Recent Advances in Optical Leak Testing (OLT)

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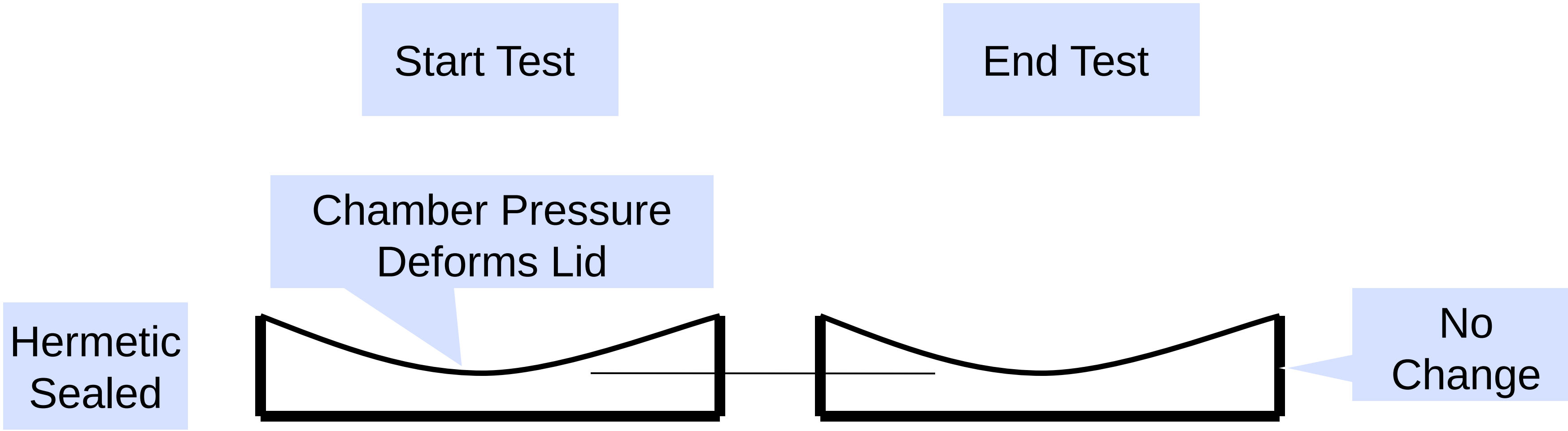
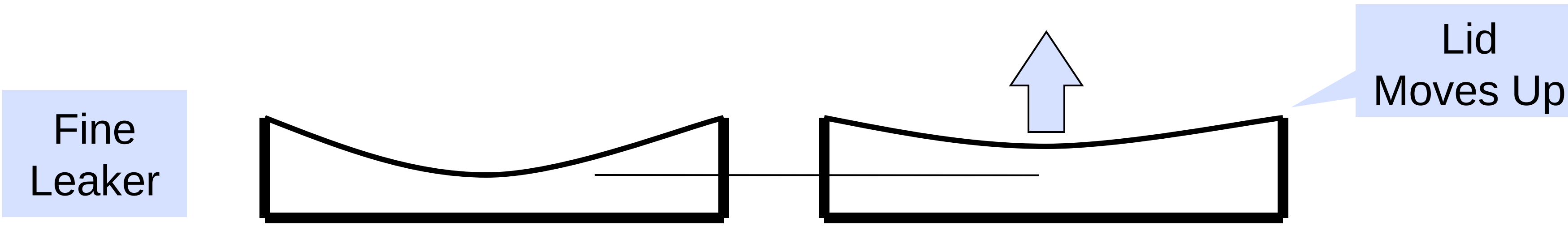
Theory of OLT (Optical Leak Test)



- Device lid deforms due to pressure increase in test chamber prior to start of test.

