Meeting the MIL-STD Space Level Hermetic Test Requirements with Optical Leak Testing (OLT)

CSME Conference

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Candidate Technologies for Hermetic Inspection to Current MIL-STD 750 and MIL-STD 883 Space Level Leak Rates

- Helium Mass Spectrometry, HMS (Fine only)
- Bubble Leak testing (Gross only)
- Optical Leak Testing, OLT (Fine and Gross)
- High Sensitivity Helium Leak Detection System, HSHLD (Fine and Gross)
- Krypton (85 Fine and Dry or Wet Test Gross)
- Cumulative Helium Leak Detection (Fine and Gross)

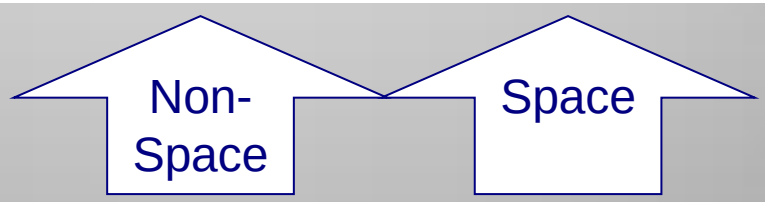
Non-Space vs Space Reject limits

MIL-STD-883K

3. FAILURE CRITERIA. Unless otherwise specified, any device tested for Fine Leak that exhibits a leakage rate equal to or greater than the test limits of table VII shall be considered a failure.

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



- Space reject limits about 100X to 50X smaller.
- OLT usually tests space limits in 0.3 to 3 hours.
  - HMS usually requires 100 to 200 hours of bomb time

HMS not Practical for Space Limits

TABLE I. Fixed conditions for condition A_1.

V Internal Free Volume of package (cm^3)	Bomb Condition Hybrid Class H and Monolithic Classes B, Q, S and V					Bomb Condition Hybrid Class K				
	Psia ±2 1/	t_1 Minimum exposure time (hrs)	t_2 Max Dwell time (hrs) 2/	**R1** Reject Limit ($atm\text{-}cm^3/s$) **He**	**L** Equivalent Leak rate ($atm\text{-}cm^3/s$) **air**	**Psia** ±2 1/	t_1 Minimum exposure time (hrs)	t_2 Max Dwell time (hrs) 2/	**R1** Reject Limit ($atm\text{-}cm^3/s$) **He**	**L** Equivalent Leak rate ($atm\text{-}cm^3/s$) **air**
>0.4 ≤1.0	30	0.5	1	2.6×10^{-8}		30	2.0	1	1.1×10^{-11}	
	30	1.0		5.2×10^{-8}		30	9.5		5.0×10^{-11}	
	45	0.5		3.9×10^{-8}		45	1.5		1.2×10^{-11}	
	45	1.0		7.8×10^{-8}		45	6.5		5.1×10^{-11}	
>1.0 ≤5.0	30	0.5	1	5.3×10^{-9}		30	9.5	1	1.0×10^{-11}	
	30	3.0		3.1×10^{-8}		30	47.5		5.0×10^{-11}	
	45	0.5		7.9×10^{-9}		45	6.5		1.0×10^{-11}	
	45	2.0		3.1×10^{-8}	$\leq 1 \times 10^{-6}$	45	32.0		5.1×10^{-11}	$\leq 1 \times 10^{-8}$

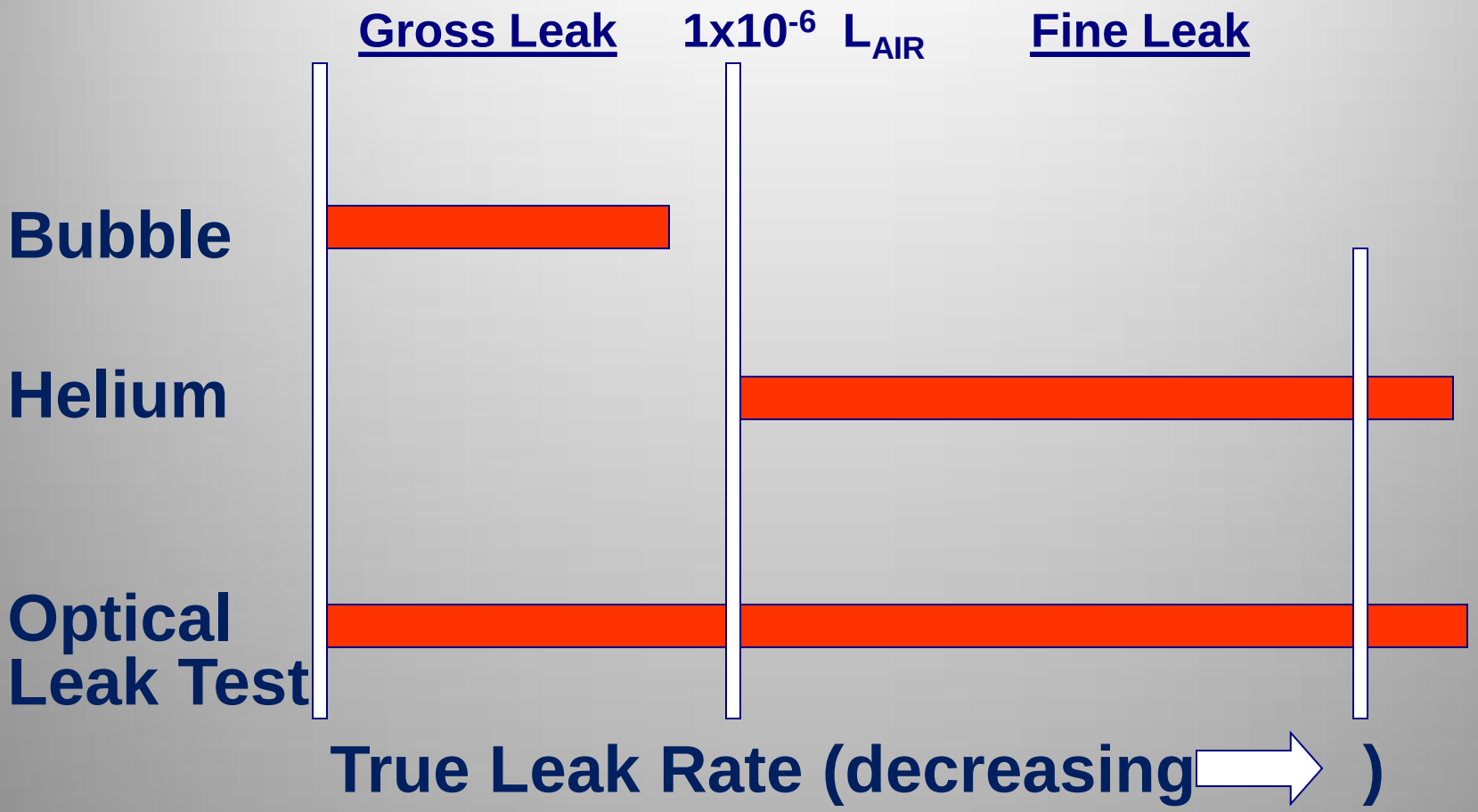
- Above table for HMS, A_1 , fixed conditions MIL-STD-883K.

