get near identical results even with slight differences in materials resulting from different lots from material suppliers.

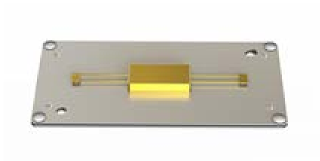
Hybrid Flatpack with Glass Feedthrough Repeat Sealing Schedule 3



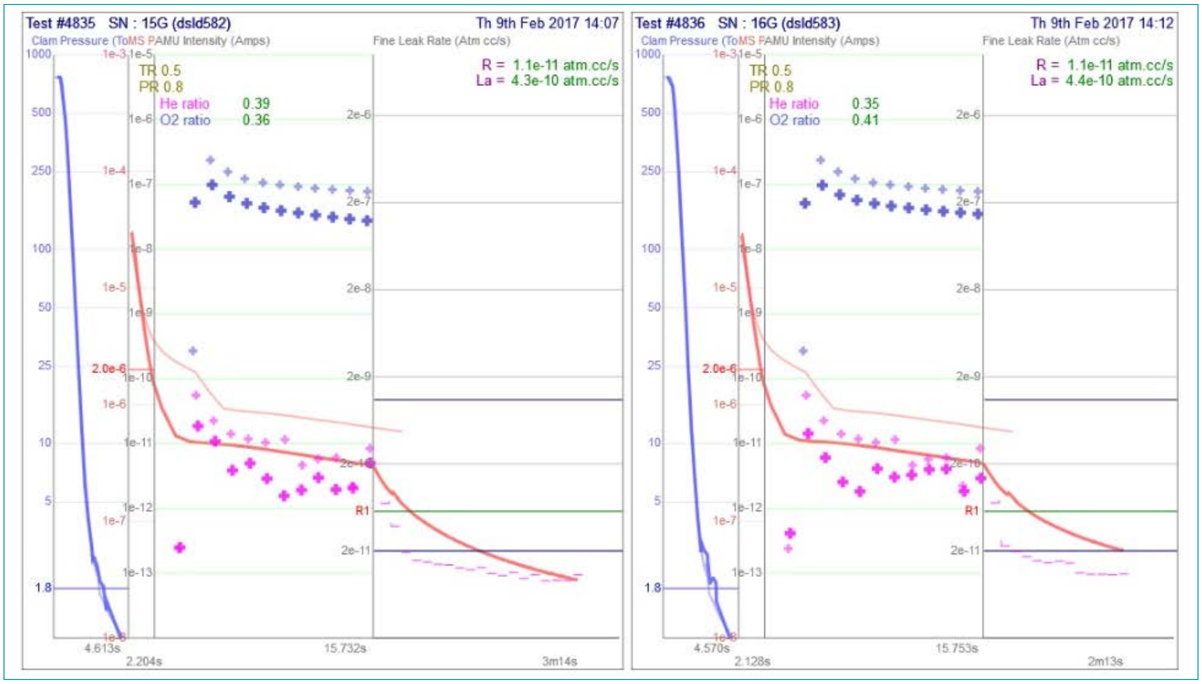
Packages with Corning Glass feedthroughs were then sealed with Sealing Schedule 3. All packages passed gross leak; the fine leak test mean of 6.2E-10 atm-cm^3/sec air with Std Dev 0.1 were realized.



Hybrid Flatpack with Glass Feedthrough Sealing Schedule 4



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 air with Std Dev 0.05 was realized.



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-cm^3/sec **Air**	0.56	16.6 Years
None	Au/Ni	0.9	2	5.4E-10 atm-cm^3/sec **Air**	0.4	20 Years
None	Au/Ni	0.9	3	4.3E-10 atm-cm^3/sec **Air**	0.35	25 Years
None (Materials Lot 2)	Au/Ni	0.9	3	4.5E-10 atm-cm^3/sec **Air**	0.35	24 Years
Corning Glass	Au/Ni	0.9	3	6.2E-10 atm-cm^3/sec **Air**	0.1	17 Years
Corning Glass	Au/Ni	0.9	4	4.4E-10 atm-cm^3/sec **Air**	0.05	24.5 Years

Figure 6

With an optimized hermetic sealing schedule on hybrid flatpacks with glass feedthroughs, per Figure 2, the hermetic package life is limited by a leak rate of 4.4E-10 atm-cm^3/sec air, which is 2.27 times less than the most stringent aerospace leak rate specification, representing an increased time to specification from 1.08 years to 24.5 years. There were no gross leakers realized in any of the sealing schedules utilized with multiple lots.

