Introduction and Overview of “Non-Hermetics” for Mil and Space

April 28, 2026

(1:00 PM – 2:30 PM)

Thomas J Green, TJ Green Associates LLC, tgreen@tjgreenllc.com

Outline

Introduction and Overview of "Non-Hermetics" for Mil and Space (1:00 PM – 2:30 PM)
Tom Green, TJ Green Associates, LLC

- Terminology overview: PEMS, plastic parts, "non-hermetics"
- What is "non-hermetic" packaging and how is it different from traditional hermetic parts?
  - Cavity and non-cavity non-hermetic packages
  - Plastic package design considerations
- Drivers for lower cost high reliability plastic packages
  - Temp range, mission life, extreme environments and availability of advanced devices
- Military Specs applicable to non-hermetics
  - Microcircuits Class Y Space qualified microcircuits, Class P
  - Mil-PRF-38534 Hybrids Appendix D "non-hermetic" packages
  - Mil-Prf-19500 JEDEC Task Group on Non-hermetics
  - NASA COTS EEE parts
- Overview of Industry Specs for Qual of plastic parts
  - J-STD-020, AEC Q100/101
  - JESD47K Stress driven qualification
  - JESD22-A101/A102 and A110
  - Review of SSB-1
- Near- Hermetic Packaging Theory
  - Fick's law of moisture diffusion
  - Quasi Steady state model to predict moisture ingress

Outline

Stress driven Qualification for Non hermetic packaging

- Overview of electronic packaging reliability
  - JEDEC standards for package reliability
    - Moisture preconditioning (Moisture Sensitivity Level (MSL) with description of the solder reflow profile
    - High Temperature Storage
    - Highly accelerated stress test (HAST) and biased HAST
    - Temperature cycling
  - Failure analysis (scanning acoustic microscopy, cross-sectional analysis)
- Stress driven qualification for Plastic Encapsulated Microcircuits (PEM)
  - Overview of temperature humidity models
  - Determination of the expected lifetime using field use condition of -55 to 125°C

How to Find the Latest Spec

DEFENSE LOGISTICS AGENCY
DLA Land and Maritime
Sourcing and Qualifications

REVIEW HOW TO CHECK FOR DOCS AT DLA

DLA Link:

https://landandmaritimeapps.dla.mil/programs/milspec/

https://landandmaritimeapps.dla.mil/programs/milspec/DocSearch.aspx

Quick Assist Link

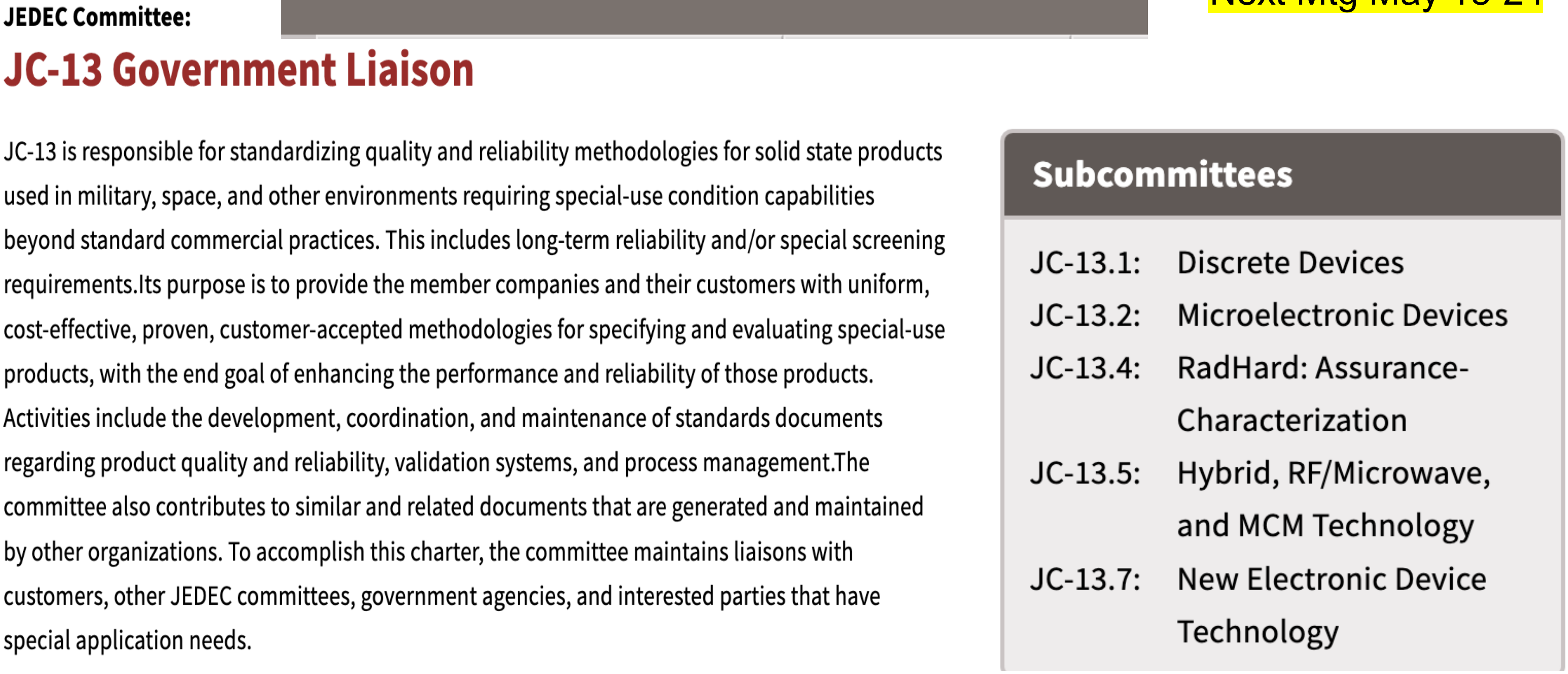
QML List Hybrid QML Listing

Lab Suitability Listing Review DLA Links
https://landandmaritimeapps.dla.mil/offices/sourcing_and_qualification/labsuit.aspx

JEDEC Joint Electron Device Engineering Council

Global Standards for the Microelectronics Industry

Next Mtg May 18-24



JEDEC Committee:

JC-13 Government Liaison

JC-13 is responsible for standardizing quality and reliability methodologies for solid state products used in military, space, and other environments requiring special-use condition capabilities beyond standard commercial practices. This includes long-term reliability and/or special screening requirements.Its purpose is to provide the member companies and their customers with uniform, cost-effective, proven, customer-accepted methodologies for specifying and evaluating special-use products, with the end goal of enhancing the performance and reliability of those products. Activities include the development, coordination, and maintenance of standards documents regarding product quality and reliability, validation systems, and process management.The committee also contributes to similar and related documents that are generated and maintained by other organizations. To accomplish this charter, the committee maintains liaisons with customers, other JEDEC committees, government agencies, and interested parties that have special application needs.

Subcommittees

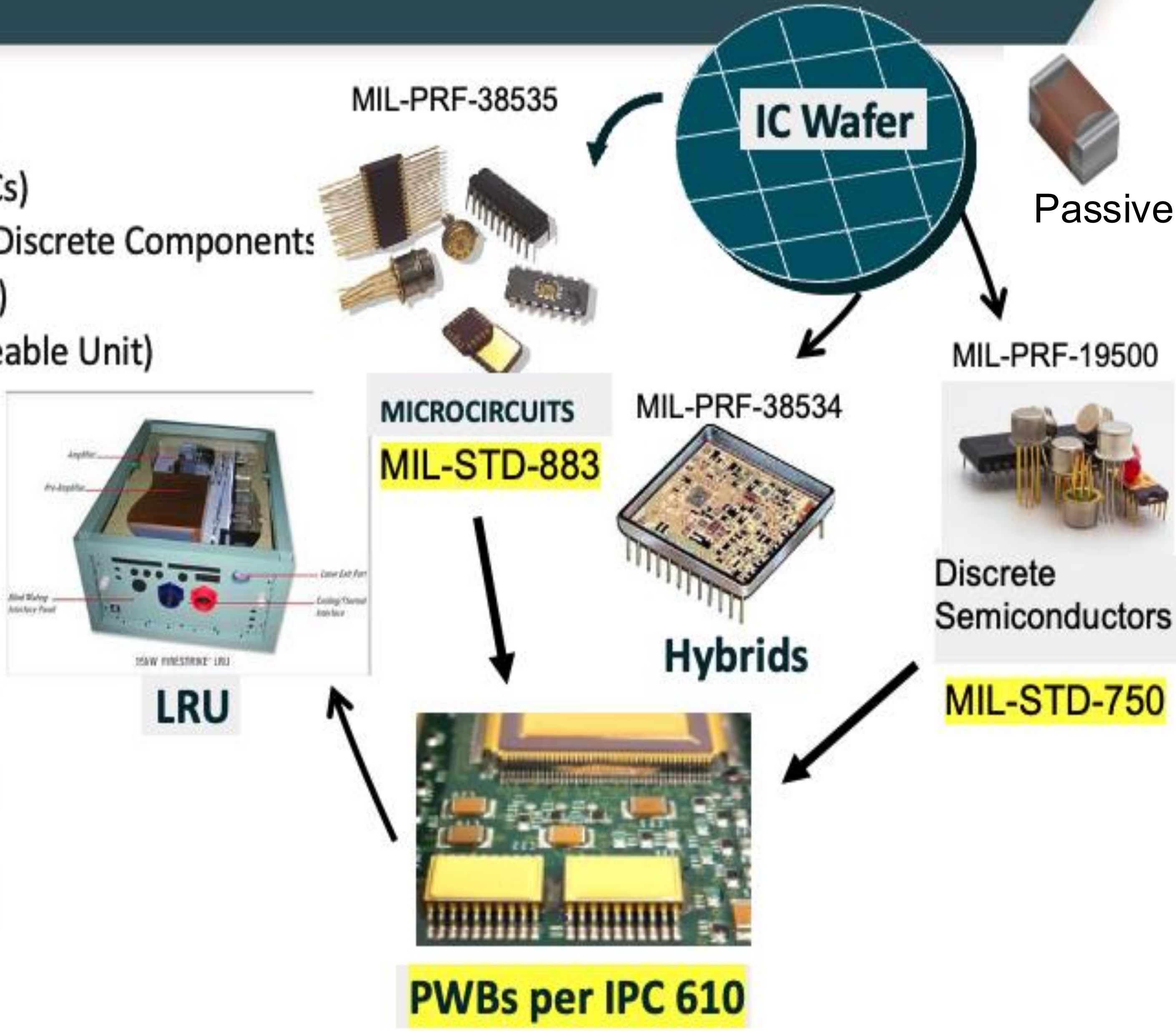
JC-13.1:	Discrete Devices
JC-13.2:	Microelectronic Devices
JC-13.4:	RadHard: Assurance-Characterization
JC-13.5:	Hybrid, RF/Microwave, and MCM Technology
JC-13.7:	New Electronic Device Technology

JEDEC Link: http://www.jedec.org/

Electronics' Packaging Hierarchy

Microcircuit Packaging Levels:

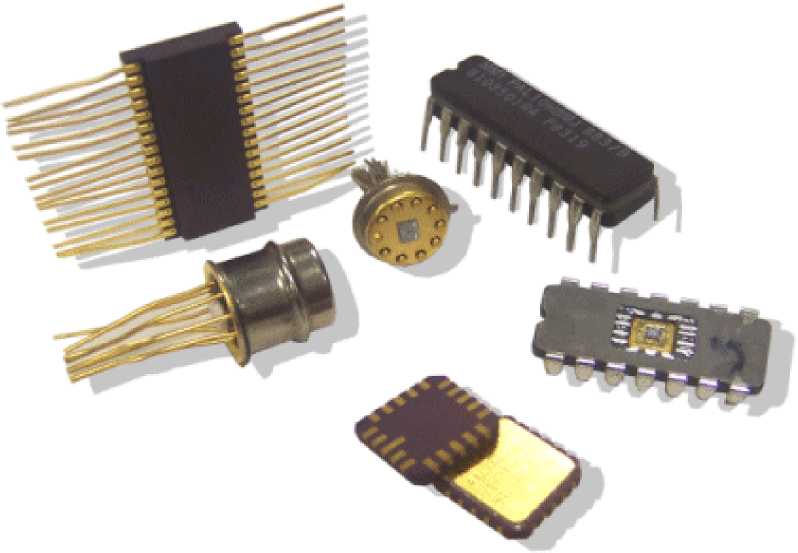
Level I: Wafer Level (ICs and MMICs)
Level II: Hybrids, Microcircuits and Discrete Components
Level III: Printed Circuit Board (PCBs)
Level IV: Black Box LRU (line Replaceable Unit)
Level V: System Level



System Level

Monolithic Integrated Circuit (MIL-PRF-38535)

Single IC Chip in 32 Pin CERDIP



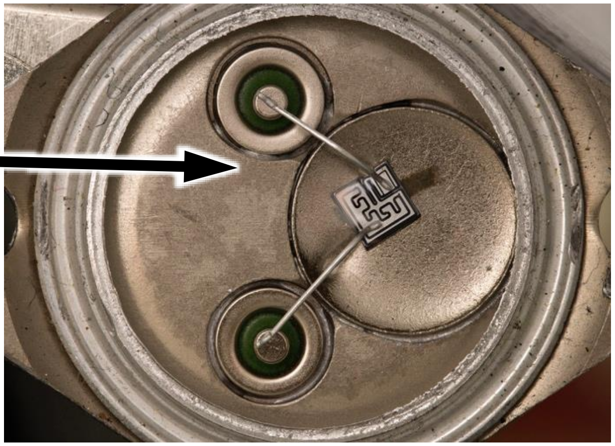
DEFINITION

Monolithic microcircuit (or integrated circuit). A microcircuit consisting exclusively of elements formed in situ on or within a single semiconductor substrate with at least one of the elements formed within the substrate.

MIL-PRF-38535

Semiconductor Circuit (MIL-PRF-19500)

TO-3 TRANSISTOR Can



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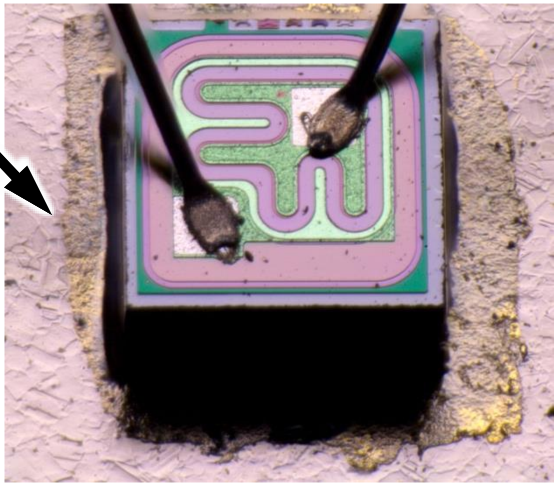
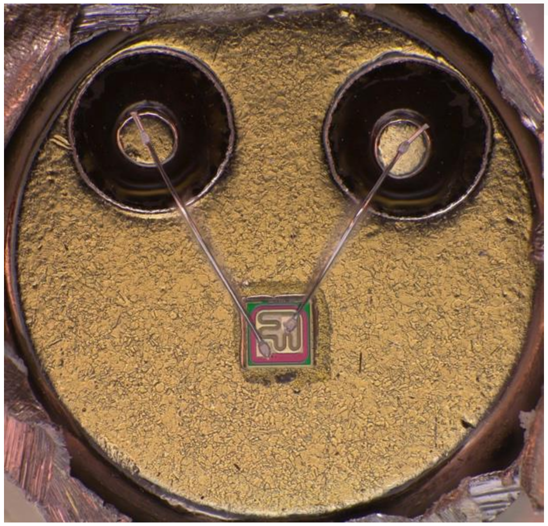




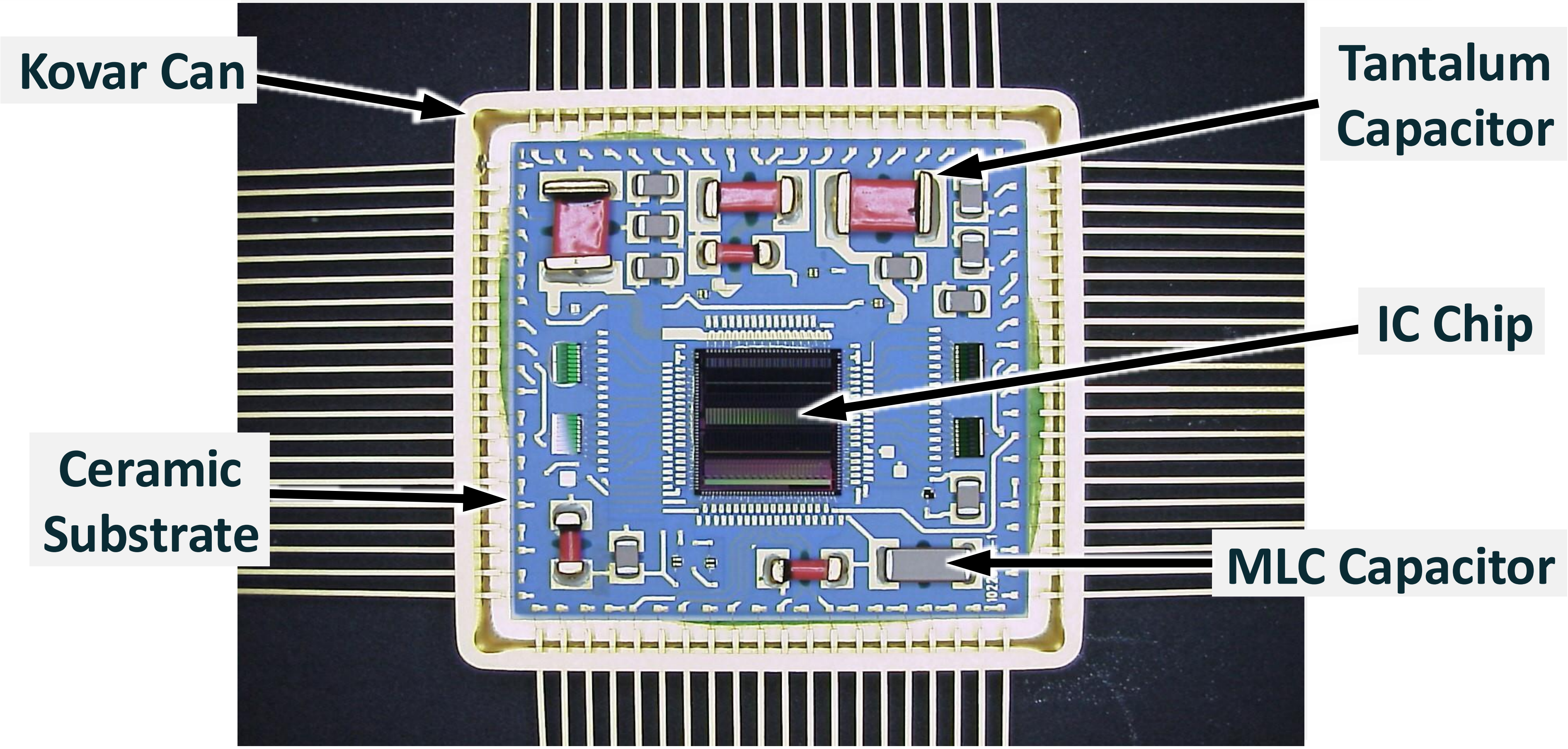
MOSFETS, diodes, transistors, microwave FETs ect

Hermetic Cans ..all different shapes and sizes

MIL-STD-883 was primarily written for Hermetic Parts

Photo Courtesy of Tom Salzer

Hybrid Circuit (MIL-PRF-38534)



A Hybrid microcircuit contains two or more of a single type, or a combination of the following types of elements with at least one of the elements being active: Film microcircuit, Monolithic microcircuit, Semiconductor element, Passive chip or printed or deposited substrate elements.

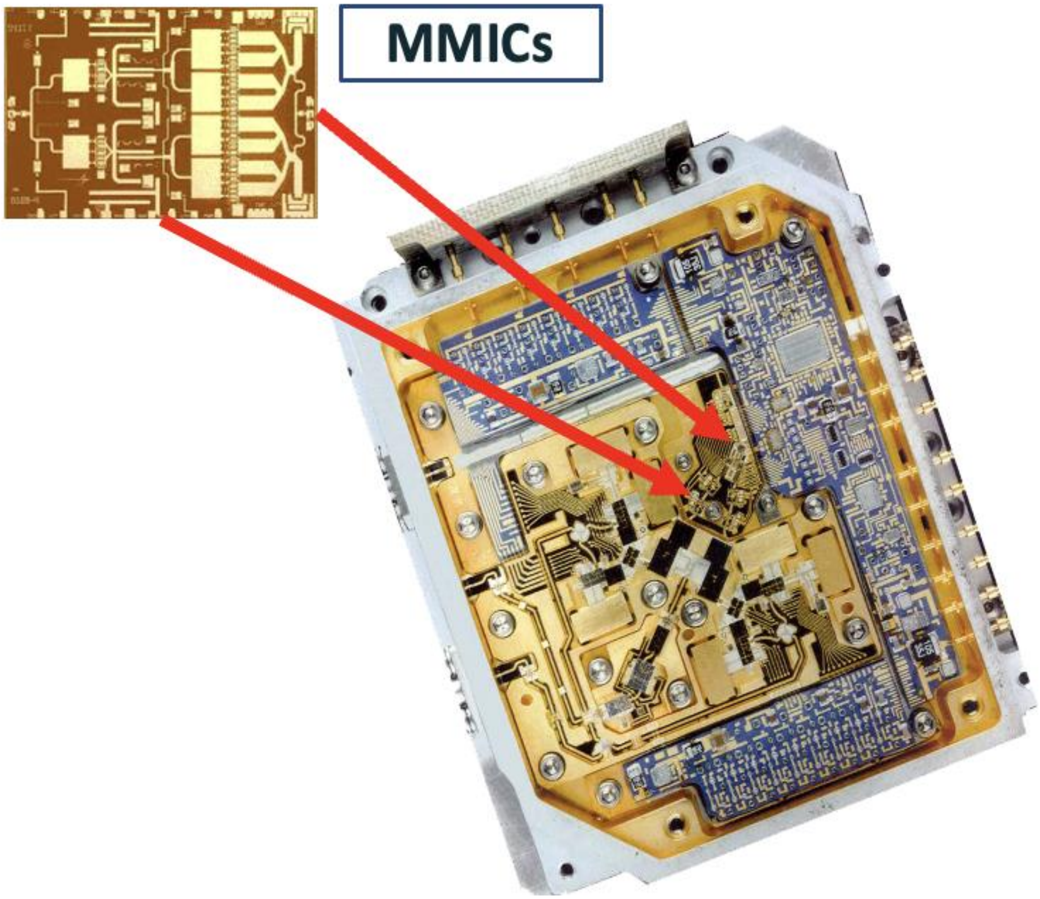
MIL-PRF-38534

RF MMIC Microwave Modules

(Monolithic Microwave Integrated Circuits)

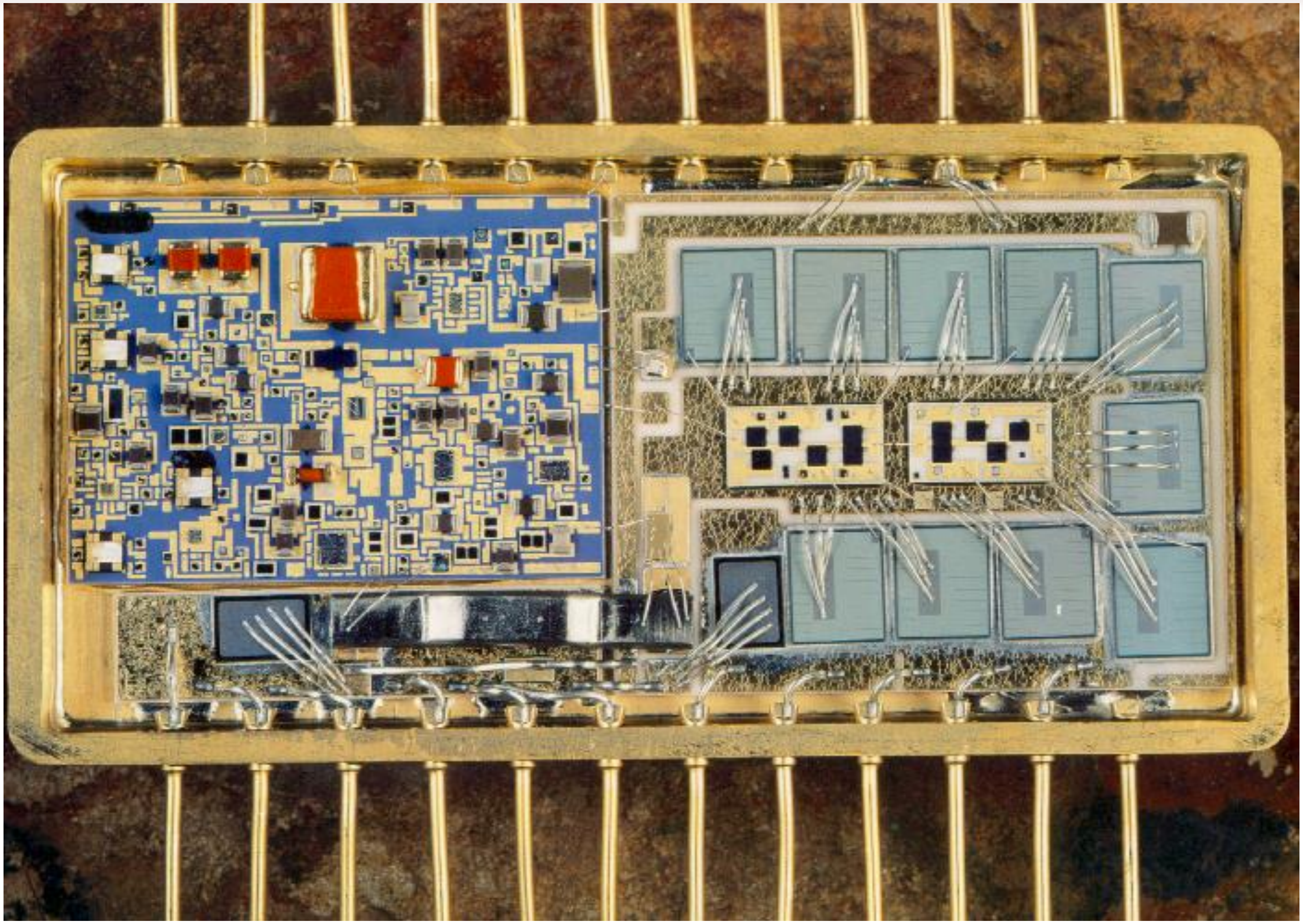
RF MMIC modules are also known as microwave hybrids or “MIC” hybrids and are like conventional hybrids in many ways but operate at much higher frequencies and make use of III-V semiconductors such as gallium arsenide (GaAs) and gallium nitride (GaN) technology and soft teflon (PTFE) substrates. The packages are typically made from aluminum and laser welded.

Inspect per: MIL-STD-883 TM 2017



RF MMIC Module

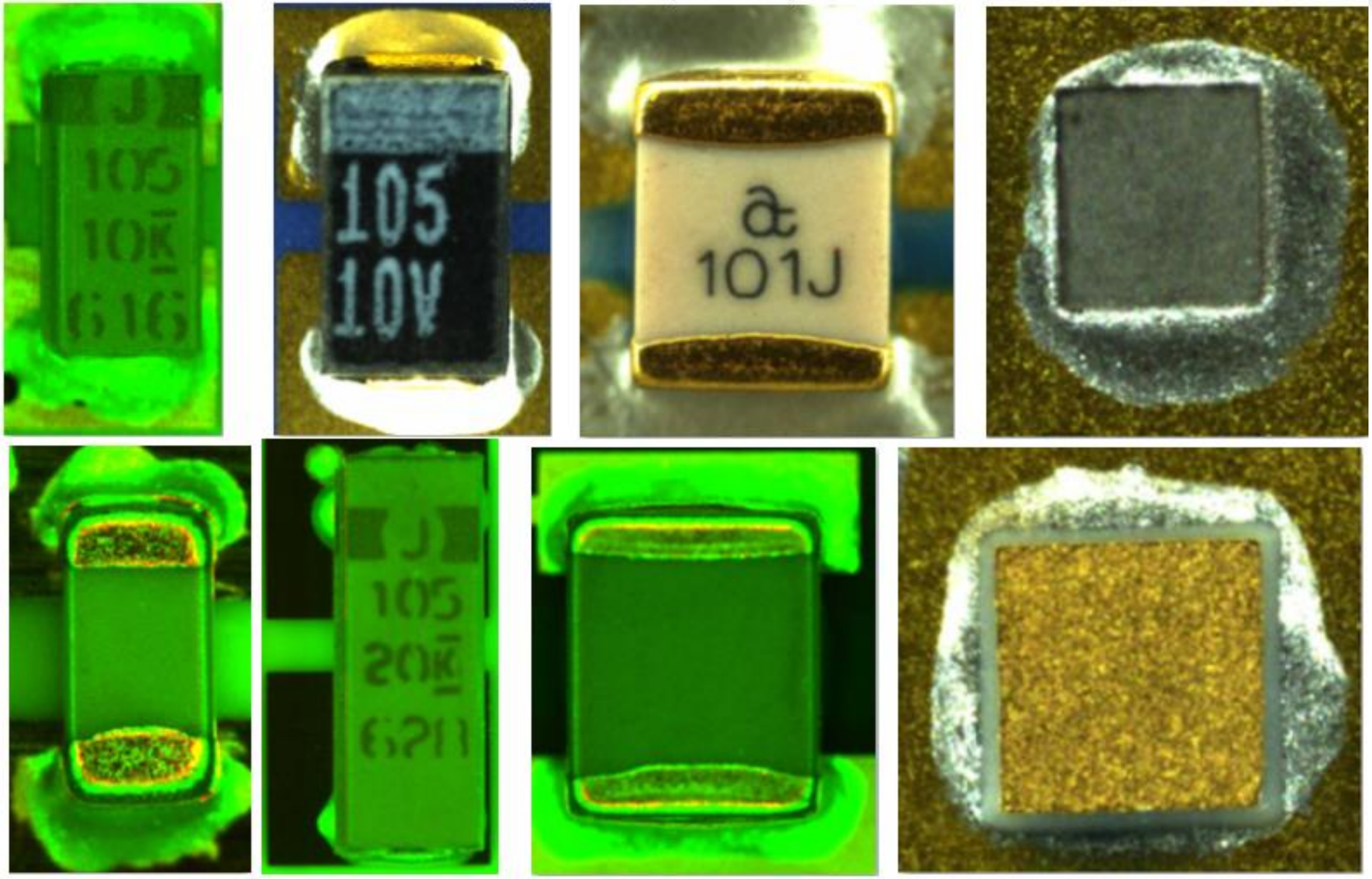
Power Hybrids



Hybrid Circuit (MIL-PRF-38534)

Ref: Teledyne Microelectronics

Capacitors Inspect per **MIL-STD-883 TM 2032**



Capacitors are passive elements that store electrical energy. They come in a variety of shapes and sizes and the unit of measure is a Farad (F).

Inspection criteria for capacitors is found in TM 2032 para. 3.3. However, the epoxy attach criteria is found in TM 2017.

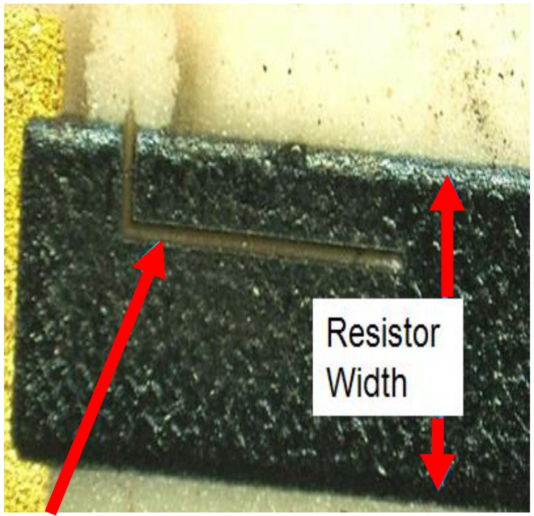
Resistors

Visual inspection criteria is contained in TM 2032:

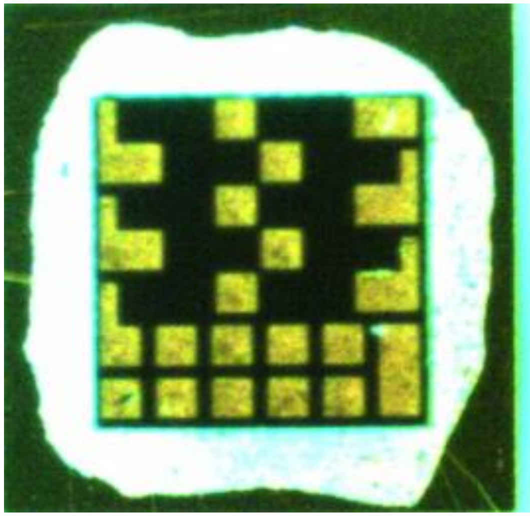
Section 3.1 for Thin Film Resistors (100X-200X)

Section 3.2 for Thick Film Resistors (10X-60X)

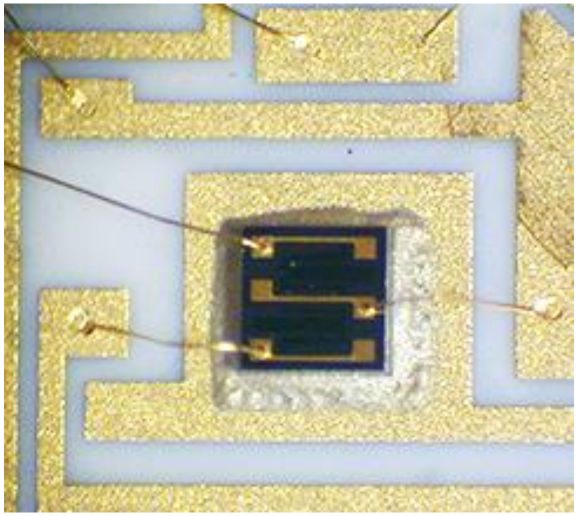
As with the capacitors, component attach and wire bond criteria is found in TM 2017



Laser trimmed thick film resistor



Multi tap thin film resistor



Select in test thin film resistor

Basic Microelectronics Processes

- *Wafer Fab Processes (Silicon and GaAs, SiC, GaN)*
- *Substrate Manufacturing*
  - *Ceramic (Thin and Thick film),*
  - *Laminate PWBs multilayers...Teflon boards (soft boards)*
- *Die/Component placement and attach*
  - *epoxies and solders*
- *Interconnect Processes*
  - *wirebond... flip chip*
- *Cleaning Processes… plasma, wet chemicals*
- *Packaging Processes*
  - *Plastic encapsulation... glob top, dam and fill*
  - *Hermetic enclosures*
- *Test…. at temperature -55C to 125C*

Presentation on Materials and Processes available in the Presentation folder

What is Hermeticity?