- Why does Class K, go to 1e-11 R, when Class H to 1e-9 R?
- Most HMS systems typically can only sense 1e-9 R.
- If 1e-9 R was used for Class K, Space Levels, then t_1 exposure time would be 100 to 200 hours.

Technical Issues with HMS and Bubble Leak Testing to Class K Space Limits

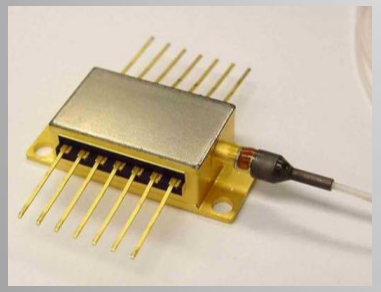
- Long helium bomb cycle times, usually 100 plus hours.
- Two helium bomb cycles.
  - One for HMS, another for bubble leak testing.
- HMS can not test at the board level.
- Gap in test coverage in the $1x10^{-5}$ cc-atm/sec range.
- Helium absorption by package causes false failures.
  - Typical problem with fiber optic cables attached.
- Product contamination by fluids during bubble testing.
- Bubble leak testing very operator dependent.
  - Possible to miss bubbles in a large tank, so leaking devices can escape.

Gap in Coverage with HMS



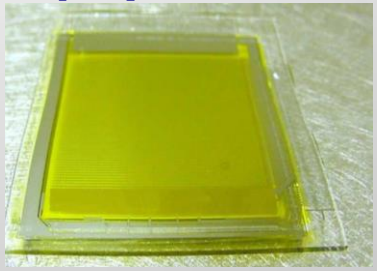
Typical Hermetic Package Styles

Butterflies

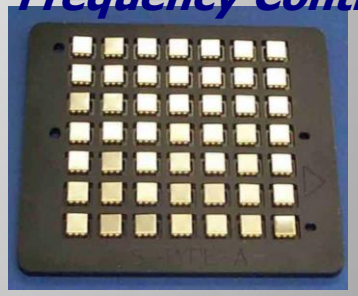


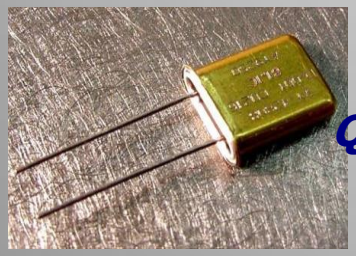
Pacemakers

Display Devices

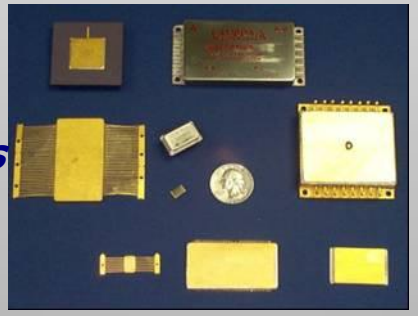


Frequency Control

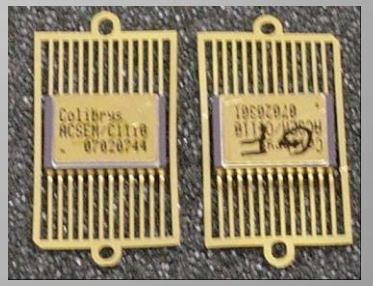




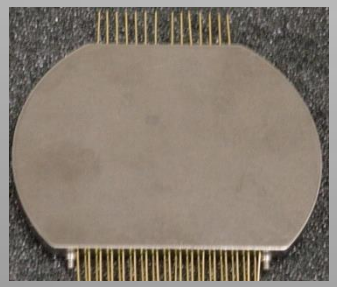