Gross Leakers

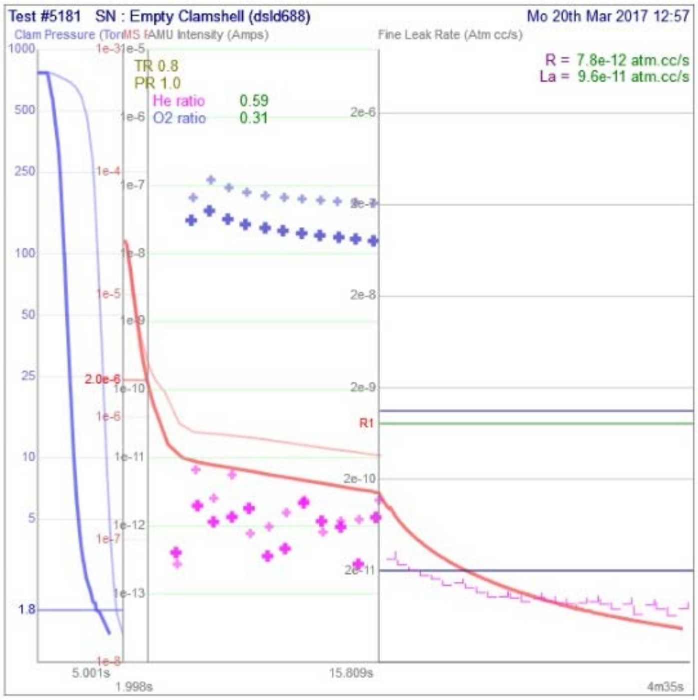
In developing the sealing process for the hybrid flatpack, MCL's development produced gross leakers by either of two causes. The first cause is a marginal seal joint. The faster the fine leak rate, the more gross leakers were realized.

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 and in all these schedules with E-10 air leak rates; no gross leakers resulted.

The Test Method 1014 seal requires gross leak testing to occur within 1 hour from sealed packages removal from the helium bombing process. Per Figure 8, gross leakers are identified in a number of ways including when a high percentage of helium is detected.

Figure 7

A database of all leak testing is created for each package tested. This enables further data to determine whether a gross leaker exists. Per Figure 9, the system can identify the maximum detectable fine leak results per the particular 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.



Test #5181 SN : Empty Clamshell (dsld688)
Mo 20th Mar 2017 12:57
Fine Leak Rate (Atm cc/s)
R = 7.8e-12 atm.cc/s
La = 9.6e-11 atm.cc/s
TR 0.8
PR 1.0
He ratio 0.59
O2 ratio 0.31
R1
5.001s
1.998s
15.809s
4m35s

Figure 8

Microwave Module

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 cm^3 would require a leak rate of 1×10^{-9} atm-cm^3/sec air to meet current standards.

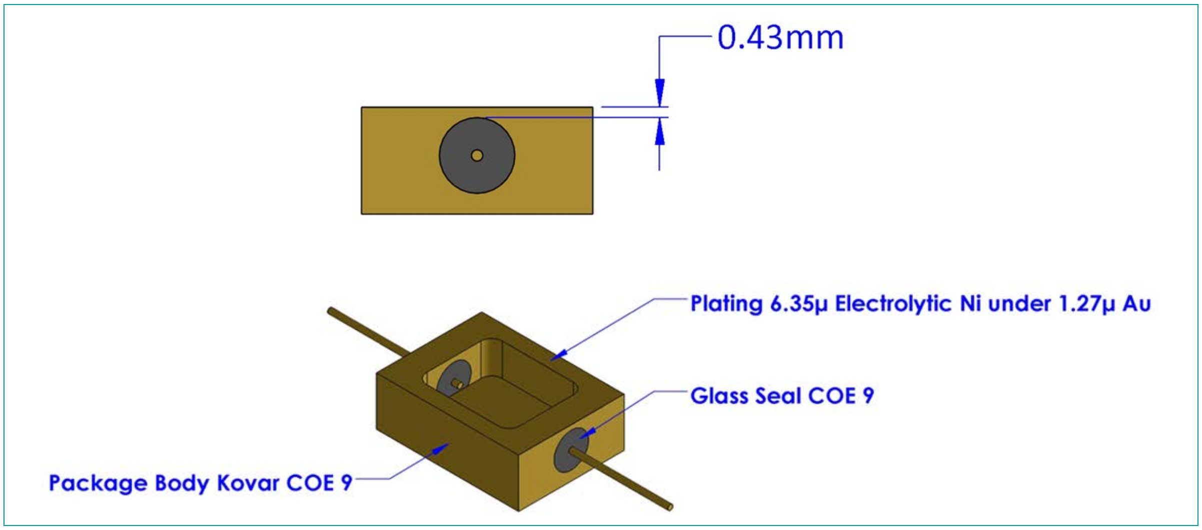


Figure 9

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 11. This process condition was repeatable on both covers with Ni plate and Au/Ni Plate.