- The dictionary definition of the term “hermetic” means a seal that is gas tight or impervious to gas flow. In the context of a microelectronic package it implies an airtight seal… to experts in the field it means it passes TM 1014 and TM 1018
- Metals, ceramics and glasses are the materials used to form the hermetic seal so we can ignore diffusion of water vapor through the bulk material.
- Test methods are based Howl and Mann equation and ideal gases flowing through a leak path.
- A properly made hermetic seal with a sufficiently low leak rate can keep a package dry and moisture free for many years
- MIL-PRF specs, MIL-STD- 883 were primarily designed for hermetic parts……. ***“But the times they are a changing”***

Why does a Package need to be free from moisture?

If water droplets form on the surface of an IC or MEMS device, the water (H_2O) combined with ionic contamination along with a bias can adversely affect the device, namely….

- Chemical corrosion …especially the exposed aluminum wires or Al bond pads
- Leakage across pins
- “Stiction” on a MEMS device
- Changes in dielectric constant in waveguides or swelling of epoxy and alignment issues in Opto packages… condensation in the optical pathway
- Ag and Au dendritic growth
- Damage to the doped layers on a silicon chip if the surface passivation isn’t good enough

The above failure moisture related failure mechanism are true for both hermetic and non-hermetic packages….and plastic parts have additional failure modes not seen in hermetic parts …..and it doesn’t take much moisture to initiate these failure mechanisms!

3 Monolayers of Water is all it Takes!

Consensus is that 3 monolayers of water is all that is required to sustain surface conduction and provided ionic contamination is present moisture related failure mechanism can progress

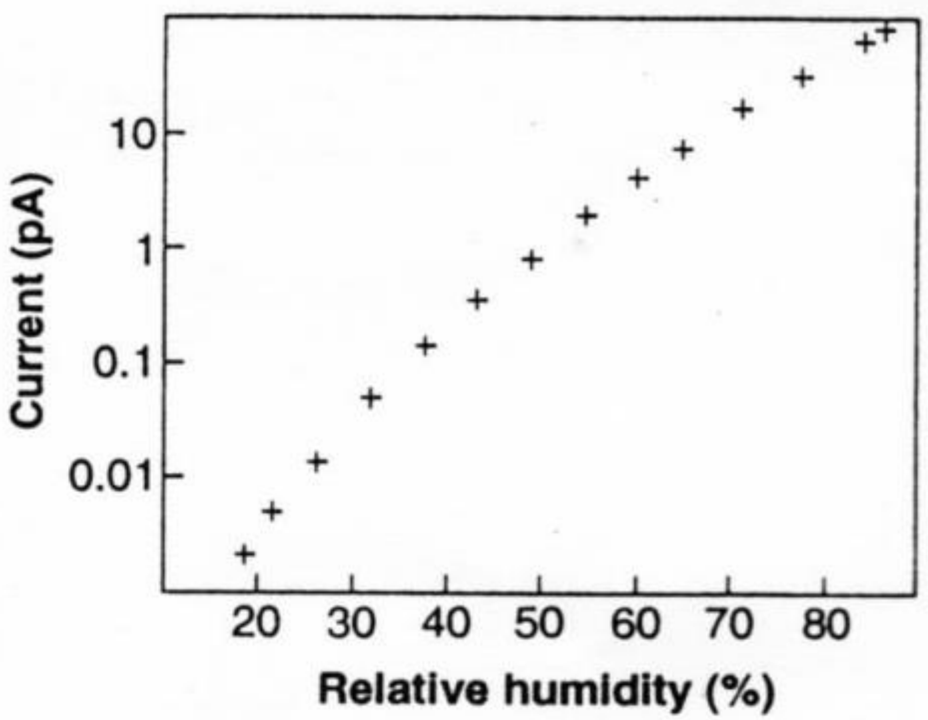
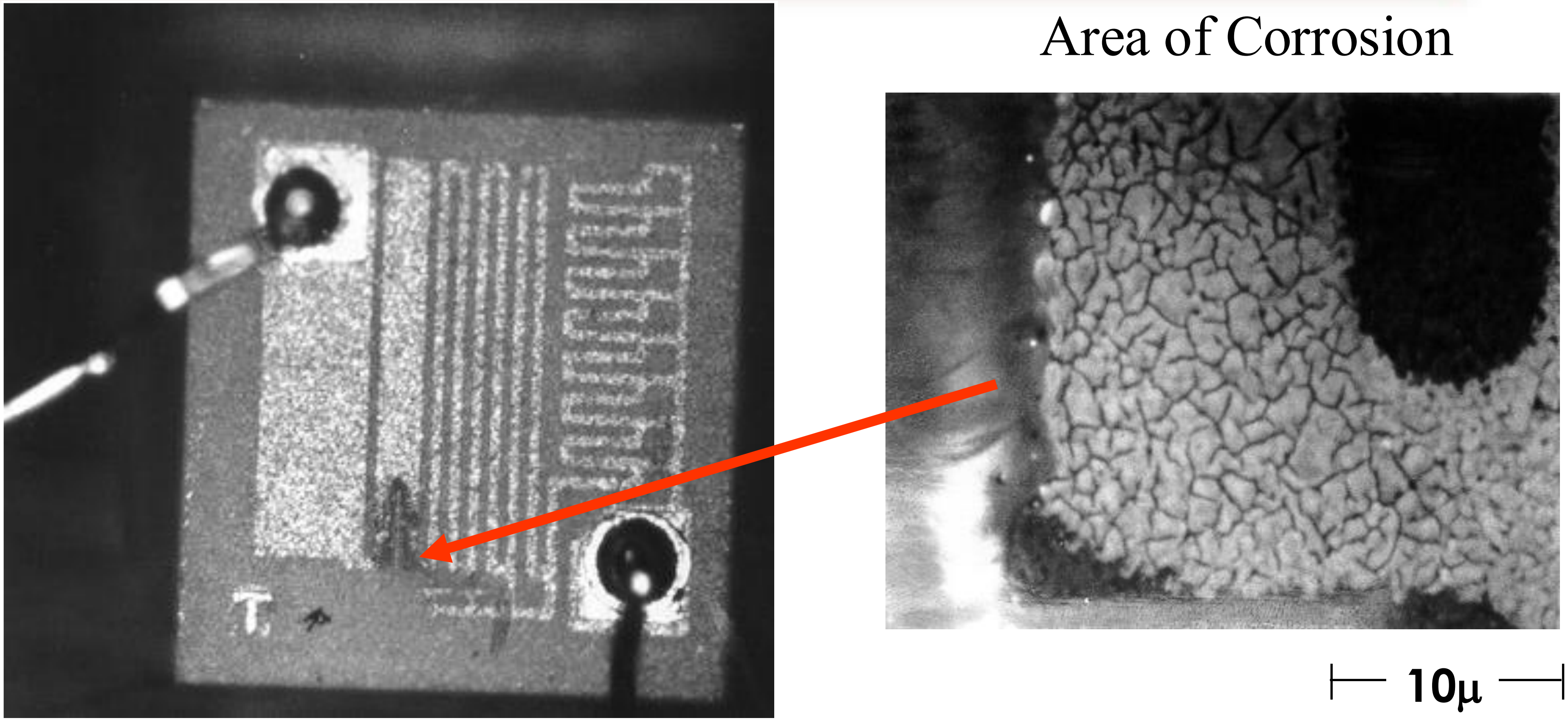


Figure 1: Electrical conductivity across mica as function of relative humidity, as determined by STM[4].

TJ Green Associates White Paper http://www.tjgreenllc.com/node/109

Corrosion Failures on a Chip Resistor


Area of Corrosion

(Enlarged View 3000X Backscatter SEM Image)

Optical photo of a NiCr Unpassivated chip resistor(100 x)

Ref: GIDEP #F3-A-94-03

Aluminum Corrosion Reaction

- Halogens + Moisture + Metals that differ widely in the electrochemical series potentials

$$\mathrm{Al\,(OH)_3 + CL^- \longrightarrow Al\,(OH)_2 + OH^-}$$

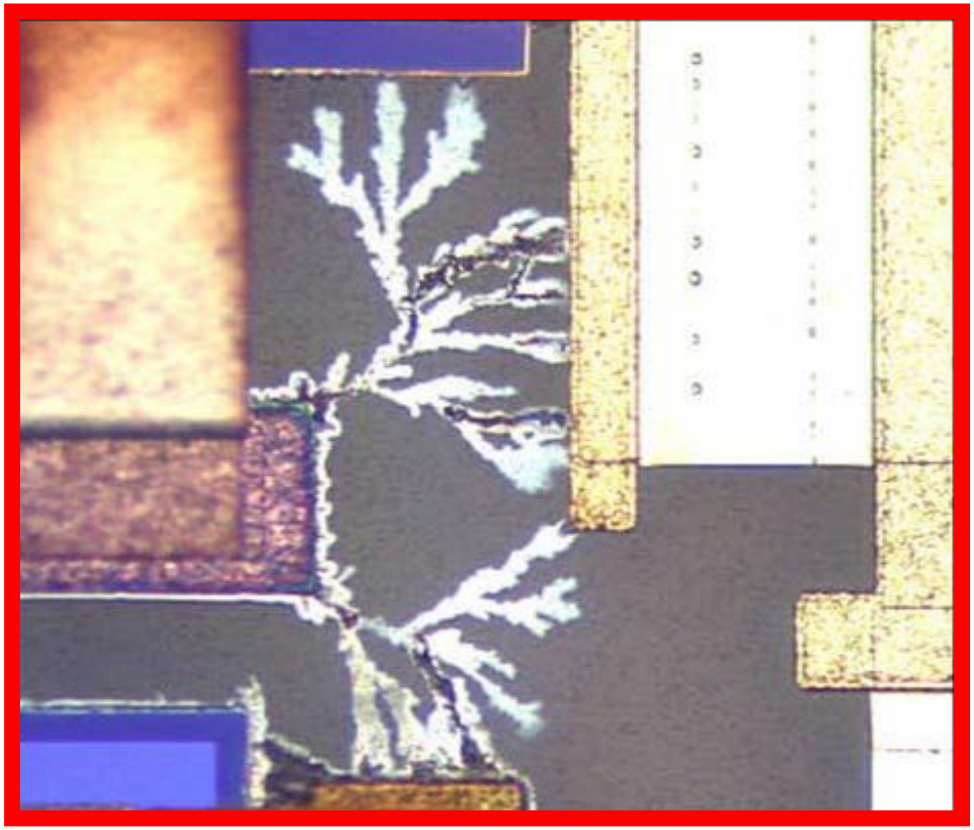
$$\mathrm{Al + 4CL^- \longrightarrow Al\,(CL)_4^- + 3e^-}$$

$$\mathrm{2AlCL_4^- + 6H_2O \longrightarrow 2Al(OH)_3 + 6H^+ + 8CL^-}$$

(The chlorine ion is liberated and available to continue the corrosion process…..this is bad news and the reason why just minute amounts of ionic contamination can cause failures downstream)

Silver Dendrites Cause Short Circuits

REJECT

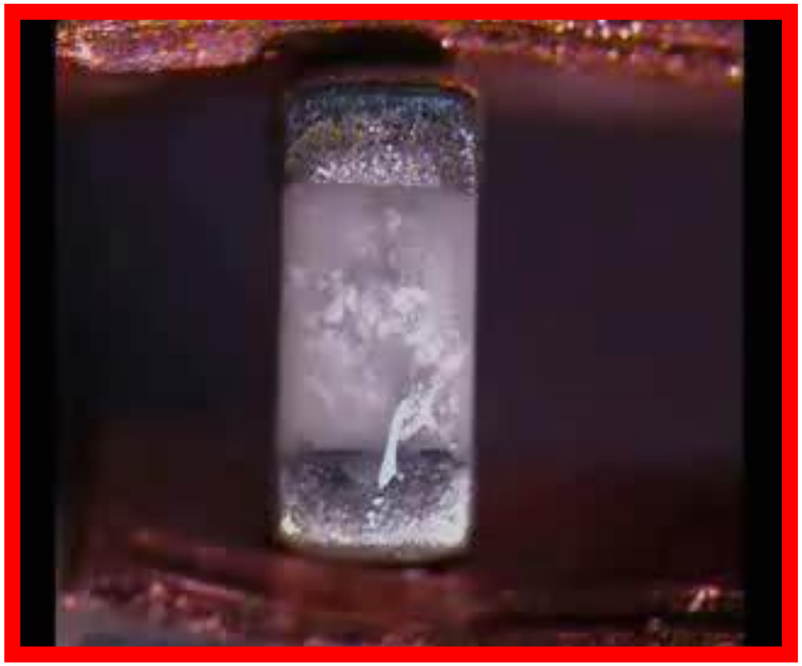


Ref: "Electrolytic Electro-migration of Metallic Material and Silver Filled Epoxy" IEEE Transactions on Reliability, Vol 44, No. 4, 1995 December.

SHOW DENDRITE VIDEO

TM 2017 Para. 3.1.2.1.g

Electrochemical Migration (ECM)



Dendrite formation is an ionic process which requires an electrolyte, bias voltage and time.

This capacitor exhibits some flux residue and alcohol (simulate moisture). It took only 2.5Vdc and 35 seconds for this dendrite to develop across the capacitor.

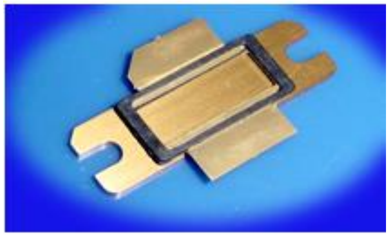
Does a Part Need to be Hermetic?

For most Space and Mil Hermeticity is still a requirement but…

- Non hermetic parts cost a lot less..an important consideration for many systems
- For years the automobile industry has assembled microelectronic devices, potted with silicones and snapped on a plastic lids ..these components are exposed to severe environments and generally last close to the advertised warranty period (unless you’re the unlucky guy’s who’s electronic engine control craps out at 102,000 miles!)
- AF Reliability without Hermeticity Program and other efforts to impart the same reliability without the cost of seal/leak test/RGA etc…
- Parts intended for use in Space… Do they need to be hermetic? Hermetic seals protect the parts only while on this planet, Space is a near perfect vacuum
- Moisture inside a hermetic part is often the result of outgassing of the epoxies or the moisture was sealed in from the start
- Some polymer sealed hybrids have lasted 23 to 27 years working successfully in an in controlled military fighter aircraft environment*
- “Non-hermetic” breathable packages may be a better choice for some applications

* D. Dylis and G.H. Ebel “Long Term Package Integrity in a Military Environment” ISTFA 1994

Industries migrated away from Hermetics



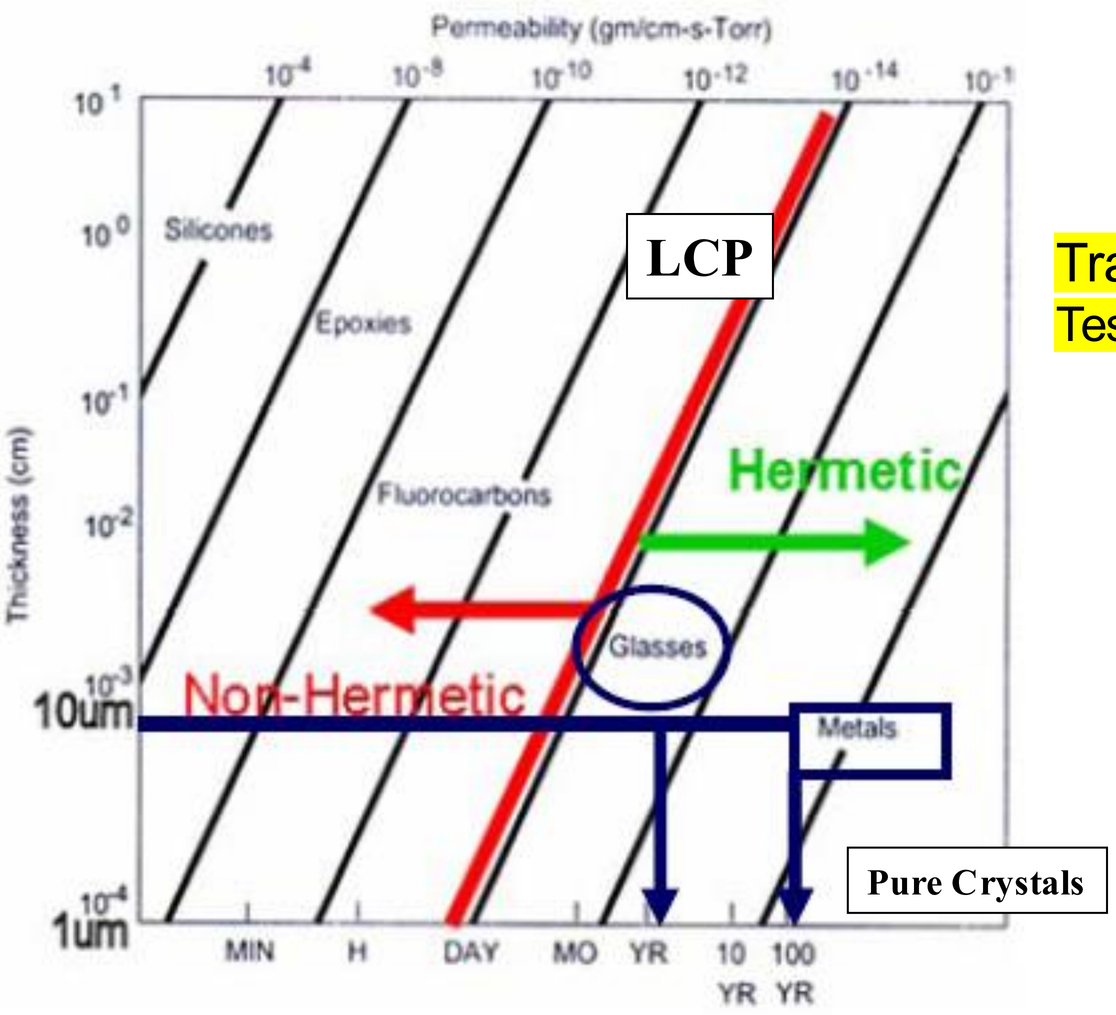
- ☐ Automotive….plastic boxes pumped full of clean well adhering silicones
- ☐ Telecom power amps for base stations
- ☐ Some opto packages….. but not those with cooled lasers
- ☐ Many microwave products especially those with all gold metal connections and gold metallized MMICs
- ☐ Some MEMS packages …based on performance
- ☐ ***Manny in the Mil and Space community are heading this way led by SPACE X and commercial small sats***

Mil and Space Reliability Concerns

- PEMs are predominately been designed for commercial and industrial applications with a reduced temp range
- Non-hermetic packages expose critical surfaces and device interfaces that are "locked away" in truly hermetic packages.
- Outgassing in vacuum also a concern for space and optical
  - TML < 1%
  - CVCM < 0.1%
- Non-hermetic integrity is much harder to assess
  - What does "hermetic" mean when package materials are gas-permeable?
- Reliability of plastic packages could vary dramatically from supplier to supplier
- Copper bond wire PEMS could pose a reliability concerns if not properly manufactured

Permeability as a Function of Material Thickness

Industry /JEDEC
Automotive or ??
Specs Apply

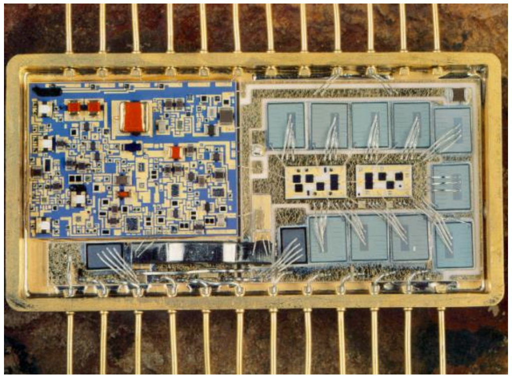


Traditional MIL SPECS
Test Methods Apply

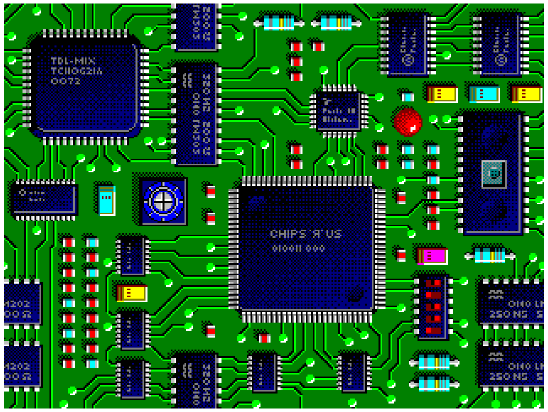
Calculated time for moisture to permeate various materials (to 50% of exterior humidity) in one defined geometry. The red line indicating the transition between hermetic and non-hermetic is somewhat arbitrary.

Hermetic (Cavity)

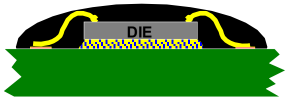
Made from glasses, metals and ceramics



Non-Hermetic (Plastic)



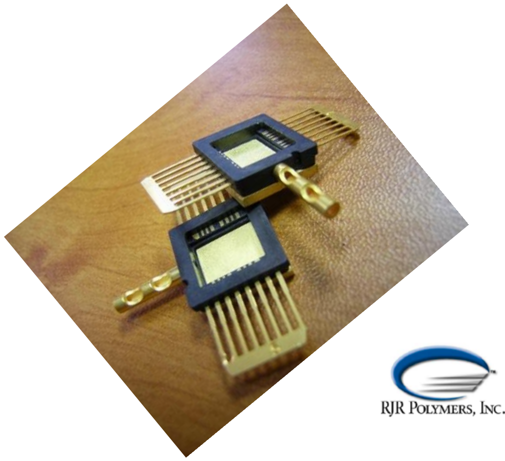
Commercial
COTS BGA's, CSPs…



Overmolded

Underfilled

"Near Hermetic" (Cavity)



RJR Polymers, Inc.

Cavity's made from polymeric materials

Quantum Leap

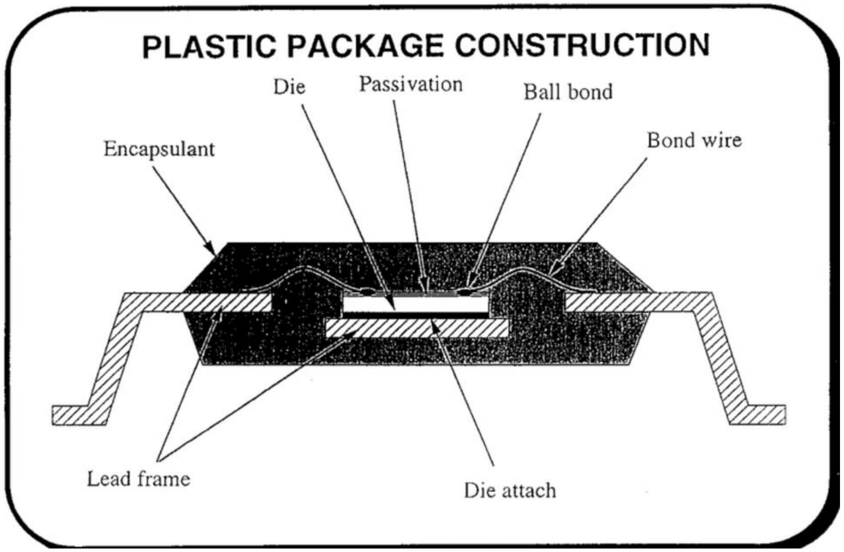
Ref : J. Roman

Non-Hermetic Package Terminology

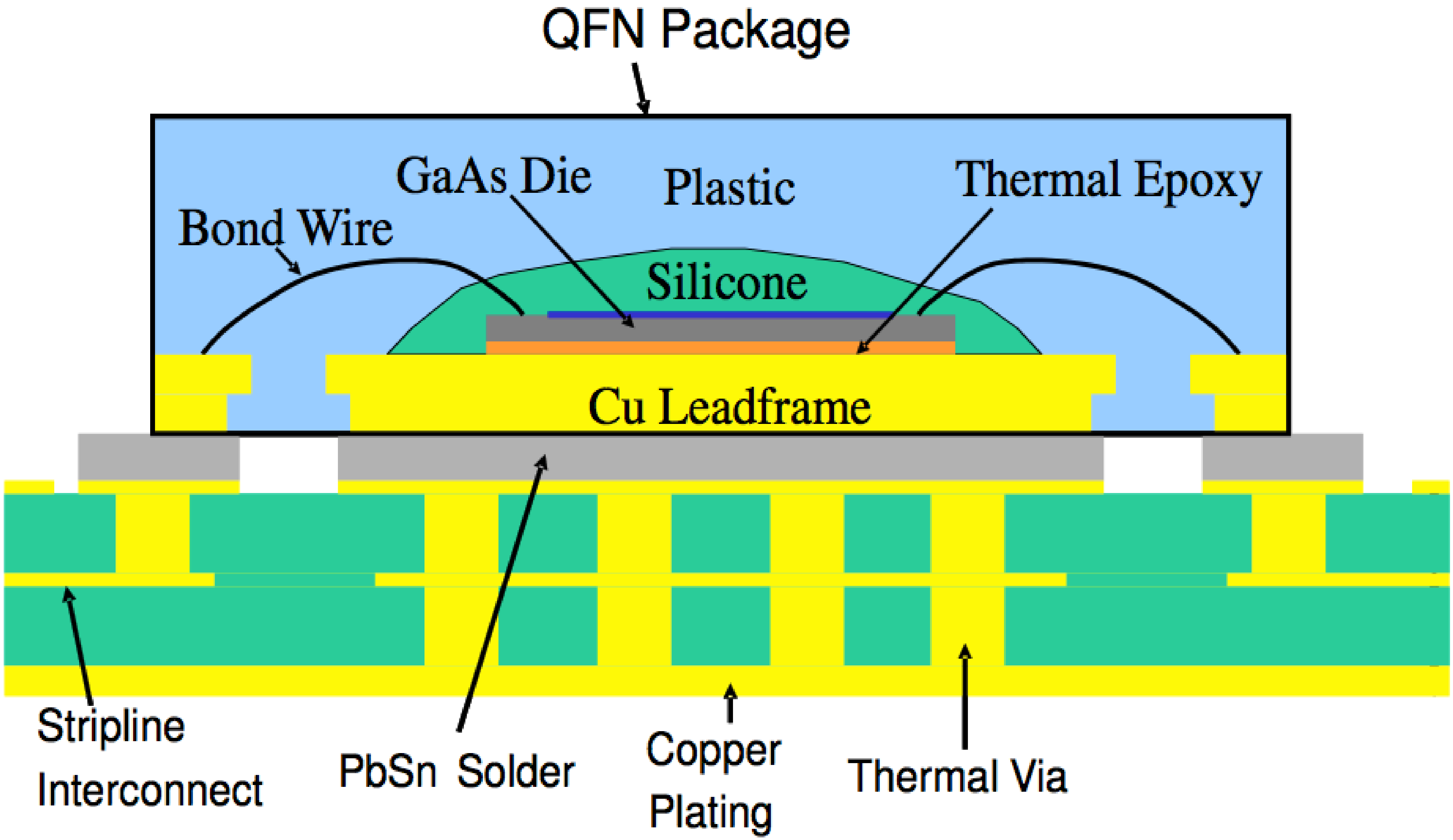
- PEMs = Plastic Encapsulated Microcircuits
  microcircuits, IC ,hybrids assembled into plastic packages
- PEDs = Plastic Encapsulated Diodes
- PETs = Plastic Encapsulated Transistors
- Flip Chip = underfilled flip chips are “non-hermetic” and in some ways a PEM
- EP= Enhanced Plastic a TI term
- COTS = Commercial off the shelf technology…. Implies low cost plastic packages
- PEMS use polymeric materials to injection or transfer mold the semiconductor device for enhanced environmental protection.
- PEMS can also just be coated ….Various coatings applied before or after wirebond are also used
- If an open cavity is required this can be achieved by simply epoxy bonding a lid onto the package

Typical PEMS aka Plastic parts

Microrel

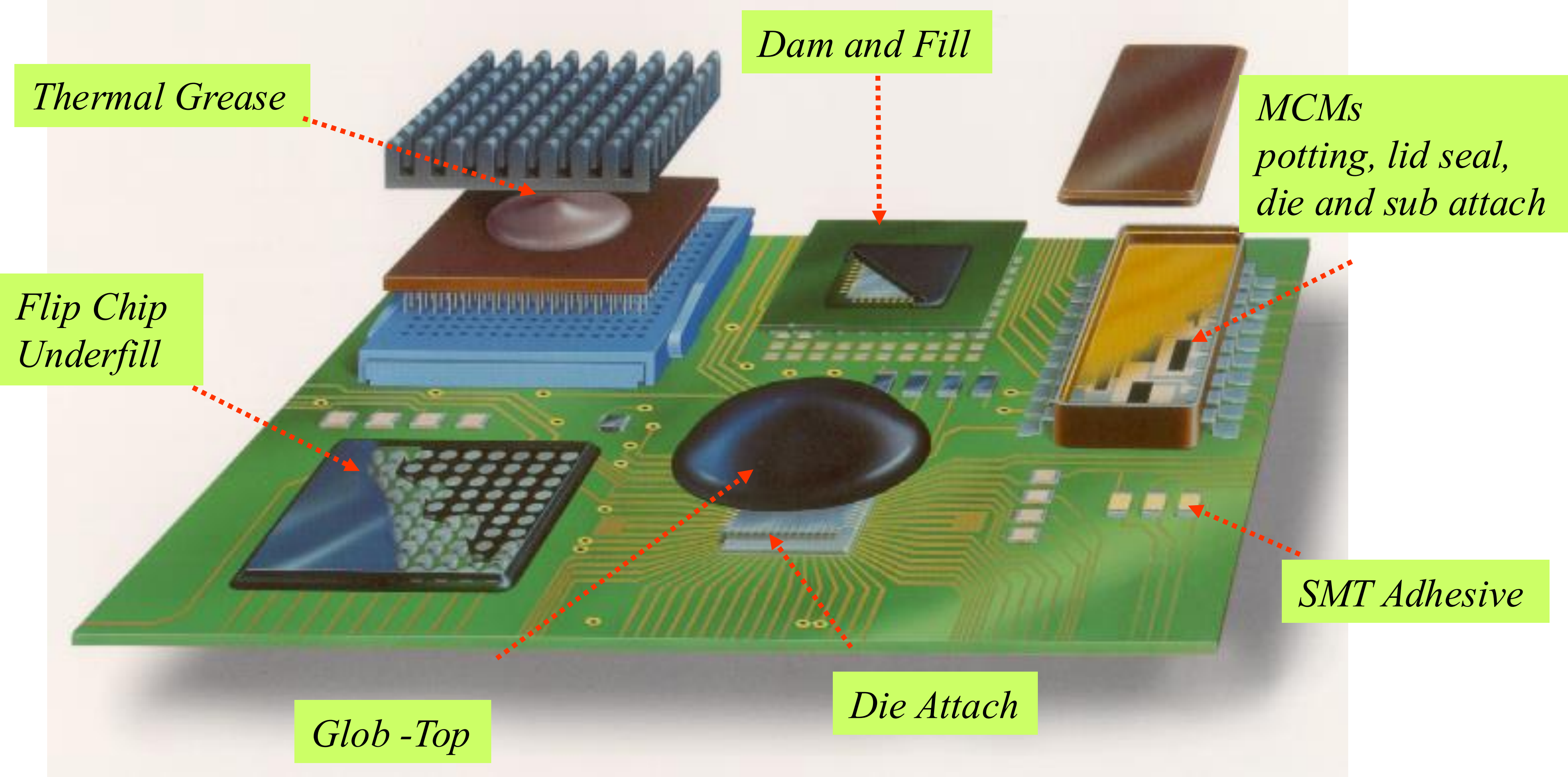


QFN Cross Section – Encapsulated Package



“Non-Hermetic Packaging of RF Multi-Chip Modules” SOURCE: Matthew Gruber Lockheed Martin – MST Moorestown, NJ
New England IMAPS Symposium 2014

Automated Fluid Dispensing Technologies (for low cost)



Injection and Transfer Molding of plastics materials and processes are ubiquitous

Ref: Lord Corp Photo

Reasons to use PEMs

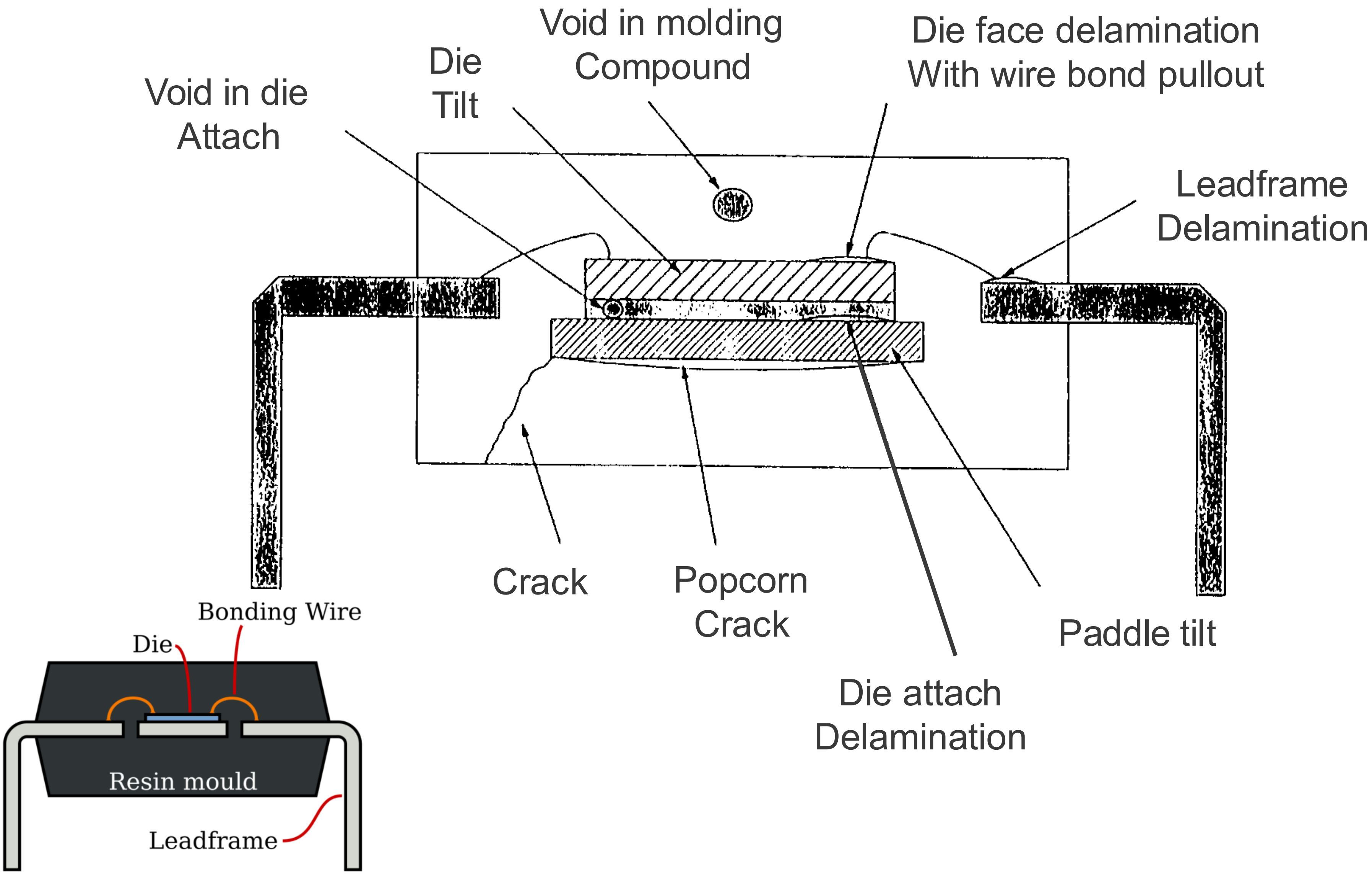
- Wide spread availability
- Higher volume/more cost effective production
- Shorter leadtimes – many products off-the-shelf
- Generally lower cost
- Greater product variety
- Mechanically more rugged
- Lighter weight - available in smaller/thinner packages
- All of the above items help reduce end system costs and accelerates time to market.