Quartz Crystals



Hybrids

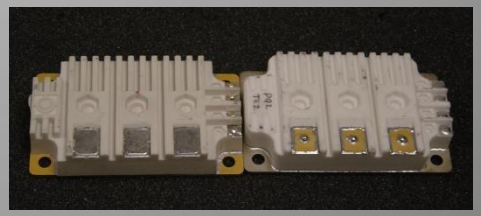


Fiber Optics



Custom

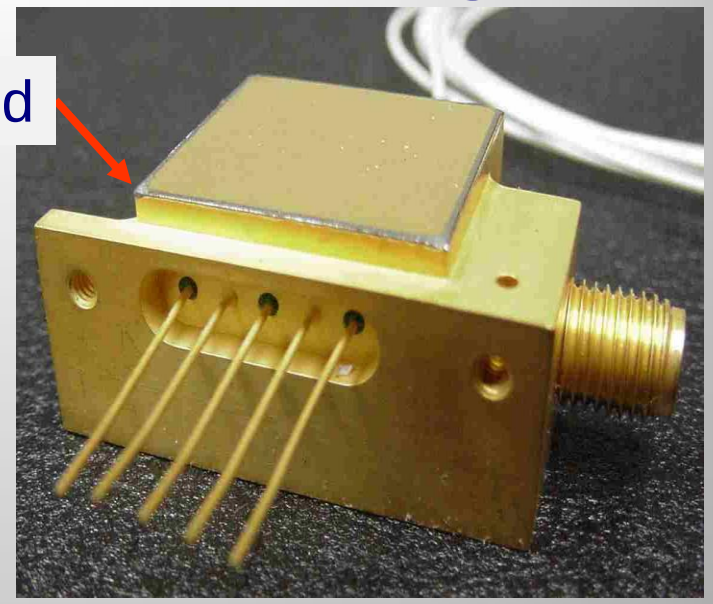
TO Styles

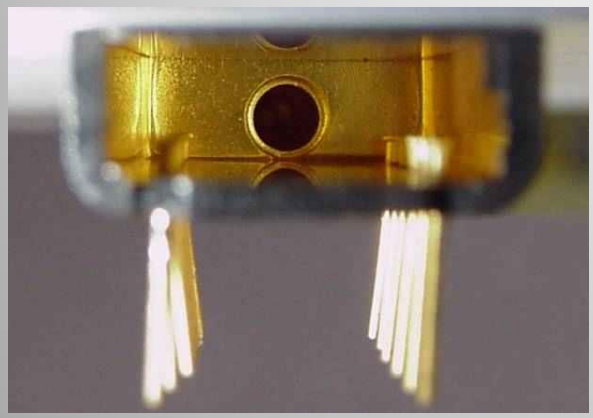


Power Devices

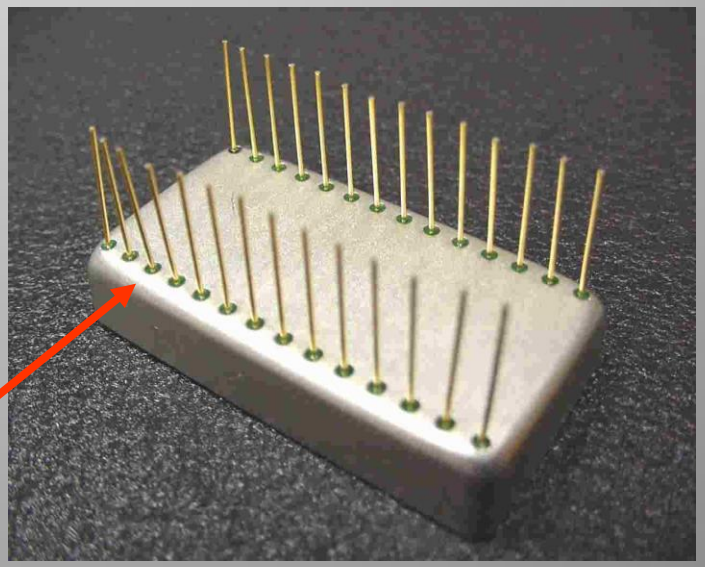
Sources of Leaks in Packages

Along the weld





A defect in the lid
or housing



At the glass to metal
feed through

Optical Leak Test

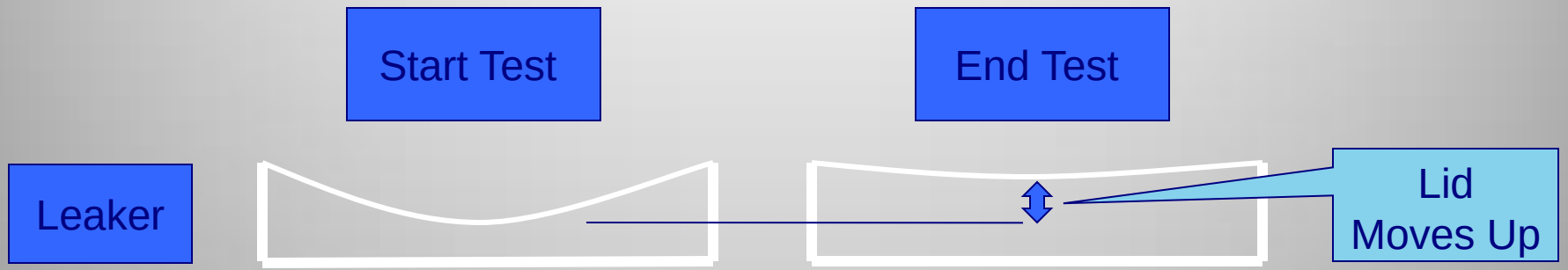
- Uses a phased stepped holographic interferometer to monitor the package lid deflection under pressure and determines how much a package is leaking
- Allows gross and fine leak inspection in one test
- Results in shorter test times by eliminating Helium bombing cycle
- Batch inspection on up to 500 devices in one test

Optical Leak Test
continued

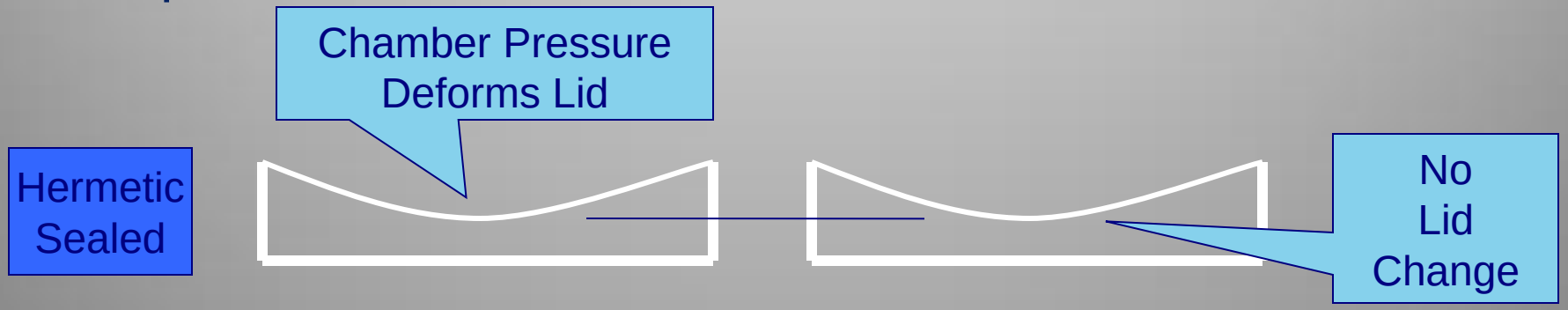
- Outputs results in L_{air} or L_{He} cc-atm/sec.
  - Reject limits in MIL-STD-883K are L_{air}
  - OLT directly measures in L_{air}.
- Tests packages mounted to a circuit board or substrate

Theory Leaking vs Hermetic

- Side view of package.
- Chamber pressure causes lid to bow down “ ”.

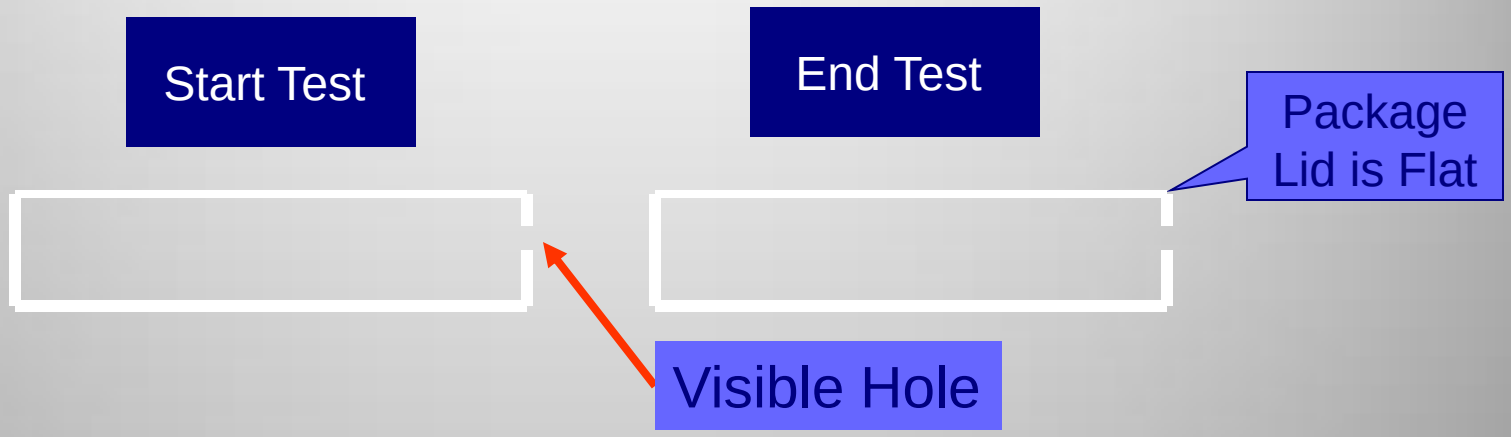


- Test gas rushes in on a leaking package to push lid up.