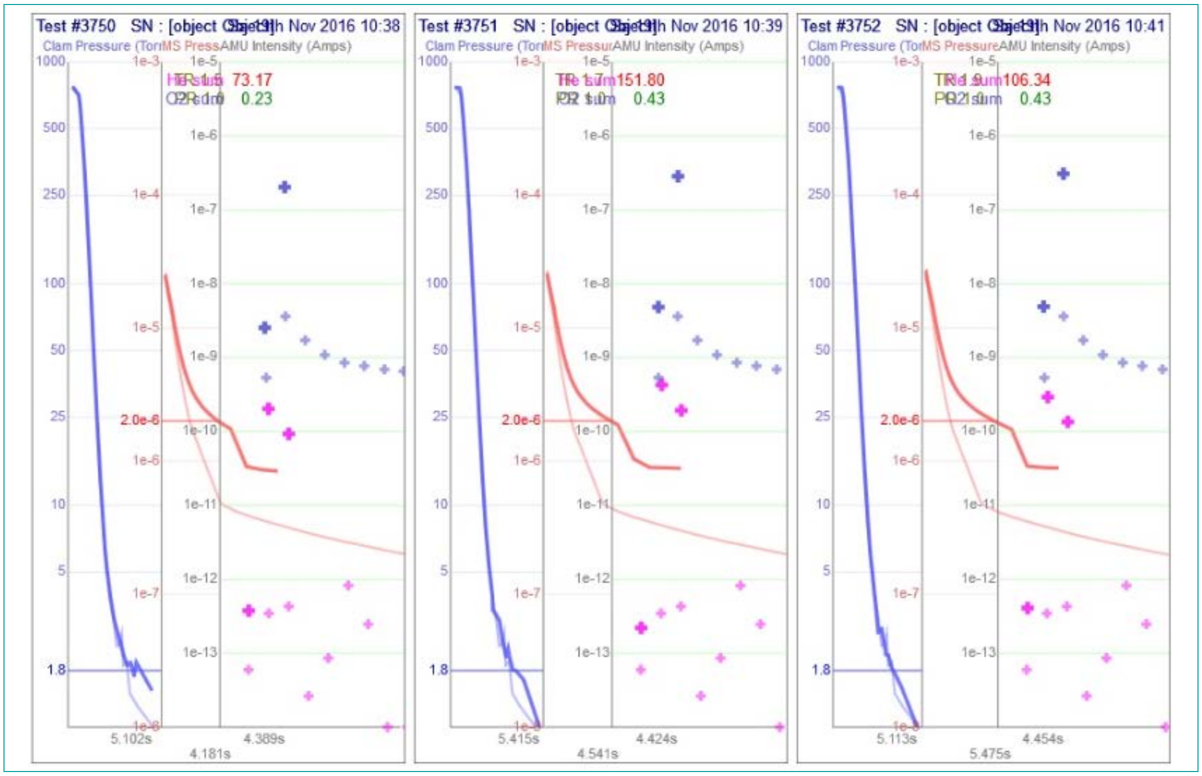


Figure 10

Development of a seal process for lower cost nickel-plated covers was performed. The Ni plate and Au/Ni plate covers required different sealing processes to minimize leak rates. In either case, the glass feedthrough seals, with the sealing process utilized, appear to determine the minimal obtainable fine leak test results.

The optimized seal schedule for covers with Ni plate for packages with glass feedthroughs indicate that further seal process development for covers with Au/Ni plate would result in lower fine leak rates to extend the hermetic life of the device.

Additionally, Sealing Schedule 3 demonstrated that this sealing technique has a margin to obtain identical results even with differing lots of covers and packages from the material suppliers.

Microwave Module Summary 0.05 cm³ Internal Volume						
Feedthrough	**Cover Plate**	**Volume cm^3**	**Schedule**	**Leak Rate Mean**	**Std Dev**	**Time to Specification**
None	Ni	0.5	1	4.3E-10 atm-cm^3/sec **Air**	0.2	1.3 Years
None	Ni	0.5	2	1.8E-10 atm-cm^3/sec **Air**	0.13	3.3 Years
Corning Glass	Ni	0.5	3	3.1E-10 atm-cm^3/sec **Air**	0.3	1.9 Years
None (Materials Lot 1)	Au/Ni	0.5	3	4.5E-10 atm-cm^3/sec **Air**	0.4	1.3 Years
None (Materials Lot 2)	Au/Ni	0.5	3	4.5E-10 atm-cm^3/sec **Air**	0.5	1.3 Years
None	Au/Ni	0.5	4	1.7E-10 atm-cm^3/sec **Air**	0.19	3.5 Years
Corning Glass	Au/Ni	0.5	4	4.4E-10 atm-cm^3/sec **Air**	0.4	1.3 Years
None	Au/Ni	0.5	5	1E-10 atm-cm^3/sec **Air**	4.80E-12	5.9 Years
Corning Glass	Au/Ni	0.5	5	4.4E-10 atm-cm^3/sec **Air**	0.4	1.3 Years

Figure 11

Microwave Module Bathtub Sealing Schedule 5

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-cm^3/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-cm^3/sec air.