INTEGRA
TECHNOLOGIES

Typical PEM Qual Failure Modes

1. Pop Corning of Plastic Package
2. Delamination
3. Die Attach Voids
4. CTE Mis-match Between Molding Compound and Base Material
    a. Cracked Package
    b. Wire breaks
    c. Cracked Die
5. Corrosion
6. Wire Lift
7. Contamination
8. Moisture Ingression / Current Leakage
9. Cracked Passivation

Typical IC Plastic Packaging Defects

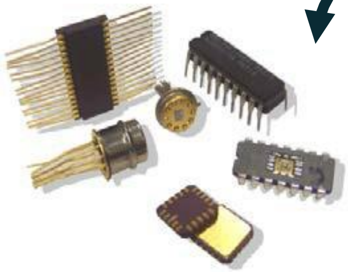


Applicable Mil Specs for Non-Hermetics

access specs here: https://landandmaritimeapps.dla.mil/programs/milspec/DocSearch.aspx

https://landandmaritimeapps.dla.mil/programs/MilSpec/

Monolithics

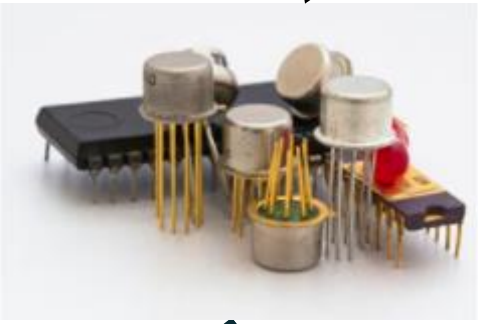


MIL-PRF-38534 Appx B
Class Y for Space
Class P, Class N

PWBs per IPC specs

Hybrids

MIL-PRF-38534 Appx D



Discrete
Semiconductors

MIL-PRF-19500R
Appendix J

JEDEC Task Groups for non-hermetic technology

MIL-PRF-38535M (IC Microcircuits)
1 November 2022

MIL-PRF-38535M
01 November 2022
SUPERSEDING
MIL-PRF-38535L
06 December 2018

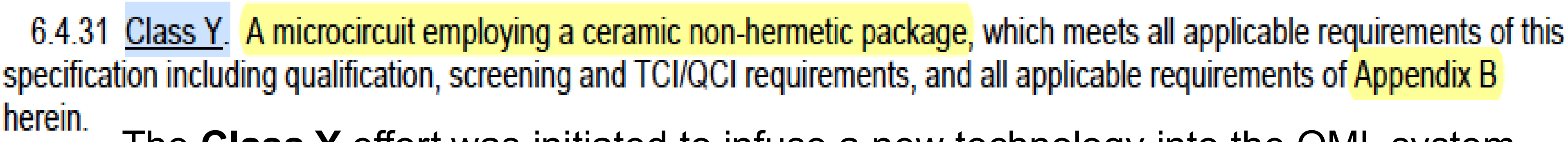
PERFORMANCE SPECIFICATION

INTEGRATED CIRCUITS (MICROCIRCUITS) MANUFACTURING, GENERAL SPECIFICATION FOR

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

The IC/microcircuits have to work reliably as per the electrical spec at -55C to 125C and all temps in between in an extreme environment for the expected mission life (30 years in some cases). Most commercial IC packaged in plastic were not designed with this in mind!

CLASS Y Non-Hermetic Parts for Space



6.4.31 Class Y. A microcircuit employing a ceramic non-hermetic package, which meets all applicable requirements of this specification including qualification, screening and TCI/QCI requirements, and all applicable requirements of Appendix B herein.

The **Class Y** effort was initiated to infuse a new technology into the QML system. Xilinx had introduced Virtex-4 and -5 field-programmable gate arrays (FPGAs) that were highly popular with hardware designers on space missions. However, these FPGAs couldn’t be procured as standard Class-V products because of their non-hermetic construction.

The Xilinx FPGAs were system-on-a-chip (SOC), representing advances in packaging, feature size, and functional complexity. Packaging features included flip-chip construction, column grid arrays (CGAs) with 1752 pins, and vented packages for thermal management.

MIL-PRF-38535L

APPENDIX B

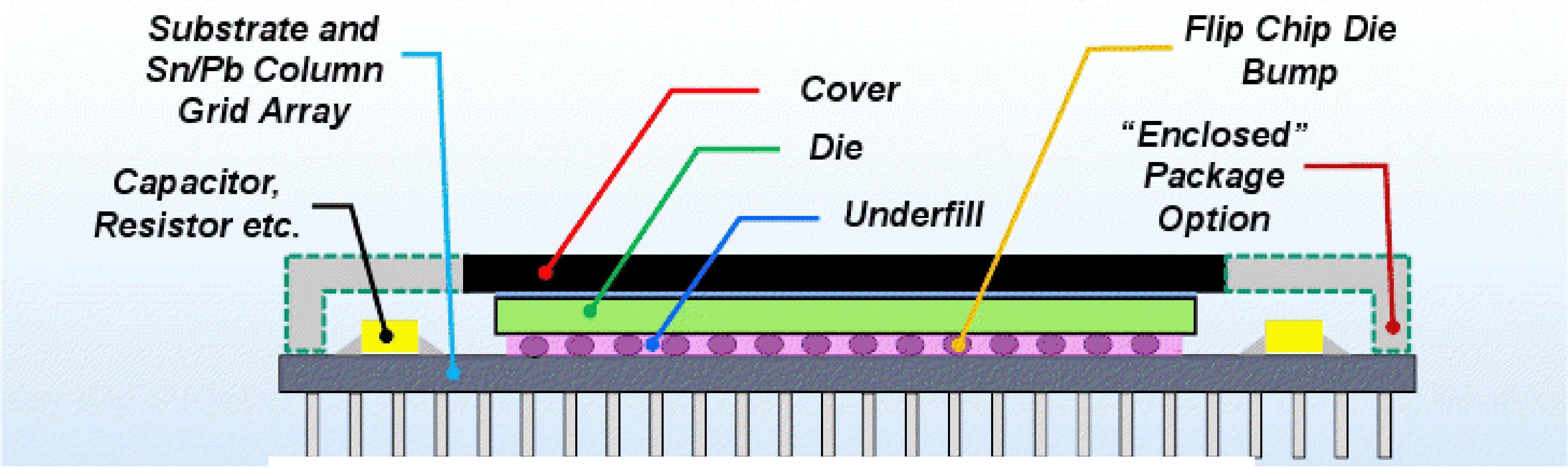
SPACE APPLICATION

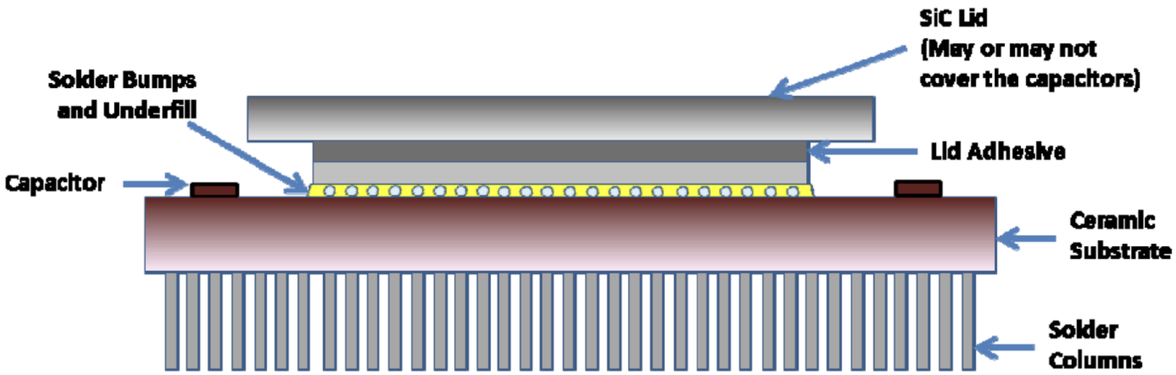
B.1 SCOPE

B.1.1 Scope. This appendix presents the requirements that are to be used to supplement this specification and the other applicable appendices for space level microcircuits. The manufacturer's process may include innovative and improved processes that result in an equivalent or higher quality product, provided that the process used to evaluate and document these changes has been reviewed and approved by the qualifying activity after coordination with the government space community (e.g., DTRA, NASA, NRO, and AFSMC). The approach outlined in this appendix is a proven baseline that contains details of the screening and technology conformance inspection (TCI) procedures. Manufacturers are to be able to demonstrate a process control system that achieves at least the same level of quality as could be achieved by complying with this appendix. This appendix is intended for product to be used in space applications. This appendix is a mandatory part of the specification. The information contained herein is intended for compliance.

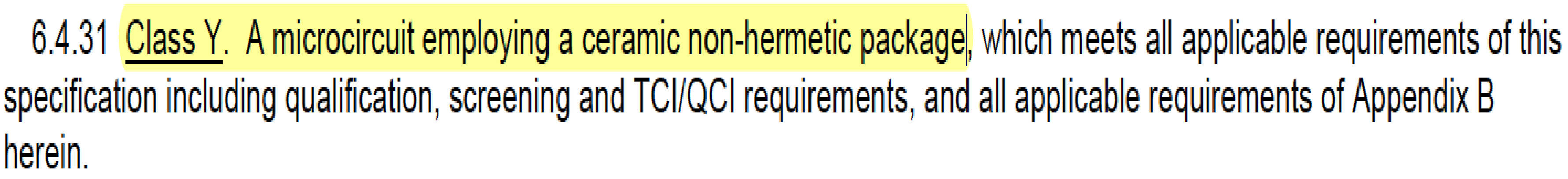
NASA Class Y "Non –Hermetic"

Non-hermetic Package, With"Space" Features (CCGA*?)

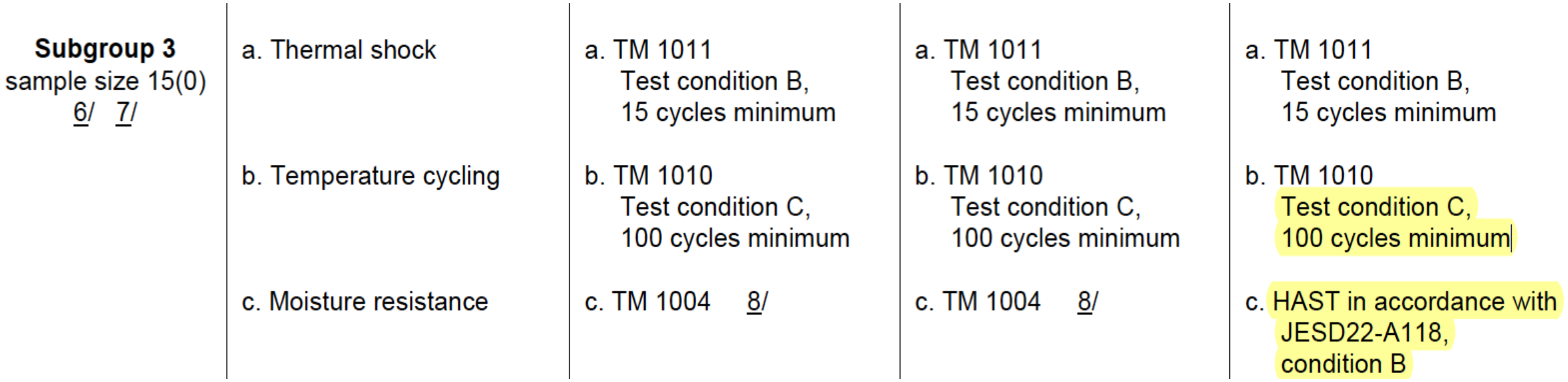




MIL-PRF-38535 Class Y Space

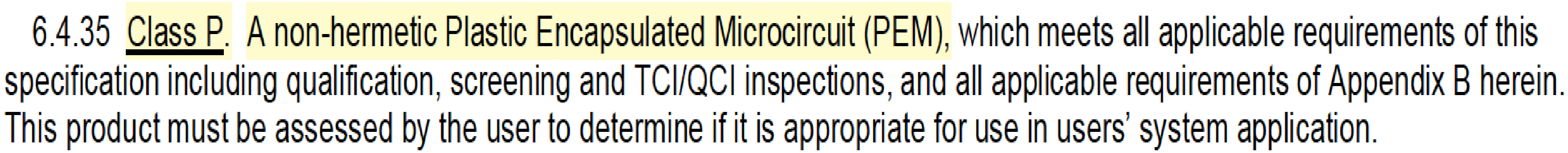


6.4.31 Class Y. A microcircuit employing a ceramic non-hermetic package, which meets all applicable requirements of this specification including qualification, screening and TCI/QCI requirements, and all applicable requirements of Appendix B herein.

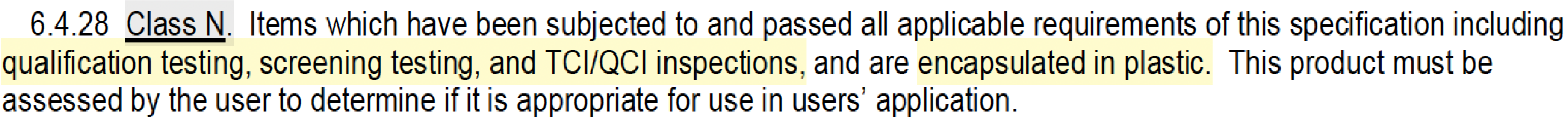


Subgroup 3 sample size 15(0) 6/ 7/	a. Thermal shock	a. TM 1011 Test condition B, 15 cycles minimum	a. TM 1011 Test condition B, 15 cycles minimum	a. TM 1011 Test condition B, 15 cycles minimum
	b. Temperature cycling	b. TM 1010 Test condition C, 100 cycles minimum	b. TM 1010 Test condition C, 100 cycles minimum	b. TM 1010 Test condition C, 100 cycles minimum
	c. Moisture resistance	c. TM 1004 8/	c. TM 1004 8/	c. HAST in accordance with JESD22-A118, condition B

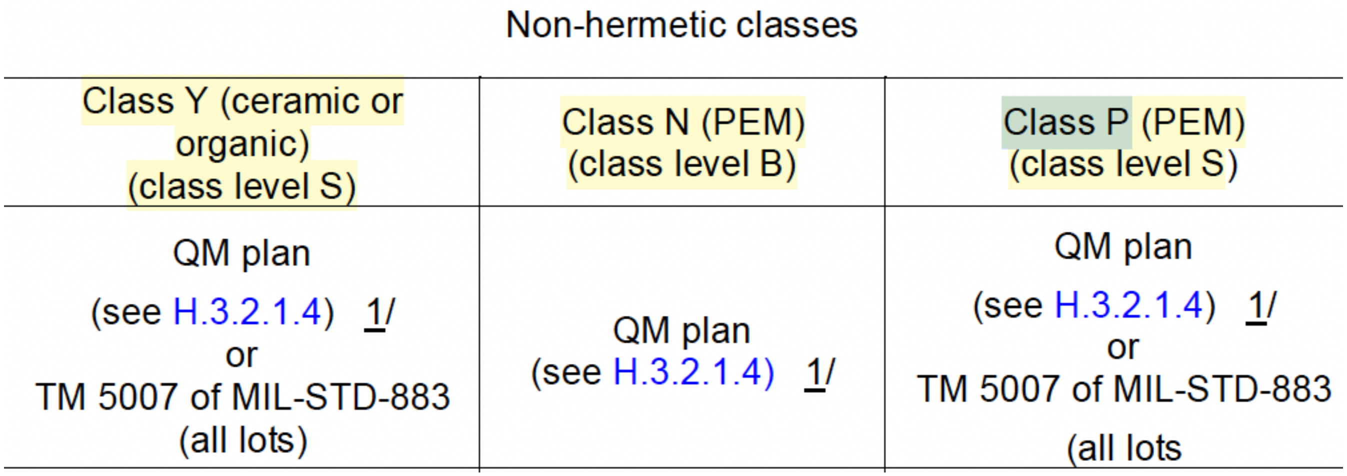
Mil-PRF-38535 Plastic PEM Specs



6.4.35 Class P. A non-hermetic Plastic Encapsulated Microcircuit (PEM), which meets all applicable requirements of this specification including qualification, screening and TCI/QCI inspections, and all applicable requirements of Appendix B herein. This product must be assessed by the user to determine if it is appropriate for use in users' system application.



6.4.28 Class N. Items which have been subjected to and passed all applicable requirements of this specification including qualification testing, screening testing, and TCI/QCI inspections, and are encapsulated in plastic. This product must be assessed by the user to determine if it is appropriate for use in users' application.

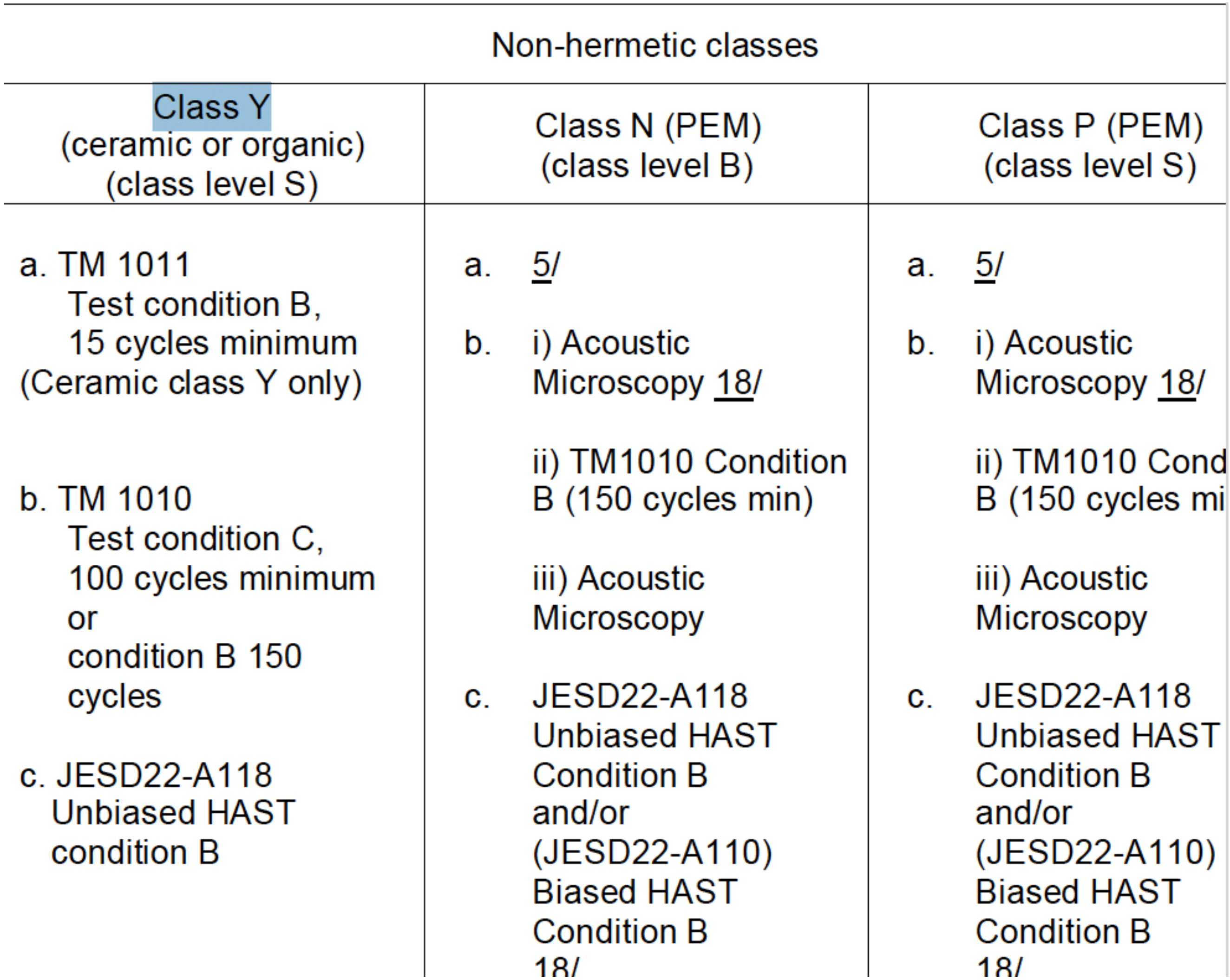


Non-hermetic classes

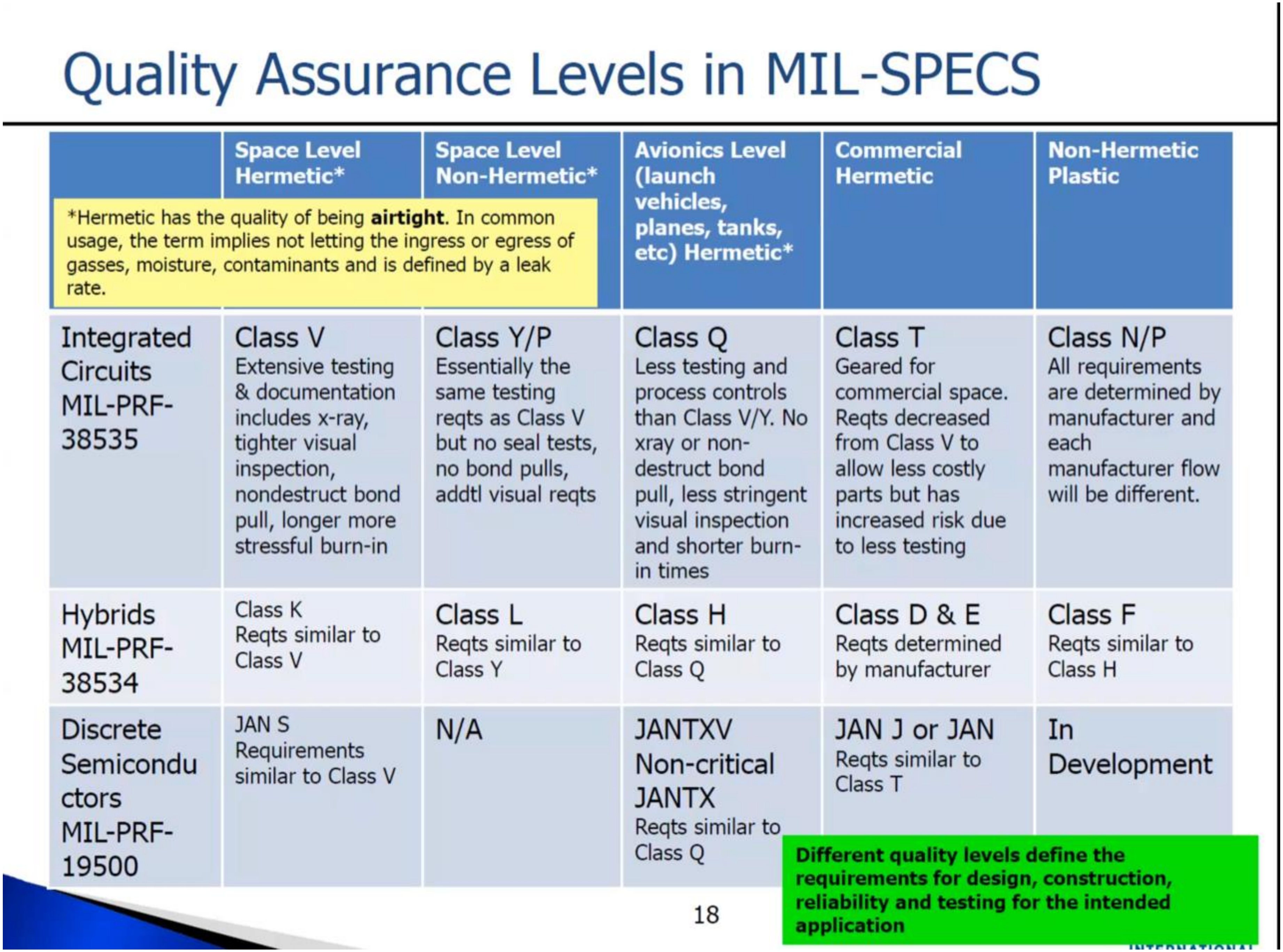
Class Y (ceramic or organic) (class level S)	Class N (PEM) (class level B)	Class P (PEM) (class level S)
QM plan (see H.3.2.1.4) 1/ or TM 5007 of MIL-STD-883 (all lots)	QM plan (see H.3.2.1.4) 1/	QM plan (see H.3.2.1.4) 1/ or TM 5007 of MIL-STD-883 (all lots

NOTES: No Hermeticity tests, no RGA, No PIND testing
Polymers per 5011 and outgassing per E595, same internal visuals per TM 2010

Group D Moisture resistance



Non-hermetic classes		
Class Y (ceramic or organic) (class level S)	Class N (PEM) (class level B)	Class P (PEM) (class level S)
a. TM 1011 Test condition B, 15 cycles minimum (Ceramic class Y only)	a. 5/	a. 5/
b. TM 1010 Test condition C, 100 cycles minimum or condition B 150 cycles	b. i) Acoustic Microscopy 18/ ii) TM1010 Condition B (150 cycles min) iii) Acoustic Microscopy	b. i) Acoustic Microscopy 18/ ii) TM1010 Cond B (150 cycles mi iii) Acoustic Microscopy
c. JESD22-A118 Unbiased HAST condition B	c. JESD22-A118 Unbiased HAST Condition B and/or (JESD22-A110) Biased HAST Condition B 18/	c. JESD22-A118 Unbiased HAST Condition B and/or (JESD22-A110) Biased HAST Condition B 18/



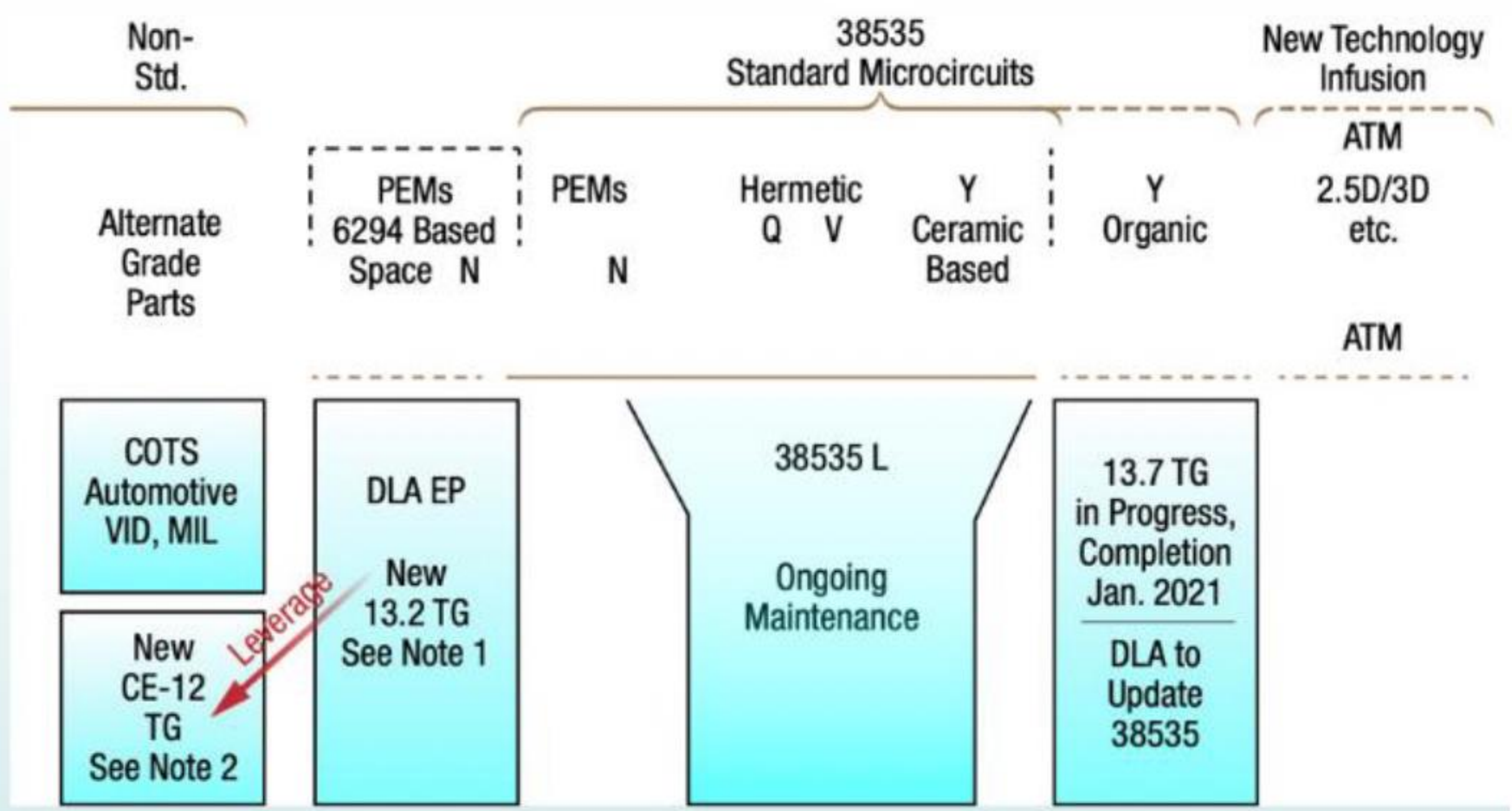
Quality Assurance Levels in MIL-SPECS

	Space Level Hermetic*	Space Level Non-Hermetic*	Avionics Level (launch vehicles, planes, tanks, etc) Hermetic*	Commercial Hermetic	Non-Hermetic Plastic
Integrated Circuits MIL-PRF-38535	Class V Extensive testing & documentation includes x-ray, tighter visual inspection, nondestruct bond pull, longer more stressful burn-in	Class Y/P Essentially the same testing reqts as Class V but no seal tests, no bond pulls, addtl visual reqts	Class Q Less testing and process controls than Class V/Y. No xray or non-destruct bond pull, less stringent visual inspection and shorter burn-in times	Class T Geared for commercial space. Reqts decreased from Class V to allow less costly parts but has increased risk due to less testing	Class N/P All requirements are determined by manufacturer and each manufacturer flow will be different.
Hybrids MIL-PRF-38534	Class K Reqts similar to Class V	Class L Reqts similar to Class Y	Class H Reqts similar to Class Q	Class D & E Reqts determined by manufacturer	Class F Reqts similar to Class H
Discrete Semiconductors MIL-PRF-19500	JAN S Requirements similar to Class V	N/A	JANTXV Non-critical JANTX Reqts similar to Class Q	JAN J or JAN Reqts similar to Class T	In Development

*Hermetic has the quality of being **airtight**. In common usage, the term implies not letting the ingress or egress of gasses, moisture, contaminants and is defined by a leak rate.

Different quality levels define the requirements for design, construction, reliability and testing for the intended application

PEMS Qual Standards



- **Note 1: Standard PEMs for Space initiative. Supported by NEPAG.**
- **Note 2: For alternate grade microcircuits, follow the activity in 13.2 TG to avoid any duplication of effort. Will be discussed on the next NEPAG telecon (slated for Sep 30 2020).**

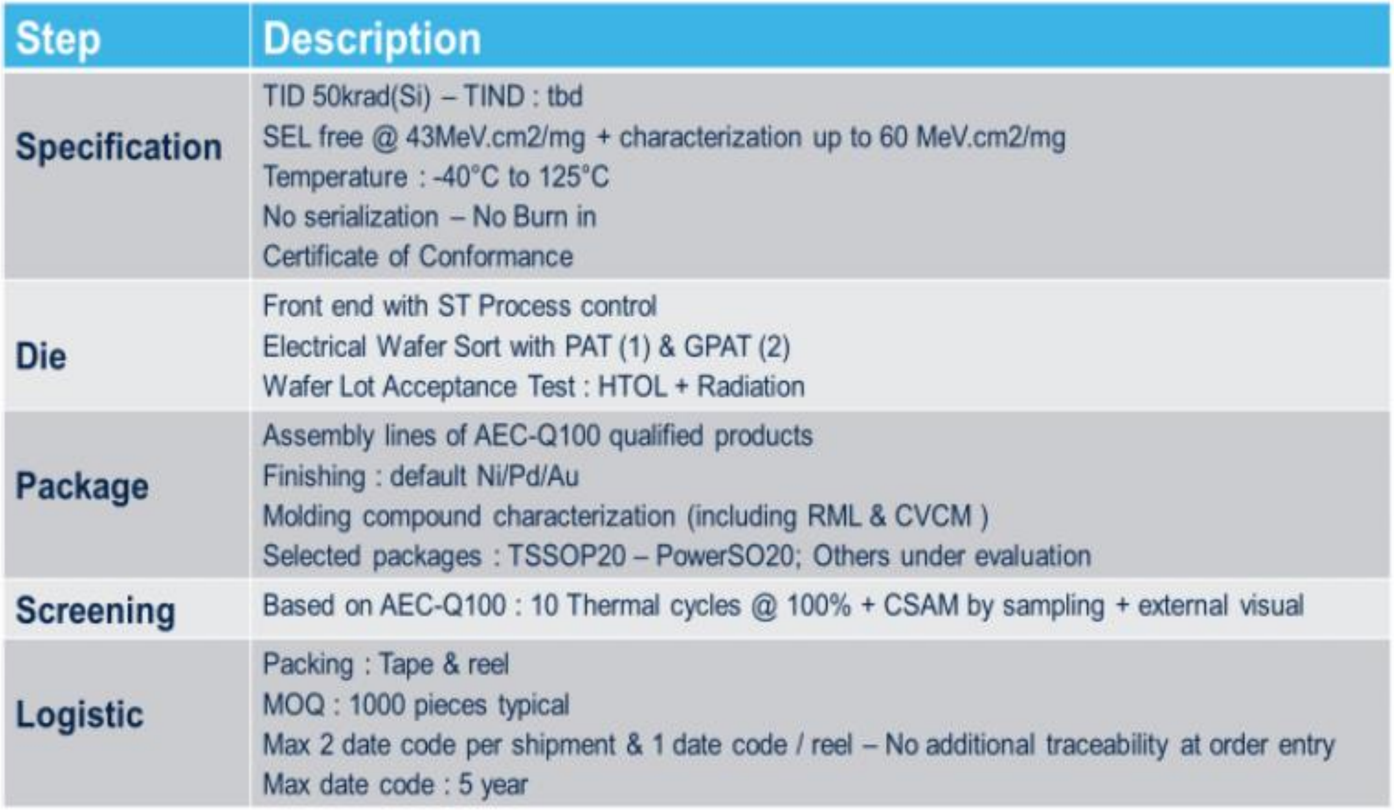
Figure 1. Options for standard, nonstandard, and new-technology microcircuits.