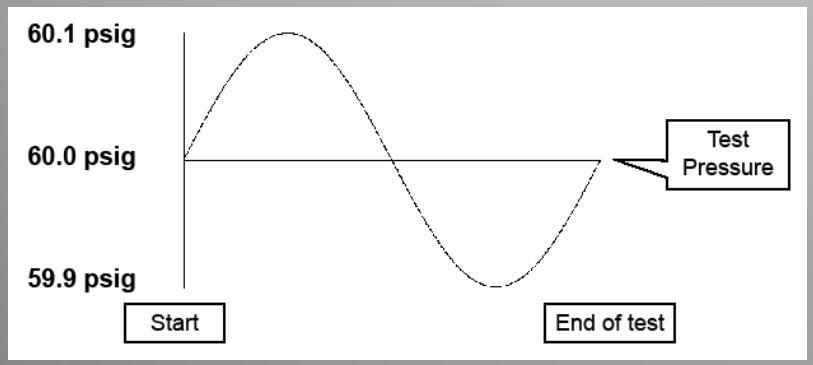


- Test gas can not get into sealed package to move lid.

Theory with Visible Hole



- Test gas rushes in through visible hole so lid stays flat.
- Add pressure modulation to measure spring rate of lid.
- Above lid stiffness is 0 um/psi. Hermetic > -0.02 um/psi.



- Typical pressure modulation for butterfly package with lid stiffness – 1um/psi.

Interference Fringes

- Fringe is short for Interference Fringe.
- Definition by britannica.com.
  - A bright or dark band caused by beams of light in phase or out of phase. Light waves will add their crests if they meet in the same phase (bright band). The troughs will cancel the crests if they are out of phase (dark band).
- Similar to dropping a pebble in water.

Convert with software

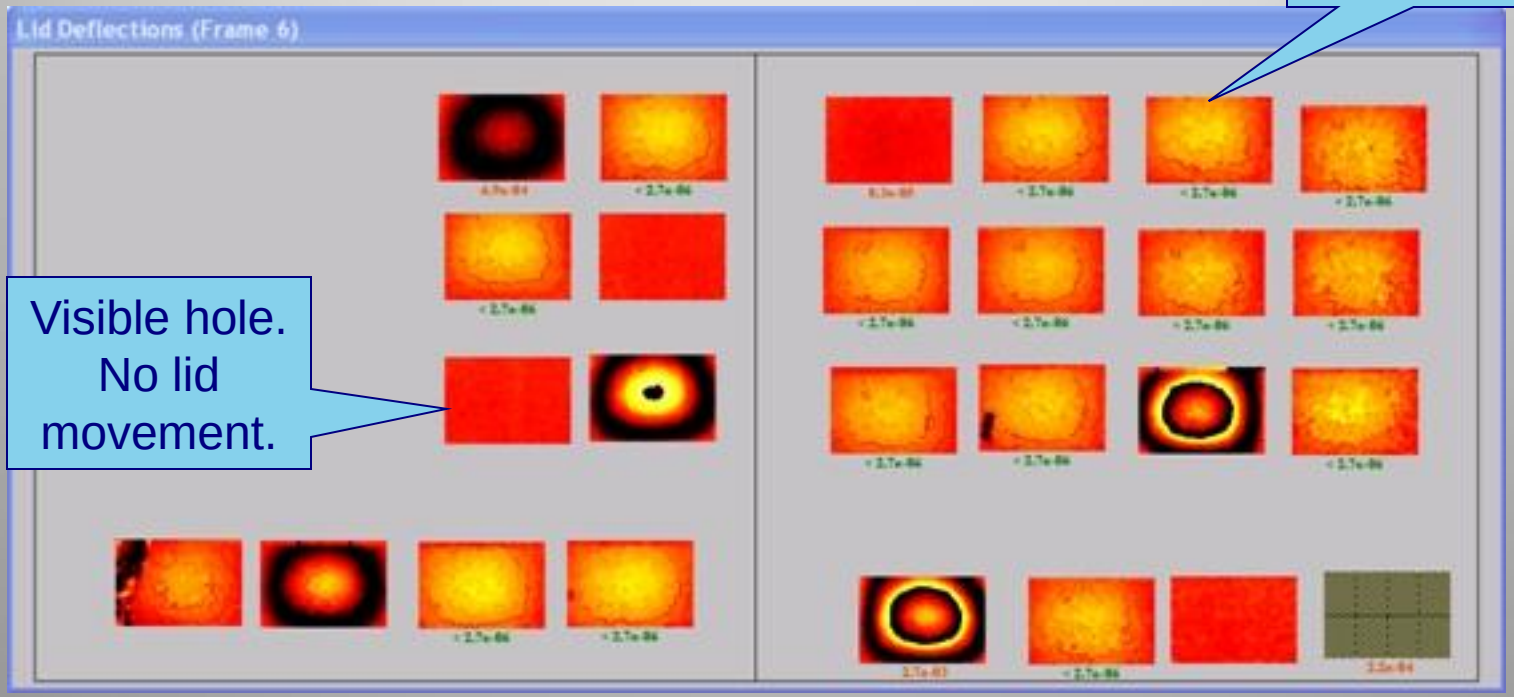
Live video fringe of package with changing pressure

Phase map showing fringes on leaking device

Laser Interferometer Phase Maps

•Phase maps taken every 6 seconds or so throughout leak test.