Photograph 4

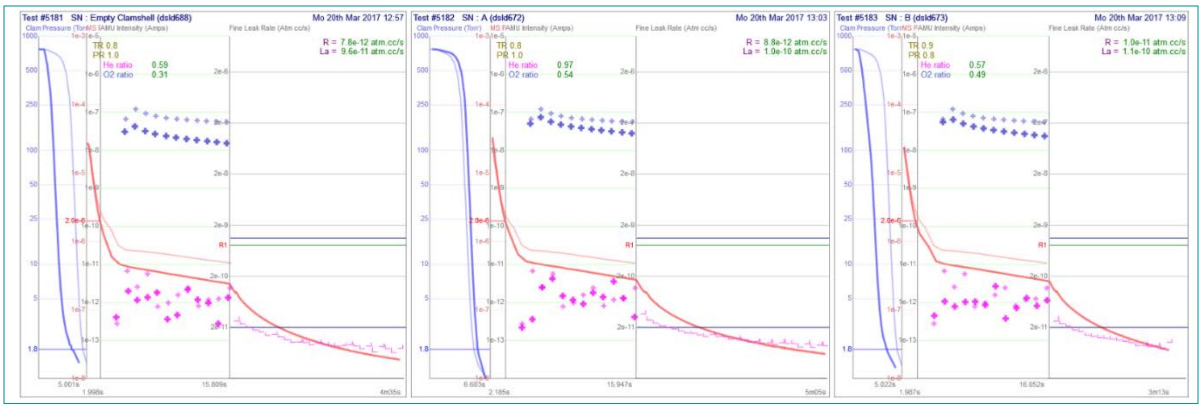


Figure 12

Microwave Module with Glass Feedthroughs Sealing Schedule 5

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-cm³/sec air with Std Dev 0.4.

Photograph 5

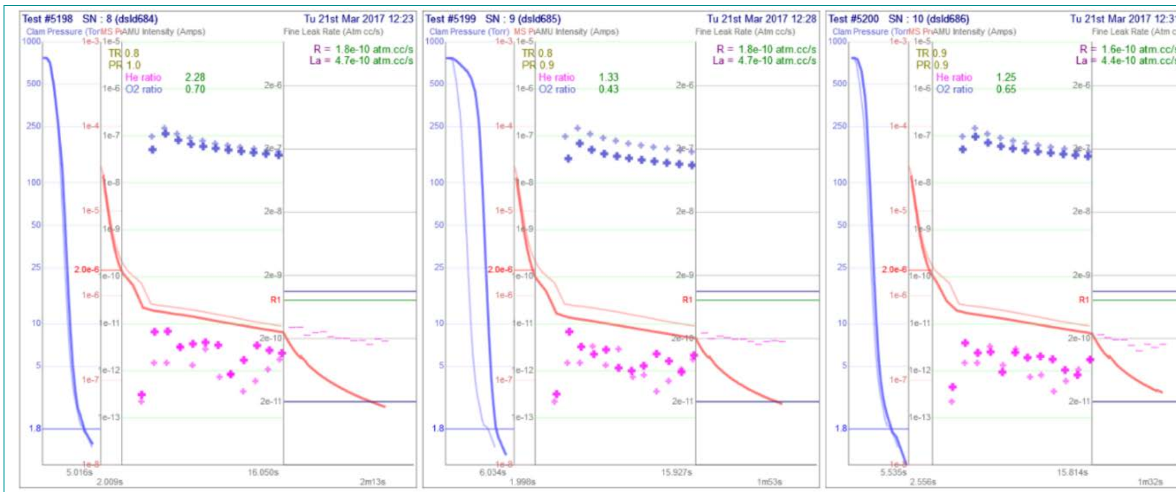


Figure 13

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.