Volume 12, Issue 1,[1] October 20th, 2020

Non-Hermetic and Plastic-Encapsulated Microcircuits, Part 2, [2] Revised April 2021

PEMS Qual Standards

Companies like STM, TI, ADI have developed new non-hermetic products to support NASA's "New Space" mission



Step	Description
Specification	TID 50krad(Si) – TIND : tbd SEL free @ 43MeV.cm2/mg + characterization up to 60 MeV.cm2/mg Temperature : -40°C to 125°C No serialization – No Burn in Certificate of Conformance
Die	Front end with ST Process control Electrical Wafer Sort with PAT (1) & GPAT (2) Wafer Lot Acceptance Test : HTOL + Radiation
Package	Assembly lines of AEC-Q100 qualified products Finishing : default Ni/Pd/Au Molding compound characterization (including RML & CVCM) Selected packages : TSSOP20 – PowerSO20; Others under evaluation
Screening	Based on AEC-Q100 : 10 Thermal cycles @ 100% + CSAM by sampling + external visual
Logistic	Packing : Tape & reel MOQ : 1000 pieces typical Max 2 date code per shipment & 1 date code / reel – No additional traceability at order entry Max date code : 5 year

Figure 6. STMicroelectronics Rad-Hard LEO product line (plastic packaging) (www.st.com).

October 2019–March 2020 • Volume 11, Issue 1,[1] May 15, 2020

Non-Hermetic and Plastic-Encapsulated Microcircuits

MIL-PRF-ATM Development

JEDEC JC 13.7 and SAE CE-12 Task Group

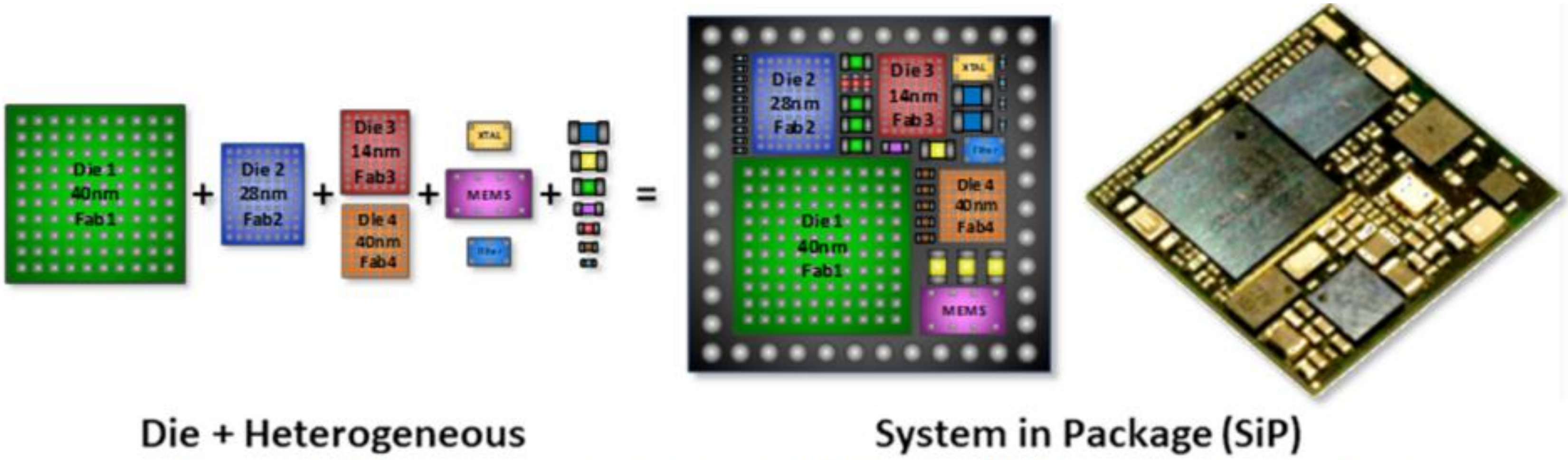
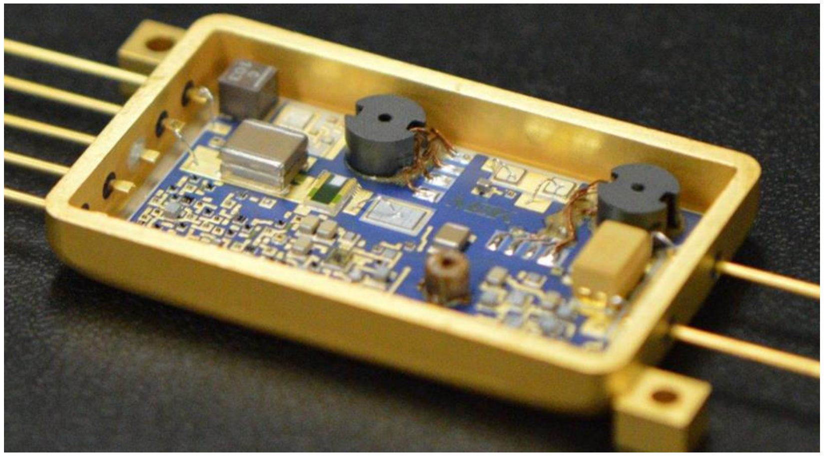


Figure 6. Heterogeneous Integration and System in Package (SiP). Source: ASE

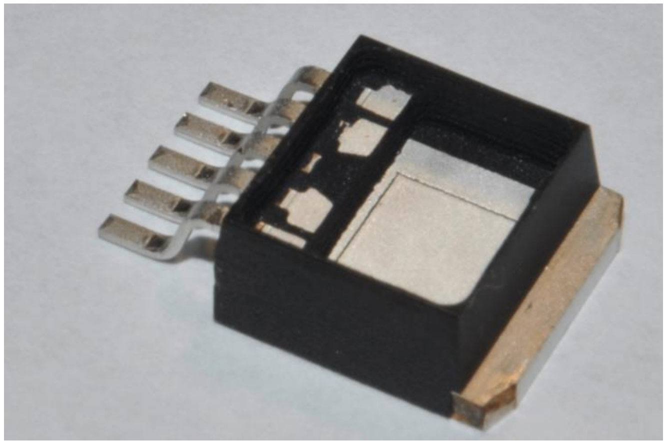
MIL-PRF-ATM (Advanced Technology Microcircuit) is intended to provide an avenue to introduce advanced packaged ICs with through silicon via (TSV) and other integration technologies into the Military and Space QML system

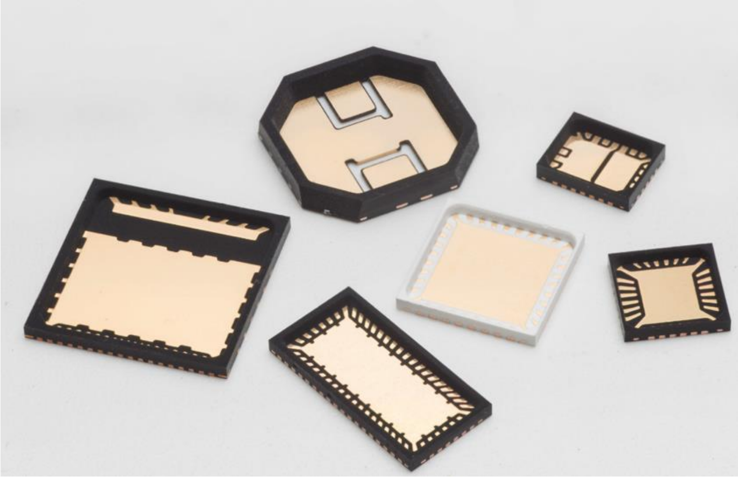
MIL-PRF-ATM works alongside MIL-PRF-38535 (Integrated Circuits) and MIL-PRF-38534 (Hybrids) to ensure there is a path for EEE components using these integration methods to be included in the QML system

Non-Hermetic Hybrid Qualification



- Traditional Hybrid in hermetic can





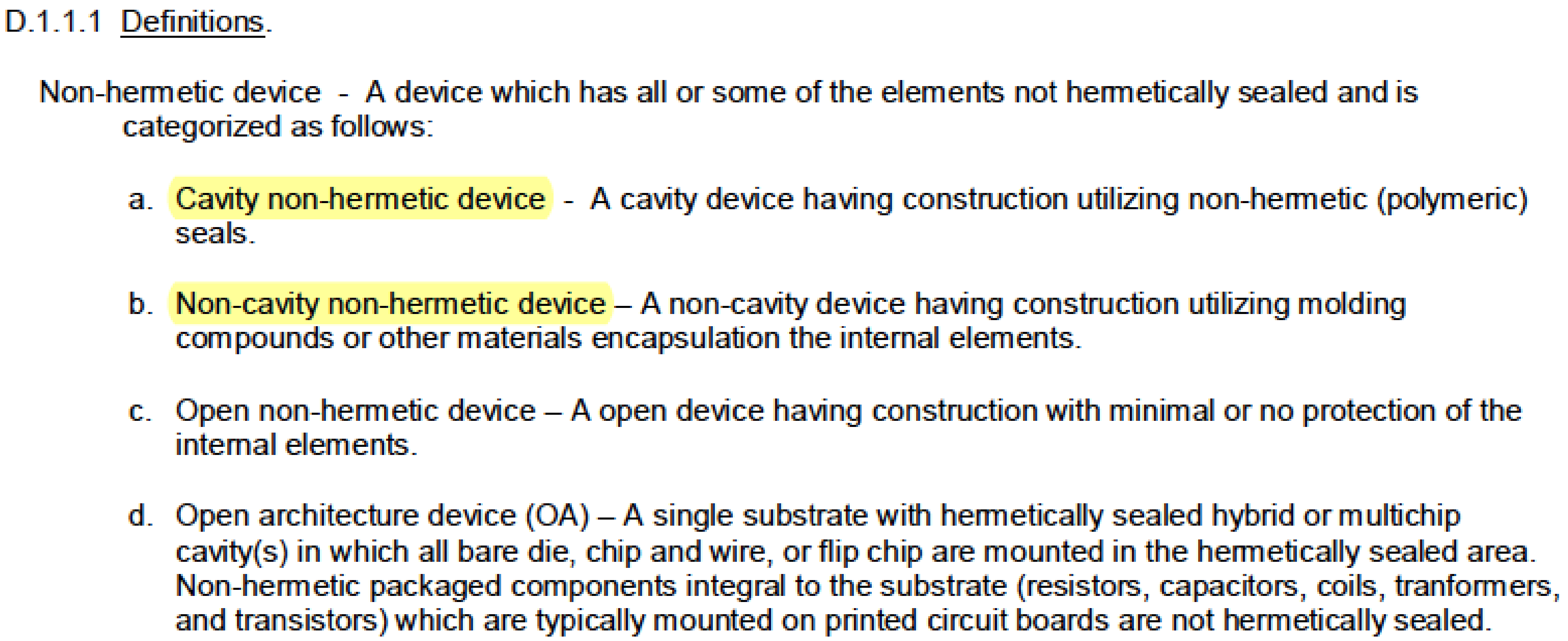
- Open Cavity Plastic Packages (OCPP) are the ideal platform for new IC prototypes, because they are mechanically and electrically identical to your future transfer molded production parts.

Open-molded Plastic Package (OmPP) is a pre-molded, air cavity QFN package (Quad Flat No-Lead)

https://www.doeeet.com/content/eee-components/actives/hermetic-packages-in-space-environment/

QPTECHNOLOGIES
FORMERLY QUIK-PAK

MIL-PRF-38534L Appendix D
Non-Hermetic Device Qual Requirements



D.1.1.1 Definitions.

Non-hermetic device - A device which has all or some of the elements not hermetically sealed and is categorized as follows:

a. Cavity non-hermetic device - A cavity device having construction utilizing non-hermetic (polymeric) seals.

b. Non-cavity non-hermetic device – A non-cavity device having construction utilizing molding compounds or other materials encapsulation the internal elements.

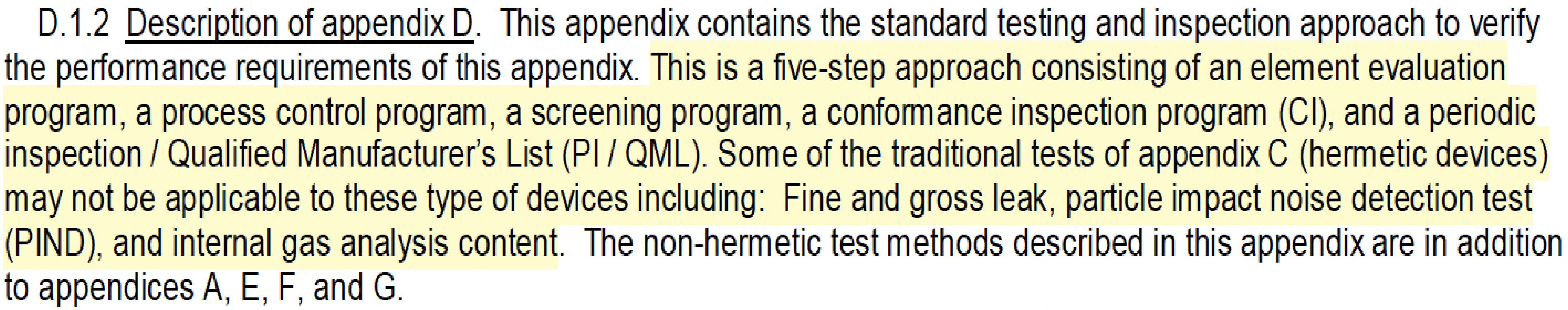
c. Open non-hermetic device – A open device having construction with minimal or no protection of the internal elements.

d. Open architecture device (OA) – A single substrate with hermetically sealed hybrid or multichip cavity(s) in which all bare die, chip and wire, or flip chip are mounted in the hermetically sealed area. Non-hermetic packaged components integral to the substrate (resistors, capacitors, coils, tranformers, and transistors) which are typically mounted on printed circuit boards are not hermetically sealed.

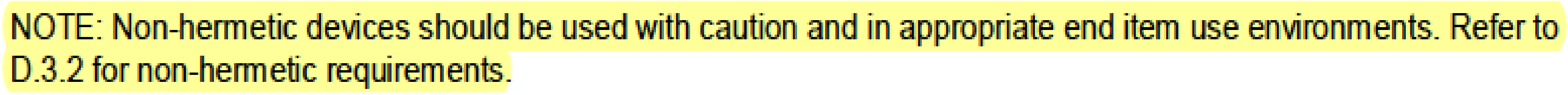
Class L Non-Hermetic (-55 to 125 C) Class F Non-Hermetic (-40 to 85 C)

MIL-PRF-38534L (Hybrids)

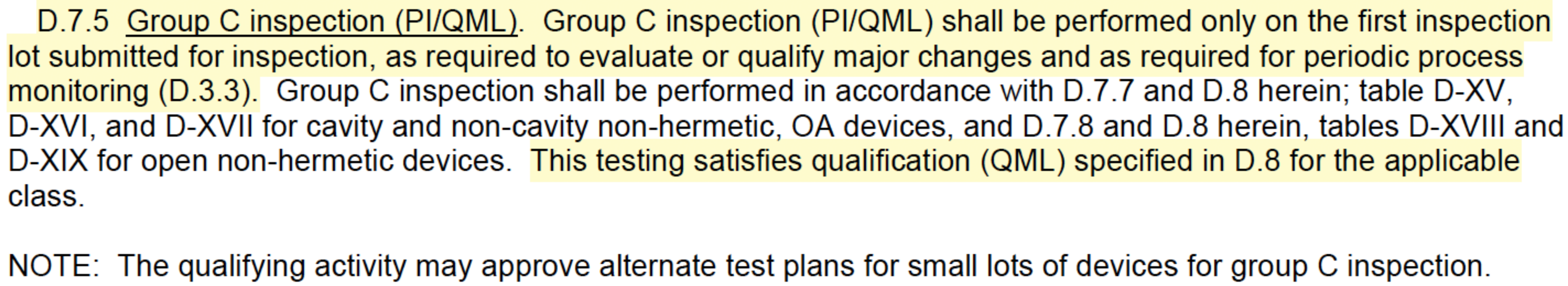
Appendix D: Non-Hermetic Device Qual Requirements



D.1.2 Description of appendix D. This appendix contains the standard testing and inspection approach to verify the performance requirements of this appendix. This is a five-step approach consisting of an element evaluation program, a process control program, a screening program, a conformance inspection program (CI), and a periodic inspection / Qualified Manufacturer's List (PI / QML). Some of the traditional tests of appendix C (hermetic devices) may not be applicable to these type of devices including: Fine and gross leak, particle impact noise detection test (PIND), and internal gas analysis content. The non-hermetic test methods described in this appendix are in addition to appendices A, E, F, and G.



NOTE: Non-hermetic devices should be used with caution and in appropriate end item use environments. Refer to D.3.2 for non-hermetic requirements.



D.7.5 Group C inspection (PI/QML). Group C inspection (PI/QML) shall be performed only on the first inspection lot submitted for inspection, as required to evaluate or qualify major changes and as required for periodic process monitoring (D.3.3). Group C inspection shall be performed in accordance with D.7.7 and D.8 herein; table D-XV, D-XVI, and D-XVII for cavity and non-cavity non-hermetic, OA devices, and D.7.8 and D.8 herein, tables D-XVIII and D-XIX for open non-hermetic devices. This testing satisfies qualification (QML) specified in D.8 for the applicable class.

NOTE: The qualifying activity may approve alternate test plans for small lots of devices for group C inspection.

To my understanding no company has successfully tested and qualified a non-hermetic hybrid as per Appendix D.

MIL-PRF-38534L (Hybrids)

REVIEW TABLE

Appendix D: Non-Hermetic Device Qual Requirements

IMO its very rigorous and maybe too much for example for the initial QML qual Class F after pre-conditioning the following tests are preformed and then repeated after 100 Temp Cycles!…….

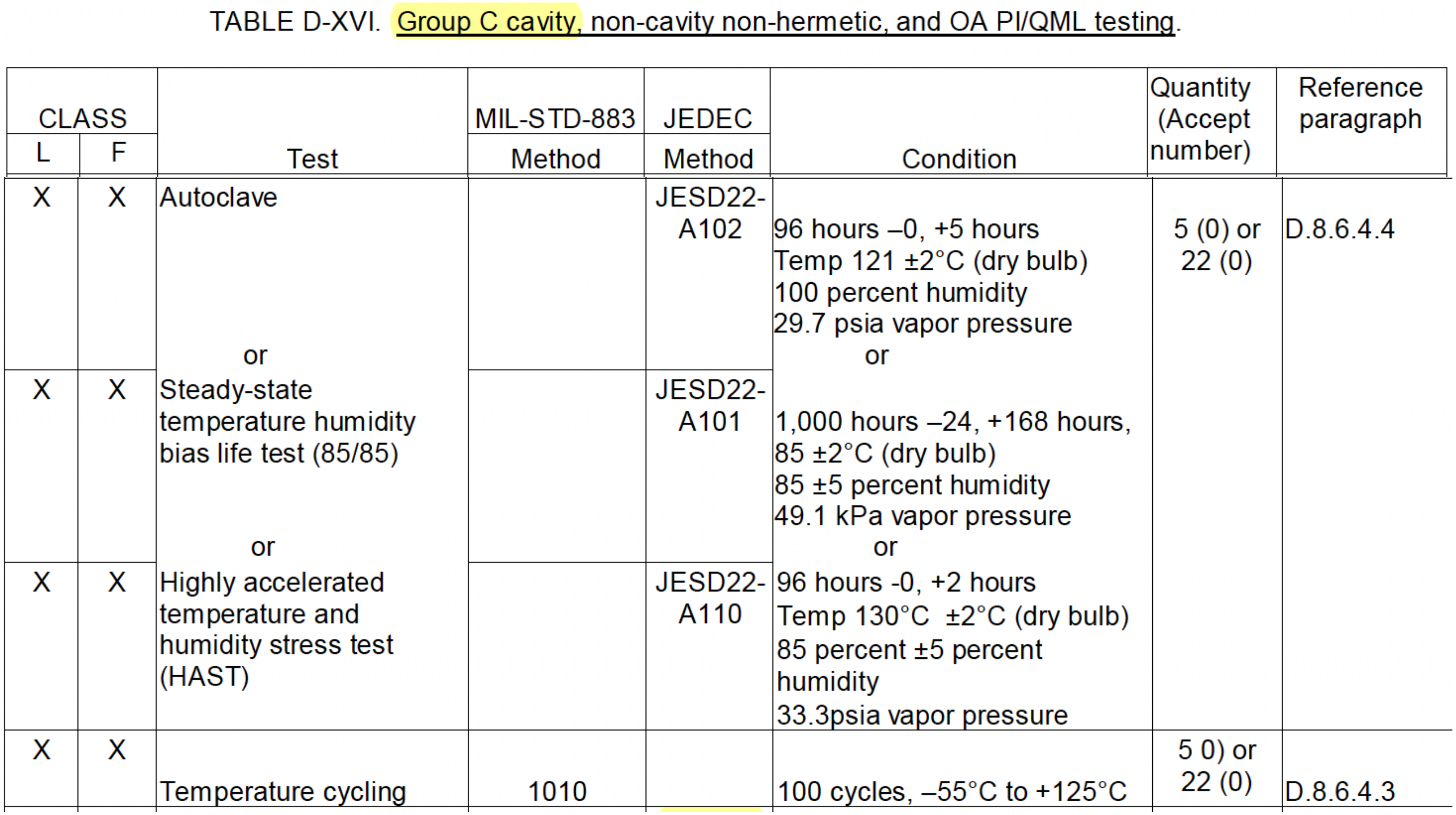


TABLE D-XVI. Group C cavity, non-cavity non-hermetic, and OA PI/QML testing.

CLASS		Test	MIL-STD-883	JEDEC	Condition	Quantity (Accept number)	Reference paragraph
L	F		Method	Method			
X	X	Autoclave		JESD22-A102	96 hours –0, +5 hours Temp 121 ±2°C (dry bulb) 100 percent humidity 29.7 psia vapor pressure	5 (0) or 22 (0)	D.8.6.4.4
		or			or		
X	X	Steady-state temperature humidity bias life test (85/85)		JESD22-A101	1,000 hours –24, +168 hours, 85 ±2°C (dry bulb) 85 ±5 percent humidity 49.1 kPa vapor pressure		
		or			or		
X	X	Highly accelerated temperature and humidity stress test (HAST)		JESD22-A110	96 hours -0, +2 hours Temp 130°C ±2°C (dry bulb) 85 percent ±5 percent humidity 33.3psia vapor pressure		
X	X	Temperature cycling	1010		100 cycles, –55°C to +125°C	5 0) or 22 (0)	D.8.6.4.3

Preconditioning for Cavity and Non-cavity

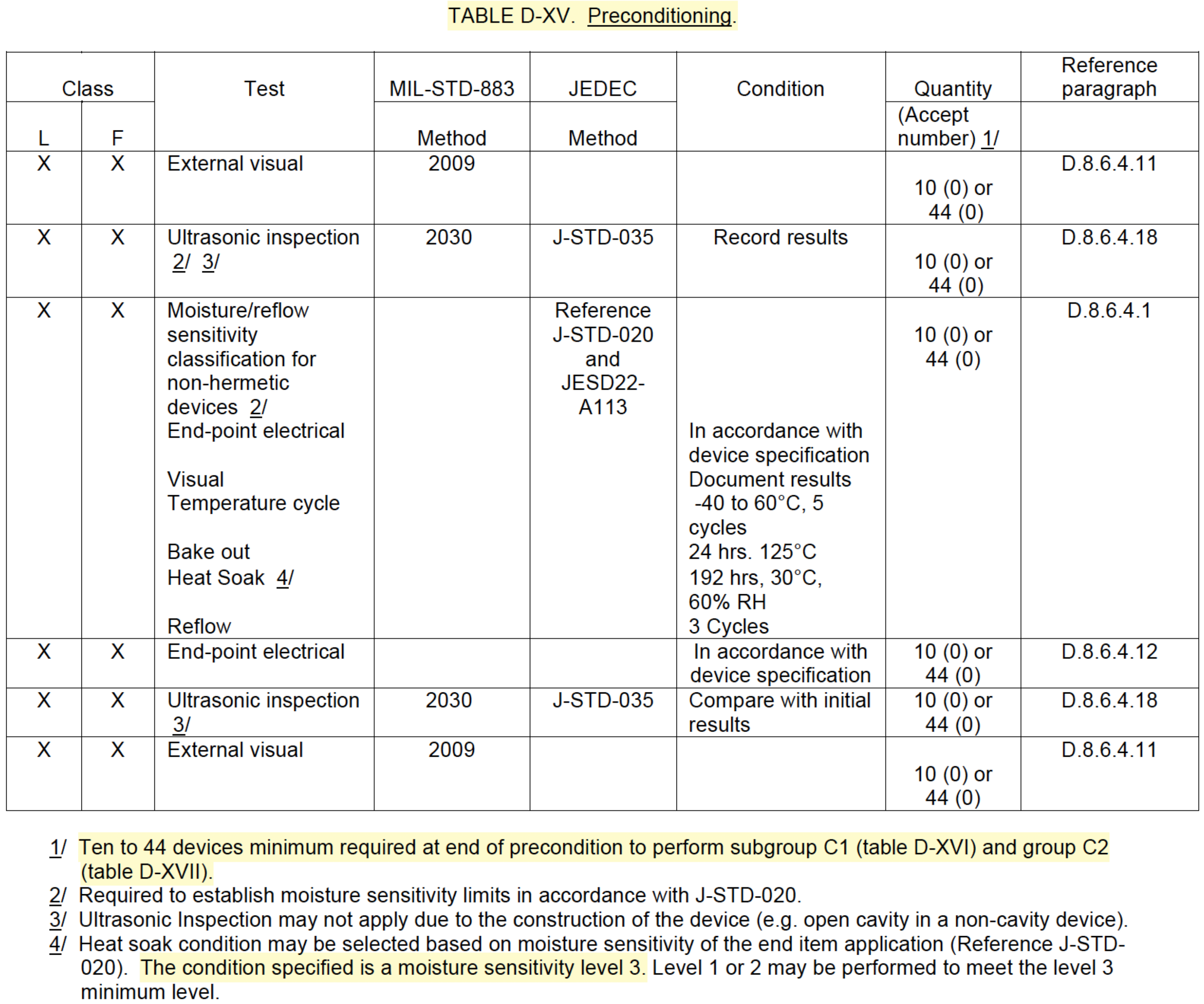


TABLE D-XV. Preconditioning.

Class		Test	MIL-STD-883	JEDEC	Condition	Quantity	Reference paragraph
L	F		Method	Method		(Accept number) 1/	
X	X	External visual	2009			10 (0) or 44 (0)	D.8.6.4.11
X	X	Ultrasonic inspection 2/ 3/	2030	J-STD-035	Record results	10 (0) or 44 (0)	D.8.6.4.18
X	X	Moisture/reflow sensitivity classification for non-hermetic devices 2/		Reference J-STD-020 and JESD22-A113		10 (0) or 44 (0)	D.8.6.4.1
		End-point electrical			In accordance with device specification		
		Visual			Document results		
		Temperature cycle			-40 to 60°C, 5 cycles		
		Bake out			24 hrs. 125°C		
		Heat Soak 4/			192 hrs, 30°C, 60% RH		
		Reflow			3 Cycles		
X	X	End-point electrical			In accordance with device specification	10 (0) or 44 (0)	D.8.6.4.12
X	X	Ultrasonic inspection 3/	2030	J-STD-035	Compare with initial results	10 (0) or 44 (0)	D.8.6.4.18
X	X	External visual	2009			10 (0) or 44 (0)	D.8.6.4.11

1/ Ten to 44 devices minimum required at end of precondition to perform subgroup C1 (table D-XVI) and group C2 (table D-XVII).
2/ Required to establish moisture sensitivity limits in accordance with J-STD-020.
3/ Ultrasonic Inspection may not apply due to the construction of the device (e.g. open cavity in a non-cavity device).
4/ Heat soak condition may be selected based on moisture sensitivity of the end item application (Reference J-STD-020). The condition specified is a moisture sensitivity level 3. Level 1 or 2 may be performed to meet the level 3 minimum level.

JESD47L vs Appendix D

- Appendix D is for QML companies already doing Element Evals, in process controls Periodic Inspection etc.
  - Element Eval for ICs, substrates and passive components as usual

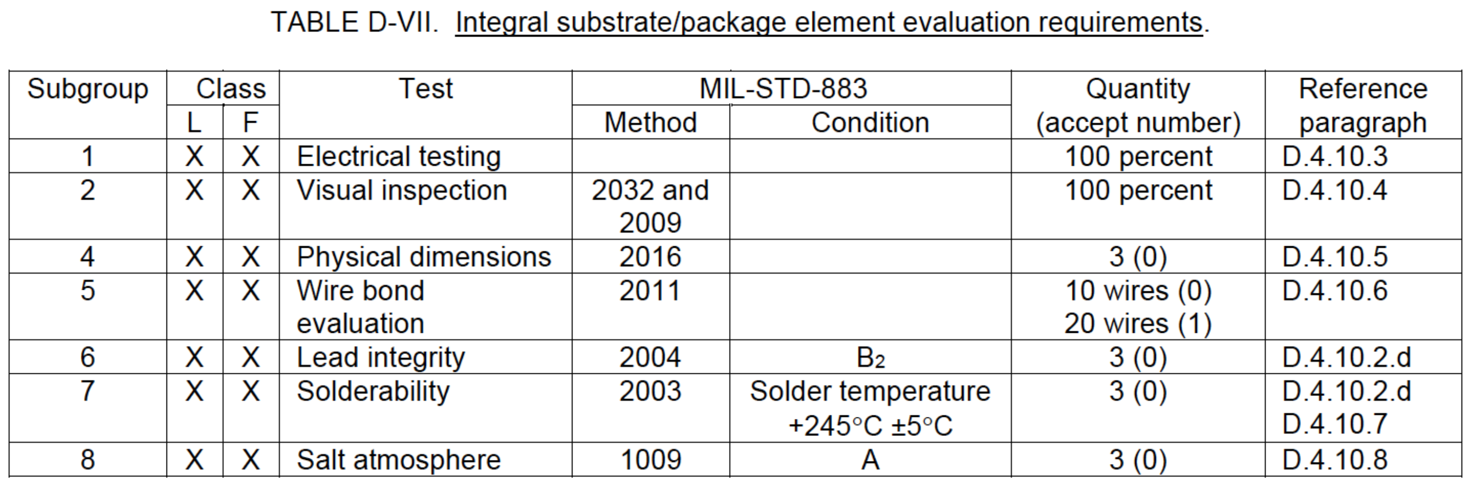
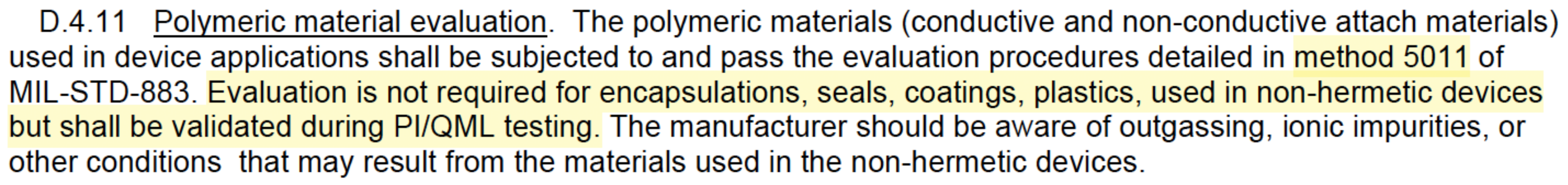


TABLE D-VII. Integral substrate/package element evaluation requirements.

Subgroup	Class		Test	MIL-STD-883		Quantity (accept number)	Reference paragraph
	L	F		Method	Condition		
1	X	X	Electrical testing			100 percent	D.4.10.3
2	X	X	Visual inspection	2032 and 2009		100 percent	D.4.10.4
4	X	X	Physical dimensions	2016		3 (0)	D.4.10.5
5	X	X	Wire bond evaluation	2011		10 wires (0) 20 wires (1)	D.4.10.6
6	X	X	Lead integrity	2004	B_2	3 (0)	D.4.10.2.d
7	X	X	Solderability	2003	Solder temperature +245°C ±5°C	3 (0)	D.4.10.2.d D.4.10.7
8	X	X	Salt atmosphere	1009	A	3 (0)	D.4.10.8

- TM 5011 compliance is only for the die attach materials

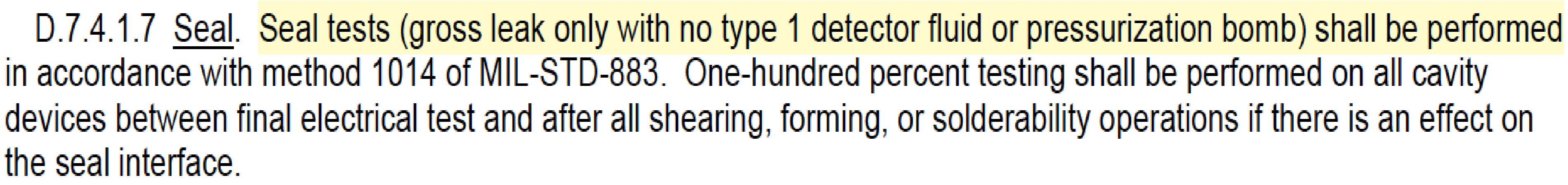


D.4.11 Polymeric material evaluation. The polymeric materials (conductive and non-conductive attach materials) used in device applications shall be subjected to and pass the evaluation procedures detailed in method 5011 of MIL-STD-883. Evaluation is not required for encapsulations, seals, coatings, plastics, used in non-hermetic devices but shall be validated during PI/QML testing. The manufacturer should be aware of outgassing, ionic impurities, or other conditions that may result from the materials used in the non-hermetic devices.