Hermetic: only one fringe

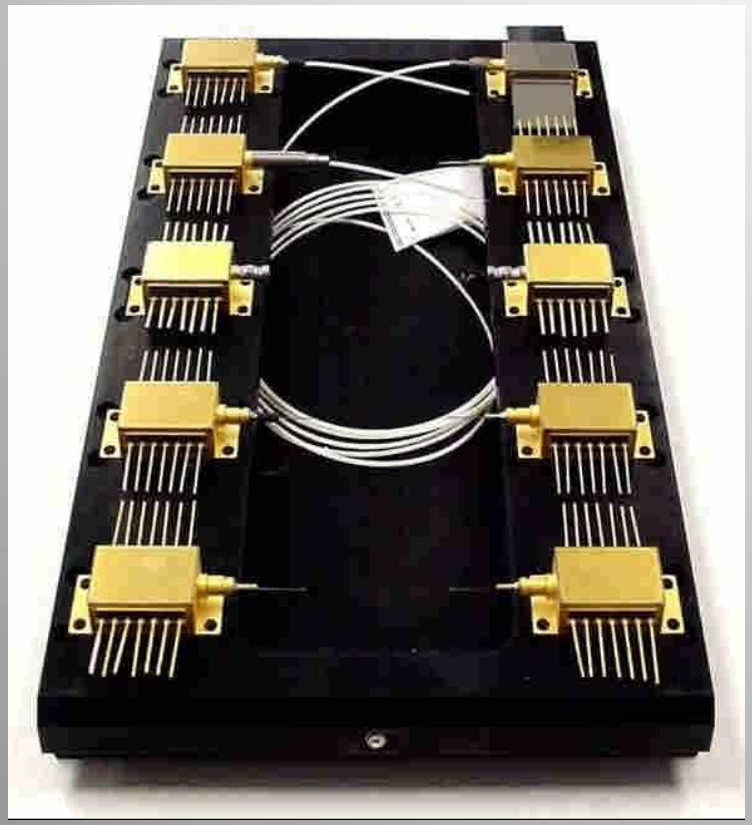


Visible hole. No lid movement.

Leaker: Many fringes indicate lid moving up.

1 fringe = 0.26 um
= ½ wavelength of light

System Operation



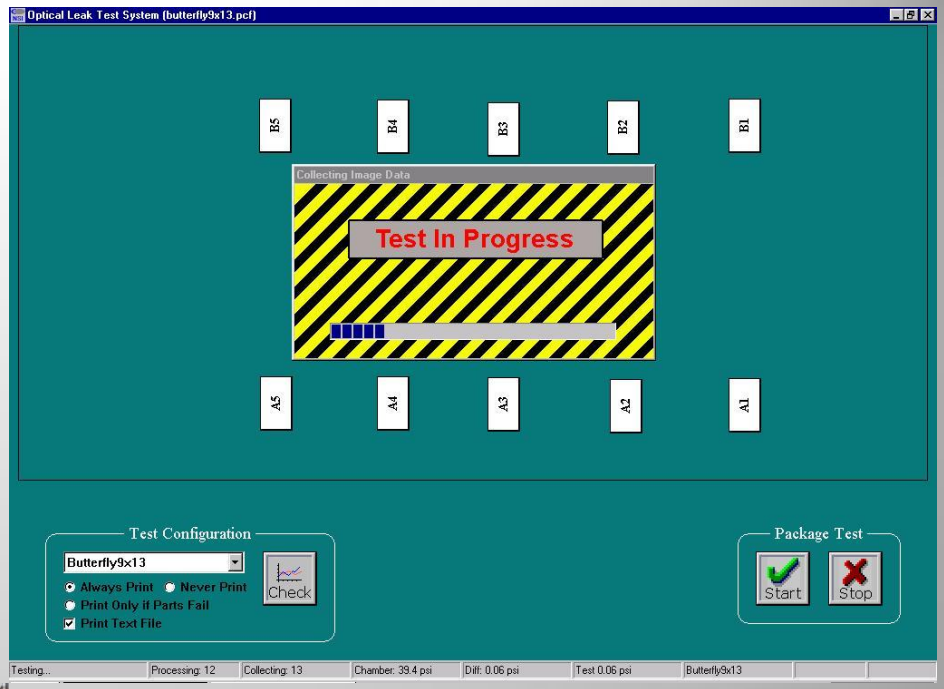
Butterfly devices with fiber optics in tray

Operator places tray into system and closes chamber door.

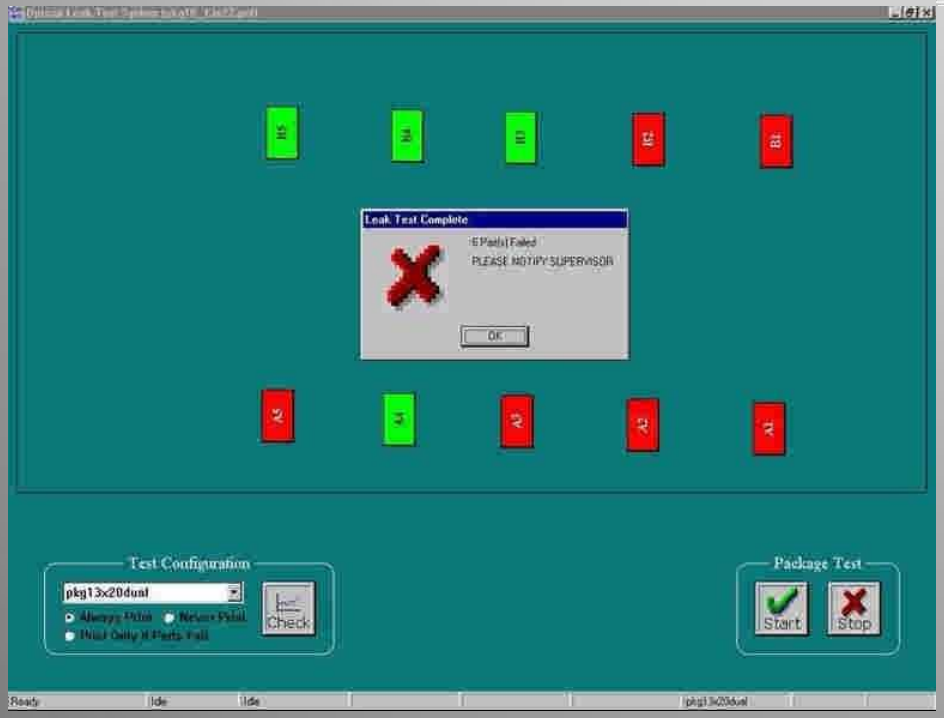
Test Results

Shows 6 failing and 4 passing packages.