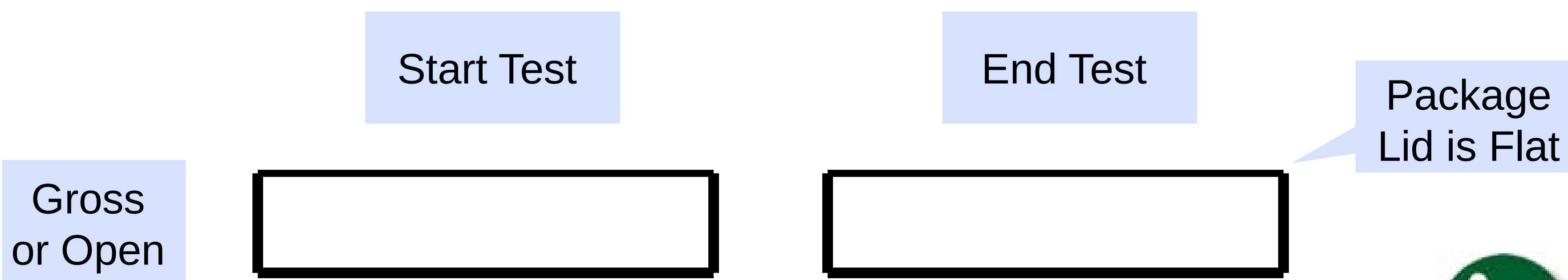
- Lid on hermetic device does not change throughout test.

Theory



• A fine leaker allows the test gas in during the test.

• Internal pressure in gross device will quickly equalize with chamber pressure and lid is flat.



Theory

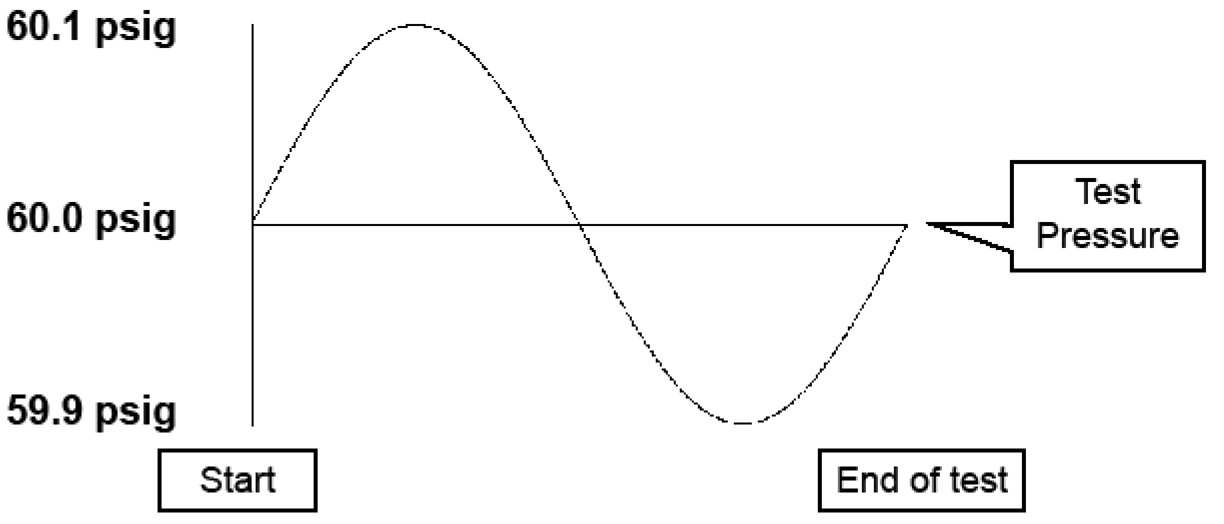
- Lids on hermetic and gross devices do not move during the test.

- Lids move during chamber pressurization prior to test.

- How to differentiate gross and hermetic?

- Pressure modulation allows measurement of lid stiffness.

Theory



• Pressure modulation for a butterfly package is small. ~ 0.1 psig.

• Hermetic butterfly package lid stiffness -1 um/psi.
• Gross ~ 0 um/psi.