- Outgassing is a concern so NASA required testing per ANSI/ASTM E 595-84 “Standard Test Method for TML and CVCM from Outgassing in a Vacuum Environment” will apply to space missions.

JESD47L vs Appendix D (Cont.)

- In-line process controls required for wirebonding but manufacturer's option to employ die shear, X-ray and/or ultrasonic methods to evaluate die attach
- Screening tests pretty much the same as Class K vs H…does 100% non-destruct pull test make sense in a plastic potted part?
- Slightly modified CI and PI
  - Resistance to solvents for marking of parts…does that make sense on plastic parts?
  - Gross Leak Test only per TM 1014 for Cavity Plastic parts



D.7.4.1.7 Seal. Seal tests (gross leak only with no type 1 detector fluid or pressurization bomb) shall be performed in accordance with method 1014 of MIL-STD-883. One-hundred percent testing shall be performed on all cavity devices between final electrical test and after all shearing, forming, or solderability operations if there is an effect on the seal interface.

JESD47L vs Appendix D (Cont.)

- PIND test is required for cavity devices….
  - Has anyone ever done a PIND test on a plastic cavity? Does it even work and how would you recover the particles?
- External Visual inspect per TM 2009 does that make sense on a plastic quad flatpack? Maybe for markings and the pins but there are no welds so sections of JEDEC 9C would be applicable
- Constant acceleration optional for non-cavity parts
- Preconditioning for devices that will be soldered with flux in reflow ovens
  - Both point to JESD 020 and JESD 22 A113
  - App D adds in ultrasonic and visuals per 883
  - If hand soldering than alternate methods must be used

JESD47L vs Appendix D (Cont.)

- Not only are the moisture stress tests applied before and after a 100 TCs but then a sample of those parts are burned in for 1,000 hrs with full electricals before and after.
  - Mil PRF-38535 do TC before HAST testing
- Not sure a chip and wire hybrid with a lid glued on will do very well in 100% humidity at 2 ATMs for 96 Hrs…100 TCs..then repeat???
  - But maybe with a coating inside and the right kind of lid seal epoxy
- This Appendix was released about 25 years ago may need to set up a JEDEC task group to revisit this
  - Look at what has been done in Mil Prf 38535 and Mil Prf 19500 and learn from that
  - Leverage off the AEC 100 but with expanded temp ranges
  - Just follow JESD 47

MIL-PRF-19500R Appendix J

This Appendix describes the verification system for Non-Hermetic qualified products for discrete semiconductors packaged as plastic molded parts

Non-hermetic packages are packages that do not contain a cavity and are molded such that the entire die is encapsulated by an epoxy thermoset molding compound. The requirements for this type of package are defined in the following paragraphs.

Method number	Test
AS6294/3	Requirements for Plastic Encapsulated Discrete Semiconductors in Space Applications
ASTM E1640	Standard Test Method for Assignment of the Glass Transition Temperature By Dynamic Mechanical Analysis
ASTM E595	Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment
J-STD-020	Joint IPC/JEDEC standard Moisture/Reflow Sensitivity Classification for Nonhermetic Solid State Surface Mount Devices
JESD22-A101	Steady-state temperature humidity bias life test (85/85) (Autoclave)
JESD22-A102	Accelerated Moisture Resistance, Unbiased Autoclave
JESD22-A110	Highly accelerated temperature and humidity stress test (HAST)
JESD22-A113	Preconditioning Procedures of Plastic Surface Mount Devices Prior to Reliability Testing
JESD22-A118	Accelerated Moisture Resistance, Unbiased HAST
MIL-STD-883-5, Method 5011	Evaluation and acceptance procedures for polymeric adhesives

MIL-PRF-19500 Appendix J:
Inclusion of Plastic Encapsulated Discrete Semiconductor Devices for Military Applications Task Group

Benny Damron
Jacobs Space Exploration Group
NASA Marshall Space Flight Center
Ronan Dillon, Microchip Ireland
Date 04-18-2019

PEMS Qual Standards

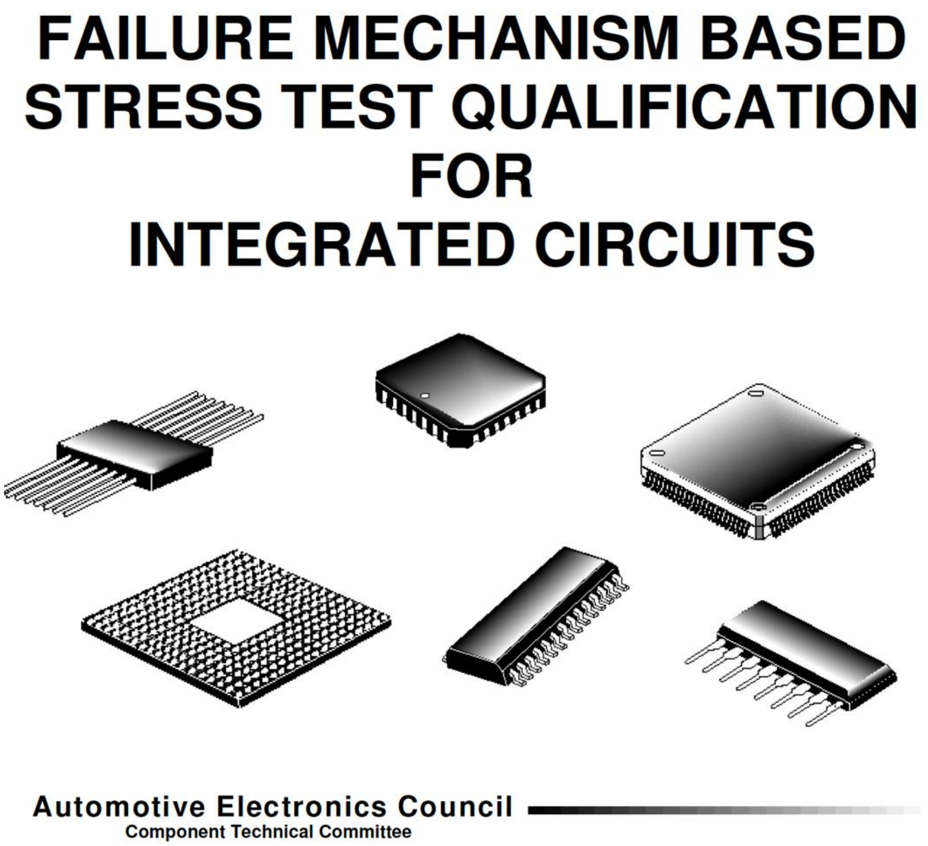
- Requirements for Plastic Encapsulated Microcircuits in Space Applications AS6294/1
- This SAE document establishes common industry practices and recommended screening, qualification, and lot acceptance testing of Plastic Encapsulated Microcircuits (PEMs) for use in space application environments
- Review NASA Note

Automotive Grade Parts AEC 100 and 200

AEC - Q100 - Rev-H
September 11, 2014

AEC - Q200 - Rev E
March 20, 2023

PASSIVE COMPONENTS



FAILURE MECHANISM BASED
STRESS TEST QUALIFICATION
FOR
INTEGRATED CIRCUITS

Automotive Electronics Council
Component Technical Committee

REVIEW DOC

- Tantalum and Niobium Capacitors
- Ceramic Capacitors
- Aluminum Electrolytic Capacitors
- Film Capacitors
- Magnetics
- Networks
- Resistors
- Thermistors
- Trimmer Capacitors/ Resistors
- Varistors
- Quartz Crystals
- Ceramic Resonators
- EMI Suppressors / Filters
- Polymeric Resettable Fuses
- Fuses
- Super Capacitors

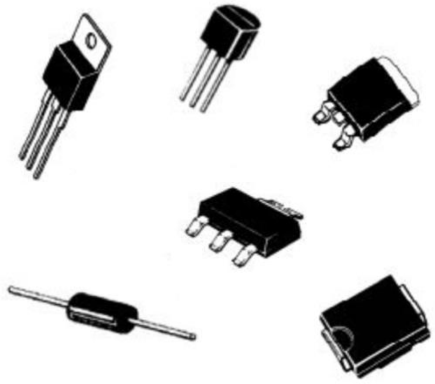
Automotive Grade Parts AEC 101

- **AEC-Q101** is a specification that defines the minimum stress test-driven qualification requirements and references test conditions for discrete semiconductors used in automotive applications. E.g. TRANSISTORS, DIODES, MOSFETS ECT

- Mil-Prf-19500 is the military equivalent for small lot sizes
- AEC-Q101 applies to discrete semiconductors such as transistors, diodes, and other non-integrated circuit devices used in automotive electronics. The minimum ambient temperature range for these devices is -40°C to +125°C, except for LEDs, which have a minimum range of -40°C to +85°C.

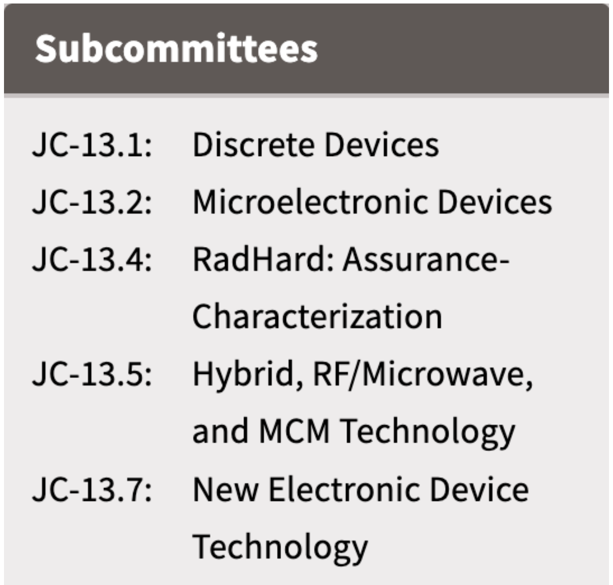
- AEC-Q101 is a comprehensive specification that outlines the stress test qualification requirements for discrete semiconductors used in automotive applications.

Plastic molded parts



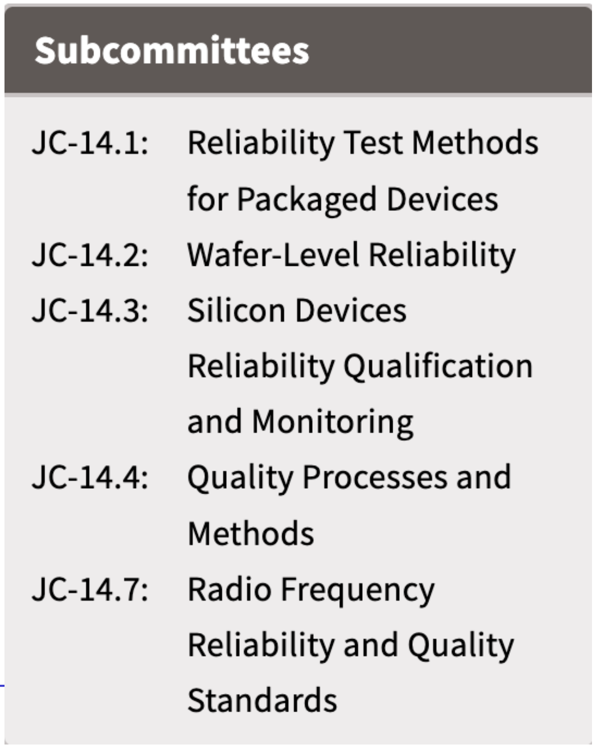
JEDEC and the SAE

- **JEDEC** Joint Electron Device Engineering Council is a subset of the **SAE** (Society of Automotive Engineers) https://www.sae.org/
- JEDEC 13 committee meets regularly three times a year to revise the Mil PRF docs and 883 and then presents the edits to DLA for approval
- The website contains a lot of useful information for IC manufacturers …
- There is a cost to join JEDEC for members specs are available at no charge
- JEDEC Link: http://www.jedec.org/
- JEDEC 14 is another important subcommittee doing a lot of work in the “non-hermetics” and next generation technology



Subcommittees

JC-13.1:	Discrete Devices
JC-13.2:	Microelectronic Devices
JC-13.4:	RadHard: Assurance-Characterization
JC-13.5:	Hybrid, RF/Microwave, and MCM Technology
JC-13.7:	New Electronic Device Technology



Subcommittees

JC-14.1:	Reliability Test Methods for Packaged Devices
JC-14.2:	Wafer-Level Reliability
JC-14.3:	Silicon Devices Reliability Qualification and Monitoring
JC-14.4:	Quality Processes and Methods
JC-14.7:	Radio Frequency Reliability and Quality Standards

IPC/JEDEC J-STD-020F

JOINT IPC/JEDEC Standard Moisture/Reflow Sensitivity Classification for Non-hermetic Surface Mount Devices (SMDs)

The purpose of this standard is to identify the classification level of non-hermetic SMDs designed for surface mount assembly that are sensitive to moisture-induced stress

The Moisture Sensitivity Levels (MSLs) rating generated for an SMD by this document is utilized to determine the soak conditions for preconditioning as per JESD22-A113

These MSL levels are important to people that use the parts and manufacture circuit boards because if the parts sit out out in ambient conditions for any length of time they will quickly absorb the moisture and than fracture during solder reflow (e.g. popcorning, delamination etc…

ALL PLASTIC PARTS HAVE SOME LEVEL OF SENSITIVITY TO MOISTURE

MSL Ratings for Plastic parts

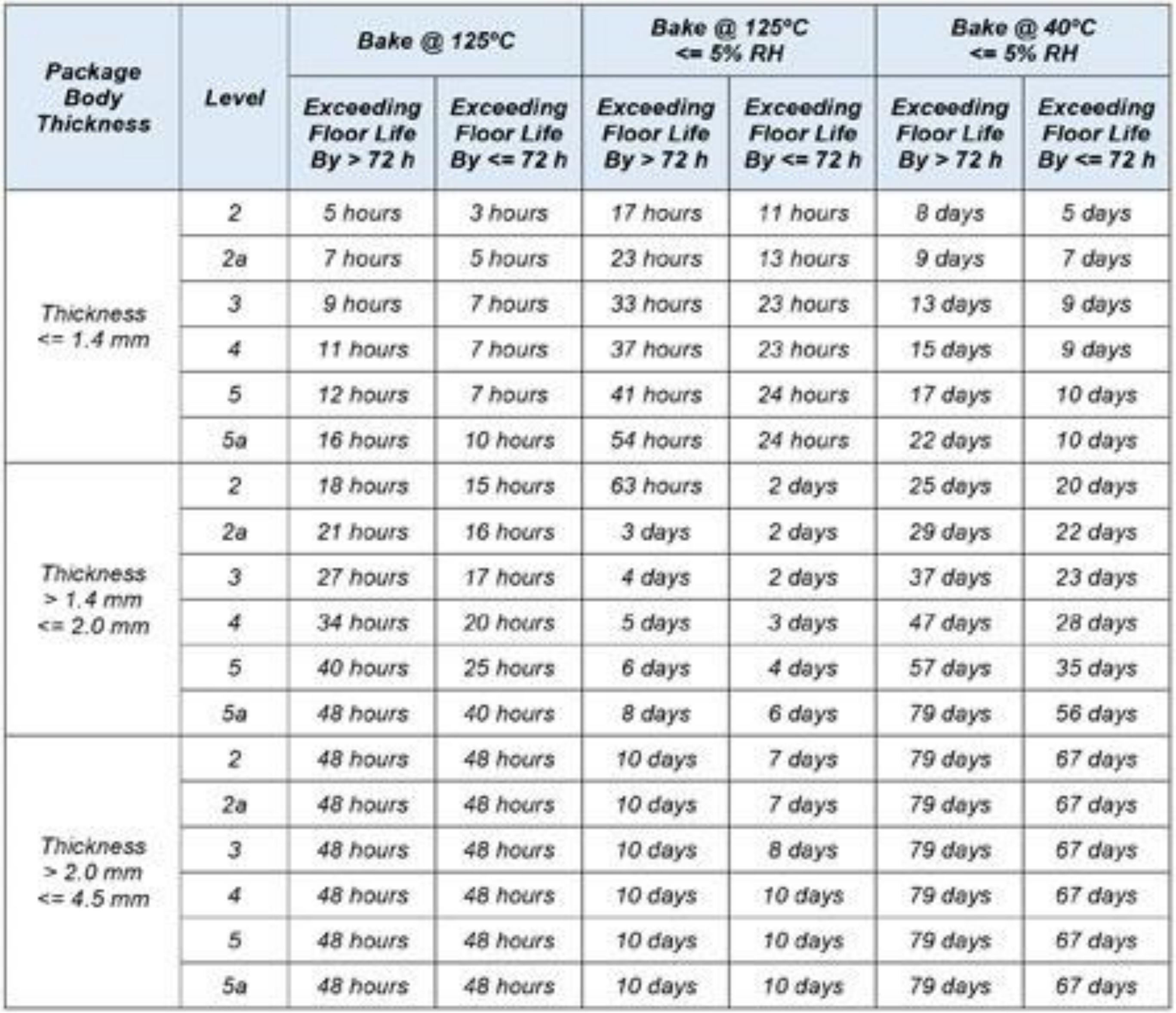
- Moisture sensitivity level (MSL) ratings relates to the packaging and handling precautions for some semiconductors. The MSL is an electronic standard for the time period in which a moisture sensitive device can be exposed to ambient room conditions (30 °C/85%RH at Level 1; 30 °C/60%RH at all other levels).
- Components such as thin fine-pitch devices and BGAs could be damaged during SMT reflow when moisture trapped inside the component expands.
- The expansion of trapped moisture can result in internal separation (delamination) of the plastic from the die or lead-frame, wire bond damage, die damage, and internal cracks. Most of this damage is not visible on the component surface. In extreme cases, cracks will extend to the component surface. In the most severe cases, the component will bulge and pop. This is known as the "popcorn" effect.
- Moisture sensitive devices are packaged in a moisture barrier antistatic bag with a desiccant and a moisture indicator card which is sealed.

MSL Levels

Table 4 — Moisture Sensitivity Levels

Level	Floor Life (Note 4)		Soak Requirements (Note 3)				
			Standard		Accelerated Equivalent (Note 1 & 5)		
					eV 0.40 - 0.48	eV 0.30 - 0.39	
	Time	Condition	Time (hours)	Condition	Time (hours)	Time (hours)	Condition
1	Unlimited	≤ 30°C/85% RH	168 +5/-0	85°C/85% RH	NA	NA	NA
2	1 year	≤ 30°C/60% RH	168 +5/-0	85°C/60% RH	NA	NA	NA
2a	4 weeks	≤ 30°C/60% RH	696 (Note 2) +5/-0	30°C/60% RH	120 +1/-0	168 +1/-0	60°C/60% RH
3	168 hours	≤ 30°C/60% RH	192 (Note 2) +5/-0	30°C/60% RH	40 +1/-0	52 +1/-0	60°C/60% RH
4	72 hours	≤ 30°C/60% RH	96 (Note 2) +2/-0	30°C/60% RH	20 +0.5/-0	24 +0.5/-0	60°C/60% RH
5	48 hours	≤ 30°C/60% RH	72 (Note 2) +2/ 0	30°C/60% RH	15 +0.5/-0	20 +0.5/-0	60°C/60% RH
5a	24 hours	≤ 30°C/60% RH	48 (Note 2) +2/-0	30°C/60% RH	10 +0.5/-0	13 +0.5/-0	60°C/60% RH
6	Time on Label (TOL)	≤ 30°C/60% RH	TOL	30°C/60% RH	NA	NA	NA

In the event that the non-hermetic package is exposed to atmosphere beyond the controlled floor life, dry-bake is required to extend floor life before future surface-mount solder reflow process. Dry-bake to extend floor life has to be performed according to the criteria and conditions in reference to the MSL classification and body thickness of the non-hermetic package. Table 4 shows the dry-bake criteria and conditions to extend floor life.



Package Body Thickness	Level	Bake @ 125°C		Bake @ 125°C <= 5% RH		Bake @ 40°C <= 5% RH	
		Exceeding Floor Life By > 72 h	Exceeding Floor Life By <= 72 h	Exceeding Floor Life By > 72 h	Exceeding Floor Life By <= 72 h	Exceeding Floor Life By > 72 h	Exceeding Floor Life By <= 72 h
Thickness <= 1.4 mm	2	5 hours	3 hours	17 hours	11 hours	8 days	5 days
	2a	7 hours	5 hours	23 hours	13 hours	9 days	7 days
	3	9 hours	7 hours	33 hours	23 hours	13 days	9 days
	4	11 hours	7 hours	37 hours	23 hours	15 days	9 days
	5	12 hours	7 hours	41 hours	24 hours	17 days	10 days
	5a	16 hours	10 hours	54 hours	24 hours	22 days	10 days
Thickness > 1.4 mm <= 2.0 mm	2	18 hours	15 hours	63 hours	2 days	25 days	20 days
	2a	21 hours	16 hours	3 days	2 days	29 days	22 days
	3	27 hours	17 hours	4 days	2 days	37 days	23 days
	4	34 hours	20 hours	5 days	3 days	47 days	28 days
	5	40 hours	25 hours	6 days	4 days	57 days	35 days
	5a	48 hours	40 hours	8 days	6 days	79 days	56 days
Thickness > 2.0 mm <= 4.5 mm	2	48 hours	48 hours	10 days	7 days	79 days	67 days
	2a	48 hours	48 hours	10 days	7 days	79 days	67 days
	3	48 hours	48 hours	10 days	8 days	79 days	67 days
	4	48 hours	48 hours	10 days	10 days	79 days	67 days
	5	48 hours	48 hours	10 days	10 days	79 days	67 days
	5a	48 hours	48 hours	10 days	10 days	79 days	67 days

Reference:

https://www.highfrequencyelectronics.com/index.php?option=com_content&view=article&id=1388:the-mystery-behind-msl-1-2-3&catid=136&Itemid=189

IPC/JEDEC J-STD-020F

Procedure:

1. Minimum sample of 22 devices for each MSL to be tested.
2. Electrical test
3. Inspect at 40X plus acoustic imaging and establish baseline for delaminations
4. Bake the devices for 24 hours minimum at 125°C +5/-0°Cto complete dry out
5. Soak per Table 5
6. Not sooner than 15 minutes and not longer than 4 hours after removal from the temperature/humidity chamber, subject the devices to 3 cycles of the appropriate reflow conditions as defined in Table 5 and in Figure 1.
7. Visual at 40X looking for cracks
8. Final Electrical
9. Final acoustic
10. **Visual at 40X looking for cracks**

IPC/JEDEC J-STD-020F

A device is considered a failure if it exhibits any of the following characteristics:

a. External crack visible using 40X optical microscope. It is highly desired to use 100X optical magnification or low vacuum scanning electron microscopy (SEM) to better observe any cracks that could be precursors to problems during the stress of operational life.
b. Electrical test failure.
c. Internal crack that intersects a bond wire, ball bond, or wedge bond.
d. Internal crack extending from any lead finger to any other internal feature (lead finger, chip, die attach paddle).
e. Internal crack extending more than 2/3 the distance from any internal feature to the outside of the device.
f. Changes in package body flatness caused by warpage, swelling, or bulging not visible to the naked eye per JESD22-B101. If parts still meet co-planarity and standoff dimensions as measured at room temperature per JESD22-B108, they shall be considered passing.

JESD22-A113I

Preconditioning of Nonhermetic Surface Mount Devices Prior to Reliability Testing

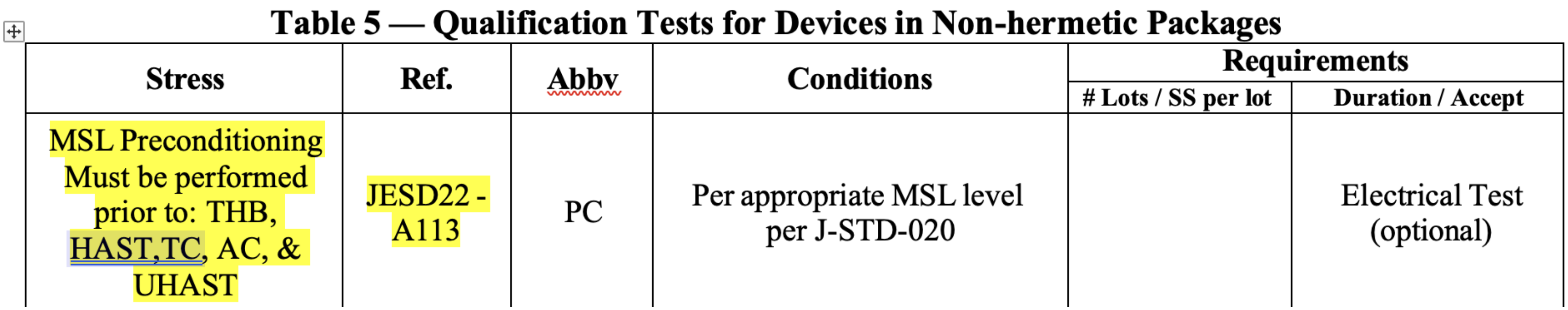


Table 5 — Qualification Tests for Devices in Non-hermetic Packages

Stress	Ref.	Abbv	Conditions	Requirements	
				# Lots / SS per lot	Duration / Accept
MSL Preconditioning Must be performed prior to: THB, HAST,TC, AC, & UHAST	JESD22 - A113	PC	Per appropriate MSL level per J-STD-020		Electrical Test (optional)

This Test Method establishes an industry standard preconditioning flow for non-hermetic solid state SMDs that is representative of a typical industry multiple solder reflow operation. These SMDs should be subjected to the appropriate preconditioning sequence of this document by the manufacturer prior to being submitted to specific in-house reliability testing (qualification and reliability monitoring) to evaluate long term reliability (which might be impacted by solder reflow).

(Review Spec if time)

SSB-1: GUIDELINES FOR USING PLASTIC ENCAPSULATED MICROCIRCUITS AND SEMICONDUCTORS IN MILITARY, AEROSPACE AND OTHER RUGGED APPLICATIONS

REVIEW SPEC

- This document describes tests frequently used in statistical reliability for PEMS and semiconductors and identifies the potential failure mechanisms monitored by these tests.
- Elevated stresses are used to produce the same failure mechanisms as would be observed under normal use conditions, but in a shorter time period.
- Describes acceleration factors that are frequently used by OEMs in conjunction with physics of failure reliability analysis to assess the suitability of plastic encapsulated microcircuits and semiconductors for specific end use applications.
- The statistical models described in this document for the basis of the testing in JESD 47 **Step-Stress Driven Qualification Testing of IC.**

Ref: Henry Livingston and G-12 committees

SSB-1 Acceleration Factors for Temp and Humidity

$$A_{ftv} = A_{ft} \bullet A_{fv}$$

Temperature - Humidity Effects (Hallberg - Peck)

$$A_f = \left(\frac{RH_t}{RH_u}\right)^3 \bullet \exp\left[\frac{E_a}{k} \bullet \left(\frac{1}{T_u} - \frac{1}{T_t}\right)\right]$$

A_f = acceleration factor

RH_u = use environment relative humidity

RH_t = test environment relative humidity

Ea = activation energy, 0.90eV

k = Boltzman's Constant (8.6171×10^{-5} eV)

T_u = use environment junction temperature (in °K)

T_t = test environment junction temperature (in °K)

$$t_t = A \bullet (\%RH)^n \bullet \exp\left(\frac{E_a}{kT}\right)$$

where t_t is time-to-failure, n = -2.66, Ea = 0.79eV, A is a constant (the temperature humidity failure rate in reference conditions)

This equation is often used to estimate acceleration factors for temperature-humidity and bias effects when applied to HAST test results, and for temperature-humidity effects when applied to autoclave (unbiased), specifically for corrosion of aluminum. Knowing the Af we can calculate and expected time to failure in the field.

JESD47L Stress-Test-Driven Qualification of Integrated Circuits

- This standard describes a baseline set of acceptance tests for use in qualifying electronic devices as new products, a product family, or as products in a process which is being changed.
- Table 5 — Qualification Tests for Devices in Non-hermetic Packages
  - See table on following pages and read the notes!
- Passing all appropriate qualification tests specified in Table 5, either by performing the test, showing equivalent data with a larger sample size, or demonstrating acceptable generic data (using an equivalent total percent defective at a 90% confidence limit for the total required lot and sample size), qualifies the device per this document.
- These stress-tests were empirically derived through the JEDEC 14.3 committee, based on results of member companies.

JESD47L Non-Hermetic Qual Sequence

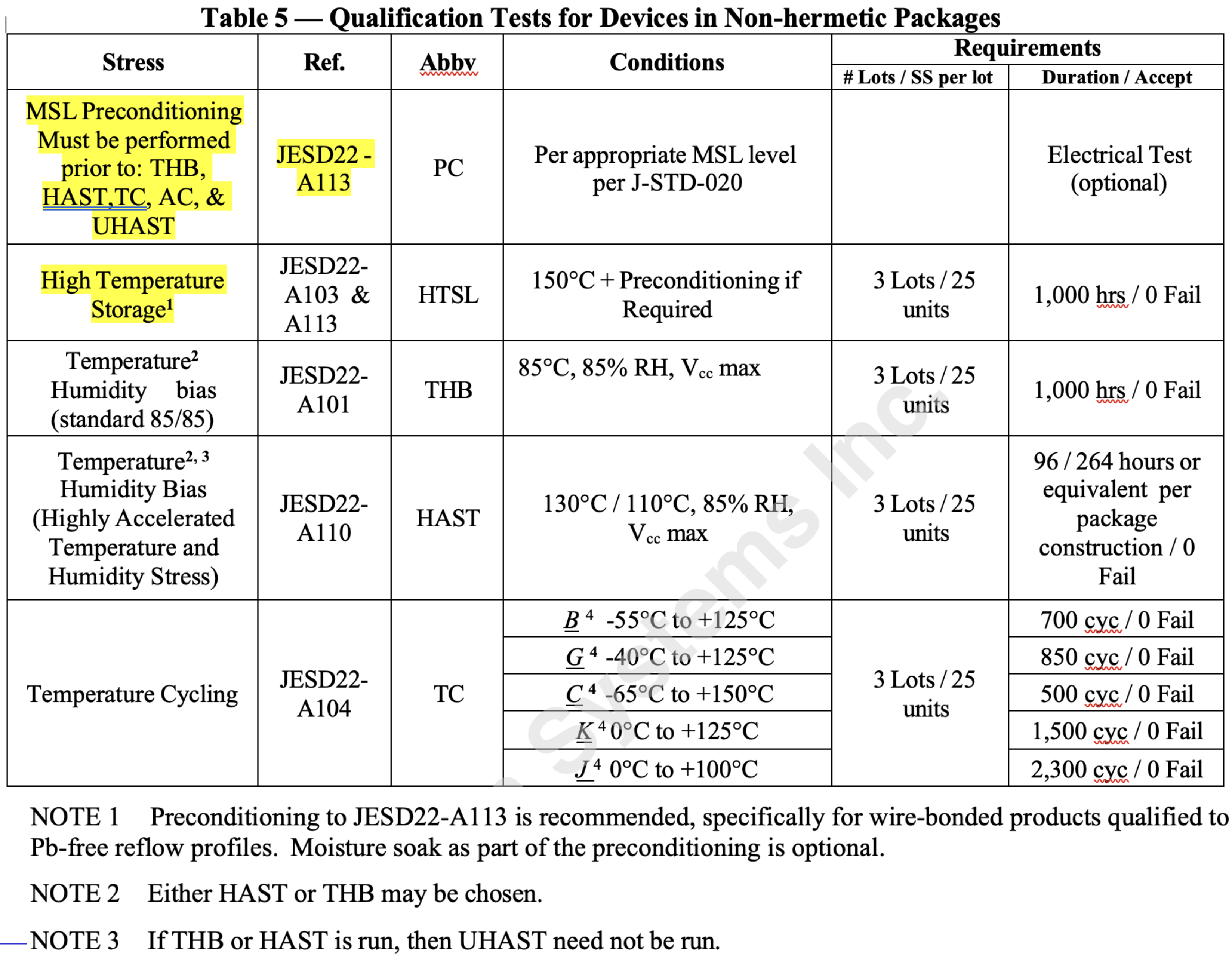


Table 5 — Qualification Tests for Devices in Non-hermetic Packages

Stress	**Ref.**	**Abbv**	**Conditions**	**Requirements**	
				# Lots / SS per lot	**Duration / Accept**
MSL Preconditioning Must be performed prior to: THB, HAST,TC, AC, & UHAST	JESD22 - A113	PC	Per appropriate MSL level per J-STD-020		Electrical Test (optional)
High Temperature Storage[1]	JESD22- A103 & A113	HTSL	150°C + Preconditioning if Required	3 Lots / 25 units	1,000 hrs / 0 Fail
Temperature[2] Humidity bias (standard 85/85)	JESD22- A101	THB	85°C, 85% RH, V_{cc} max	3 Lots / 25 units	1,000 hrs / 0 Fail
Temperature[2, 3] Humidity Bias (Highly Accelerated Temperature and Humidity Stress)	JESD22- A110	HAST	130°C / 110°C, 85% RH, V_{cc} max	3 Lots / 25 units	96 / 264 hours or equivalent per package construction / 0 Fail
Temperature Cycling	JESD22- A104	TC	B[4] -55°C to +125°C	3 Lots / 25 units	700 cyc / 0 Fail
			G[4] -40°C to +125°C		850 cyc / 0 Fail
			C[4] -65°C to +150°C		500 cyc / 0 Fail
			K[4] 0°C to +125°C		1,500 cyc / 0 Fail
			J[4] 0°C to +100°C		2,300 cyc / 0 Fail

NOTE 1 Preconditioning to JESD22-A113 is recommended, specifically for wire-bonded products qualified to Pb-free reflow profiles. Moisture soak as part of the preconditioning is optional.

NOTE 2 Either HAST or THB may be chosen.

NOTE 3 If THB or HAST is run, then UHAST need not be run.