After Test



During Test



Test Report

System ID:	LEAKTEST628-PC		
Software:	LeakTest (20.1.0.0)		
Config:	Butterfly1.pcf		
File Name:	20170214_0956_Butterfly1.txt		
Test Date:	2/14/2017		
Test Time:	9:56:53		
Package:	Butterfly1		
Duration:	5	min	
Pressure:	30.002	psi	
Modulation:	0.13	psi	
Stiffness:	-1	um/psi	
Volume:	1	cc	
Sensitivity:	8.67E-07		atm-cc/sec
Crit Leak:	1.00E-06		atm-cc/sec

ID	Status	Leakage psi	Stiff um/psi	Lair Leak Rate atm-cc/sec	S/N
A01	Fail	0.001	-0.797	< 1.0e-06	B7
A02	Fail	2.345	-0.012	Gross	B8
A03	Fail	10.678	-0.794	4.51E-04	B9
A04	Pass	0.002	-0.791	< 1.0e-06	B22
A05	Fail	1.192	-0.842	8.30E-05	B6
B01	Fail	20.946	-0.703	2.50E-03	902
B02	Fail	1.257	-0.022	Gross	B10
B03	Pass	0.004	-0.865	< 1.0e-06	123
B04	Pass	0.001	-0.927	< 1.0e-06	B1
B05	Pass	0.011	-0.830	< 1.0e-06	B5