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 14

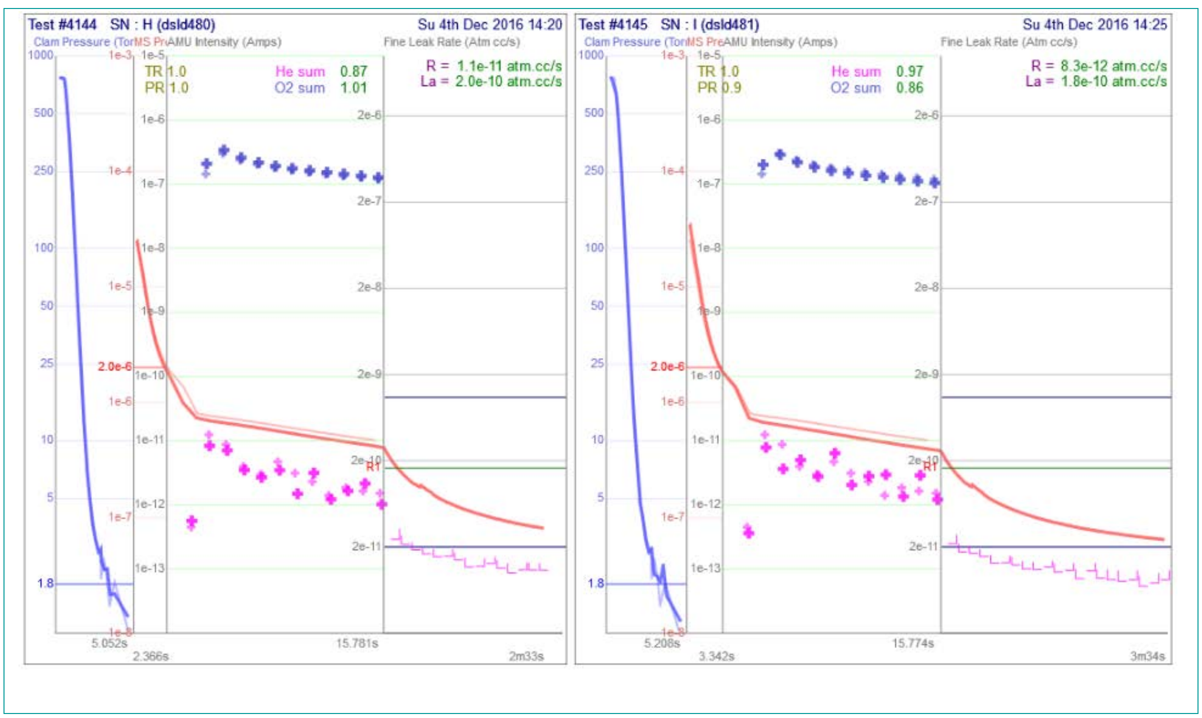


Figure 15

Power Hybrid Summary
2.2 cm³ Internal Volume

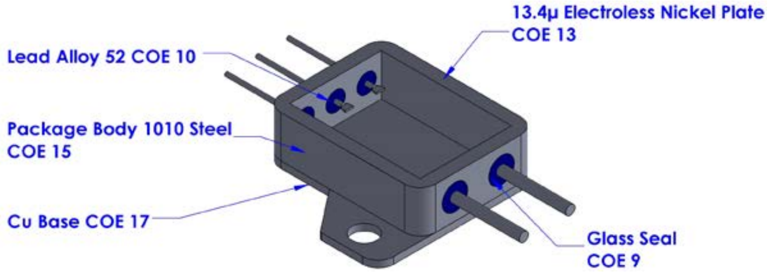


Figure 16

Photograph 7

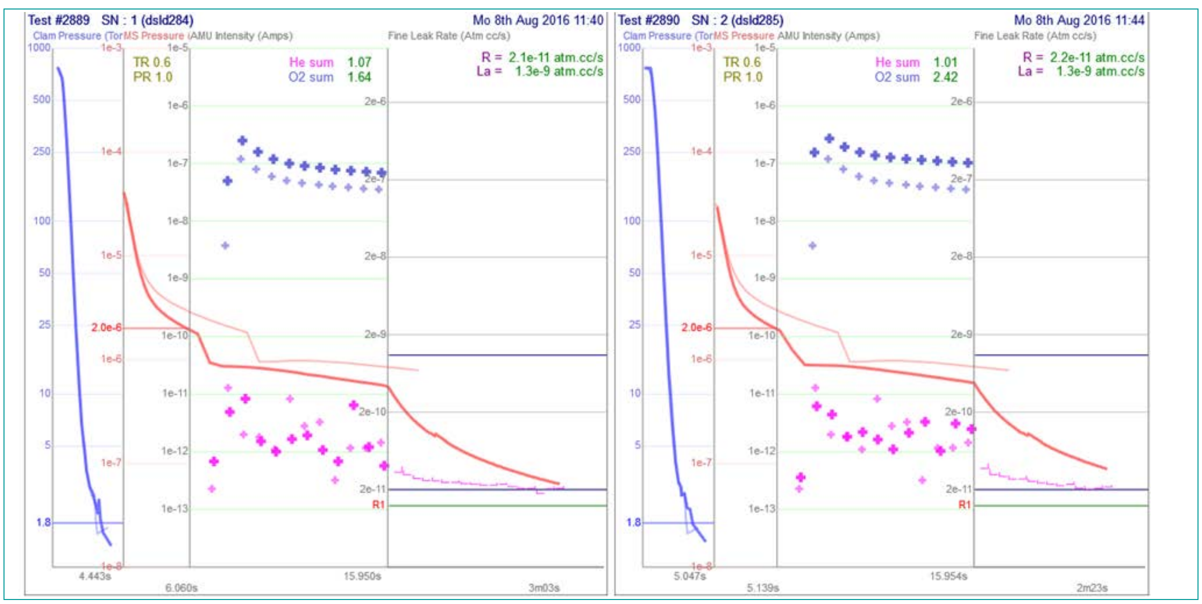
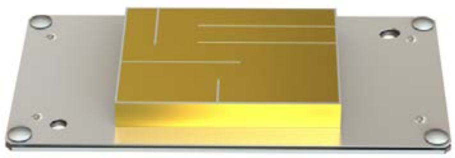