Interference Fringes

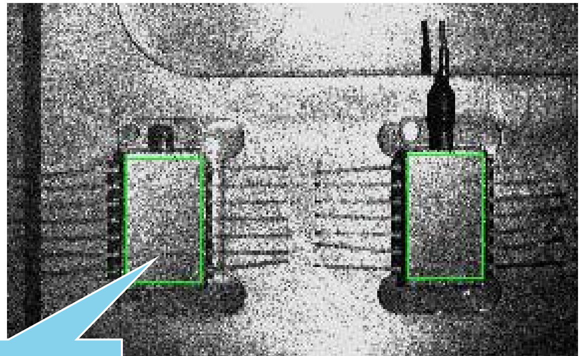
- Fringe is short for Interference Fringe.

- Definition by britannica.com.
- A bright or dark band caused by beams of light that are in phase or out of phase with one another. Light waves, when superimposed, will add their crests if they meet in the same phase. The troughs will cancel the crests if they are out of phase.

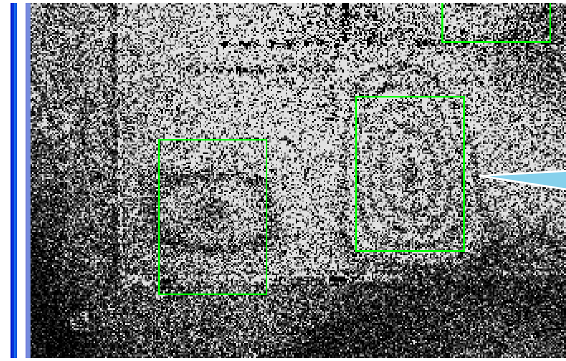
- Similar to dropping a pebble in water.

- No lid movement = no fringe pattern.

Interference Fringes



Normal Video



Subtracted Mode:
Object Beam – Reference Beam

- One fringe ring = 0.26um or ½ wavelength of 532nm laser source.

- Right view shows fringes due to subtracted mode and lid is moving due to internal pressure change.

Wafer Level MEMs Testing

Cavity size 5mm square. Presented last May at IMAPS.

Customers Want Smaller Electronics

- Cavity sizes dropping from 5mm to nearly 1 mm.

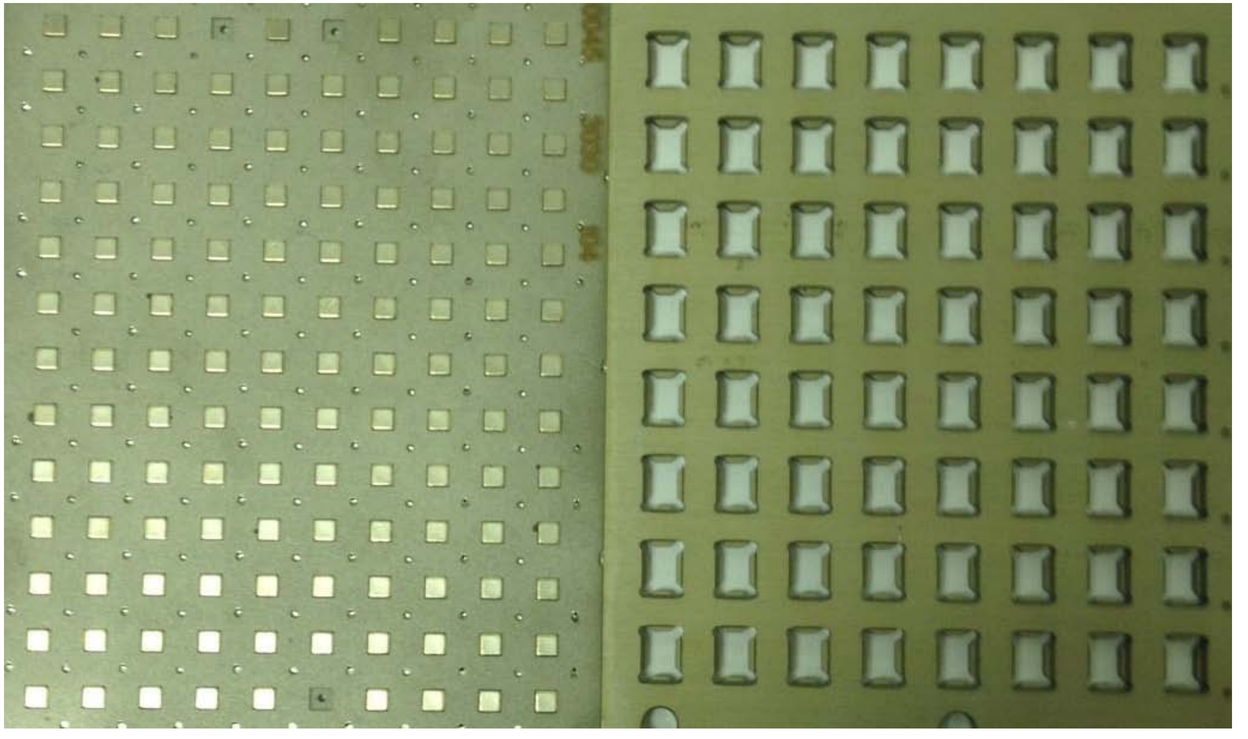
- Causes two problems.
  - Stiffer lids may be untestable.
  - Require magnification to see the devices.