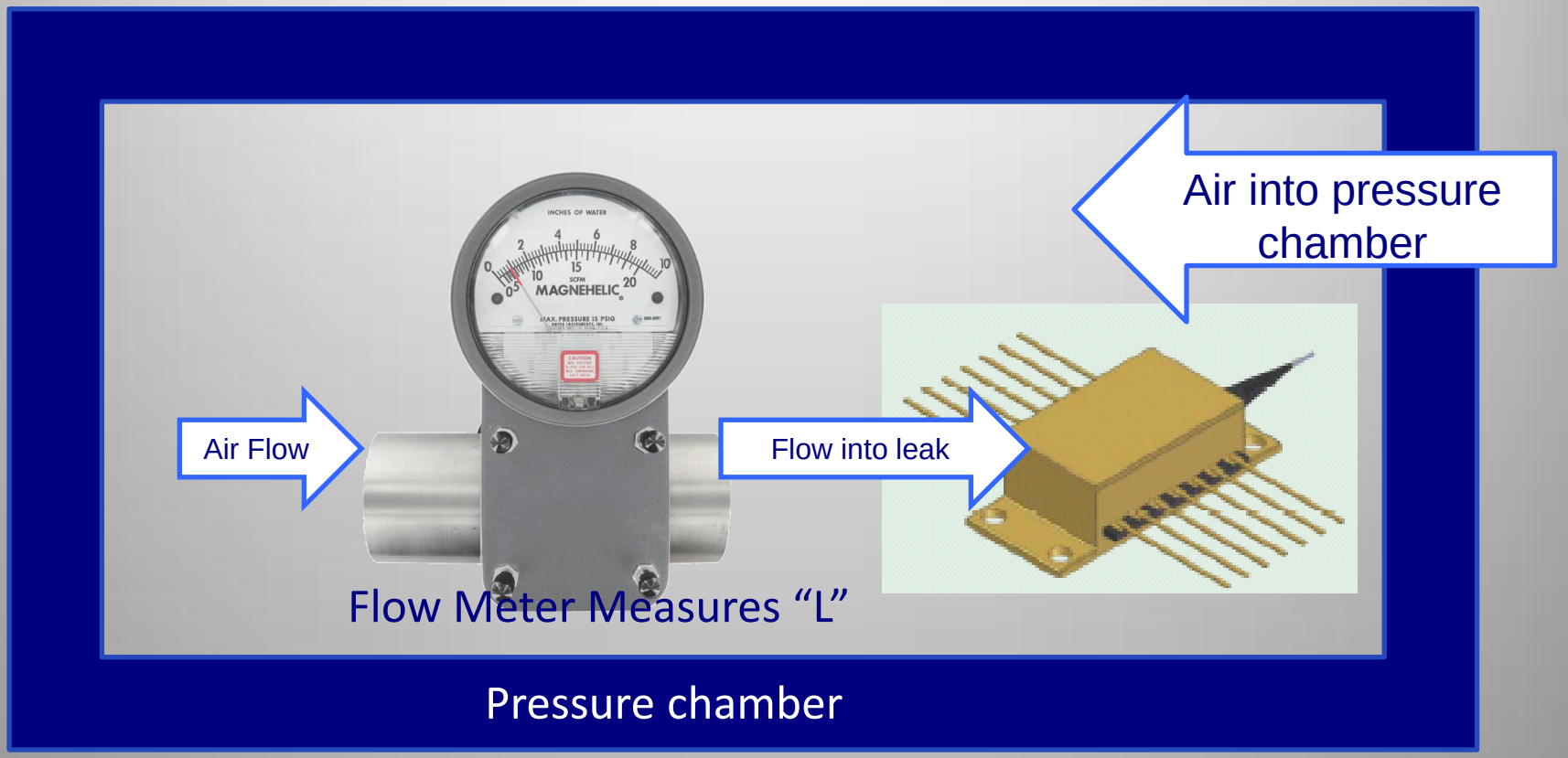
Pressure and Time

Status

Leak Rate

Serial #

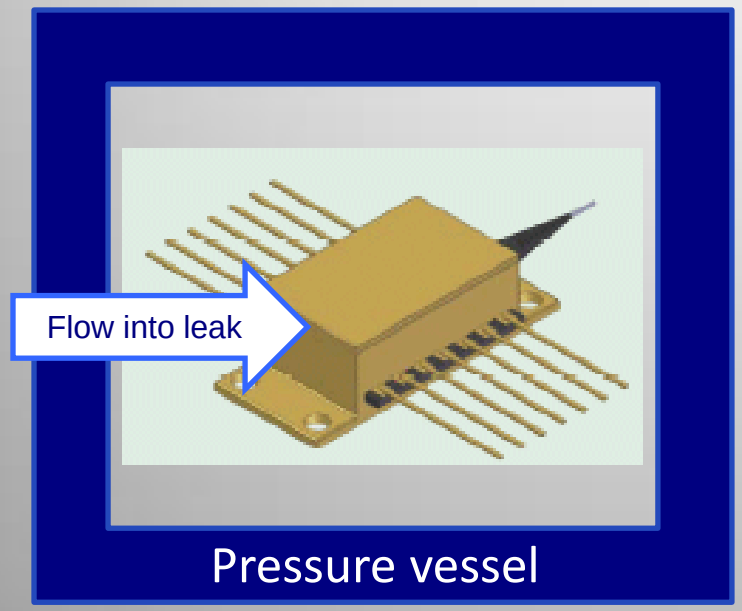
True Leak Rate “L” by OLT



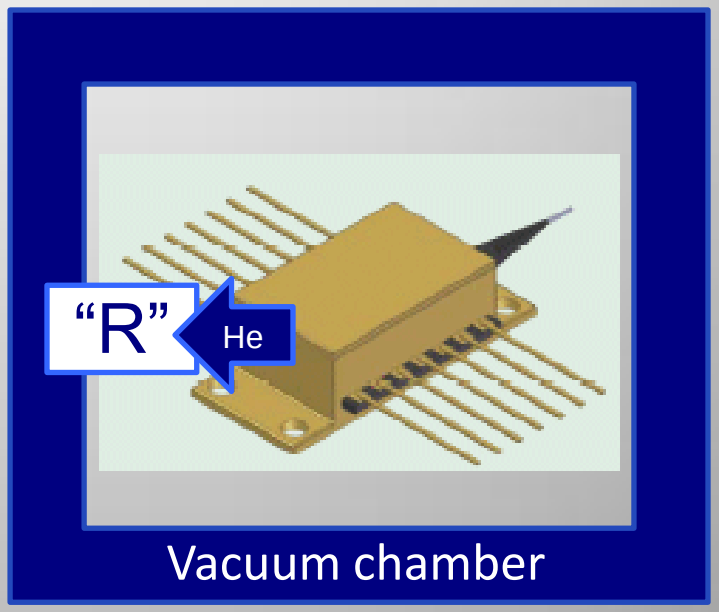
- Assume a flow meter inside a pressure chamber with a hose hooked up to a leak on the weld on the lid.
- The flow meter would measure “L” or true leak rate as OLT (optical leak testing) does.

Tracer Gas Leak Rate “R” by HMS

Step 1: Bomb with helium



Step 2: Measure helium escaping



- Bomb package with helium for many hours.
- Move package to vacuum chamber with proper sensor to measure “R”.

R versus L Type of Leak Rate

TABLE I. Fixed conditions for condition A_1.

V Internal Free Volume of package (cm^3)	Bomb Condition Hybrid Class H and Monolithic Classes B, Q, S and V					Bomb Condition Hybrid Class K				
	Psia ±2 1/	t_1 Minimum exposure time (hrs)	t_2 Max Dwell time (hrs) 2/	**R1** Reject Limit ($atm\text{-}cm^3/s$) **He**	**L** Equivalent Leak rate ($atm\text{-}cm^3/s$) **air**	**Psia** ±2 1/	t_1 Minimum exposure time (hrs)	t_2 Max Dwell time (hrs) 2/	**R1** Reject Limit ($atm\text{-}cm^3/s$) **He**	**L** Equivalent Leak rate ($atm\text{-}cm^3/s$) **air**
>0.4 ≤1.0	30	0.5	1	2.6×10^{-8}		30	2.0	1	1.1×10^{-11}	
	30	1.0		5.2×10^{-8}		30	9.5		5.0×10^{-11}	
	45	0.5		3.9×10^{-8}		45	1.5		1.2×10^{-11}	
	45	1.0		7.8×10^{-8}		45	6.5		5.1×10^{-11}	
>1.0 ≤5.0	30	0.5	1	5.3×10^{-9}		30	9.5	1	1.0×10^{-11}	
	30	3.0		3.1×10^{-8}		30	47.5		5.0×10^{-11}	
	45	0.5		7.9×10^{-9}		45	6.5		1.0×10^{-11}	
	45	2.0		3.1×10^{-8}	≤1 X 10^{-6}	45	32.0		5.1×10^{-11}	≤1 X 10^{-8}

100 X

1,000 X

- Above useful to show difference between R & L.
- Shows R_1 or tracer gas leak rate for HMS.
  - is 100 to 1,000 smaller.
  - than L or true leak rate for OLT.

OLT Measures Directly in L_{air}

•Table VII in MIL-STD-883K is proper table for reject limits, which are in L_{air} .

• HMS uses Howl Mann equation to convert R to L.

• OLT can directly measure L_{air} with air.

• L_{air} is more useful in calculating exchange rates for turnover of internal atmosphere.

- Aids calculation of reject limit for specific application.

- While R and L_{he} both use helium
  - and have the same units: atm-cc/sec
    R is 100 to 1,000 bigger for the same flow rate.

OLT Test Sensitivity

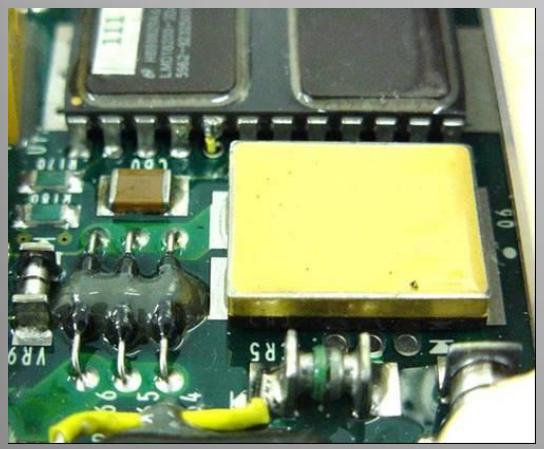
Recent test on wafer level device.

- 24 hours, 64 psig, 0.01 cc,
- stiffness -0.05 um/psi.

- $L_{he} = 1.04 \times 10^{-10}$ cc-atm/sec (actual)
- $L_{air} = 3.87 \times 10^{-11}$ cc-atm/sec (calculated)
- $R_1 = 3.93 \times 10^{-14}$ cc-atm/sec (calculated)