JESD47L Non-Hermetic Qual Sequence (Con’t)

Solder Ball Shear	JESD22-B117	SBS	Characterization	30 balls / 5 units	
Wire Bond Pull[7]	JESD22-B120	BPS	Characterization, Pre Encapsulation	1 Lot / 30 bonds / 5 units	Ppk ≥ 1.66 or Cpk≥1.33 (note 6)
Bond Shear[7]	JESD22-B116	BS	Characterization, Pre Encapsulation	1 Lot / 30 bonds / 5 units	Ppk ≥ 1.66 or Cpk≥1.33 (note 6)
Solderability	M2003 J-STD-002	SD	Characterization	3 lots / 22 leads	0 Fail
Tin Whisker Acceptance	JESD22-A121 through rqmts of JESD201	WSR	Characterization per JESD201	See JESD201	See JESD201, Based on Appropriate Classification

Non-Hermetic Theory

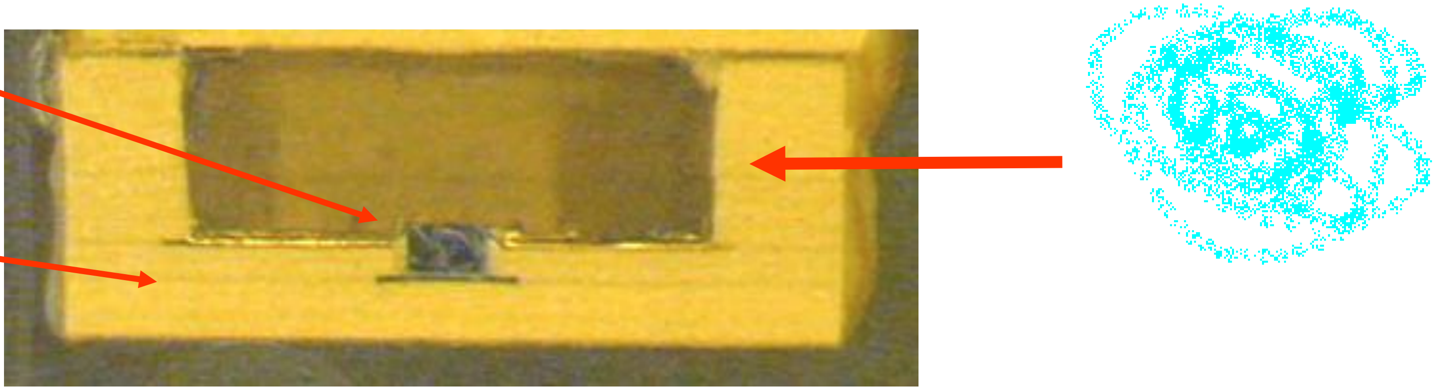
- Per the mil specs epoxies or other polymers cannot be used to create or fix a hermetic seal
- Some polymeric materials are better than others in terms of moisture permeability, and an epoxy sealed package may pass leak test, but that doesn't make it hermetic!
- In time all epoxies will allow moisture into the cavity.
- The problem now becomes one of moisture and other gases diffusing through the bulk materials and interacting with polymers.
- Ficks' 1st and 2nd laws of diffusion are the governing theory ...TM 1014 does not apply, although the gross leak methods can be used to assure a lid is glued on properly

Moisture Ingress Pathways

Water vapor

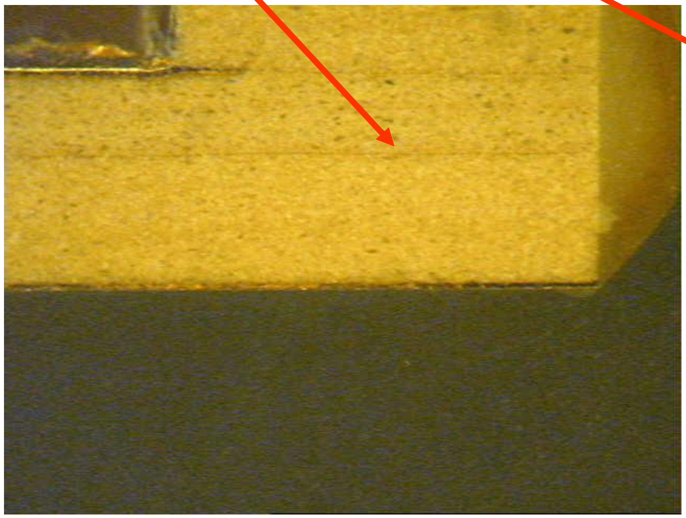
Sensor Chip

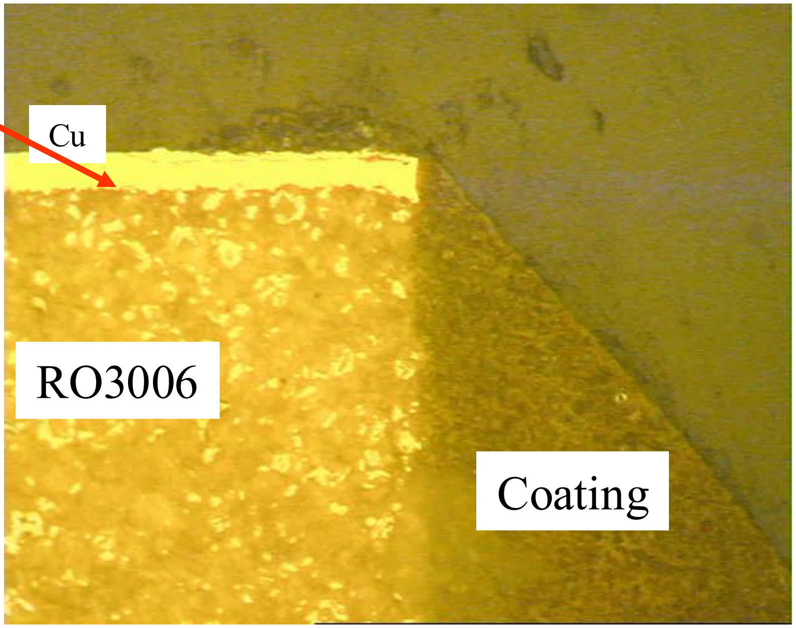
RO 3006



Moisture Pathways

Moisture ingress between the Copper clad and teflon bond

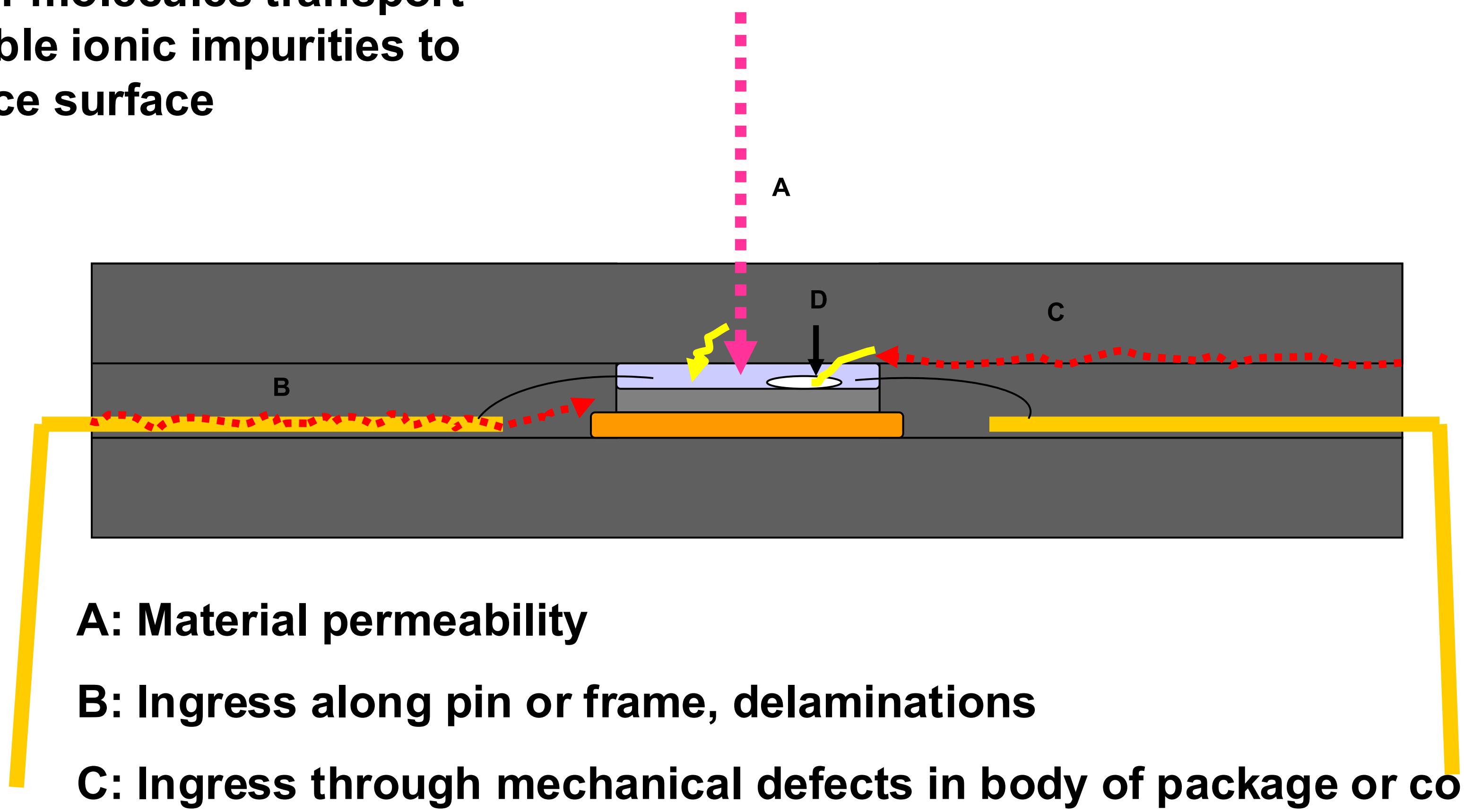




Bulk or in between layers

IONICS IN A NONHERMETIC PACKAGE, NO HEADSPACE

PROBLEM: Permeating water molecules transport soluble ionic impurities to device surface



A: Material permeability

B: Ingress along pin or frame, delaminations

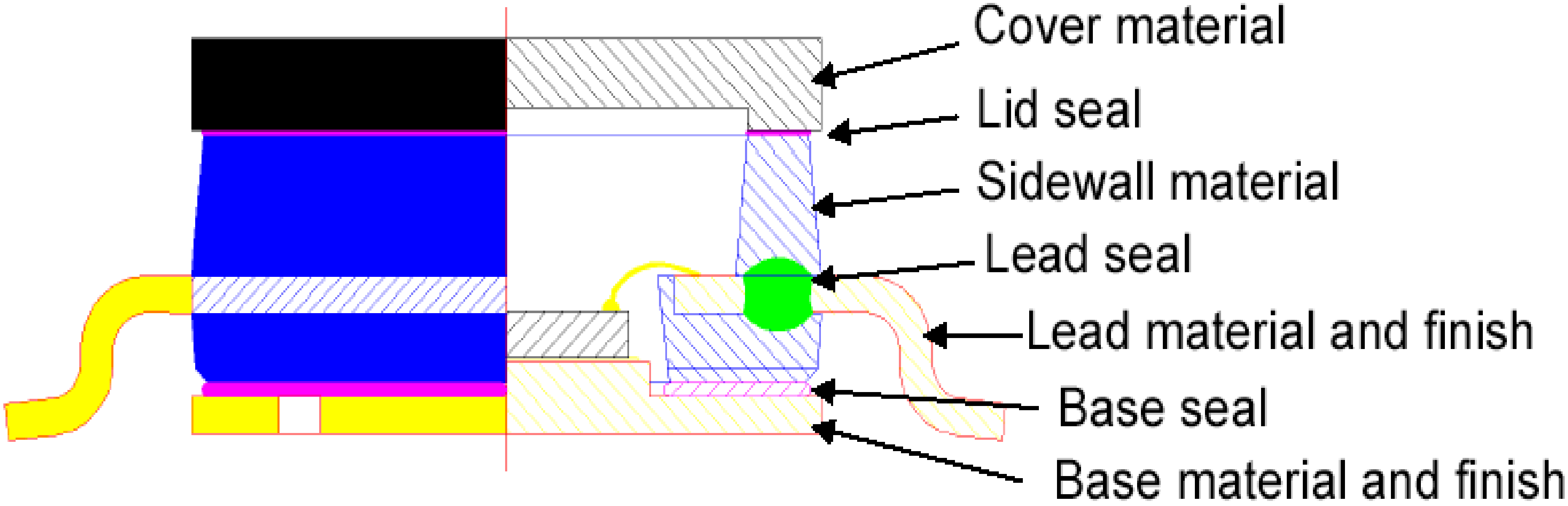
C: Ingress through mechanical defects in body of package or coat material

D: Accumulation in microvolume of delamination at die surface

Moisture Ingress into Non-Hermetics

- When considering how moisture moves through "non hermetic" packages (e.g. LCP, Molding compounds, Teflon etc,) or low moisture barrier coatings the problem now becomes one of diffusion of water vapor and other harmful gases through the package and therefore the typical hermeticity tests per TM 1014 do not apply and cannot be interpreted in the same manner.
  - A plastic cavity style package that passes helium fine leak testing will still not provide moisture protection like a hermetic part.
- In a non hermetic or plastic package moisture will not only creep in along cracks and seams at the interfaces, but will saturate the package and ultimately evolve into the cavity or collect at the interface between the polymer and sensitive die surface.
- As the moisture moves through the plastic it may interact with elements in the compound or encapsulant
  - Moisture will interact with chlorides and bromides in molding compounds and transfer those ionic contaminants to the sensitive interface of the die surface e.g when Sumitomo first introduced green molding compounds

A Commercial "Near" Hermetic LCP



LCP possesses excellent moisture barrier properties but there are other paths that moisture diffusion can take - namely capillary flow along interfaces especially at the lead to sidewall interface.

The Total Package Solution
RJR Polymers, Inc.

Ref: J. Roman

Fick’s Law of Diffusion Non Hermetic Theory

According to the First Law of Diffusion, the transfer of solute atoms per unit area in a 1-dimensional flow can be described by the following equation:

$$J = -D \frac{\partial C(x,t)}{\partial x}$$

where J is the particle flux, C is the concentration of the solute, D is the diffusion coefficient, x is the distance into the substrate, and t is the diffusion time. From the Conservation of Mass, we also know that:

$$\frac{\partial C}{\partial t} = -\frac{\partial J}{\partial x}$$

If we combine this relationship with the 1st Law of Diffusion, then we have derived the 2nd Law of Diffusion (otherwise known as Fick's Law), which states:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}$$

In order to solve Fick's Law, one initial condition and two boundary conditions are required.

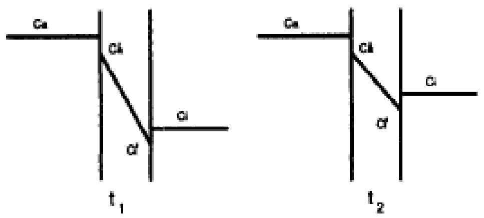
Quasi-Steady State Model to Predict Moisture Ingress

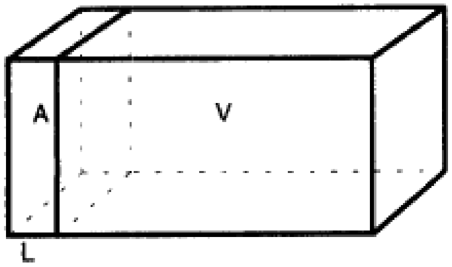
(Enclosure without desiccant)

Fick's first law: $F = -D\frac{\partial c}{\partial x}$

Fick's second law: $\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x^2}$

$$c_i = c_a\left[1 - \exp\left(-t/\tau\right)\right]$$





QSS model gives:

$$\boxed{\tau = \frac{VL + V_{wall}LK/2}{AP} = \frac{VL}{AP} + \frac{V_{wall}L^2}{2VD}}$$

Large cavity, thin walls

Small cavity, thick walls

Plot ln(RH_a-RH_i) versus time slope gives τ (measured).
Compare measured τ versus predicted τ from QSS.

Ref: R. Pearson

Quasi-Steady State Model to Predict Moisture Ingress

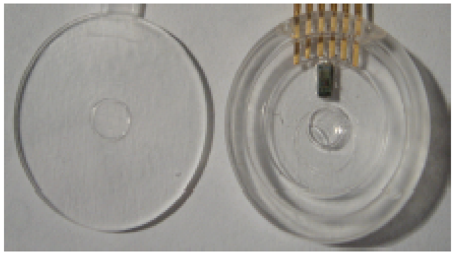
$$\tau = \frac{\left(V + \frac{K}{2}\sum_{k} V_k\right)}{P\left(\sum_{k} \frac{A_k}{L_k}\right)}$$

Where V is the volume of the cavity, K is the partition coefficient (calculated to be 14.5 for this LCP), V_k are the volumes for the walls (side walls, floor and lid), P is permeability (3.92×10^{-10} cm^3/s for this LCP), A_k are the ingress areas of walls, and L_k are the thickness of the walls.

Michal Tencer, "Moisture Ingress into Nonhermetic Enclosures and Packages: A Quasi-Steady State Model for Diffusion and Attenuation of Ambient Humidity Variations," in Proceedings of the 44th Electronic Components and Technology Conference, IEEE, (1994) pp. 196-209.

Ref: R. Pearson

Model PC Package - COT



Picture of PC lid plus base.

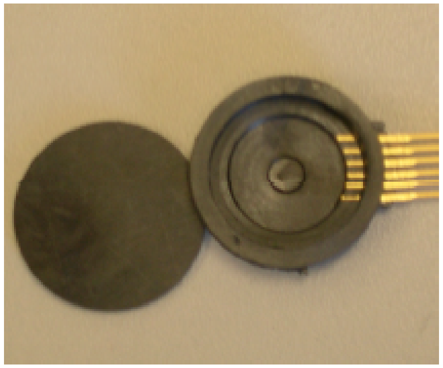
$$\tau = \frac{\left(V + \frac{K}{2}\sum_k V_k\right)}{P\left(\sum_k \frac{A_k}{L_k}\right)}$$

Volume Cavity		0.386
Upper Wall	vol	0.178352
Lower Wall	vol	0.178352
Floor	vol	0.0816714
Lid	vol	0.1582874
sum Vk	vol	0.5966628
V + K/2*sumVk		42.4507274
Upper Wall	A/L	4.4588
Lower Wall	A/L	1.1147
Floor	A/L	8.16714
Lid	A/L	15.82874
Sum (A/L)		29.56938
P*Sum (A/L)		0.0003312
Time Constant		36 hours

P is permeability is $1.12\text{x}10^{-5}\text{cm}^2/\text{s}$
D is $8.06\ \text{x}10^{-8}\text{cm}^2/\text{s}$
K is 141

Package is 18.2 mm in diameter with 2 mm thick walls and 4 mm thick shelf. It has a 1.0 mm lid.

Model LCP Package - COT



$$\tau = \frac{\left(V + \frac{K}{2}\sum_k V_k\right)}{P\left(\sum_k \frac{A_k}{L_k}\right)}$$

P is permeability is $3.92\text{x}10^{-8}$ cm^2/s
K is 14.5 for this LCP

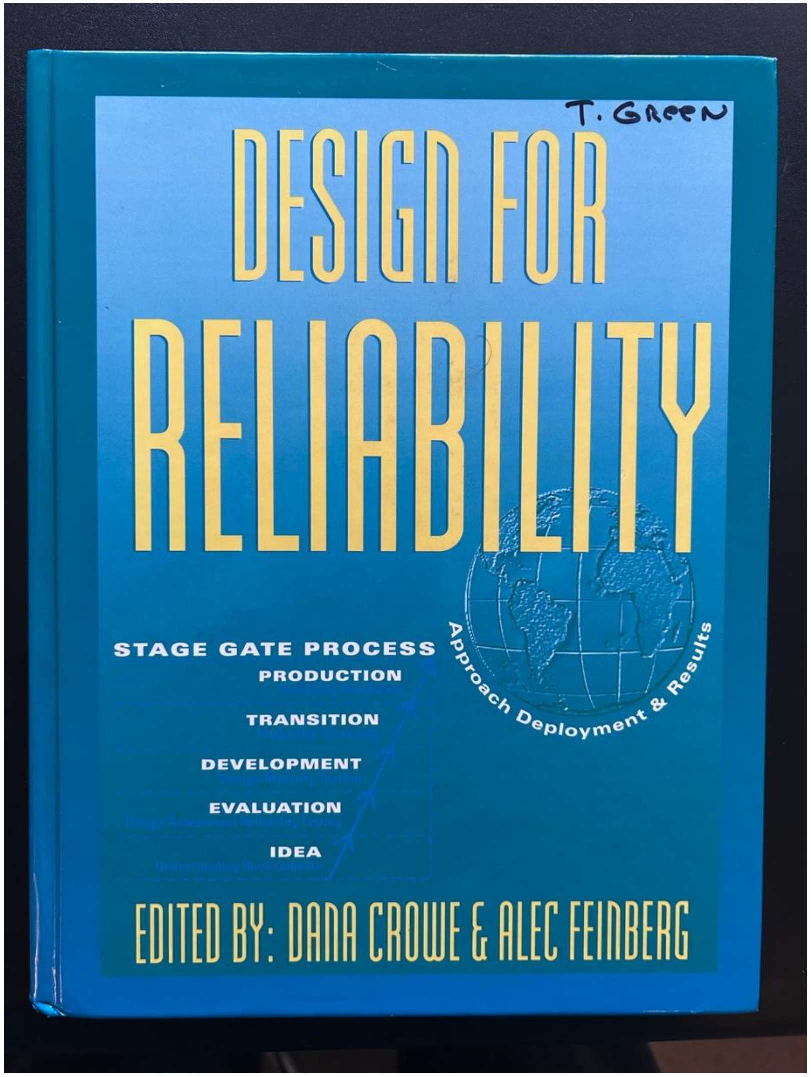
Volume Cavity		0.386	
Upper Wall	vol	0.178352	
Lower Wall	vol	0.178352	
Floor	vol	0.0816714	
Lid	vol	0.1582874	
		0.5966628	
V + K/2*sumVk		4.7118053	
Upper Wall	A/L	4.4588	
Lower Wall	A/L	1.1147	
Floor	A/L	8.16714	
Lid	A/L	15.82874	
Sum (A/L)		29.56938	
P*Sum (A/L)		1.1591E-08	
Time Constant		12.9	years

Package is 20.2 mm in diameter with 2 mm thick walls and 4 mm thick shelf. It has a 1.0 mm lid.

Package Design Considerations

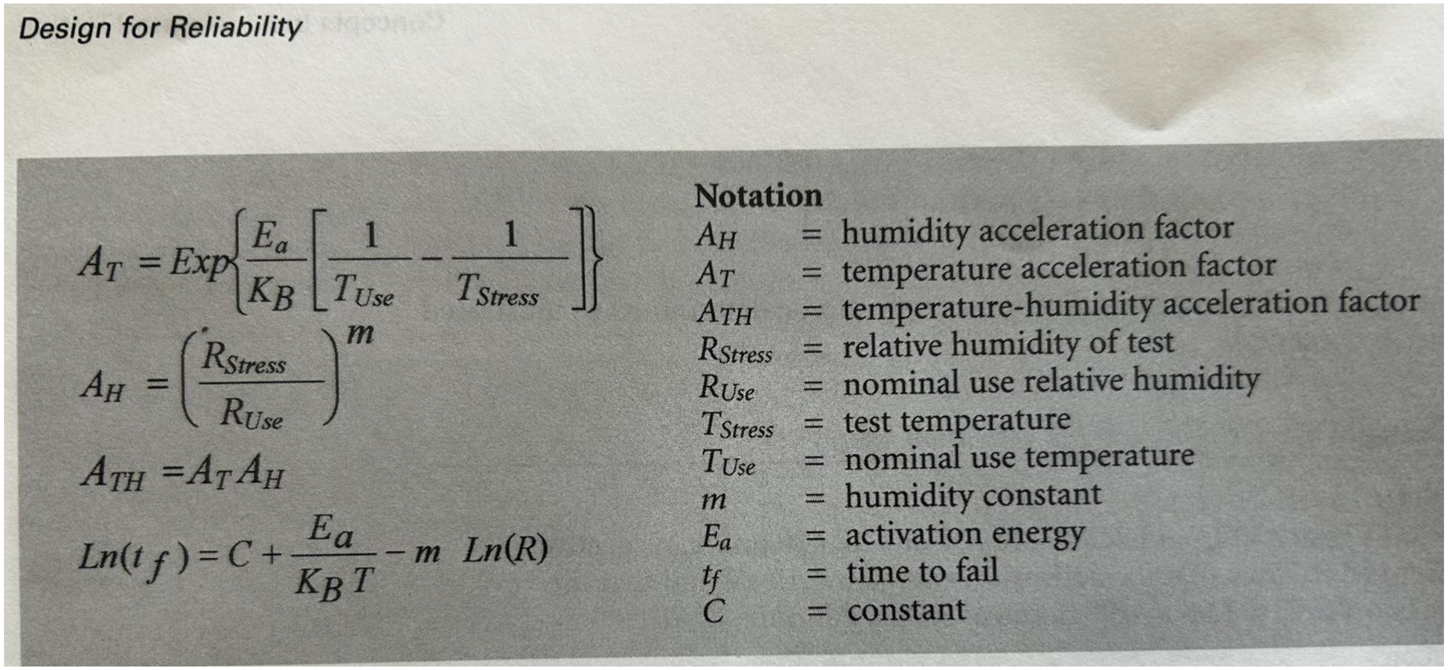
- ***Susceptibility of the component to moisture and other harmful gases***
  - Remember Au doesn’t corrode and most active areas on chip have pretty good passivation these days. Packaging materials hydrophobic vs. Hydrophilic?
  - Keeping moisture out means keeping moisture and other harmful gases like hydrogen in
- ***Expected end use Environment and Service Life***
  - Do the parts run hot? Do they run continuously? What are the temp extremes and T/C cycling environment? How often will the device pass through the dew point? How many layers of moisture will form? Will the moisture have an effect on the device performance electrical specs? Long term dormant storage?
- ***Cost Considerations***
  - Hermetic parts cost more to build and test
  - Silicones, LCPs and other “near hermetic” or novel non hermetic approaches may allow for suitable moisture protection at a greatly reduced cost.
  - However: Part costs must be measured relative to the cost of system failure!!

Design for Reliability



- Excellent reference book with lots of practical examples
- Helps to answer questions like what is an appropriate PEMS qualification sequence to to achieve 20 years of life in an expected use environment of…..

THB Acceleration Model (Example Calculation)



Design for Reliability

$$A_T = Exp\left\{\frac{E_a}{K_B}\left[\frac{1}{T_{Use}} - \frac{1}{T_{Stress}}\right]\right\}$$

$$A_H = \left(\frac{R_{Stress}}{R_{Use}}\right)^m$$

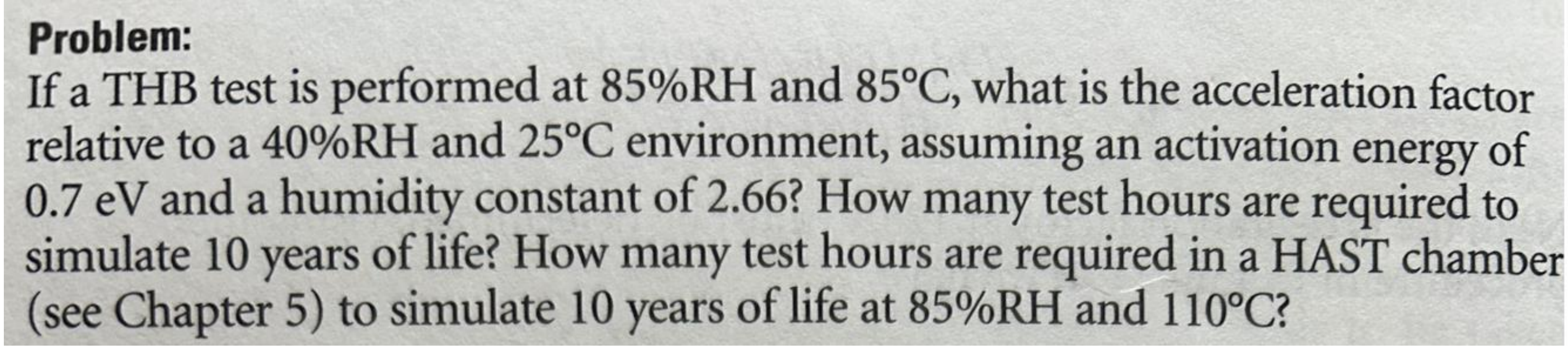
$$A_{TH} = A_T A_H$$

$$Ln(t_f) = C + \frac{E_a}{K_B T} - m\ Ln(R)$$

Notation

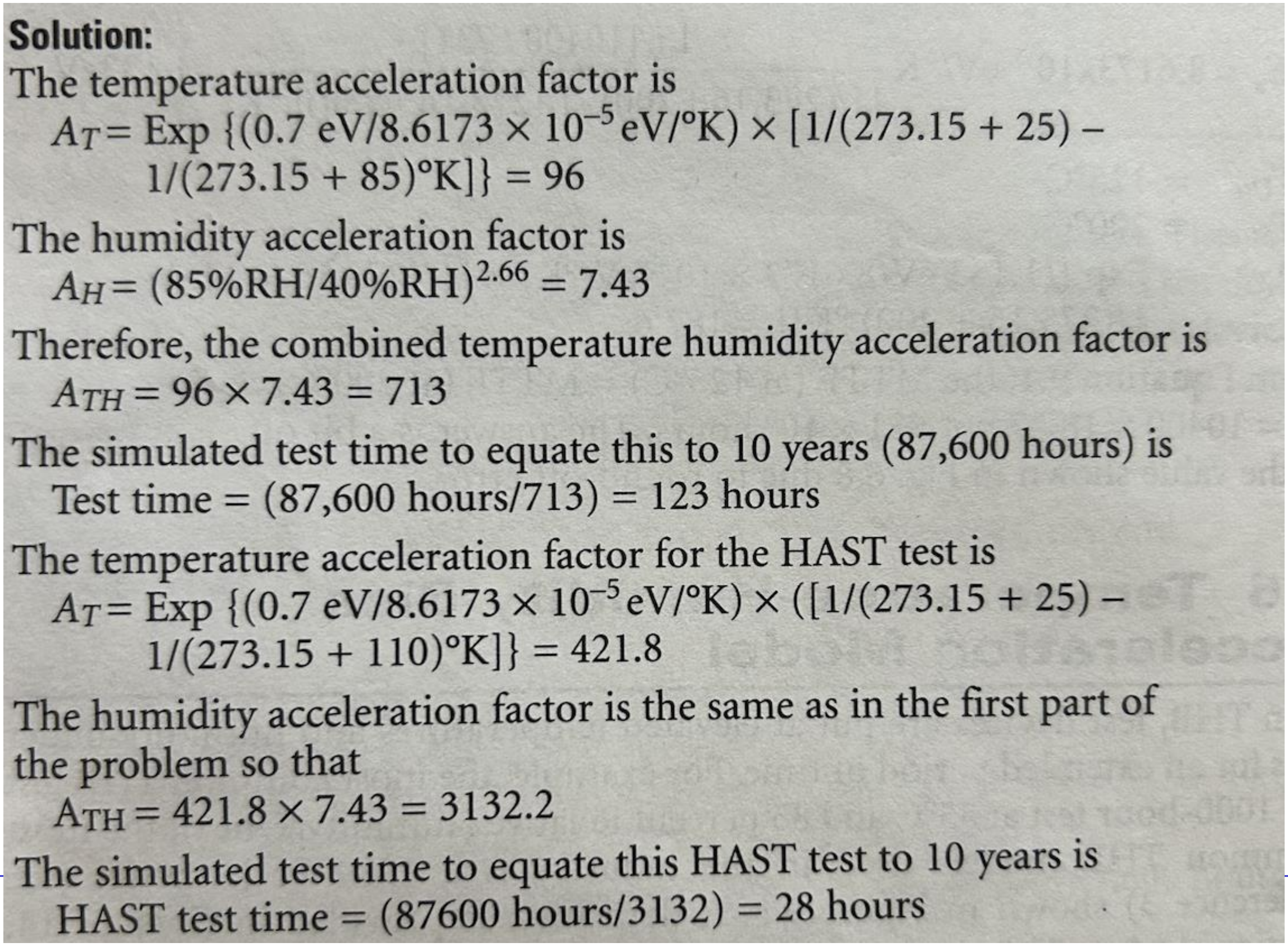
A_H = humidity acceleration factor
A_T = temperature acceleration factor
A_{TH} = temperature-humidity acceleration factor
R_{Stress} = relative humidity of test
R_{Use} = nominal use relative humidity
T_{Stress} = test temperature
T_{Use} = nominal use temperature
m = humidity constant
E_a = activation energy
t_f = time to fail
C = constant

- In THB and HAST the devices are ”stressed” at elevated temp and humidity under bias e.g. 85C/85RH testing.
- An acceleration factor is calculated to relate the the test conditions to and expected lifetime in the field under nominal use conditions.
- This model includes a relationship between life and temperature (Arrhenius model) and life and humidity (Peck model) so that the product of the two yields and overall acceleration factor.



Problem:

If a THB test is performed at 85%RH and 85°C, what is the acceleration factor relative to a 40%RH and 25°C environment, assuming an activation energy of 0.7 eV and a humidity constant of 2.66? How many test hours are required to simulate 10 years of life? How many test hours are required in a HAST chamber (see Chapter 5) to simulate 10 years of life at 85%RH and 110°C?



Solution:

The temperature acceleration factor is

$$A_T = \text{Exp}\,\{(0.7\ \text{eV}/8.6173 \times 10^{-5}\ \text{eV/°K}) \times [1/(273.15 + 25) - 1/(273.15 + 85)\text{°K}]\} = 96$$

The humidity acceleration factor is

$$A_H = (85\%\text{RH}/40\%\text{RH})^{2.66} = 7.43$$

Therefore, the combined temperature humidity acceleration factor is

$$A_{TH} = 96 \times 7.43 = 713$$

The simulated test time to equate this to 10 years (87,600 hours) is

Test time = (87,600 hours/713) = 123 hours

The temperature acceleration factor for the HAST test is

$$A_T = \text{Exp}\,\{(0.7\ \text{eV}/8.6173 \times 10^{-5}\ \text{eV/°K}) \times ([1/(273.15 + 25) - 1/(273.15 + 110)\text{°K}]\} = 421.8$$

The humidity acceleration factor is the same as in the first part of the problem so that

$$A_{TH} = 421.8 \times 7.43 = 3132.2$$

The simulated test time to equate this HAST test to 10 years is

HAST test time = (87600 hours/3132) = 28 hours

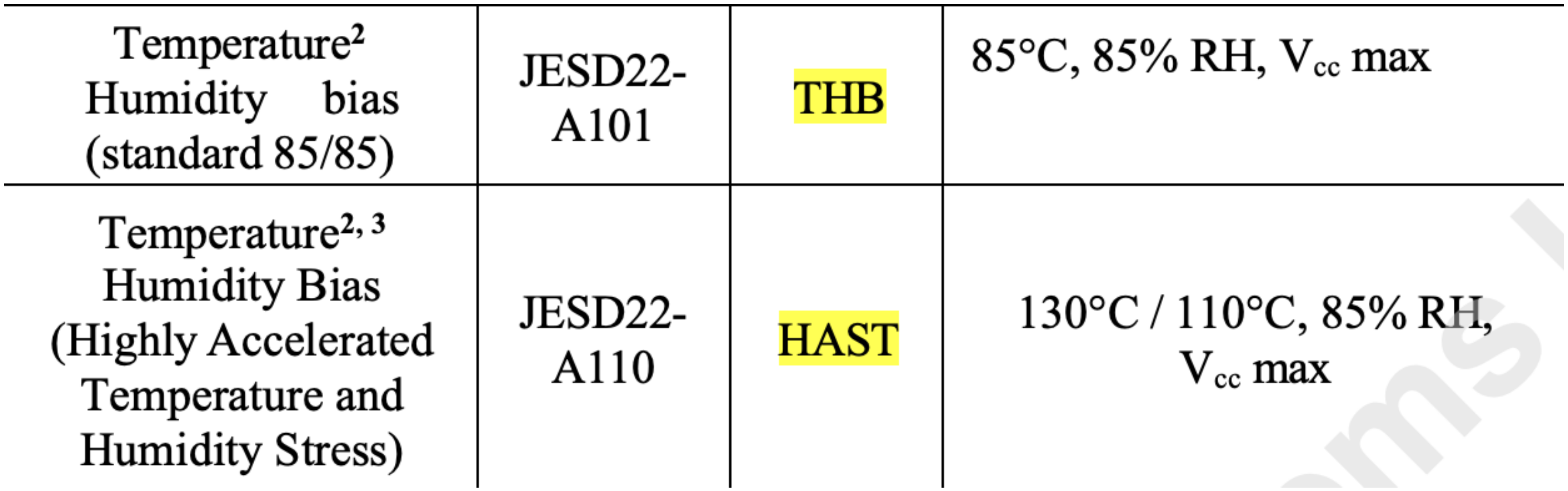
Comments on example problem:

Compare with table 5 in JESD47L

This example was for relatively benign field use conditions whereas the table is for a much harsher end use environment.