- Implemented 3X magnification for 3mm cavity.

- Reduces area per camera from 6” square to 2”.

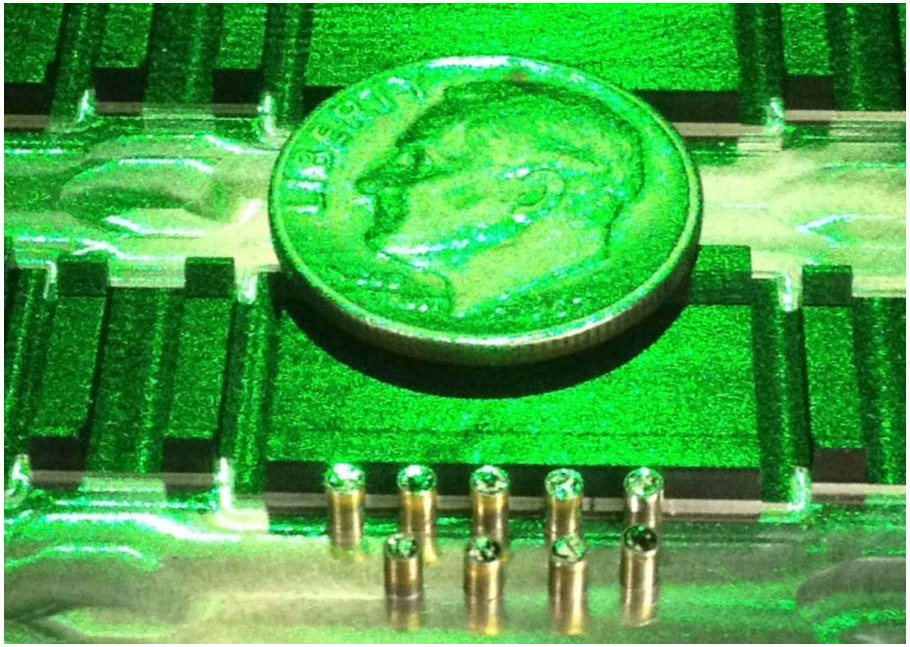
- Future development: Adjustable zoom to optimize throughput per device size.