Figure 17

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 18

Microwave Hybrid
6.48 cm³ Internal Volume



Photograph 8

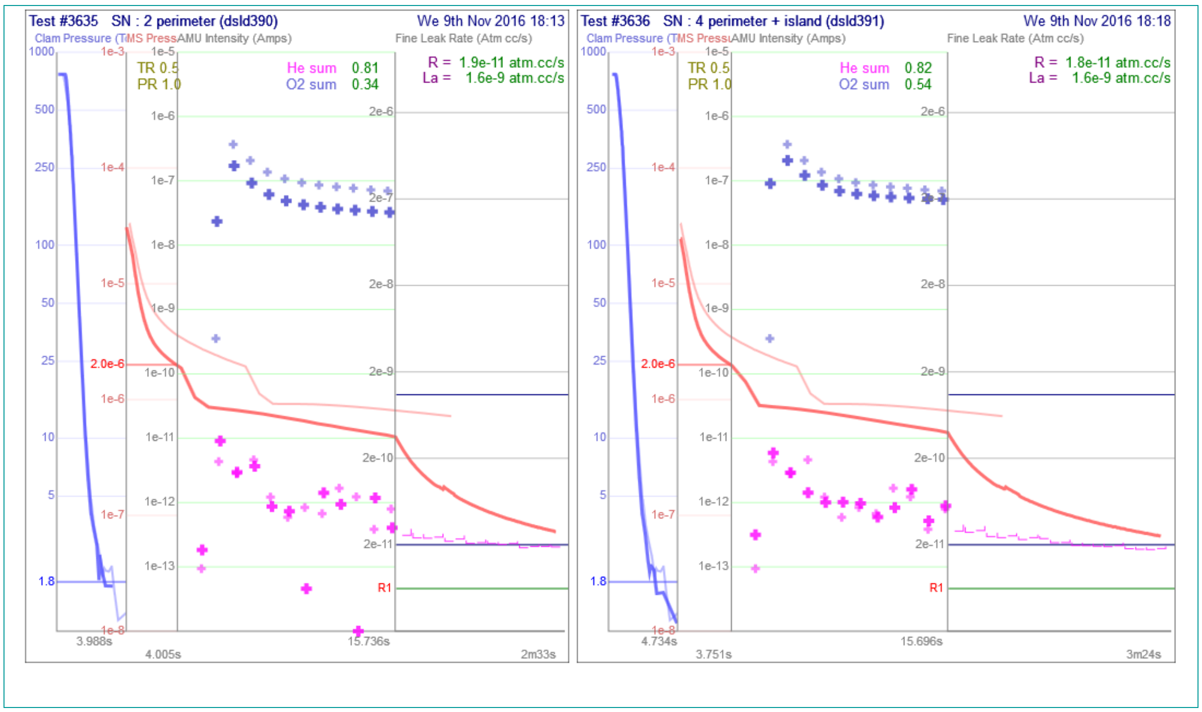


Figure 19

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 20

TO package sealing is performed by one-shot resistance welding. Short duration, high-energy electrical pulses are provided for localized heat in the welding zone with no heat build-up in the microelectronic package. This process enables control over the internal atmosphere and temperature of the device during the seal process. Materials are Grade A nickel, Kovar™ with either Au/Ni or Ni plate. Packages with glass feedthroughs through the bottom of the package are sealed in this method.

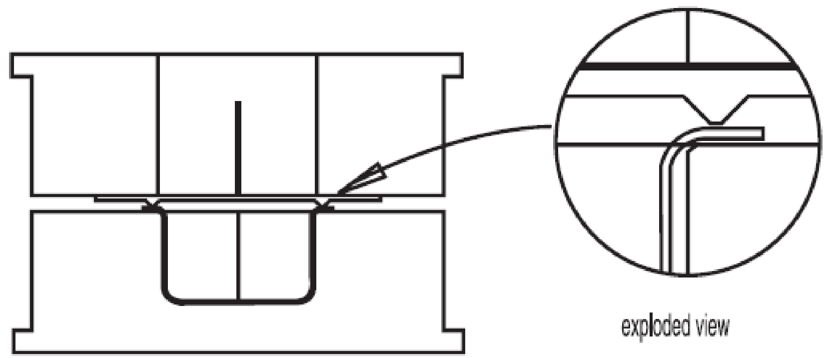
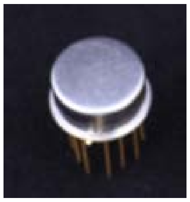


Figure 21: One Shot Welding Electrode/Package Cross Section

TO-8 with Grade A Nickel Cover
0.5 cm³ Internal Volume



Photograph 9

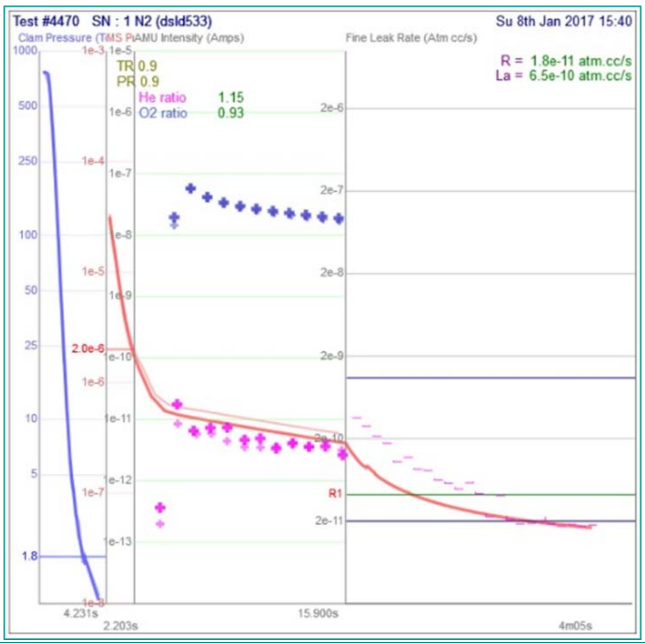
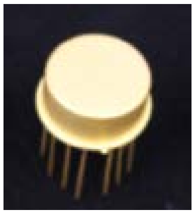