Table 5 allows for either biased THB or HAST with a bias.

THB: 85°C, 85% RH, Vcc max
HAST: 130°C / 110°C, 85% RH,Vcc max



Temperature[2] Humidity bias (standard 85/85)	JESD22-A101	THB	85°C, 85% RH, V_{cc} max
Temperature[2, 3] Humidity Bias (Highly Accelerated Temperature and Humidity Stress)	JESD22-A110	HAST	130°C / 110°C, 85% RH, V_{cc} max

Materials and Processes for Non-Hermetic Packages TESTING

- Coating material evaluation, testing and effectiveness
    - Conformance to surface topography
    - Permeability/diffusion properties
    - Pinholes/cracks/Adhesion
- IPC -CC-830 Moisture and Insulation testing
- Moisture diffusion rate testing WVTR
- Inherent moisture content of materials TGA/TML
    - Moisture uptake (absorption) by materials
- RGA for non-hermetic devices
- Ampule Testing
- TM 5011 and NASA Specs
- Moisture sensors

DESIRABLE COATING PROPERTIES

- Exceedingly low absorption/uptake of moisture
- High resistance to permeation or diffusion by all gaseous species
- Intimate adhesion to all critical surfaces: no delamination or gaps between coating and surface
- Freedom from physical defects: cracks, pinholes, bubbles, etc.
- Ultra-low water-soluble ionic impurities
- CTE match to materials
- Complete conformality to coated surface
- Physically and chemically stable over expected temperature operating range

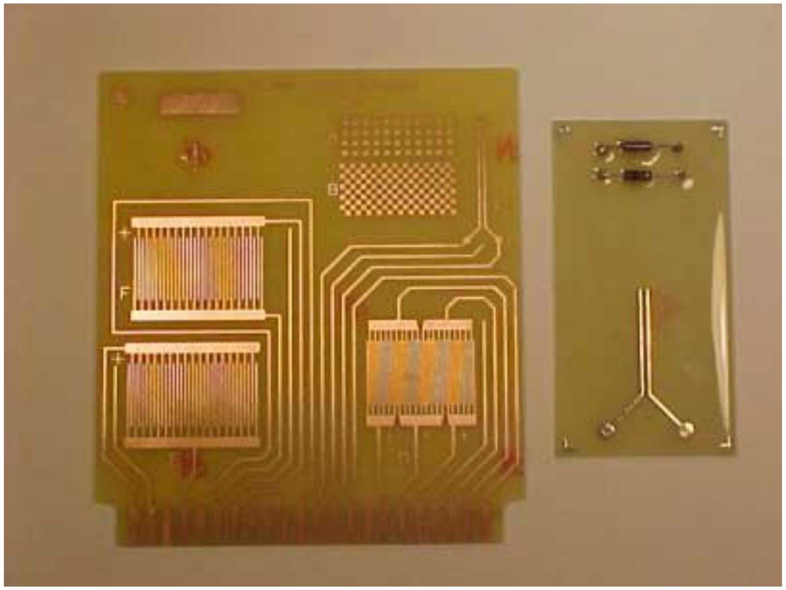
COATING TESTING

ATTRIBUTE	METHODOLOGY
Outgassing behavior	Ampule test/mass spectrometry; Oneida Research, see a following slide
Moisture uptake	Humidity exposure (85/85), weight gain, TGA or microbalance
Permeability/diffusion	Diffusion cell, Mocon, see a following slide
Conformality	High mag optical, SEM inspection
Chemical resistance	Immerse in chemical; weight change, TGA or microbalance, visual inspection
Pinholes/cracks	Immerse in chemical that would corrode substrate, visual inspection
Adhesion	Sticky tape pull test
Mechanical props; CTE	Thermomechanical analysis (TMA); determine glass transition
Surface energy/ hydrophobicity	Contact angle goniometry
Ionic impurities	Extraction and ion chromatography

IPC-CC-830 Board Level Testing

Moisture and Insulation Resistance

Moisture and Insulation Resistance is performed to evaluate, in an accelerated manner, the resistance of materials to the deteriorative effects of high temperature/humidity conditions



IPC-B-25A test board and Y-pattern (MIL-I-46058)

https://blog.humiseal.com/a-quick-guide-to-understand-ipc-cc-830b-qualification-standard

Permeation of gas through solids

Permeation is the movement of a gas or vapor through a semi-permeable barrier such as the wall of a film, whole package, medical device, or even a flexible electronic display. The gas or vapor is driven to move from an area of high concentration to an area of low concentration.

- The permeation mechanism has three steps:
  - Permeant molecules absorb into the surface (high concentration side)
  - Permeant molecules move or diffuse through the barrier material
  - Permeant molecules desorb out of the other side (low concentration side)

TESTING FOR GASEOUS PERMEABILITY/DIFFUSION

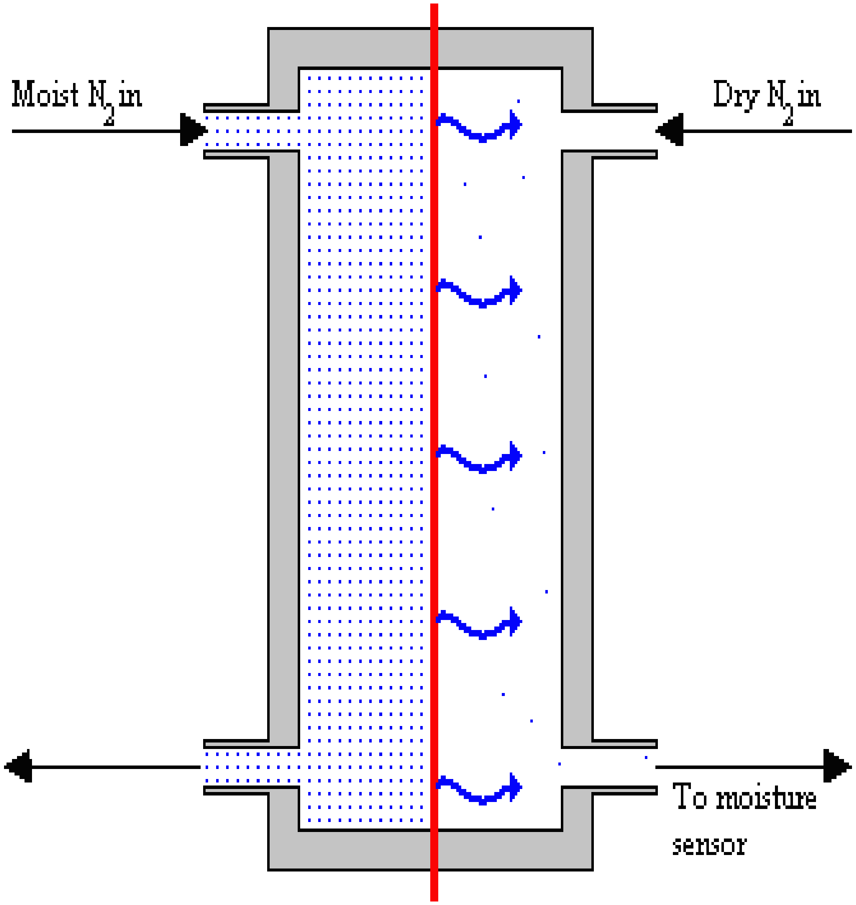
- **Applicable for water vapor, oxygen, and other permeates**
- **Sample of coating must be physically isolated**
- **Sample is mounted as a test “membrane” between cells containing high purity inert gas and a flow of the same inert gas containing analyte gas**
- **Analyte gas in the inert gas cell is detected**
- **Diffusion/permeation rates are determined**
- **Equipment or test services available from**

Mocon, Inc., 763-493-6370

http://www.mocon.com/

WVTR Testing per ASTM F-1249

- The rate at which water vapor will pass through a material under specified conditions and specimen geometry. The volume of water vapor that will pass through a unit thickness of material per unit area per unit time per unit barometric pressure.
- The test specimen is held such that it separates two sides of a test chamber. The "wet side" of the specimen is exposed to a high relative humidity atmosphere, while the "dry side" is subjected to a zero relative humidity atmosphere. Infrared sensors on the "dry side" detect the amount of water vapor present. Testing is complete when the concentration of water vapor in the dry side atmosphere is constant



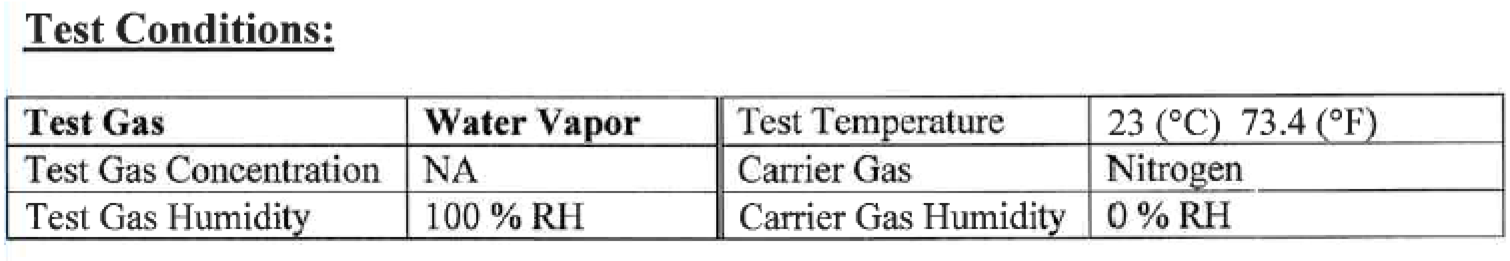
https://www.ametekmocon.com/knowledge/learnaboutpermeation/whatispermeation

WVTR Testing per ASTM F-1249

WVTR Water Vapor Transmission Rate

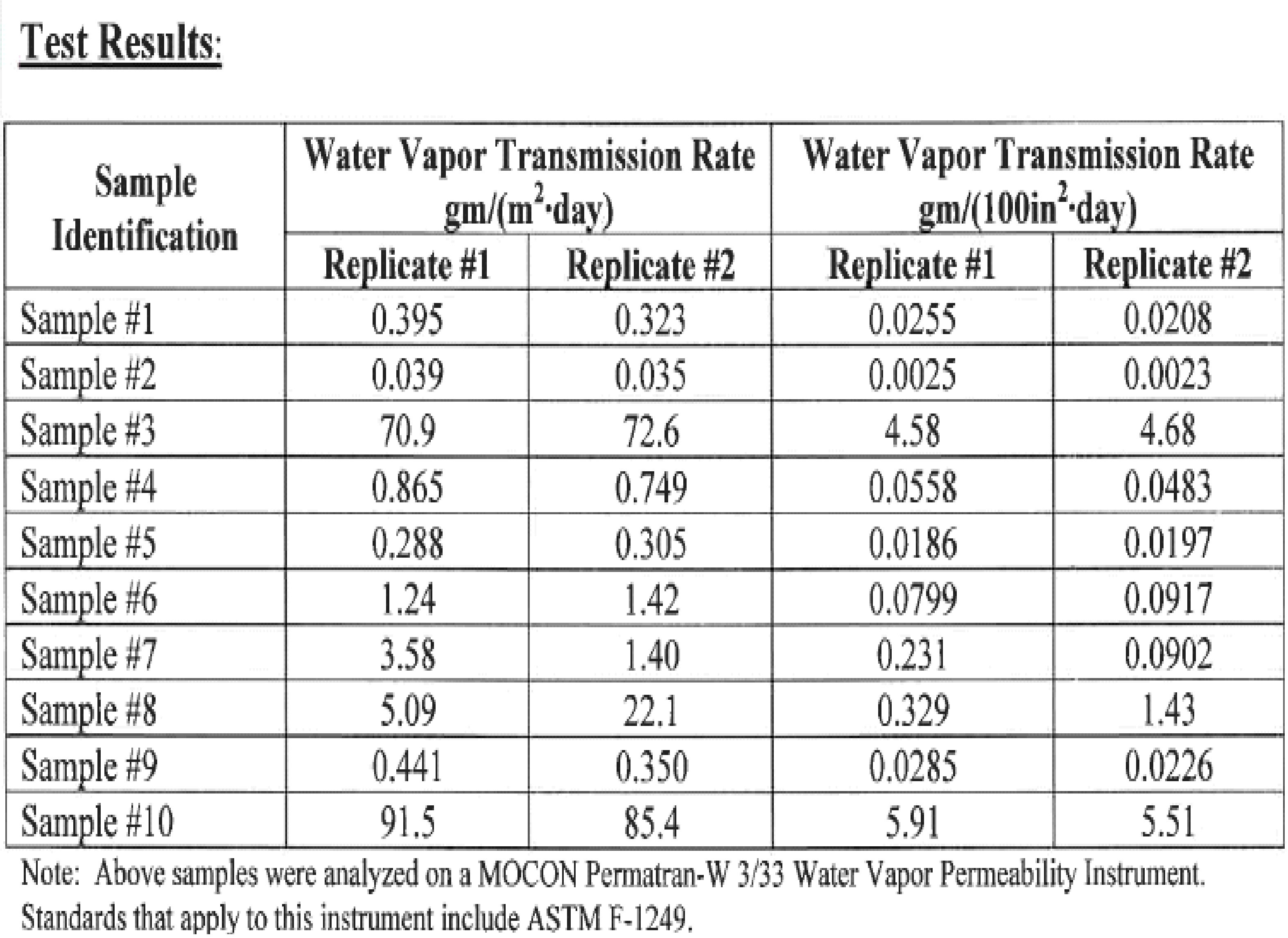
Typical Units: gm/(m^2-day) or gm/(100in^2-day)

Results reported after steady state is achieved



Test Conditions:

Test Gas	**Water Vapor**	Test Temperature	23 (°C) 73.4 (°F)
Test Gas Concentration	NA	Carrier Gas	Nitrogen
Test Gas Humidity	100 % RH	Carrier Gas Humidity	0 % RH



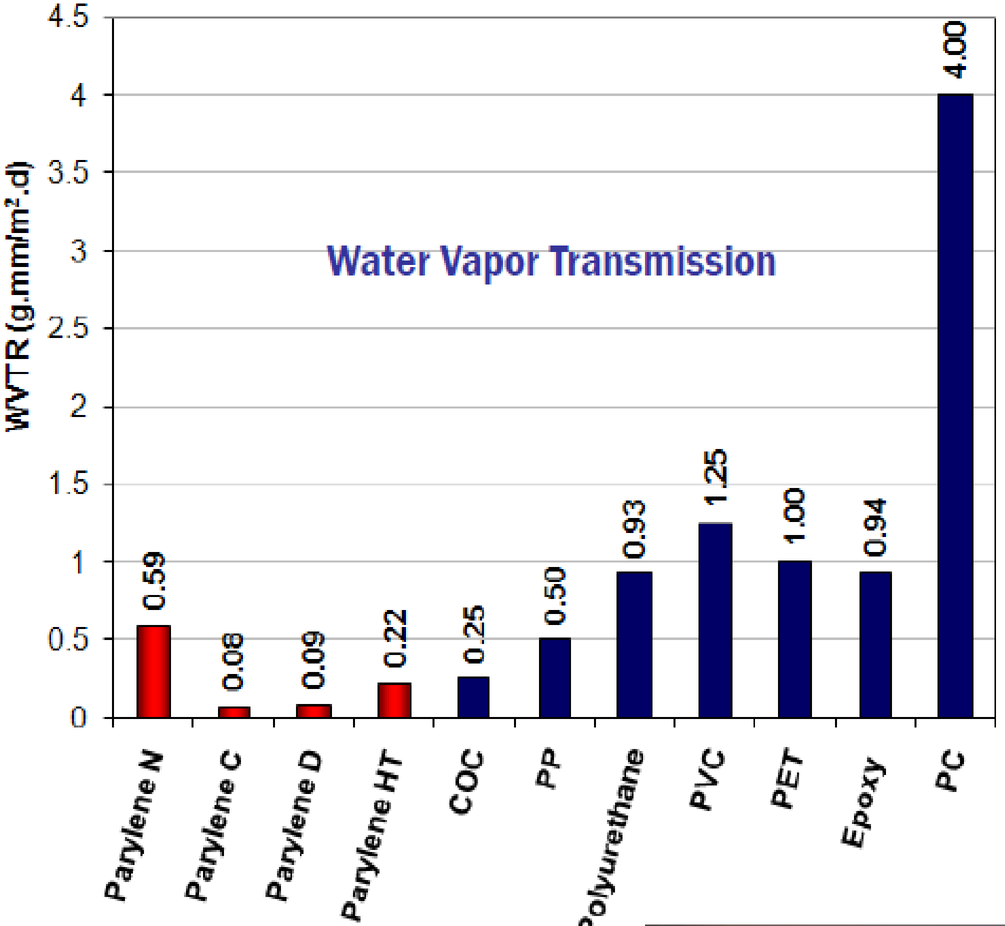
Test Results:

Sample Identification	Water Vapor Transmission Rate gm/(m^2·day)		Water Vapor Transmission Rate gm/(100in^2·day)	
	Replicate #1	Replicate #2	Replicate #1	Replicate #2
Sample #1	0.395	0.323	0.0255	0.0208
Sample #2	0.039	0.035	0.0025	0.0023
Sample #3	70.9	72.6	4.58	4.68
Sample #4	0.865	0.749	0.0558	0.0483
Sample #5	0.288	0.305	0.0186	0.0197
Sample #6	1.24	1.42	0.0799	0.0917
Sample #7	3.58	1.40	0.231	0.0902
Sample #8	5.09	22.1	0.329	1.43
Sample #9	0.441	0.350	0.0285	0.0226
Sample #10	91.5	85.4	5.91	5.51

Note: Above samples were analyzed on a MOCON Permatran-W 3/33 Water Vapor Permeability Instrument. Standards that apply to this instrument include ASTM F-1249.

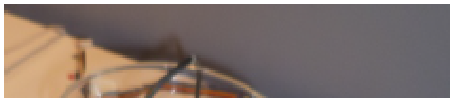
DATA ABOVE IS FROM VARIOUS COATINGS AND COATING THICKNESSES ON TEFLON BOARDS (PTFE)…SHOW SAMPLE

Parylene Barrier Properties



Gas Permeability at 25°C, (cc•mm)/(m^2•day•atm)^a

Polymer	N_2	O_2	CO_2	H_2
Parylene N	3	15.4	84.3	212.6
Parylene C	0.4	2.8	3	43.3
Parylene HT	4.8	23.5	95.4	–
Epoxy (ER)	1.6	4	3.1	43.3
Polyurethane (UR)	31.5	78.7	1,181	–
Silicone (SR)	–	19,685	118,110	17,717



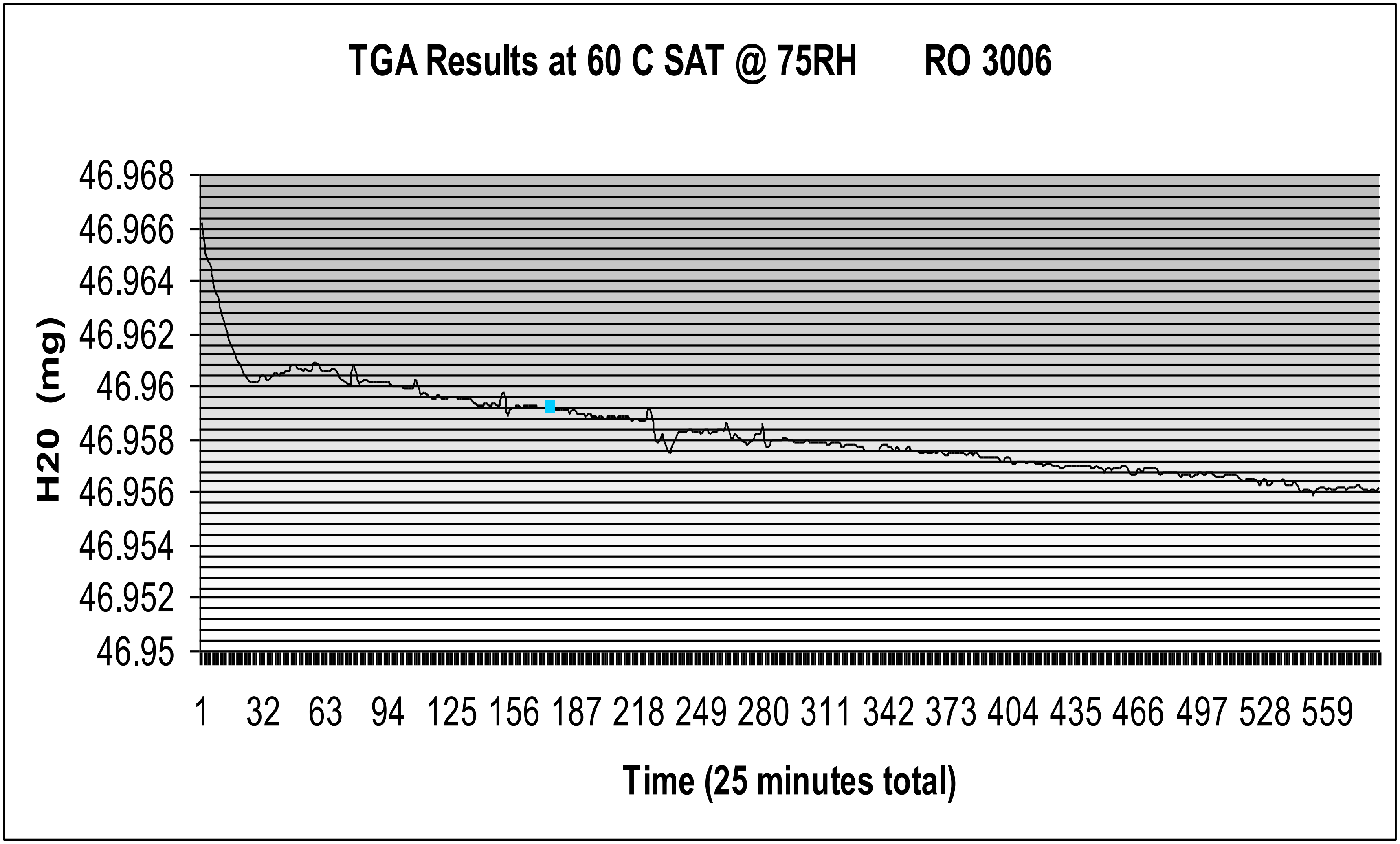
Thermogravimetric Analysis (TGA)

Thermogravimetric Analysis (TGA) measures the amount and rate of change in the weight of a material as a function of temperature or time in a controlled atmosphere. Measurements are used primarily to determine the composition of materials and to predict their thermal stability at temperatures up to 1000°C. The technique can characterize materials that exhibit weight loss or gain due to decomposition, oxidation, or dehydration.

What Does TGA Tell You?

- Moisture and Volatiles Content of Materials
- Composition of Multicomponent Systems
- Thermal Stability of Materials
- Oxidative Stability of Materials
- Decomposition Kinetics of Materials
- The Effect of Reactive or Corrosive Atmospheres on Materials

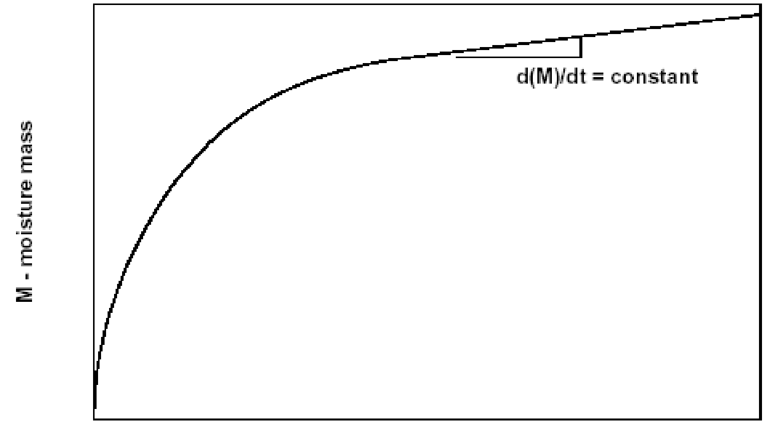
TGA Test Results

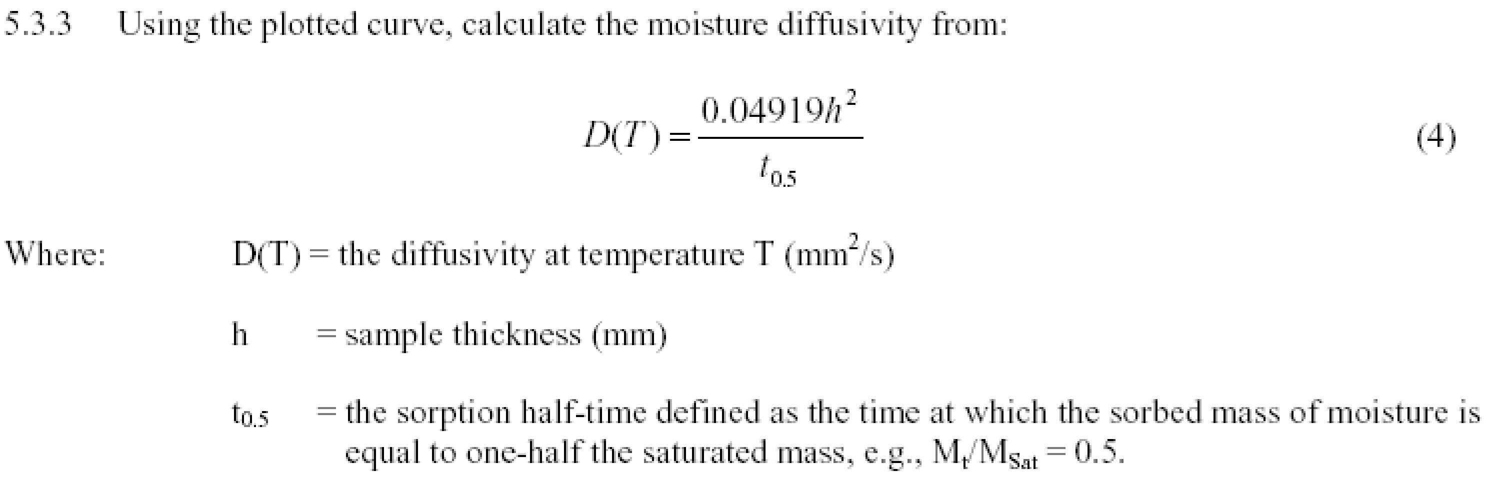


Calculated Diffusion Constant = 2.87 EE-07 cm^2/sec per JESD A120

JESD22- A120 Moisture Diffusion

Test Method for Measurement of Moisture Diffusivity and Water Solubility in Organic Materials Used in Integrated Circuits





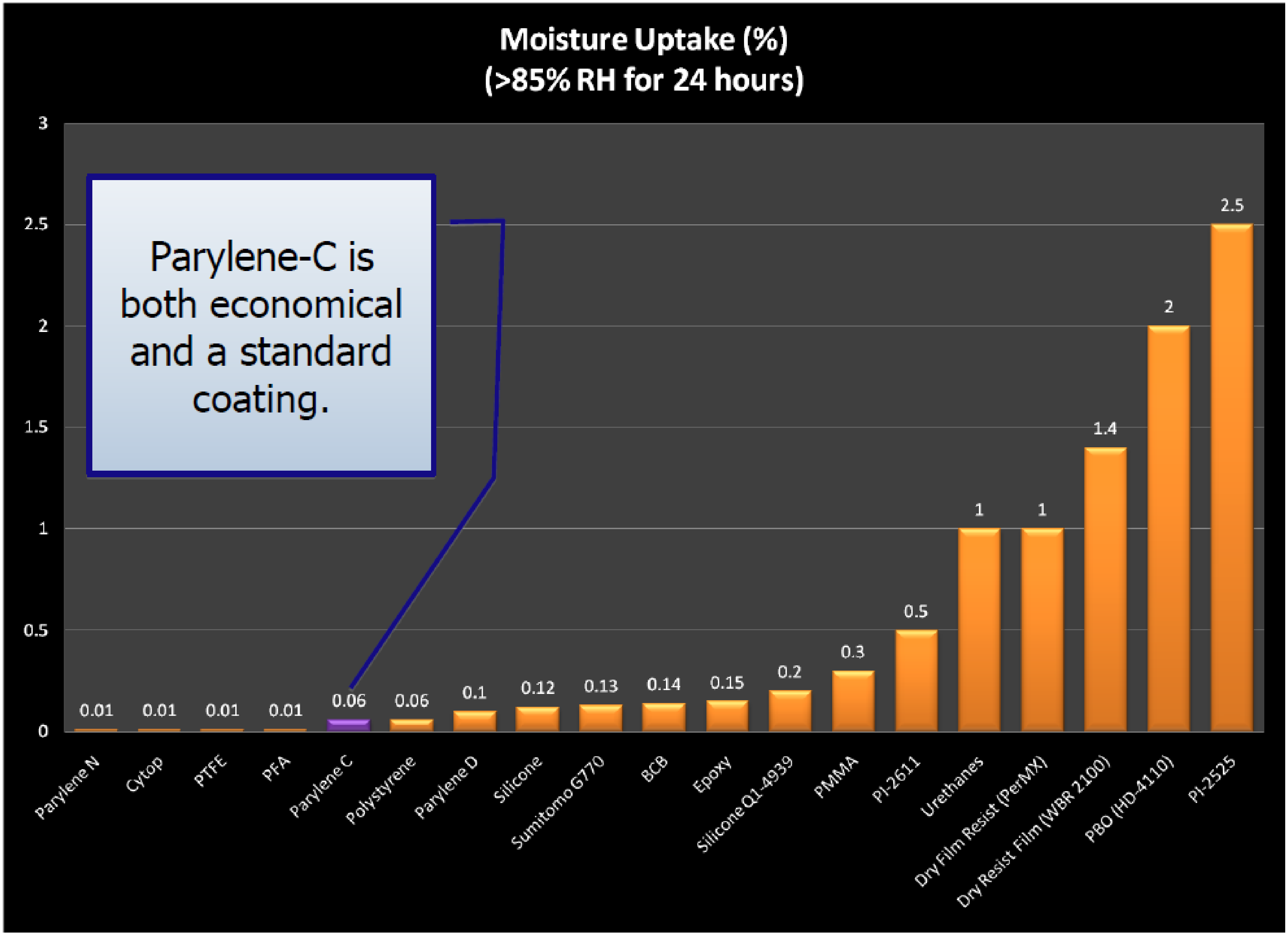
5.3.3 Using the plotted curve, calculate the moisture diffusivity from:

$$D(T) = \frac{0.04919h^2}{t_{0.5}} \qquad (4)$$

Where: $D(T)$ = the diffusivity at temperature T (mm^2/s)

h = sample thickness (mm)

$t_{0.5}$ = the sorption half-time defined as the time at which the sorbed mass of moisture is equal to one-half the saturated mass, e.g., $M_t/M_{Sat} = 0.5$.



Parylene-C is both economical and a standard coating.