3mm Square Cavity



3mm square vs. 5mm x 7mm

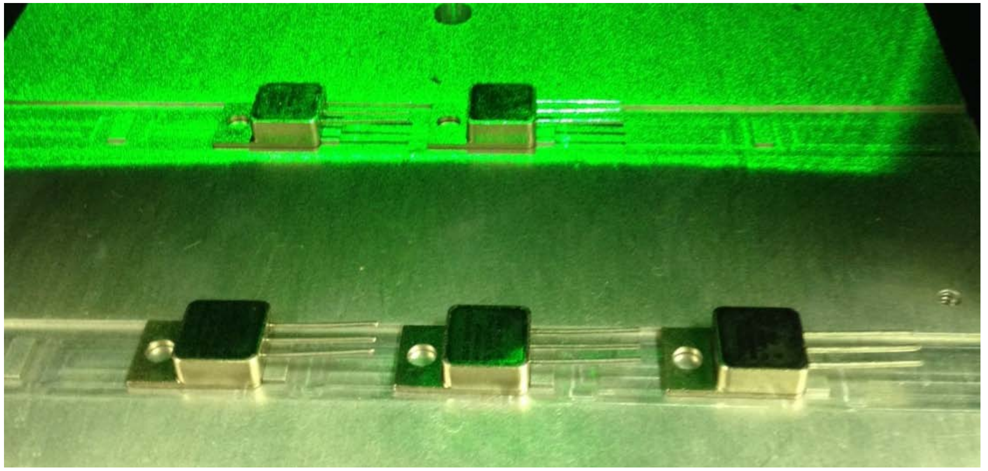
1.2mm Diameter Tube



- 1.2 mm diameter tube with 4 µm membrane.
- Required 6x magnification.

Thermal Effect on OLT

- Supplier “M” qualifying OLT to meet Class K.



Above TO-257 are similar to parts in study but not actual.

- Space level leak rate 5 x 10 $^{-9}$ L_{air} atm-cc/sec.
- Or ~ 6 x 10 $^{-11}$ R_1 atm-cc/sec with HMS
  - Per Table 1 Fixed Conditions A_1 MIL-STD-883

Qualification Plan

- 100% Pass with 52 minute test.

- 100% Passed the 520 minute test however most of the parts did not go to the test sensitivity of $< 5 \times 10^{-10}\ L_{air}$.

- All devices were known to meet $<5 \times 10^{-10}\ L_{air.}$

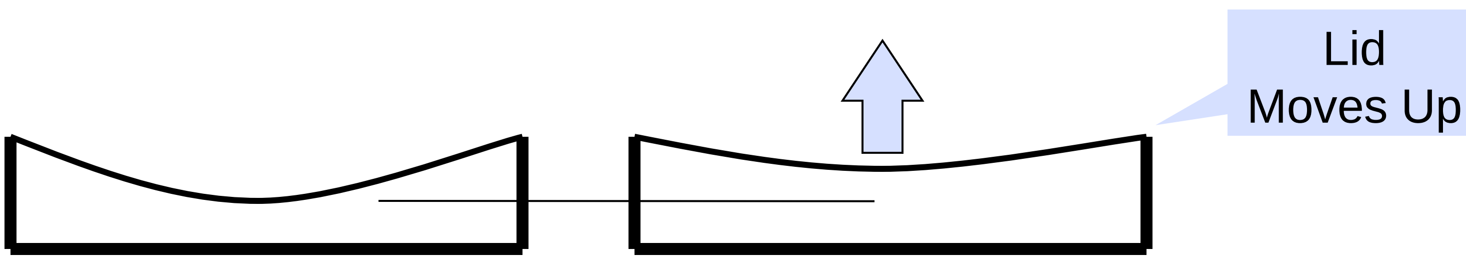
- A 3.2º C temperature increase caused the leak test readings to be larger than actual.

- Potential to fail good parts. At least fail safe.

Why is This Happening?

• Noticed the temperature increased 3.2º C over the 520 minute test.

• Could a temperature rise increase the internal pressure and cause the lid to move up?