Figure 22

Feedthrough	Cover Plate	Volume cm³	Schedule	Leak Rate Mean	Std Dev	Time to Specification
Glass	Grade A Ni	0.5	1	6.5E-10 atm-cm³/sec **<u>Air</u>**	NA	9.2 Years

Figure 23

TO-8 with Au/Ni Plate Kovar Cover
0.5 cm³ Internal Volume



Photograph 10

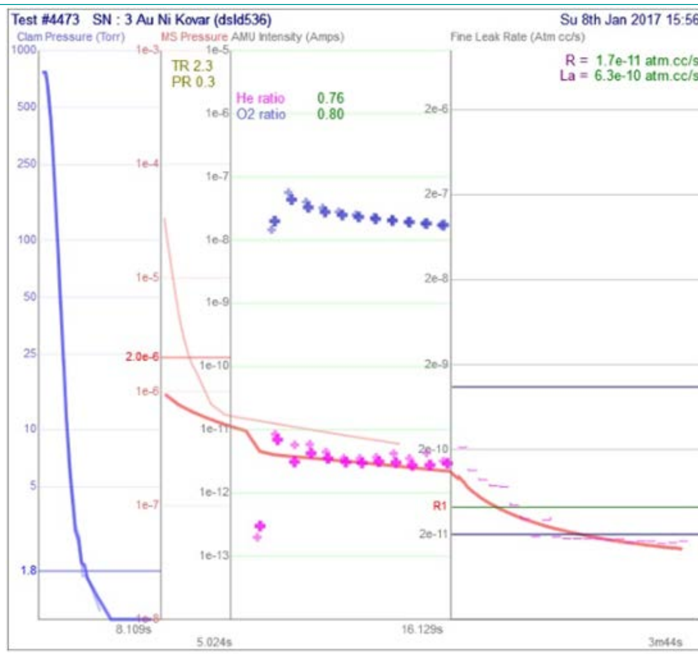
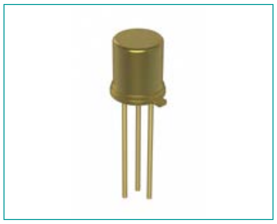


Figure 24

Feedthrough	Cover Plate	Volume cm³	Schedule	Leak Rate Mean	Std Dev	Time to Specification
Glass	Au/Ni Kovar	0.5	1	6.3E-10 atm-cm³/sec **Air**	NA	9.5 Years