TESTING FOR VOLATILE SPECIES FROM COATING MATERIALS

- Applicable for all volatile species
- Can be used to optimize cures, bakes, etc.
- Sample of coating must be physically isolated
- Sample is placed into a glass ampule which is sealed under inert gas
- Ampule is heated for specified times/temperatures appropriate for material being studied
- Ampule is broken and volatilized gases inducted into a mass spectrometer to both identify and quantify volatiles

Analytical services available from

Oneida Research Services   http://www.orslabs.com/

Sealed ampule containing material sample

MIL STD 883L, TEST METHOD 5011.7

Evaluation and Acceptance Procedures for Polymeric Adhesives

- Adhesives
- α-absorbers
- Film dielectrics
- Particle getters
- Desiccants
- Junction coatings}
- T-wave absorbers
- Encapsulating compounds

17 varying test methods

TM 5011 ….Evaluation and Acceptance Procedures for Polymeric Adhesives

- User and supplier responsibilities for certification and acceptance testing to assure clean/consistent material from lot to lot
- Viscosity and pot life checked and measured
- Shelf life…….12 months at -40C
- IR spectrum of uncured material supplied
- TGA analysis required to determine thermal stability
- Outgassed materials test <5000 ppm
- Ionic impurities tested Na,K,F, along with total ionic content
- Other tests; coefficient of linear expansion, thermal conductivity, volume resistivity, dielectric constant, bond strength and the sequential test environment

NASA OUTGASSING TEST METHOD

- **ASTM E595-15, "Total Mass Loss (TML) and Collected Volatile Condensable Materials (CVCM) from Outgassing in a Vacuum Environment"**

Acceptance Criteria

- **Total Mass Loss: <1.00% of initial sample mass.**
  - **Predicated on fact that many materials show mechanical and physical degradation when TML exceeds from 1 to 5%.**
- **Collected Volatile Condensable Materials: <0.10% of initial sample mass.**
  - **Predicated on fact that 0.1% condensate from 1kg of material would cover 100m^2 of surface area with a uniform 10^{-6}g/cm^2 layer of material corresponding to about 20 monolayers to a thickness of about 10^{-6}cm.**

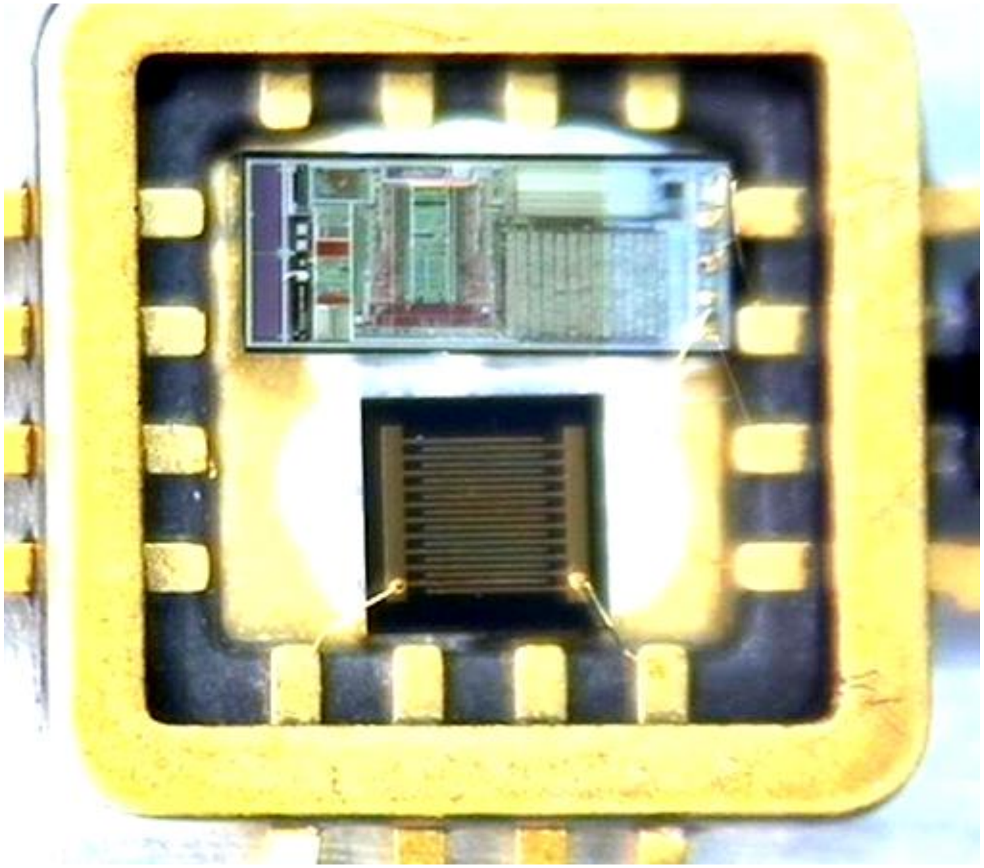
https://outgassing.nasa.gov/

Out-gassing Properties for Space Applications

	RT/Duroid 6002 [1]	**ANSI/ASTM E595-84 Spec Limits [3]**
Total Mass Loss (% TML)	0.02	<1%
Collected Volatile Condensable Material (% CVCM)	0.01	<0.1%
Water Vapor Recovered (% WVR)	0.01	<0.1%

1. Data supplied by Rogers Corporation
2. NASA required testing per ANSI/ASTM E 595-84 “Standard Test Method for TML and CVCM from Outgassing in a Vacuum Environment”

Moisture Sensors



(SHOW VIDEO)

Leak Rate (TM 1014) and RGA (TM 1018) data are measurements made at a single point in time under specified testing conditions. What is really needed is the rate at which moisture enters a package so meaningful projections can be made with regards to the expected useful life of the product.

Moisture Sensors

Bare silicon die

Approx:

Size 3mm X 1mm X .05mm

RH accuracy +/- 3.0 %

Temp +/- .5 C at RT

Calibrated on wafer

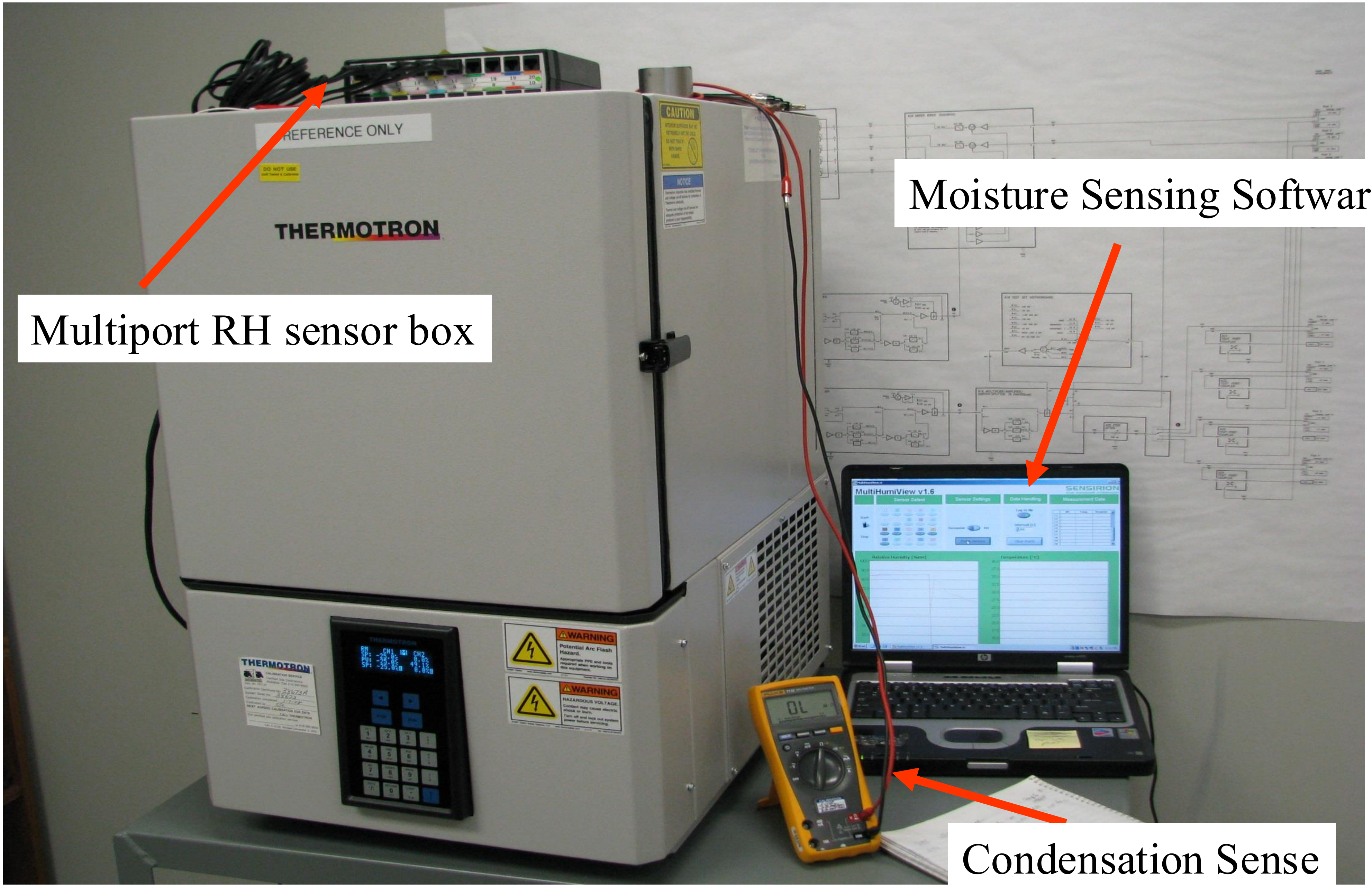
Range:

RH 0 to 100%

Temp -40 to 123.8 C

HTV Lab Test Set Up

Live Class Demo



Multiport RH sensor box

Moisture Sensing Software

Condensation Sense

SHOW VIDEO

What Are Getters?

- A getter is a substance that removes molecules from the gas phase by a chemical or physical reaction on its active surface.
- Getters can be viewed as clean chemical pumps that remove offending gas species from inside the hermetic enclosure
- Getters are chemical vacuum pumps that take over when an purged or evacuated volume is sealed off from mechanical pumps. These can be gas filled or vacuum systems.
- Getters react with the active gases, such as H2,O2, N2, H2O, CO and CO2, to form chemical compounds or solid solutions.

Sputtered Hydrogen Getters

- Getters are materials applied to the inside of the package lid (sputtered metal films) that chemically absorb harmful gases inside a hermetically sealed device
- Special zirconium alloy films will absorb H_2O,O_2,CO,CO_2,N_2 and H_2 and maintain vacuum inside a MEMS device
- Getter films are usually just a few microns thick and need to be thermally activated (350-450 C for 45 minutes for a MEMS application) before the getter begins to “pump out” the contaminant gas
- Choice of getter and application method must be tailored to the application

Ref: www.saesgetters.com

Cookson Moisture and Hydrogen Getters

- H2-3000 is a unique getter, which employs an active hydrogen getter and desiccant for water absorption, dispersed in a flexible silicone polymer matrix.
- It is made with Palladium Oxide (PdO) which absorbs and converts the hydrogen to water that is then removed by a moisture getter in the same material.
- The high permeability of the polymer matrix to both hydrogen and moisture assures rapid uptake of both gases.
- The getter operates through a reaction which is irreversible. Therefore, there are no hazardous or problematic side effects, once the absorbed gasses are trapped from harming the device.

www.cooksonsemi.com

How Does H2-3000 Work?

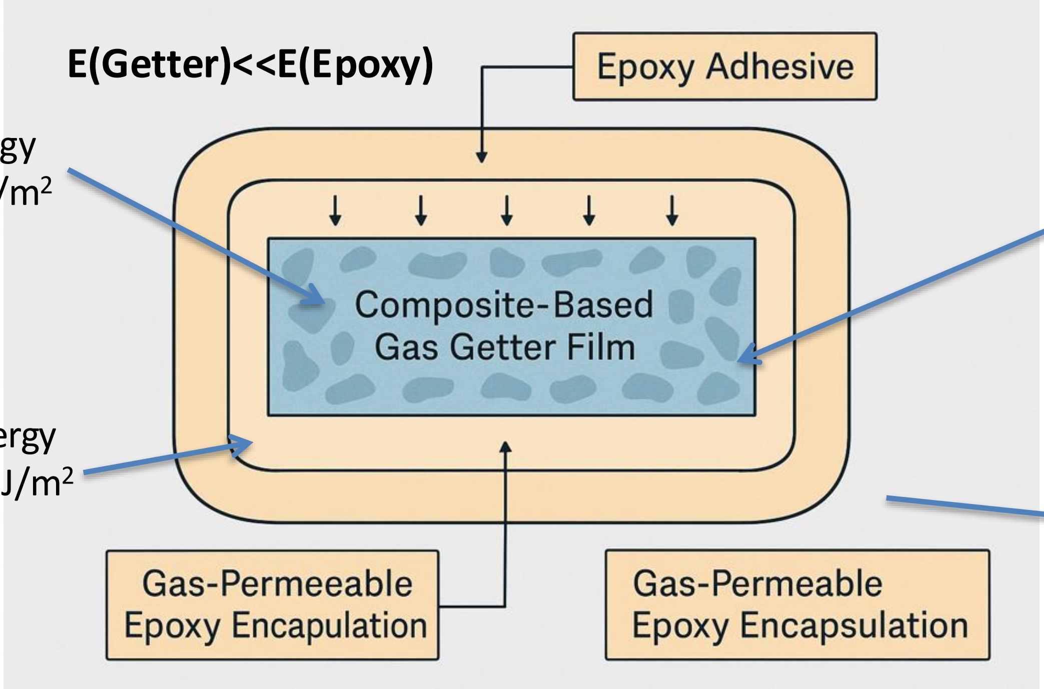
- Contains palladium oxide; PdO
- Pd and compounds adsorb H_2
- PdO converts H_2 to H_20
- $PdO + H_2 \longrightarrow H_2O + Pd$

  $H_2O \downarrow$ desiccant → locked in
- Free Hydrogen is permanently removed from system.

Encapsulated Getter by Gas-Permeable Epoxy Adhesive

Getter surface energy
E(Getter)=25-35 mJ/m^2

Epoxy surface energy
E(epoxy) =40-50 mJ/m^2



E(Getter)<<E(Epoxy)

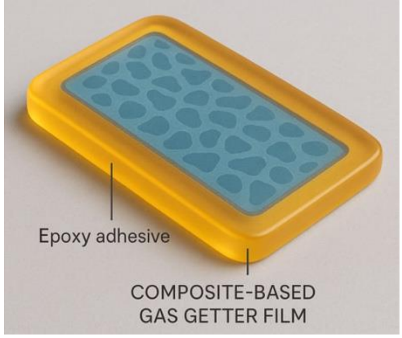
Epoxy Adhesive

Composite-Based
Gas Getter Film

Gas-Permeeable
Epoxy Encapulation

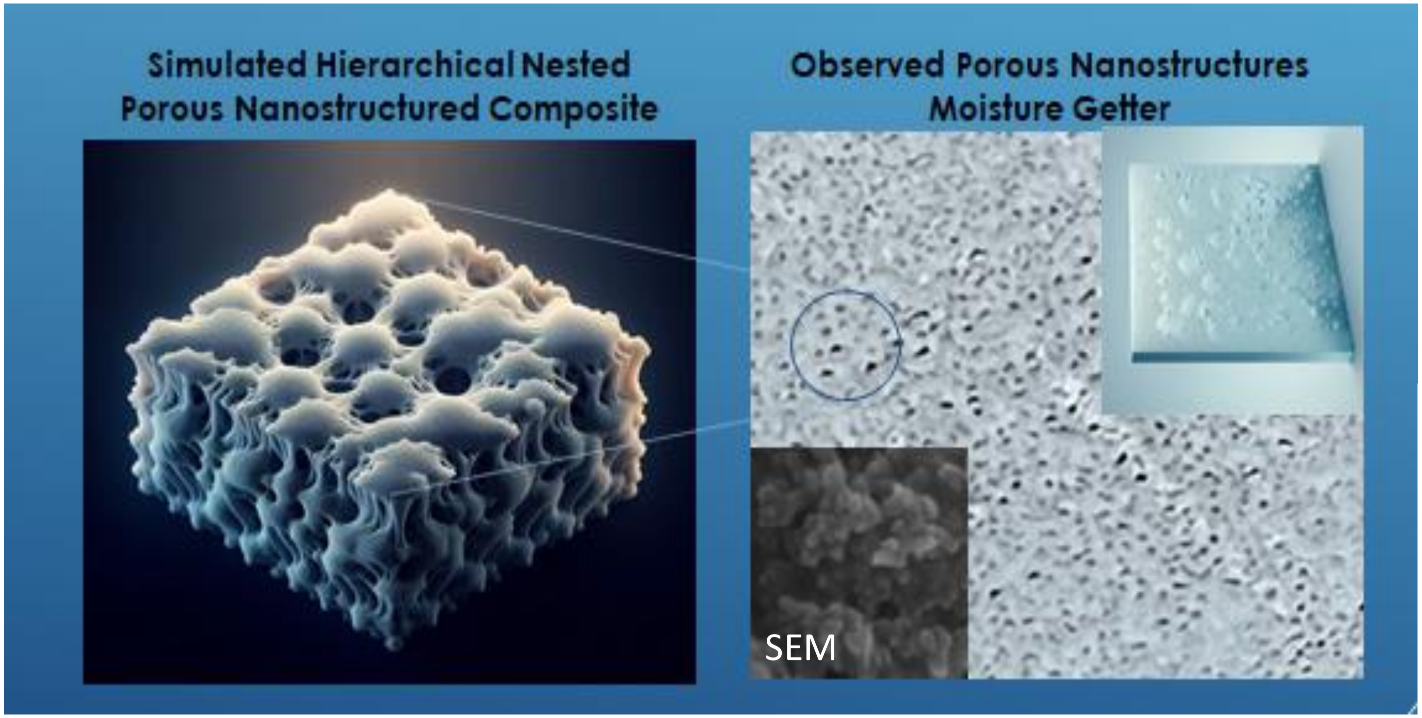
Gas-Permeable
Epoxy Encapsulation

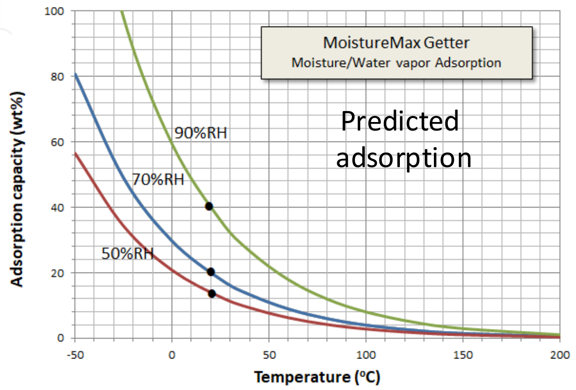
Getter films

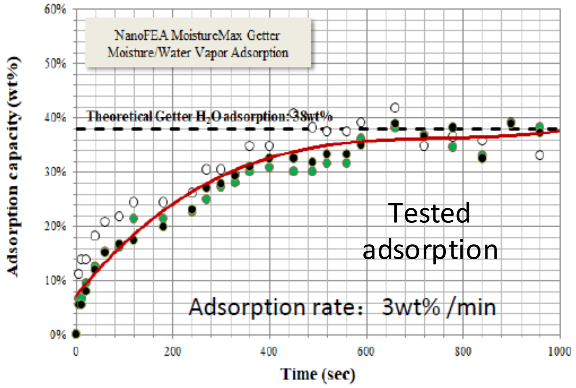


NanoFEA gas-permeable epoxy or lightly cross-linked epoxies/adhesives encapsulating full getter film

NanoFEA High-Capacity NanoMax Getters







NanoFEA US Patent Application# 2025/0073666A1 and 2025/0091030 A1

Epoxy Suitable for Gas-permeable

1. **Epoxy/E-Glass Composites**: Research has been conducted on the permeability of epoxy/E-glass composites using optical coherence tomography to improve permeability predictions.
2. **Silica-Filled Epoxy Composites**: Epoxy composites filled with silica nanoparticles have been studied for their permeability characteristics, showing reduced water permeability with increasing silica content
3. **Graphite/Epoxy Laminates**: Studies on graphite/epoxy composite laminates have examined gas permeability for cryogenic storage systems, which may provide insights into selecting an appropriate formulation
4. **Master Bond Epoxy Systems**: Master Bond offers specialized epoxy formulations designed for extreme temperatures. Some of their high-performance adhesives and coatings maintain flexibility and permeability within your specified range.

https://www.masterbond.com/techtips/gas-permeability-epoxies-and-silicones

Polymers infused with Getters

While it is feasible to use epoxy to seal a getter, potential challenges must be considered—specifically, the risk of the epoxy sealing the getter's porous surface, which could impede its ability to adsorb moisture, CO, CO2, SO2, and VOCs. NanoFEA's NanoMax material, akin to parylene polymer used in sealing LCP modules, offers significant advantages beyond typical conformal coatings.

1. **Surface Energy Mismatch**: NanoMax exhibits a high surface energy mismatch with epoxy adhesive, ensuring a reduced likelihood of epoxy molecules diffusing into the getter's porous structure.
2. **Versatile Adsorption Capabilities**: In addition to moisture, NanoMax adsorbs CO_2, CO, SO_2, hydrocarbons, and VOCs, making it highly effective across a wide range of applications.
3. **Coefficient of Thermal Expansion (CTE) Mismatch**: The significant CTE mismatch between NanoMax and epoxy prevents bonding, preserving the getter's functionality.

David DeWire

ddewire@nanofea.com

Dr. Hua Xia

hxia@nanofea.com

Minnowbrook
Moisture in Microelectronics

November 3-6, 2026

University of Syracuse Conference Center
Adirondack Mountains, New York

Minnowbrook
Microelectronics

A forested retreat at the University of Syracuse Conference Center in the Adirondack Mountains of New York where engineers, scientists and technologists meet to explore solutions to the deleterious effects of moisture in microelectronics. Minnowbrook is quite different from the typical technical conference. It utilizes a casual workshop format where questions and discussions often take longer than presentations. Its an educational experience that makes a difference.

https://www.tjgreenllc.com/minnowbrook/

A view of Blue Mountain Lake from Castle Rock

TJ Green Associates LLC

Course Summary

- Hermetic packages have been around forever and a day. A proven track record albeit costly relative to plastic parts.
- In some cases "non hermetic" packages may be just as good at a lower cost, but plastic parts require a different way of thinking in terms of the design and qual/screen testing required.
- ***Most importantly…. understand the mission and the end use environment, customer expectations and moisture sensitivity of the enclosed components…and choose the right package and testing to satisfy your customer!!!!***
- ***Proceed with Caution!***

THE END

Thomas J. Green
TJ Green Associates, LLC
739 Redfern Lane
Bethlehem, PA 18017
Email: tgreen@tjgreenllc.com
Website: www.tjgreenllc.com
Phone: 610-625-2158

"A Veteran-Owned Small Business"

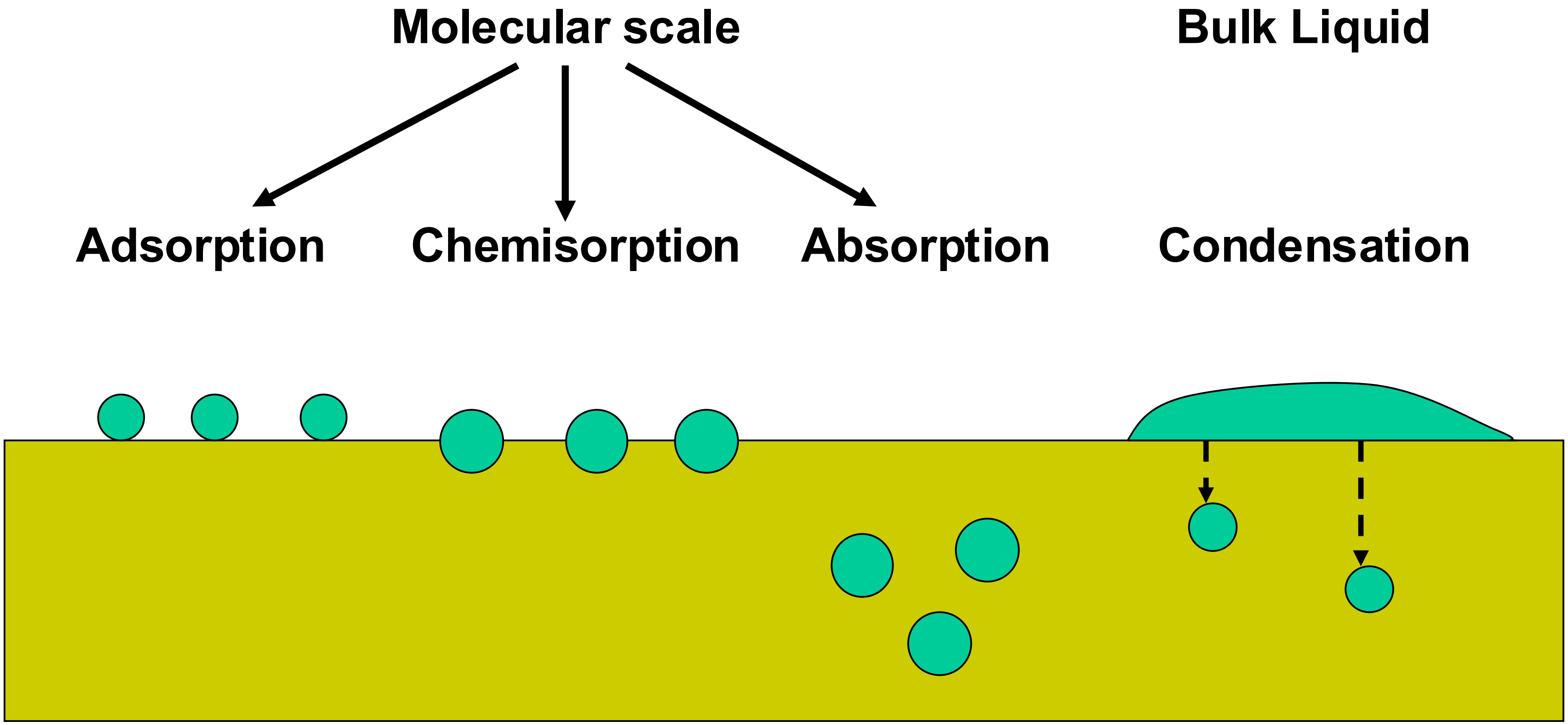
Back Up Slides

REF MIKE SAMPSON

GETTING SURFACES CLEAN

- Liquid processes
  - Aqueous rinsing
  - Solvent rinsing
  - Specialty formulations
  - Liquid ultrasonics
  - Vapor degreasing
- Dry processes
  - Dry gas blowoff
  - O_2 plasma
  - Ar plasma
  - UV/O_3
  - Sublimation (super-critical CO_2)

ADSORPTION, CHEMISORPTION, ABSORPTION, CONDENSATION



Molecular scale

Bulk Liquid

Adsorption

Chemisorption

Absorption

Condensation

REF R. Lowry

Solvent Cleaning Methods

- Acetone, IPA (electronic grade) MEK, DI water used under fume hood with spray atomizers
- Problem with solvents
  - May work well on one contaminant but not another
  - Leaves residue upon drying
  - Environmental and safety issues
  - Montreal Protocol CFC reduction
- Cobhen Enclosed Cleaning System

Fine Spray of Solvents (Cobehn System)

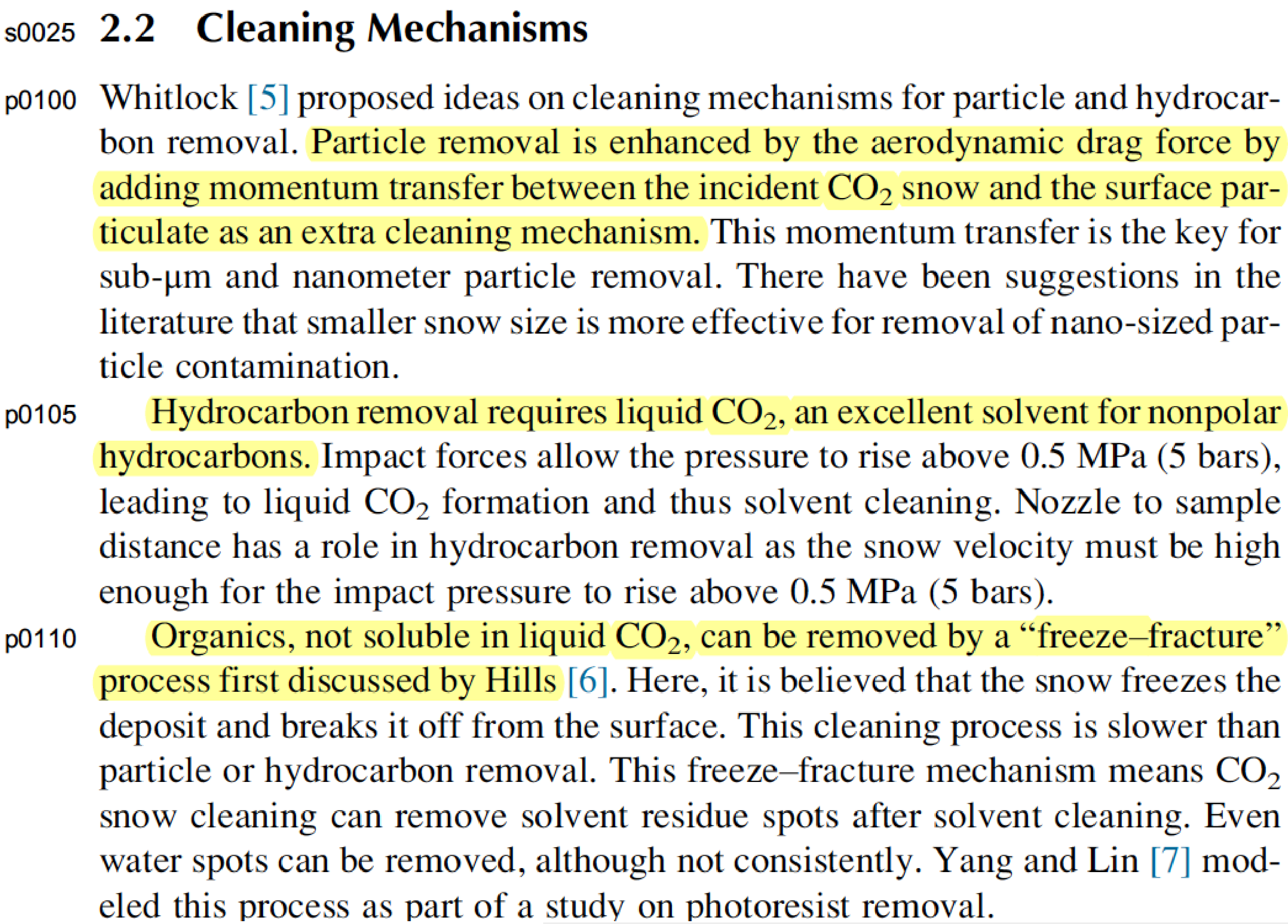
Cobehn Cleaning Systems https://cobehnsystems.com/high-purity-so

Different solvents available including IPA

Filtered and reused in contained systems

Can be automated.

Snow Cleaning



s0025 **2.2 Cleaning Mechanisms**

p0100 Whitlock [5] proposed ideas on cleaning mechanisms for particle and hydrocarbon removal. Particle removal is enhanced by the aerodynamic drag force by adding momentum transfer between the incident CO_2 snow and the surface particulate as an extra cleaning mechanism. This momentum transfer is the key for sub-µm and nanometer particle removal. There have been suggestions in the literature that smaller snow size is more effective for removal of nano-sized particle contamination.

p0105 Hydrocarbon removal requires liquid CO_2, an excellent solvent for nonpolar hydrocarbons. Impact forces allow the pressure to rise above 0.5 MPa (5 bars), leading to liquid CO_2 formation and thus solvent cleaning. Nozzle to sample distance has a role in hydrocarbon removal as the snow velocity must be high enough for the impact pressure to rise above 0.5 MPa (5 bars).

p0110 Organics, not soluble in liquid CO_2, can be removed by a "freeze–fracture" process first discussed by Hills [6]. Here, it is believed that the snow freezes the deposit and breaks it off from the surface. This cleaning process is slower than particle or hydrocarbon removal. This freeze–fracture mechanism means CO_2 snow cleaning can remove solvent residue spots after solvent cleaning. Even water spots can be removed, although not consistently. Yang and Lin [7] modeled this process as part of a study on photoresist removal.

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UV Ozone Cleaning

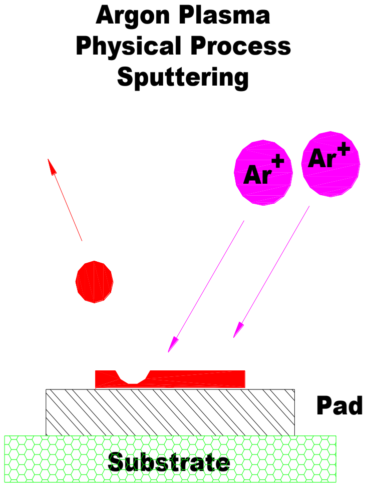
- Need a chamber with low pressure mercury lamps emitting radiation at 1849 A and 2537 A wavelenghts
- At these frequencies O2 molecules in the air break up to form atomic oxygen and ozone O3, which then reacts with hydrocarbons on the surface and leave the device surface as a gas
- Ozone is considered dangerous and gas must be exhausted from the area
- Turns silver epoxy black
- Ref papers.. https://www.samcointl.com/category/surface-treatment/uv-ozone/

What is UV-Ozone Cleaning used for?

- surface cleaning of silicon wafers and plastic packages
- lead frame and bond pad cleaning for device packaging
- surface modification of polymer substrates
- surface activation
- wettability improvement of microfluidics channels
- adhesion improvement for direct substrate bonding such as glass, PDMS, PMMA, COC and COP
- surface oxidation (thin oxidized layer deposition)
- organic contamination removal
- surface cleaning of Quartz Crystal Micro-balance (QCM) sensors
- UV crosslinking of polymers and photoresist
- Others

Physical Plasmas

Physical
- Sputtering - Argon Plasma
- Ar^+ Ion Attracted to (-) Electrode
- Operated at Lower Pressures - 50 to 300 mTorr
- Lower Pressure increases the Mean Free Path
- Impact Force Removes Contamination



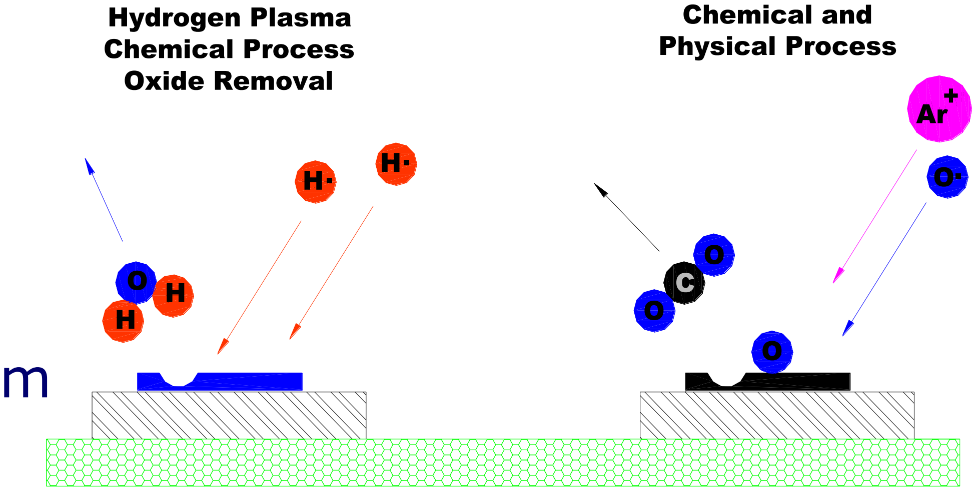
Advantages
- Non-Chemical Reaction: No Oxidation
- Pure Substrate Remaining

Disadvantages - Easy to Minimize
- Substrate Damage: Impact, and Overheating
- Poor Selectivity
- Low Etch Rate
- Contaminant Redeposition

Ref: L Wood March Plasma Systems

Chemical Plasmas

Plasma Generated Reactive
  Chemical Species
- Source Chemicals Include:
  - H_2, O_2, CO_2, N_2O, and CF_4
- Ionized Source Chemical
  - Produces Reactive Species
- Gas Phase Products Produced From Reactions with Substrate Surface



Advantages
- High Cleaning Speed
- High Selectivity
- Effective for Organic Contaminants

Disadvantages - Oxides Can Be Produced

TJ Green Associates LLC

Ref: L Wood March Plasma Systems

Plasma Cleaning

CHEMICAL REACTIONS (Oxygen Plasma)

Uses free radicals to chemically etch surface

$$O_2 + e \longrightarrow 2O \quad + C_xH_y \longrightarrow CO_2 + CO + H_2O$$

PHYSICAL REACTIONS (Argon Plasma)

Heavy ions physically break weak organic bonds

$$Ar + e \longrightarrow Ar^+ \quad + 2e^- \longrightarrow Ar^+ + C_xH_y$$