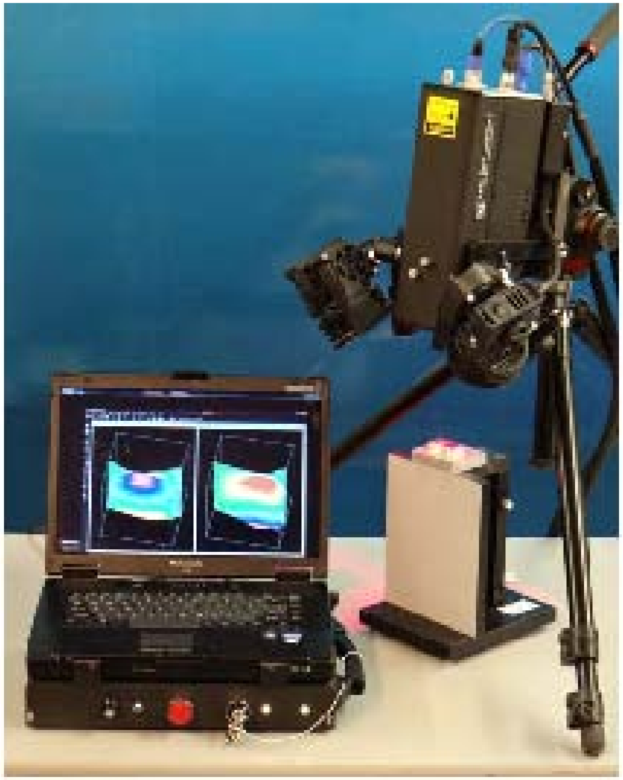


• Remember, a fine leaking device will have the lid rise up over the course of the test.

Ideal Gas Law

- Ideal Gas Law: $pV=nRT$.
- Solving for Temperature Compensation Factor (TCF) per Ideal Gas Law = 0.05 psi/ C.
- Recalculating the leak rate does not come close to < 5×10^{-10} L_{air}.
- Perform following experiment to understand full effects of temperature.

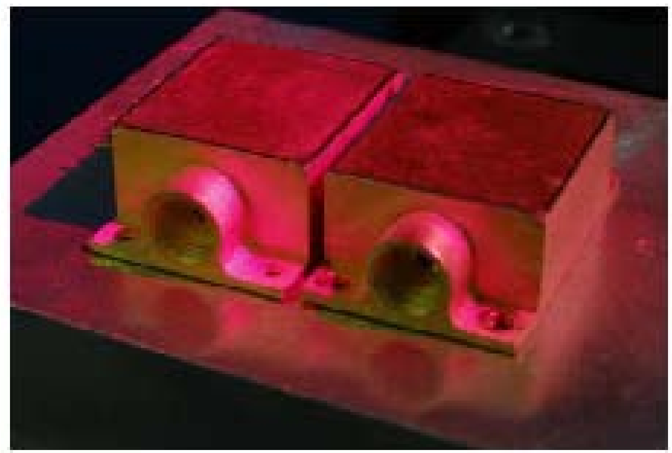
Experiment on Lid Deflection



Left: LTI-2100 shearography camera imaging two packages shown below.

Package lids measure 0.810x0.775 inches.

Packages heated with two 250W thermal lamps from 71° to 74°F.



- Laser shearography equipment shown above, like the holography camera in the OLT system, is another type of optical imaging interferometer capable of measuring Z-axis deformations.