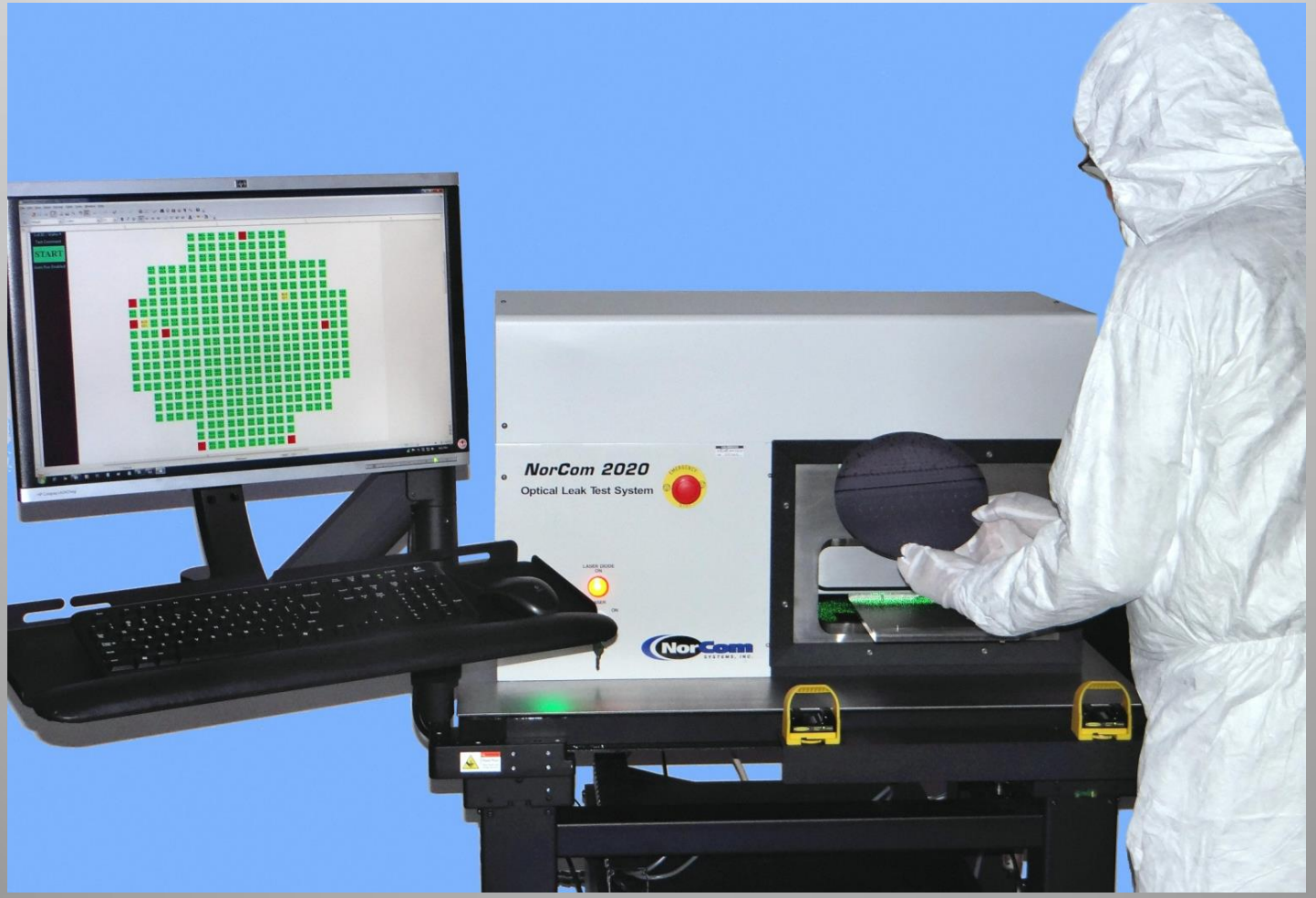
Typical Optical Leak Test System

Testing Board Mounted Devices



- Hermetic devices may fail during board assembly due to high temperature soldering process.
- Optical Leak Testing is not subject to gas absorption issues, so can test devices on assembled circuit boards.
- Since boards usually absorbs helium, HMS can be problematic.

Wafer Level MEMs Testing

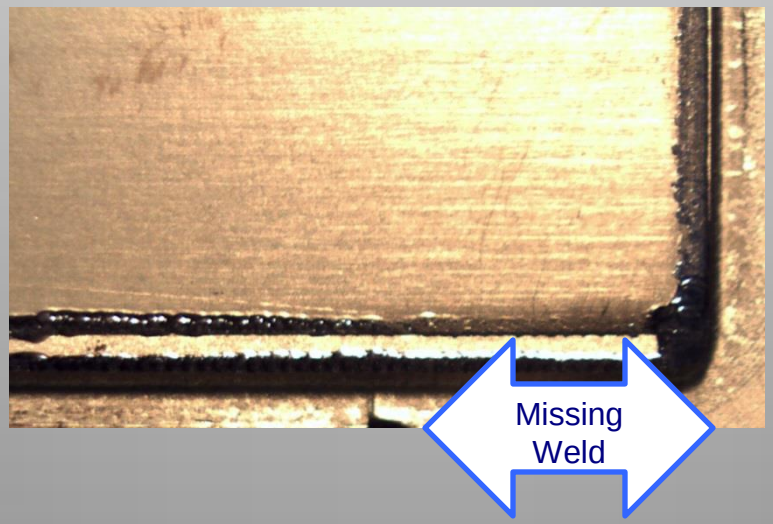


Cavity size is 5 mm square.

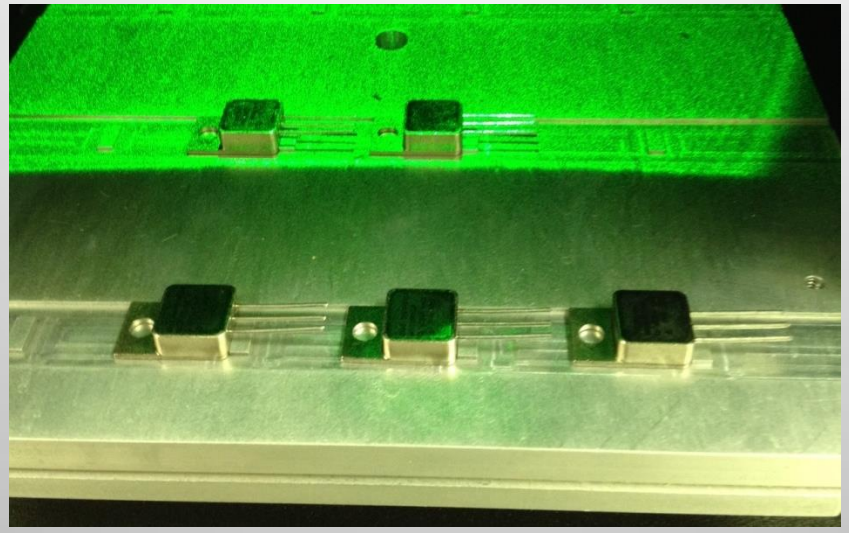
Recent OLT Applications

- A recent lot of 50 packages were tested by a Company with conventional bubble leak for gross and HMS for fine and all 50 passed.

- The packages were then tested with OLT and 1 out 50 was found to be a gross leaking device.



OLT Testing at Class K Levels



- Study with TO-257 showed excellent correlation between Kr85 and OLT.

S/N	374	277	23	372	290	203	131	134	3	53	364	36
Kr85 L_{air}	8.20E-09	6.70E-09	2.00E-08	4.80E-08	3.40E-08	3.90E-08	6.80E-08	1.70E-07	2.45E-07	2.18E-07	2.40E-07	2.90E-07
OLT L_{He}	2.00E-09	8.90E-09	1.90E-08	3.00E-08	1.70E-08	4.70E-08	8.80E-08	1.80E-07	2.20E-07	2.20E-07	2.50E-07	3.20E-07

Optical Leak Testing History
MIL-STD 883

- Included into Mil-STD-883 Method 1014 in 1995
- Updated in 2004 in 2004 for Gross and Fine leak testing on both individual components and circuit board level testing
  - The system outputs true leak rate instead of lid deflection
  - Leaking device samples are no longer needed for calibration and set up
- Revision K draft was published in April 2016
  - Failure criteria and test methodology is better defined

Presentation Contact

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