Figure 25

TO-18 with Au/Ni Plate Kovar Cover
0.05 cm³ Internal Volume



Photograph 11

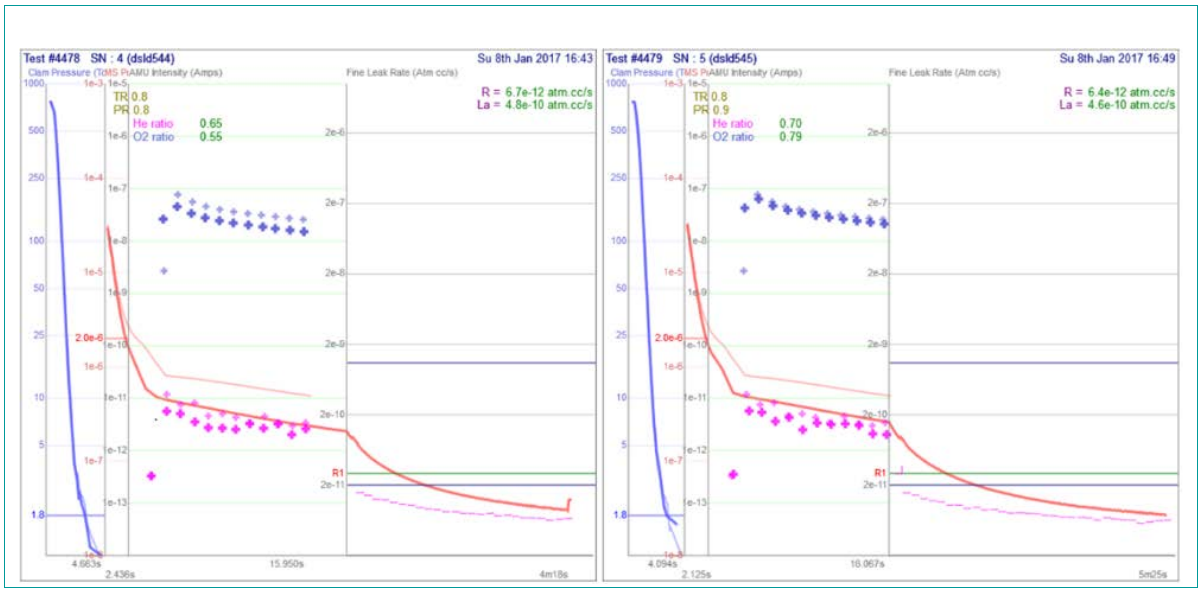


Figure 26

Feedthrough	Cover Plate	Volume cm³	Schedule	Leak Rate Mean	Std Dev	Time to Specification
Glass	Grade A Ni	0.5	1	4.8E-10 atm-cm³/sec **Air**	NA	1.27 Years

Figure 27

Conclusions

Utilizing existing parallel seam sealers and one-shot welders, a new seal processing technique can be utilized that eliminates gross leakers and provides ultrafine leak rates significantly lower than those required by the recently updated, most stringent leak standards.

Feedthrough	Package Type	Volume cm^3	Schedule	Leak Rate Mean	Time to Specification
None (Materials Lot 1)	Microwave	0.05	3	4.5E-10 atm-cm^3/sec **Air**	1.3 Years
None (Materials Lot 2)	Microwave	0.05	3	4.5E-10 atm-cm^3/sec **Air**	1.3 Years
None	Microwave	0.05	4	1.7E-10 atm-cm^3/sec **Air**	3.5 Years
Corning Glass	Microwave	0.05	4	4.4E-10 atm-cm^3/sec **Air**	1.3 Years
None	Microwave	0.05	5	1E-10 atm-cm^3/sec **Air**	5.9 Years
Corning Glass	Microwave	0.05	5	4.4E-10 atm-cm^3/sec **Air**	1.3 Years
None	Hybrid Flatpack	0.9	1	6.5E-10 atm-cm^3/sec **Air**	16.6 Years
None	Hybrid Flatpack	0.9	2	5.4E-10 atm-cm^3/sec **Air**	20 Years
None	Hybrid Flatpack	0.9	3	4.3E-10 atm-cm^3/sec **Air**	25 Years
None (Materials Lot 2)	Hybrid Flatpack	0.9	3	4.5E-10 atm-cm^3/sec **Air**	24 Years
Corning Glass	Hybrid Flatpack	0.9	3	6.2E-10 atm-cm^3/sec **Air**	17 Years
Corning Glass	Hybrid Flatpack	0.9	4	4.4E-10 atm-cm^3/sec **Air**	24.5 Years
None	Ceramic LCC	0.02	1	2.4E-10 atm-cm^3/sec **Air**	364 Days
None	Ceramic LCC	0.02	2	2.9E-10 atm-cm^3/sec **Air**	302 Days
None	Ceramic LCC	0.02	3	1.9E-10 atm-cm^3/sec **Air**	460 Days
None	Ceramic LCC	0.02	4	1.1E-10 atm-cm^3/sec **Air**	2.1 Years
Compressed Glass	Power Package	2.2	1	1.3E-10 atm-cm^3/sec **Air**	20 Years
None	Large Module	6.48	1	2.9E-10 atm-cm^3/sec **Air**	38 Years
None	Large Module	6.48	2	1.6E-10 atm-cm^3/sec **Air**	59 Years
One Shot Welding					
Glass	TO-8 (Grade A Ni)	0.5	1	6.5E-10 atm-cm^3/sec **Air**	9.2 Years
Glass	TO-8 (Kovar)	0.5	1	6.3E-10 atm-cm^3/sec **Air**	9.5 Years
Glass	TO-18 (Grade A Ni)	0.05	1	4.8E-10 atm-cm^3/sec **Air**	1.27 Years

Figure 28

The time to specification, after seal, of a hermetic package can be determined by the leak rate, the moisture sealed into the package at the time of seal, outgassing of materials into the sealed headspace, and external environment conditions of temperature and humidity. Excluding other factors, the leak rates using this new technique provided the longest time to specification.

Optimizing the internal atmosphere of an internal hermetic microelectronic package is the topic of future development from MCL.

Endnotes

1 Philip Schuessler. Outgassing species in optoelectronic packages. *International Journal of Microcircuits and Electronic Packaging*. Volume 24, Number 2 (ISSN 1063-1674).

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.

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VEECO PSP Model 2400e Parallel Seam Sealer, User Manual
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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.

About the Author

Rich Richardson is president of MicroCircuit Laboratories (MCL), which provides solutions for design, development and production, from pilot to HVM, of hermetic package seals with ultra-fine leak rates. Prior to MCL, Rich led Solid State Equipment Corporation for 28 years, where he developed expertise in processing and manufacturing solutions for compound semiconductor, photonics, advanced packaging, MEMS, microwave, power and semiconductor applications.