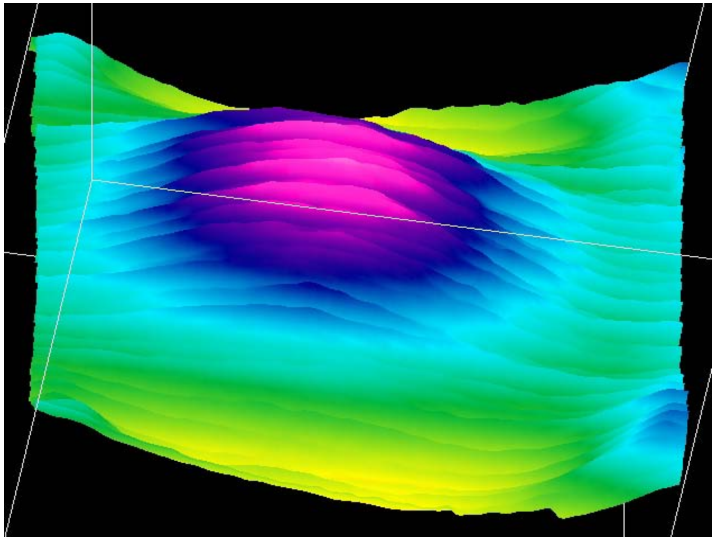
Experiment on Lid Deflection

- Two butterfly packages tested to < 8.5E-9 L_{He}.
- One packages vented by drilling open exit tube.
- Heated with two thermal lamps.
- Vented package deformed due to thermal mismatch between lid and different base material.
- Sealed package deformed due to increased gas pressure and thermal expansion of the lid.

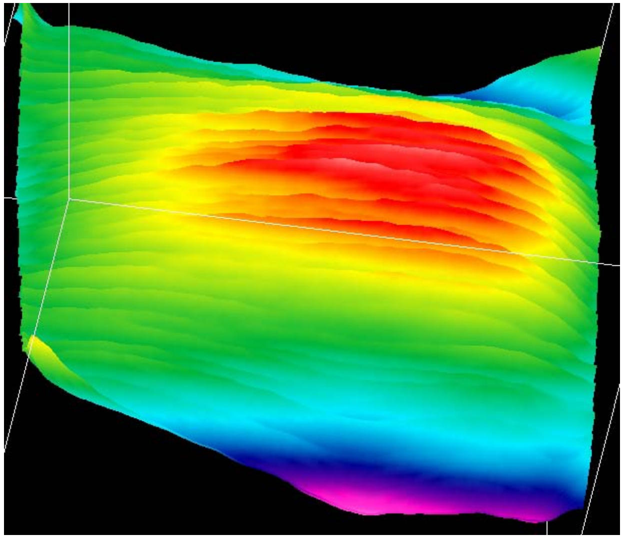
Experiment on Lid Deflection

- During repeated tests with a 3°F ΔT (1.67 C).
- Sealed package lid deformed by 0.21 µm.
- Vented package by 0.17 µm.

- Plots of lid deformation shown below.



Sealed Package ΔZ=0.21 µm



Vented Package ΔZ=0.17 µm

Experiment on Lid Deflection

• Sealed package lid deformation due to gas expansion ΔZ_{GE} , and thermal expansion ΔZ_{TE}.
• $\Delta Z_{GE} + \Delta Z_{TE} = 0.21$ µm.

• Vented package lid deformation to thermal exp.
• $\Delta Z_{TE} = 0.17$ µm.

• Solving for ΔZ_{GE}: $\Delta Z_{GE} + 0.17$ µm = 0.21 µm.
• $\Delta Z_{GE} = 0.04$ µm.

• Approx. 20% of lid deflection to gas expansion.
• Remaining 80% due to thermal expansion of the lid and package.

Revised Temp. Comp. Factor (TCF)

- Explains why using the TCF based solely on the Ideal Gas law is well short of the actual leak rate.

- Hermetic part has leakage of 0 or no lid deflection.

- Calculate TCF based on highest ΔP (leakage) will result in leak rate going to test sensitivity < 1.1E-09.

- TCF = 0.567 psi / 3.25 C = 0.174 psi / C.

- Ideal Gas Law TCF of 0.05 is 29% of 0.174 psi /C.

- Roughly matches % from experiment.

TCF built into Software

- Chamber heater now standard on 2020 only used during set-up.

- One time set-up for TCF for each part type with known good parts.

- In most cases a TCF is not needed for the tighter Class K test limits if the test time is < 1 hour.

- However to be safe, check all Class K parts and if not needed the system will automatically set TCF=0.

Presentation Contact

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TABLE VII in MIL-STD-883J

TABLE VII. Test limits for all fine leak methods. 1/ 2/

Internal Free Volume of package (cm^3)	L Failure Criteria atm-cm^3/sec (air) Hybrid Classes B and H, and Monolithic Classes B, S, Q and V	L Failure Criteria atm-cm^3/sec (air) Hybrid Classes S and K only
≤ 0.05	$5 X10^{-8}$	$1 X 10^{-9}$
>0.05 - ≤ 0.4	$1 X 10^{-7}$	$5 X 10^{-9}$
> 0.4	$1 X 10^{-6}$	$1 X 10^{-8}$

- **Flexible Method only method for HMS**
- **Fixed Method only if called by contract.**

TABLE I Fixed Conditions A1 (883J)

V Internal Free Volume of package (cm^3)	Bomb Condition — Hybrid Classes B and H and Monolithic Classes B, S, Q and V: Psia ±2 1/	t_1 Minimum exposure time (hrs)	t_2 Max Dwell time (hrs)	R1 Reject Limit (atm-cm^3/s) He	L Equivalent Leak rate (atm-cm^3/s) air	Bomb Condition — Hybrid Classes S and K only: Psia ±2 1/	t_1 Minimum exposure time (hrs)	t_2 Max Dwell time (hrs)	R1 Reject Limit (atm-cm^3/s) He	L Equivalent Leak rate (atm-cm^3/s) air
<0.05	75	5.0	1	3×10^{-8}	$\leq 5 \times 10^{-8}$	75	5	1	1.32×10^{-11}	$\leq 1 \times 10^{-9}$
	75	1.0		5×10^{-9}		90	5		1.60×10^{-11}	
	90	4.0		3×10^{-8}						
	90	1.0		5×10^{-9}						
≥0.05 <0.1	75	2.5	1	3×10^{-8}	$\leq 1 \times 10^{-7}$	75	2	1	6.58×10^{-11}	$\leq 5 \times 10^{-9}$
	75	0.5		5×10^{-9}		90	2		7.89×10^{-11}	
	90	2.0		3×10^{-8}						
	90	0.5		5×10^{-9}						
≥0.1 <0.4	60	12.0	1	3×10^{-8}		60	8	1	5.26×10^{-11}	
	60	2.0		5×10^{-9}		75	6		4.94×10^{-11}	
	75	9.5		3×10^{-8}						
	75	2.0		5×10^{-9}						
≥0.4 <1.0	30	1.0	1	3×10^{-8}	$\leq 1 \times 10^{-6}$	45	6	1	4.74×10^{-11}	$\leq 1 \times 10^{-8}$
	30	0.5		5×10^{-9}		60	4		4.21×10^{-11}	
	45	0.5		3×10^{-8}		75	3		3.95×10^{-11}	
	45	0.5		5×10^{-9}						
≥1.0 <5.0	30	3.0	1	3×10^{-8}		30	48	1	5.05×10^{-11}	
	30	0.5		5×10^{-9}		45	12		1.89×10^{-11}	
	45	2.0		3×10^{-8}		60	10		2.11×10^{-11}	
	45	0.5		5×10^{-9}						

Ideal Gas Law

- Ideal Gas Law: $pV=nRT$.

- Pressure and temperature at start is p1, T1.
- End of the test is p2, T2. Package volume does not change V, n, and R drop out:

$$\frac{p1}{T1} = \frac{p2}{T2}$$

- Assume p1 =1 atm, T1= 295.15 Kelvin (72 F).
- To get ΔT= 1 C, T2= 296.15 Kelvin

- Solving for p2 get Temperature Compensation factor per Ideal Gas Law = 0.05 psi/ C.

- **OLT can test to the ‘11’s L_{air} or ‘14’s R_1**

- Recent test on wafer level device.
  - 24 hours, 64 psig, 0.01 cc.
  - stiffness -0.05 um/psi.

  - L_{He} = 1.04 x 10^{-10} cc-atm/sec (actual)
  - L_{air} = 3.87 x 10^{-11} cc-atm/sec (calculated)
  - R_1 = 3.93 x 10^{-14} cc-atm/sec (calculated)

NorCom SYSTEMS, INC.